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Co-funded by the European Union

North Sea Hydrogen Valley Ports

Creating the hydrogen corridor between North Sea ports

Deliverable D 1.1

Governance Issues Affecting Hydrogen (H_2) Production, Storage, and Transport

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DOCUMENT INFORMATION

Grant agreement number	
Project acronym	NSH2V Ports
Work package	WP 1
WP activity	1.1
Title of activity	Governance Issues Affecting Hydrogen Production, Storage, and Transport
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DOCUMENT HISTORY

Version	Date	Description	Reviewer
Draft 0.0	27/05/2025	Document Draft and structure definition	Hamid Gualous, Raffaele Petrone, Abdelilah Hammou, Jayang Gu
Draft 0.1	13/06/2025	Literature review sum-up / Document under writing	
Draft 0.2	20/06/2025	Final draft	
Draft 0.3	24/06/2025	Final Draft Review	Fabienne Vallée
Draft 0.4	30/06/2025	Final Draft Review	Woltmann

Contents

1. Introduction

In the context of the energy transition, hydrogen is widely regarded as one of the most promising energy carriers. However, while the public generally accepts its environmentally friendly role and applications, perceptions of hydrogen technologies and their potential for market penetration remain mixed [1].

Over the last decade, public awareness of hydrogen technologies has grown, supported by new demonstration projects and related communication efforts. Today, most people are familiar with the concept of green hydrogen and view it as a credible means to reduce CO2 emissions and mitigate climate change. Still, perceptions vary depending on the group involved: stakeholders (investors), customers (end users), or local residents. Overall, the expectation of benefits such as local economic growth and job creation is a strong motivator for all groups [1,2]. At the same time, there is a continued need for clarity on issues such as potential risks, system lifetime, and cost structures [1–7].

Different groups emphasise different aspects. Customers are primarily interested in green hydrogen production, distribution infrastructure, and prices. Investors, on the other hand, focus more on technological costs (including investment, production, and maintenance), system durability, and prospects for market deployment. The wider public emphasises the importance of a clear and accessible regulatory framework, pointing to existing gaps in private funding and policy support [1–3].

While European public funding has encouraged a steady rise in collaborative and demonstrator projects, full commitment from private investors, particularly banks and commercial partners, is still limited. This reluctance stems largely from uncertainty in long-term policy direction, concerns about the durability of innovation deployment, and the absence of clear regulatory standards and simplified procedures [1,2]. As a result, public concerns remain centred on infrastructure development and the lack of visibility in regulatory frameworks at the local policy level.

To address these challenges, greater efforts are required in scaling-up strategies for hydrogen technology standardisation and industrialisation. This will help reduce costs, provide clearer roadmaps and business plans, and establish durable long-term strategies to support the emerging hydrogen economy. Ultimately, strong governance will be essential to foster investor confidence, enable industrial growth, and drive the transition forward.

2. Governance Scenario in Energy Transition and Green Hydrogen Economy: Current Actors, Actions, and Pending Questions

Governance refers to the establishment of a coherent set of rules, policies, regulations, and decision-making processes that guide the behaviour of corporations, partnerships, and public institutions. For governance to be effective, it must embody key principles such as clarity, accountability, fairness, responsiveness, effectiveness, and efficiency. A suitable governance structure requires a clear definition of purpose, the processes to be managed, expected performance outcomes, and the main actors involved. It must also define how people behave and perform within the process: who makes decisions, who has the authority and expertise to act, who bears accountability, and how responsibilities are shared and enforced.

In the context of the energy transition, governance takes on particular importance. Current challenges are not only about reducing CO2 emissions but also about reshaping the local and national energy mix through the integration of renewable energy sources and the introduction of new energy carriers such as hydrogen. As illustrated in Figure 1.1, these challenges are largely influenced by local, regional, and national policies and development plans. While the specific goals of energy transition vary by country depending on local resources and policy priorities, certain constants can be observed.

For mature technologies such as solar and wind, governance structures typically begin at a supra-national level (for example, the European Union), where broad policies, directives, and master plans are established. These are then adapted and implemented by individual member states and regions. Hydrogen technologies, though still at an earlier stage of maturity, are now being positioned within this same governance framework. They align with the objectives of the emerging energy economy, including decarbonization, energy security, and industrial competitiveness. As a result, a similar governance pattern is emerging in which European-level strategies set the tone, and member states progressively adopt and adapt rules, standards, and policies.

One of the most visible elements of governance in this field has been European funding for collaborative research, development, and demonstration projects. These projects not only accelerate technological progress but also serve as tools for communication, public

engagement, and familiarisation with hydrogen technologies. Demonstration projects have shown tangible benefits such as the potential to create new jobs, stimulate local business opportunities, and provide flexible solutions to balance growing energy demand.

Nonetheless, several governance gaps remain. Despite the momentum, there is still insufficient visibility and alignment in common policies and long-term strategies. The lack of harmonised technical standards across member states hinders market consolidation and creates uncertainty for investors. In addition, hydrogen infrastructure, pipelines, storage facilities, refuelling stations, and related logistics services remain underdeveloped, limiting the sector's capacity to scale. These barriers reflect the absence of a fully coherent governance framework that can provide clear guidance, reduce risks, and create a stable environment for both public and private investment.

Addressing these gaps will require efforts in three main areas: first, the creation of harmonised standards and certification schemes to ensure interoperability and safety across markets; second, the design of long-term, predictable policy frameworks that give investors confidence; and third, the integration of infrastructure planning with broader energy system governance to ensure hydrogen is deployed efficiently alongside other renewables. Without these, the energy transition risks stalling at the demonstration stage rather than moving toward full industrialisation and market deployment.

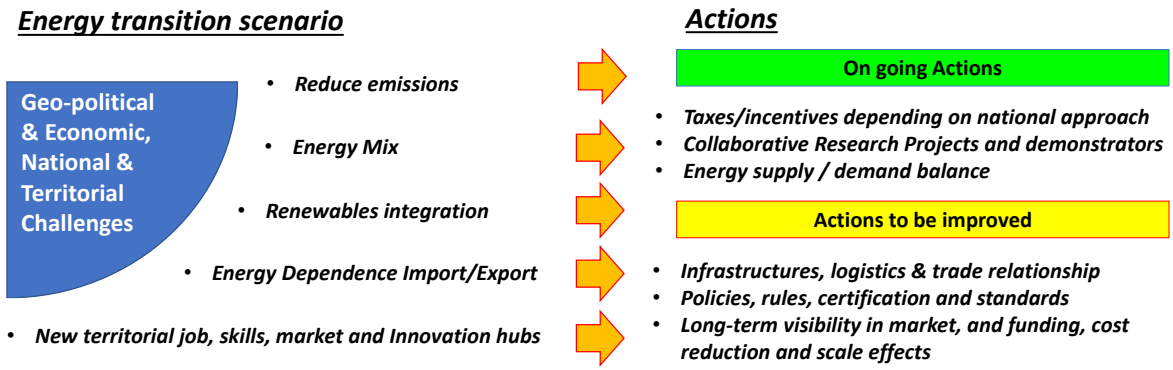

Figure 1.1: Hydrogen actions in the energy transition scenario.

Based on this scenario, it is evident that the establishment of strategies to make green hydrogen more affordable and widely available is essential for building a sustainable, resilient, and equitable zero-carbon economy. This should be a central purpose of emerging hydrogen governance [8]. Accordingly, the entire hydrogen value chain—production, storage, distribution, and end-use—must be systematically studied, regulated, and managed.

Three main working areas can be identified as critical pillars of hydrogen governance [9]:

- end-use sectors;
- infrastructure and trade;
- environmental and socio-economic sustainability.

Consolidation of these pillars is mandatory in order to address pending questions such as how to balance hydrogen production and demand, achieve market stability, and establish comprehensive certifications and standards.

The ramp-up of the hydrogen market is closely tied to a range of potential end-use activities, many of which are still under development [9]. While hydrogen production methods, such as "power-to-gas" or "gas-to-power", are already well-established, the long-term viability and sustainability of end-use applications remain unclear. In particular, the design of effective hydrogen and hydrogen-derivative markets will depend on governance capacity to overcome persistent challenges, including high costs, lack of infrastructure, and regulatory barriers [8]. For this reason, it is essential to accelerate development across end-use sectors and their associated sub-sectors, industrial applications, transportation, the power sector, pipelines, and refuelling stations. Each requires focused efforts in cost reduction, safety assurance, performance demonstration, technology deployment, and sustainability integration. In parallel, hydrogen production, import/export policies, and delivery strategies must also be improved in order to extend deployment to remote and less connected regions.

One strategy already being adopted is the creation of local hydrogen networks and hubs, which serve as institutional architectures to support project development [9]. Investment in infrastructure is central: boosting production capacity (through automation and scaling-up), while also creating strong distribution networks, sufficient refuelling stations, and well-structured import/export channels. Achieving this requires joint efforts and financing from both public and private sectors, with active involvement of banks and investors. At present, private participation is limited, often due to the complexity of dealing with multiple regulatory authorities. Among the major barriers are delays caused by lengthy certification and permitting procedures, as well as the high upfront investment costs. To overcome these, priority should be given to standardising processes, permits, and certification pathways, as well as broadening funding mechanisms. Equally important is the clear identification of actors and responsibilities across the hydrogen value chain, to ensure equity and reduce business risks [9].

Currently, most industrial stakeholders are driven primarily by public funding initiatives, with private-sector funding still lagging while investors wait for clearer long-term policy signals. At the global level, the most proactive actors in the hydrogen ramp-up include the United States, European Union, China, and Japan, followed by energy-intensive or resource-based economies such as Canada, India, Brazil, South Korea, and the United Arab Emirates [8,9]. Established global governance institutions in the energy sector, traditionally centred on oil and gas, are now integrating hydrogen into their strategies, promoting it as the most promising energy carrier for a low-carbon future. These actors are extending existing governance mechanisms, ranging from tax incentives and carbon-reduction policies to structured funding institutions and standardisation processes, in order to support hydrogen projects and hybrid applications.

High-level international summits such as the G7, G8, and G20 also play a significant role, fostering dialogue between political and industrial actors, setting commitments, and defining priorities [9]. These forums serve as important platforms for lobbying and coalition-building around green hydrogen and its derivatives. While a minority of energy governance structures remain committed to traditional fuels, the prevailing trend in summit declarations points toward facilitating fossil fuel phase-out, particularly coal, in a more equitable manner. As a direct consequence, the past decade has seen the emergence of a global network of institutions focused on hydrogen transport, certification, and end-use applications.

In Europe, strong investment has gone into developing regional hydrogen markets, coastal industry integration, and exchanges of best practices at the local level. The EU has recognised that creating robust, interconnected energy infrastructures is central to its governance approach, and hydrogen is no exception. The Trans-European Networks for Energy (TEN-E) policy has long been an instrument for strengthening cohesion and cooperation across the EU by connecting national energy networks. In its current form, TEN-E explicitly supports hydrogen infrastructure development, including the creation of three regional hydrogen corridors that link transport and industrial hubs [10].

To complement infrastructure policies, the EU has also introduced measures to improve investment security. The establishment of the European Hydrogen Bank (EHB) marks the first major government-driven multilateral effort to share risk and leverage large-scale fiscal capacity, with the goal of de-risking private capital and accelerating the development of a functioning hydrogen market [11].

Despite these advances, governance for hydrogen remains fragmented globally. Many coalitions still operate only at the local level, tailored to specific ecosystems, policies, and infrastructures. Global sustainability criteria and certification schemes are still under development. On the regulatory side, a patchwork of standards exists for hydrogen production, transport, and use—including ATEX norms for pressurised and flammable gases, as well as protocols for cryogenic storage and refuelling stations. While these are essential, the proliferation of disparate standards makes it difficult to ensure globally consistent criteria.

The EU has made progress in harmonisation. Directive 2014/94/EU, adopted by the European Parliament in 2014, was the first step toward integrating and standardising alternative fuel infrastructure development in Europe. It required member states to create national frameworks for alternative fuels markets and infrastructure, aligned with common technical specifications. In 2023, this directive was repealed and replaced with Regulation (EU) 2023/1804, which provides a more comprehensive focus on the deployment of alternative fuels infrastructure, including hydrogen [12]. In parallel, international organisations such as the International Organisation for Standardisation (ISO) continue to set technical standards. For example, ISO 14687:2025 specifies hydrogen quality requirements for use across residential, industrial, vehicular, and stationary applications [13]. A chronological study of regulations, codes, and standards for hydrogen filling stations highlights the wide range of requirements for storage systems (compressed or cryogenic), compressors, cooling systems, and ancillary equipment [14].

In conclusion, the first governance processes for the green hydrogen economy have only begun to take shape in recent years. Initially, hydrogen governance developed through institutions and structures that were originally created to support the broader energy market and the energy transition, before gradually evolving into dedicated organisations. In Europe, this process has been accelerated through public funding programmes and directives from the European Parliament, which subsidise investment in hydrogen projects, establish regulations, and, most notably, have created the European Hydrogen Bank (EHB) to de-risk investment and stimulate market growth. For comparative insights into organisations and directives supporting hydrogen development in the United States, the reader may refer to [8], while an exhaustive review of European actors is provided in [9].

Although progress has been made, hydrogen governance remains in an early stage of development, and the list of required actions is far from complete. Many governance structures

are still local in scope, underlining the need for greater standardisation and internationalisation to ensure a coherent global hydrogen economy.

The key pending questions can be summarised in four priority areas:

1. **Visibility and sustainability of end-use applications**: the ramp-up of the hydrogen market depends on the development and validation of diverse end-use activities, many of which remain at a pre-commercial or early demonstration stage.
2. **Infrastructure, logistics, and trade**: robust governance must support the creation of logistics and trade frameworks by forming local networks, establishing new hydrogen hubs, and integrating import/export policies, delivery strategies, and infrastructure capable of connecting both central and remote geographical areas.
3. **Socio-economic sustainability**: scaling up hydrogen production and distribution requires strong investment in facilities and networks. This can only be achieved through joint efforts between the public and private sectors to remove financial and technical barriers, broaden funding opportunities, and establish common standards and certification systems.
4. **Roles and responsibilities of actors**: governance must clearly define decision-making authority, the distribution of expertise, and accountability mechanisms across the value chain. Clarifying who makes decisions, who has the authority to act, and who is accountable is critical to ensuring transparency, efficiency, and trust. Together, these actions highlight that while the foundation of hydrogen governance has been laid, much work remains to create a stable, standardised, and internationally coordinated framework capable of supporting the transition to a resilient green hydrogen economy.

3. Establish Governance Scenario for Hydrogen-oriented Green-Ports Sustainability: possible barriers and guidelines

Ports are commonly associated with international trade and tourism, serving as key nodes for both economic exchange and coastal activities. Beyond their role in maritime shipping logistics and coastal tourism, ports are also major energy users. Their energy demand varies depending on the nature of operations, which typically include ship transfers, approaching and mooring, cargo handling and logistics, ship repair and maintenance (including fuels and energy supply), port management, and increasingly, emerging activities such as offshore wind energy integration. As a result, in line with energy transition objectives, the development of alternative maritime power strategies and governance frameworks has become crucial.

Global governance efforts in this area aim to balance local market development with international trade, encouraging actors to strengthen local production capacities while also enhancing import/export strategies. In the context of the NS H2VPorts project, the central challenge is to create a collaborative framework across the North Sea region for integrating hydrogen production and use into port activities. This begins with the exchange of best practices and knowledge-sharing on local hydrogen applications. Each port ecosystem is analysed to evaluate its potential in terms of local hydrogen production, distribution, and use. Based on this, import and export strategies can be designed to facilitate exchanges between actors.

The overarching objective is to identify a suitable equilibrium between hydrogen utilisation, production, and import/export strategies that supports port sustainability. Once this balance is achieved at the local level, hub configurations can be developed to enable broader trade flows and, eventually, internationalisation. However, because the North Sea involves multiple EU Member States with differing policies and priorities, it is not possible to apply a single governance model. Instead, multiple strategies must be considered, each adapted to the specific case study. The following analysis highlights the differences in port administration models and governance barriers, comparing them to the outstanding questions in hydrogen governance identified previously. The goal is to anticipate potential governance challenges and provide short guidelines to harmonise procedures and mitigate risks in port and hub management.

To do so, the current situation of ports is examined, with a focus on their main needs and barriers. Ports vary widely in their services, cargo type, ownership, organisation, and administration. While the first three are closely tied to port activities, administration structures vary more significantly, being managed by local port authorities, municipalities, national governments, private entities, or hybrid combinations. This diversity is particularly pronounced in Europe, where three distinct models of port administration are typically identified [15]:

1. **The North-West European (Hanseatic) model**, characterised by decentralised municipal port administrations.
2. **The Latin model** (France, Italy, Spain, Portugal), characterised by stronger state-controlled administration.
3. **The Anglo-Saxon model**, where ports are operated by private and independent organisations.

Green ports, those integrating sustainability and alternative power systems, inherit these same differences in administrative structures, while facing additional constraints linked to new energy integration and power management requirements. Governance, therefore, must account for these complexities. Administrative structures often represent the first consideration when designing governance frameworks for hydrogen and green energy integration.

For green port development, it is essential to evaluate both port activities and their specific energy needs. This requires a clear definition of the port environment, encompassing its ecosystem, stakeholder landscape, and strategic priorities (Figure 1.2). The first step in this process is dedicated to data collection, information sharing, and analysis, which then provides the foundation for defining case-study objectives. Setting these objectives is critical, as they guide subsequent governance design, technical planning, and stakeholder engagement.

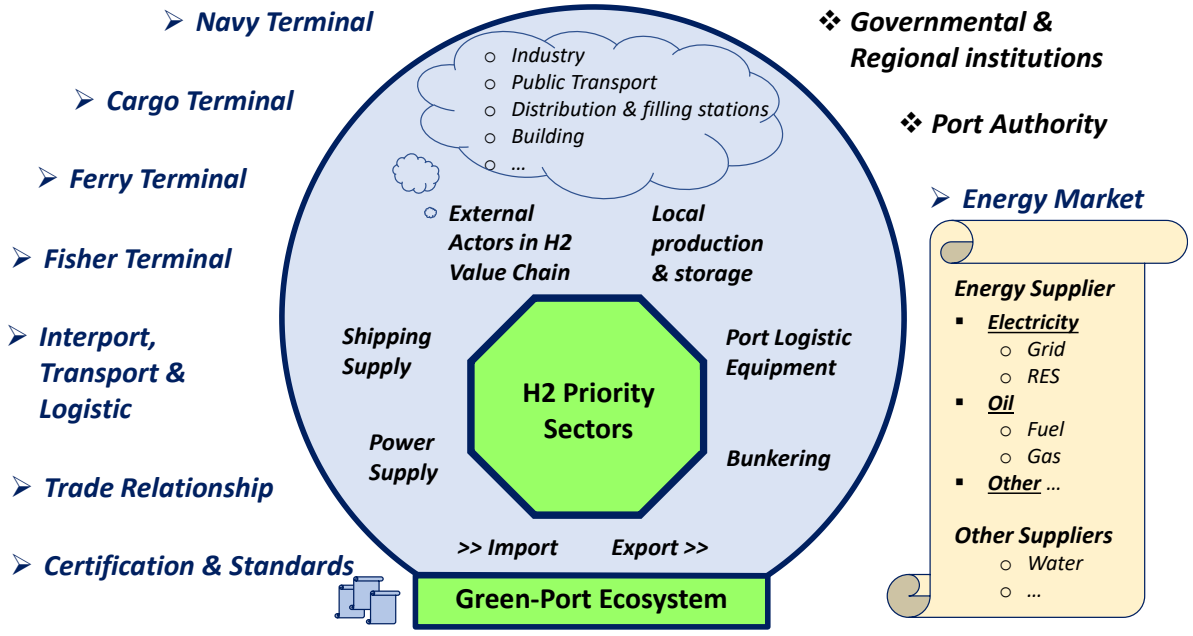

Figure 1.2: Green ports ecosystem and Priority Sectors in H2 deployment.

Figure 1.3 illustrates a generic approach for developing case-study proposals and defining objectives. In this framework, the port's energy resources and hydrogen-related priorities are organised in line with local authority strategies. These priorities are then translated into milestones and required actions, as well as the necessary equipment and services. This step focuses on opportunity evaluation, identifying specific targets, available resources, and key areas of intervention.

It is important to note that different development scenarios can be envisaged depending on the characteristics and priorities of each port. For example, some ports may prioritise local hydrogen production, using onshore or offshore renewable energy plants, and subsequently develop the entire value chain from production to end-use. Others may choose to focus instead on hydrogen import strategies, limiting their role to end-use applications, distribution, and the design of import/export logistics.

Given the current fragmented and heterogeneous conditions across European ports, targets will inevitably be shaped by local policies and governance structures. This phase of planning is therefore heavily influenced by barriers identified in the pending governance questions outlined earlier—namely:

1. the visibility and sustainability of end-use applications,
2. the development of infrastructure, logistics, and trade systems, and

3. the need for funding, policies, and common standards.

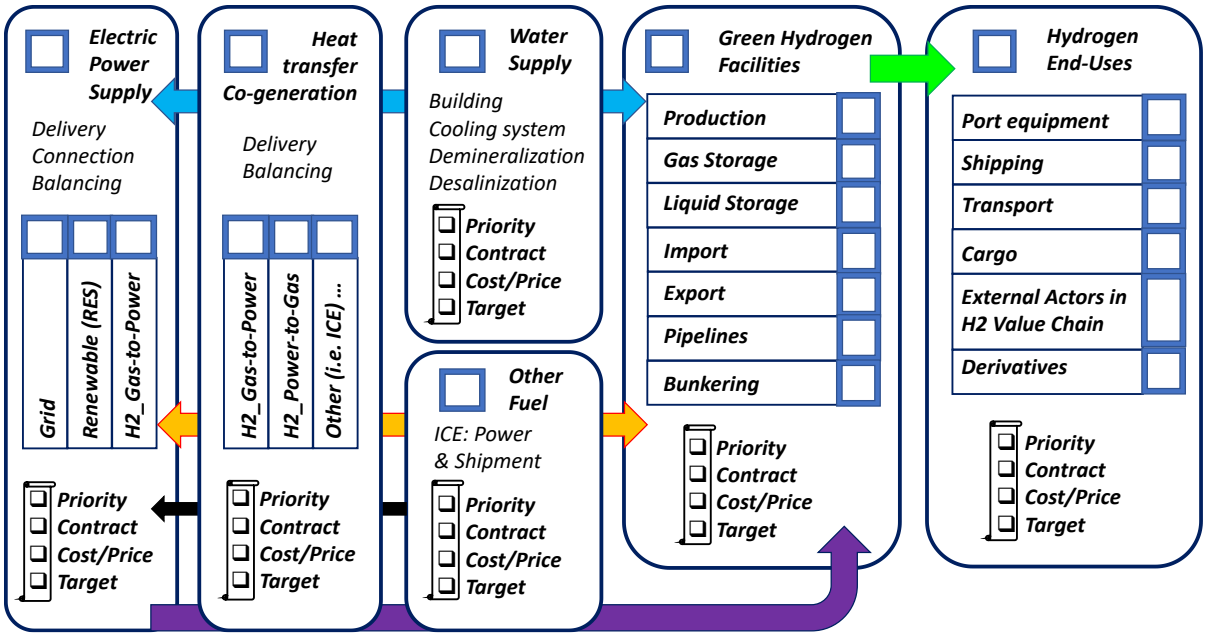

Figure 1.3: Green ports case-study proposal for objectives definition and activities plan.

Once targets and objectives are established, it becomes essential to define how the process will be carried out—what actions must be taken, how they should be implemented, and who holds responsibility. This corresponds directly to the still pending governance question 4: *How do actors behave and perform the process?* While targets and objectives can be tailored to each port ecosystem depending on local policies and funding availability, the definition of governance actions, tasks, and stakeholder responsibilities is more complex.

Based on literature sources [16–21], the most critical factors affecting the development of green-port economies can be grouped into three major categories:

1. Technical concerns

Power supply switching, technology performance, quality, and standards are central issues for port decarbonisation. They involve the management of power generation, voltage and frequency stability, and the safe and efficient integration of multiple systems—vessels, grids, renewable energy sources (RES), hydrogen facilities, and ancillary equipment (e.g., cooling systems, compressors, water demineralisation units). The main bottleneck here is the shortage

of expertise. The lack of skilled personnel, hands-on knowledge, training, and certification often slows down integration and represents a significant additional cost.
To tackle this barrier, it is essential to establish training centres, enhance certification systems, and develop a workforce pipeline of qualified workers to ensure safe and efficient technology deployment.

2. Economic and financial concerns

High investment costs for new facilities and technologies, coupled with significant operating and maintenance costs (for both ships and port equipment), continue to hold back private investors. A major bottleneck lies in the perceived risk that benefits may not sufficiently outweigh the costs compared with conventional fuel-based solutions.

To tackle this barrier, it is essential to reduce technology payback times (ROI), de-risk investments through subsidies, support the end-use market by building infrastructure, and maintain robust funding and incentive programmes.

3. Port administration and management concerns

Port administration involves the coordination of port operations, energy systems, logistics, and maintenance services. These require alignment between the port authority, renewable energy systems, the local power grid, and maritime activities. The bottleneck is the lack of long-term policy visibility and harmonised standards. For example, responsibilities for accident and risk management remain unclear, while the absence of feedback mechanisms and regulatory guidance complicates failure prevention. Furthermore, obtaining permits and certifications for installing new technologies often involves excessive delays.

To address these concerns, it is essential to strengthen governance by establishing clearer import/export policies, delivery strategies, and consolidated master plans. Create enabling infrastructures to attract investment by broadening funding opportunities and aligning stakeholders around common standards and certifications. Most importantly, governance must define decision-making structures—clarifying who makes decisions, who has authority, and who bears accountability.

In summary, barriers in port management are directly related to external governance factors, particularly:

Policies and regulatory systems: Absence of a common governance framework, unclear responsibilities, and fragmented regulations across local, national, and EU levels (covering technical, environmental, safety, import/export, and tax domains).

Financial support systems: Lack of structured funding mechanisms, limited access to subsidies (local, national, EU, or private), insufficient fiscal incentives (e.g., tax reductions), and uncertainty over whether green solutions can deliver clear benefits compared with fossil-based options.

Standards for services and infrastructure: Lack of harmonised technical standards for port infrastructure, power supply systems, port equipment, and ship interfaces, slowing deployment and creating investor risk.

4. Conclusion

This document presents a state-of-the-art overview of current governance actions and outstanding questions in the green hydrogen economy. To provide context, consolidated governance frameworks from the broader energy transition domain are first analysed, followed by the emerging actions and directives of hydrogen-specific organisations.

It is observed that green hydrogen production is increasingly driven by a growing array of institutions and actors, with a clear acceleration since 2022. Many of these organisations aim to stimulate investment demand and market development by mitigating risks and creating enabling conditions. At present, initiatives remain predominantly public-driven, with private stakeholders still hesitant due to cost, infrastructure, and regulatory uncertainties. The EU Parliament has responded by issuing directives and targets to enhance investment security—through certification schemes, infrastructure development, and the use of state aid—and by establishing the European Hydrogen Bank as a dedicated financing mechanism. In parallel, hydrogen-specific organisations have begun to focus their efforts on sustainability, standardisation, and certification.

Nevertheless, these initiatives remain at an early stage and are largely local or regional in scope. The next step will be to move from regional to interregional scale in order to support the formation of a global hydrogen market. In this context, the list of required governance actions remains open-ended. Four priority working areas for governance enhancement can be identified:

1. **End-use applications:** accelerate hydrogen market ramp-up by supporting and scaling diverse end-use activities, many of which are still under development.
2. **Infrastructure creation:** establish logistics frameworks by building local hydrogen networks, and integrating import/export policies, delivery strategies, and infrastructure from central hubs to remote areas.
3. **Socio-economic sustainability:** support investment by scaling production facilities, expanding distribution networks, and reducing risks. This requires addressing financial and technical barriers, lowering costs, and advancing standards and certification.

4. **Actors and responsibilities:** strengthen governance by defining decision-making authority, training skilled personnel, and clarifying roles, responsibilities, and accountability mechanisms.

Furthermore, because the North Sea represents a vast region involving several EU Member States, priorities for hydrogen utilisation and port administration are shaped by diverse local policies. This suggests the need for a generic governance approach adaptable to multiple case studies.

In conclusion, the main issues facing hydrogen-based port development stem from limited visibility on how to manage and optimise the governance process. The most significant barriers are external and systemic, particularly the absence of common policies, harmonised standards and regulations, and well-defined frameworks for services and infrastructure. Addressing these challenges will be essential for ports to fulfil their role as hubs of the emerging hydrogen economy.

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