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D 1.2 - H2-Derivative Port Infrastructure and Bunker Supply Guideline

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H2Deri@BSP - A cooperation project to develop proof-of concepts for the uptake of H2 derivative fuels!	Lead Partner

Content

1. Executive Summary

This interim report documents the progress, intermediate results, and strategic implications of the activities implemented under **Group of Activities (GoA) 1.2** within Work Package 1 of the H2Deri@BSP project.

GoA 1.2 represents one of the central technical pillars of the project, addressing both **analytical modelling and physical infrastructure preparation** required to enable hydrogen derivatives—particularly methanol—within Baltic Sea Region (BSR) ports. The activity integrates four interdependent components:

- (a) Techno-economic and commercial analysis model
- (b) Port bunkering mapping instrument
- (c) Methanol bunker tank trailer specification
- (d) Methanol bunker vessel specification

The work undertaken demonstrates a **high degree of maturity and coherence across analytical and engineering domains**, ensuring that outputs are not limited to conceptual frameworks but extend toward implementation-ready solutions.

Key achievements during the reporting period include:

- Completion of a **comprehensive renewable energy market analysis** forming the foundation for techno-economic modelling
- Successful **procurement and onboarding of external expert support (Ramboll)** for advanced model development
- Development of a **GIS-based techno-economic modelling framework** capable of evaluating renewable energy, PtX production, and bunkering potential
- Near-finalisation of **methanol tank trailer technical specifications**, including safety validation and operational procedures
- Completion of **methanol bunker vessel demand analysis, economic evaluation, and conceptual design**
- Establishment of a **structured framework for port bunkering mapping**, integrating safety, regulatory, and operational criteria

The work confirms that **technical feasibility of hydrogen derivatives in port environments is largely achievable**, while highlighting that **market readiness, regulatory alignment, and supply chain maturity remain the primary barriers**.

The transnational cooperation embedded in GoA 1.2 has enabled consolidation of knowledge across ports, resulting in a **scalable, transferable framework applicable beyond the Baltic Sea Region**.

2. Introduction

2.1 Context and Strategic Relevance

The decarbonisation of maritime transport is a central pillar of European climate policy and global emissions reduction strategies. Shipping accounts for a significant share of global greenhouse gas emissions, and ports are increasingly recognised not only as logistics hubs but as **integrated energy nodes** within emerging low-carbon value chains. In this context, hydrogen derivatives—particularly methanol and ammonia—are considered among the most promising fuel pathways due to their scalability, transportability, and compatibility with existing fuel handling infrastructure.

Within the Baltic Sea Region (BSR), the transition towards alternative maritime fuels is both an opportunity and a challenge. The region benefits from strong renewable energy potential—especially wind—as well as a dense and interconnected port network. However, the deployment of hydrogen derivatives is still at an early stage, constrained by regulatory fragmentation, limited infrastructure readiness, and uncertainties related to market demand and supply chains. These factors create a significant barrier for ports and industrial stakeholders when making investment decisions.

In response to these challenges, GoA 1.2 is designed to bridge the gap between **strategic ambition and practical implementation.** It provides structured tools and engineering-level outputs that support ports in evaluating their role within emerging hydrogen derivative value chains. By combining techno-economic modelling with infrastructure planning and specification development, the activity enables stakeholders to move from conceptual discussions toward **bankable, implementation-oriented solutions**.

Key contextual elements addressed in GoA 1.2 include:

- Increasing regulatory pressure for maritime decarbonisation (e.g. FuelEU Maritime)
- Emerging role of ports as energy hubs and PtX production locations
- Growing interest in methanol as a near-term scalable marine fuel
- Fragmentation of regulatory and infrastructure approaches across EU ports
- Need for investment-grade analytical tools and infrastructure readiness

2.2 Objectives of GoA 1.2

The overarching objective of GoA 1.2 is to develop a **comprehensive, practical, and transferable toolkit** that enables ports and industrial stakeholders to assess, plan, and implement hydrogen derivative solutions. The activity is structured around four interlinked components, each targeting a critical element of the value chain—from energy generation and fuel production to bunkering infrastructure and operations.

At its core, GoA 1.2 aims to establish a **decision-support ecosystem** that reduces uncertainty and supports investment decisions. The techno-economic model provides analytical capabilities for assessing renewable energy potential, PtX production pathways, and infrastructure feasibility. In parallel, the bunkering mapping instrument translates regulatory, safety, and operational requirements into a structured planning tool applicable across different port contexts.

Complementing these analytical components, the development of detailed technical specifications for methanol bunkering infrastructure—both truck-based and vessel-based—ensures that the outputs are directly applicable in real-world settings. These specifications are aligned with international standards and industry practices, enabling ports and operators to accelerate deployment and reduce implementation risks.

The four core components of GoA 1.2 are:

- **(a) Techno-economic and commercial analysis model**
  → Assessment of renewable energy potential, PtX production, and investment feasibility
- **(b) Port bunkering mapping instrument**
  → Structured framework for planning and permitting bunkering infrastructure
- **(c) Methanol bunker tank trailer specification**
  → Technical and operational definition of truck-to-ship bunkering solution
- **(d) Methanol bunker vessel specification**
  → Design and performance parameters for maritime bunkering operations

Together, these components form a coherent framework that supports ports in transitioning from early-stage exploration toward **implementation and market deployment** of hydrogen derivatives.

2.3 Position within the Project

GoA 1.2 plays a central role within the H2Deri@BSP project by acting as a **link between strategic analysis and operational deployment**. While earlier activities focus on policy frameworks, stakeholder engagement, and high-level assessments, GoA 1.2 translates these inputs into concrete tools, models, and specifications that can be directly applied in practice.

The outputs of GoA 1.2 are closely connected to subsequent activities, particularly those within Work Package 2, where pilot implementations and testing of bunkering solutions take place. The techno-economic model provides the analytical foundation for identifying viable pilot scenarios, while the infrastructure specifications enable the physical realisation of these pilots. This ensures that project activities are aligned across different phases, reducing the risk of disconnect between planning and execution.

In addition, GoA 1.2 contributes significantly to the **transnational dimension of the project**. By integrating knowledge and experience from multiple Baltic Sea Region ports, the activity supports the development of harmonised approaches and shared methodologies. This is particularly important given the current fragmentation of regulatory and operational practices across EU ports. The tools and frameworks developed are therefore designed to be transferable and scalable, supporting replication beyond the initial project scope.

The positioning of GoA 1.2 within the project can be summarised as follows:

- Bridge between strategic frameworks (WP1) and pilot implementation (WP2)

- Provider of analytical tools for investment and planning decisions
- Enabler of infrastructure deployment through technical specifications
- Contributor to knowledge transfer and replication (WP3)
- Driver of transnational harmonisation across BSR ports

3. Methodological Framework

3.1 Integrated Approach

The implementation of GoA 1.2 follows a **multi-layered and integrated methodological approach**, combining analytical modelling, technical specification development, and stakeholder-driven validation. This approach reflects the complexity of hydrogen derivative deployment in port environments, where technical, economic, regulatory, and operational factors are closely interlinked.

Rather than addressing these dimensions in isolation, the methodology is designed to ensure **system-level consistency**, linking renewable energy generation, fuel production, logistics, and bunkering infrastructure within a unified analytical and implementation framework. This is particularly important given the early-stage maturity of the market, where uncertainties require iterative development and continuous validation.

A key principle applied throughout the activity is the combination of **top-down analytical modelling with bottom-up technical and operational insights**. While the techno-economic model provides a structured and quantitative assessment framework, the technical workstreams (tank trailer, bunkering vessel, and mapping instrument) ensure that outputs remain grounded in real-world port conditions and constraints.

The methodology also incorporates an **iterative development logic**, allowing continuous refinement based on stakeholder input, partner experience, and evolving market conditions. This has been particularly relevant in addressing uncertainties related to fuel availability, demand development, and regulatory requirements.

The overall methodological approach is structured around the following pillars:

- **Analytical modelling and scenario development**
  → Assessment of renewable energy potential, PtX pathways, and economic feasibility
- **Engineering and technical specification development**
  → Design of bunkering infrastructure solutions aligned with safety and operational standards
- **Stakeholder engagement and co-creation**
  → Continuous validation of assumptions and outputs with ports and industry actors
- **Iterative development and validation cycles**
  → Progressive refinement of tools and specifications based on feedback and data availability

This structured approach ensures that GoA 1.2 delivers outputs that are not only technically robust but also **operationally feasible and transferable across different port contexts**.

3.2 Analytical Modelling Methodology

The techno-economic and commercial analysis model constitutes the analytical core of GoA 1.2 and is developed using a **GIS-based, scenario-driven modelling approach**. The methodology integrates multiple data layers and analytical dimensions, enabling a comprehensive assessment of hydrogen derivative value chains within port environments.

The model is designed to evaluate the full system, including renewable energy generation, hydrogen production, conversion into derivatives (e.g. methanol), storage, and bunkering. Particular emphasis is placed on **spatial analysis**, ensuring that infrastructure configurations are aligned with land availability, safety constraints, and proximity to existing port facilities.

The modelling approach is primarily focused on **indigenous production scenarios**, reflecting the strategic importance of local renewable energy integration and supply security. At the same time, the framework allows for future integration of import scenarios, which have been identified as relevant for subsequent development phases.

Development of the model is carried out in collaboration with external experts, applying an **agile sprint-based approach**. This allows for incremental development, continuous validation, and alignment with stakeholder requirements. The involvement of Ramboll ensures methodological robustness and alignment with industry practices.

A key challenge identified during development relates to **data availability and uncertainty**, particularly for emerging technologies and market parameters. To address this, the model incorporates flexibility through scenario and sensitivity analysis, allowing users to adjust key assumptions and explore different development pathways.

The analytical modelling methodology includes:

- **GIS-based spatial analysis**
  → Identification of suitable areas for renewable energy generation and PtX facilities
- **Energy system modelling**
  → Simulation of hydrogen production and conversion into derivatives
- **Economic and commercial assessment**
  → Evaluation of CAPEX, OPEX, and cost competitiveness
- **Scenario and sensitivity analysis**
  → Assessment of different development pathways and key influencing parameters
- **Integration of spatial and safety constraints**
  → Ensuring alignment with real-world port conditions

The modelling process follows an **iterative development logic**, where initial assumptions are continuously refined based on stakeholder feedback and newly available data. This ensures that the model evolves in parallel with the project and remains relevant to real-world conditions. Through this approach, the model provides a **decision-support tool capable of informing investment planning and infrastructure development**.

3.3 Engineering and technical development Methodology

The development of technical specifications for bunkering infrastructure follows a structured engineering approach, combining **industry standards, operational requirements, and safety considerations**.

For the methanol bunker tank trailer, the methodology included:

- assessment of port-specific operational constraints, particularly maneuverability limitations in ports such as Tallinn and Helsinki,
- selection of an appropriate vehicle configuration (4x2) balancing capacity and flexibility,
- definition of a standardised truck-to-ship (TTS) bunkering process, including all operational steps and safety measures,
- integration of regulatory requirements, including classification of methanol (UN 1230) and compliance with ADR transport regulations.

The specification development also incorporated **HAZID and HAZOP methodologies**, ensuring that safety considerations are systematically addressed. This includes identification of hazards, definition of safety zones, and development of operational procedures to mitigate risks.

For the bunkering vessel, the methodology followed a phased approach:

- demand analysis to determine potential fuel volumes and use cases,
- economic evaluation to assess business case viability,
- technical definition of vessel parameters, including capacity and transfer performance.

The Port Bunkering Mapping Instrument was developed using a **criteria-based approach**, integrating multiple dimensions of bunkering feasibility. This includes location characteristics, vessel parameters, operational conditions, and environmental factors. The methodology also incorporates both qualitative and quantitative risk assessment approaches, including dispersion modelling for safety distance determination.

The engineering methodology includes:

- **Application of international standards and regulatory frameworks**
  → Ensuring compliance with ISO and ADR requirements
- **Risk assessment methodologies (HAZID, HAZOP, QRA)**
  → Identification and mitigation of safety risks
- **Operational analysis and validation**
  → Integration of real port conditions and constraints
- **Criteria-based assessment framework (mapping instrument)**
  → Structured evaluation of bunkering feasibility
- **Iterative refinement based on stakeholder input**
  → Continuous improvement of technical solutions

This structured approach ensures that the developed specifications are **fit-for-purpose, safe, and aligned with industry expectations**, supporting their use in both pilot activities and future replication. It also ensures that all technical outputs are **implementation-ready and aligned with real operational conditions**.

3.4 Stakeholder Engagement

Stakeholder engagement has been a central element of the methodology, ensuring that all outputs are grounded in **practical experience and real-world requirements**. The activity involves continuous interaction with ports, energy companies, and technical partners, enabling co-creation of solutions.

Regular coordination has been maintained through:

- Jour Fixe meetings,
- partner workshops,
- targeted technical discussions.

These interactions have been essential for:

- validating modelling assumptions,
- identifying operational constraints,
- aligning technical specifications with user needs.

Stakeholder input has been particularly important in the development of the tank trailer specification, where practical considerations such as maneuverability, safety procedures, and operational workflows were refined based on partner experience. Similarly, the bunkering mapping instrument benefits from cross-port input, ensuring that the criteria catalogue reflects diverse conditions.

The engagement process also supports **knowledge exchange across the Baltic Sea Region**, enabling partners to learn from each other and align approaches.

Key elements of stakeholder engagement include:

- **Regular coordination meetings (JF, partner meetings)**
  → Ensuring alignment and progress tracking
- **Technical workshops and consultations**
  → Addressing specific technical and operational topics
- **Integration of feedback into development process**
  → Continuous refinement of outputs
- **Cross-port knowledge exchange**
  → Sharing experiences and best practices

This approach enhances the **practical relevance and acceptance** of the developed solutions, increasing their likelihood of successful implementation and replication.

3.5 Procurement and External Expertise

To ensure technical quality and methodological robustness, a structured procurement process was implemented to engage external expertise for the development of the techno-economic model.

The process included:

- definition and refinement of the technical scope,
- preparation of tender documentation,
- evaluation of proposals,
- contracting of Ramboll as the external service provider.

The involvement of external expertise enables the integration of **advanced modelling capabilities**, including GIS-based analysis and techno-economic evaluation, while ensuring alignment with industry standards.

At the same time, close coordination between the contractor and project partners ensures that the model remains aligned with project objectives and user requirements. Regular interaction and feedback loops are maintained to support integration of external work into the overall framework.

The procurement and external expertise integration process includes:

- **Structured tendering and selection process**
  → Ensuring transparency and quality
- **Clear definition of scope and deliverables**
  → Alignment with project objectives
- **Continuous coordination with project partners**
  → Integration of external work into overall framework
- **Knowledge transfer and capacity building**
  → Ensuring long-term usability of the model

This approach ensures that the project benefits from **high-level expertise while maintaining ownership and usability of outputs within the consortium**.

4. Detailed Progress by Component

4.1 Techno-economic and Commercial Analysis Model

4.1.1 Objective and Scope

The techno-economic and commercial analysis model constitutes the **core analytical component of GoA 1.2**, providing a structured decision-support tool for assessing the feasibility and commercial viability of hydrogen derivative deployment in port environments. The model is designed to support port authorities, industrial stakeholders, and investors in evaluating the potential for integrating renewable energy, hydrogen production, and derivative fuel supply chains within port and port-adjacent areas.

The scope of the model covers the full value chain, including renewable energy generation, hydrogen production via electrolysis, conversion into derivatives such as methanol, storage, transport, and bunkering. By integrating these elements, the model enables a comprehensive assessment of system configurations and investment options.

A key objective of the model is to reduce uncertainty in early-stage decision-making by providing **quantitative insights into technical feasibility, spatial constraints, and economic performance**. This is particularly relevant in the current market context, where hydrogen derivative deployment is still at an early stage and characterised by limited empirical data and evolving assumptions.

The main objectives of the techno-economic model include:

- Assessment of renewable energy generation potential in ports and surrounding areas
- Evaluation of hydrogen production and conversion into derivatives (e.g. methanol)
- Identification of optimal infrastructure configurations and locations
- Analysis of economic feasibility (CAPEX, OPEX, cost competitiveness)
- Support for investment planning and stakeholder decision-making

4.1.2 Model Development Approach

The model is developed using a **GIS-based and scenario-driven approach**, integrating spatial, technical, and economic data into a unified analytical framework. This approach ensures that the results are not only theoretically robust but also aligned with real-world constraints in port environments.

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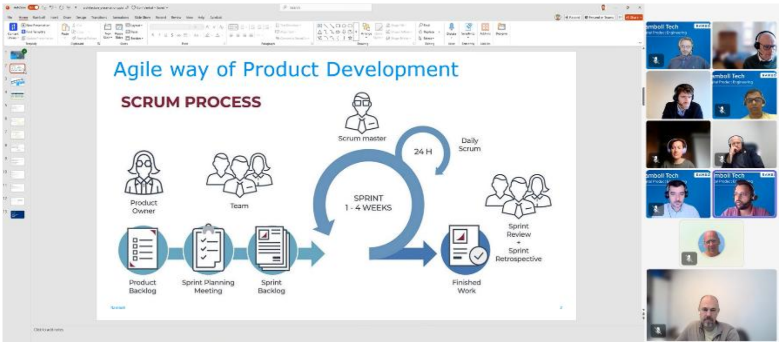
Access to GIS layers

Port of Ventspils

Development is carried out in collaboration with external experts (Ramboll), following a structured and iterative process. The model development is organised in phases, including:

- market analysis and input data preparation,
- definition of model architecture and parameters,
- implementation and testing of model functionalities,
- validation and refinement based on stakeholder feedback.

An **agile sprint-based methodology** is applied, allowing incremental development and continuous validation. This approach enables the model to evolve in response to new data, partner input, and changing market conditions.



Agile way of Product Development

SCRUM PROCESS

The model is primarily focused on **indigenous production scenarios**, reflecting the strategic importance of local renewable energy integration and supply security. Import scenarios have been identified as relevant but are not the primary focus in the current development phase.

Key elements of the model development approach include:

- **GIS-based modelling framework**
  → Integration of spatial data and infrastructure constraints
- **Scenario-driven analysis**
  → Evaluation of different development pathways
- **Iterative development process**
  → Continuous refinement based on feedback

- **External expertise integration (Ramboll)**
  → Ensuring methodological robustness and industry alignment
- **Focus on local production scenarios**
  → Reflecting strategic priorities in the BSR

4.1.3 Conceptual Framework and Model Architecture

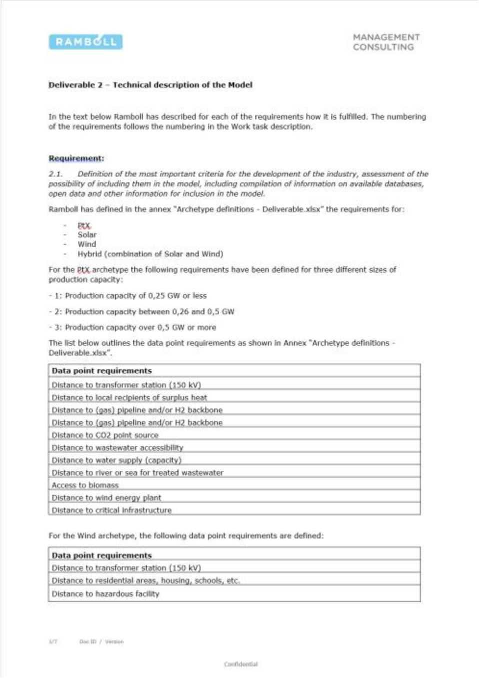
The model architecture is structured around multiple interconnected components representing the hydrogen derivative value chain. These components are integrated to enable system-level analysis and identification of optimal configurations.

The renewable energy component assesses the availability and potential of energy sources, particularly wind and solar, which form the basis for hydrogen production. The hydrogen production component simulates electrolysis processes and energy conversion efficiencies.

The derivative production component focuses on the conversion of hydrogen into fuels such as methanol, incorporating process efficiencies and resource requirements. This is linked to infrastructure components, including storage, transport, and bunkering systems.

A key feature of the model is the integration of **spatial constraints**, including land availability, safety distances, and proximity to existing infrastructure. This ensures that model outputs reflect realistic conditions and can be applied in practical planning.

The economic component evaluates cost structures, including capital and operational expenditures, and provides insights into cost competitiveness under different scenarios.



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MANAGEMENT
CONSULTING

Deliverable 2 – Technical description of the Model

In the text below Ramboll has described for each of the requirements how it is fulfilled. The numbering of the requirements follows the numbering in the Work task description.

Requirement:

2.1. Definition of the most important criteria for the development of the industry, assessment of the possibility of including them in the model, including compilation of information on available databases, open data and other information for inclusion in the model.

Ramboll has defined in the annex "Archetype definitions - Deliverable.xlsx" the requirements for:

- PtX
- Solar
- Wind
- Hybrid (combination of Solar and Wind)

For the PtX archetype the following requirements have been defined for three different sizes of production capacity:

- 1: Production capacity of 0,25 GW or less

- 2: Production capacity between 0,26 and 0,5 GW

- 3: Production capacity over 0,5 GW or more

The list below outlines the data point requirements as shown in Annex "Archetype definitions - Deliverable.xlsx".

Data point requirements
Distance to transformer station (150 kV)
Distance to local recipients of surplus heat
Distance to (gas) pipeline and/or H2 backbone
Distance to (gas) pipeline and/or H2 backbone
Distance to CO2 point source
Distance to wastewater accessibility
Distance to water supply (capacity)
Distance to river or sea for treated wastewater
Access to biomass
Distance to wind energy plant
Distance to critical infrastructure

For the Wind archetype, the following data point requirements are defined:

Data point requirements
Distance to transformer station (150 kV)
Distance to residential areas, housing, schools, etc.
Distance to hazardous facility

1/7 Doc ID / Version

Confidential

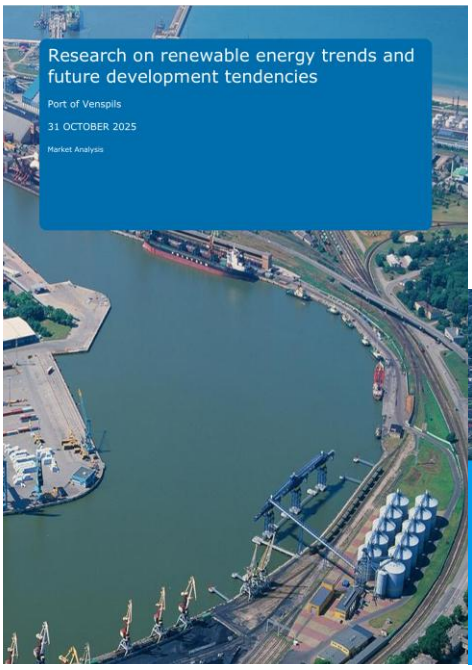
The model architecture includes the following components:

- **Renewable energy module**
  → Assessment of wind and solar potential
- **Hydrogen production module**
  → Simulation of electrolysis processes
- **Derivative production module**
  → Conversion into methanol and other fuels
- **Infrastructure and logistics module**
  → Storage, transport, and bunkering systems
- **Economic assessment module**
  → CAPEX, OPEX, and cost competitiveness
- **Spatial analysis component**
  → Integration of land use and safety constraints

4.1.4 Data Inputs and Assumptions

The model relies on a combination of **project-specific data, external datasets, and assumptions**, reflecting the current state of knowledge in the hydrogen derivatives sector. Given the early-stage nature of the market, many parameters are subject to uncertainty and require careful consideration.

Data inputs include renewable energy resource data, infrastructure characteristics, and economic parameters. Where direct data is not available, assumptions are derived from market studies and expert input.



Research on renewable energy trends and future development tendencies

Port of Venspils

31 OCTOBER 2025

Market Analysis

RAMBOLL

Market analysis

Study on renewable energy trends and future development

Port of Ventspils

A key challenge identified during development is the **limited availability of reliable and harmonised data**, particularly for emerging technologies and future market conditions. This affects parameters such as cost projections, efficiency values, and demand forecasts.

To address these uncertainties, the model incorporates **flexibility through scenario and sensitivity analysis**, allowing users to adjust key variables and explore different outcomes.

Key data inputs and assumptions include:

- Renewable energy resource data (wind, solar)
- Electricity prices and grid conditions
- Electrolysis efficiency and cost parameters
- Methanol production parameters
- Infrastructure costs (storage, transport, bunkering)
- Demand scenarios for maritime fuel consumption
- Spatial and safety constraints

4.1.5 Scenario Development and Analytical Capabilities

A central feature of the techno-economic model is its ability to perform **scenario-based analysis**, enabling stakeholders to explore different development pathways and assess their implications. This is particularly important in a context characterised by high uncertainty, where multiple future scenarios must be considered.

The model allows users to define and compare scenarios based on key variables such as:

- scale of renewable energy deployment
- location and size of PtX facilities
- fuel demand levels
- energy price trajectories
- regulatory conditions

By running multiple scenarios, the model provides insights into **system sensitivity**, highlighting which parameters have the greatest impact on economic viability. This supports more informed decision-making and helps identify robust strategies that remain viable under different conditions.

In addition to scenario analysis, the model includes capabilities for **sensitivity analysis**, allowing users to systematically vary individual parameters and observe their effects on outputs. This is particularly useful for understanding risks and uncertainties associated with investment decisions.

Key analytical capabilities include:

- Scenario comparison (e.g. local production vs. import)
- Sensitivity analysis (e.g. electricity price, CAPEX variations)
- Spatial optimisation of infrastructure locations
- Identification of bottlenecks and constraints
- Estimation of levelised cost of fuel (LCOF)

4.1.6 Preliminary Results and Key Insights

The application of the techno-economic model has already generated a number of **important preliminary insights** relevant to the Baltic Sea Region.

One of the key findings is the strong potential for **renewable energy-driven PtX production**, particularly in ports with access to wind resources. However, the analysis also highlights that economic viability is highly sensitive to electricity prices and utilisation rates of production facilities.

Another important insight is the critical role of **local production**. While import scenarios may be viable in some cases, local production offers advantages in terms of supply security, cost stability, and integration with port operations. This reinforces the strategic role of ports as energy hubs rather than purely logistical nodes.

Key preliminary findings include:

- High potential for wind-based hydrogen production
- Strong dependence of economic viability on electricity costs

- Importance of local production for long-term competitiveness
- Need for flexible, scalable infrastructure solutions
- Early-stage market maturity with limited current demand

4.1.7 Challenges and Limitations

Several challenges have been identified in the development and application of the techno-economic model.

A primary challenge is the **uncertainty of input data**, particularly for emerging technologies and future market conditions. This requires the use of assumptions and scenario analysis, which introduces variability in results.

Another challenge relates to the **complexity of the model**, which integrates multiple analytical dimensions. Ensuring consistency and usability requires careful design and continuous refinement.

Additional considerations include:

- IT platform requirements and licensing,
- long-term maintenance and updating of the model,
- ensuring accessibility for different user groups.

Key challenges include:

- Limited availability of reliable data
- Uncertainty in market and cost parameters
- Complexity of integrating multiple data layers
- IT and platform-related constraints
- Need for long-term maintenance and usability

4.1.8 Current Status and Next Steps

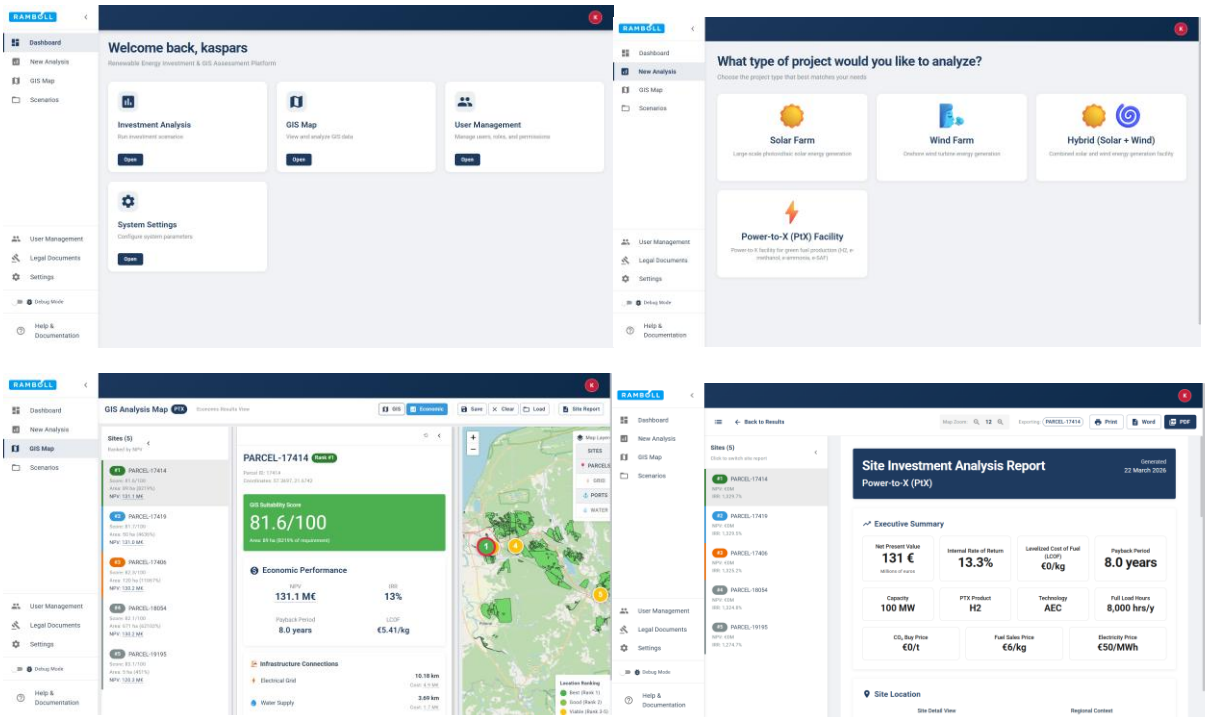
At the current stage, the techno-economic model has reached an **advanced development phase**, with core functionalities established and undergoing validation. Initial versions of the model have been deployed in a test environment, enabling partners to provide feedback and identify areas for improvement.

The next steps focus on:

- finalising model development and validation
- refining user interface and documentation

- incorporating additional data and scenarios
- preparing guidelines for use and maintenance

In parallel, efforts are being made to ensure that the model remains **sustainable and usable beyond the project duration**, including considerations for hosting, licensing, and future updates.



Welcome back, kaspars

Renewable Energy Investment & GIS Assessment Platform

Investment Analysis

GIS Map

User Management

System Settings

What type of project would you like to analyze?

Solar Farm

Wind Farm

Hybrid (Solar + Wind)

Power-to-X (PtX) Facility

GIS Analysis Map PTX

Sites (5)

#1 PARCEL-17414

#2 PARCEL-17419

#3 PARCEL-17406

#4 PARCEL-18054

#5 PARCEL-19195

PARCEL-17414 Rank #1

GIS Suitability Score 81.6/100

Economic Performance

NPV 131.1 M€

IRR 13%

Payback Period 8.0 years

LCOF €5.41/kg

Infrastructure Connections

Electrical Grid 10.18 km

Water Supply 3.69 km

Site Investment Analysis Report

Power-to-X (PtX)

Generated 22 March 2026

Executive Summary

Net Present Value 131 €

Internal Rate of Return 13.3%

Levelized Cost of Fuel (LCOF) €0/kg

Payback Period 8.0 years

Capacity 100 MW

PTX Product H2

Technology AEC

Full Load Hours 8,000 hrs/y

CO_2 Buy Price €0/t

Fuel Sales Price €6/kg

Electricity Price €50/MWh

Site Location

Site Detail View

Regional Context

Planned next steps include:

- Completion of Deliverables 3–5 (model, manuals, maintenance)
- Integration of stakeholder feedback into final version
- Validation against pilot cases in WP2
- Preparation for dissemination and replication

4.2 Port Bunkering Mapping Instrument

4.2.1 Objective and Functional Scope

The Port Bunkering Mapping Instrument is developed as a **structured planning and assessment tool** to support ports in evaluating the feasibility and requirements for implementing bunkering operations for hydrogen derivatives, with a primary focus on methanol. The instrument addresses a critical gap identified during the project: the lack of **systematic and harmonised methodologies** for planning bunkering infrastructure in port environments.

Given the early-stage maturity of hydrogen derivative deployment, ports currently face significant uncertainty when assessing where and how bunkering operations can be implemented. These uncertainties relate to safety requirements, regulatory approval processes, operational constraints, and interactions with existing port activities. The mapping instrument responds to these challenges by providing a **criteria-based framework** that enables structured and transparent decision-making.

The instrument is designed to be **applicable across different port contexts and fuel types**, ensuring that it can support not only methanol but also other hydrogen derivatives in future applications. It therefore contributes to both project-specific objectives and broader standardisation efforts at the Baltic Sea Region and EU level.

The main objectives of the bunkering mapping instrument are:

- Provide a structured framework for assessing bunkering feasibility
- Support port authorities in planning and permitting processes
- Identify suitable locations for bunkering infrastructure
- Integrate safety, regulatory, and operational considerations
- Enable standardisation and transferability across ports

4.2.2 Conceptual Design

The instrument is built around a **multi-layered conceptual framework**, combining generalised bunkering setups with site-specific case evaluation. This approach allows for the development of standardised methodologies while maintaining flexibility for adaptation to local conditions.

At the core of the instrument is a **criteria catalogue**, which defines all relevant parameters influencing bunkering feasibility. This catalogue is structured to ensure comprehensive coverage of technical, operational, and environmental aspects.

The methodology distinguishes between:

- a **general bunker setup**, defining standard configurations and operational concepts,
- and a **bunker case**, representing the application of these configurations to a specific port location.

This distinction enables a systematic transition from general planning to detailed site-specific analysis.

The instrument also incorporates a **stepwise workflow**, guiding users through the assessment process from initial screening to detailed safety evaluation, including quantitative risk assessment where required.

The core structure of the instrument includes:

- **Criteria catalogue (central component)**
  → Comprehensive list of factors influencing bunkering feasibility
- **General bunker setup definition**
  → Standardised configurations and operational concepts
- **Bunker case development**
  → Application to specific port locations
- **Assessment workflow**
  → Stepwise evaluation from screening to detailed analysis
- **Integration of safety and risk assessment**
  → Including qualitative and quantitative approaches

This structured approach ensures that all relevant aspects are systematically addressed and that results are **consistent, transparent, and reproducible**.

4.2.3 Criteria Catalogue and Assessment Dimensions

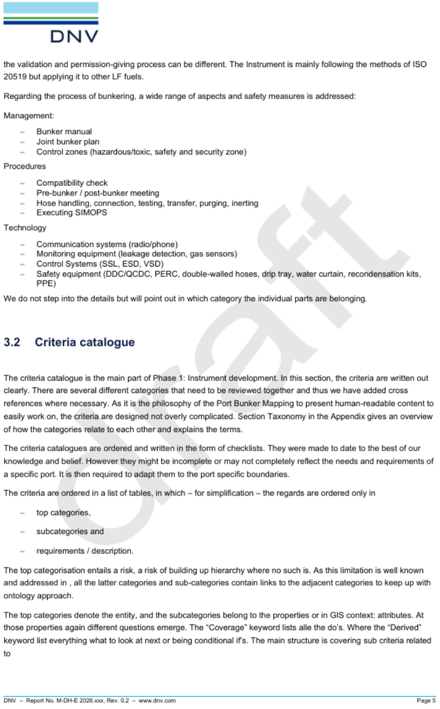
The criteria catalogue represents the **analytical core of the mapping instrument**, providing a comprehensive framework for evaluating bunkering feasibility. It integrates multiple dimensions, reflecting the complexity of port environments and bunkering operations.

The catalogue includes criteria related to:

- location and site characteristics,
- bunkering technology and parameters,
- vessel characteristics,
- operational conditions,
- environmental and proximity constraints.

These criteria are interdependent and must be assessed in an integrated manner to ensure realistic and reliable outcomes.

A key feature of the catalogue is its ability to support **structured comparison between potential bunkering locations**, enabling ports to prioritise options based on defined parameters.



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the validation and permission-giving process can be different. The Instrument is mainly following the methods of ISO 20519 but applying it to other LF fuels.

Regarding the process of bunkering, a wide range of aspects and safety measures is addressed:

Management:

- Bunker manual
- Joint bunker plan
- Control zones (hazardous/toxic, safety and security zone)

Procedures

- Compatibility check
- Pre-bunker / post-bunker meeting
- Hose handling, connection, testing, transfer, purging, inerting
- Executing SIMOPS

Technology

- Communication systems (radio/phone)
- Monitoring equipment (leakage detection, gas sensors)
- Control Systems (SSL, ESD, VSD)
- Safety equipment (DDC/QCDC, PERC, double-walled hoses, drip tray, water curtain, recondensation kits, PPE)

We do not step into the details but will point out in which category the individual parts are belonging.

3.2 Criteria catalogue

The criteria catalogue is the main part of Phase 1: Instrument development. In this section, the criteria are written out clearly. There are several different categories that need to be reviewed together and thus we have added cross references where necessary. As it is the philosophy of the Port Bunker Mapping to present human-readable content to easily work on, the criteria are designed not overly complicated. Section Taxonomy in the Appendix gives an overview of how the categories relate to each other and explains the terms.

The criteria catalogues are ordered and written in the form of checklists. They were made to date to the best of our knowledge and belief. However they might be incomplete or may not completely reflect the needs and requirements of a specific port. It is then required to adapt them to the port specific boundaries.

The criteria are ordered in a list of tables, in which – for simplification – the regards are ordered only in

- top categories,
- subcategories and
- requirements / description.

The top categorisation entails a risk, a risk of building up hierarchy where no such is. As this limitation is well known and addressed in , all the latter categories and sub-categories contain links to the adjacent categories to keep up with ontology approach.

The top categories denote the entity, and the subcategories belong to the properties or in GIS context: attributes. At those properties again different questions emerge. The "Coverage" keyword lists alle the do's. Where the "Derived" keyword list everything what to look at next or being conditional if's. The main structure is covering sub criteria related to

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Key dimensions within the criteria catalogue include:

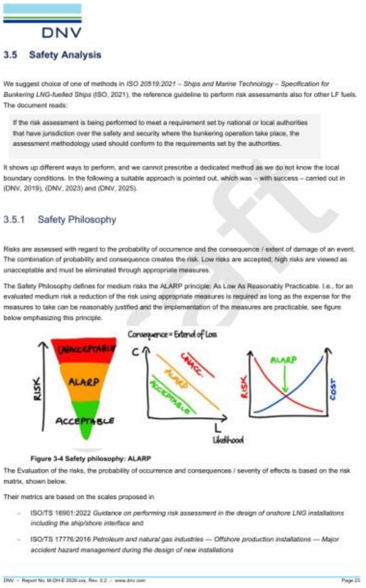
- **Location and site characteristics:**
    - Accessibility and infrastructure availability
    - Terminal layout and space constraints
    - Proximity to residential or sensitive areas
    - Potential for future port development
- **Bunkering technology and parameters:**
    - Type of bunkering (e.g. truck-to-ship, ship-to-ship)
    - Transfer rates and operational requirements
    - Equipment compatibility
- **Vessel characteristics:**
    - Vessel size and fuel demand
    - Compatibility with bunkering infrastructure
    - Technical requirements for fuel transfer
- **Operational conditions:**

    - SIMOPS (Simultaneous Operations) constraints
    - Interaction with port traffic (marine and landside)
    - Scheduling and frequency of operations
- **Environmental and proximity constraints:**
    - Weather and climate conditions
    - Safety zones and exclusion areas
    - Environmental protection requirements

This comprehensive structure ensures that the instrument captures all relevant factors influencing bunkering feasibility and supports **holistic decision-making**.

4.2.4 Safety Analysis and Risk Assessment Integration

Safety considerations are fully integrated into the mapping instrument, reflecting the hazardous nature of hydrogen derivatives such as methanol. The methodology incorporates both **qualitative and quantitative risk assessment approaches**, ensuring alignment with regulatory requirements and approval processes.



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3.5 Safety Analysis

We suggest choice of one of methods in *ISO 20519:2021 – Ships and Marine Technology – Specification for Bunkering LNG-fuelled Ships* (ISO, 2021), the reference guideline to perform risk assessments also for other LF fuels. The document reads:

> If the risk assessment is being performed to meet a requirement set by national or local authorities that have jurisdiction over the safety and security where the bunkering operation take place, the assessment methodology used should conform to the requirements set by the authorities.

It shows up different ways to perform, and we cannot prescribe a dedicated method as we do not know the local boundary conditions. In the following a suitable approach is pointed out, which was – with success – carried out in (DNV, 2019), (DNV, 2023) and (DNV, 2025).

3.5.1 Safety Philosophy

Risks are assessed with regard to the probability of occurrence and the consequence / extent of damage of an event. The combination of probability and consequence creates the risk. Low risks are accepted; high risks are viewed as unacceptable and must be eliminated through appropriate measures.

The Safety Philosophy defines for medium risks the ALARP principle: As Low As Reasonably Practicable. I.e., for an evaluated medium risk a reduction of the risk using appropriate measures is required as long as the expense for the measures to take can be reasonably justified and the implementation of the measures are practicable, see figure below emphasizing this principle.

Figure 3-4 Safety philosophy: ALARP

The Evaluation of the risks, the probability of occurrence and consequences / severity of effects is based on the risk matrix, shown below.

Their metrics are based on the scales proposed in

- ISO/TS 16901:2022 *Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface* and
- ISO/TS 17776:2016 *Petroleum and natural gas industries — Offshore production installations — Major accident hazard management during the design of new installations*

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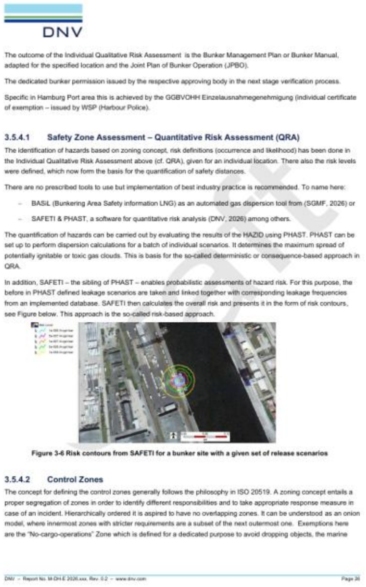

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The outcome of the Individual Qualitative Risk Assessment is the Bunker Management Plan or Bunker Manual, adapted for the specified location and the Joint Plan of Bunker Operation (JPBO).

The dedicated bunker permission issued by the respective approving body in the next stage verification process.

Specific in Hamburg Port area this is achieved by the GGBVOHH Einzelausnahmegenehmigung (individual certificate of exemption – issued by WSP (Harbour Police).

3.5.4.1 Safety Zone Assessment – Quantitative Risk Assessment (QRA)

The identification of hazards based on zoning concept, risk definitions (occurrence and likelihood) has been done in the Individual Qualitative Risk Assessment above (cf. QRA), given for an individual location. There also the risk levels were defined, which now form the basis for the quantification of safety distances.

There are no prescribed tools to use but implementation of best industry practice is recommended. To name here:

- BASiL (Bunkering Area Safety information LNG) as an automated gas dispersion tool from (SGMF, 2026) or
- SAFETI & PHAST, a software for quantitative risk analysis (DNV, 2026) among others.

The quantification of hazards can be carried out by evaluating the results of the HAZID using PHAST. PHAST can be set up to perform dispersion calculations for a batch of individual scenarios. It determines the maximum spread of potentially ignitable or toxic gas clouds. This is basis for the so-called deterministic or consequence-based approach in QRA.

In addition, SAFETI – the sibling of PHAST – enables probabilistic assessments of hazard risk. For this purpose, the before in PHAST defined leakage scenarios are taken and linked together with corresponding leakage frequencies from an implemented database. SAFETI then calculates the overall risk and presents it in the form of risk contours, see Figure below. This approach is the so-called risk-based approach.

Figure 3-6 Risk contours from SAFETI for a bunker site with a given set of release scenarios

3.5.4.2 Control Zones

The concept for defining the control zones generally follows the philosophy in ISO 20519. A zoning concept entails a proper segregation of zones in order to identify different responsibilities and to take appropriate response measure in case of an incident. Hierarchically ordered it is aspired to have no overlapping zones. It can be understood as an onion model, where innermost zones with stricter requirements are a subset of the next outermost one. Exemptions here are the "No-cargo-operations" Zone which is defined for a dedicated purpose to avoid dropping objects, the marine

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The instrument applies a tiered approach to risk assessment:

- initial qualitative assessment (HAZID),
- development of general risk scenarios,

- site-specific qualitative evaluation,
- quantitative risk assessment (QRA) where required.

Quantitative analysis includes the use of **dispersion modelling tools** (e.g. Phast, BASiL) to determine safety distances and assess potential impact zones. These analyses provide a scientific basis for defining exclusion zones and ensuring compliance with safety regulations.

The integration of safety analysis directly into the mapping instrument ensures that **risk considerations are addressed from the earliest stages of planning**, rather than being treated as a separate process.

Key safety and risk assessment elements include:

- Hazard identification and classification
- Definition of safety distances using dispersion modelling
- Assessment of interaction with other port activities
- Evaluation of emergency response requirements
- Integration of environmental and weather-related factors

4.2.5 Workflow and Application Process

The mapping instrument follows a structured workflow, guiding users from initial concept development to final feasibility assessment. This ensures consistency in application and supports both internal decision-making and external communication with authorities.

The process begins with the definition of a **general bunkering setup**, which establishes the baseline configuration. This is followed by the identification of potential locations and the development of **site-specific bunker cases**.

Each case is then evaluated using the criteria catalogue, allowing for systematic assessment of feasibility. Where necessary, detailed safety analysis is conducted, including quantitative risk assessment.

The workflow also supports **iterative refinement**, allowing assumptions and configurations to be adjusted based on findings and stakeholder input.

The application workflow includes:

- Definition of general bunkering setup
- Identification of potential locations
- Application of criteria catalogue
- Development of site-specific bunker cases
- Safety and risk assessment (including QRA where required)

- Final evaluation and decision-making

This process ensures that bunkering solutions are **evaluated in a structured, transparent, and repeatable manner**.

4.2.6 Strategic Value and Transnational Applicability

The bunkering mapping instrument provides significant strategic value by enabling ports to move from **conceptual planning to structured implementation**. By standardising the assessment process, it reduces uncertainty and facilitates more efficient decision-making.

One of the key strengths of the instrument is its **transnational applicability**. By incorporating input from multiple ports across the Baltic Sea Region, the instrument reflects a wide range of operational conditions and regulatory environments. This ensures that it can be adapted to different contexts while maintaining a consistent methodological framework.

The instrument also contributes to **harmonisation efforts at EU level**, addressing the current fragmentation of approaches to hydrogen derivative bunkering. By providing a common framework, it supports the development of shared standards and best practices.

Strategic benefits include:

- Reduction of planning uncertainty
- Support for regulatory compliance and permitting
- Facilitation of investment decisions
- Promotion of standardisation and harmonisation
- Enablement of knowledge transfer across ports

4.2.7 Challenges and Limitations

Several challenges have been identified in the development and application of the mapping instrument.

One key challenge is the **variability of port conditions**, requiring the instrument to balance standardisation with flexibility. Differences in layout, traffic patterns, and regulatory frameworks necessitate site-specific adaptation.

Another challenge relates to the **evolving regulatory environment**, where standards for hydrogen derivatives are still under development. This requires continuous updates to the instrument.

Data availability also remains a constraint, particularly for detailed site-specific assessments and risk analysis.

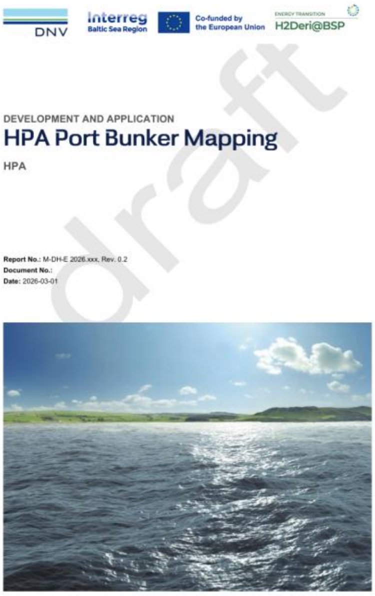
Key challenges include:

- Variability of port environments

- Lack of harmonised regulatory frameworks
- Limited operational experience with hydrogen derivatives
- Data gaps for site-specific analysis
- Need for continuous updates and refinement

4.2.8 Current Status and Next Steps

The Port Bunkering Mapping Instrument has reached a **well-developed stage**, with the conceptual framework and criteria catalogue established. Current efforts focus on validation and refinement through partner engagement and alignment with pilot activities.



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DEVELOPMENT AND APPLICATION
HPA Port Bunker Mapping
HPA

Report No.: M-DH-E 2026.xxx, Rev. 0.2
Document No.:
Date: 2026-03-01

The next phase will involve applying the instrument in real-world contexts, enabling validation of its functionality and identification of areas for improvement.

Planned next steps include:

- Validation through pilot applications (WP2)
- Refinement of criteria and workflow based on feedback
- Development of user guidelines and documentation
- Integration with other project outputs
- Preparation for dissemination and replication

4.3 Methanol Bunker Tank Trailer

4.3.1 Objective and Scope

The methanol bunker tank trailer specification represents a **key implementation-oriented output** of GoA 1.2, focusing on enabling **truck-to-ship (TTS) bunkering operations** as an initial and flexible solution for hydrogen derivative deployment in ports.

The development of this component responds directly to the current market conditions identified within the project. Given the **limited and uncertain demand for methanol as marine fuel**, as well as delays in the availability of green methanol supply, fixed infrastructure investments are associated with significant risk. In this context, mobile bunkering solutions provide a **pragmatic entry point**, allowing ports and operators to initiate operations while maintaining flexibility.

The tank trailer specification is therefore designed to support:

- early-stage deployment,
- operational testing and validation,
- gradual scaling of bunkering activities.

At the same time, the specification is developed to a level that enables **direct procurement and implementation**, ensuring practical applicability within the project and beyond.

The main objectives of this component are:

- Define technical requirements for methanol tank trailer suitable for port operations
- Enable safe and efficient truck-to-ship bunkering procedures
- Support early-stage deployment of methanol as marine fuel
- Provide a scalable and transferable solution across BSR ports
- Establish a basis for procurement and pilot implementation

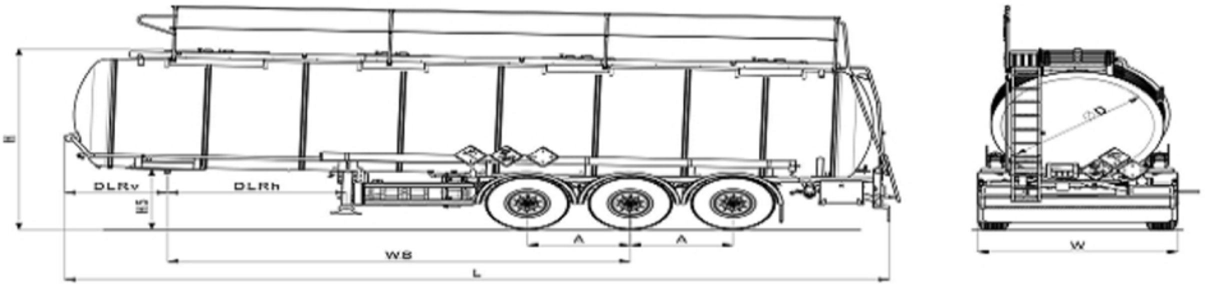
4.3.2 Technical Specifications and Design Parameters

The technical specification of the methanol bunker tank trailer has been developed based on **operational requirements, safety considerations, and port-specific constraints**, with direct input from partner experience.

A key design driver identified during the development process was the need to ensure **high maneuverability within constrained port environments**. Observations from ports such as Tallinn and Helsinki highlighted limitations related to quay layouts, turning radii, and space availability. As a result, the selected configuration prioritises operational flexibility over maximum capacity.

The specification defines a tank trailer with:

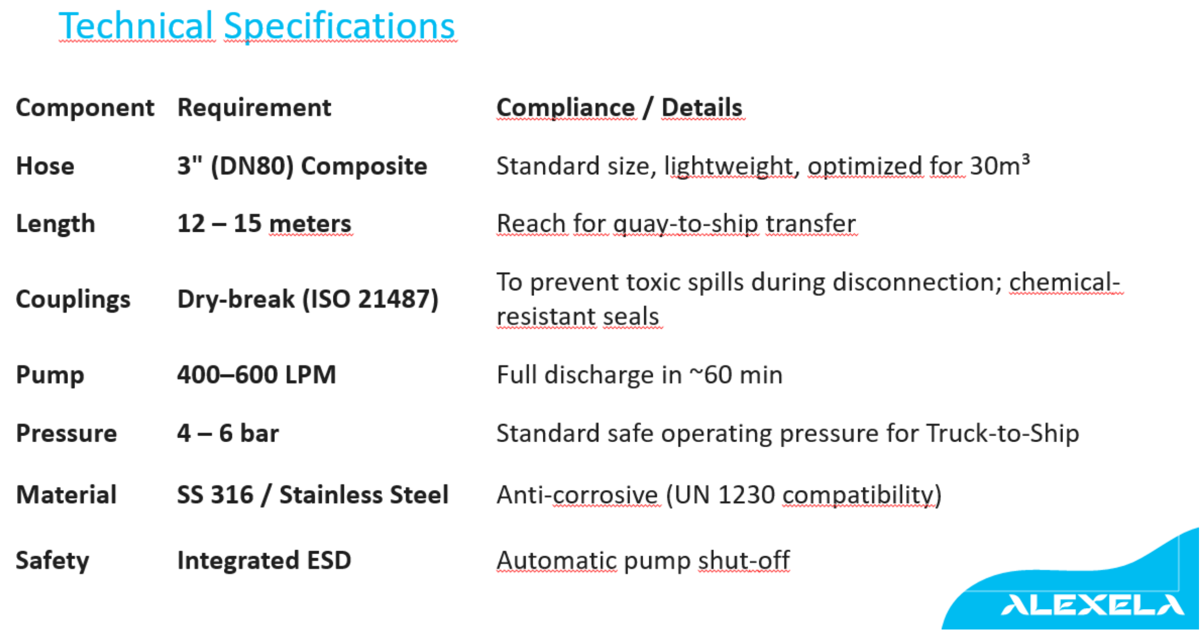
- approximately **30,000 litres capacity**,
- **stainless steel tank construction**, ensuring compatibility with methanol,
- **4x2 vehicle configuration**, optimised for maneuverability and operational flexibility.



These parameters reflect a balanced approach, enabling sufficient bunkering capacity while ensuring that the trailer can operate effectively within real port conditions.

Key technical specifications include:

- **Capacity:** approx. 30,000 litres
- **Material:** stainless steel tank construction
- **Vehicle configuration:** 4x2 chassis for improved maneuverability
- **Design focus:** compatibility with constrained port environments



Technical Specifications

Component	Requirement	Compliance / Details
Hose	**3" (DN80) Composite**	Standard size, lightweight, optimized for 30m³
Length	**12 – 15 meters**	Reach for quay-to-ship transfer
Couplings	**Dry-break (ISO 21487)**	To prevent toxic spills during disconnection; chemical-resistant seals
Pump	**400–600 LPM**	Full discharge in ~60 min
Pressure	**4 – 6 bar**	Standard safe operating pressure for Truck-to-Ship
Material	**SS 316 / Stainless Steel**	Anti-corrosive (UN 1230 compatibility)
Safety	**Integrated ESD**	Automatic pump shut-off

The specification is developed to a **procurement-ready level**, forming the basis for the Request for Quotation (RFQ) process.

4.3.3 Operational Concept: Truck-to-Ship Bunkering Process

The tank trailer specification is complemented by a **standardised truck-to-ship (TTS) bunkering procedure**, ensuring safe and consistent operations.

The bunkering process is structured into clearly defined steps, covering preparation, transfer, and completion phases. Particular emphasis is placed on safety measures and operational control.

The procedure includes:

- establishment of safety zones and pre-operation checks,
- secure connection of transfer systems,
- **inerting using nitrogen purging**, to eliminate oxygen and reduce explosion risk,
- controlled fuel transfer with continuous monitoring,
- disconnection, purging, and documentation (including bunker delivery note).

This structured workflow ensures that all critical aspects of bunkering operations are addressed systematically and that procedures can be **replicated across different ports and use cases**.

The operational concept includes:

- Preparation and safety setup
- Connection and inerting (nitrogen purging)
- Controlled fuel transfer
- Disconnection and purging
- Documentation and completion

The definition of this process provides a **practical operational framework** supporting both pilot activities and future deployment.

4.3.4 Safety Framework and Regulatory Compliance

Safety considerations are central to the development of the tank trailer specification, reflecting the hazardous nature of methanol. The specification integrates multiple layers of safety measures, including technical design, operational procedures, and regulatory compliance.

Methanol is classified as a hazardous substance (**UN 1230**), requiring adherence to **ADR regulations for transport**. In addition, the specification aligns with relevant bunkering safety standards and incorporates structured safety documentation.

The development process includes:

- identification of hazards and operational risks,
- definition of safety procedures and requirements,
- integration of safety documentation and checklists.

Risk assessment methodologies such as **HAZID and HAZOP** are applied to ensure systematic identification and mitigation of risks.

The specification also considers regulatory aspects related to **fuel classification and taxation (CN code)**, which may vary depending on the intended use of methanol and national regulations.

Key safety and regulatory elements include:

- Compliance with ADR regulations for hazardous materials
- Integration of HAZID and HAZOP methodologies
- Standardised safety procedures and documentation
- Consideration of fuel classification and taxation aspects
- Alignment with relevant bunkering safety standards

This framework ensures that the solution is **compliant, safe, and suitable for real-world implementation**.

4.3.5 Comparative Positioning: Methanol vs. LNG

As part of the specification development, a comparative assessment between methanol and LNG was conducted to contextualise the design choices and operational approach.

Methanol offers several advantages:

- Liquid state at ambient temperature (no cryogenic storage required)
- Lower infrastructure complexity
- Absence of boil-off gas issues

However, it also presents challenges:

- Lower energy density compared to LNG
- Toxicity considerations requiring specific safety measures

Despite these differences, the analysis confirms that methanol is well-suited for **early-stage deployment**, particularly in applications where flexibility and simplicity are prioritised over maximum energy density.

4.3.6 Market Context and Deployment Strategy

The development of the tank trailer specification is closely linked to the current **market conditions for methanol as marine fuel**, which remain at an early stage.

A key challenge identified during the reporting period is the **absence of confirmed end-user cases**, limiting opportunities for immediate pilot deployment. In addition, delays in the availability of green methanol supply have been observed, impacting the timeline for testing activities.

In response, a **flexible deployment approach ("Plan B")** has been adopted, focusing on:

- the use of **rental solutions instead of direct procurement**,
- reduction of upfront investment risks,
- maintaining readiness for deployment once supply and demand conditions improve.

This approach reflects the need to adapt to market realities while ensuring that project objectives can still be achieved.

Key market-related challenges include:

- Lack of confirmed end-user demand
- Delayed availability of green methanol supply
- Uncertainty in market development

Mitigation measures include:

- Adoption of rental-based deployment approach
- Focus on flexible and scalable solutions
- Continued monitoring of market developments

4.3.7 Transnational Applicability and Scalability

The tank trailer specification is developed with a strong emphasis on **transferability and applicability across the Baltic Sea Region**.

By incorporating input from multiple ports and aligning with international standards, the specification provides a **reference solution** that can be adopted by other ports and operators. The modular and flexible nature of the solution allows it to be adapted to different operational contexts and infrastructure conditions.

The specification also contributes to the development of **harmonised approaches to methanol bunkering**, supporting broader standardisation efforts.

Key aspects of applicability include:

- Adaptability to different port layouts and constraints

- Compatibility with various vessel types
- Alignment with international standards
- Potential for replication across BSR ports

4.3.8 Challenges and Limitations

Several challenges have been identified in the development and implementation of the tank trailer specification.

These include:

- dependency on fuel availability,
- uncertainty in demand development,
- regulatory variability across countries,
- limited operational experience with methanol bunkering.

These factors highlight the importance of maintaining flexibility and ensuring that solutions can evolve with market conditions.

Key challenges include:

- Limited availability of methanol supply
- Uncertain demand and utilisation rates
- Regulatory differences across countries
- Limited operational experience

4.3.9 Current Status and Next Steps

The methanol bunker tank trailer specification has reached a **procurement-ready stage**, representing a significant milestone within GoA 1.2. Current stage has also indicated an opportunities for the rental fo the equipment as alternative patway due to the failure of atempt to secure first viable delivery of the green methanol due to late production promised by the seller of the fuel.

Current status includes:

- completion of technical specifications,
- definition of operational procedures,
- establishment of safety framework,
- preparation for RFQ process.

The next steps focus on:

- launching the procurement process,
- conducting further validation and safety discussions,
- preparing for pilot implementation (subject to fuel availability),
- integrating lessons learned into final deliverables.

Planned next steps include:

- Launch of RFQ process
- Validation through pilot preparation
- Refinement based on stakeholder feedback
- Integration with WP2 activities

4.4 Methanol Bunker Vessel Specification

4.4.1 Objective and Scope

The methanol bunker vessel specification addresses the need for **scalable, vessel-based bunkering solutions**, enabling the transition from flexible, early-stage deployment (e.g. truck-to-ship) toward **higher-capacity and regular fuel supply operations**.

While the tank trailer solution provides a practical entry point, it is not sufficient to support long-term market development. As demand for hydrogen derivatives increases, ports will require dedicated bunkering vessels capable of supplying larger volumes and serving multiple locations efficiently. The development of this specification therefore represents a **forward-looking component** of GoA 1.2, aligned with future scaling needs.

At the same time, the work acknowledges current market constraints. The development of bunkering vessels must be grounded in **realistic demand projections and economic feasibility**, as premature investments in large-scale infrastructure carry significant risks.

The main objectives of this component are:

- Define technical specifications for methanol bunkering vessels
- Assess demand and market potential for vessel-based bunkering
- Evaluate economic feasibility and operational requirements
- Support future infrastructure planning and investment decisions
- Provide a transferable specification for use across BSR ports

4.4.2 Development Process and Analytical Approach

The development of the methanol bunker vessel specification followed a **phased approach**, integrating market analysis, economic evaluation, and technical design. This structured methodology ensures that the final specification is grounded in both **market realities and engineering feasibility**.

The process included three main stages:

- **Market demand analysis (November 2025)**
  → Assessment of current and projected demand for methanol as marine fuel
- **Economic evaluation (January 2026)**
  → Analysis of business case viability and operational requirements
- **Technical specification and design concept (February 2026)**
  → Definition of vessel characteristics and performance parameters

This phased approach allowed for iterative refinement, ensuring that technical design decisions are directly informed by market and economic insights. It also enabled alignment with stakeholder expectations and project objectives.

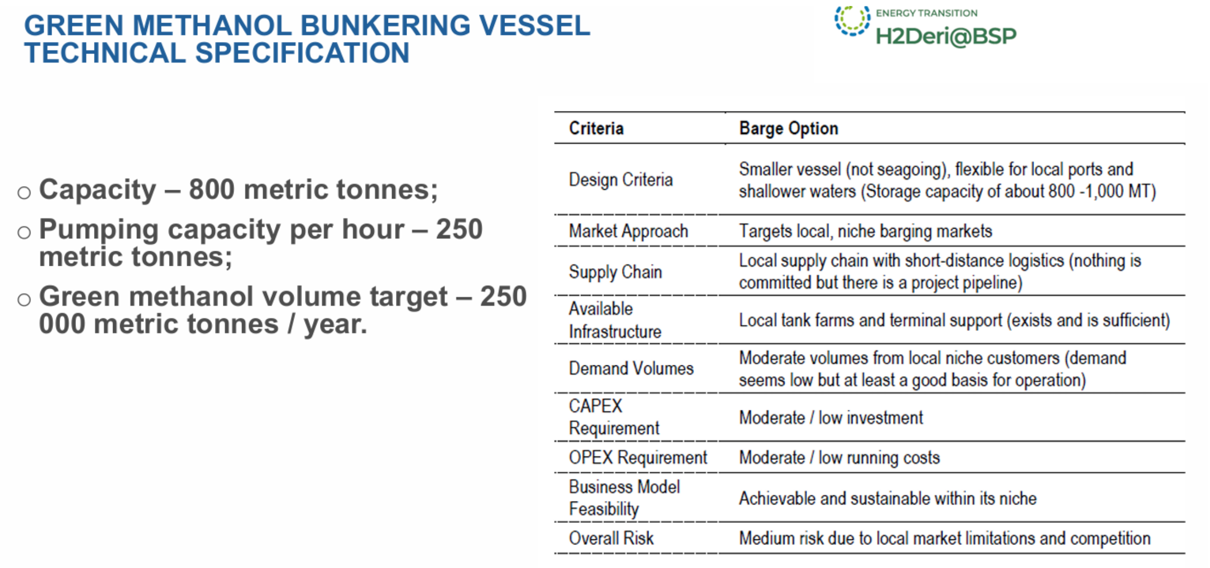
4.4.3 Technical Specifications and Design Parameters

The technical specification of the methanol bunker vessel defines the core characteristics required for effective bunkering operations in port environments. These specifications are based on a balance between operational efficiency, safety, and economic feasibility.

The vessel is designed to provide sufficient capacity and transfer performance to support regular bunkering operations while remaining adaptable to different port conditions and vessel types.

Key technical parameters include:

- **Carrying capacity:** approximately 800 metric tonnes
- **Pumping capacity:** approximately 250 tonnes per hour
- **Operational scope:** supply of methanol to seagoing vessels



GREEN METHANOL BUNKERING VESSEL TECHNICAL SPECIFICATION

- Capacity – 800 metric tonnes;
- Pumping capacity per hour – 250 metric tonnes;
- Green methanol volume target – 250 000 metric tonnes / year.

Criteria	Barge Option
Design Criteria	Smaller vessel (not seagoing), flexible for local ports and shallower waters (Storage capacity of about 800 -1,000 MT)
Market Approach	Targets local, niche barging markets
Supply Chain	Local supply chain with short-distance logistics (nothing is committed but there is a project pipeline)
Available Infrastructure	Local tank farms and terminal support (exists and is sufficient)
Demand Volumes	Moderate volumes from local niche customers (demand seems low but at least a good basis for operation)
CAPEX Requirement	Moderate / low investment
OPEX Requirement	Moderate / low running costs
Business Model Feasibility	Achievable and sustainable within its niche
Overall Risk	Medium risk due to local market limitations and competition

These parameters reflect a medium-scale bunkering solution, suitable for regional deployment within the Baltic Sea. The design prioritises operational flexibility and compatibility with existing port infrastructure, enabling integration into diverse port environments.

GREEN METHANOL BUNKERING VESSEL DESIGN CONCEPT

In addition to capacity and transfer rates, the design concept also considers broader aspects such as vessel configuration, safety systems, and interaction with port operations. While detailed engineering design is beyond the scope of this deliverable, the specification provides a **clear framework for future vessel construction and procurement**.

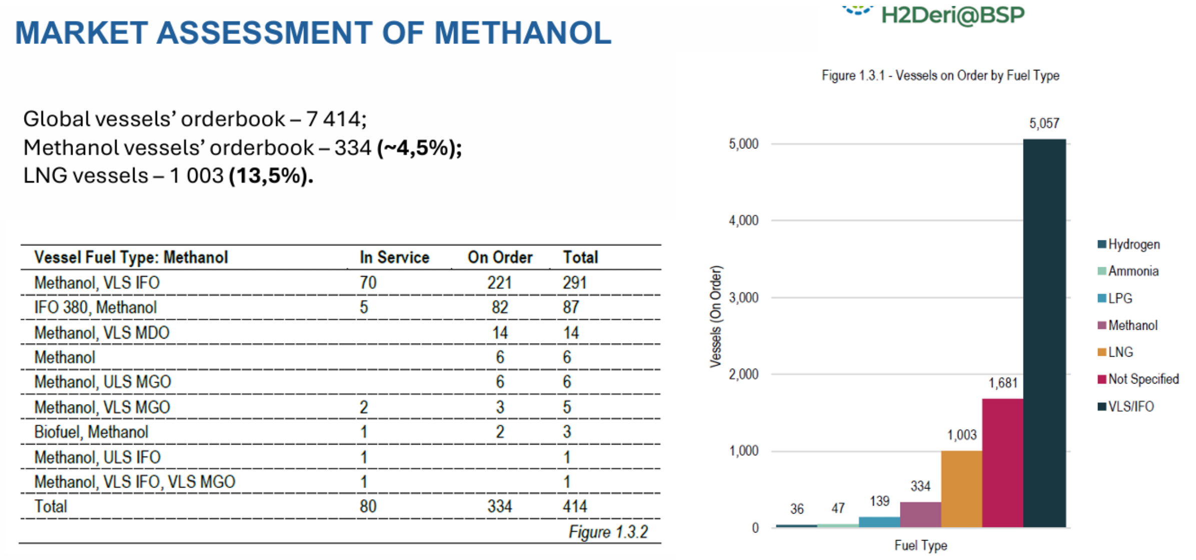
4.4.4 Market Assessment and Demand Analysis

The development of the bunker vessel specification is closely linked to an analysis of **market demand for methanol as a marine fuel**. The findings indicate that methanol currently represents a relatively small share of the global maritime fuel market, but with potential for growth in specific segments.

Global vessel orderbook data shows:

- Total vessels: ~7,400
- Methanol-powered vessels: ~334 (~4.5%)
- LNG-powered vessels: ~1,000 (~13.5%)

This indicates that while methanol adoption is increasing, it remains significantly less widespread than LNG. However, methanol is gaining traction in certain vessel categories, particularly where regulatory pressure and corporate sustainability goals are strong.



MARKET ASSESSMENT OF METHANOL

H2Deri@BSP

Global vessels' orderbook – 7 414;
Methanol vessels' orderbook – 334 **(~4,5%);**
LNG vessels – 1 003 **(13,5%).**

Vessel Fuel Type: Methanol	In Service	On Order	Total
Methanol, VLS IFO	70	221	291
IFO 380, Methanol	5	82	87
Methanol, VLS MDO		14	14
Methanol		6	6
Methanol, ULS MGO		6	6
Methanol, VLS MGO	2	3	5
Biofuel, Methanol	1	2	3
Methanol, ULS IFO	1		1
Methanol, VLS IFO, VLS MGO	1		1
Total	80	334	414

Figure 1.3.2

Figure 1.3.1 - Vessels on Order by Fuel Type

The analysis also identifies specific segments where methanol is likely to play a role:

- Container vessels (primary adopters)
- Passenger vessels (ferries, Ro-Ro ships, cruise ships)

Within the Baltic Sea Region, demand is expected to grow gradually, driven by both regulatory requirements and industry initiatives.

Key demand insights include:

- Methanol demand in BSR expected to exceed 160,000 tonnes by 2040
- Klaipėda port projected to reach 23–25 thousand tonnes demand by 2040
- Minimum annual volume of 2,000–3,000 tonnes required for viable business case

These findings confirm that demand is:

- currently limited,
- geographically concentrated,
- dependent on further market development.

Key demand-related findings include:

- Methanol remains a niche marine fuel segment
- Demand growth expected in specific vessel categories
- Regional demand expected to increase gradually
- Minimum volume thresholds required for viability

4.4.5 Economic Considerations and Business Case

The economic evaluation highlights several critical factors influencing the feasibility of methanol bunkering vessels.

Methanol is currently **less cost-competitive** compared to LNG and is expected to remain so in the medium term. Projections indicate that:

- LNG will remain more cost-effective until at least 2040,
- ammonia may become competitive in the longer term.

Despite this, methanol offers operational advantages, including:

- liquid state at ambient conditions,
- simpler storage and handling,
- compatibility with existing infrastructure.

The viability of bunkering vessels is therefore strongly dependent on:

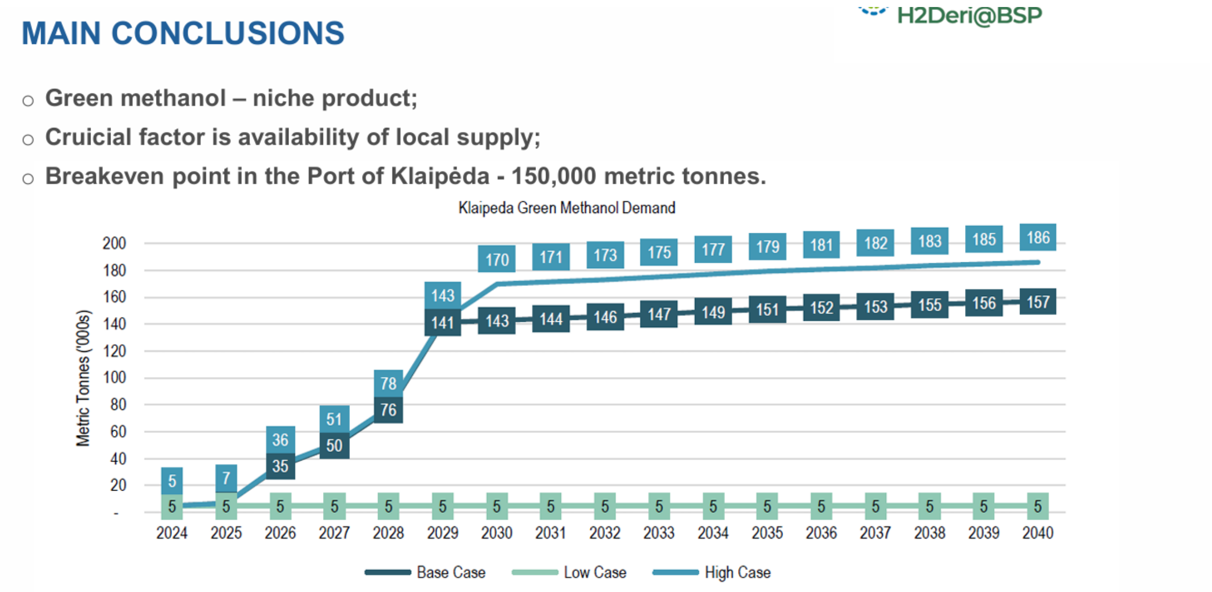
- availability of local fuel supply,
- concentration of demand in specific ports,
- utilisation rates of the vessel.

The analysis confirms that **underutilisation represents a key risk**, particularly in early market stages.

Key economic factors include:

- Higher cost of methanol compared to LNG
- Dependence on local supply availability

- Need for sufficient demand aggregation
- Sensitivity to utilisation rates



MAIN CONCLUSIONS

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- Green methanol – niche product;
- Cruicial factor is availability of local supply;
- Breakeven point in the Port of Klaipėda - 150,000 metric tonnes.

The analysis also identifies a **breakeven threshold**, indicating that sufficient fuel volumes must be achieved to justify investment in bunkering vessels. This reinforces the importance of coordinated development across ports to aggregate demand and reduce risks.

4.4.6 Operational Considerations and Deployment Context

Operational feasibility is a critical aspect of bunker vessel deployment. The specification considers multiple operational factors influencing performance and integration within port environments.

These include:

- interaction with port traffic and operations,
- availability of suitable berths,
- scheduling of bunkering activities,
- compatibility with different vessel types.

The vessel-based solution provides advantages in terms of:

- flexibility to serve multiple locations,
- higher transfer capacity compared to truck-based solutions,
- ability to support regular bunkering operations.

However, these advantages are contingent on sufficient demand and coordinated operations.

Key operational considerations include:

- Interaction with port traffic and logistics
- Scheduling and frequency of bunkering operations
- Compatibility with port infrastructure
- Integration with existing operations

4.4.7 Strategic Positioning of Methanol as Marine Fuel

The analysis confirms that methanol currently occupies a **niche position** within the maritime fuel landscape. While it offers significant potential for decarbonisation, its adoption is constrained by cost and limited supply.

At the same time, methanol benefits from:

- existing industrial production and handling experience
- relatively straightforward storage requirements
- growing interest from shipping companies

The strategic positioning of methanol is therefore characterised by:

- near-term applicability in specific segments
- potential for gradual scaling
- role as a transitional or complementary fuel

A critical factor for success is the **availability of local supply**, which directly influences both cost and operational feasibility. Without reliable supply chains, the deployment of bunkering infrastructure remains challenging.

Analysis also confirms that methanol bunkering vessels represent a **second-phase deployment solution**, following initial implementation of flexible options such as tank trailers.

This phased approach is necessary to:

- reduce investment risks,
- align infrastructure development with demand growth,
- ensure efficient utilisation of assets.

The role of bunker vessels is therefore to:

- support scaling of operations,
- enable higher fuel volumes,

- facilitate regional supply networks.

At the same time, their deployment is dependent on:

- sufficient demand aggregation,
- availability of fuel supply,
- supportive regulatory frameworks.

The role of bunker vessels can be summarised as:

- Scaling solution for growing demand
- Complement to truck-based bunkering
- Enabler of regional fuel distribution
- Long-term infrastructure component

4.4.8 Challenges and Limitations

Several challenges have been identified in the development and deployment of methanol bunkering vessels.

These include:

- **Limited market maturity**
  → Methanol remains a niche fuel with uncertain demand
- **Economic competitiveness**
  → Higher costs compared to LNG and future ammonia
- **Dependence on local supply availability**
  → Critical factor for viability
- **Infrastructure and investment risks**
  → High CAPEX with uncertain utilisation rates
- **Regulatory and operational uncertainties**
  → Evolving standards and limited experience

These challenges highlight the importance of phased development and close coordination between stakeholders.

4.4.9 Current Status and Next Steps

The methanol bunker vessel specification has reached an **advanced conceptual stage**, with key analytical and technical components completed.

Current status includes:

- completed demand analysis,
- completed economic evaluation,
- defined technical parameters,
- ongoing stakeholder validation.

The next steps focus on:

- further validation and refinement,
- alignment with pilot activities,
- monitoring of market developments,
- preparation for potential future implementation.

Planned next steps include:

- Continued stakeholder validation
- Integration with WP2 pilot activities
- Refinement based on market developments
- Preparation for future deployment scenarios

Further work will also consider the evolution of market conditions and regulatory frameworks, ensuring that the specification remains relevant and adaptable.

5. Transnational Value

5.1 Strategic Rationale for Transnational Cooperation

The development and deployment of hydrogen derivatives in ports is inherently a **transnational challenge**, particularly within the Baltic Sea Region (BSR), where maritime transport networks, energy systems, and industrial value chains are deeply interconnected. The transition toward alternative fuels such as methanol cannot be effectively addressed at the level of individual ports or countries, as it requires coordinated action across multiple jurisdictions, infrastructure systems, and market actors.

In this context, GoA 1.2 has been designed to leverage transnational cooperation as a **core enabling mechanism**, rather than a supplementary feature. The activity recognises that key barriers—such as regulatory fragmentation, lack of standardised procedures, and limited operational experience—can only be overcome through **joint development, shared learning, and harmonisation of approaches**.

The Baltic Sea Region provides a particularly relevant setting for such cooperation. It includes a mix of large and medium-sized ports, varying regulatory environments, and different levels of readiness for hydrogen derivative deployment. This diversity creates both challenges and opportunities, making transnational collaboration essential for identifying scalable solutions that can be adapted across contexts.

The strategic rationale for transnational cooperation in GoA 1.2 includes:

- Overcoming fragmentation in regulatory and operational frameworks
- Sharing knowledge and experience across ports with different maturity levels
- Creating economies of scale for emerging fuel markets
- Supporting the development of interoperable infrastructure solutions
- Accelerating learning curves and reducing duplication of efforts

5.2 Integration of Multi-Port Knowledge and Experience

A key strength of GoA 1.2 lies in the **integration of expertise and practical experience from multiple ports across the Baltic Sea Region**. The development of all four components—modelling, mapping instrument, tank trailer, and vessel specification—has been informed by continuous input from project partners, ensuring that outputs reflect real operational conditions.

This integration is particularly evident in the techno-economic model, where different ports contribute data, assumptions, and validation inputs, enabling the model to capture a wide range of scenarios and conditions. Similarly, the bunkering mapping instrument incorporates insights from multiple port environments, ensuring that the criteria catalogue reflects diverse operational realities.

The tank trailer specification benefits from **field-level assessments** conducted in ports such as Tallinn and Helsinki, where spatial constraints and operational challenges were directly analysed. The bunker vessel specification, in turn, integrates demand projections and market insights relevant to the broader BSR, including specific case studies such as Klaipėda.

By combining these inputs, GoA 1.2 achieves a level of robustness and relevance that would not be possible through isolated, single-port approaches.

Key aspects of multi-port knowledge integration include:

- Use of diverse port case studies for validation of tools and specifications
- Incorporation of operational constraints from different port layouts and sizes
- Alignment of methodologies across participating countries
- Continuous feedback loops through meetings and workshops
- Cross-comparison of assumptions and results

5.3 Harmonisation and Standardisation Potential

One of the most significant contributions of GoA 1.2 is its potential to support **harmonisation and standardisation of hydrogen derivative deployment in ports**. Currently, the absence of unified frameworks leads to inefficiencies, delays, and increased risks for stakeholders.

The outputs developed under GoA 1.2 address this issue by providing:

- standardised analytical methodologies (techno-economic model)
- structured planning frameworks (bunkering mapping instrument)
- harmonised technical specifications (tank trailer and vessel)

These outputs are designed to be **generalisable and adaptable**, enabling their application across different ports while maintaining a consistent methodological foundation. This approach supports the development of common practices and reduces the need for each port to develop its own solutions from scratch.

The bunkering mapping instrument, in particular, plays a key role in this context, as it translates complex regulatory and safety requirements into a **clear and structured framework**. By doing so, it contributes to the gradual convergence of approaches across the BSR and potentially at EU level.

Harmonisation contributions of GoA 1.2 include:

- Development of common criteria for bunkering assessment
- Alignment of safety and operational procedures
- Standardisation of technical specifications for infrastructure
- Reduction of regulatory interpretation gaps
- Facilitation of cross-border interoperability

5.4 Transferability and Replication Potential

A central requirement of Interreg projects is the ability to generate outputs that are **transferable beyond the immediate project partners**. GoA 1.2 has been explicitly designed with this objective in mind, ensuring that all deliverables can be applied in other ports and regions.

The transferability of the outputs is supported by several factors:

- modular and flexible design of tools and frameworks
- use of widely recognised standards and methodologies
- documentation and guidance materials
- validation across multiple port contexts

The techno-economic model, for example, allows users to adjust key parameters and adapt the analysis to their specific conditions. Similarly, the bunkering mapping instrument is structured as a general framework that can be customised for different fuels and port environments.

The technical specifications for the tank trailer and bunker vessel provide **reference designs** that can be used as a starting point for procurement and implementation in other locations.

Key elements supporting transferability include:

- Modular design of analytical and planning tools
- Fuel-agnostic approach of mapping instrument
- Use of international standards in technical specifications
- Cross-port validation within the project
- Preparation of user guidelines and documentation

5.5 Contribution to Market Development and Ecosystem Building

Beyond technical outputs, GoA 1.2 contributes to the broader objective of **market development for hydrogen derivatives** in the Baltic Sea Region. By providing tools and specifications that reduce uncertainty and enable investment, the activity supports the creation of an emerging ecosystem involving ports, energy producers, logistics providers, and shipping companies.

The work addresses the well-known “chicken-and-egg” problem in alternative fuel markets, where infrastructure and demand must develop simultaneously. By enabling early-stage deployment through flexible solutions (e.g. tank trailers) and preparing for scale-up (e.g. bunker vessels), GoA 1.2 helps to break this cycle and create momentum.

The transnational nature of the activity further strengthens this effect by enabling coordination across ports, which is essential for achieving sufficient demand and supply volumes.

Ecosystem contributions include:

- Reduction of entry barriers for new market participants
- Support for investment readiness and project development
- Facilitation of cross-border supply chains
- Strengthening of collaboration between ports and industry
- Acceleration of learning and experience sharing

5.6 Alignment with EU Policies and Strategic Frameworks

The outputs of GoA 1.2 are closely aligned with key European policy frameworks related to decarbonisation, energy transition, and sustainable transport. These include:

- FuelEU Maritime
- Alternative Fuels Infrastructure Regulation (AFIR)
- EU Hydrogen Strategy
- Trans-European Transport Network (TEN-T) policy

By supporting the development of infrastructure and tools required for alternative fuels, GoA 1.2 contributes directly to the implementation of these policies. It also provides practical insights that can inform future policy development, particularly in areas such as standardisation and regulatory harmonisation.

The transnational approach ensures that the project outputs are relevant at **European scale**, supporting the broader objective of creating a unified market for hydrogen derivatives.

Policy alignment includes:

- Support for maritime decarbonisation targets
- Contribution to alternative fuels infrastructure development
- Alignment with hydrogen and PtX strategies
- Integration with TEN-T and port development frameworks

5.7 Challenges in Transnational Implementation

While transnational cooperation provides significant benefits, it also introduces challenges that must be managed.

Differences in:

- national regulations,

- administrative procedures,
- levels of market maturity,
  create complexity in implementation.

In addition, coordination across multiple partners requires continuous communication and alignment, particularly when integrating technical and analytical outputs.

Data sharing and confidentiality considerations also need to be addressed, especially when dealing with commercially sensitive information.

Key challenges include:

- Regulatory differences across countries
- Variability in port readiness and infrastructure
- Complexity of multi-partner coordination
- Data availability and sharing constraints

Despite these challenges, the project demonstrates that structured cooperation and clear methodologies can effectively manage these complexities and deliver meaningful results.

5.8 Conclusions on Transnational Value

GoA 1.2 demonstrates a strong and well-founded transnational dimension, delivering clear added value beyond what could be achieved through isolated national or local initiatives.

The activity successfully:

- integrates knowledge and experience across multiple ports
- develops harmonised tools and frameworks
- enables transferability and replication
- supports market development and policy implementation

By addressing both technical and systemic challenges, GoA 1.2 contributes to the creation of a **coherent and scalable approach to hydrogen derivative deployment in ports**, reinforcing the strategic importance of transnational cooperation within the Baltic Sea Region and the European Union.

6. Challenges and Risks

6.1 Overview of Key Challenges

The implementation of GoA 1.2 takes place within a **highly dynamic and uncertain environment**, characterised by emerging technologies, evolving regulatory frameworks, and early-stage market development for hydrogen derivatives. The challenges identified during the reporting period are therefore not limited to project execution but reflect broader systemic conditions affecting the sector.

Across all components of GoA 1.2, a consistent pattern emerges: while **technical solutions are largely available and definable**, the main barriers are related to **market readiness, supply availability, and regulatory fragmentation**. These factors influence the timing, scale, and feasibility of infrastructure deployment.

At the same time, project-level challenges—such as data availability, procurement processes, and coordination across multiple partners—require careful management to ensure progress.

The main categories of challenges identified are:

- Market-related challenges (demand, fuel availability)
- Regulatory and administrative challenges
- Technical and data-related challenges
- Operational and implementation challenges
- Project management and coordination challenges

These categories provide the basis for a structured assessment of risks and mitigation measures.

6.2 Market and Supply Chain Challenges

The most significant challenges identified relate to the **early-stage development of the methanol market as a marine fuel**. Demand remains limited and uncertain, with adoption concentrated in specific vessel segments and locations.

This has direct implications for infrastructure deployment. The development of the tank trailer solution, for example, has been affected by the **absence of confirmed end-user cases**, limiting opportunities for immediate pilot implementation. In addition, delays in the availability of green methanol supply have been observed, impacting the timeline for testing activities.

The bunker vessel analysis further confirms that methanol remains a **niche fuel**, with lower market penetration compared to LNG and uncertain long-term competitiveness. Economic viability is strongly dependent on achieving sufficient demand volumes and utilisation rates.

These conditions create a “wait-and-see” dynamic, where stakeholders are hesitant to invest in infrastructure without clearer market signals.

Key market-related challenges include:

- Limited current demand for methanol as marine fuel
- Absence of confirmed end-user cases for pilot implementation
- Delayed availability of green methanol supply
- Uncertainty in future demand development
- Economic competitiveness challenges compared to LNG

Mitigation measures implemented:

- Adoption of **flexible deployment strategies**, including rental-based solutions for tank trailers
- Focus on **scalable and modular infrastructure**, allowing phased development
- Continuous monitoring of market trends and demand projections
- Alignment with pilot activities to identify potential use cases

This approach allows the project to maintain progress while adapting to evolving market conditions.

6.3 Regulatory and Administrative Challenges

The regulatory environment for hydrogen derivatives remains **fragmented and under development**, creating challenges for planning and implementation. Differences in national regulations, particularly regarding fuel classification, safety requirements, and taxation, introduce complexity for cross-border operations.

Methanol classification (e.g. UN 1230) requires compliance with **ADR regulations for transport**, while bunkering operations must align with evolving safety standards. In addition, variations in fuel classification (e.g. fuel vs. industrial product) may affect taxation and permitting processes.

The absence of harmonised frameworks results in **case-by-case approval processes**, increasing uncertainty and administrative burden for ports.

The Port Bunkering Mapping Instrument directly addresses these challenges by integrating regulatory and safety considerations into a structured framework, supporting more efficient planning and approval.

Key regulatory challenges include:

- Lack of harmonised EU-wide standards for methanol bunkering
- Variability in national regulations and permitting processes
- Uncertainty in fuel classification and taxation
- Evolving safety requirements and guidelines

Mitigation measures implemented:

- Development of a **criteria-based mapping instrument** to support permitting processes
- Integration of **international standards (ADR, ISO)** into technical specifications
- Application of **risk assessment methodologies (HAZID, HAZOP, QRA)**
- Continuous alignment and knowledge exchange between partners

These measures contribute to reducing uncertainty and supporting compliance.

6.4 Technical and Data-Related Challenges

The development of the techno-economic model and other analytical tools has highlighted challenges related to **data availability, quality, and consistency**. Given the early-stage nature of hydrogen derivative markets, many parameters must be based on assumptions or projections rather than empirical data.

This is particularly relevant for:

- cost parameters (CAPEX, OPEX)
- efficiency of emerging technologies
- future energy price scenarios
- demand projections

In addition, the integration of multiple data layers—such as GIS data, infrastructure constraints, and safety distances—adds complexity to the modelling process. Ensuring consistency and reliability across these datasets requires significant effort and coordination.

The need to balance model complexity with usability also represents a challenge, as the tool must remain accessible to non-technical users while providing sufficient analytical depth.

Key technical challenges include:

- Limited availability of reliable data for emerging technologies
- Uncertainty in key modelling parameters
- Complexity of integrating spatial, technical, and economic data
- Need for user-friendly interface and documentation

Mitigation measures implemented:

- Use of scenario and sensitivity analysis to manage uncertainty
- Incorporation of user-defined parameters for flexibility
- Iterative model development with stakeholder validation
- Engagement of external expertise (Ramboll) to ensure methodological robustness

6.5 Operational and Implementation Challenges

Operational challenges arise primarily from the need to integrate new bunkering solutions into **existing port environments**, which are often constrained in terms of space, traffic, and infrastructure.

For the tank trailer solution, maneuverability constraints in ports such as Tallinn and Helsinki required careful optimisation of the vehicle configuration. Similarly, the implementation of bunkering operations must consider **SIMOPS conditions**, ensuring safe interaction with other port activities.

The deployment of bunker vessels introduces additional operational challenges, including:

- scheduling and coordination of bunkering operations,
- availability of suitable berths,
- achieving sufficient utilisation rates.

These factors highlight the importance of aligning technical solutions with real operational conditions.

Key operational challenges include:

- Spatial constraints and maneuverability limitations
- Interaction with existing port operations (SIMOPS)
- Limited operational experience with methanol bunkering
- Uncertainty in utilisation of bunkering assets

Mitigation measures implemented:

- Optimisation of technical design for operational flexibility
- Integration of operational criteria into mapping instrument
- Development of standardised bunkering procedures
- Phased deployment approach (TTS before vessel-based solutions)

6.6 Project Management and Coordination Challenges

Given the transnational nature of GoA 1.2, project implementation involves coordination across multiple partners, countries, and work streams. This introduces challenges related to communication, alignment, and synchronisation of activities.

The procurement process for the techno-economic model, for example, required careful coordination and resulted in a structured but time-intensive process. Similarly, aligning inputs from different partners for model development and validation requires continuous engagement and iterative refinement.

The need to synchronise activities with other work packages, particularly WP2 (pilot implementation), also adds complexity, as delays or changes in one area can impact others.

Key coordination challenges include:

- Complexity of managing multi-partner collaboration
- Alignment of timelines across different components
- Integration of external contractor work
- Dependency on parallel activities (e.g. pilot implementation)

Mitigation measures implemented:

- Regular coordination through Jour Fixe and partner meetings
- Clear definition of roles and responsibilities
- Structured planning and milestone tracking
- Continuous communication and feedback loops

6.7 Risk Outlook and Adaptive Management

The challenges identified above are not static but evolve over time as the project progresses and external conditions change. As such, GoA 1.2 adopts an **adaptive management approach**, allowing for adjustments in strategy and implementation as new information becomes available.

This approach is particularly important in the context of emerging markets, where uncertainty is high and flexibility is essential. By continuously monitoring risks and implementing mitigation measures, the project ensures that progress can be maintained despite external constraints.

A key strength of the approach is the combination of **analytical tools, flexible infrastructure solutions, and stakeholder engagement**, which together provide a robust framework for managing uncertainty.

The adoption of **phased deployment strategies**, starting with flexible solutions such as tank trailers and progressing toward larger-scale infrastructure, represents a key element of this adaptive approach.

6.8 Conclusions on Challenges and Risks

The implementation of GoA 1.2 demonstrates that while the deployment of hydrogen derivatives in ports faces significant challenges, these can be effectively managed through structured methodologies and adaptive strategies.

The key risks identified—market immaturity, regulatory fragmentation, data uncertainty, and operational constraints—are inherent to the early stage of the sector. However, the project has successfully addressed these challenges through:

- development of flexible and scalable solutions
- integration of safety and regulatory considerations
- continuous stakeholder engagement
- iterative and adaptive implementation

As a result, GoA 1.2 not only delivers concrete outputs but also provides valuable insights into how such challenges can be managed in future projects and real-world deployments.

7. Next Steps & Outlook

7.1 Finalisation of GoA 1.2 Deliverables

As GoA 1.2 progresses toward its final phase, the primary focus is on the **completion, consolidation, and validation of all developed outputs**. While significant progress has already been achieved, the remaining steps are essential to ensure that the deliverables are fully operational, coherent, and ready for application.

For the techno-economic model, this includes finalising the development of core functionalities, completing documentation, and ensuring usability for stakeholders. Particular attention is given to the preparation of **user manuals and maintenance frameworks**, enabling long-term use beyond the project duration.

The Port Bunkering Mapping Instrument will undergo further refinement based on partner feedback and alignment with pilot activities. This process ensures that the criteria catalogue and workflow are both comprehensive and practical for real-world application.

The tank trailer specification has already reached a **procurement-ready stage**, and the next steps focus on initiating procurement processes and preparing for implementation. Similarly, the bunker vessel specification will be further refined and validated in line with market developments and stakeholder input.

Key next steps for deliverable finalisation include:

- Completion of techno-economic model and documentation
- Refinement of bunkering mapping instrument
- Finalisation of technical specifications and supporting materials
- Integration of partner feedback and validation results
- Preparation of deliverables for dissemination

7.2 Validation through Pilot and Practical Application

A critical next phase for GoA 1.2 is the **validation of developed tools and specifications through practical application**, particularly in connection with activities under Work Package 2.

The techno-economic model will be applied to **real port scenarios**, enabling validation of assumptions, identification of gaps, and refinement of outputs. This step is essential to ensure that the model provides reliable and actionable insights under real-world conditions.

Similarly, the bunkering mapping instrument is designed to be **tested and implemented in pilot contexts**, where its criteria and workflow can be applied to actual site selection and planning processes . This validation phase will provide important feedback on usability, completeness, and adaptability.

For the tank trailer component, the next steps include progressing toward **procurement (RFQ phase)** and preparing for operational testing, subject to the availability of methanol supply . While delays in fuel availability have been identified, preparatory steps ensure readiness once supply becomes available.

The bunker vessel specification will continue to be **validated through stakeholder discussions and alignment with market developments**, ensuring that it remains relevant and aligned with evolving demand conditions.

Key validation activities include:

- Application of techno-economic model to partner port scenarios
- Testing of bunkering mapping instrument in pilot cases
- Preparation and launch of tank trailer procurement (RFQ) or alternative pathway of rental
- Stakeholder validation of bunker vessel specification
- Integration of feedback into final deliverables

7.3 Integration Across Project Work Packages

The outputs of GoA 1.2 are closely linked to other project activities, and the next phase will focus on **strengthening integration across work packages**, particularly WP2 (pilot implementation) and WP3 (knowledge transfer).

This integration ensures that analytical and technical outputs are effectively translated into practical outcomes. The techno-economic model supports identification of viable pilot scenarios, while the mapping instrument and technical specifications enable their implementation.

At the same time, the results of GoA 1.2 will be incorporated into dissemination and replication activities, supporting broader uptake across the Baltic Sea Region.

Key integration actions include:

- Alignment of model outputs with pilot implementation scenarios
- Application of mapping instrument in planning pilot activities
- Use of technical specifications in demonstration projects
- Transfer of knowledge to WP3 dissemination activities
- Coordination of timelines and deliverables across work packages

7.4 Preparation for Post-Project Use and Sustainability

Ensuring that the outputs of GoA 1.2 remain usable beyond the project duration is a key priority. The developed tools and specifications are designed to support **long-term planning, investment decision-making, and infrastructure development**.

For the techno-economic model, sustainability considerations include:

- hosting and accessibility of the model platform,
- maintenance and updating of input data and assumptions,
- provision of user support and documentation.

The model's modular design enables future updates and adaptation to evolving market conditions, but requires clear arrangements for ownership and maintenance.

The bunkering mapping instrument is designed as a **transferable framework**, supported by guidance materials that enable adoption by ports beyond the project consortium.

The technical specifications for tank trailers and bunker vessels provide **reference documents** that can be used in future procurement and implementation processes.

Key actions for post-project sustainability include:

- Development of user manuals and guidance materials
- Establishment of maintenance and update mechanisms for the model
- Ensuring accessibility of tools and documentation
- Preparation of dissemination materials for wider uptake
- Support for stakeholder capacity building

7.5 Contribution to Long-Term Impact and Market Development

The outputs of GoA 1.2 contribute to **long-term impact in the Baltic Sea Region**, supporting the development of hydrogen derivative markets and infrastructure.

By providing analytical tools and implementation-ready specifications, the activity reduces uncertainty and supports investment decisions. This is particularly important in addressing the "chicken-and-egg" challenge between fuel supply and infrastructure development.

The phased approach identified within the project—starting with flexible solutions such as tank trailers and progressing toward vessel-based systems—provides a **practical pathway for market development**.

The work also contributes to:

- strengthening cross-border supply chains,

- supporting maritime decarbonisation,
- aligning port development with energy transition objectives.

Expected long-term impacts include:

- Increased readiness of ports to handle hydrogen derivatives
- Acceleration of alternative fuel infrastructure deployment
- Development of regional fuel supply chains
- Support for decarbonisation of maritime transport
- Contribution to EU energy transition goals

7.6 Outlook and Strategic Direction

Looking ahead, the work under GoA 1.2 highlights both the opportunities and challenges associated with hydrogen derivative deployment in ports. While technical feasibility has been largely demonstrated, the pace of market development will depend on external factors such as policy support, fuel availability, and industry adoption.

The next phase of development will require continued coordination between ports, industry stakeholders, and policymakers to ensure that infrastructure development aligns with demand and regulatory frameworks. The tools and specifications developed under GoA 1.2 provide a strong foundation for this process.

At the same time, the experience gained through the project underscores the importance of **flexibility and adaptability**, particularly in early-stage markets. Solutions must be scalable and capable of evolving as conditions change.

Strategic outlook considerations include:

- Continued monitoring of market and regulatory developments
- Alignment with EU policy frameworks and funding opportunities
- Expansion of use cases and pilot implementations
- Strengthening of transnational cooperation networks
- Ongoing refinement and adaptation of tools and methodologies

7.7 Conclusions on Next Steps and Outlook

GoA 1.2 is entering a phase where the focus shifts from development to **validation, integration, and long-term impact**. The next steps are designed to ensure that the outputs are not only completed but also effectively utilised and sustained beyond the project.

The combination of analytical tools, planning instruments, and technical specifications provides a **comprehensive foundation for continued development of hydrogen derivatives in ports**. By aligning these outputs with pilot activities and ensuring their transferability, the project maximises its contribution to both regional and European energy transition objectives.

8. Conclusions

GoA 1.2 is on the path to deliver a **coherent and multi-layered analytical and implementation framework** for hydrogen derivative deployment in Baltic Sea Region ports, integrating techno-economic modelling, infrastructure planning tools, and detailed technical specifications. The activity demonstrates clear progress from initial concept development toward **procurement-ready and pilot-ready outputs**, as evidenced by completed market studies, model development, and finalized technical specifications for key bunkering solutions .

A central outcome of the activity is the establishment of a **robust techno-economic and commercial analysis model**, supported by a completed market analysis of renewable energy trends and Power-to-X developments in the Baltic region. The analysis confirms that while there is **strong long-term potential driven by renewable energy expansion (notably offshore wind)**, practical deployment of hydrogen derivatives remains at an early stage, with limited current market maturity and infrastructure readiness .

The technical workstream has reached a high level of maturity. The development of **methanol bunker tank trailer specifications (30,000 L capacity, stainless steel design, RFQ-ready documentation)** provides a directly actionable solution for early-stage deployment via truck-to-ship bunkering. This solution is supported by **validated operational procedures, safety concepts (HAZID/HAZOP), and standardized documentation**, ensuring alignment with current safety and regulatory requirements . In parallel, the **methanol bunkering vessel concept** has advanced through demand analysis, economic evaluation, and technical specification phases, defining key parameters such as capacity (~800 tonnes) and operational performance .

At the system level, the development of the **Port Bunker Mapping Instrument** represents a critical enabling tool. By establishing a structured catalogue of criteria (e.g. safety distances, terminal surroundings, nautical constraints), it enables ports to systematically assess bunkering feasibility and approval requirements. The instrument is designed for **broad applicability across fuels and port contexts**, supporting harmonisation and future replication .

The findings across all components consistently confirm that **technical feasibility is not the primary barrier**. Methanol, in particular, benefits from relatively mature handling practices, ambient storage conditions, and compatibility with existing logistics systems. However, deployment is constrained by **market and systemic factors**, including:

- limited and uncertain demand (with methanol expected to remain a niche fuel segment),
- dependency on local fuel availability,
- economic competitiveness challenges compared to LNG and future ammonia pathways,
- fragmented regulatory and approval frameworks.

Demand projections indicate moderate but growing uptake, concentrated in larger Baltic ports, with **threshold volumes (e.g. 2,000–3,000 tonnes/year for initial viability)** and longer-term growth potential toward 2040 . These insights reinforce the need for **phased and scalable infrastructure approaches**, starting with flexible solutions such as truck-based bunkering before transitioning to dedicated vessel-based systems.

The activity also highlights the importance of **safety-driven and site-specific implementation**. The hazardous nature of methanol (flammability, toxicity) requires rigorous risk assessments, tailored safety zones, and comprehensive documentation procedures. Partner discussions and technical work confirm that **operational adaptability and strict safety compliance are essential prerequisites** for deployment .

From a transnational perspective, GoA 1.2 has enabled **strong coordination between ports, energy companies, and technical partners**, resulting in harmonised approaches and shared methodologies. The developed outputs—models, specifications, and assessment tools—are explicitly designed for **transferability across Baltic Sea Region ports**, supporting wider uptake and reducing duplication of effort.

The main conclusions of GoA 1.2 can be summarised as follows:

- Hydrogen derivative deployment in ports is technically feasible and operationally definable
- Market maturity and fuel availability remain the primary constraints
- Flexible, phased infrastructure solutions are essential in early stages
- Structured analytical and planning tools significantly reduce uncertainty
- Transnational cooperation enables harmonisation and scalability

In conclusion, GoA 1.2 demonstrates that the deployment of hydrogen derivatives in ports is **technically feasible and operationally definable**, with concrete solutions already available for early implementation. However, the pace of adoption will depend on resolving **market, regulatory, and supply-side constraints**. The activity provides a **solid, evidence-based foundation for decision-making, pilot implementation, and future scaling**, positioning Baltic Sea Region ports to act as early movers in the transition toward alternative maritime fuels.