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H2YDEA

Boosting the hydrogen transition in the Atlantic Area ports

Deliverable D 5.1.5

HYDEA case studies for PORTUGAL

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EXECUTIVE SUMMARY

The objective of this deliverable D5.1.5 “HYDEA case studies for Portugal” is to summarize the key features of the two use cases and inherent case studies allocated to UPORTO and APDL. These are related to i) import/export of hydrogen (H_2) based energy vectors (*e.g.*, methanol and ammonia), and ii) supply of alternative green fuels from H_2 and other energy vectors, namely through carbon capture and methanol sources.

Being the main objective of the project to boost the hydrogen transition in the Atlantic Area ports, the present Work Package (WP) 5 is aimed at developing a Decision Support Tool (DST) for H_2 applications in ports. This tool will ultimately support future decision-making and the evaluation of individual hydrogen technologies in different scenarios.

The DST will be developed using data and conclusions gathered from the technical, economic, environmental and societal assessment of different case studies in the Atlantic Area (AA). Project HYDEA has outlined the case studies of interest for each of the ports in the project under the D.4.4.1 Opportunities of H_2 application in HYDEA ports. As such, this Deliverable provides the case studies description allocated to the Portuguese partners, focused on the Port of Leixões as the local reference for AA ports.

Follow-up work will focus on leveraging information from previous WPs, such as WP4, to further characterize the use cases and corresponding case studies towards establishing a reliable and versatile DST, though each use case will be tailored to the availability of information, specific goals and integration viability with the DST. In detail, this will comprise on:

- Case study description (focus of the current Deliverable)
- Technical assessment
- Economical assessment
- Environmental assessment
- Social assessment

The resulting document, as seen in the upcoming pages, provides the main outline of the aforementioned case studies, which will be further developed in the upcoming months. The information and description will provide a crucial starting point towards not only the incorporation into the DST, but also the development of the pilot studies for WP6.

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ABBREVIATIONS AND ACRONYMS

AA – Atlantic Area
APDL – Port Authority of the Douro, Leixões and Viana do Castelo
CAPEX – Capital Expenditures
DST – Decision Support Tool
IMO – International Maritime Organization
HVO – Hydrotreated Vegetable Oil
H_2 – Hydrogen
LCOM – Levelized Cost of Methanol
MGO – Marine Gasoil
OPEX – Operational Expenditures
TCO – Total Cost of Ownership
UPORTO – University of Porto
WP – Work Package

1 Introduction

The HYDEA project aims at accelerating the deployment and integration of green hydrogen-based technologies with marine and other renewable energies at AA ports, with the ultimate goal of energy efficiency and contributing to a decarbonised energy economy. This change in direction proves pivotal, considering the maritime industry is a keystone for the worldwide logistics network.
Along the HYDEA project individual steps are taken to achieve the development of a DST that will aid in the decision-making process of introducing hydrogen-based technologies in ports of the Atlantic Area.
With the objective of evaluating, developing and promoting the use of hydrogen-based technologies, different case studies are assessed by the project partners. The results of this evaluation will feed the DST tool, helping in the logic of the tool when it comes to hydrogen-based technologies.
For the Portuguese context, this involves the characterization of two use cases and respective case studies:

- Import/export of $H_{2,}$ ammonia and methanol (use case and case study);
- Supply of alternative green fuels from $H_{2,}$ ammonia and methanol (use case), carbon capture and methanol (case study).

2 Case study and use case description

2.1 Location

The Portuguese HYDEA case study will be conducted across two complementary Atlantic ports: Port of Leixões and Port of Viana do Castelo, Figure 1. Both are managed by APDL and located on the northern Atlantic coast of Portugal and fall fully within the HYDEA geographical scope. Their combined characteristics offer two distinct but connected operational environments for hydrogen deployment: a high-traffic multimodal core port (Leixões) and a specialized coastal port with strong offshore and industrial relevance (Viana do Castelo).
The Port of Leixões (PTLEI) is located in Matosinhos, within the Metropolitan Area of Porto, and is part of the Atlantic Corridor of the TEN-T network. It is the second largest port in Portugal in cargo throughput and the main gateway for the Northern region. In 2024, it handled approximately 19.5 million tonnes of cargo, received around 2,575 vessel calls, and processed 683,000 TEU. Energy demand associated with port operations and concessionaires remains significant: the APDL's baseline energy consumption in 2019 totaled 38 GWh, of which 15 GWh corresponded to electricity and 23 GWh to fossil fuels. Its coastal location and industrial hinterland make it a relevant candidate for hydrogen use in port equipment, yard operations, service fleets, and potentially OPS (Onshore Power Supply) or bunkering in the medium term.
The Port of Viana do Castelo (PTVCA), further North, serves a different operational profile. With annual volumes of approximately 409,000 tonnes, 244 vessel calls, and about 1.14 million GT, it plays a key role in shipbuilding, offshore wind logistics and industrial support. Its proximity to floating offshore wind deployment zones, particularly the WindFloat Atlantic area, increases its relevance for future hydrogen production, storage and supply linked to offshore and port support operations.

Figure 1 Geographical location of the Ports of Leixões (PTLEI) and Viana do Castelo (PTVCA).

2.1.1 Geographic and climatic characteristics relevant to hydrogen

Both ports are located in a temperate Atlantic climate zone with mild temperature variations, high atmospheric humidity and exposure to coastal winds. The prevailing northerly wind regime ("Nortada") during Spring and Summer provides favorable conditions for wind energy, while solar availability, though more moderate compared to Southern Portugal, can complement hydrogen production through electrolysis. There is also a significant wave energy resource to be exploited in the region, with companies such as CorPower and Eco Wave Power installing their devices for sea trials. The marine environment introduces technical requirements related to salinity and corrosion, which must be considered for hydrogen storage, compression and pipeline infrastructure. Temperature ranges, generally between 10–25 °C across the year, support stable performance of electrolysers and fuel cell systems without excessive thermal stress.

2.1.2 Operational and energy profile relevant to hydrogen deployment

Leixões presents a diversified operational base with container terminals, liquid and dry bulk, ro-ro and passenger operations. Its energy consumption profile (38 GWh) and dependence on diesel and electricity in cargo handling equipment, support fleets and logistics services highlight areas where hydrogen-based derivatives could act as an alternative energy vector. The high volume of vessel traffic also creates medium-term potential for OPS integration combined with hydrogen use in auxiliary port operations.

Viana do Castelo, despite lower throughput, presents an industrial and offshore-oriented setting that is well suited for pilot applications in hydrogen-fueled port machinery, maintenance equipment, service vessels and support to offshore wind operations. The geography and proximity to renewable energy developments reinforce the feasibility of local or near-site hydrogen generation, providing unique opportunities for co-location of the two activities: energy generation through marine renewables, and energy storage through hydrogen-based energy vectors.

Together, these two Atlantic ports provide contrasting but complementary contexts—large-scale multimodal port operations in Leixões and specialized offshore-industrial activity in Viana do Castelo—

allowing HYDEA to assess hydrogen production, storage and use under different environmental, operational and infrastructural conditions within the same national case study.

2.2 Partners

This case study was prepared by the two Portuguese partners of the HYDEA project: UPORTO, acting as lead partner, and APDL, as supporting partner. UPORTO is further divided into the UPORTO.DECG and UPORTO.DEQB departments (originally designated as UPORTO.DEC and UPORTO.DEQ, respectively):

Civil Engineering Department group (UPORTO.DECG) was the coordinator of the recently finished PORTOS - Ports Towards Energy Self-sufficiency project (to be concluded by 31/07/2023), which intended on developing and promoting the implementation of renewable energy, especially marine renewable energies, such as wave, tidal and wind energy, at Atlantic Area ports. Moreover, it addresses two important environmental priorities for ports, reduction of greenhouse gases emissions and air pollution, by providing renewable energy-based solutions to harvest the renewable energy potential of Atlantic Area coastal areas. The main competences of the group are the development, modelling, design and optimization of technologies towards a vast array of coastal and marine uses and applications. These range from marine renewable energy assessment and conversion to novel green-grey interventions capable of withstanding the harsh sea environment in a context of climate change. For that purpose, the group uses both physical modelling in state-of-the-art experimental facilities (e.g., large wave basin and wave-current flume) and advanced numerical models via the application of several hydrodynamic and morphodynamic numerical codes. The group is committed to the development of cross-cutting, sustainable and low-carbon advanced technologies/solutions to harness and withstand marine blue energies, mitigating climate change effects in the long term.

Chemical Engineering Department group (UPORTO.DEQB) is the R&D coordinator of the 1st Portuguese Mobilizing Alliance for green H_2, biogenic CO_2 capture/use and e-methanol synthesis. H2Driven Agenda aims to develop innovative technologies to produce, for example, green-methanol and maritime fuel, within the National Recovery and Resilience Program – RRP, where Port of Leixões is a partner institution. In the chemical engineering department, HYDEA project is hosted by LEPABE research unit. This project is developed within the Processes Products and Energy group led by Prof. Mendes which comprises 76 researchers with research interests focused in electrolysis, fuels cells, CCUS, membrane and adsorbent-based gas separations, methane decomposition, thermal energy storage, photoelectrochemical cells, 3rd generation of solar cells, phenomenological modelling and simulation of chemical engineering processes. The Prof. Mendes' group holds a patent (WO2020075075A1) for the production of carbon molecular sieve membranes (CMSM) from a regenerated cellulose precursor using an ionic liquid displaying excellent separation performance to capture CO_2.

Administração dos Portos do Douro, Leixões e Viana do Castelo (APDL) manages two ports, the Port of Leixões, the Port of Viana do Castelo and the Douro's Inland Waterway, all located in the north of Portugal. APDL has a roadmap for carbon neutrality and self-sufficiency in 2035, 15 years before the limit set by the EU to reduce polluting emissions from European port terminals to zero. The port of

Viana do Castelo has an offshore renewable energy production project, with which they would like to link this energy with the production of hydrogen for storage and use in the port facilities themselves. In the port of Leixões, they are deploying the first phases of a renewable methanol generation project from green H2 and CO2 from a biomass combustion plant in the vicinity. The port wants to have an offtaker role in its own facilities and as an exporter.

2.3 Topic

This case study addresses the implementation of hydrogen-based technologies in the Ports of Leixões and Viana do Castelo, with a strong comparative dimension including methanol, ammonia, and electrification as alternative or complementary pathways. The aim is to identify the most viable solutions for decarbonizing port operations and maritime activities under HYDEA's Atlantic port framework.

2.3.1 Overview of current technologies

At present, most port operations in Leixões and Viana rely on fossil fuels. Diesel fuel (EN 590) and marine gasoil (MGO) dominate tugboats, pilot boats, terminal trucks, reach stackers, and cranes, while vessels at berth continue to depend on auxiliary engines. This creates high emissions of CO_2, NO_x, SO_x, and particulates. The port electrical grid already supports OPS (onshore power supply) planning but lacks sufficient capacity for large-scale electrification of heavy-duty equipment and maritime operations.

Hydrogen-based technologies to be considered:

- Import, export, storage, and bunkering of hydrogen and hydrogen derivatives (methanol, ammonia) at Leixões;
- Fuel cell tugboats, pilot boats, and auxiliary vessels;
- Hydrogen-powered yard tractors, straddle carriers, and reach stackers;
- H_2-based OPS units for electricity supply at berth, either standalone or integrated with renewables;
- Synergies with hinterland logistics platforms (e.g., Mangualde-Leixões corridor) for methanol export/import.

Alternative pathways under evaluation:

- Electrification: Battery-electric reach stackers, cranes, and straddle carriers; electric tugboats and pilot boats in the long term; expanded OPS for containerships and cruise vessels;
- Methanol: Import/export hub with 2 × 8,000 t storage tanks; bunkering for SR (10–15,000 t) and MR tankers (25–35,000 t), plus methanol-ready short-sea vessels; retrofitting of tugboats and auxiliary vessels;
- Ammonia: Future option for green fuel bunkering and potentially for retrofitted maritime engines, providing moderate volumetric energy density and easier storage than liquid hydrogen but with higher safety requirements;

Comparison of pathways

- Efficiency: Direct electrification offers the highest efficiency but is limited by grid capacity and the lack of large-scale energy storage. Hydrogen has lower efficiency in the full energy cycle (electrolysis, storage and reconversion) but greater flexibility for heavy-duty and long-range applications. Methanol and ammonia are less efficient in conversion and end-use but benefit from existing or easily adaptable infrastructure, making them easier to store and scale at global level;

- Emissions: All vectors reduce emissions when renewable-based. Electrification and hydrogen provide zero local emissions; methanol and ammonia emit CO_2 or NOx but can reach neutrality with sustainable production and capture/storage solutions;
- Infrastructure: Hydrogen and methanol require new import/export terminals, bunkering infrastructure, and dedicated safety systems. Ammonia demands stricter handling protocols. Electrification requires major OPS expansion and grid reinforcement. Autonomy and self-sufficiency should be prioritized under electrification, to avoid eventual disruptions caused by dependencies upon the national grid (*e.g*. blackouts);
- Operational impacts: Electrification suits yard operations and short-sea vessels; hydrogen and methanol are more suitable for tugs, tankers, and hinterland logistics; ammonia remains long-term;
- Costs: Electrification is currently the most cost-competitive where feasible. Hydrogen and methanol involve higher CAPEX but gain relevance with EU decarbonization incentives, with the former being more cost-effective, currently, and more prevalent in ship orderbooks (see Section 3).

2.3.2 Motivation and feasibility

The feasibility of these transitions is reinforced by the ports' Atlantic context, rich in offshore wind and solar resources, supporting green H_2 production. The methanol scenarios (import/export hub, bunkering, hinterland distribution) position Leixões as a regional hub for synthetic fuels. Hydrogen and electrification provide complementary pathways, especially for port equipment, while ammonia is considered a longer-term solution for larger vessels.

Expected benefits:

- Reduction of GHG emissions and air pollutants across port operations;
- Enhanced competitiveness of Leixões and Viana as green ports in the Atlantic Area;
- Improved integration of port and hinterland logistics (road/rail corridors) for energy vectors;
- Strengthened positioning of APDL in European hydrogen and green fuels corridors.

This case study will, therefore, compare hydrogen, methanol, ammonia, and electrification across short-, medium-, and long-term scenarios, identifying the optimal combination of technologies for decarbonization of Atlantic Area ports.

2.4 Objectives and scope

With regards to the cases allocated to the Portuguese partners, the following objectives are proposed for each scenario.

2.4.1 Case study 1: Import/export of H_2, ammonia and methanol

For case study 1, on indicators, the analysis should provide the Levelized Cost of Methanol (LCOM) for each scenario, along with a Total Cost of Ownership (TCO) assessment for relevant end-use cases. The resulting analysis will yield, as a prime objective, combinations of scenarios towards assessing the most cost and time-effective solution, supported by a sensitivity assessment of costs magnitude and critical expenditures.

The methanol storage capacity is fixed to avoid the need for additional environmental impact assessments, which would be required for a capacity above 8000 tons. For operational efficiency, two storage tanks of equal capacity are considered, each connected through internal pipelines to allow parallel operations (e.g., ship unloading while trucks or railcars are loaded). These operations can occur independently if required, provided segregated lines and pumping systems are in place. Depending on operational needs, tanks may either remain segregated to preserve product traceability or be equalized after operations. As second-level objectives, timelines and/or routes of import/export, storage capacity and overall operation times will be assessed. In general, conducting this analysis requires knowledge of capital expenditure (CAPEX), fixed operational expenditure (fixed OPEX), and variable operational expenditure (variable OPEX). This will equally take into account import/export rates, intake, transport and storage rates of methanol, and bottleneck identification to mitigate risks inherent to imbalance between imports, exports, consumption, transportation and storage.

2.4.2 Case study 2: Supply of alternative green fuels

For case study 2, on indicators, the analysis should provide the Levelized Cost per energy vector for each scenario, along with a TCO assessment per relevant end-use cases. There will also be an assessment of costs at current, near-future and long-term timeframes. Each scenario will equally consider distinct equipment/vessels for retrofitting, thus including the associated costs. Hence, an extensive range of scenarios will be evaluated, as a prime objective. Unitary values will be setup as a baseline, in order to provide a more generic framework to be used in other ports, where multiple units can exist (i.e., cumulative costs).

This case study serves as an example and can be expanded further, for instance, by identifying the optimal electrolyzer type and/or alternative means of synthesis that minimizes the Levelized Cost and incorporating it into the TCO analysis – second-level objectives. Still, the focus will be on evaluating scenarios and respective sub-scenarios as the main goal, in order to identify the most cost-effective and viable options, to be also considered by the port authorities towards implementing the pilot tests and determining the ideal development path for H_2-based energy vectors at the Port of Leixões.

2.5 Use cases that the study covers

This section presents an overview description of the two case studies to be developed by UPORTO and APDL, within the framework of WP5 and the establishment of the DST. Note that, as defined in D5.1.1., "case study" and "use case" are different concepts. While they both relate to the implementation of technological solutions, they have different objectives and approaches. The difference between a "use case" and a "case study" lies in their focus: a use case is the strategy for building solutions; it's the idea of how something will work, while a case study is the embodiment of the solution. Hence, the following "use cases" and "case studies" are proposed for Portugal, Table 1.

USE CASES	DESCRIPTION
Import/Export of H_2, ammonia and methanol	Handling logistics, storage, transport and distribution for hydrogen-based products
H_2 storage, distribution and infrastructure: H_2 refuelling station	Development of storage and refuelling infrastructure for port operations
H_2 FC application for vehicles and equipment	Use of hydrogen fuel cells for port vehicles and equipment
Production of H_2 from marine and other renewable energies	Hydrogen production from renewable energy sources, such as offshore wind or solar power
Supply of alternative green fuels from H_2 (methanol, ammonia)	Production of green fuels (methanol, ammonia) from hydrogen for maritime decarbonization
Hydrogen based fuels for vessels	Use of hydrogen-based fuels (ammonia, methanol) for powering vessels.
H_2 based electrical power production for port consumption	Hydrogen used for electricity generation to meet port energy needs

Table 1 Use cases and case studies: Portuguese partners.

Being a methanol-based case study, the parameters may incorporate the methanol production technology. This could involve values such as conventional production methods and new/emerging technologies. While methanol storage tanks are technically suitable for other liquid commodities (e.g., gasoline or other chemicals), such alternative uses are considered outside the scope of this study.

2.6 Use case/case study 1

Use case/case study 1 are described below, in Table 2 to Table 4. A detailed overview of the main context – import/export of H_2-based energy vectors – is provided, showcasing the need for selecting an optimal location towards establishing entry/exit routes at the Port of Leixões, evaluate the road-railway options that are available, ensuring that storage capacities are kept under the required thresholds, and that multiple operational scenarios are simulated in order to find the most competitive and reliable option, per the prime objective of the use case/case study at hand. This will promote Leixões as a major import/export hub of H_2-based energy vectors in the North of Portugal.

Item	Description	Content of the proposed case study
1	**Location**	Portugal – Port of Leixões Energy vector import/export: import, export and storage sites, including the port area itself, nearby APDL-managed logistics zones, and hinterland platforms—linking Mangualde and Leixões via rail and road for inbound flows and methanol export. Ship fuel supply (bunkering) to be explored in medium-term.
2	**Partners**	UPORTO and APDL
3	**Use Cases covered by the Case Study**	Import/Export of H_2, ammonia and methanol - Handling logistics, storage, transport and distribution for hydrogen-based products
4	**Description**	• Choose the best location in Leixões for entry/exit points of H_2-based energy vector import and export • Sensitivity assessment of existing options, in order to find the most cost-effective options • Combined road-railway transportation, focused on methanol • Storage kept under 8000 m^3 per tank to avoid extensive environmental procedures. Two tanks considered, with internal pipeline, to cater for charge/discharge procedures
5	**Implementation timeline**	To be defined, but within the allocated project timeline

Table 2 Case study 1 description.

Parameters	**Values**
Region of consideration	Leixões
Entry routes (pipeline – road/rail connection)	• Road: Mangualde > Leixões • Rail: Mangualde > Leixões
Storage sites and capacity	• Location of storage to be defined • Methanol capacity: 2 x 8000 tonnes
Reception rates	• Road: to be calculated • Rail: to be calculated
Exports	• to be defined, according to ship capacity
Methanol transportation mode	• to be calculated
Operation time	• determine the overall charge/discharge time of trucks and trains
End users	SR/MR tankers

Table 3 Detailed description of parameters for use case/case study 1.

Scenario	Region	Entry Routes and storage sites	Reception rates	Methanol transportation mode	Operation time	End user
1 Base case (SR tanker export)	Leixões	Road + Rail – Entry Point 1 (Mangualde > Leixões) + 2 × 8000 t tanks	2 × 2500 t/10 days	10 trucks/day + 1 rail convoy	2, 10h/day	SR tanker (10–15,000 t)
2 MR tanker export	Leixões	Road + Rail – Entry Point 2 (expanded terminal access) + 2 × 8000 t tanks	2 × 3500 t/10 day	14 trucks/day + 1.5 rail convoys	2, 10h/day	MR tanker (~25–35,000 t)
3 Export + Bunkering (mixed demand)	Leixões	Road (primary) + Rail (secondary) + 2 × 8000 t tanks	2 × 2500 t/10 days	8 trucks/day + 1 rail convoy	3, 10h/day	Mix: SR tanker (~15,000 t) + bunkering (short-sea methanol-ready vessels, 500–2000 t each)
4 Hinterland export hub	Leixões	Rail-dominant flow (Mangualde > Leixões) + 2 × 8000 t tanks + optional satellite depot	2 × 5000 t/15 days	1.5–2 rail convoys/day	3, 10h/day	MR tanker (25–35,000 t) + inland distribution (hinterland industries via rail backhaul)

Table 4 Scenarios to be evaluated for use case/case study 1. Additional scenario combinations may be considered, if pertinent.

2.7 Use case/case study 2

Use case/case study 2 are described below, in Table 5 to Table 7. Here, the scenarios to be evaluated comprise of three timeframes, multiple port consumers – equipment and transports –, and distinct energy vector options – H_2-based, electric, fossil fuel-based, etc. The main objective, as stated previously, is to compare multiple supply scenarios and identify the most competitive and promising options amongst the existing alternatives, under present and future timelines. This will provide APDL with a clear and dedicated strategy towards retrofitting and investing in its portfolio of equipment and transportation at the Port of Leixões, while also creating a structured framework for engaging concessionaires in their own fleet transition pathways. It will also bolster ongoing decarbonization efforts at the port, which can be extended, if feasible, to the Port of Viana do Castelo, also under the jurisdiction of APDL.

Item	Description	Content of the proposed case study
1	**Location**	Portugal – Port of Leixões Supply of H_2 vectors: retrofitting and decarbonizing key port energy consumers (equipment, marine mobility and land mobility)
2	**Partners**	UPORTO and APDL
3	**Use Cases covered by the Case Study**	Supply of alternative green fuels from H_2 (methanol, ammonia) - Production of green fuels (methanol, ammonia) from hydrogen for maritime decarbonization
4	**Description**	• Three timeframes: current, near future, and long-term. For each one, consumption will be characterized based on current energy source and the most likely alternatives going forward • Key port energy consumers: terminal trucks/straddle carriers, tugboats, pilot boats, reach stackers, bulk cargo cranes and container yard and ship-to-shore cranes • Energy supply options currently under consideration: HVO, Biodiesel, Electric, H_2, Methanol, Diesel and Diesel with Carbon Capture • External contacts with the Ports of Valencia, Auckland and Busan for insights into the implementation procedures
5	**Implementation timeline**	To be defined, but within the allocated project timeline

Table 5 Case study 2 description.

Parameters	**Values**
Region of consideration	Leixões/Viana do Castelo
Energy vectors	• Methanol • Ammonia • Hydrogen • Others (HVO, Electric, Biodiesel, etc.)
Timeframe	• Current • Near-future (e.g., 2030) • Long-term (e.g., 2050)
End users	• Terminal trucks/straddle carriers • Tugboats • Pilot boats • Reach stackers • Bulk cargo cranes • Containership park/ship cranes

Table 6 Detailed description of parameters for use case/case study 2.

Scenario	Region	Energy Vectors	Timeframe	End user
1	Leixões	Methanol, Ammonia, H_2, others	Current versus near-future versus long-term	Tugboats
2	Leixões	Electric,H_2,	Current versus near-future versus long-term	Reach stackers
4	Leixões	Electric, H_2	Current versus near-future versus long-term	Terminal trucks/straddle carriers
5	Leixões	Electric, H_2	Current versus near-future versus long-term	Bulk cargo cranes
6	Leixões	Electric, H_2	Current versus near-future versus long-term	Pilot boats

Table 7 Scenarios to be evaluated for use case/case study 2. Additional scenario combinations may be considered, if pertinent.

If the Levelized Costs are assumed rather than calculated, the case study does not need to include hydrogen production and distribution parameters. Instead, the focus should shift to inputs relevant to the end-use application under consideration. Once more, conducting this analysis requires knowledge of CAPEX, fixed and variable OPEX. The data will be obtained per typology of equipment, and considering both current and future cost scenarios.

3 Information sources for case study characterization

As a complementary procedure to defining the use cases and corresponding case studies, UPORTO and APDL already underwent a preliminary selection, assessment and triage of key information sources. These include detailed reports from trustworthy sources, such as the Methanol Institute, DNV, Maersk and the International Maritime Organization (IMO). These are recent (past 5 years) data sources that include expansion and cost scenarios of implementing distinct energy vectors at seaports, including those based on H_2. There are also maps analogous to those prepared within the initiatives´ identification process of WP4, from the HYDEA project, as seen in Figure 2 and Figure 3.

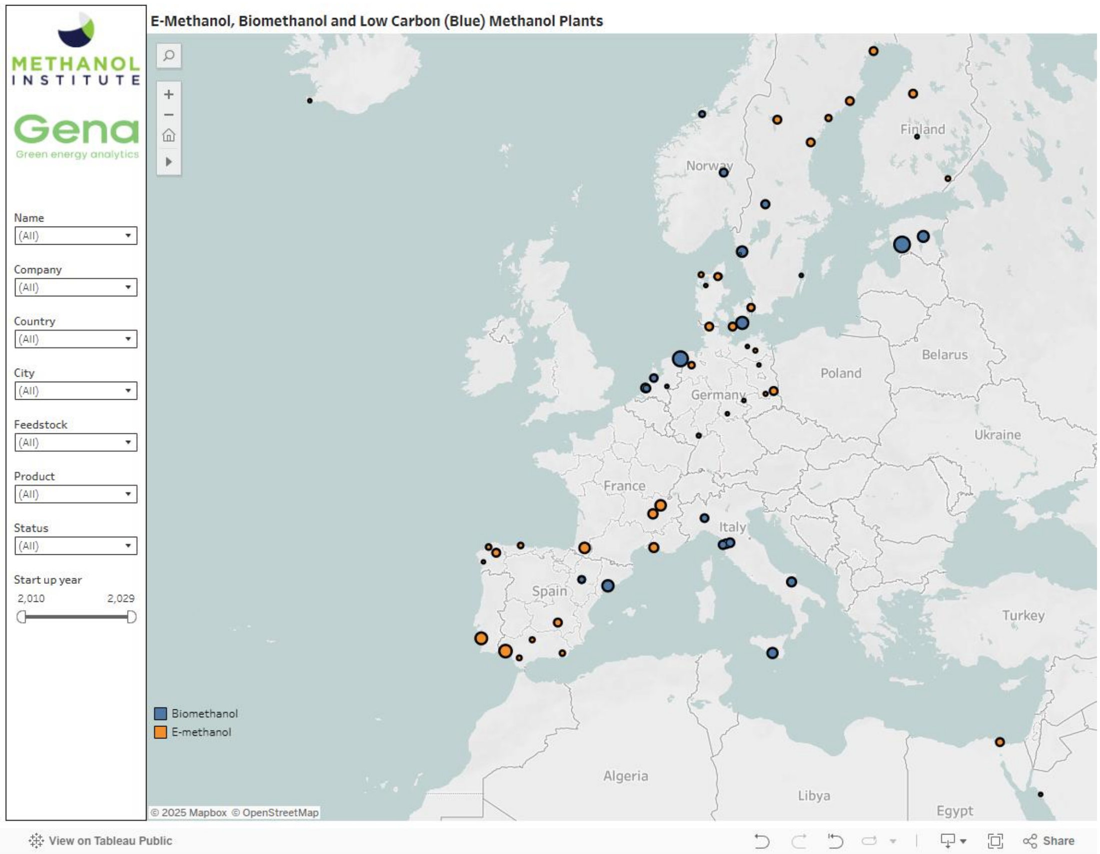

Figure 2 Map of methanol plants and projects at ports in Europe. *Source*: Methanol Institute.

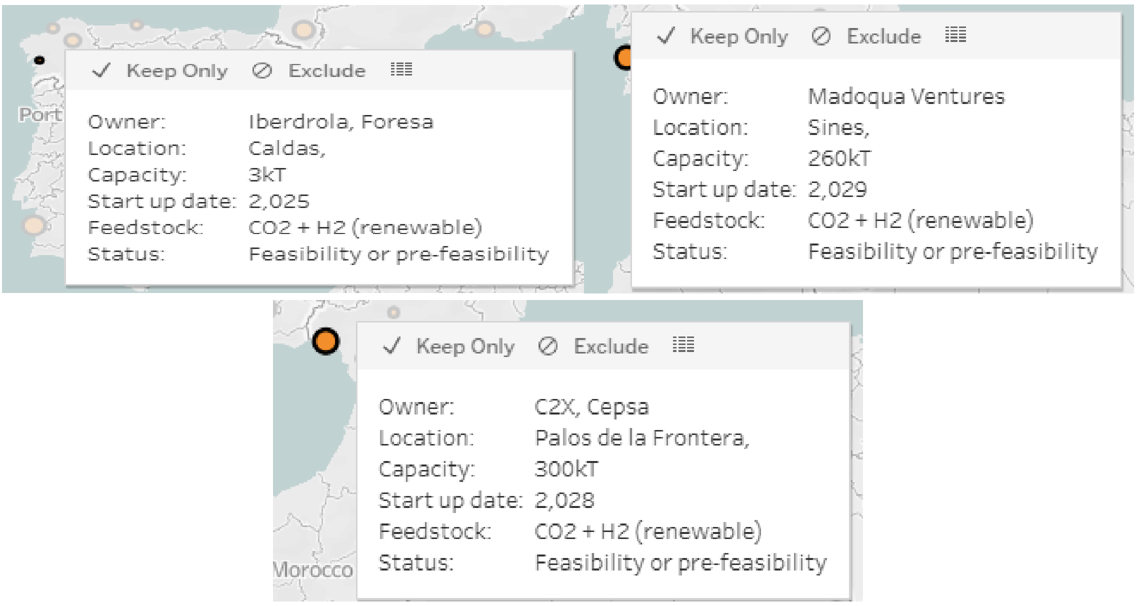

Figure 3 Project description example in the Iberian Peninsula. *Source*: Methanol Institute.

The IMO's *Future Fuels* platform features a "Fuel Uptake" dashboard powered by DNV's Alternative Fuels Insight (AFI), offering a transparent, real-time overview of global uptake trends for alternative marine fuels and supporting infrastructure. This tool tracks key metrics such as the number of vessels using hydrogen, ammonia, methanol, LNG, and other fuels, as well as the scale and location of bunkering facilities, as exemplified in Figure 4. To these add other information sources on expected expenditures per fuel type (2030 and 2050 as the most common timeframes), retrofitting costs per design ship reference (bulker, tanker, container, etc.), specific sources of energy vector (*e.g.*, bio-methanol, e-methanol), regional trade flows, and comparison between energy vectors (maturity, applications, advantages and challenges). This has been shared with the HYDEA partners to assist in their own case studies.

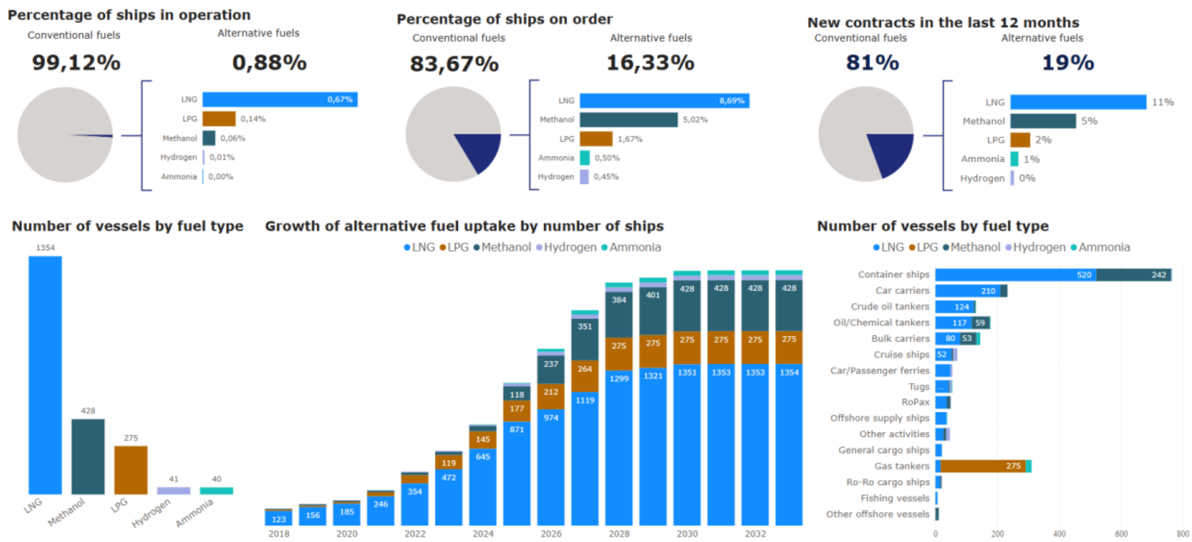

Figure 4 Market trends and orderbooks of shipping vessels. *Source*: IMO and DNV.

CONTACT DETAILS

Victoria León Carpintero
Project Coordinator
ITG
www.eu-hydea.eu