HYPOBATT

Hyper powered vessel battery charging system

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LIST OF ABBREVIATIONS, ACRONYMS AND DEFINITIONS

Abbreviation	Word
e-port	Electrified port

Acronym	Name
BESS	Battery energy storage systems
CAPEX	Capital expenditure
IMO	International Maritime Organization
KPI	(Business) key performance indicator
MW	Mega watt
MWh	Mega watt hours
OPEX	Operating expenditure

Concept	Definition
Model	A model is a simplification of reality that supports reflection before action.
Business model	A business model addresses the logic behind how an organization creates, delivers, and captures value. It reflects the architecture and financial structure of the organization. A business model helps to answer the questions related to what companies are offering to their customers in terms of products/services. This includes how and where they are planning to do that, and why they think they can do it profitably.
Foresighting	Foresight refers to the ability to anticipate future events, trends, or developments based on current information, analysis, and understanding of underlying factors. It involves a systematic process of gathering insights, analysing data, identifying patterns, and projecting potential future scenarios to inform decision-making and strategic planning. Foresight often involves considering multiple possible futures and assessing their impact and unpredictability. It is essential for organizations, governments, and individuals to navigate uncertainties, mitigate risks, and seize opportunities in an ever-changing world.
Scenario planning	The process of trying to make sense of the future through multiple plausible images (scenarios).

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1. EXECUTIVE SUMMARY

The goal is to develop analytical support to enable evaluation of new business models in view of the innovation associated with the hyper powered battery charging system and informed by consideration of future business environments in which ports might operate.

A mixed methods approach is designed to integrate layers of analysis, from consideration of the external and largely uncontrollable business environment, through to the creation of models for decisions framed (i) more broadly for the business ecosystem associated with electrified ports through to (ii) more narrowly bounded for decisions around the implementation of the hyper powered battery charging system in a port.

Through a foresighting process involving HYPOBATT partners, four future scenarios for the business environment have been co-created. These cover a range of circumstances around the speed and nature of the energy transition that might enable or hinder the adoption of the hyper powered battery charging system. Summary characteristics of the scenarios are as follows.

1. *Fair Winds*: Lower rates of climate change and costs of alternative source of energy, strong governmental net zero policies/initiatives and stable global supply chains,
2. *En Route*: Lower costs of alternative sources of energy but higher rates of climate change, lower levels of funding for port infrastructure and slow adoption of alternative fuels in maritime transportation.
3. *Bite the Bullet*: Lower rates of climate change but higher costs of alternative sources of energy, high digitalization of maritime transportation and not fully stable global supply chains.
4. *In Irons*: Higher rates of climate change and costs of alternative sources of energy, limited net zero government policies/initiatives and unstable global supply chains.

Consideration of future business environments, which explore how transitions to a green economy might plausibly emerge, enables theoretical models to be reasoned to examine the implications of systemic business choices given radical (macro) uncertainties. Multiple alternative business models are characterised for a generic ecosystem aligned with the four contrasting future business environment scenarios created. The implications of the different futures reveal different priorities for the service offering, the degree of investment and the nature of partnerships in each situation. These business models are abstractions since to be valuable in practice, the details of a business model should be created in partnership with the organization(s) offering a product and/or service. Also, these business models are framed at the level of an electrified port more generally, for which solutions such as the hyper powered battery charging system is one, but not necessarily the only, innovation.

To consider the more specific choices associated with adopting a hyper powered battery charging system in a port, we have co-created a decision model with partners to capture the relationships between key choices, consequences, and uncertainties. Three key decisions emerged corresponding to the choice of:

1. MW capacity of the hyper powered battery charging system to be installed.
2. Size of on-site energy production, which could be in the form of PV, wind, etc. or through a combination of battery and energy production.
3. Pricing strategy to be adopted by the port, which might be static or dynamic.

Business performance indicators, such as income generated, OPEX and CAPEX, capture the consequences of decisions. Uncertainties included within the boundaries of this decision model include the variability in the price in energy production on-site at a given time, the price of energy purchased from the grid at a given time and the amount of MW that the hyper powered battery charging system can transfer in a time window to vessels requiring a charging service in a port.

This decision model can be expressed mathematically and codified to support analysis. An example is provided to illustrate how to interpret output. This example shows the proof-of-concept of the decision model which is capable of being applied in use cases and of being extended to relax some assumptions to create more sophisticated modelling if required by application to specific ports. For example, we currently assume no degradation in the charging system by treating it as always in an 'as-new' state. Further, this version of the model assumes a particular form of uncertainty distribution on model parameters that is requisite but again the class of distributions could be extended as required.

A novel approach for supporting analysis of the business value of the hyper powered battery charging system and the context in which it will be used has been achieved. The approach also provides the foundation upon which to extend and develop analysis associated with business model choices during the HYPOBATT project.

Keywords: Foresighting the business environment, Eco-systemic business modelling, Decision model for analysing business value of hyper powered battery charging system

2. OBJECTIVES

The goal is to develop analytical support to enable evaluation of new business models in view of the innovation associated with the hyper powered battery charging system and informed by consideration of future business environments in which ports might operate.

The objectives are:

- To foresight future business environments in which ports and other actors in the ecosystem might plausibly operate.
- To create multiple business model alternatives and the associated value proposition under sets of plausible future business environments.
- To create a replicable modelling process to support analysis of different business models by explicating dependencies between different uncertainties and the relationships between inputs (choices) and outputs (business consequences/KPIs).
- To inform the evaluation space for use cases drawing on future scenario characteristics and framing of model decision support.

3. INTRODUCTION

To create value from technology innovations, such as the hyper powered battery charging system, it is important to consider the business perspective and the context in which that business operates. This deliverable reports the process of creating analytical support for business modelling and the results associated with three key analytical elements in the context of the HYPOBATT project. The three elements correspond to:

- The future business environment and how the transition to a green economy might plausibly manifest itself as described in multiple scenarios. These scenarios enable the implications of business models to be examined and to inform robust choices given future (macro) uncertainties.
- The characteristics of alternative business models for a generic port ecosystem for each of the four contrasting future business environment scenarios. Such business models can be further developed in specific use case contexts, including in partnership with those owning the corporate port business decisions.
- The modelling of decisions associated specifically with the implementation of a hyper powered battery charging system in a generic port that enables articulation/ quantification of the key uncertain factors and the relevant business performance indicators. The model framing, structuring, and reasoning has been informed by the ports within HYPOBATT but is designed to be generic so that future applications/use cases can be conducted to explore the optimal choices to maximise value creation.

The work reported in D6.2 relates to the overall consideration of business aspects in Workpackage 6. For example, stakeholder analysis in Task 6.1 informs our consideration of actors in the business models for the port ecosystem, while the outputs of Task 6.2 will inform the use cases and development of specific business models in Tasks 6.3–6.5.

The work reported in D6.2, is informed by project deliverables published to date (e.g., to understand the technology and its implications for port operations) and specifically models created for different but related purposes. For example, the digital twin (Workpackage 2) has the purpose of supporting real-time operational decisions in ports about the hyper powered battery charging system. While the business model planning horizon is much longer than that of the digital twin, information from the digital twin at discrete points relevant to the business planning cycle can inform data input to the decision model. Equally, since the model developed in D6.1 has the purpose of supporting choices about PV integration (and since this is one of the options associated with variables in the D6.2 decision model concerning alternative energy sources), then D6.1 model outputs can inform some inputs to the decision model in D6.2. We deliberately use the expression "inform inputs" since these models are aligned with different purposes (e.g., not necessary support same decision-makers and certainly not over the same planning horizons and speed of updating) and hence are related but it is not appropriate to digitally connect them.

4. METHODOLOGY

4.1 Rationale

Figure 1 illustrates the rationale of the business modelling approach adopted. We posit that the design and implementation of technology innovation adopts a cause-effect relationship consistent with choices taken by a business with the intent of making a (positive) impact on the markets. In contrast the business modelling approach adopted views the cause-effect relationship in terms of making commercial decisions that will ensure a positive outcome for the business given uncertainties about the operating environment into which the technology innovation has to perform and compete. In view of this, we consider three levels of business model analysis, working from a more global to local framing of the challenge.

1. First, the consideration of the uncertainties and unpredictability of high impact events within the wider business environment since this represent future worlds within which the outcomes from business decisions taken now will be realised.
2. Second, exploration of multiple business model alternatives from the perspective of a port ecosystem including with a view to their responsiveness and robustness under contrasting scenarios of future business environments.
3. Third, alternative business options associated with key decisions specifically facing ports who choose to implement a hyper powered battery charging system.

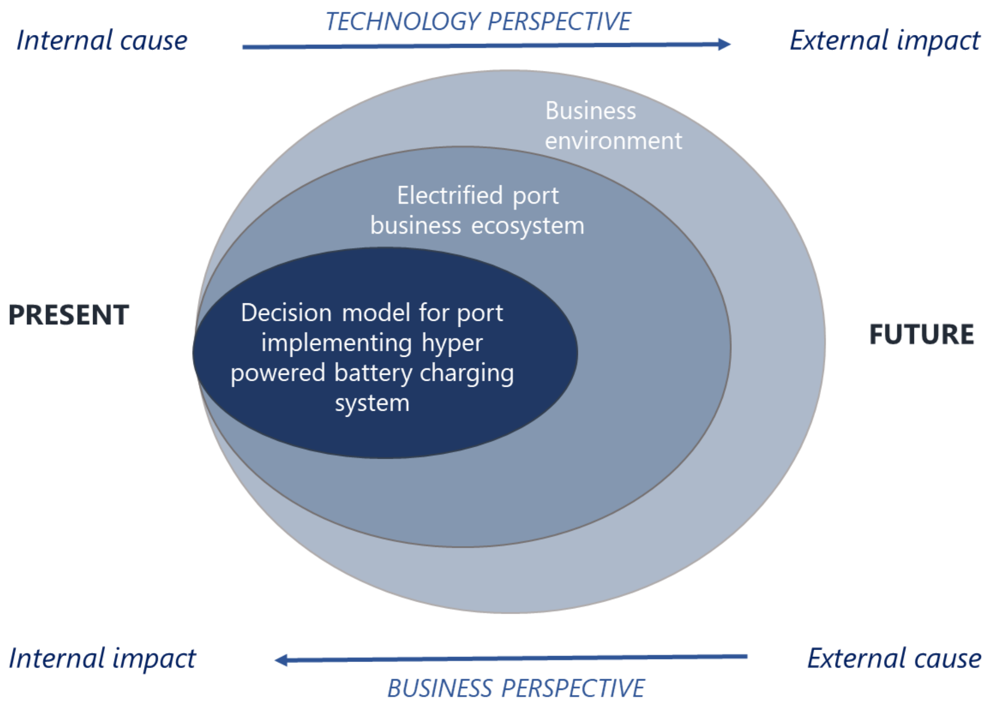

Figure 1 Business modelling rationale

4.2 Mixed Methods Approach

We have designed a mixed-method approach [1] consistent with our rationale. Figure 2 shows the key stages of the process linking the methods selected as well as the input data sources. The three methods selected are:

1. Scenario planning – selected as the method to foresight the future business environment because it is a process that uses the collective understanding and intuition of knowledgeable people in participating organizations and is a recognised means to support foresighting, improve sensemaking and anticipation of the future [2].
2. Business Model Canvas – selected as the basis of an adapted method for reasoning through business model alternatives under contrasting futures because it is an established process for examining the different facets of the business model (for a conventional business model canvas see [3]) and their inter-relationships (through an extension of the business model canvas method).
3. Decision model – selected to co-create causal diagrams because it is a means of explicating choices, uncertainties and consequences associated with bounded decision problems (such as a business adopting a technology innovation) by both visually representing the problem as viewed by those who understand it, as well as supporting mathematical/computational analysis [4].

The following sub-sections outline the key elements of each method as implemented.

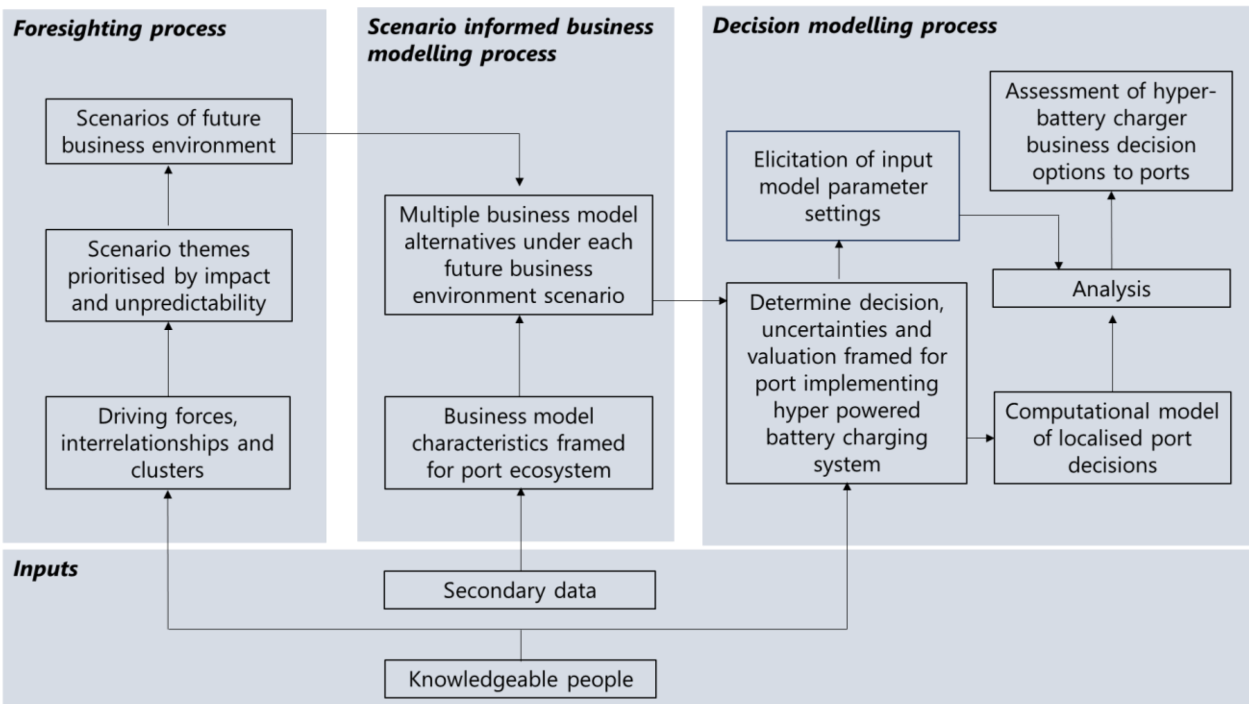

Figure 2 Key stages and activities in the HYPOBATT business modelling process

4.2.1 Scenario Planning

Scenario planning is an umbrella term which refers to a range of methods whose philosophy is that we cannot forecast every detail about the future because there can be many "known (and unknown) unknowns" – i.e., radical uncertainties. From the different schools of scenario planning methods, we select the Intuitive Logic approach because this is based on eliciting the qualitative causal reasoning of relevant knowledgeable persons. Details of the method can be found in, for example, [5] and [6]. Figure 3 shows the key steps in the Intuitive Logics Method process adopted as an elaboration of the foresighting phase of the modelling process shown in Figure 2.

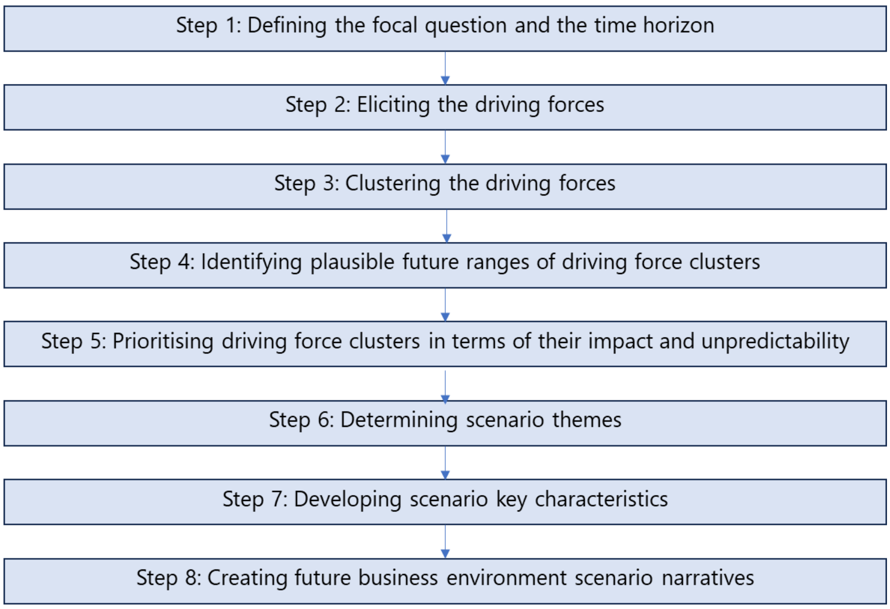

Figure 3 Key steps in scenario planning process

4.2.2 Eco-Systemic Business Modelling

A 'business ecosystem' is considered a structured economic community and a complex network of organizations that collectively create value for customers based on a common, integrated technological system. Based on shared capabilities, business ecosystems aim to create core products and services by exploiting those capabilities [7]. Ecosystems represent the integration of technological processes with organizational activities. In designing the architecture of a business ecosystem, elements such as type of actors (e.g., market intermediaries, suppliers, complementors, system integrators, distributors, finance providers, customers), infrastructure, governance model, operation and business model, customer attraction mechanisms as well as regulation and ethical standards need to be considered, [8] and [9]. Business ecosystems consist of a complex network of organizations, each with its own business model. However, the collective aim is to develop a comprehensive shared business model within the ecosystem. This can unlock varied types of value across the maritime industry and society, such as those identified by [10]:

1. Economic value: by preventing nonessential costs and empowering more generation capacity.
2. Environmental value: by terminating the application of fossil fuel power plants and assimilating eco-friendly sources of energy.
3. Reliability value: by reinforcing sustainability through technological developments.
4. Energy security value: by upgrading distributed generation to substantially downscale dependency on depleting fossil fuel resources.
5. Engagement and interaction value: by enabling consumers and prosumers to get involved in the energy market more vigorously.

Business models explain how organizations operate, showing a system of interdependent activities both within and across organizations' boundaries. Business models describe the rationale of how an organization creates, delivers, and captures value [11] and [12]. Values can be divided into two categories: 1) quantitative, including price, cost, speed of service, or risk reduction, and 2) qualitative, including design, brand, customer experience, or convenience and usability. According to [13] and [14]:

1. Value creation is related to engendering value for all stakeholders involved in transactions by exploiting its internal and external resources and capabilities, technologies or equipment, processes or structures, and new partnerships.
2. A value proposition is focused on the customer, showing how value is offered and delineates the interrelationships of activities with business customers and distribution channels.
3. Value capture entails the financial strategies practiced monetizing the offered value by using revenue models and cost structures.

The business model of an organization is a system of compatible and interrelated activities. The activity system perspective demonstrates "how organizations do business" and it empowers the focal company in decision-making about its business model design [14]. Figure 4 shows an extension of the business model canvas that captures the nature of dependencies between elements, rather than just the elements alone (which is the more usual representation of the business model canvas). Following [15], the key elements are:

- Offering or value proposition characterizes the inclusive package of products and services a company provides for its customers.
- Target customers refer to the specific customer segments a company target to satisfy their needs.
- Distribution channels comprise the distinct methods and routes a company utilizes to communicate with its customers.
- Value creation happens through the distribution of activities and resources.
- Core capabilities form the critical competencies needed to execute the company's business model.

- Partnership defines the collaborative agreements among companies which is necessary for effective offerings and commodifying value.
- Cost structure outlines the economic indications of the resources and activities applied in the business model.
- Revenue model depicts the way a company earns income via various revenue streams.

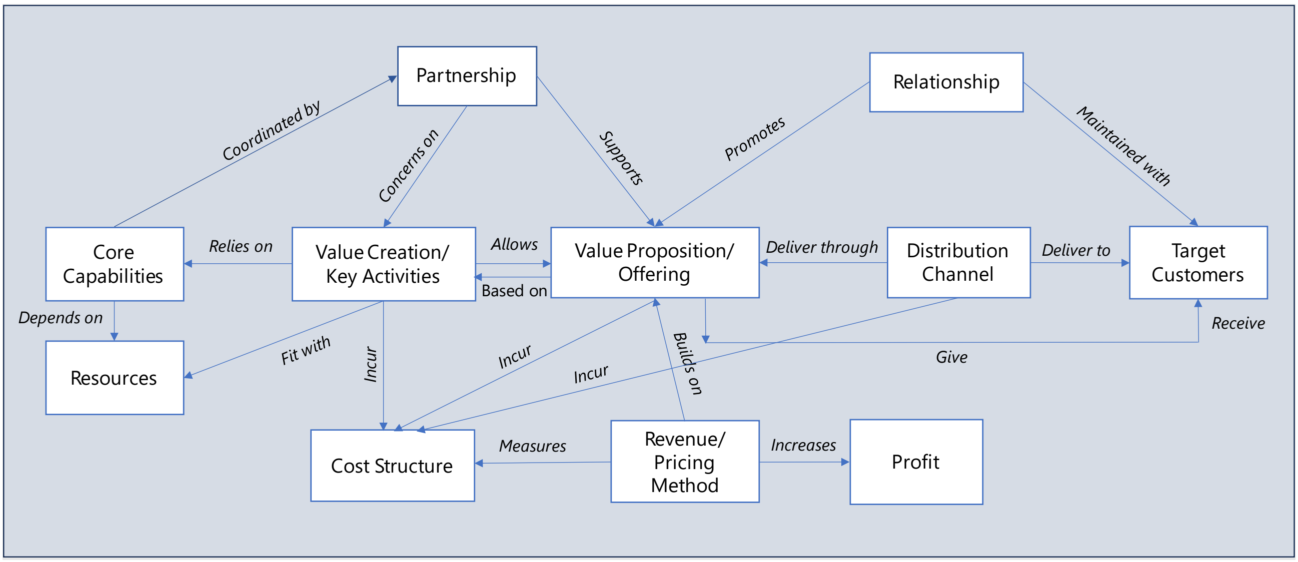

Figure 4 Extended cause-effect representation of business model canvas adopted and modified from [16]

The scenario informed business modelling process phase (Figure 2) shows how we apply the extended business model canvas method to create eco-systemic business models under the scenarios created via foresighting.

4.2.3 Decision Modelling

The purpose of the decision model is to inform choices made by a port (e.g., an engineering manager) regarding the value to be generated by adopting the hyper powered battery charging system in view of the associated uncertainties arising due to the technology, industry, and contextual business environment.

We have chosen to represent the decision model as a graphical causal model (informed by the formal notation of an influence diagram [4]) since this is a methodology for graphically capturing dependency structures and presenting this in an easily digestible manner to those who understand the decision problem. Graphical models can be created in two phases: qualitative, then quantitative. The purpose of qualitatively structuring the graph is to capture the dependency between decisions (e.g., choice options), uncertainties (e.g., critical to affecting relationship between choices and consequences) and consequences (e.g., valuation in form of key business performance indicators) within the underlying problem. Then in the quantitative stage, a mathematical dependency structure can be expressed for the graphical model to support computations and produce outputs informative to key business decisions. It is appropriate to structure the causal model in partnership with domain specialists (e.g., representatives from ports and other project partners with expertise in the maritime sector). The aim of the analysts (i.e., authors of this deliverable) has been to work with problem owners and the data provided to define a model accurately, without bias, and using terminology and tools that do not require those applying to the tool or using the information it creates to become decision modelling experts.

The decision modelling process phase (Figure 2) describes the key steps in building this model.

4.3 Data Collection

Data have been collected and knowledge elicited in each phase of the implementation of the mixed-methods approach adopted (shown in Figure 2). Table 1 summarises the purpose, type, source, and timing of data collection.

Table 1 Data collection and knowledge elicitation summary

Method	Type	Purpose	Source	Month
Scenario planning	Interviews	Step 1- Understand the context, determine the focus of the scenarios and the time horizon	HYPOBATT partners (Bring, Valencia, Frisia, Motus)	May 2023
	Desktop research	Steps 4, 6, and 8 – Required given not feasible to conduct in-person workshop lasting 3 days	Secondary data (industry reports; academic articles)	May and Sep-Nov 2023
	Face-to-face workshops	Step 2, 7 – multiple sessions each of 1 hour within two General Assembly Meetings. First to brainstorm driving forces, second to develop scenarios in groups	GA1 (Bilbao) GA2 (Brussels)	Jun 2023 and Nov 2023
	Virtual workshops	Step 3 – Teams/Miro enabled 1 hour workshop to cluster driving forces and mapping of relationships between clusters	HYPOBATT partners (15 participants)	Sep 2023
	Online survey	Step 5 – Qualtrics survey to determine most impactful and unpredictable clusters of driving forces through prioritization.	HYPOBATT partners (12 respondents)	Oct 2023
Eco-systemic business modelling	Desktop research	Use the extended business model canvas to create candidate business models under the four scenarios of future business environments co-developed with partners drawing on evidence documented	HYPOBATT deliverables and secondary data (industry reports, journal articles)	Oct 2023 - Mar 2024
Decision modelling	Interviews	Understand key decisions facing ports in relation to the hyper powered vessels battery charging system as well as business relevant KPIs (of value created) and near-term uncertainties	HYPOBATT partners (e.g., Frisia, Valencia ports, Flanders Make, CEA, Motus, Otaskies)	Dec 2023 – Jan 2024
	Desktop research	Develop graphical representation of the choices, consequences and uncertainties as viewed by ports and informed by business model options created under future business environment scenarios	Modeller knowledge	Feb 2024
	Interviews	Face validation of the decision model by partners to ensure multiple perspectives represented logically and coherently	HYPOBATT partners (as for interviews)	Mar 2024
	On-line elicitation	Elicit input values for decision model parameter settings for an example to illustrate application	HYPOBATT partner (Otaskies)	Apr 2024

5. FORESIGHTING THE BUSINESS ENVIRONMENT

5.1 Focal Question – Business Environment up to 2050

The focus of the intervention is the "Future of Sustainable Maritime Transportation". Informed by partner interviews, this focus provides the frame to address the future uncertainties faced by this industry, while being inclusive to describe alternative scenarios of the future for the contextual environment of the project partners.

The time horizon chosen is 2050. This time horizon is selected to match the target date for the net zero transition. During the initial interviews it became apparent that EU net zero transition targets and dates were guiding the thinking of participants.

5.2 Driving Forces

5.2.1 Individual Driving Forces

The first face-to-face partner workshop brainstormed 105 driving forces. A post-workshop review led to deletion of 25 duplicates/imprecisely specified driving forces and addition of 15 new ones based on desktop research. Table 2 shows an extract from the PESTLE categorization of these individual driving forces (the complete set is given in Section 12.1, Appendix 1).

Table 2 Extract of PESTLE categorization of selected driving forces in future business environment

Political	Economic	Socio-Cultural	Techno-logical	Environ-mental / Ecological	Legal
Stability of Russian Federation	Energy price from fossil fuel	Labels for clarification of travel time/distance.	Level of ports' integration	Local air quality requirement	Level of emission related clauses to the law
Changes of Global Net Zero Targets	Energy price from sustainable sources	Awareness of about climate change	Emergence of Swappable batteries technology	Availability of new routes through the north pole	Level of discounts/ benefits in port fee given sustainability record
Pressure /lobbying from non-green industries	Level of demand for zero emission transportation	People's trust on the safety of vessels that use alternative fuels	Adoption of alternative fuels to in maritime transportation	Speed at which climate phenomena are occurring	CO_2 emission taxes
Countries commitment to IMO targets and the Paris Agreement	Availability of rare earth materials	Image of climate change effects on media	Advancements of H_2 fuel technology	Public pressure towards high CO_2 industries	Penalties for the amount of emissions produced

5.2.2 Clusters of Driving Forces

A virtual partner workshop enabled the relationships between driving forces to be investigated and clusters formed. The 11 clusters co-created are as follows.

1. Rate of climate change
2. Levels of ports integration
3. Level of funding for port infrastructure
4. Level of demand for zero emission transportation
5. Adoption of alternative fuels in maritime transportation
6. Governmental initiatives/policies to net zero
7. Cost of energy from alternative sources
8. Availability of sufficient electrical grid capacity
9. Stability of global supply chains
10. Digitalisation of maritime transportation
11. Energy optimization

Section 12.2 (Appendix 2) shows the visual clustering of driving force relationships output from the workshop.

5.3 Plausible Ranges of Driving Forces

Based on desktop research, and face validation by partners, plausible lower and upper bounds of the values of each driving force cluster in the 2050 business environment time horizon are assessed as plausible maximum and minimum values respectively. These values are shown in Table 3.

5.4 Scenario Themes

An online survey enabled partners to make individual assessments of the relative impact and degree of unpredictability of each driving force cluster to inform the selection of those most critical to shaping the future business environment. Figure 5 shows the relative positioning of clusters indicating that "rate of climate change" and "cost of energy from alternative sources" are regarded as the two most impactful and unpredictable issues.

The plausible low-high ranges of the cluster states in 2050 are a +1.5°C and +4°C increase in the average temperature of the earth when compared with the pre-industrial figures, and €2MWh and €60MWh for cost of energy from alternative sources. See Figure 6.

Table 3 Plausible upper and lower bounds assessed for each driving force cluster in 2050

Driving Force Cluster	Upper Bound	Lower Bound
Rate of climate change (temperature increase relative to pre-industrial levels)	+1.5°C	+4°C
Levels of ports integration **Technology** **Infrastructure** **Processes**	Limited integration Basic Integration in technology Lack of integration in infrastructure Basic harmonisation of processes	Extensive Collaboration – establishment of international standards
Level of funding for port infrastructure (global) $223B (today)	€300B	€768B
Level of demand for zero emission transportation	30%	100% (enforced by legislation)
Adoption of alternative fuels in maritime transportation	20%; Biofuels; Hydrogen,	100%; Green Hydrogen; electric vessels by renewable energy sources (large scale)
Governmental initiatives /policies to net zero (EU)	€1.5T	€2.4T
Cost of energy from alternative sources	€2MWh	€60MWh
Availability of sufficient electrical grid capacity	€400B investment in EU; 40% of energy from renewable; grid: 2 times bigger than today	€800B investment in EU; 80% of energy from renewable; grid: 5 times bigger today
Stability of global supply chains	High trade barriers Low reliability High costs Up to 2 years delays	Stable, diverse and coordinated supply chains
Digitalisation of maritime transportation	Lack of interest due to low profit margins, risky business-wis, legal requirements, cybersecurity	High integration; Wide data sharing; Autonomous/Crewless vessels.
Energy optimization utilisation	1% of Global CO2	17% of Global CO2

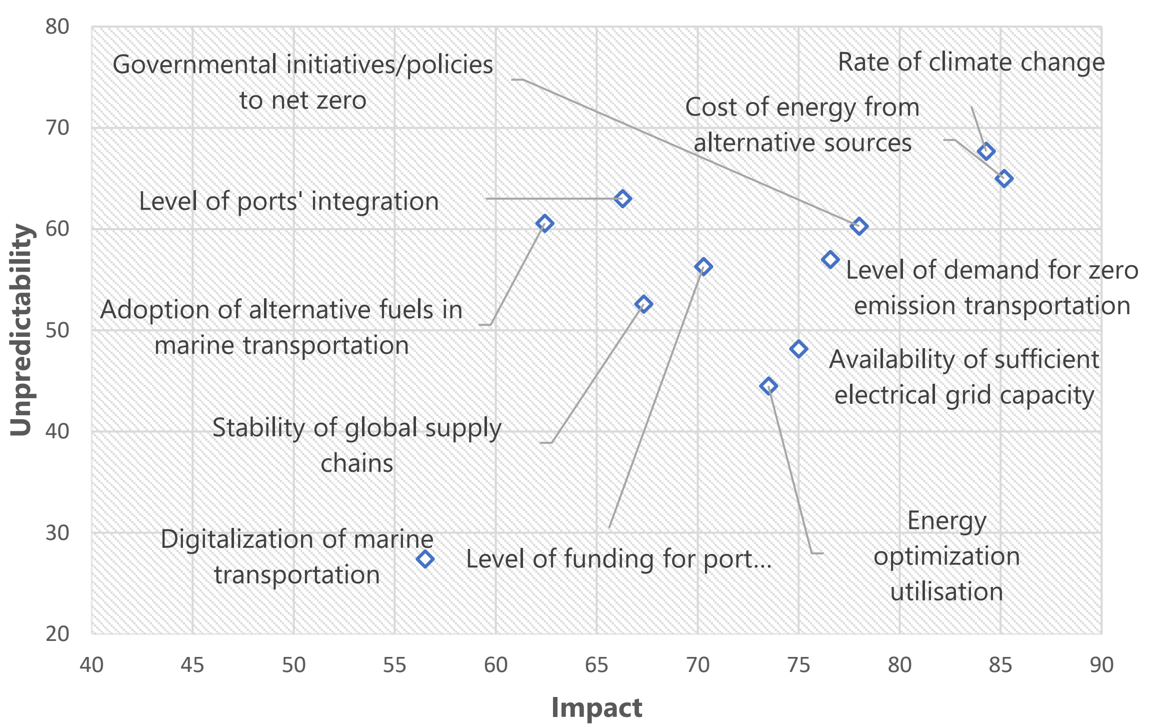

Figure 5 Relative impact-unpredictability assessment of driving force clusters (higher score implies higher impact and unpredictability)

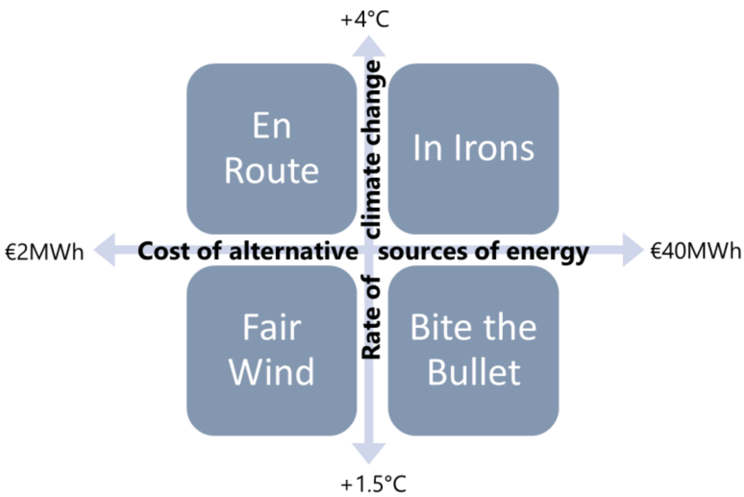

Figure 6 Four scenario themes represented by 2050 upper and lower bounds on the two most impactful and unpredictable driving force clusters

5.5 Plausible Future Business Environment Scenarios

The characteristics of each of the four scenario themes were co-developed during the second in-person workshop with partners and are summarised in Table 4. Narratives for each scenario are documented in Section 12.3 (Appendix 3)

Table 4 Summary of scenario characteristics in relation to each driving force cluster

Driving Force Clusters	*Scenario 1* Fair Wind	*Scenario 2* Bite the Bullet	*Scenario 3* En Route	*Scenario 4* In Irons
Rate of climate change (temperature increase relative to pre-industrial levels)	+1.5°C	+1.5°C	+4°C	+4°C
Cost of energy from alternative sources	€2MWh	€60MWh	€2MWh	€60MWh
Levels of ports integration	Very high	High	Med	Low
Level of funding for port infrastructure (global) $223B (today)	Med	High	Low	Med
Level of demand for zero emission transportation	Very High	High	Med	Med to High
Adoption of alternative fuels in maritime transportation	Med to High	High	Med	Med
Governmental initiatives/policies to net zero (EU)	Very High	Med	Low	Low
Availability of sufficient electrical grid capacity % of energy from renewable Level of EU investment	Med Very High	Med High	High Med	Low Low
Stability of global supply chains	Stable	Not fully stable; high costs	Low reliability	Unstable
Digitalisation of maritime transportation	Focus on autonomous vessels	High	Med	High
Energy optimization utilisation	High	Med	Very High	Low

5.6 Summary

Four scenarios for future business environments associated with sustainable maritime transportation are presented, and the process by which these have evolved is described. Anticipating the future business environment is important if robust and responsive business models are to be developed. In Sections 6 and 7 we show how these scenarios can inform modelling choices associated by decisions framed from both the ecosystem involving multiple actors (including ports) and taken by a port alone. In Section 10 we discuss how the scenarios can inform project tasks still to be conducted (e.g., in Tasks 6.3-5).

6. ECO-SYSTEMIC BUSINESS MODELLING

6.1 Key Actors

Exploiting the business potential of the hyper powered vessel battery charging system necessitates novel organizational attempts and activities wherein resources are singled out and arranged in new ways across an ecosystem that encompasses multiple actors. The term actor rather than stakeholder is deliberately chosen because each actor will take responsibility for making choices about their own business, albeit this operates within an ecosystem involving a network of organizations.

Figure 7 shows the key actors in the context of this project. For example, ports can search for methods to handle their resources beyond their current business model, adjusting to the expected changes in the future business landscape (e.g., as represented in the scenarios described in Section 5) and building upon the relationships with port owners or authorities in which they simultaneously engage in both cooperation and competition, (a strategy named as co-opetition, see e.g., [12,13]). This approach potentially enhances the dynamic growth and competitive advantage of a port, as it permits cooperation with one competitor, like collectively boosting the value generated from electrification, while competing with another. By considering future technological advancements and continually updating the electrification infrastructure and equipment, ports can stay competitive and aligned with evolving industry standards.

Eco-systemic business models reflect possible responses by ports to future uncertainties within the maritime industry over the defined time horizon.

Figure 7 Business ecosystem key actors

6.2 Future Scenario Informed Business Models

Future-oriented business models are presented for electrified ports in the context of their ecosystem and informed by the future business environment scenarios (from Sections 5.5 and 12.3). These business models are created through desk research as an illustration of how business models need to be responsive to external trends and unpredictable events in the business environment that are beyond the control of a port choosing to adopt new technology, such as a hyper powered vessel battery charging system.

Although theoretical, the following sections present multiple alternative business models that could be adopted (or at least inform real business model development which would require in-depth workshops with key organizational decision-makers). By interpreting the driving forces in relation to their own organization and future goals, port owners/authorities can reflect and make more informed decisions. Adopting an approach to developing a new business model grounded in scenario thinking, not only enables anticipating and accommodating opportunities, but can also provide insight towards creating new visions and discovering their possible business outcomes.

To develop alternative multiple business models, first we created a generic business model for e-ports offering "charging" as a service. This business model was developed based on the analysis of the scientific literature, industry reports as well as project deliverables. Then, analysis of how each cluster of driving forces (shown in Figure 8) emerged and developed within each scenario, enabled us to determine which part/element of the business model is likely to be primarily influenced by that driver. Next, elements from the generic business model that we considered would not work given the negative presence/impact of that driver were removed. Accordingly, we created an alternative business model for each of the four future business environment scenarios based on the approach shown in Figure 2. Each business model has six building blocks including services or offering, partners and suppliers, value creation or key activities, customer segments, cost drivers and revenue stream. Within each block there are a set of activities required to run the business. These activities reflect the factors that port owner/authority or port decision makers can consider when they want do business.

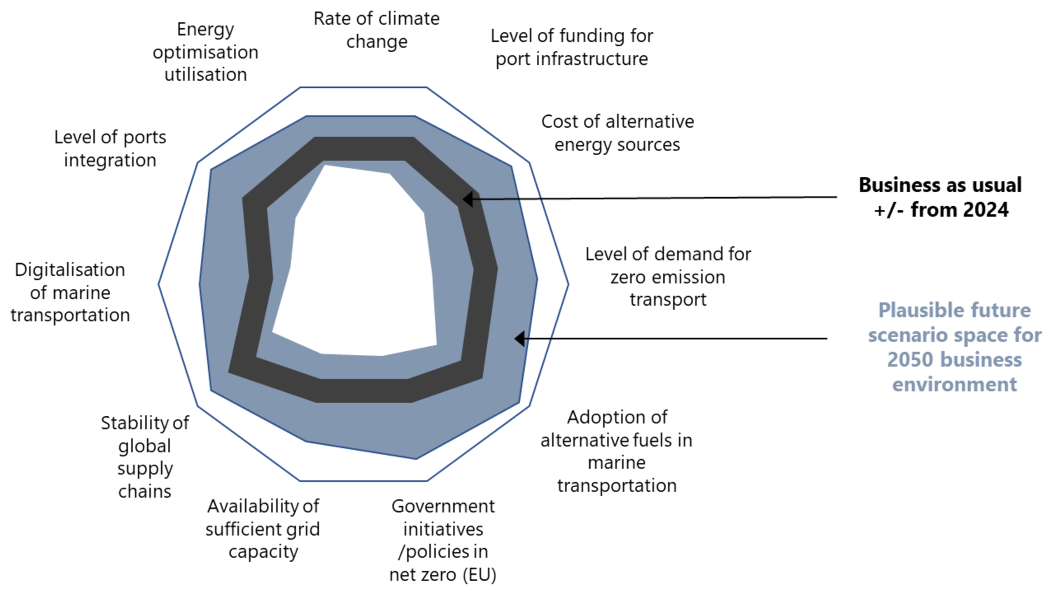

Figure 8 Driving force clusters created by foresighting scenarios for the 2050 business environment

6.2.1 Scenario 1 – Fair Wind Business Model

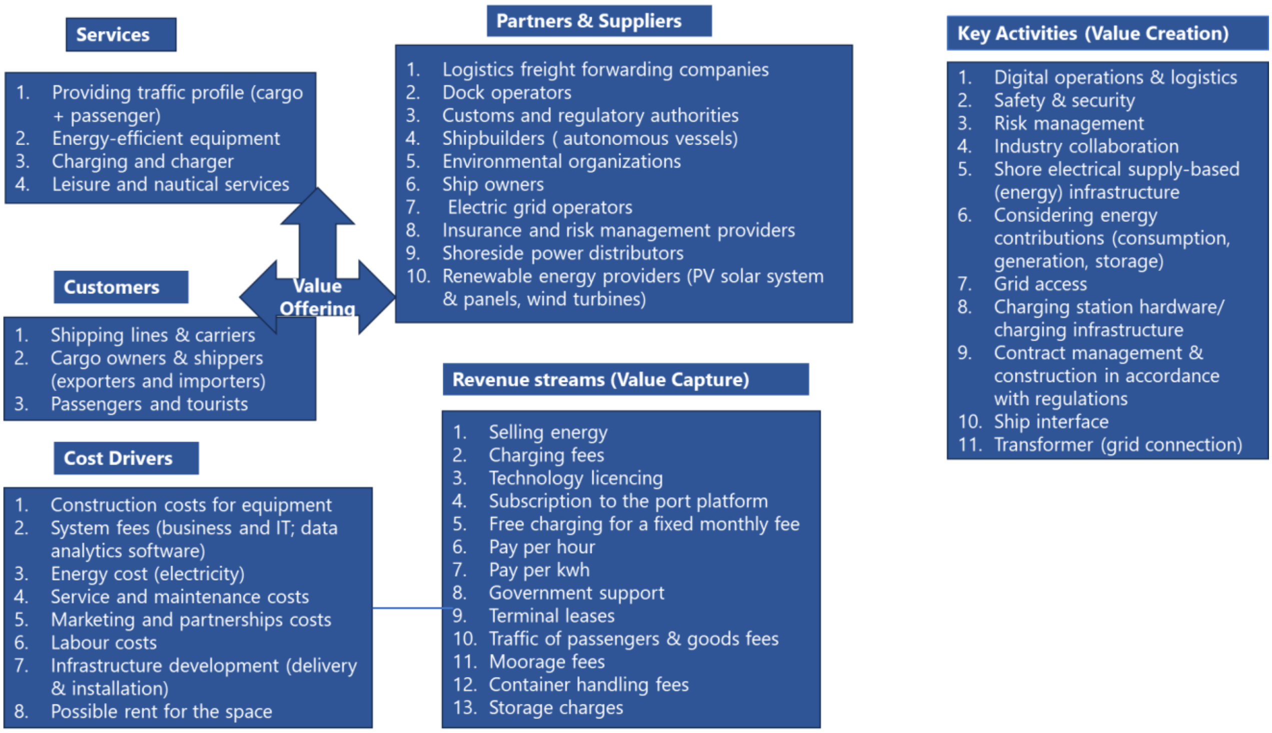

Figure 9 Business model for Fair Wind scenario 1

Figure 9 summarises the business model under the Fair Wind scenario. Under this scenario using energy from solar system, PV, wind, etc., ports might offer services like a hyper powered battery charging system as well as back-up batteries for vessels/ship owners and provide/use energy-efficient equipment. Since the government's support for developing infrastructure required for net zero is very high, ports might generate extra revenue by being proactive in reforming and upgrading their infrastructure. This could influence the quality of their services for charging and could increase use energy efficient equipment. The slower rate of climate change could enable a port's network of suppliers (i.e., renewable energy providers, shoreside power distributors, electric grid operators, ship builders, dock operators and logistics freight forwarding companies) to integrate digital operations and logistics. Also, on-shore electrical supply-based energy infrastructure (e.g., optimized grid access, grid connection/transformer and estimated energy consumption, generation and storage, battery management system, charging station hardware and ship interface for their activities) could be developed. A port's main cost drivers are likely to be the construction costs for equipment, system fee (i.e., business and IT, data analytics software), energy cost (electricity), service and maintenance cost, labour cost and marketing and partnership cost. Port revenue could be generated through selling energy, charging fees, storage charges, technology licencing, moorage fees, terminal leases, container handling fees and traffic of passengers and goods fees.

6.2.2 Scenario 2 – Bite the Bullet Business Model

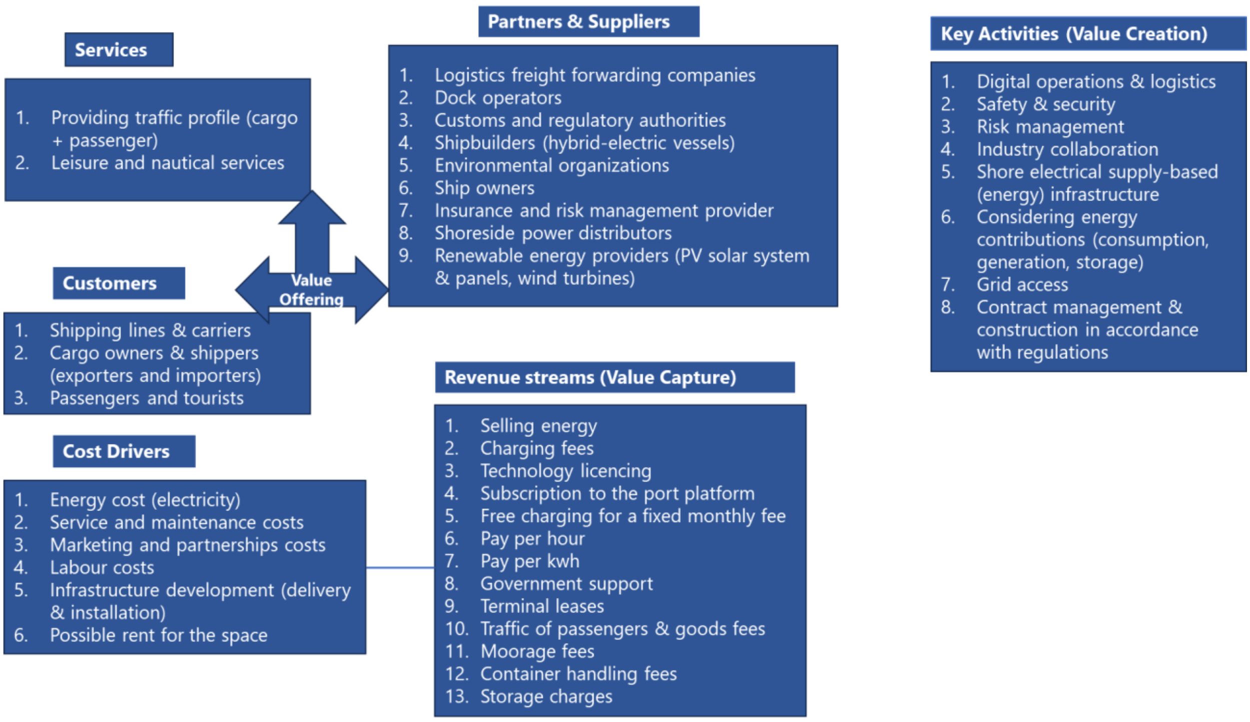

Figure 10 Business model for Bite the Bullet scenario 2

Figure 10 summarises the business model under the Bite the Bullet scenario. In this context, the price of energy from alternative sources and the associated operational costs are likely to be high implying that the demand for clean and sustainable sources of energy might be low. Since services for charging and electricity provisioning are likely to be limited, a port might mainly handle cargo and passenger traffic and offer leisure and nautical services for shipping lines/carriers as well as cargo owners. Since costs are high, investment in R&D projects and governmental initiatives to enable transition to net zero is likely to be reduced. This could affect a port's revenue from technology licencing and government support for developing their infrastructure. However, as demand for zero emission transportation is relatively high and the marine industry is aware of the lower rate of climate change, a port could try to address proactive governmental policies. To do that, port partners and suppliers (i.e., global supply chain including logistic freight forwarding companies, dock operators, shipbuilders, ship owners, environmental organizations and customs and regulatory authorities and renewable energy providers) could establish an industry collaboration so that a port has strong partner integration of digital operations and logistics. This extends to consideration of the required energy consumption, generation, and storage to create access to grids and upgrade shore electrical supply-based energy infrastructure in accordance with regulations as well as safety and security measures. Port electrification could result in a cost for generating/purchasing energy including electricity, service/maintenance, marketing/partnership relationships and infrastructure development (delivery and maintenance). On the other hand, a port could generate revenue through selling energy, charging fees, terminal leases, subscription to the port platform, moorage fees, traffic of passengers and goods, container handling fees and storage charges.

6.2.3 Scenario 3 – En Route Business Model

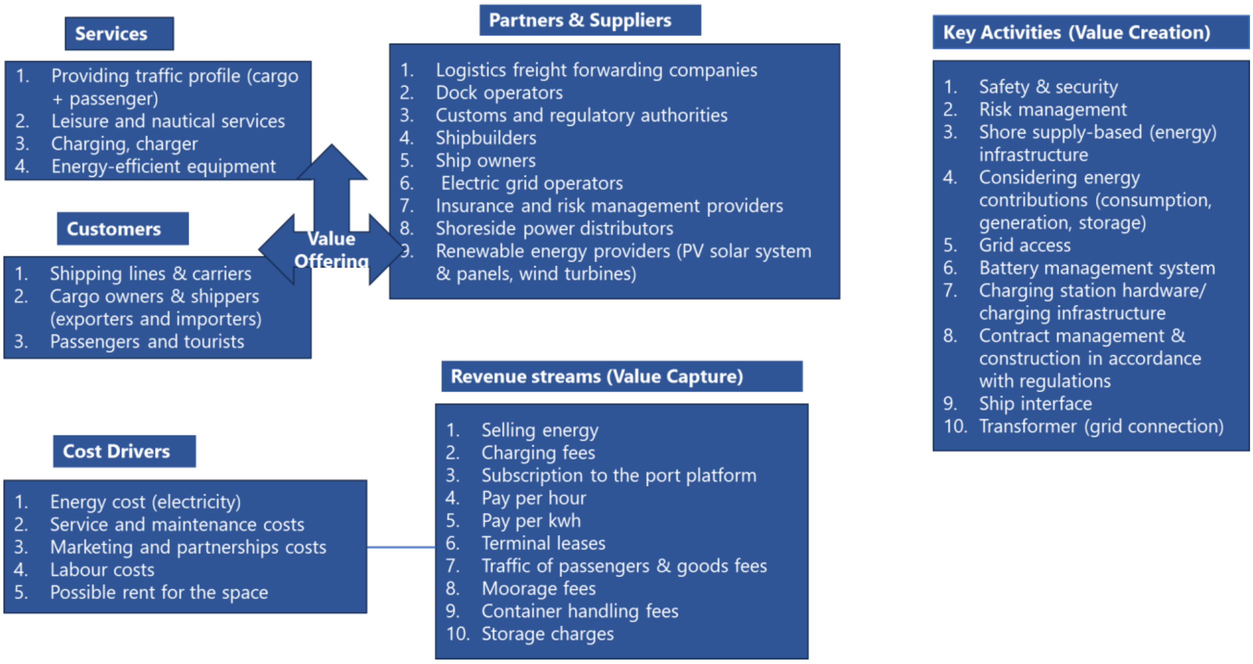

Figure 11 Business model for En Route scenario 3

Figure 11 shows the business model for the En Route to net zero scenario. In this context, a port could have abundant access to cheap clean energy from the grid and grid capacity is deemed acceptable (medium) to meet the demand. Additionally, ports are likely to need to address the climate change challenges through sustainability initiatives. This incentivises extensive use of electricity to provide services including charging and energy-efficient equipment on top of regular services offered by a port, such as leisure and nautical services as appropriate. Although the cost of energy from renewable sources is low, the cost of services and consequently a port's cost structure might be affected by the cost of investments on assets and technologies which take advantage of the low renewable energy as well as maintenance, labour and marketing and partnership costs. Accordingly, port revenue is likely to decrease, with income earned coming mainly from, for example, charging fees, selling energy, traffic of passengers and goods, moorage fees or subscription to port platform, as appropriate. Government initiatives and funding for net zero transition is likely to be low. Combined with a mid-level of demand for zero emission transportation, a port may not invest heavily in infrastructure development, electrical grid adoption and digitalised operations. Thus, port revenue and services might remain limited. Although technology development continues, opportunities for optimization of port activities (e.g., maintenance) and data utilization are not likely to be taken. There is unlikely to be strong investment in developing innovative technologies alone or through collaborations with partners, such as academia, other ports, electric grid operators, renewable energy providers, shoreside power distributors and dock operators.

6.2.4 Scenario 4 – In Irons Business Model

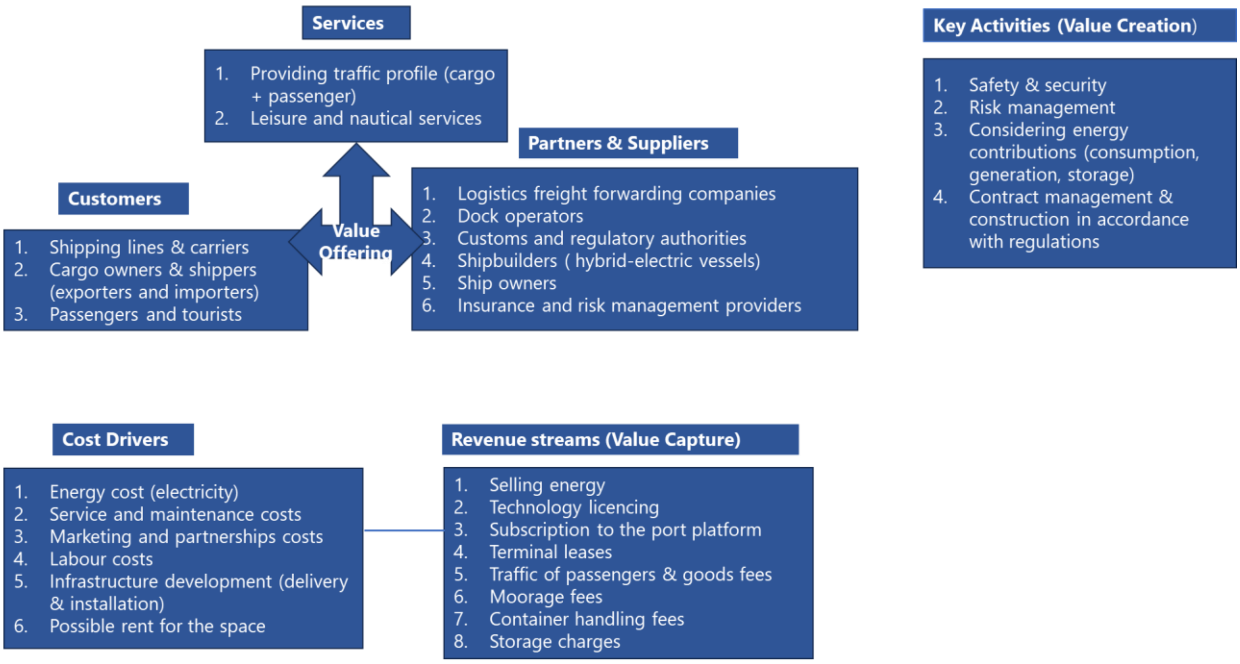

Figure 12 Business model for In Irons scenario 4

Figure 12 shows the business model for the In Irons scenario. In this context, climate change has led to high temperature increases meaning that a port's key activities on energy consumption, energy generation and energy storage strategies are likely to have become very important. As the cost of energy from alternative sources rises, services based on electricity are likely to reduce. This may lead to a change in the types of vessels that can be serviced. If resources are scarce, then they are likely to be expensive. Limited development of grid infrastructure and low renewable energy supply in this context, implies any growth in the revenue streams may be constrained meaning less profit margin. This is likely to lead to less investment by a port into the initiatives such as developing the electrification infrastructure. In turn, this could result in a limited number of electric vessels using the port, and hence less charging need and income. Since the level of demand for electrified ports is likely to be relatively low then the level of global funding for developing port infrastructure is also likely to shrink with the consequences that no/limited new services can be created. Even through the stability of the supply chain suggests a demand from, for example, logistics and freight forwarding companies since they might be facing no major challenges. Even though there is likely to be advancement in digitalization, the level of energy optimization might be low and thus the resources could not be fully exploited. This indicates that the level of port integration with the battery supply chain, electric charging suppliers and renewable energy providers might be limited or not very efficient. A port might mainly generate revenue by selling fossil fuels, moorage fees, container handling fees, traffic of passengers and goods fees, terminal leases, and subscription to the port platforms, as appropriate. The main cost drivers for a port are likely to be energy cost (mainly fossil fuels), service and maintenance cost and labour cost.

6.3 Summary

By presenting multiple alternative business models towards net-zero transition, the examples illustrate how different external environments in which the business might operate could affect the drivers for revenue generation and costs. The implications of different contexts reveal different priorities for the service offering, the degree of investment, the nature of partnerships in each situation and the consequences for revenue generation, costs and hence profitability.

The business models presented are theoretical only and framed from the perspective of the port within an ecosystem. Real business models belong to an organization and can be developed in partnership with relevant decision-makers and organizational participants using, for example, an extended business model canvas approach (Figure 4). This will enable translation of the abstracted business modelling reasoning presented in this section to the use context of a specific port owner/authority and the associated network of suppliers and partners in the ecosystem.

7. DECISION MODEL FOR PORT ADOPTING CHARGING SYSTEM

7.1 Model Purpose and Framing

The decision model is framed from the perspective of the port decision-maker who needs analysis to inform choices associated with creating business value from adoption of the hyper powered battery charging solution. The model brings together the business elements of the technology innovation to create analysis aligned with understanding the technology adoption risk.

The model purpose is to inform choices made by a port regarding the value to be generated by adopting the hyper powered battery charging system in view of the associated uncertainties arising due to the technology, industry, and contextual business environment. The methodological approach shown in Figure 2 has been used to create the model.

7.2 Qualitative Representation of Decision Model

The graphical version of the qualitative decision model was developed through a collaborative effort with all Task 6.2 partners (see Figure 2 in Section 4.3). Partners from Valencia Port and Frisia Port played a key role in the initial stages of model development. To capture the real-world complexities faced by port operators, interviews were conducted and focused on identifying the critical decisions ports make, the uncertainties they encounter, and the objectives they aim to optimise. Based on insights gathered from these interviews, a preliminary decision model was created.

Additionally, to determine the model boundary and scope we considered both the clusters of driving forces created during the foresighting process (Section 5) and the characteristics of the business models developed under the four future business environment scenarios (Section 6). Most future driving uncertainties are out with the bounds of the decision model, but they can be built into downstream analysis (e.g., simulation experiments) to examine the robustness of choices in view of external, uncontrollable factors in the business environment.

7.2.1 Graphical Version of Model

Figure 13 shows the decision model in the form of a causal graph. Note we have followed conventional influence diagram notation in that a linked arrow leaves a decision node only. This implies decisions are dependent upon the nodes to which the decisions are connected, although the inferential logic allows analysis to be of the form: either “given a decision, then what might be the effect on a given performance indicator?”; or “given a need to optimise a set of performance indicators, then what is best setting of decision options?”.

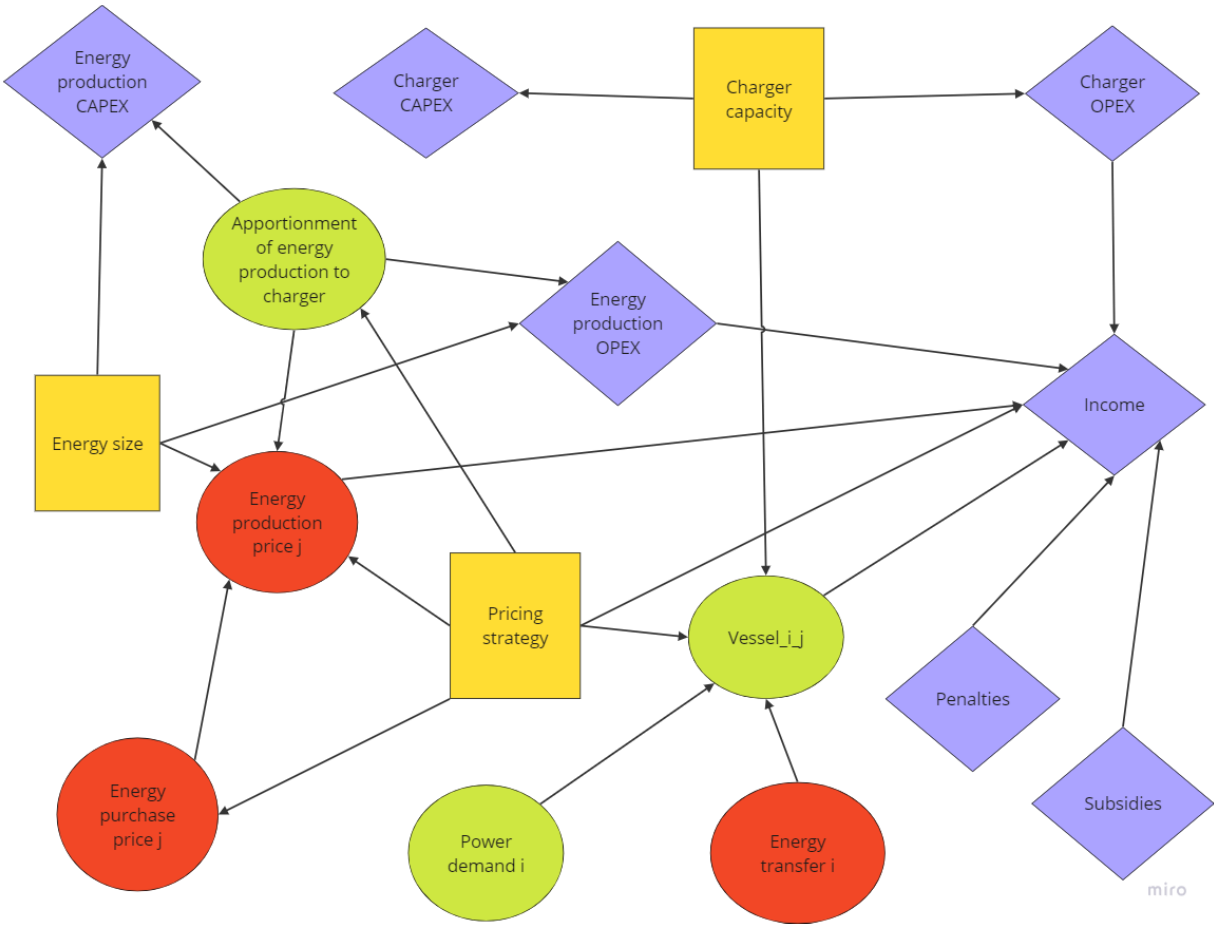

Figure 13 Decision model shown in form of a causal graph (yellow rectangles are decisions, red ovals are uncertain variables, green ovals are deterministic variables, diamonds are business key performance measures, arrows show dependency relationships)

7.2.2 Variables and Definitions

Table 5 through to Table 8 list the labels and descriptions of the variables in the decision model, grouped by the type of variable.

Table 5 Decision variables

Variable	Variable description
Charger capacity	This variable specifies the MW capacity of the hyper powered battery charging system.
Energy size	This variable specifies the anticipated MWh size of on-site energy production. This could be through the form of PV, wind, etc., and could also be associated with a stationary storage system (e.g., Battery Energy Storage System, see Section 12.4, Appendix 4). The user must specify the expected energy accessible per year.
Pricing strategy	This variable specifies the pricing strategy of the port. If 'static' is chosen, then the price is always the same. If 'variable' is chosen, the user must specify the % uplift during peak times.

Table 6 Consequence variables (i.e., business relevant key performance measures)

Variable	Variable description
Charger OPEX	This variable specifies the per day OPEX of the charging system.
Charger CAPEX	This variable specifies the CAPEX of the charging system.
Energy production OPEX	This variable specifies the per day OPEX of the energy production of the site.
Energy production CAPEX	This variable specifies the CAPEX of the site's energy production
Subsidies	This is the per day subsidies, if any, that the site gets for offering charging facilities.
Income	This variable is the per day income, minus the OPEX. This is calculated as the number of vessels charged of type *i* during time *j*, multiplied by the cost to customer, minus the OPEX of the charger, the OPEX of the energy production, and the penalties.
Penalties	This variable measures the financial penalty of not charging a vessel that arrives at the site.

Table 7 Deterministic variables

Variable	Variable description
Apportionment of energy production to charger	This variable, measured as a %, specifies the apportionment of the on-site energy production to the charger.
Vessel_*i*_*j*	This variable is the number of vessels of type_*i*, at time period_*j*, that arrive.
Power demand_*i*	This variable is the power demand, in MW, of vessel of type_*i*.

Table 8 Uncertain variables

Variable	Variable description
Energy production price_*j*	This variable is an uncertain variable, modelled using a triangular distribution. The user must provide a minimum, most likely, and maximum value. This variable measures the energy production price at time period *j*.
Energy purchase price_*j*	This variable is an uncertain variable, modelled using a triangular distribution. The user must provide a minimum, most likely, and maximum value. This variable measures the energy price at time period *j* that the site purchases.
Energy transfer_*i*	This variable is an uncertain variable, modelled using a triangular distribution. The user must provide a minimum, most likely, and maximum value. This variable measures the amount of MW that can be transferred per hour (i.e., MWh).

7.2.3 Interpretation of the Decision Model

The logical structure of the model can be described as follows.

The charger capacity chosen will impact both the charger OPEX and CAPEX, as well as impacting the charging capacity over a specific time period *j*.

The energy production solution chosen will impact the energy production OPEX and CAPEX. The energy production OPEX and CAPEX will also be impacted by the amount of energy that is apportioned to the charger from the overall site. For example, for a large site like Valencia Port, only a small amount of energy generated may be directed towards the charger. In contrast, for a smaller site like Frisia Port, a larger percentage of the energy produced may be directed towards the charger. The model allows for an adjustment in this way according to local site applicability.

The energy production solution will also impact the price of energy generated, particularly at different time periods of the day. Note that during discussions with partners, it was noted that different energy solutions would have different levels of certainty in terms of the cost of the energy. Hence, it was decided that the variable *Energy Production Price_j* would be considered as an uncertain variable.

The price of energy supplied to the customer is dependent on three things: first, the price of the energy generated; second, the percentage apportionment of generated energy to the charger, and third, the price of the energy purchased from an energy supplier. Note that this new variable, *Energy Purchase Price*, was also considered to be an uncertain variable. Both sites (Valencia and Frisia Ports) had differing relationships with energy suppliers that meant that different levels of certainty about the cost could be assumed.

The price of energy supplied to the customer together with the pricing strategy adopted influences the cost to vessel *i* at time *j*. While not at the forefront of the ports view at present, over time it may become natural that different types of vessels would be charged more (potentially to prioritise them), or that different vessels would be charged more at different times of the day (e.g., depending on the cost of energy at that time), or due there is some sort of modification in the pricing strategy. It is assumed that the pricing strategy could remain static (i.e., customers all pay the same uplift on the cost of energy), or that different uplifts could be applied at different time (i.e., a premium may be made for customers charging during peak times, and a discount offered to customers during off-peak times).

The key business performance indicator of the model is *Income*. This is influenced by two variables; the number of vessels of each type over the entire day multiplied by the cost of the energy to the different customers. A key variable is the number of vessels of each type that can be charged throughout the day. There are several factors to consider when determining the number of vessels that can be charged. First, how many vessels of each type and at what time of day vessels arrive to be charged? Second, for the number of vessels that place a demand on the charger, does the charger have sufficient capacity to charge all vessels? Third, for the number of vessels that place a demand on the charging system, is there sufficient time to charge them all in the time period? To calculate this, we need to know the power demand of the vessel and the charge time. At this stage, it was considered that the charge time was an important variable to model as an uncertain variable, as current technology remains uncertain, and future developments may mean significant improvements over a longer time period.

Consequently, we can calculate the number of vessels charged, and therefore the income generated, and at the same time we can calculate the number of vessels not charged. With this, and the estimated penalty or reputational damage not offering services (which may be zero), we can calculate any potential loss. This can then be included within the income.

7.3 Assumptions

Key assumptions underpinning the decision model are the following.

1. We assume that the cost charged to the customer is a % uplift of the cost to produce/buy the energy. Note that it is possible that this may take a value of zero, where the transfer of energy is within the organization, and hence considered to be 'at-cost'. During conversations with both ports, they felt it was unlikely that a commercial price would be set, but rather a price dependent on the cost of energy to produce.
2. We assume that all vessels of a certain type require the same amount of power during charging, and that the speed of charge, is only dependent on the type of vessel. This assumption can be easily modified by simply extending the type of vessels, i.e,. i.
3. We assume the underlying process representing the decision model over the time horizon of analysis is stationary.
4. For simplicity we assume that any partially charged vessels do not count towards the income.
5. We assume that a port will choose to consume energy from the cheapest available source (e.g., own production, grid).
6. We assume there is no degradation in the charging system reliability, although this could be relaxed should degradation condition impact performance.
7. We assume the variation in the uncertain variables is represented by a triangular distribution for mathematical convenience. This can be modified by changing to alternative probability distributions although this will bring extra complexity in uncertainty elicitation.
8. For each uncertain variable, we simulate 1000 possible realisations. These uncertainties in the three variables are propagated across the decision model. 1000 is chosen for the number of simulations to ensure reasonable statistically reliable results. The number of simulations can be modified to increase if greater estimation precision is required. Reducing the number of simulations implies we might get less reliable estimates.

7.4 Computational Model

The validation process for the above decision model involved Task 6.2 partners, including the Ports of Valencia and Frisia. These partners evaluated the model's logic and relevance, ensuring that it effectively represents the decision-making environment and challenges specific to ports making implementation decisions regarding the hyper-powered battery charging system. Post face validation, the analytical model has been codified in a spreadsheet tool to support analysis.

7.5 Example Application

To demonstrate how the model can be used, we explore a case study using realistic but fictional data. The purpose of this example is to demonstrate how the output of the model can be interpreted by a decision maker and used to support a wider consideration of the decision options. Data was provided by Otaskies.

The analytical focus of the model is on the variable *Income*. As such, here, we focus on exploring the range of outputs for *Income*, given the deterministic and uncertain outputs provided. As a reminder, for each of the uncertain variables, we simulate 1000 runs. However, to simplify the visuals, we truncate to show the first 100 runs only.

Figure 14 - Figure 16 show scatterplots showing the results of income for the range of simulated values for the variables *Energy Purchase Price*, *Energy Production Price* and *Energy Transfer*.

Note: this is a fictional example and any conclusions drawn from these figures are for illustrative purposes only.

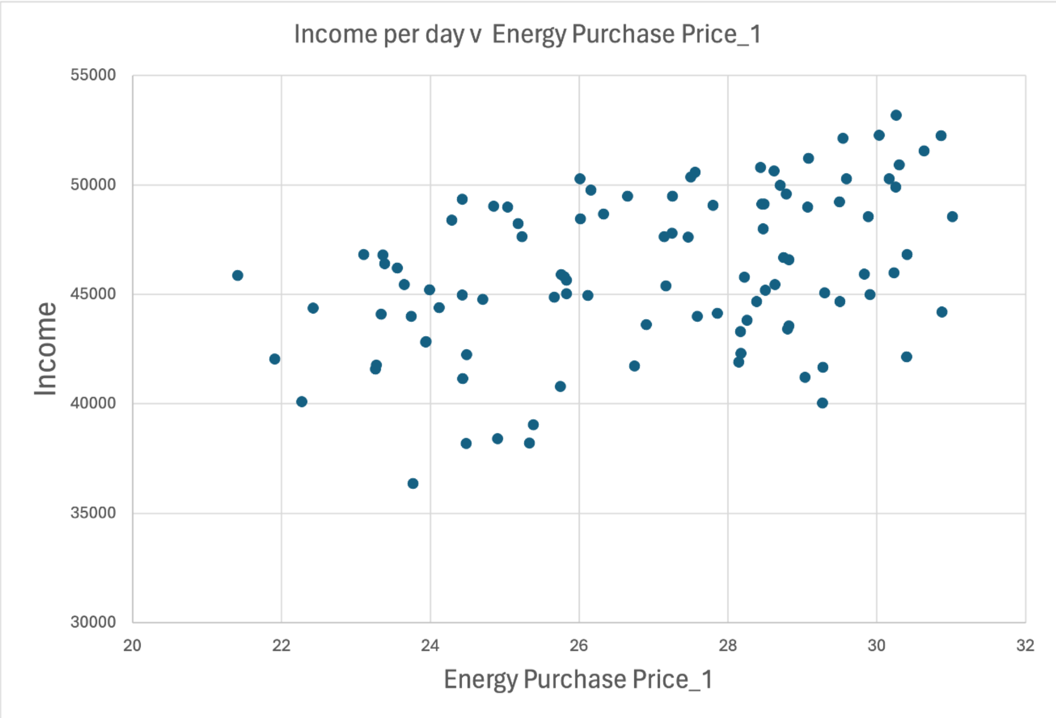

Figure 14 Scatterplot showing the change in income per day for varying values of energy purchase price, illustrating a positive relationship between price of purchasing energy and income.

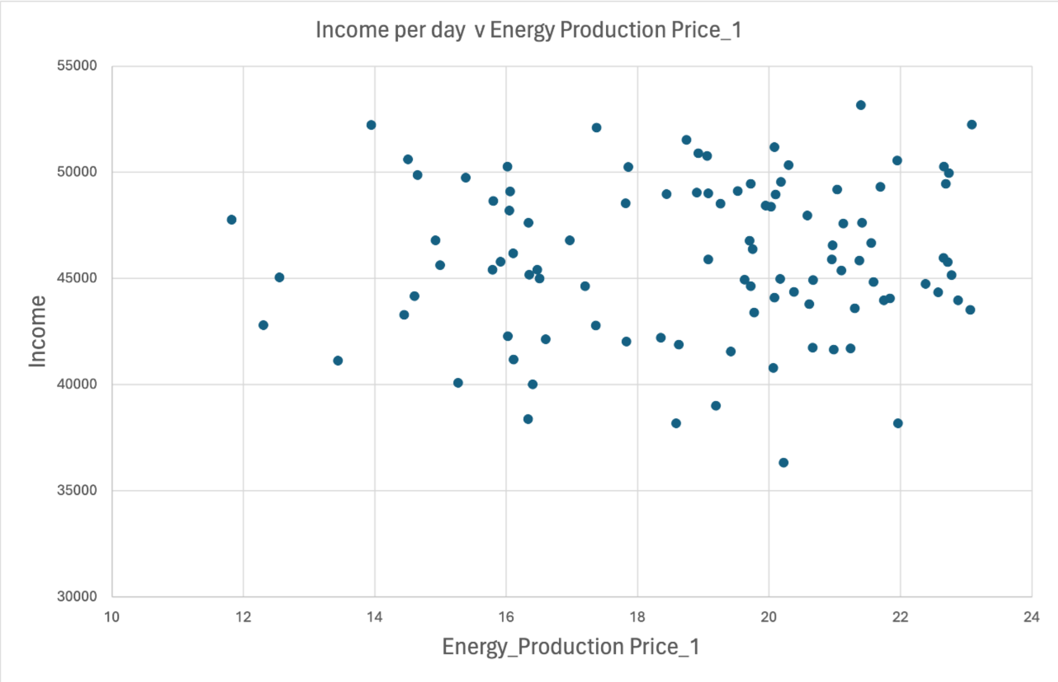

Figure 15 Scatterplot showing the change in income per day for varying values of energy production price, illustrating a lack of relationship between production and income.

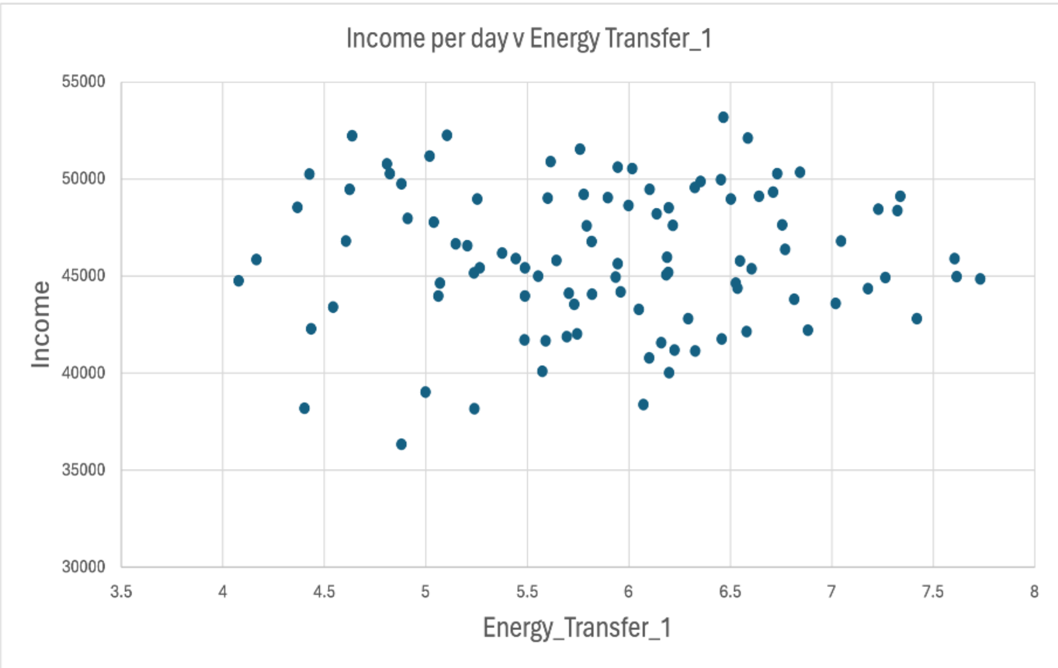

Figure 16 Scatterplot showing the change in income per day for varying values of MW of energy transferred per time period, illustrating a weak relationship between energy transfer and income.

Figure 14 and Figure 15, respectively, show that the income per day for a port increases slightly or negligibly as the costs for producing its own energy increases and as the costs of purchasing energy increases. As the model uses an uplift of energy prices to calculate the cost to customer, this result is rather obvious. However, the model shows that the relationship with income seems to be stronger for the situation where a port purchases energy rather than producing its own energy. This may be due to the relatively low amount of apportionment of energy produced to the actual charger in this example and the model assumption that a port will use energy from the cheapest energy source.

Figure 16 shows evidence of no relationship between the energy transfer time and income. No conclusions should be drawn from this other than the model supports the investigation of changes in parameters that will be of interest to the wider stakeholders in the project.

The model also allows comparisons to be made between different groups of decisions. For example, we can explore the potential impact of spending more on energy production, thereby increasing CAPEX and OPEX, but potentially reducing the cost to the customer. We can explore purchasing larger transfer capacity, or by purchasing an 'improved' charger that transfers energy quicker. The model facilitates the exploration of the impact of these technology innovations against key business performance indicators with analysis providing evidence for a business case.

To illustrate the model capability, we ran four additional cases with the model (in addition to the case reported above), modifying certain variables such as CAPEX and OPEX, as we change the engineering capability of the system. For example, to consider choices between different number of modular charging systems each capable of servicing different vessel demand profiles. Since we aim only to illustrate the capability of the model, we choose example settings only. In future applications, justifying the choice of engineering capability settings and interpreting the meaning of results for port decision-makers will be important and will be a downstream activity in Workpackage 6.

Figure 17 illustrates a box plot for the five cases corresponding to the each of the different hypothetical decision sets, showing the spread and overlap of each. While Figure 18 illustrates the change in income against changing CAPEX.

Figure 17 shows considerable overlap between to four of the five the boxplots corresponding the decision cases. Decision cases 4 and 5 have much larger spreads on the potential income generated under these options. In comparison decision case 2 has a smaller spread.

However, the analysis shown in Figure 17 does not take CAPEX into account, yet it is reasonable for a decision maker to want to consider the change in CAPEX against income. Hence the income distribution (in terms of its minimum, mean, and maximum) is shown in Figure 18 for a range of CAPEX values associated with the same five decision cases. The visual illustrates the trade-off between CAPEX and predictability of income generation with the cheapest decision case (case 1) showing relatively greater spread in income for lowest CAPEX investment. For the values given, it is estimated to take between 402 days and 660 days for the CAPEX costs to be recouped.

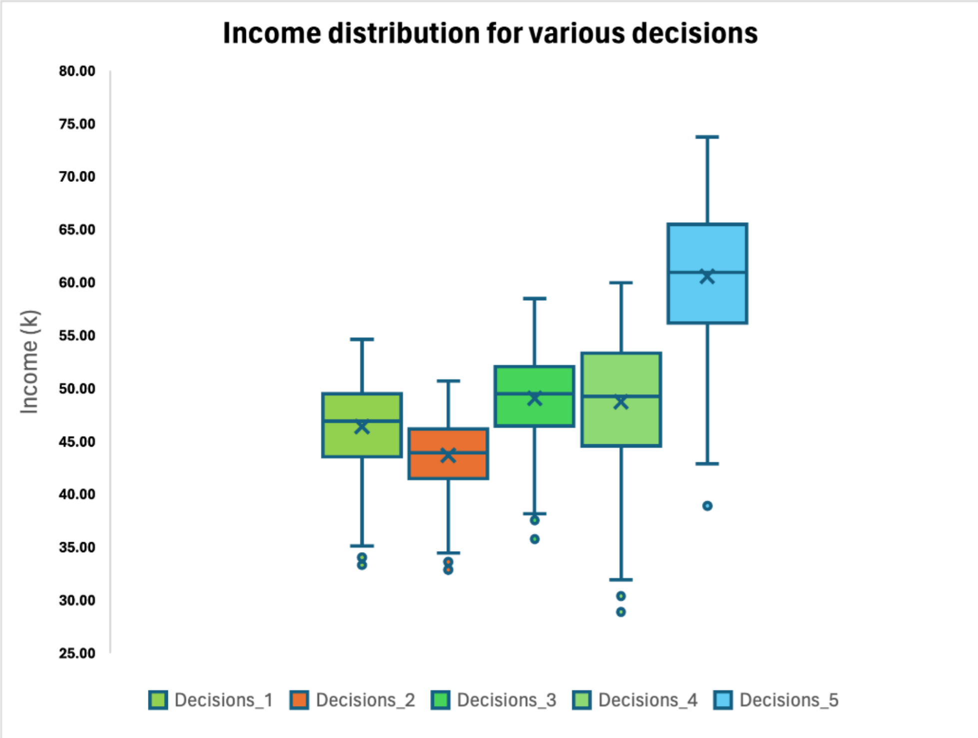

Figure 17 Boxplots showing the change in income distribution for five different hypothetical cases (Decisions 1 -5), illustrating that different decisions can lead to wider spread and higher income

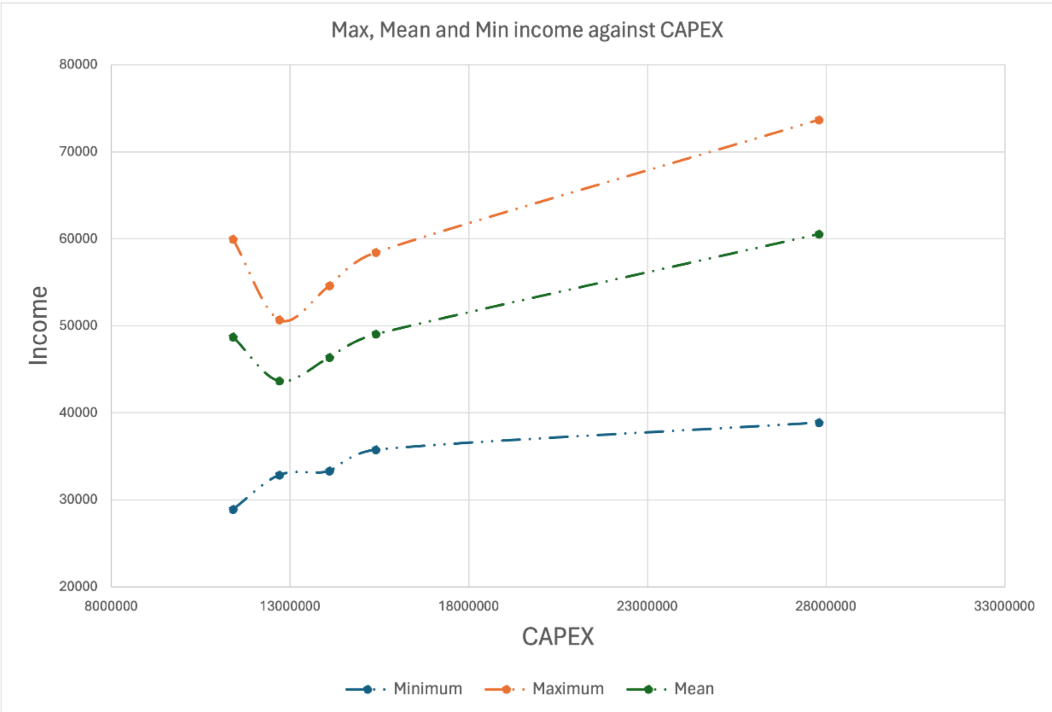

Figure 18 Scatterplot showing the change in income (max, mean, min) given changes in CAPEX illustrating for the five decision cases (marked by circles) where income tends to increase as CAPEX increases, with the cheapest option having a greater relative spread

7.6 Summary

A novel decision model bespoke to HYPOBATT has been co-created with partners and expressed visually and codified in a spreadsheet tool to enable analysis.

All assumptions made in this version of the model can be relaxed and a more complex version of the model developed if required by relaxing relevant assumptions. At this stage, the basic model is requisite to explicate relationships between variables important to supporting a first-order analysis of the business value from adopting a hyper powered battery charging system.

Analysis has been shown for an example informed by the problem context. This is a fictional example only since the primary purpose is to illustrate the application of the model. Extended and more exhaustive analysis can be conducted in later tasks for Work Package 6. For example, to explore the robustness of decision options under future business environments for use cases.

8. DISSEMINATION, EXPLOITATION AND STANDARDISATION

To the best of our knowledge there is no reported analysis of the work discussed in this deliverable. That is no reported foresighting of sustainable maritime transportation, or eco-systemic business modelling for electrified ports, or decision models to provide analytical evidence to inform choices facing ports choosing to adopt a hyper powered battery charging system. Hence the work reported in this deliverable will be further developed for scholarly academic publication as well as wider dissemination to practice via conferences/industry publications.

9. CRITICAL RISKS

Critical risks assessed by Work Package 6 leads for the remaining tasks (Tasks 6.3-Tasks 6.5) are as follows.

ID	WP/ Task	Risk item	Effect	Proba-bility[1]	Sever -ity[2]	Counter measures	Risk owner
	WP6	Not being able to provide interlinks in developing the business models' and associated method-ology	Mod-erate	Mod-erate	Mod-erate	Development of business models based existing interlinks and using similar approach in the automotive sector	OTASKIES
	WP1 WP2 WP3 WP5 WP6	Battery lifetime degrad-ation in demon-stration not in accord-ance with estimated and required to achieve the calculated TCO	Major	Mod-erate	Med-ium-High	Improved charging profiles and thermal precondition-ing of battery pack controlled by the charger to minimize effect of charging on degradation	BRING, OTASKIES

[1] Severity / Contribution to the failure of the project: Negligible, minor, serious, critical, catastrophic

[2] Probability of occurrence: improbable, remote probable, medium, probable, definite

	WP3 WP4 WP6	Not being able to come up with a modular solution that remains cost effective in the business case	Mod-erate	Mod-erate	Mod-erate	Heliox and STT have a good knowledge of the market and what is a conform pricing, if based on that the WP6 calculated TCO becomes too high, other module and cabinet sizing to be chosen to optimize it.	HELIOX, STT
	WP5 WP6	FRISIA Energy cost is around 250.000EUR instead of 40.000EUR, due to the grid's fee above 1.5KV.	Extreme	Likely	High	Power Cabinet's output to be maintained at 2.5MW while peak input coming from the grid to be capped at 400kW	FRISIA, ALL

10. CONCLUSIONS

The business modelling approach created is distinctive to the project, both in terms of the mixing of methods and the models created by applying the methods. While scenario planning and business model creation combinations are typical in practice, our extension to create models capable of supporting quantitative rather than just qualitative analysis for specific business decisions is novel. The combination of modelling methods to examine business implications of technology innovation framed for different decision-making scopes and temporal implications is a contribution beyond the state of the art.

Through appropriate co-creation and use of relevant secondary data, the modelling and analysis has delivered the following outputs.

1. Future scenarios of the maritime transportation business environment in which ports and other actors in the ecosystem might be operating. The scenarios represent contrasting contexts covering the degree to which net zero transition occurs driven by, e.g., speed of climate change, alternative energy costs, government policies, electrical grid capacity, global supply chain stability.
2. Multiple alternative qualitative business models for the port ecosystem, reasoned by combining theoretical knowledge of the relationship between business model elements and applied knowledge represented in the future business environment scenarios. These models articulate the value creation (key activities), proposition (service offering) and capture (revenue streams) arising from the interplay between supply and demand, partnerships, and suppliers.
3. A quantitative decision model to support analysis of key choices facing managers responsible for making/informing decisions about the adoption of a hyper powered battery charging system. An example illustrates the application of the co-created decision model using a prototype computational spreadsheet tool.

All methods embrace uncertainties that may be realised over different time horizons. Foresighting considers the longer-term uncertainties (especially events that cannot be predetermined) for the wider business environment, while the decision model considers more localised nearer-term business contexts recognising that investment payback from adopting the charging system might be over much longer time periods. Methods used are grounded in causal reasoning and co-created drawing on the knowledge of relevant partners and analysts to ensure we balance problem application meaning with theoretical coherence.

Limitations of the work include:

1. *Co-creation has been with partners within the project only* - while these partners cover a cross-section of knowledge across the maritime transportation context, we acknowledge that there is incomplete coverage of knowledge bases (e.g., limited number of ports, limited representation of business decision-makers).
2. *Scenarios have been co-created for 2050* – this was justified as the date by which the EU aims to transition to net zero. This might be viewed as a lengthy time horizon in

relation to typical business cycles. The scenario creation process as implemented required us to accommodate a mix of in-person and virtual activities over a staggered calendar time window (see Table 1). This meant discontinuities occurred in the causal and temporal reasoning processes of participants (who also varied in some cases between activities at different steps). When using the scenarios for further analysis (e.g., experimental simulations under different business environments to assess robustness in use cases), we recommend further consideration of the temporal causality of scenario driving forces.

3. *Eco-systemic business models are theoretical only* – while business model creation is usually a qualitative process, it is one that typically involves those within organizations possessing the power to make and influence decisions. In this work we have been limited to drawing on our knowledge of the application domain via secondary data – some specific to the project as documented in deliverables, and some general to the sector as reported in public documents, articles, and reports. The models presented should be regarded as indicative only until these are fully developed in bespoke decision-making contexts for organizations.
4. *Decision model analysis reports illustrative example* – the decision model formalism has been co-created, face validated and verified in partnership with relevant knowledge partners. Of the stated key assumptions, some are quite restrictive but could be relaxed to extend the modelling capabilities. Only one fictional example is presented. While useful to show how the model can be populated and interpreted, the analysis to date should be regarded as proof-of-concept and the basis for supporting further analysis (e.g., use cases).

The Task 6.2 results reported collectively enable delivery against the stated objectives.

- To foresight future business environments in which ports and other actors in the ecosystem might plausibly operate.
- To create multiple business model alternatives for the port ecosystem and the associated value proposition under sets of plausible future business environments.
- To create a replicable modelling process to support analysis of different business models by explicating dependencies between different uncertainties and the relationships between inputs (choices) and outputs (business consequences/KPIs).
- To inform the evaluation space for use cases drawing on future scenario characteristics and framing of model decision support.

The results reported facilitate the achievement of the following objectives through further work in WP6.

- Identification of early indicators of change informing the timely investment and strategic response of ports (e.g., through use of the scenarios created in the business strategy making process).
- Enabling the exploration of a range of port characteristics and market conditions to investigate profitability for the port owner/authority (e.g., through use case/simulation experiments).

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12. APPENDICES

12.1 Appendix 1 Driving Forces of Future Business Environment

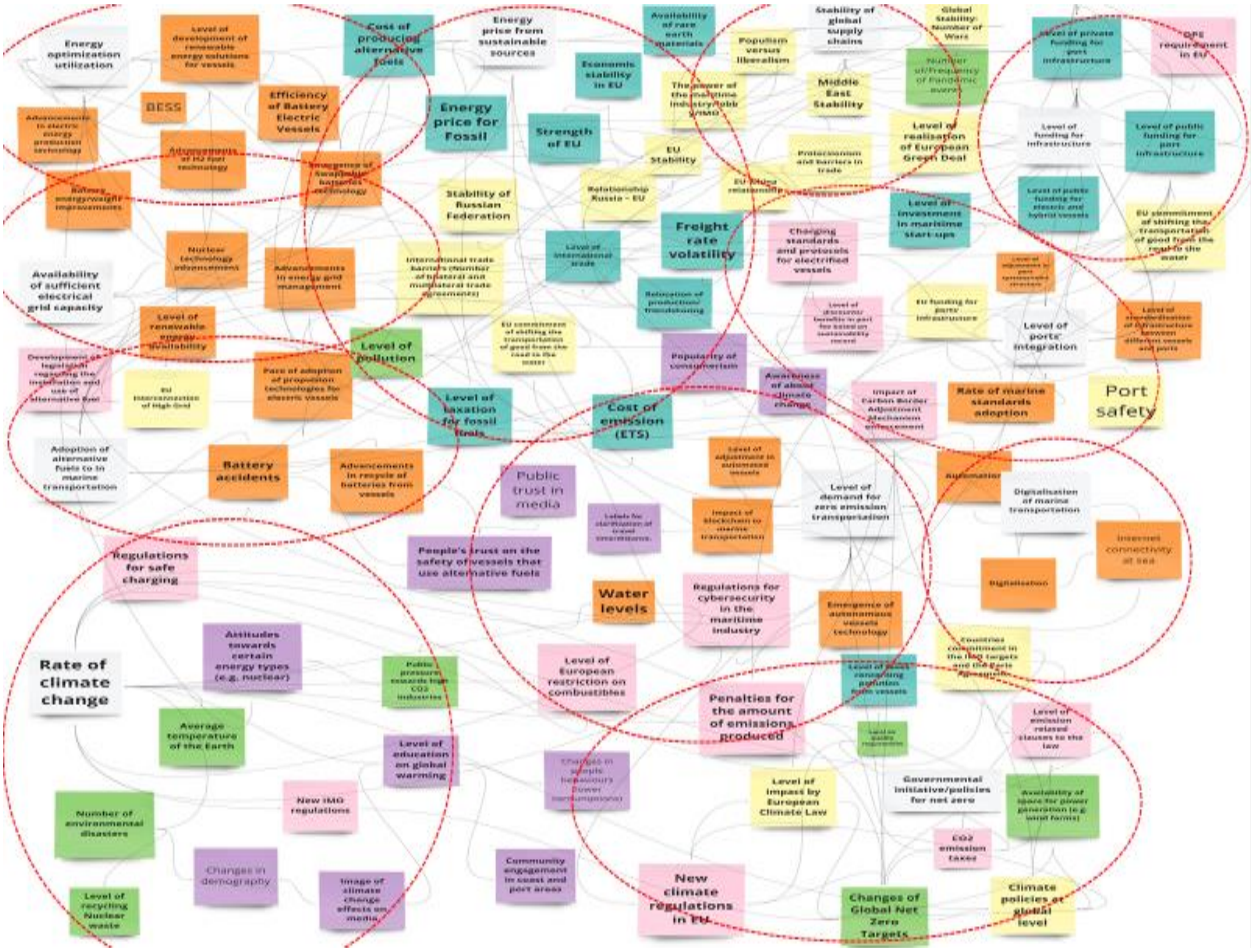
PESTLE Category	Driving Force
Political	Stability of Russian Federation
	Changes of Global Net Zero Targets
	Pressures/lobbying from non-green industries
	Countries commitment in the IMO targets and the Paris Agreement
	EU funding for ports' infrastructure
	Relationship Russia – EU
	EU Stability
	Port safety
	EU commitment of shifting the transportation of good from the road to the water
	National funding for ports' infrastructure
	EU Interconnection of High Grid
	Middle East Stability
	Global Stability: Number of Wars
	Level of realisation of European Green Deal
	International trade barriers (Number of bilateral and multilateral trade agreements)
	EU- China relationship
	The power of the maritime industry/lobby/IMO
	Level of impact by European Climate Law
Economic	Energy price from fossil fuel
	Energy price from sustainable sources
	Level of demand for zero emission transportation
	Availability of rare earth materials
	Level of unemployment
	Level of international trade
	Level of taxes concerning pollution from vessels
	Sustainability of Crypto currencies
	Cost of producing alternative fuels
	Level of taxation for fossil fuels
	Economic stability in EU
	Freight rate volatility
	Stability of global supply chains
	Level of investment in maritime start-ups
	Level of public funding for port infrastructure
	Level of private funding for port infrastructure
	Level of public funding for electric and hybrid vessels
Socio-Cultural	Labels for clarification of travel time/distance.
	Awareness of about climate change
	People's trust on the safety of vessels that use alternative fuels

	Image of climate change effects on media
	Birth rate
	Level of education on global warming
	Popularity of consumerism
	Attitudes towards certain energy types (e.g., nuclear)
	Public trust in media
	Level of demand for sustainable shipping
	Community engagement in coast and port areas
Technological	Level of ports' integration
	Emergence of Swappable batteries technology
	Adoption of alternative fuels to in maritime transportation
	Advancements of H_2 fuel technology
	Emergence of autonomous vessels technology
	Advancements in energy grid management
	Nuclear technology advancement
	Water levels
	Energy optimization utilization
	Battery accidents
	Advancements in electric energy production technology
	Availability of sufficient electrical grid capacity
	Efficiency of Battery Electric Vessels
	Maritime standards are not reached in 2030, so industry cannot really experiment a wide-spread uptake
	Level of adjustment in automated vessels
	Level of adjustment in port systems/infrastructure
	Level of standardisation of infrastructure between different vessels and ports
	Battery energy/weight improvements
	Impact of blockchain to maritime transportation
	Digitalisation
	Internet connective at sea
	Level of development of propulsion technologies for electric vessels
	Pace of adoption of propulsion technologies for electric vessels
	Level of development of renewable energy solutions for vessels
	Advancements in recycle of batteries from vessels
Environmental / Ecological	Local air quality requirement
	Availability of new routes through the north pole (due to climate change)
	Speed at which climate phenomena are occurring
	Number of/frequency of pandemic events
	Level of recycling nuclear waste
	Availability of space for power generation (e.g., wind farms)
	Average temperature of the Earth increases
	Level of pollution
	Public pressure towards high CO2 industries
Legal	Level of emission related clauses to the law
	Level of discounts/benefits in port fee based on sustainability record
	CO2 emission taxes

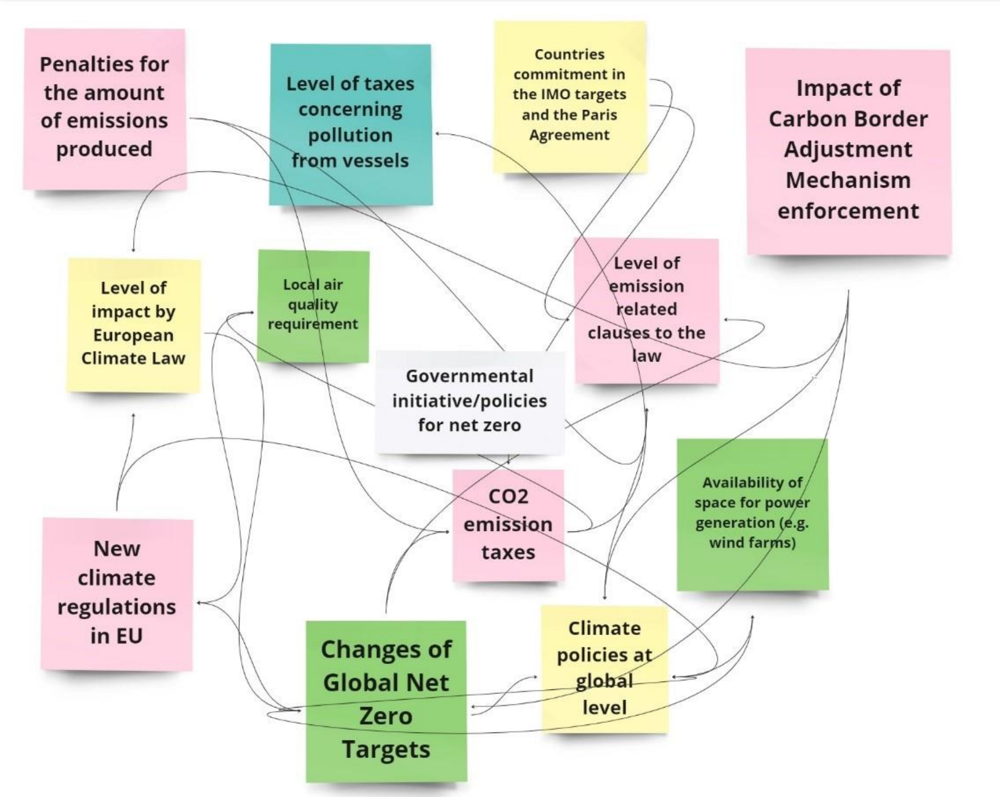
	OPS requirement in EU
	Development of clear legislation regarding the installation and use of alternative fuel
	Level of European restriction on combustibles
	Impact of Carbon Border Adjustment Mechanism enforcement
	Penalties for the amount of emission produced
	Legislation regarding biodiversity conservation
	Regulations for cybersecurity in the maritime industry
	Regulations for save charging
	Charging standards and protocols for electrified vessels

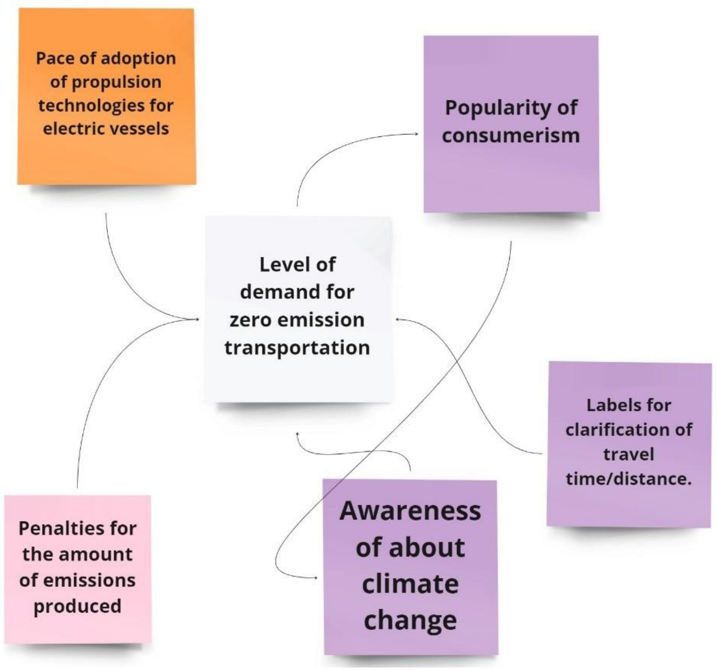
12.2 Appendix 2 Driving Force Cluster Relationships

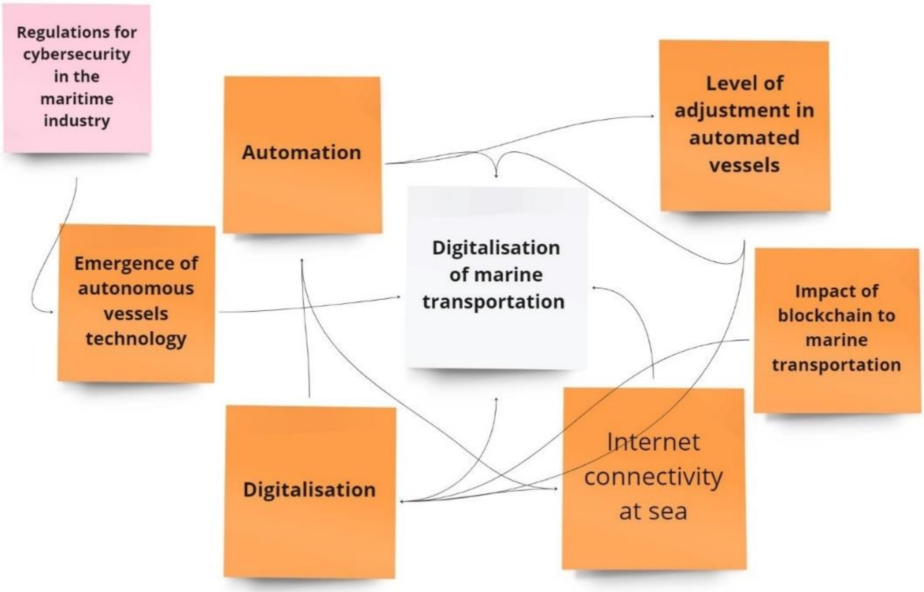
This appendix presents the clustering and clusters created with the brainstormed driving forces. This was conducted at step 3 of the scenario planning process and took place as a virtual facilitated workshop.

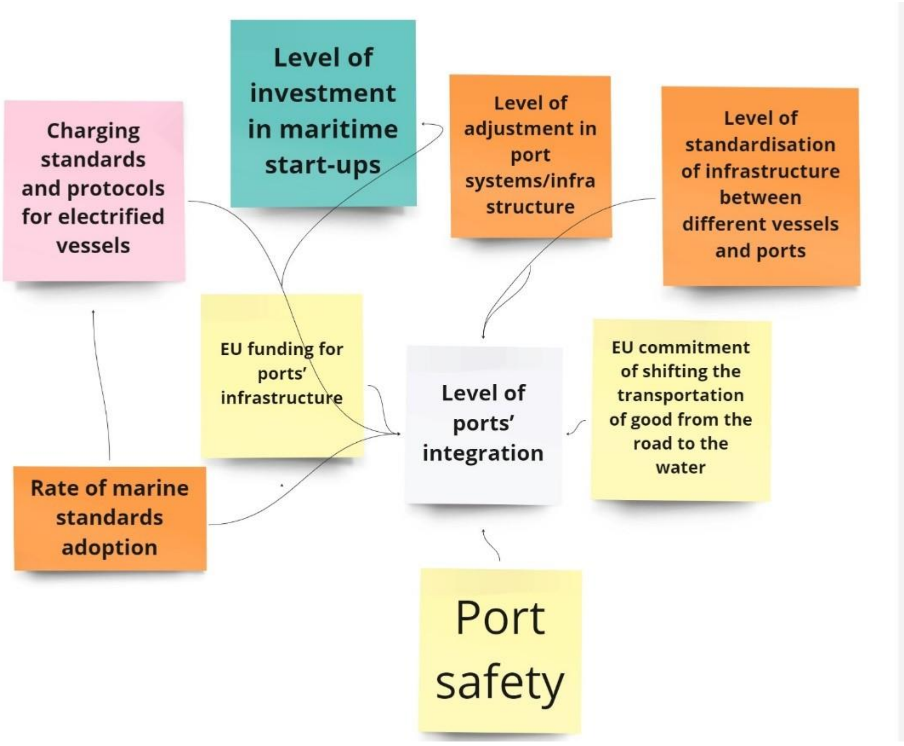


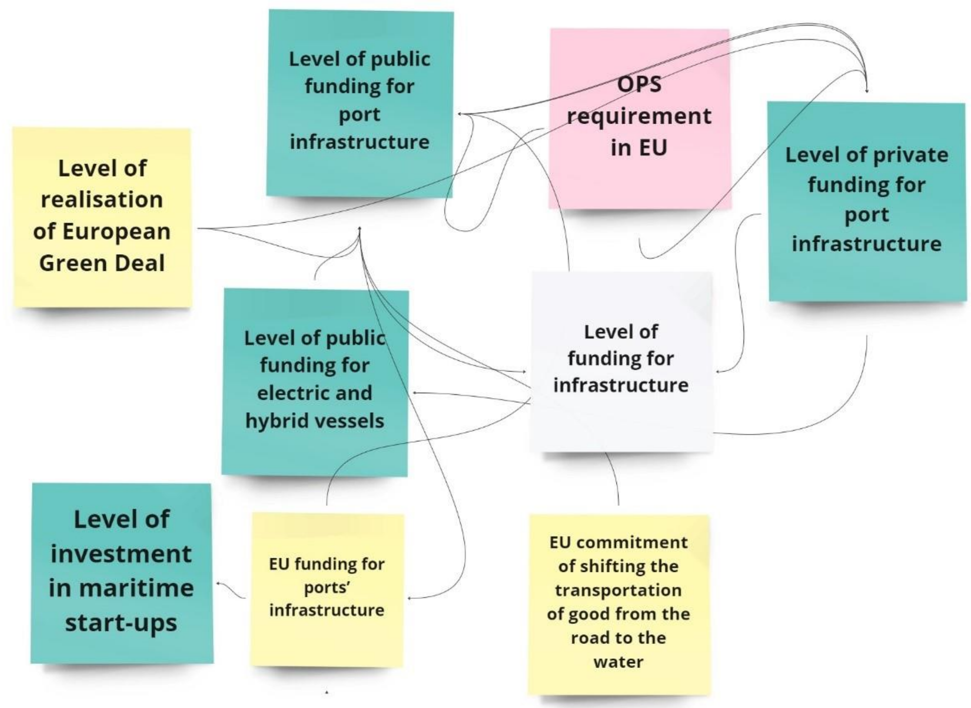
The visual above shows all clusters. To enable each cluster to be viewed in greater detail we reproduce these in the remainder of this appendix.

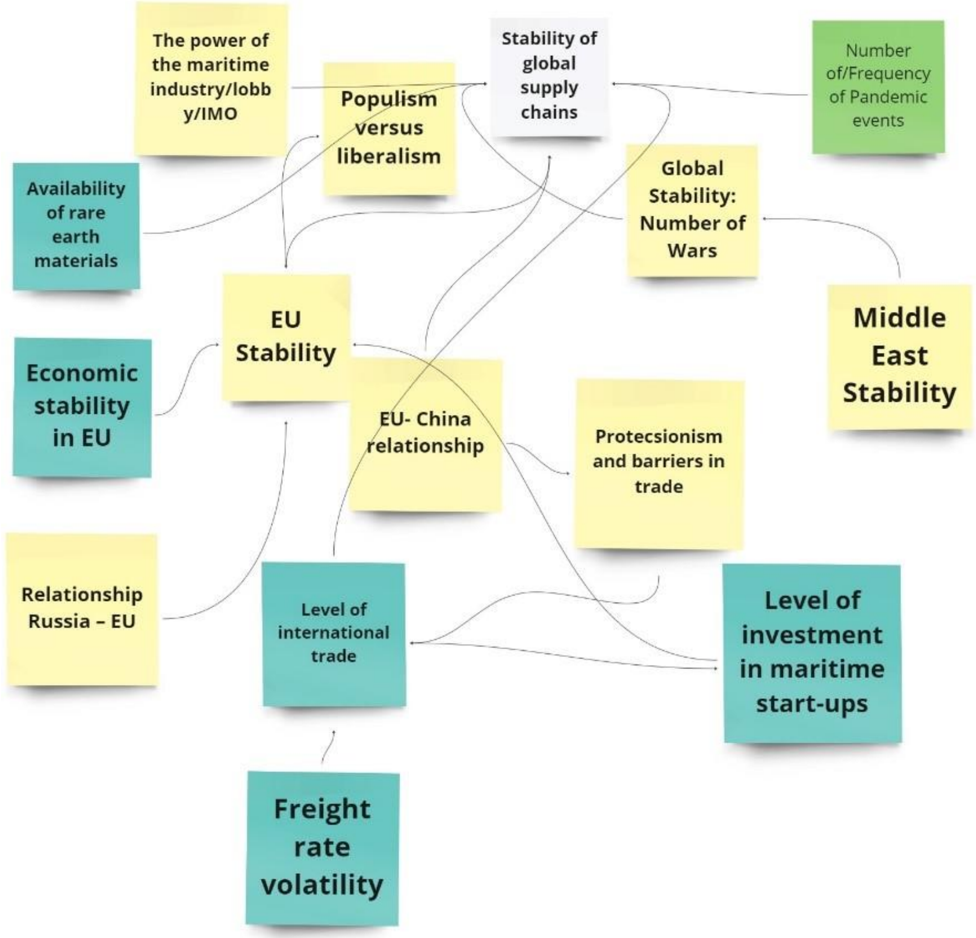

Penalties for the amount of emissions produced
Level of taxes concerning pollution from vessels
Countries commitment in the IMO targets and the Paris Agreement
Impact of Carbon Border Adjustment Mechanism enforcement
Level of impact by European Climate Law
Local air quality requirement
Level of emission related clauses to the law
Governmental initiative/policies for net zero
CO2 emission taxes
Availability of space for power generation (e.g. wind farms)
New climate regulations in EU
Changes of Global Net Zero Targets
Climate policies at global level

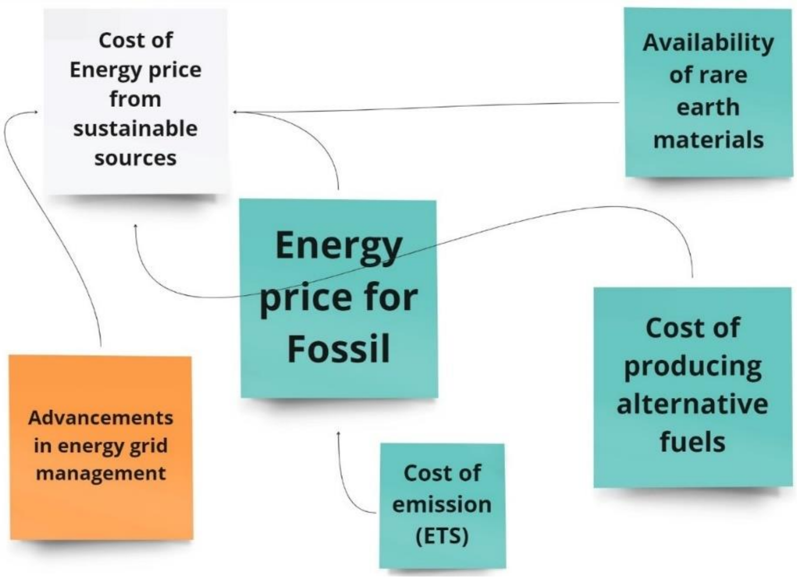

Pace of adoption of propulsion technologies for electric vessels
Popularity of consumerism
Level of demand for zero emission transportation
Labels for clarification of travel time/distance.
Penalties for the amount of emissions produced
Awareness of about climate change

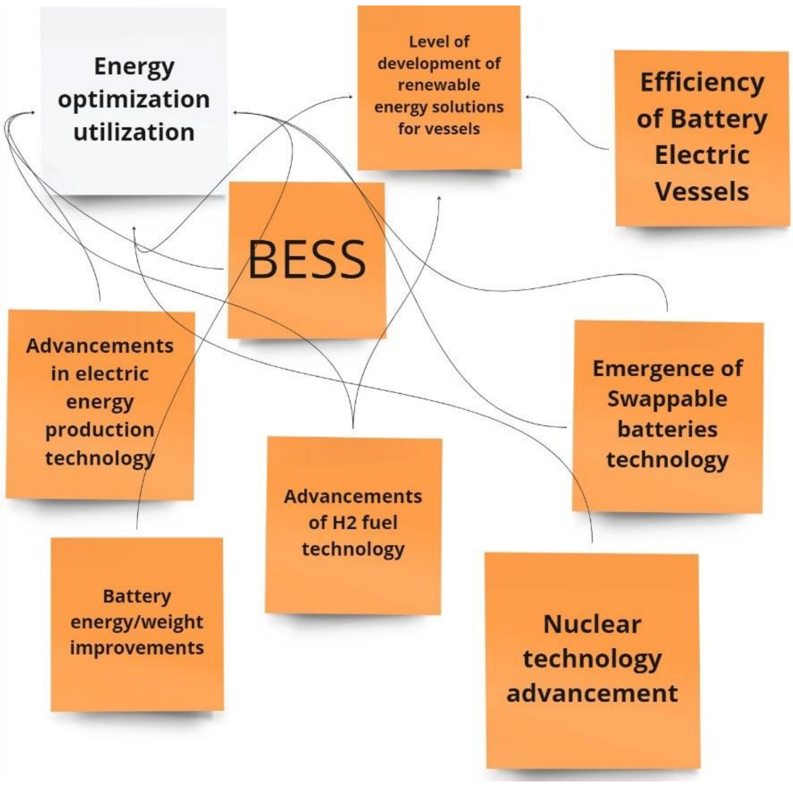

Regulations for cybersecurity in the maritime industry
Automation
Level of adjustment in automated vessels
Emergence of autonomous vessels technology
Digitalisation of marine transportation
Impact of blockchain to marine transportation
Digitalisation
Internet connectivity at sea

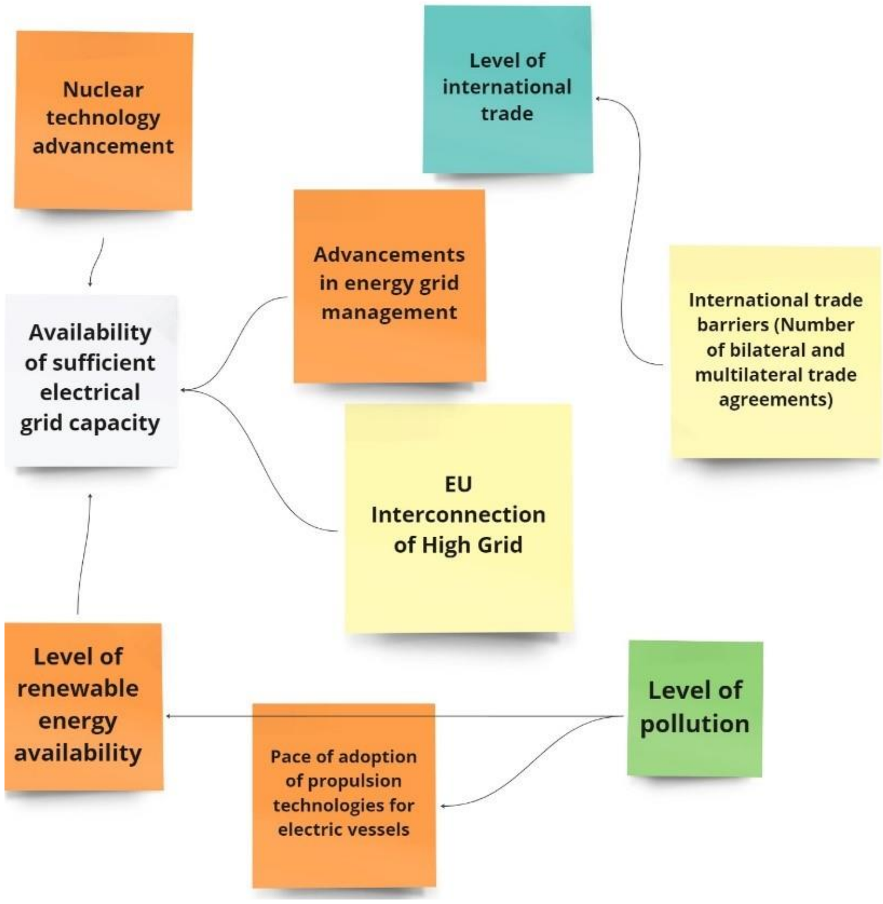

Level of investment in maritime start-ups
Charging standards and protocols for electrified vessels
Level of adjustment in port systems/infra structure
Level of standardisation of infrastructure between different vessels and ports
EU funding for ports' infrastructure
Level of ports' integration
EU commitment of shifting the transportation of good from the road to the water
Rate of marine standards adoption
Port safety

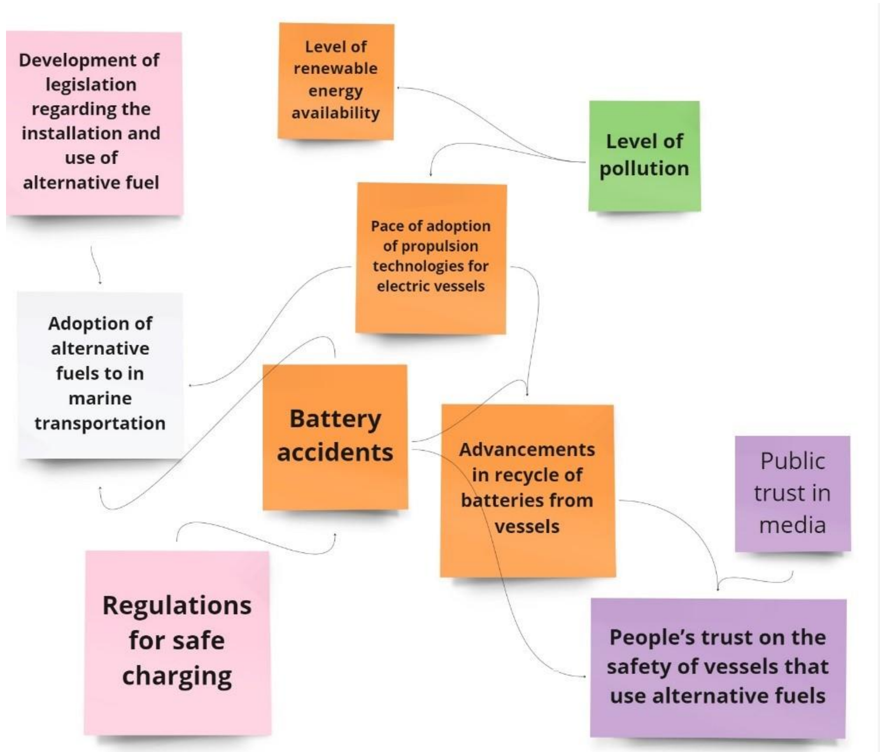

Level of public funding for port infrastructure
OPS requirement in EU
Level of realisation of European Green Deal
Level of private funding for port infrastructure
Level of public funding for electric and hybrid vessels
Level of funding for infrastructure
Level of investment in maritime start-ups
EU funding for ports' infrastructure
EU commitment of shifting the transportation of good from the road to the water

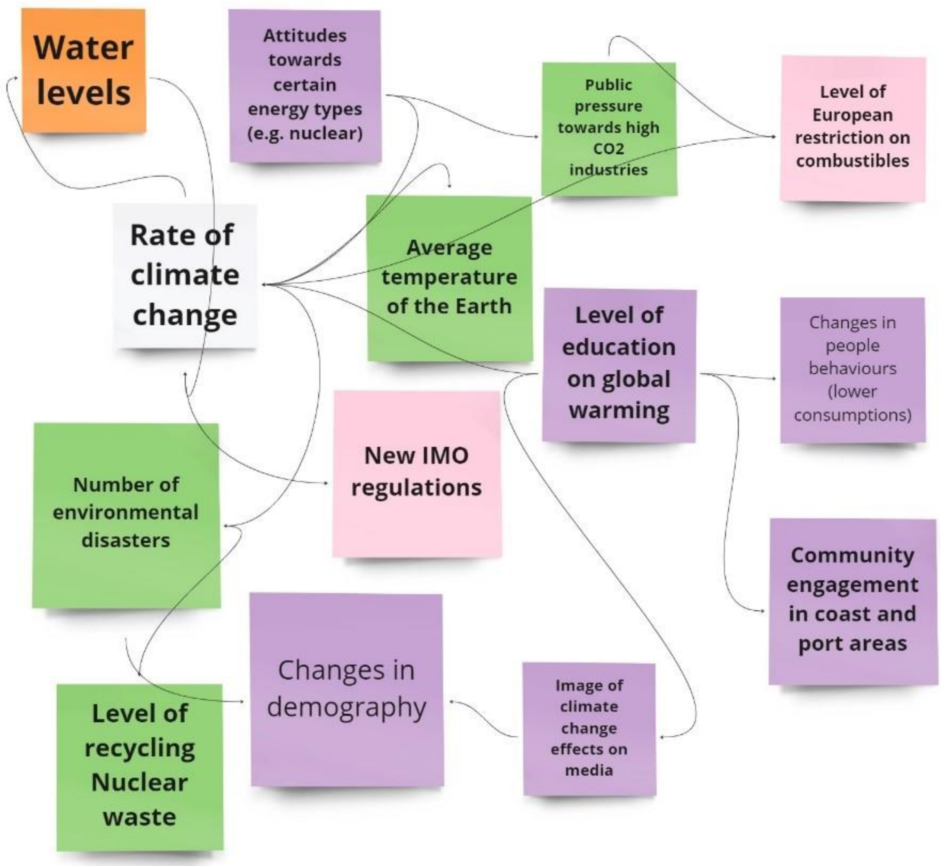

The power of the maritime industry/lobby/IMO
Populism versus liberalism
Stability of global supply chains
Number of/Frequency of Pandemic events
Availability of rare earth materials
Global Stability: Number of Wars
EU Stability
Middle East Stability
Economic stability in EU
EU- China relationship
Protecsionism and barriers in trade
Relationship Russia – EU
Level of international trade
Level of investment in maritime start-ups
Freight rate volatility


Cost of Energy price from sustainable sources
Availability of rare earth materials
Energy price for Fossil
Cost of producing alternative fuels
Advancements in energy grid management
Cost of emission (ETS)


Energy optimization utilization
Level of development of renewable energy solutions for vessels
Efficiency of Battery Electric Vessels
BESS
Advancements in electric energy production technology
Emergence of Swappable batteries technology
Advancements of H2 fuel technology
Battery energy/weight improvements
Nuclear technology advancement


Nuclear technology advancement
Level of international trade
Advancements in energy grid management
Availability of sufficient electrical grid capacity
International trade barriers (Number of bilateral and multilateral trade agreements)
EU Interconnection of High Grid
Level of renewable energy availability
Level of pollution
Pace of adoption of propulsion technologies for electric vessels


Development of legislation regarding the installation and use of alternative fuel
Level of renewable energy availability
Level of pollution
Pace of adoption of propulsion technologies for electric vessels
Adoption of alternative fuels to in marine transportation
Battery accidents
Advancements in recycle of batteries from vessels
Public trust in media
Regulations for safe charging
People's trust on the safety of vessels that use alternative fuels


Water levels
Attitudes towards certain energy types (e.g. nuclear)
Public pressure towards high CO2 industries
Level of European restriction on combustibles
Rate of climate change
Average temperature of the Earth
Level of education on global warming
Changes in people behaviours (lower consumptions)
New IMO regulations
Number of environmental disasters
Community engagement in coast and port areas
Changes in demography
Image of climate change effects on media
Level of recycling Nuclear waste

12.3 Appendix 3 Scenario Narratives

12.3.1 Scenario 1: Fair Wind

It is the year 2050, the Earth experiences a moderate increase in temperature, reaching +1.5°C due to the ongoing effects of climate change. This scenario envisions a world where the cost of energy from alternative and sustainable sources is remarkably low, reshaping the global energy landscape and influencing various sectors.

The +1.5°C temperature rise prompts a balance between adaptation and mitigation efforts. Environmental challenges persist, but the world is on a trajectory towards a more sustainable future. The global emphasis on sustainability and a low-carbon future has transformed industries, with a focus on green practices leading to a significant reduction in carbon emissions. The challenges associated with high energy costs from alternative sources are alleviated, paving the way for widespread adoption of sustainable energy. The availability of low-cost sustainable energy transforms the energy landscape. Alternative sources become the primary choice for industries, businesses, and households, accelerating the transition to a green economy. Industries relying on traditional energy sources may face economic challenges as the shift to low-cost sustainable energy disrupts established markets. The economic transition is underway, with industries adapting to the new normal of low-cost sustainable energy. Governments implement policies to support affected sectors in the shift towards green technologies and practices. The shift to low-cost sustainable energy requires adjustments in socio-political dynamics as nations navigate economic and geopolitical implications. Societies embrace a sustainable lifestyle, with a heightened awareness of the interconnectedness of energy choices and environmental impact. Cities adopt eco-friendly urban planning, and consumers prioritize sustainable products. Nations compete for raw material used for green technologies. Large nations and institutions support financially the transition for poorer nations, while enforcing standards that push for the adoption of green practices.

The combination of a moderate increase in temperature and low-cost sustainable energy creates a world where industries, governments, and individuals actively contribute to a more sustainable and resilient future. The energy revolution becomes a driving force for positive change, fostering global cooperation and ushering in an era of environmental responsibility and economic growth.

The maritime industry stands at the forefront of sustainability and innovation amidst a world grappling with a +1.5°C rise in average temperature. Despite the challenges posed by the high cost of alternative energy at $2 per MWh, concerted global efforts and supportive government policies have transformed marine transportation into a model of environmental responsibility.

Climate and environmental landscape: The +1.5°C temperature rise necessitates a balance between adaptation and mitigation efforts. Environmental challenges persist, but the maritime industry has become a proactive force in combating climate change. Maritime stakeholders recognise the urgency of sustainable practices, leading to a shift towards eco-friendly technologies and operational strategies.

Low-Cost Sustainable energy: The cost of alternative energy is high, yet governments provide tax relaxations to incentivize the adoption of green technologies. Despite the cost challenges, the maritime sector benefits from government support, accelerating the transition to sustainable energy sources. The high price tag becomes a minor obstacle in the face of long-term environmental benefits.

Economic shifts: The transition to alternative fuels poses economic challenges for traditional energy-dependent industries within maritime. Governments' tax relaxation initiatives alleviate economic strains, fostering a seamless transition to sustainable energy and technologies. Industries adapt and find opportunities in green practices.

Global collaboration and supply chains: The current challenge globally is to maximise collaboration in order to create stable supply chains. This is driven by international diplomacy and particularly by leading role of most developed economically countries.

Maritime Technology: The maritime industry embraces autonomous technology, enhancing efficiency and safety. The extensive investment in electrical grid capacity facilitates the seamless integration of autonomous vessels into global shipping networks.

Energy Efficient optimisation: The maritime sector has embraced technological developments focusing on green practices which has increased the energy efficiency. Its contribution to the global CO2 emission remains below 5%.

The maritime industry has become a beacon of sustainability, navigating the challenges of a warming world through innovation, government support, and global cooperation. The key stakeholders collectively contribute to a future where economic prosperity aligns harmoniously with environmental well-being.

12.3.2 Scenario 2: Bite the Bullet

It is the year 2050, the global community is navigating a climate reality marked by a +1.5°C temperature increase, achieving the targets of the Paris Agreement. Despite efforts to curb climate change, the cost of energy from alternative and sustainable sources has reached unprecedented heights, presenting a unique set of challenges for nations, industries, and individuals.

The world experiences noticeable climate impacts at +1.5°C; approximately 15% of the population experiences a heatwave once every 5 years. Nations focus on adaptation strategies, with an emphasis on building climate-resilient infrastructure, implementing sustainable land-use practices, and developing early-warning systems for extreme weather events. The cost of energy from alternative and sustainable sources is exceptionally high, creating economic challenges and inhibiting widespread adoption. Traditional energy sources, despite environmental concerns, remain economically favourable. Economic barriers hinder the transition to sustainable energy. Governments, businesses, and individuals face tough decisions on balancing environmental responsibility with the economic feasibility of adopting green technologies. Industries striving for sustainability face higher operational costs, while those reliant on traditional energy enjoy economic advantages. This creates economic disparities and raises questions about the feasibility of a green transition. Governments grapple with the need to stimulate economic growth while adhering to climate goals. Policies must strike a balance between incentivising sustainable practices and mitigating the economic impact on industries. The high cost of sustainable energy limits investment in research and development for green technologies, hindering progress in energy efficiency and renewable energy solutions.

The pace of technological innovation slows down. Governments and businesses must strategically allocate resources to incentivize and fund research in sustainable technologies to drive down costs and make green solutions more accessible. Societal tensions arise as communities grapple with the economic disparities associated with energy costs. The dilemma between environmental responsibility and economic stability becomes a focal point of public discourse. Governments face public pressure to address both economic concerns and environmental imperatives. Policymakers must communicate the importance of sustainable practices while implementing policies that cushion the economic impact on vulnerable populations. The global community struggles to coordinate efforts in the face of divergent energy policies. Geopolitical tensions rise as nations prioritize their economic interests over collective environmental responsibility. Achieving global cooperation becomes challenging. Diplomatic efforts intensify to find common ground on shared environmental goals. International agreements become essential to fostering collaboration and addressing the collective challenges posed by climate change.

The world finds itself at a pivotal juncture, striving to balance environmental stewardship with economic realities. The decisions made in the coming years will determine the feasibility of sustainable energy adoption and the ability of nations to collaboratively address the impacts of climate change at the +1.5°C threshold.

The global community faces the challenges of a world where the average temperature has risen by +1.5°C. However, in this world there is a positive picture for the maritime industry, with a commitment to sustainability, substantial investments, and proactive governmental policies.

Climate and environmental landscape: The Earth experience the impacts of a modest temperature rise, prompting heightened environmental awareness. However, proactive policies and efforts mitigate the severity of climate-related challenges. The maritime industry finds itself in a position to lead the way in environmental stewardship, capitalizing on the awareness to implement sustainable practices.

Energy cost dynamics: The cost of energy from alternative sources is exceptionally high, reaching $60 per MWh, posing economic challenges for the industry. Stakeholders must innovate and seek efficiency gains to offset high energy costs. This scenario encourages the exploration of cost-effective green technologies and the optimization of energy use.

Port infrastructure and harmonisation: Medium harmonization between ports poses operational challenges, requiring collaboration and standardization efforts. High funding for port infrastructure becomes a catalyst for change. Ports leverage investment to enhance harmonization, streamline operations, and accommodate the growing demand for sustainable transportation.

Demand for zero emission transportation: Very high levels of demand for zero-emission transportation drive the need for rapid industry adaptation. Stakeholders respond by accelerating the adoption of alternative fuels and green technologies, meeting consumer demands and positioning the industry as a leader in sustainability.

Government initiatives: Governments are actively pursuing environmental policies, but large-scale funding commitments are required. Robust governmental support becomes a driving force. Policies incentivize the adoption of green technologies, spurring innovation and propelling the industry towards a sustainable future.

Electric grid capacity and sustainable energy: Although more than half of the energy consumed comes from sustainable sources, there are challenges associated with extensive investment in electrical grid capacity. Stakeholders must collaborate to address grid capacity challenges. Investments in infrastructure and technological advancements become essential to ensure a reliable and sustainable energy supply.

Global supply chains: Global supply chains are reliable but not entirely stable, with high costs associated with ensuring sustainability. The maritime industry becomes a linchpin for supply chain resilience. Stakeholders focus on building agile and adaptive supply chains while managing costs through sustainable practices.

Digitalisation of the maritime sector: High levels of digitalisation present both opportunities and challenges in terms of cybersecurity and system integration. The industry embraces digitalization to enhance efficiency, improve safety, and optimize operations. Stakeholders invest in robust cybersecurity measures to safeguard critical systems.

Energy efficiency optimisation: High energy costs drive a focus on energy efficiency optimization, resulting in low levels of CO_2 emissions. The maritime sector becomes a beacon of sustainability. Stakeholders prioritize energy-efficient technologies, reducing environmental impact and contributing to global climate goals.

The maritime industry emerges as a pioneer in sustainability, navigating challenges with a proactive approach to environmental responsibility, innovation, and collaboration. Stakeholders can shape a resilient and eco-friendly future for marine transportation.

12.3.3 Scenario 3: En Route

It is the year 2050, the Earth faces the profound challenges of a substantial +4°C temperature increase due to the acceleration of climate change. However, revolutionary developments shape the energy landscape — the cost of energy from alternative and sustainable sources is remarkably low. The challenges associated with climate change are mitigated by the availability of very low-cost sustainable energy. Urgent and comprehensive adaptation and mitigation measures are imperative. Despite the severity of climate change impacts, the availability of very low-cost sustainable energy becomes a powerful tool for mitigating further environmental damage. This sets the stage for a collective effort to address climate challenges through sustainable practices. The challenges associated with climate change are mitigated by the availability of very low-cost sustainable energy. The low cost of sustainable energy transforms the energy landscape.

Alternative sources become the dominant energy providers, encouraging industries and societies to embrace greener practices without compromising economic viability. Industries must adapt to the changing climate, but the low cost of energy from sustainable sources fosters economic growth. Economic shifts prioritize sustainability. Industries invest in green technologies and practices, creating a synergy between economic development and environmental responsibility. The need for innovation remains high to address climate challenges despite the low cost of energy. Research and development flourish as governments, industries, and academia collaborate to find innovative solutions. Breakthroughs in climate-resilient technologies and sustainable practices redefine the global approach to climate change.

Societies navigate changes in lifestyle and consumption patterns in response to the impacts of climate change. A societal shift towards sustainability gains momentum. Governments and communities work together to implement policies that encourage eco-friendly practices, fostering a culture of environmental consciousness. Ensuring global cooperation in implementing sustainable practices becomes crucial. The shared urgency to combat climate change fosters unprecedented global cooperation. Nations collaborate to share resources, technologies, and best practices, creating a united front against the challenges posed by a +4°C world. Energy efficiency optimization becomes a top priority despite the low cost of energy.

The emphasis on energy efficiency drives continuous improvement. Smart technologies, green infrastructure, and sustainable practices ensure that the benefits of low-cost energy are maximized while minimizing environmental impact. the availability of very low-cost sustainable energy serves as a catalyst for global transformation. The collective efforts of governments, industries, and communities result in a world that not only adapts to the challenges of a warmer climate but also thrives in an era of accessible and affordable sustainability.

The world faces the formidable challenge of a +4°C temperature increase due to accelerated climate change. This scenario envisions a future for marine transportation where the cost of energy from alternative sources is exorbitantly high, posing significant obstacles to sustainability. The maritime industry grapples with slow adoption of green technologies, low infrastructure harmonization, and insufficient support, presenting complex challenges for key stakeholders.

Climate and environmental landscape: The +4°C temperature rise exacerbates climate change impacts, including extreme weather events, rising sea levels, and ecological disruptions. The maritime sector faces heightened challenges, requiring robust adaptation measures. The urgency to address environmental concerns clashes with economic barriers, setting the stage for complex decision-making.

Extremely high cost of alternative energy: The extremely high cost of alternative energy poses significant economic challenges for the maritime industry. The adoption of sustainable practices becomes a luxury rather than a norm. Industries struggle to balance economic viability with environmental responsibility, leading to slow adoption of alternative fuels and technologies.

Medium harmonisation and low funding of ports: Medium harmonization and low funding for ports hinder the industry's ability to develop and implement sustainable infrastructure. Ports become bottlenecks for sustainable progress. Inconsistent technology standards and inadequate infrastructure limit the efficiency gains that could be achieved through harmonization and investment.

Medium demand for zero emission transportation: Medium demand for zero-emission transportation hampers the incentives for the maritime sector to transition to greener practices. The industry lacks the necessary market pressure to drive significant changes. Limited demand reduces the urgency for companies to invest in cleaner technologies and fuels.

Slow adoption of alternative fuels and governmental policies: Slow adoption of alternative fuels is coupled with unsuccessful governmental policies focused on cost reduction rather than comprehensive sustainability. The maritime industry struggles to align with global sustainability goals. Governmental policies fall short, emphasizing short-term cost reduction over long-term environmental benefits, impeding the transition to greener practices.

Investment in electrical grid and digitalisation: Significant investments in the electrical grid contrast with very low levels of digitalization in the marine sector. While the electrical grid capacity improves, the lack of digitalization hampers efficiency gains. The industry misses out on opportunities for optimization, predictive maintenance, and data-driven decision-making.

Very low energy efficient optimisation: Very low energy efficiency optimization exacerbates the industry's environmental impact. The industry becomes a significant contributor to carbon emissions due to inefficient practices. The lack of optimization stifles progress towards achieving sustainability goals.

Overall, the maritime industry struggles to balance economic pressures with environmental responsibility. Key stakeholders face significant hurdles in achieving sustainability goals, with the slow adoption of green technologies and inadequate governmental policies hindering progress towards a more sustainable future.

12.3.4 Scenario 4: In Irons

It is the year 2050, our planet grapples with the profound consequences of climate change, with temperatures soaring to an alarming +4°C above pre-industrial levels. This unprecedented warming has ushered in a new era of environmental challenges, fundamentally altering the dynamics of energy production and consumption. The impacts of climate change are starkly evident. Rising sea levels, extreme weather events, and disruptions to ecosystems are commonplace. Governments, industries, and communities are forced to confront the consequences of a world in which the global thermostat has shifted to a staggering +4°C. Amidst the environmental turmoil, the energy landscape faces its own set of challenges. The cost of energy from alternative and sustainable sources has skyrocketed, reaching levels previously unimaginable. The dream of a widespread transition to green energy faces the harsh reality of economic constraints, posing a significant barrier to sustainable development.

The expense associated with harnessing energy from sustainable sources has become a major economic challenge. Despite the urgent need for cleaner alternatives, the exorbitant cost hampers the widescale adoption of green technologies. The prohibitively high cost of sustainable energy has hindered the widespread adoption of green practices across industries. Many sectors continue to rely on traditional, carbon-intensive sources due to economic constraints. The economic ramifications are profound, affecting industries, businesses, and households alike. The strain on economic systems is palpable as the high cost of sustainable energy permeates through supply chains, production processes, and everyday life. The pressing need for affordable sustainable energy drives intense research and development. Breakthroughs in energy storage, efficiency, and novel renewable technologies become essential to make green energy more accessible.

The high cost of sustainable energy triggers shifts in economic structures. Industries are compelled to re-evaluate their energy-intensive processes, exploring efficiency measures and alternative technologies to stay competitive. The economic burden of high energy costs falls disproportionately on vulnerable communities, exacerbating social inequalities. Access to clean energy becomes a luxury for the privileged, further dividing societies. The urgency to address the energy crisis fosters unprecedented levels of innovation and collaboration. Governments, businesses, and research institutions come together to find affordable, scalable solutions for sustainable energy. Governments reassess and adapt their energy policies, seeking a delicate balance between environmental stewardship and economic stability. The global community engages in diplomatic efforts to align policies and foster international cooperation. High energy costs drive changes in consumer behaviour. Individuals become more conscious of their energy consumption, prompting a shift toward energy-efficient practices and a demand for sustainable alternatives.

The world faces a dual imperative: to confront the harsh realities of a climate-changed environment and to overcome the economic barriers hindering the transition to sustainable energy. The path forward requires unparalleled innovation, collaboration, and a shared commitment to forging a sustainable future in the face of formidable obstacles.

As we enter the year 2050, the maritime industry faces an intricate web of challenges that demand innovative solutions to secure a sustainable future.

Environmental Challenges: The Earth has warmed by +4°C, resulting in unprecedented environmental shifts. The cost of energy from alternative sources has soared to an astronomical $60 per MWh. Unfortunately, only half of large vessels have transitioned to alternative fuels, contributing to high levels of CO_2 emissions due to low energy efficiency optimization in the sector.

Infrastructure and Funding Issues: Low harmonization between ports, coupled with inadequate funding for port infrastructure, hampers the industry's ability to create a cohesive, green network. Governmental initiatives for achieving net-zero emissions remain limited, reflecting the broader global challenges and priorities.

Technological Landscape: Despite these challenges, the marine sector experiences a surge in digitalization, leading to high integration between electrical grids and ports. However, limited investment in electrical grid capacity poses a bottleneck to the full potential of these advancements.

Economic and Political Instability: Global political instability casts a shadow over the industry, negatively affecting global supply chains. The high cost of alternative energy exacerbates economic challenges, putting pressure on stakeholders to find cost-effective and sustainable solutions.

The maritime industry is at a crossroads. Success in navigating these challenges hinges on collaborative efforts, technological innovation, and a collective commitment to sustainability. The stakeholders in the maritime sector must work hand-in-hand to address the economic, environmental, and political hurdles, forging a path towards a more resilient and eco-friendly future.

12.4 Appendix 4 Influence of Port's BESS towards low energy prices

Integrating stationary battery energy storage systems (BESS) into port architecture should reduce electricity costs, by taking advantage of lower off-peak rates and mitigating the impact of demand charges. This strategic energy management might not only lower the overall electricity bill but also enhance the port's energy availability, ensuring a reliable power supply even during high-demand periods or unexpected blackouts. Moreover, the integration of BESS supports the adoption of renewable energy sources, such as solar or wind, by storing excess generation and providing a buffer against their intermittency. This alignment with sustainable practices not only can bolster the port's resilience and operational efficiency but can also contribute to environmental objectives, positioning the port as a leader in energy innovation and sustainability.

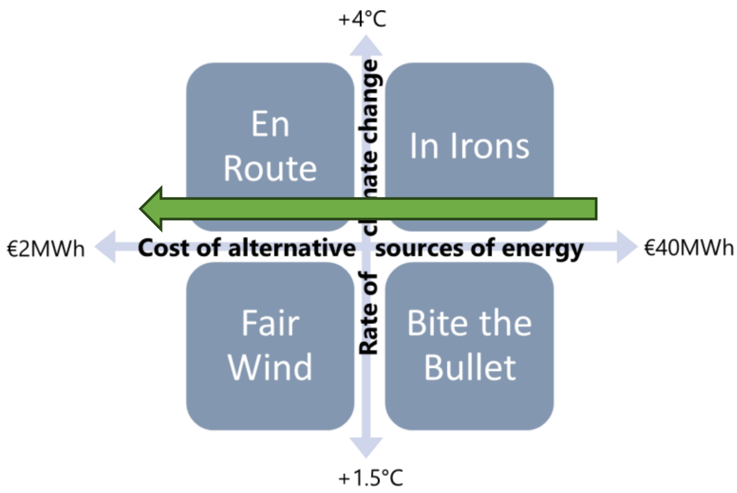


Figure 19 Targeted shift of "Cost of alternative energy sources" variable towards cost-effective scenarios

To enforce profitable scenarios in the X axis (Cost of alternative sources of energy) through fundamental energy storage revenue services for a port's stationary BESS, the estimation of BESS investments and lifetime cost is important for assessing the economics of a storage project with a specific technology and application. The first step in determining lifetime cost is to choose Levelized cost of storage (LCOS) or Annuatized capacity cost (ACC) as the metric, based on what is paid for by the application.

12.4.1 Brief overview of investment cost

- **Levelized cost of storage (LCOS)** for applications that value the provision of energy:

LCOS divides all costs incurred over the technology lifetime by discharged energy. The lowest LCOS across major storage technologies is achieved for applications that require 4-10 hours discharge per cycle and continuous operation.

$$LCOS = \frac{\sum_n^N \frac{cost\ (n)}{(1+r)^n}}{\sum_n^N \frac{E_{out}\ (n)}{(1+r)^n}}$$

Where $E_{out}(n)$—electricity discharged per year, n—year, N—lifetime in years, r—discount rate, $cost = (\sum_n^N \frac{Investment\ (n)}{(1+r)^n} + \sum_n^N \frac{Replacement\ (n)}{(1+r)^n} + \sum_n^N \frac{O\&M\ (n)}{(1+r)^n} + \sum_n^N \frac{Charging\ (n)}{(1+r)^n} + \sum_n^N \frac{EdnOf\ Life\ (n)}{(1+r)^n})$. *For simplicity, construction time is neglected.*

- **Annuitized capacity cost (ACC)** for applications that value the provision of power:

ACC divides these costs by power capacity and lifetime of the technology. The lowest ACC is achieved for applications that require less than 1 hour discharge each cycle and less than 300 cycles per year.

$$LCOS = \frac{\sum_n^N \frac{cost\ (n)}{(1+r)^n}}{\sum_n^N \frac{Cap_{p,nom}\ (n)}{(1+r)^n}}$$

Where $Cap_{p,\ nom}$—nominal power capacity, n—year, N—lifetime in years, r—discount rate, $cost = (\sum_n^N \frac{Investment\ (n)}{(1+r)^n} + \sum_n^N \frac{Replacement\ (n)}{(1+r)^n} + \sum_n^N \frac{O\&M\ (n)}{(1+r)^n} + \sum_n^N \frac{Charging\ (n)}{(1+r)^n} + \sum_n^N \frac{EdnOf\ Life\ (n)}{(1+r)^n})$. *For simplicity, construction time is neglected.*

Lifetime cost is minimized by optimizing capital efficiency. This means optimizing energy-specific and power-specific investment cost for the applications discharge duration and then distributing the resulting total investment cost over as many discharge cycles as possible (LCOS) or as many lifetime years as possible (ACC). The different optima mean that there is no one storage technology that offers lowest cost for both types of service.

12.4.2 Brief overview of revenue streams

Electricity storage creates economic value through four fundamental services.

- Power Quality: Keeping frequency and voltage within permissible limits.
- Power Reliability: Providing electricity in case of supply reduction or interruption.
- Increased utilization: Optimizing use of existing assets in the power system.
- Arbitrage: Exploiting temporal price differentials.

The finances of energy storage projects are described by standard profitability metrics: net present value (NPV), internal rate of return (IRR), and payback period. NPV determines the present value of the sum of all cash flows over the life of a project. All revenue and cost cash flows are discounted and summed. The sum of all discounted cost is then subtracted from the sum of all discounted revenues. If the NPV is greater than 0, the project will be profitable.

$$NPV = \sum_n^N \frac{revenue\ (n)}{(1+r)^n} - \sum_n^N \frac{cost\ (n)}{(1+r)^n}$$

Using Energy Storage technical theory, as well as the price for each unit of energy discharged Pe (e.g. EUR/MWh) and the price for each unit of power provided per year Pp (e.g. EUR/kW-year), the NPV formula for energy storage projects can be tabulated as follows:

$$NPV = \left[\sum_n^N \frac{P_p(n) \cdot E_{out}(n)}{(1+r)^n} + \sum_n^N \frac{P_p(n) \cdot C_{p,nom}(n)}{(1+r)^n}\right] - \left[\sum_n^N \frac{Investment\ (n)}{(1+r)^n} + \sum_n^N \frac{Replacement\ (n)}{(1+r)^n} + \sum_n^N \frac{O\&M\ (n)}{(1+r)^n} + \sum_n^N \frac{Charging\ (n)}{(1+r)^n} + \sum_n^N \frac{EdnOf\ Life\ (n)}{(1+r)^n}\right]$$

The internal rate of return represents the discount rate r that returns an NPV of 0. It must be calculated iteratively through trial and error or by using software programmed to calculate IRR.

$$NPV = 0 = \sum_{n}^{N} \frac{revenue\ (n)}{(1+IRR)^n} - \sum_{n}^{N} \frac{cost\ (n)}{(1+IRR)^n}$$

The payback period describes the time it takes to recover the cost of an investment. It is the year (and month, depending on modelling granularity) at which the cumulative cash flows (revenue and cost) turn positive. If there is an initial investment and fixed cash flows thereafter, the payback period can be determined as follows.

$$Payback\ period\ (in\ years) = \frac{Initial\ investment}{Annual\ cash\ flow}$$

However, for energy storage projects as well as most other investments, cash flows are not constant. Therefore, models that determine the cash flows in each time period are required to determine the payback period. Payback period can be determined as simple or discounted payback period. Simple payback period is determined without discounting future cash flows. Discounted payback period is determined by discounting future cash flows.

The development of such quantitative economic studies, combining different energy technologies (as the hereabove mentioned BESS technology, besides PV systems, multidirectional charging services and the rest of business indicators. See Appendix 1) will be developed further and integrated within the HYPOBATT deliverables D6.3 to D6.5, to provide relevant economic indicators at port level thanks to business models for different use-cases, related to different port's energy architectures.

At the last instance, these final outcomes from HYPOBATT Work Package 6 will enable good understanding of possible revenue streams for ports to ensure the deployment of MW charging systems in the maritime sector, which in turns, will pave the path towards net-zero Ports' ecosystems.