NS H2V Ports | Interreg North Sea | Co-funded by the European Union

Interreg North Sea | Co-funded by the European Union

North Sea Hydrogen Valley Ports

Creating the hydrogen corridor between North Sea ports

Deliverable D 1.3

Methodology for Individual Port Hydrogen Production, Storage and Infrastructure Plans, including Modelling Approach

DOCUMENT INFORMATION

Grant agreement number	
Project acronym	NSH2V Ports
Work package	WP 1
WP activity	1.3
Title of activity	Agree Methodology for Individual Port Hydrogen Production, Storage and Infrastructure Plans, including Modelling Approach
Lead Author(s)	Abdelilah Hammou, Raffaele Petrone,
Author(s)	Abdelilah Hammou, Raffaele Petrone, Jayang Gu

DOCUMENT HISTORY

version	date	description	reviewer
Draft 0.1	24/05/2025	Draft version before partner sharing for review	Hamid Gualous, Raffaele Petrone, Abdelilah Hammou, Jayang Gu
Draft 0.2	29/06/2025	Initial Review	Marjia Jovic
Draft 0.3	29/06/2025	Final review	Joshua Dauda

Contents

Abbreviations

ROI	Return on Investment
SWOT	Strengths, Weaknesses, Opportunities, Threats
CAPEX	Capital Expenditures
OPEX	Operational Expenditures
ICE	Internal Combustion Engines
R&D	Research and Development

Executive Summary

The North Sea region is strategically positioned to lead Europe's maritime energy transition, with its ports acting as essential nodes for creating a robust hydrogen corridor. As high-energy users and vital logistics hubs, ports require highly tailored strategies to integrate green hydrogen production, storage, and distribution. This report details a comprehensive methodology to guide the four North Sea Hydrogen Valley Ports (Bremen, Brest, Den Helder, and Esbjerg) in developing their individual, economically viable master plans.

The methodology is structured around a multi-phase approach, beginning with the Preparatory Phase for extensive data collection on port ecosystems, energy consumption, and local authority strategies. This foundational data is used for Model Fitting, creating a simple yet accurate "port avatar"—a virtual simulation of the port's energy balance and system interactions.

The core is the Decision Support phase, which employs advanced optimization algorithms. Local Optimization determines the optimal sizing and configuration of hydrogen infrastructure (electrolysers, storage) to minimize costs for the individual port, while Global Optimization maximizes the efficiency of hydrogen import/export exchanges across the entire four-port regional hub. These technical results, along with an Economic Analysis assessing ROI and cash flow, are finally translated into a clear, validated roadmap in the Planning Phase, providing the necessary rigor for successful hydrogen deployment.

1. Introduction

Ports play a central role in coastal tourism and maritime logistics, but they are also among the highest energy consumers. As a result, the development of alternative power solutions for maritime activities has become a key challenge within current energy transition pathways. In response, global and regional governance frameworks increasingly aim to stimulate local green energy market development and trade by encouraging actors to invest in local production and use within ports.

Against this backdrop, the North Sea Hydrogen Valley Ports project seeks to accelerate the development of green hydrogen production, storage, distribution, and use across North Sea ports. A core challenge within the project is to build effective regional collaboration for integrating hydrogen into coastal and port-related activities. In line with this objective, Activity 1.3 of Work Package 1 provides a generic framework to support green ports in their hydrogen production and infrastructure planning efforts.

These plans focus on the development of hydrogen production, storage, and distribution systems. A range of technologies is considered, including electrolysis, pressurised and underground storage, and pipeline infrastructure, with due attention to both logistical and economic factors. As local policies and governance frameworks differ, the specific approach will naturally vary across ports, reflecting the characteristics of each port ecosystem and the strategic priorities of the responsible authorities.

To support the ports involved in the project with this planning process, this deliverable provides a clear methodology that can be used as a practical template. In addition, the approach is designed to be easily adaptable by other ports in the North Sea region, allowing them to tailor the framework to their own local contexts and development objectives.

1.1. Methodology overview

The methodology described in this document describes a step by step and structured approach to developing green hydrogen production strategies in Ports. The methodology supports decision making on task definition and resource allocations; the resulting template of which can be adapted/implemented to each port. The methodology rests on two pillars: Preparatory phase and planning phase as illustrated in figure 1 below.

➢ ***General Methodology to develop planning phase***

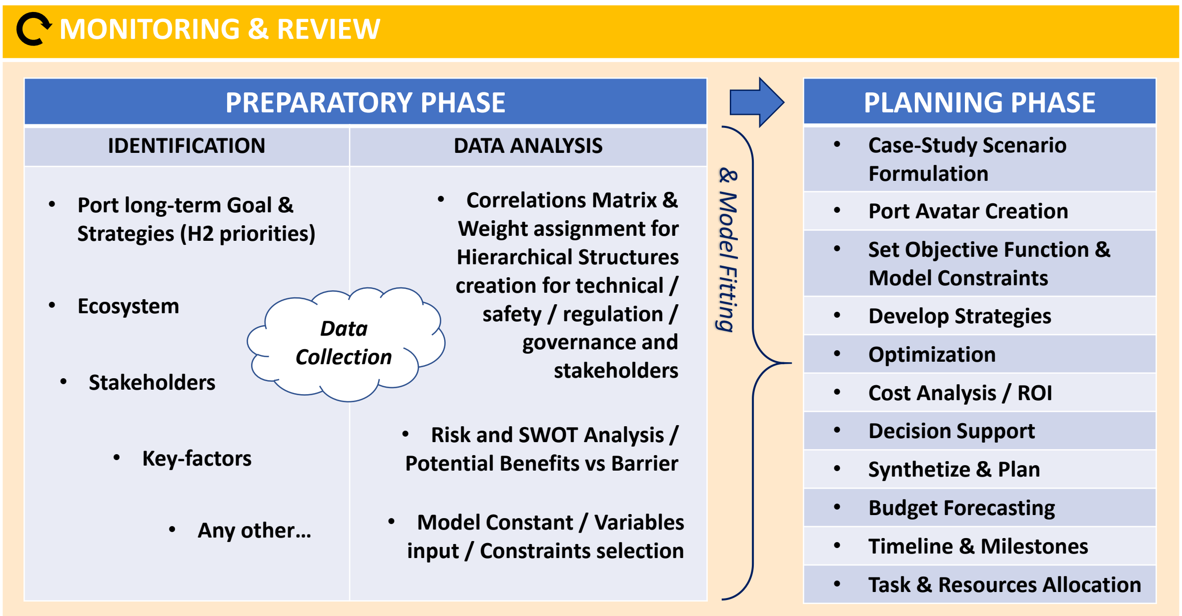

Figure 1. Methodology to implement strategies for project planning.

1.1.1. Preparatory Phase

The first step of the proposed methodology is data collection to define the port ecosystem, its needs, and its limits [1]. This is referred to as the preparatory phase. Based on each port's long-term strategies, priorities, and governance structures, data are collected on both key actors (such as energy suppliers, investors, and port authorities) and key factors (such as regulations, incentives, and funding schemes).

1.1.2. The planning phase

The second phase is the planning phase. This phase defines scenarios, constraints, and optimisation strategies, supported by an economic analysis of hydrogen infrastructure costs including CAPEX and OPEX. Modelling and optimisation are used to determine the best configuration of hydrogen and renewable systems, resulting in a digital "port avatar" that tests strategies for strengthening the hydrogen value chain while minimising costs. A decision-support tool then consolidates modelling and scenario results to guide governance and investment choices. Finally, all outputs are translated into a concrete project plan with budgets, timelines, milestones, and stakeholder responsibilities, aligning technical, economic, and governance aspects into a single implementation roadmap.

Chapter 2 explains, in more detail, the template for developing the green hydrogen Port production strategy.

2. Methodology Template

This chapter deals with the methodology template presentation. The main objective is to clarify the procedure for a better understanding of how to use the template. Figure 2 represents the step-by-step structured process, with the different phases and the expected results.

2.1. Preparatory Phase

The first step of the methodology is the preparatory phase. As its name suggests, this phase represents the preliminary study aimed at gathering data on port terminals, including their equipment, activities, and energy needs, as well as the policies and administrative frameworks of local authorities. This operation allows for the identification of port infrastructure, import/export strategies, and overall energy consumption patterns.

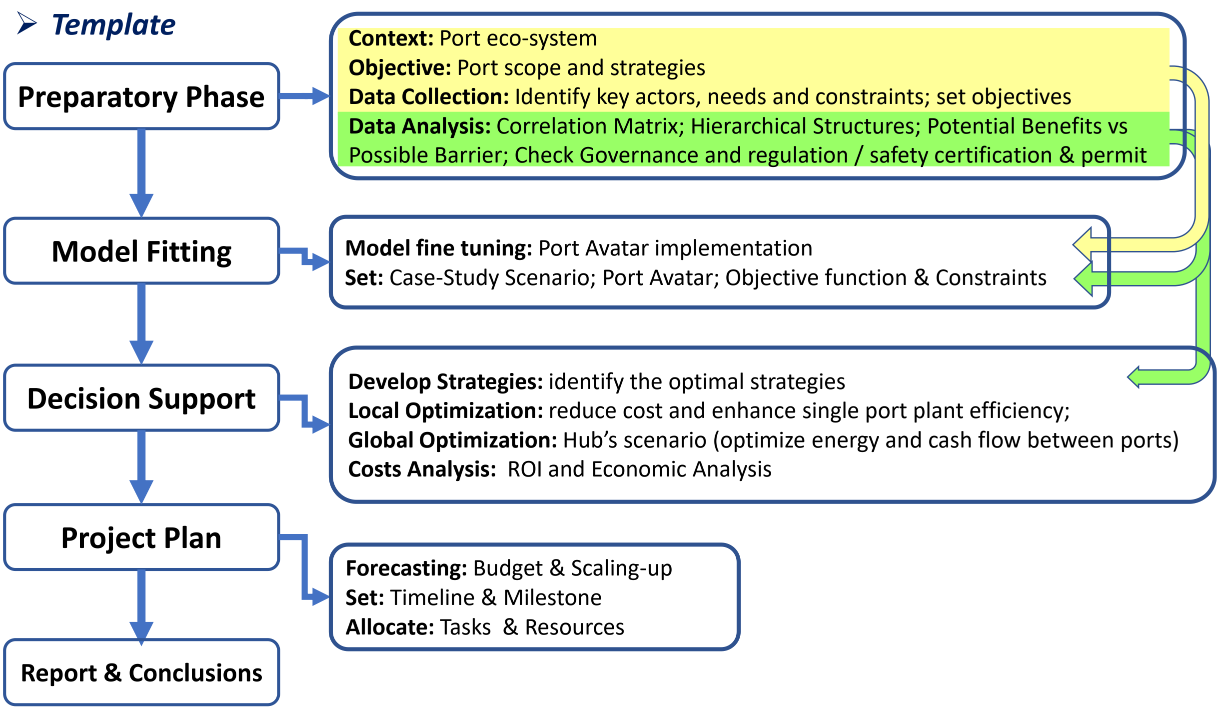

Figure 2: Template for port hydrogen production, storage, and infrastructure planning.

To achieve this, it is essential to define the port environment, which includes the port ecosystem and its strategic priorities (Figure 3). Within this scope, hydrogen facilities—whether existing or potential—are mapped as strategic assets for enhancing the port's green hydrogen value chain (Figure 4). The port's energy resources and hydrogen priorities are then organised in line with local authority strategies, listing milestones, required actions, equipment, and services [1]. This stage, therefore, involves an evaluation of opportunities, with the aim of identifying priorities, targets, and resources.

It is important to note that multiple development scenarios can be considered. For example, some ports may prioritise local hydrogen production based on onshore or offshore renewable energy plants, thereby developing the entire value chain. Others may focus primarily on hydrogen import strategies, limiting their activities to end-use applications. Similar considerations apply to hydrogen storage and bunkering technologies (e.g. liquid versus gaseous hydrogen), as well as transportation methods (pipelines, vessels, containers, etc.).

In parallel with this analysis, an equally important task of the preparatory phase is data collection. This activity is dedicated to systematic information sharing in order to define the guidelines for each case study. Data collection for each port is carried out through contributions from project partners, as part of Activity 1.2 of WP1.

Once collected, data are classified into two separate databases:

- The first dataset is used for model fitting, allowing calibration of technical and economic models.
- The second dataset is used to generate hierarchical structures, which can later be exploited in the decision-support phase.

Finally, a risk analysis is performed, comparing potential benefits with outstanding barriers. Once topics and key factors are identified, the process advances to the planning phase, where case-study scenarios, constraints, and strategies for model fitting and optimisation are defined.

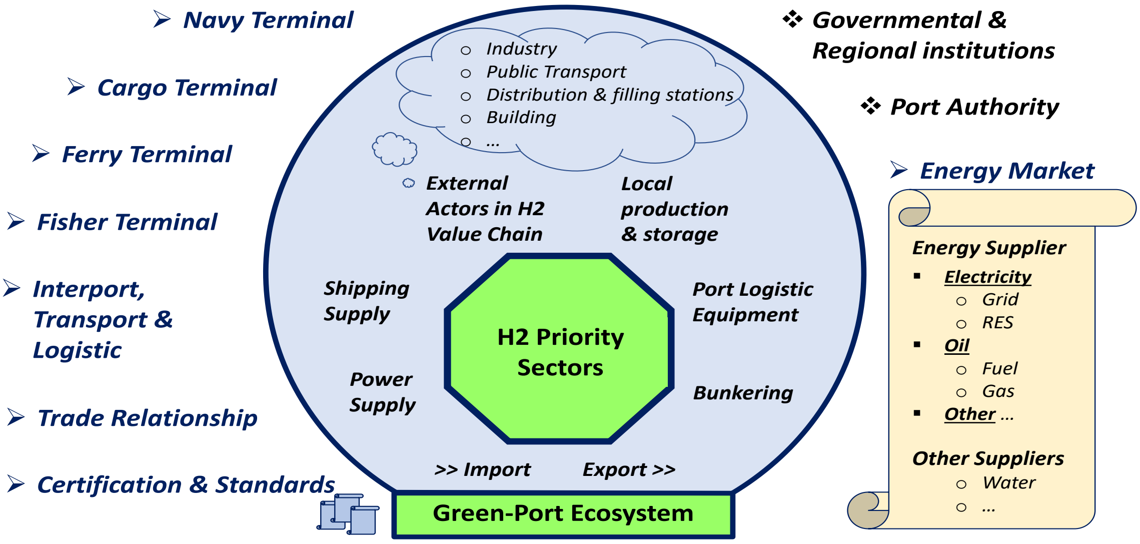

Figure 3: Green ports ecosystem and Priority Sectors in H2 deployment.

Figure. 4: Green Hydrogen facilities.

2.2. Modelling and Model Fitting

Port modelling consists of creating a mathematical model that simulates the energy behaviour of power installations within the port ecosystem [2]. The objective is to develop a simple yet accurate model that reflects the port's behaviour while avoiding high complexity and long computation times. Each power system of the port (Renewable energy sources, electrolysers, batteries, etc.) is presented by mathematical equations that link the inputs and the outputs and the internal state of the system, such as state of charge for batteries and pressure for the hydrogen tank; as shown in Figure 5. Information related to the port's ecosystem and strategies is also expected to be exploited during the optimisation process (refer to the decision support phase).

Model fitting consists of updating the model's parameters based on the previous information and data collected in the previous steps, in order to create the port avatar. This virtual model aims to simulate the behaviour and the interactions between the different renewable energy sources and storage systems in the ports and the energy flow between port equipment. The port avatar also considers the port energy activities and the meteorological data.

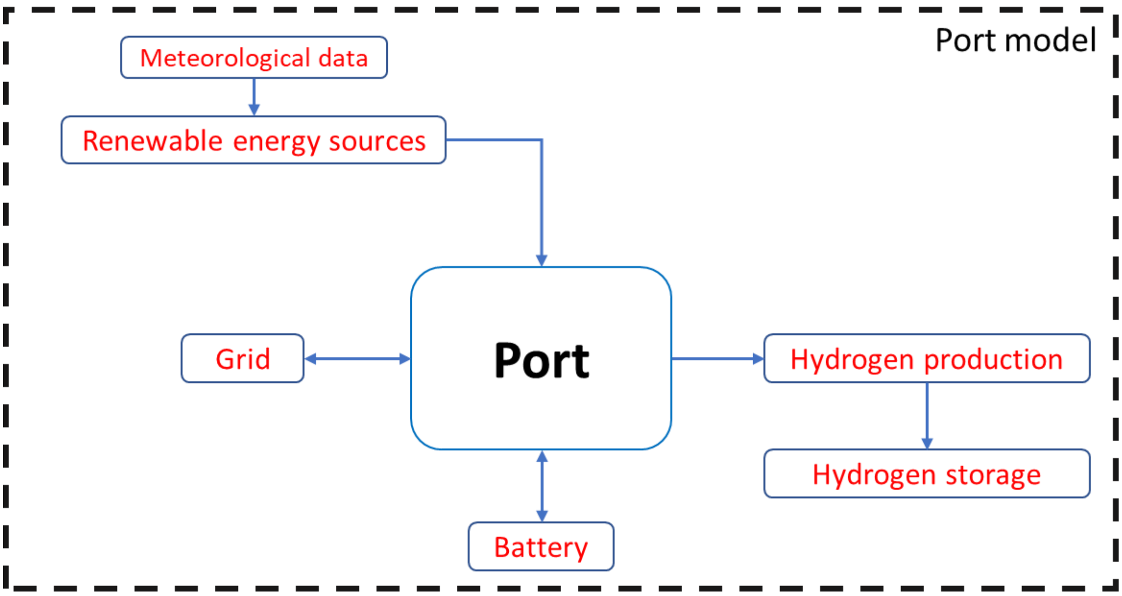

Figure 5: Green Port modelling for Avatar creation.

2.3. Decision Support

Once the port's strategies and Avatar are defined, the decision support phase is introduced. Particularly, this step is composed of several processes: the extrapolation of the data analysis started in the preparatory phase, the model optimisation (local and global) and the economic analysis.

2.3.1. Data analysis extrapolation

The data analysis and extrapolation phase is the direct continuation of the data treatment initiated during the preparatory phase (Figure 6). In this step, the collected information is processed and classified, with each item assigned a specific weight or priority to create hierarchical structures [3].

Part of this dataset is applied to model optimisation, while the remaining information supports comparative studies, risk analysis, and decision-making processes. Hierarchical or weighted structures are particularly important, as they guide the prioritisation of decisions based on port strategies and goals defined earlier. Figure 7 illustrates an example of case-study strategy selection: depending on the priorities identified in the planning document, the information is ordered accordingly. As a result, potential solutions must align with the established hierarchy.

This approach is especially useful for qualitative data, which are classified to support comparative analyses [3,4]. Meanwhile, quantitative data are primarily treated through modelling and optimisation techniques. Ultimately, the outputs from both the decision-support process and the modelling activities are integrated within the economic analysis, ensuring that technical, strategic, and financial considerations are assessed together.

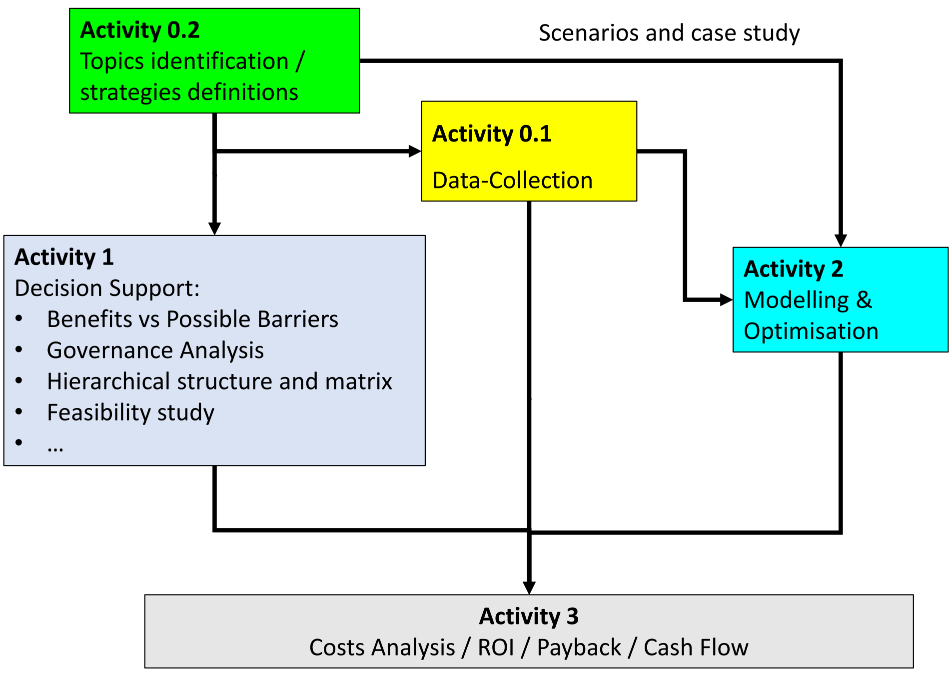

Figure. 6: Data treatment for decision-making support.

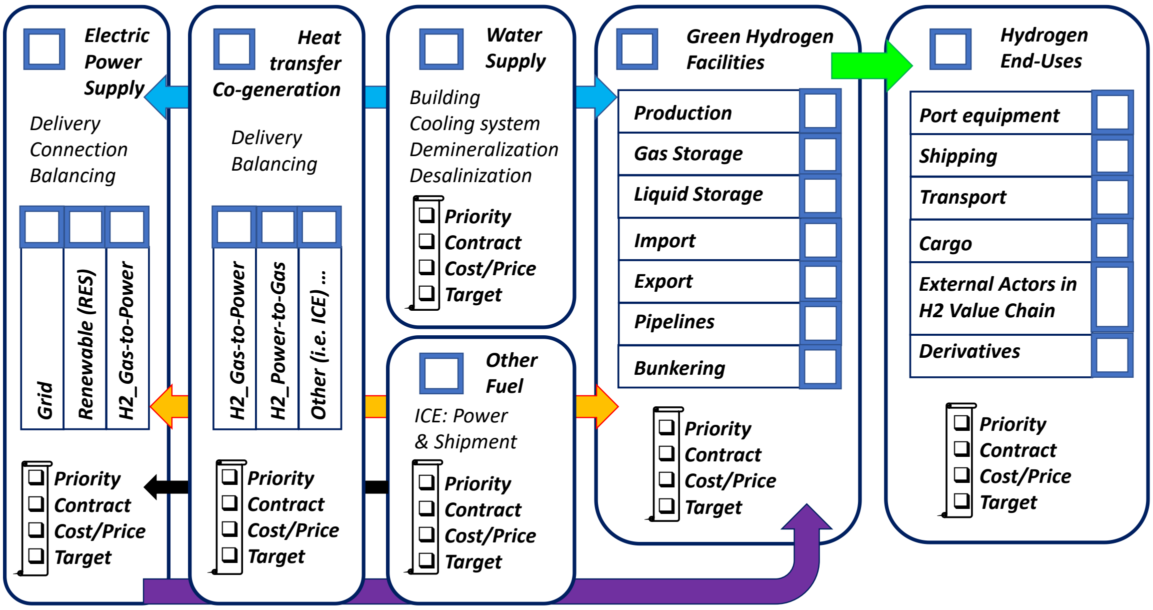

Figure 7: Case-study proposal for objectives definition and activities plan.

2.3.2. Local optimisation

Given the persistently high costs of hydrogen technologies, effective energy management and optimal system sizing are essential to reduce investment expenditures and improve operational efficiency. The main objective of the local optimisation algorithm is therefore to determine the optimal configuration and sizing of the different power devices—such as renewable energy sources, hydrogen storage, electrolysers, and batteries [2].

This optimisation is carried out on the single port avatar, taking into account the specific ecosystem characteristics, operational requirements, and local constraints. Where available from the data collection phase, additional parameters such as system ageing and maintenance costs can also be integrated into the optimisation process to improve accuracy and ensure long-term sustainability of the proposed solutions.

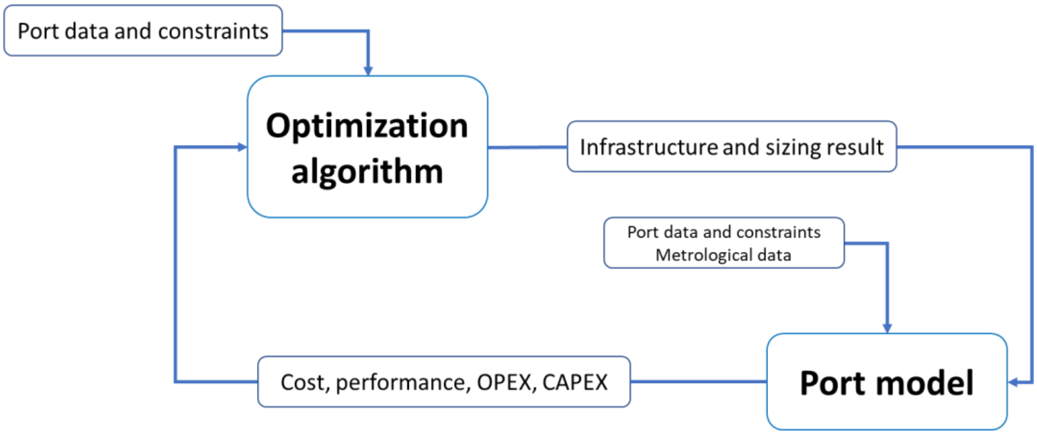

Figure 8. The architecture of the optimisation algorithm.

The local optimisation algorithm behaviour is represented in Figure 8. It will provide the optimal sizing of the different energy systems of the port with respect to the defined constraints and limitations. Moreover, it provides information on plant performance and costs. It is possible to state the produced/imported and/or the consumed/exported hydrogen (depending on port applications and strategies), and evaluate benefits, by analysing cash flows, return on investment, and payback indicators.

The local optimisation is performed based on linear programming or an equivalent method, which is a mathematical approach to minimise an objective function, with respect to constraints and limitations that are expressed in the form of inequalities or linear equations. In this case, the objective function will be expressed based on cost and plant efficiency, while port constraints and limitations, such as power limitations, budget limitations, and power balance, will be reformulated as inequalities or linear equations. The adopted optimisation algorithm is a simple, efficient, and flexible method. By reducing its computational efforts, the model is simulated for several years to enable in-depth analysis over long-term periods.

2.3.3. Global optimisation

Ports may have different ecosystems, activities, administrative constraints, and barriers. Therefore, the results of this local optimisation will vary from one port to another. For example, some ports may need hydrogen for their activities but may not be able to produce it, or produce insufficient quantities. Others, however, may have the potential to produce large quantities of hydrogen without a significant internal need. In this context, the scenario of a hydrogen hub, based on an exchange between the four ports, would allow for greater infrastructure sharing and profitability [4]. The global optimisation aims to maximise the hydrogen exchanges between the North Sea ports. To maximise the profits and optimise the hydrogen traffic, the global optimisation takes into consideration the needs in terms of hydrogen import export of each port, the hydrogen transportation methods (pipelines, vessels, etc.), the distance, and the time.

2.3.4. Economic analysis

Economic analysis builds on the outcomes of both local and global optimisation. While decision-support tools will guide qualitative choices, the optimisation results will provide a quantitative assessment of costs and benefits.

Local optimisation focuses on determining the total cost of hydrogen production and storage at each port, alongside local benefits and efficiency levels. Global optimisation, in turn, assesses hydrogen imports and exports across ports, capturing the associated costs and benefits of these exchanges.

Key economic indicators—such as return on investment, payback period, and cash flow—will then be calculated to evaluate overall project performance. These results will feed directly into the business plan, supporting financial consolidation and budget forecasting.

2.4. Planning Phase

This phase forms the core of the document. It is here that all elements come together to develop the business plan and budget forecast, define the roadmap with clear timelines and milestones, and allocate tasks and resources. It is important to note that while the applied methodology provides inputs for comparative and descriptive analysis, and the model optimisation supports the evaluation of energy balance, hydrogen facility sizing, and cost analysis, each port remains responsible for preparing and validating its own roadmap and business plan. This includes developing budget forecasts and setting timelines and targets, as illustrated in Figure 9.

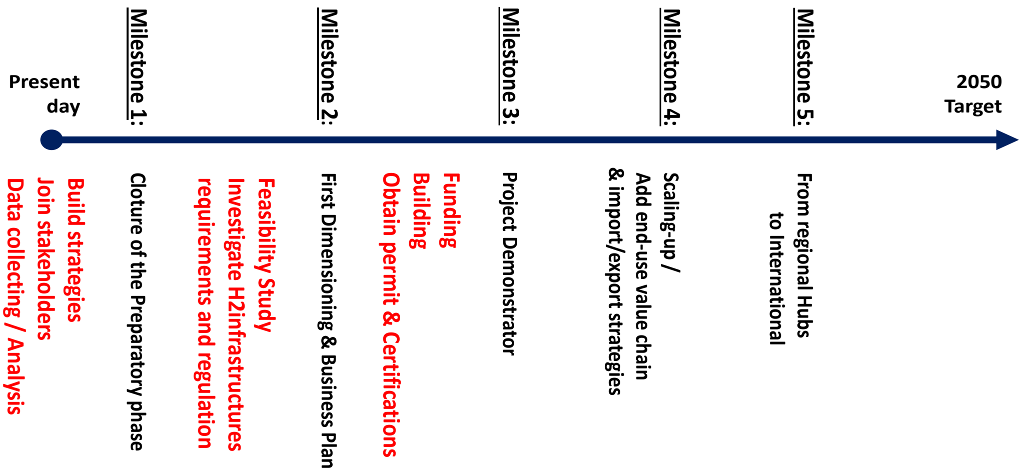

Figure 9: Timeline proposal.

Additional documents may be included depending on each port's internal procedures and standards. A simple proposal for task allocation among stakeholders is presented in Table 1. The purpose is to clarify the role of each actor, indicating whether they are responsible for decision-making, providing expertise or consultation, carrying out specific actions, or serving as end users [1].

Table. 1: Stakeholder tasks and responsibilities matrix proposal.

Stakeholders List: [1) Port Authority; 2) Government institution; 3) Municipality; 4) Private company part of port ecosystem; 5) Green energy supplier; 6) H2 end-user; 7) logistics; 8) port equipment; 9) ship; N) …]

Tasks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**…**
Develop H2 strategies									
Monitor H2 market									
Enhance renewables Ecosystem									
Define R&D areas for H2									
Investigate H2 requirement and needs									
Upscale electrical distribution infrastr.									
Port equipment electrical/H2 powered									
Port ship electrical/H2 powered									
H2 system facilities									

H2 system maintenance									
H2 production									
H2 gas storage									
H2 liquid storage									
Pipelines									
Filling station for port vehicles									
Filling station for public transport									
Bunkering									
Ship equipment									
Port terminal equipment									
Ship permitting contact & certification									
Port permitting contact & certification									
H2 import									
H2 export									
Develop logistic and support structures									
Business case H2 vs maritime fuels									
Secure public/private funding									
Port management									
Ship management									
Asses scaling-up									
Set up partnership for H2 sharing									
Enhance end-use H2 value chain									
Build coalitions/create hub ecosystem									
…									

2.5. Final Reports

The last phase is characterised by a procedure sum-up, with the creation of a suited portfolio structure, as represented in Figure 10. Portfolio must be synthetic, ordered, and it must contain all the performed analyses. The case-study number, scenario and targets have to be accessible in the document head, followed by comparative and descriptive analysis, such as comparison between the potential benefits and possible barriers. Subsequently, quantitative results and economic analysis are presented before the real work plan documents' presentation. A final report summing up monitoring activities and recommendations can also be attached.

Case-Study N° # **NS H2VPorts**

Geographical Area	Port	Long-Term Objectives	Relevant actors
NS Area	#####	Green H2 production, storage, distribution & use @ one port size to be extended to hub's scenarios	Private authority, Public authority, Institutions in general, Infrastructures and Service Providers, General Public

Case-Study Context	Scope
Ecosystem: Stakeholders / Governance / Targets / Strategies	Production / import / consumption for port equipment / consumption for transport / end-uses' value chain / infrastructure creation / Bunkering / create partnership

Potential Benefits vs.	Possible Barriers and Risk Analysis
New Economy & Job positions / Local energy autonomy / CO2 reduction (environment + incentives' possibility)	Safety / Regulation / Certification & Permits / investment cost / Storage & vessel pending questions (Liquid? Gas? Containers?)

Economic Analysis
Costs analysis / ROI / Feasibility study / Business plan / Budget forecasting for Funding

Work Plan
Road Map / Timeline & Milestones / Tasks and Resources

Figure 10: Example of Portfolio including all the documents to finalise in the planning phase.

3. Conclusion

The comprehensive methodology outlined in this report is a critical step towards realizing the North Sea Hydrogen Corridor. Moving beyond simple feasibility studies, the structured approach ensures that the hydrogen economy is built on sound technical and financial foundations.

The creation of the detailed "port avatar" and the deployment of sophisticated Local Optimization tools allow each participating port to minimize costs and maximize efficiency for their specific infrastructure needs. Crucially, the Global Optimization layer leverages this individual planning to realize the shared vision of a highly profitable, interconnected regional hydrogen hub. This transition from fragmented local efforts to a harmonized, optimized regional network will firmly establish the North Sea ports as the vanguard of Europe's maritime decarbonization before 2030.

4. References

[1] https://www.clean-hydrogen.europa.eu/media/publications/study-hydrogen-ports-and industrial-coastal-areas-reports_en

[2] Yuxin Li, Daogui Tang, Chengqing Yuan, Cesar Diaz-Londono, Gibran David Agundis-Tinajero, Josep M. Guerrero, "The roles of hydrogen energy in ports: Comparative life-cycle analysis based on hydrogen utilization strategies," International Journal of Hydrogen Energy, Volume 106, 2025, Pages 1356-1372, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2025.02.075.

[3] Xiaohui Jia, Yongmei Cui, "Examining interrelationships of barriers in the evolution of maritime port smartification from a systematic perspective," Transport Policy, Volume 114,2021, Pages 49-58, ISSN 0967-070X, https://doi.org/10.1016/j.tranpol.2021.09.004.

[4] Elnaz Irannezhad, Mark Hickman, Carlo G. Prato, "Modeling the Efficiency of a Port Community System as an Agent-based Process," Procedia Computer Science, Volume 109, 2017, Pages 917-922, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2017.05.422.