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A Transnational Perspective to Stimulate Hydrogen Penetration in Port Areas and Transform Mediterranean Ports into Sustainable Maritime Hubs

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ABSTRACT

The global initiative to diminish reliance on non-renewable fuels has intensified in light of climate change imperatives. Green hydrogen, produced via renewable-powered electrolysis, is emerging as a critical solution for decarbonizing challenging sectors such as maritime transport. This paper discusses insights from the EU Interreg Marittimo-IT FR-Maritime H2MOVE project, a transnational effort to enhance green hydrogen utilization in Mediterranean ports. The project includes establishing a strategic cooperation committee, mapping the hydrogen ecosystem, analyzing legal frameworks, and developing a comprehensive "Masterplan" alongside technical feasibility studies. It emphasizes green hydrogen's vital role in reducing maritime greenhouse gas emissions while addressing pertinent technical, economic, and regulatory challenges. Key barriers include high production costs and logistical complexities. The H2MOVE project aims to provide a strategic framework for transforming Mediterranean ports into sustainable, decarbonized hubs, thereby contributing to a more environmentally friendly maritime industry.

1. INTRODUCTION

The maritime transport and port sector constitutes a global trade and economic infrastructure cornerstone, facilitating approximately 80% of international trade. Despite its essential economic role, the sector significantly contributes to environmental degradation, responsible for over 70% of total gaseous emissions, with additional pollutants stemming from port operations and infrastructure [1-3]. Decarbonizing Industrial Port Areas (IPAs) presents a complex challenge that needs a structured, phased approach, including energy efficiency measures, optimized logistical and spatial planning, and the integration of renewable energy sources (RES) [4, 5]. A comprehensive analysis by Pivetta et al. [6] in 2024 underlines the vital importance of hydrogen (H_2) and its production technologies in decarbonization strategies for IPAs. This study highlights that while the increased adoption of RES can effectively reduce emissions, achieving complete decarbonization extends beyond mere electrification, requiring complex, capital-intensive solutions, particularly in large-scale H_2 storage and carriers to harmonize RES supply with variable demand, amidst existing technical and economic barriers [1]. The European Union (EU) has designated H_2 as a keystone for future energy systems, notably through the REPowerEU initiative [7], which aims to produce and import 10 million tons of renewable H_2 by 2030 [2]. Green H_2 is foreseen to serve as a strategic enabler, interlinking various industrial sectors including maritime, oil and gas, and cruise tourism, many of which are prevalent in port environments [3]. Research by Deloitte Belgium Energy and Climate for the Clean Hydrogen Partnership [8] reaffirms the significance of port ecosystems in the future H_2 economy, projecting ports to become energy transit hubs for H_2 import and distribution while investing in infrastructure for H_2 production and storage [9]. The study employs a scenario-based framework to forecast H_2 demand and supply across European ports for 2030, 2040, and 2050, delineating the infrastructural requirements of the H_2 value chain and proposing a strategic investment roadmap. Notably, up to 42% of the EU's annual H_2 demand by 2050 could be concentrated in port areas, underscoring the imperative for a "European Hydrogen Roadmap for Ports" to harness their full decarbonization potential. One case study examining Tuscany's western coast, particularly the ports of Livorno, Piombino, and Portoferraio, estimated H_2 demand at approximately 39,000 tons by 2050, assuming centralized production in Livorno with a projected installed capacity of 172,500 MW. The study explored the decarbonization of maritime transport through H_2-powered ferries and ammonia fueled container vessels, suggesting ports could function as autonomous energy consumers. The strategic geographical positioning of Piombino suggests it could emerge as a key H_2 hub, facilitating import flows from Latin America, North

Africa, and the Middle East into Europe [4].

Nevertheless, H_2, which presently constitutes only a modest fraction of both the global and European energy mix, remains predominantly derived from fossil fuels, particularly natural gas and coal, which emit between 70 and 100 million tons of CO_2 annually within the European Union. To substantively contribute to attaining climate neutrality, H_2 production must be exponentially scaled and, crucially, transition to a fully carbon-free process. In the strategic framework for a climate-neutral European Union published in November 2019, it is anticipated that H_2 will comprise a quarter of final energy consumption by 2050 [5].

A binational initiative, H2MOVE – Hydrogène pour une MObilité VErte et durable, has been initiated under the Interreg Italy–France Maritime Programme 2021–2027, aiming to bolster mobility resilience and enhance cross-border accessibility by developing an integrated strategy and action plans for H_2-based systems in vehicular applications and port interconnections, extending to urban and industrial sites. Key activities include establishing a strategic cooperation committee to guide H_2 development, mapping the regional H_2 ecosystem, conducting regulatory analyses, assessing regional and EU strategies, drafting guiding principles, formulating a transnational "Masterplan" and executing technical and economic feasibility studies.

2. INTERREG ITALY-FRANCE MARITIME PROGRAM

The Interreg Italy–France Maritime Programme 2021–2027 constitutes a cross-border initiative co-financed by the European Regional Development Fund (ERDF), within the framework of the European Territorial Cooperation (ETC) objective under the European Union's Cohesion Policy for the programming period 2021–2027.

The program is formulated upon the following strategic priorities:

Priority 1: An attractive cross-border area of intelligent and sustainable modernization;

Priority 2: A resilient and resource-efficient cross-border area;

Priority 3: A physically and digitally connected cross-border area;

Priority 4: A cross-border area efficient in social capital and distinguished by the quality of its human capital;

Priority 5: Better cross-border governance.

With a total financial allocation of €193,296,077, the overarching objective of the programme is reinforcing institutional and territorial cooperation between the participating regions. It aspires to foster the emergence of a cross-border area that is not only economically competitive and socially cohesive but also environmentally sustainable, positioning it as a model of integrated development within the broader European and Mediterranean landscape.

3. H2MOVE - HYDROGENE POUR UNE MOBILITE VERTE ET DURABLE

The "H2MOVE" project, part of the Interreg Maritime initiative, is financed under the first call for proposals launched by the Italy-France Maritime Interreg Cooperation Program 2021–2027. It falls within Priority 3: A physically and digitally connected cross-border area, with priority specific objective to create and establish an advance a sustainable, intelligent, and climate-resilient intermodal mobility system at national, regional, and local levels, with a particular focus on enhancing access to the TEN-T network and fostering cross-border mobility.

With a total budget of €4,320,441.05, of which FESR funds €3,456,352.82 and has a duration of 42 months, the H2MOVE project is spearheaded by the Regional Chamber of Commerce of Provence-Alpes-Côte d'Azur. The initiative is supported by a consortium of 14 cross-border partners (CAP_CapEnergies, CCI de Corse_Chamber of Commerce and Industry of Corse, UDCPP_University of Corsica Pasquale Paoli, RL_Liguria Region, AdSPMLOr_Eastern Ligurian Sea Port System Authority, CCIAA Genova_Genoa Chamber of Commerce, Industry, Handicraft and Agriculture, UNIGE_University of Genoa, RT_Tuscany Region, ADSP MTS_The North Tyrrhenian Sea Ports System, UNIPI_University of Pisa, RAS_Autonomous Region of Sardinia, UNICA_Interuniversity Economic Research and Mobility Center - University of Cagliari, REGION SUD_Regional Council Provence Alpes Côte d'Azur, MINES_MINES Paris PSL) operating within the geographical cooperation regions as represented in Figure 1.

Figure 1. Geographic cooperation regions

The H2MOVE project tackles the challenge of resilient accessibility by strategically planning measures to reduce environmental impacts in port areas, thereby promoting territorial continuity. Aligned with the overarching goal of achieving climate neutrality in the cross-border maritime sector, the initiative seeks to define a comprehensive macro-strategy for H_2 development in ports and related areas. This strategy will serve as a coordinated framework complementing current and future national initiatives, including those in Italy's and France's 2030 recovery plans.

To achieve this, the project is structured into three interrelated work packages (WP), each with defined objectives, corresponding activities, and deliverables.

3.1 WP1 - Governance and preliminary analysis

This WP aims to establish a strategic cooperation committee contributing to H_2 mobility development through coordinated planning, impact assessment, and scientific support, as well as to develop a comprehensive mapping of H_2-related stakeholders, projects, and initiatives in the maritime area.

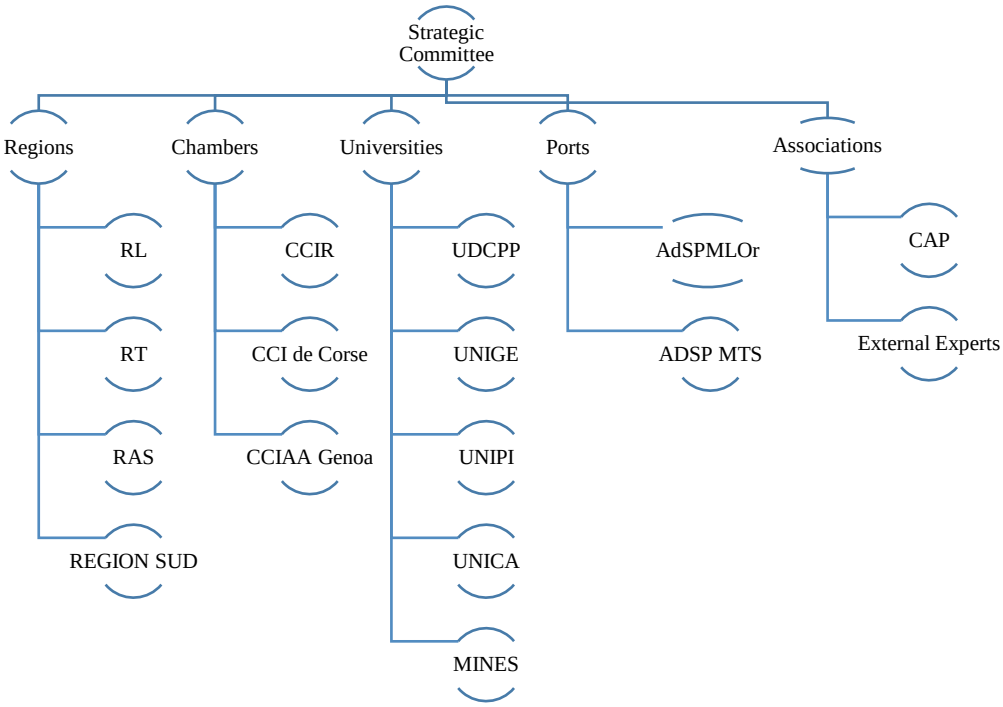

Figure 2. Strategic committee composition

Activity 1.1: Strategic Cooperation Committee

The strategic cooperation committee (see Figure 2) is formed to guide H_2 development in the cooperation area. Based on the quintuple helix model, the committee will provide strategic oversight, coherence, impact evaluation, and coordination. Members will include academic partners, local authorities, chambers of commerce, H_2 associations (e.g., France Hydrogène, H2IT), and port authorities.

Activity 1.2: Ecosystem Mapping

A detailed segmentation and mapping of the H_2 ecosystem will be conducted, covering both supply and demand. It will identify producers, existing and potential value chain actors, end-users, and relevant ongoing projects. This will support the creation of a digital platform to visualize the ecosystem and its capacities.

Activity 1.3: Legal Framework Analysis

This activity analyzes the cross-border regulatory landscape, focusing on H_2 classification, tracking mechanisms, and support schemes. The goal is to identify legal barriers and promote regulatory alignment between Italy and France.

Activity 1.4: Strategic Context Review

The component concludes with a comparative review of regional, national, and EU H_2 strategies, identifying gaps and best practices.

3.2 WP2 - Cross-Border Masterplan

This component is focused on developing a comprehensive Cross-Border Masterplan, serving as a strategic roadmap for the H_2 sector within the cooperation area. Based on the results of WP1 and aligned with 2030 and 2050 decarbonization objectives, the Masterplan will be articulated through five regional action plans, each tailored to the territorial specificities and strategic needs of the partner regions. The component also includes a robust dissemination strategy, fostering awareness among scientific, institutional, and general audiences, and cultivating broad support for H_2 as a clean energy vector.

Activity 2.1: Strategic Guidelines for the Masterplan and Action Plans

This activity entails formulating a methodological framework to guide the development of the Masterplan and the associated regional action plans. With inputs from the strategic cooperation committee, the framework will define the analytical structure, data collection protocols, decision making processes, and thematic chapters necessary to ensure a coherent and systematic approach. It will act as a foundational tool to streamline collaboration and optimize the implementation of H_2 mobility strategies.

Activity 2.2: Formulation of the Cross-Border Masterplan

The Masterplan will offer a strategic vision for the cross-border H_2 sector, promoting a unified and sustainable approach to H_2 mobility in response to shared climate challenges. Fueled by the conclusions of WP1 (notably deliverable D.1.4), the plan will outline medium and long term development trajectories (to 2030 and 2050), aligning regional policies and guiding stakeholders toward an integrated H_2 economy. The plan will be developed collaboratively with the strategic committee to ensure policy coherence and operational relevance.

Activity 2.3: Regional Action and Perspective Plans

To account for territorial diversity within the cooperation area, the Masterplan will be operationalized through five regional action and foresight plans, structured around three core dimensions:

- Mobility Perspective: Deployment of H_2-based solutions in cross-border maritime and land transport.
- Industrial Perspective: Application of H_2 in port and industrial ecosystems, supporting decarbonization and

territorial connectivity.

- Civil and Residential Perspective: Promoting H_2 technologies in households, public buildings, and urban infrastructure, complementing broader clean energy efforts.

Each plan will incorporate a holistic vision of the H_2 value chain, encompassing production, transport, and storage.

3.3 WP3 - Implementation

This component focuses on transitioning from strategic planning to practical action, prioritizing the initial deployment of pilot initiatives based on regional action plans, with a strong emphasis on a green transition for port ecosystems. Central to this phase is integrating green H_2 into port areas, cross-border mobility, industrial sectors, and private operations to support decarbonization, territorial cohesion, and environmental sustainability.

This phase aims to engage stakeholders across the quintuple helix: academia, industry, government, civil society, and the environmental sectors, leveraging the consortium's technical expertise and the strategic cooperation committee's outreach capabilities.

Activity 3.1: Stimulating Demand and Structuring Supply

This activity will launch a cross-border digital platform to map key H_2 ecosystem actors, infrastructures, and capacity. The platform will:

- facilitate business matchmaking and knowledge exchange;
- aid public authorities in identifying local assets for infrastructure development;
- provide data on local H_2 production relative to forecasted demand.

Activity 3.2: Governance and Territorial Planning Tools

The territorial planning tool consists in a Decision Support System (DSS) to guide land-use planning and H_2 infrastructure investments. Building on territorial modeling tools, the DSS will be adapted to the cross-border maritime context, offering:

- simulations and visualizations for informed decision making;
- assessment of spatial and environmental impacts of different strategies;
- alignment with regional and transnational planning frameworks.

Activity 3.3: Techno-Economic Feasibility Studies

This activity encompasses feasibility studies to evaluate H_2 use in port operations, logistics, and energy systems, including:

- port operations: H_2 as fuel for vehicles and equipment;
- maritime transport: H_2 for vessels serving minor islands;
- energy networks: H_2 integration into port-based energy systems;
- logistics: H_2 use in freight handling and distribution logistics;
- energy sourcing: Analysis of green electricity options for H_2 production.

These studies will provide valuable insights for investment and policy planning, ensuring that H_2 infrastructure development meets both economic and environmental goals.

4. PROJECT IMPLEMENTATION STATUS

The H2MOVE project started in March 2024 and is scheduled for completion in August 2027. It comprises seven semi-annual periods to ensure structured implementation and progress monitoring. The project is currently in Period P3, which will conclude in August 2025. Some deliverables are scheduled for each end period.

As part of the WP1 “Governance and preliminary analysis”, four deliverables were prepared.

The D1.1.1 consists in the composition of the strategic cooperation committee (see Figure 2), within the cooperation area, providing planning methodologies, coherence analyses, impact assessments, and coordination functions. The role of this committee is crucial in addressing the technical and logistical challenges associated with the potential creation of a cross-border H_2 valley between Italy and France. The project aims to foster a transition towards climate neutrality by focusing on the maritime dimension and positioning the ports as drivers of sustainable mobility. This strategic collaboration will enable the exploration of new solutions for sustainable mobility, considering the local specificities and the involved needs of the territories. Participation was not limited to project partners; it also included external experts, and it will be maintained beyond the project duration to strengthen sustainable territorial continuity.

The second deliverable, D1.2.1, denominated “Segmenting and mapping the hydrogen ecosystem” within the H2MOVE cooperation area aims to identify and map H_2-related projects within the maritime cooperation region and its surrounding areas, thereby supporting the formulation of cross-border strategic plans and contributing to the development of a comprehensive H_2 roadmap for ports and adjacent zones. It contains initiatives related to H_2 production, transportation, or consumption, including its derivatives such as methanol, ammonia, syngas, and electro-fuels. A preliminary investigation based on the websites of the Clean Hydrogen Partnership [7], which addresses the Clean Hydrogen Valleys, the EU Green Deal Alliance concerning pipeline initiatives, and the International Energy Agency (IEA) [9] database, has identified approximately 200 active, approved, or to be activated projects within Italy. This initial survey was subsequently supplemented by a comprehensive analysis utilizing data from various informational sources, including media outlets, official websites, data providers, and interviews with local stakeholders and experts engaged in these projects. As a result, the study has catalogued a total of 122 H_2-related initiatives, comprising 78 in France and 44 in Italy, and provided a mapping of several linear infrastructure projects (H_2 pipelines); such maps are now accessible online in both French and Italian versions, as represented in Figure 3.

The dataset offers detailed and structured insights for each project, encompassing the nature of the initiative, the lead developer or operating entity, the associated stakeholders, the projected production capacity, the implementation status, the anticipated commencement date, the primary energy source, the electrolyzer specifications, and H_2 storage and generation parameters.

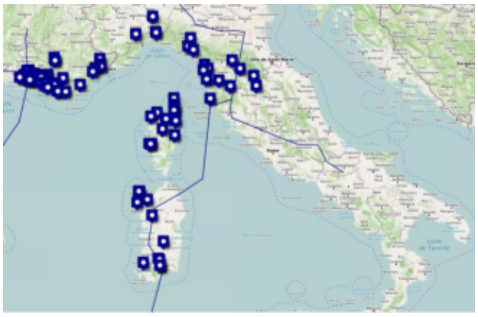

Figure 3. H_2 projects mapping (Overview of the projects in the cooperation area) [6, 11]

D1.3.1, devoted to the legal framework in both countries and to the barriers to overcome, provides an overview of the regulatory landscape governing the installation of green H_2 facilities in Italy and France, highlighting key administrative procedures based on the electrolyzer's capacity and location. It outlines the applicable legal regimes as Free Activity, Simplified Enabling Procedure (PAS), and Single Authorization (AU), offering a structured synthesis of the authorization pathways and potential legal barriers to cross-border H_2 development.

D1.4.1 provides an in-depth analysis of the role of H_2 in the energy transition, focusing on strategies for H_2 deployment in EU member states leading the H_2-driven transition. It explores the EU regulatory framework governing H_2 production, transport, storage, distribution, and end-use. Special attention is given to technical regulations related to H_2 production, transportation, and distribution, as well as its industrial applications and use in mobility. Additionally, the report identifies key challenges related to H_2 safety and lists the international and national safety regulations, such as EC 60079 and IEC 80079 for explosion protection, and ISO 22734 and ISO 19880 for infrastructure, providing essential guidelines. At the European level, CEN/CLC/JTC 6/WG 3 focuses on H_2 safety standards.

The National Fire Protection Association (NFPA) has developed the NFPA 2: H_2 Technologies Code, which addresses the safe handling of H_2 in various forms (GH2 and LH2). NFPA standards often complement European regulations by covering additional scenarios.

Additionally, the Bureau de normalisation du Québec (BNQ) established the CAN/BNQ 1784-000/2022 standard for H_2-related installations in Canada, ensuring alignment with Canadian and ISO requirements.

These standards are critical in overcoming safety concerns and facilitating the widespread adoption of H_2 technologies.

Regarding WP2, just the deliverable 2.1.1 "Guidelines for the strategy and action plans" is already defined, which consists of developing a structured and jointly agreed framework to guide the formulation of the Masterplan and regional action plans. This framework outlines the methodologies for data collection, analysis, and decision-making processes, while identifying the key chapters to be developed, thus ensuring a coherent, systematic, and harmonized approach across the cross-border area.

5. CONCLUSIONS

The H2MOVE project represents a critical step towards decarbonization in the cross-border Italy-France maritime region, facilitating the transition to a sustainable H_2-based economy. By establishing Strategic Cooperation, creating a Strategic committee, comprehensively mapping the H_2 ecosystem, and analyzing legal frameworks, the project lays the groundwork for a coordinated and integrated H_2 infrastructure.

The project's focus on governance, feasibility studies, and cross-border planning ensures a systematic approach to overcoming technical, regulatory, and logistical challenges.

A key deliverable of the initiative is the Cross-Border Masterplan, which plays a fundamental role in aligning regional strategies with EU decarbonization goals. It provides a structured, forward-looking framework to guide investments, infrastructure development, and policy alignment across different territorial contexts. This strategic roadmap ensures coherence among regional action plans and helps steer stakeholder collaboration toward a shared vision for H_2 deployment in transport, industry, and civil sectors.

Notable achievements, such as identifying the hydrogen-related initiatives, demonstrate significant progress in aligning regional actions with EU decarbonization objectives. The development of strategic guidelines and regional action plans further supports the creation of a cohesive H_2 roadmap for ports and industrial sectors. The successful execution of these initiatives will be pivotal in meeting the EU's climate neutrality targets by 2050.

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