HARNESSING THE NORTHERN SEAS ENERGY POTENTIAL TO MEET CLIMATE TARGETS

A meta-study of existing system integration studies for the Hydrogen Networks of the Northern Seas (HyNOS)

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Executive summary

The Northern Seas possess significant potential to support Europe's transition to a low-carbon economy, with offshore hydrogen production emerging as a critical enabler. To consolidate fragmented research and provide actionable insights, Hydrogen Networks for the Northern Seas (HyNOS), a group of gas and hydrogen network operators in countries with access to the North, Baltic and Irish Seas, commissioned a meta study conducted by Frontier Economics. This study synthesises existing evidence on offshore hydrogen production in integrated areas – where offshore wind energy is transmitted through both electricity and hydrogen connections – and highlights their role in in the future low-carbon energy system.

Key Findings at a glance

1. **Integrated areas reduce the costs Europe's decarbonisation costs by 5-11 bn € per year out to 2050,** compared to stand-alone electricity configurations that transmit offshore energy directly to shore as electricity for onshore electrolysis or direct electricity use**.** The main drivers are lower transport costs of hydrogen compared to electricity and operational flexibility – allowing the most suitable energy vector to be delivered based on system needs and enabling optimal storage.
2. **Offshore hydrogen** production in **integrated areas** helps **maximise the offshore wind potential.** By 2050, offshore wind capacity in the North Sea could be **88-121 GW higher with integrated areas** compared to stand-alone electricity connections due to cost savings, contributing to achieving the 300 GW target for the North Seas in the Ostend Declaration.
3. **International interconnection of integrated areas** enables **additional cost savings of 1-4 bn € per year** in Europe out to 2050 compared to a point-to-point system. This interconnection can occur via power lines alone or a combination of power lines and hydrogen pipelines, with greater savings expected when both are integrated. Savings result from the optimal use of infrastructure – leveraging variations in wind and solar patterns and demand to direct renewable energy where it is most valuable – and reducing reliance on hydrogen imports from outside Europe.

This meta study confirms that offshore hydrogen production in integrated areas offers significant cost savings, supports renewable energy expansion and contributes to energy security. Realising this potential requires addressing regulatory barriers, encouraging infrastructure investments, and mitigating disincentives affecting hydrogen supply and demand so that Europe can fully harness the Northern Seas' energy potential to achieve its climate goals efficiently and securely.

1 Introduction

The Northern Seas are well positioned to support Europe's transition to a low-carbon economy, with offshore hydrogen production emerging as a key enabler. While numerous studies have explored this potential, their findings vary in scope, assumptions and level of detail, making it difficult to distil clear and actionable insights.

To address this, Hydrogen Networks for the Northern Seas (HyNOS) , a group of gas and hydrogen network operators in countries with access to the North, Baltic and Irish Seas, has commissioned Frontier to conduct a meta-study of existing research. The aim is to synthesise the evidence on the role of offshore hydrogen production at integrated areas – where offshore wind energy is collected with both electricity and hydrogen connections – and provide focused insights to inform discussions on future energy systems and network development.

By consolidating existing knowledge, this study aims to provide a foundation for gas transmission system operators (TSOs) and future hydrogen network operators (HNOs) to communicate a clear narrative and support strategic decision-making.

We have conducted the study in three stages. First, we reviewed existing 21 studies to identify recurring statements on the role of offshore hydrogen production in integrated areas (see list of references at the end for an overview of the studies we reviewed). In the second stage, we analysed these statements in detail, examining the supporting arguments and rationale. Finally, we synthesised the findings into concise messages and a coherent narrative, which are presented in this report.

2 The Northern Seas offer valuable energy potential to support the climate goals of surrounding countries

The European Union (EU), the United Kingdom (UK), and Norway have set ambitious targets to reduce greenhouse gas (GHG) emissions and transition towards low-carbon economies. Both the EU[1] and the UK[2] aim to achieve net-zero GHG emissions by 2050, while Norway[3] targets a 90–95% reduction in emissions below 1990 levels within the same timeframe, positioning itself as a low-emission economy.

Hydrogen and its derivatives are recognised as a strategic enabler to meet these decarbonisation goals. They are seen as a cost-effective solution for reducing emissions in hard-to-electrify sectors, particularly energy-intensive industries and long-distance transport

1 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 on establishing the framework for achieving climate neutrality (European Climate Law), OJ L 243, 9.7.2021, p. 1–17. Available at: EUR-Lex

2 The Climate Change Act 2008 (2050 Target Amendment) Order 2019, No. 1056. Available at: UK Legislation

3 Act relating to Norway's climate targets (Climate Change Act), Section 4. Available at: Lovdata

such as aviation and shipping. Hydrogen is also recognised for its potential long-duration storage, helping to address seasonal variations in renewable energy supply, with production typically higher in summer and demand peaking in winter when solar availability is reduced.

To contribute to the realisation of hydrogen's potential, the following targets have been set:

- The **EU** has set a target of 660 TWh hydrogen supply by 2030, evenly divided between domestic production and imports, supported by 40 GW of installed electrolysis capacity in the EU.[4]
- The **UK** aims to develop 10 GW of low-carbon hydrogen capacity by 2030, with at least half of this derived from electrolysis. [5]
- **Norway** has committed to establishing hydrogen production and use by 2030 as a key component of its strategy to achieve a low-emission economy. [6]

In addition, to contribute to climate and environmental ambitions, Northern Seas countries have pledged substantial offshore wind capacity as outlined in the **Ostend Declaration (2023)**. The declaration sets a target of **120 GW offshore wind capacity by 2030** and **300 GW by 2050**, leveraging the Northern Seas' energy potential to drive decarbonisation and energy security.[7]

Recent energy crises have underscored the economic and geopolitical risks of relying on a limited number of energy suppliers, highlighting the need for a balanced and resilient energy system. Hydrogen production within Europe, supported by offshore wind in the Northern Seas, offers a cost-effective solution.

While imports from regions with lower renewable energy costs may seem attractive, high transportation and processing expenses often make domestic production more competitive. Studies suggest that by 2050, most hydrogen demand will be met regionally, with international trade focused on easier-to-transport derivatives like ammonia. Investing in hydrogen infrastructure linked to Northern Seas wind power can reduce reliance on external supplies, stabilise cost and increase energy security.[8]

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[4] European Commission, 'A hydrogen strategy for a climate-neutral Europe', COM(2020) 301 final, 8 July 2020. Available at: EUR-Lex

[5] HM Government, *British Energy Security Strategy*, 7 April 2022. Available at: GOV.UK

[6] Norwegian Ministry of Petroleum and Energy, *The Norwegian Government's Hydrogen Strategy: Towards a Low Emission Society*, June 2020. Available at: Regjeringen.no

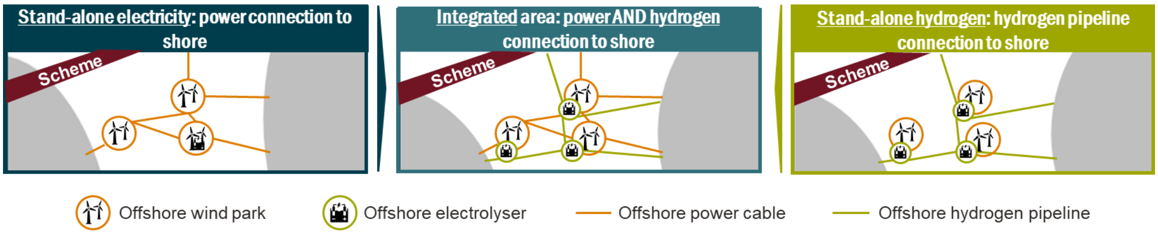
[7] Ostend Declaration on the North Seas as Europe's Green Power Plant, 24 April 2023. Available at: GOV.UK

[8] DNV**,** *Specification of a European Offshore Hydrogen Backbone*, DNV, 2023, pp. 13–20. Available at: https://aquaductus-offshore.de/wp-content/uploads/2023/03/DNV-Study_Specification_of_a_European_Offshore_Hydrogen_Backbone.pdf

3 Offshore hydrogen production at integrated areas contributes to cost savings

Offshore wind energy can be used to produce hydrogen through different infrastructure configurations, as summarised in **Figure 1**. The first is a **stand-alone electricity** configuration, where electricity from offshore wind turbines is transmitted to shore via power lines. The second, a **stand-alone hydrogen configuration** used in parts of the German North Sea,[9,10] involves producing hydrogen offshore and transporting it to shore via a hydrogen pipeline. The third approach, known as an **integrated areas**, combines both methods, enabling transmission through power lines and hydrogen pipelines.

Figure 1 Infrastructure configurations for offshore wind powered hydrogen production



Source: Frontier Economics

Compared to stand-alone electricity configurations, **integrated areas reduce the costs to decarbonise the energy system in Europe by 5-11 bn € per year** (0.7 – 1.5% of total system cost) out to 2050.[11,12] Figure 2 provides a breakdown of the upper end of these cost savings.

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9 Federal Maritime and Hydrographic Agency (BSH), *Site Development Plan 2023*, 2023. Available at: https://www.bsh.de/EN/TOPICS/Offshore/Sectoral_planning/Site_development_plan_2023/_Anlagen/Downloads/English/Site_development_plan_2023.pdf

10 Wind Energy at Sea Act (WindSeeG), as amended by the *Second Act Amending the Wind Energy at Sea Act and Other Provisions*, 2022. Available at: https://www.clearingstelle-eeg-kwkg.de/gesetz/6468

11 Glaum et al. (2024) find 5.4-11.8 bn €/y cost savings in Europe excluding Iceland (0.7 – 1.5% of total costs), most of these in the North Sea. The variation in cost savings depends on factors such as the presence of international interconnections, onshore wind potential, and the scale of the onshore transmission network (see page 21).

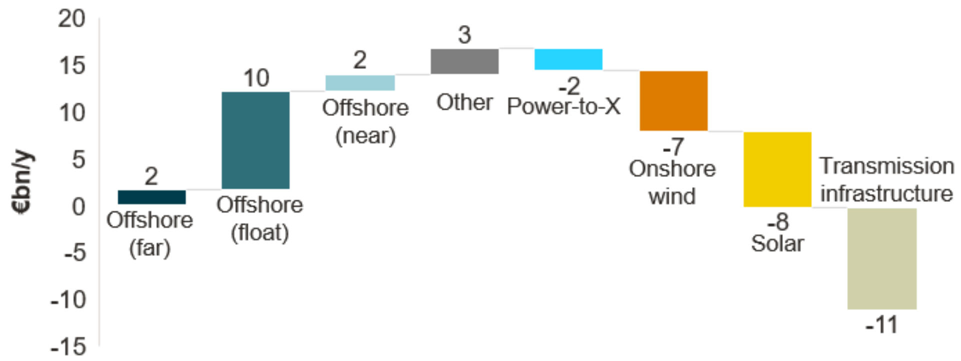
Martínez-Gordon et al. (2022) project even higher annual savings of €6.0–14.9 billion (1.6–2.8% of total costs) for North Sea countries when adopting internationally connected integrated areas instead of stand-alone radial power connections. Their study introduces the North Sea Offshore Grid (NSOG) concept, where offshore wind farms connect to offshore hubs, which are then linked to each other and onshore energy systems.

However, the Martínez-Gordon et al. study does not assess scenarios with integrated areas that lack international interconnections, making it unable to isolate the effects of interconnection from integrated infrastructure design. Given this, we conservatively cite the cost savings due to integrated areas in the range of €5–11 billion per year, while noting that the findings from Martínez-Gordon et al. align with those of Glaum et al., considering the methodological differences between the studies.

12 Gea-Bermúdez et al. (2023), using a different reference scenario—stand-alone hydrogen configurations in the North Sea and most Baltic countries—estimate annual cost savings of €9.4–27.8 billion (4.4–12.8%) (see page 13). However, these results are largely theoretical, as most existing offshore wind farms are already connected to the grid via power lines. For this reason, we do not include them in the headline findings above.

It shows that the higher costs associated with integrated areas – primarily due to the need for additional offshore wind farms – are more than offset by savings onshore, including reduced reliance on onshore photovoltaic and wind capacity, as well as lower transmission infrastructure costs, leading to total net cost savings of 11 bn € per year.

Figure 2 Breakdown of cost savings from integrated areas compared to stand-alone electricity configurations by 2050



Source: *Frontier Economics based on Glaum et al. (2024)*

Operational flexibility is one of the drivers of the cost advantages of integrated infrastructure over stand-alone electricity configuration. When offshore wind plants are connected to shore only through electricity cables, this entails a trade-off in choosing the optimal cable capacity. Any decision involves the risk of either high wind offshore curtailment or very low electricity transmission link utilisation once the investment was done and assets are operational. Allowing the option to generate hydrogen offshore helps to ease this trade-off and supports a more efficient infrastructure setup.[13]

Even if transmission capacity were unlimited, dispatch optimisation between electricity and hydrogen could still deliver system-wide benefits. Retaining the flexibility to transmit offshore power either as electricity or convert it to hydrogen provides added value. For instance, hydrogen offers advantages for mid-to-long-term storage,[14] while electricity remains more competitive for short- term storage.

Transport cost savings represent another driver of the cost advantages offered by integrated areas, complementing the operational flexibility discussed earlier. Singlitico et al. (2021) highlight differences in the Levelised Cost of Hydrogen (LCOH) between offshore hydrogen production in integrated areas and onshore hydrogen production powered by offshore wind

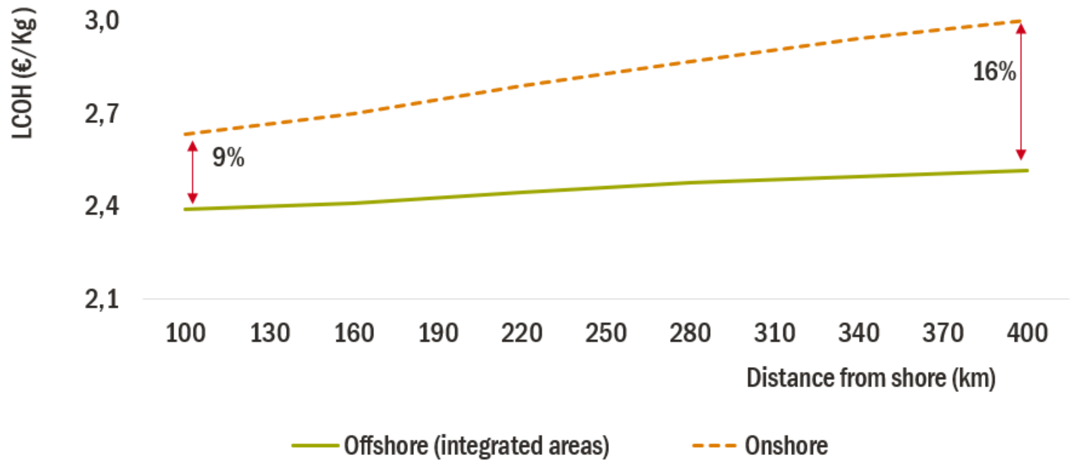
13 Glaum et al. (2024) estimate that integrating offshore hydrogen reduces offshore wind curtailment by half—from 11.38 TWh (0.84% of installed potential) to 6.64 TWh (0.35% of installed potential). See page 16.

14 Fluxys (2024), page 14; Koning et al. (2024), page 2.

Hydrogen's role in energy storage does also become apparent in a scenario analysis presented in Gea-Bermudez et al. (2023). Introducing the possibility to use offshore caverns as hydrogen storage increases the share of offshore hydrogen generation from 0-2% to 10%. See page 10.

electricity that is transported to the onshore electrolysis via a subsea electricity cable. The study finds cost savings of 9–16% when offshore wind energy is prioritised for electrolysis and 3–9% when only excess electricity is used (see Figure 3). These savings depend on the offshore offshore wind park's distance from shore, with observed benefits at distances of 100–400 km.

Figure 3 Levelized cost of offshore wind powered hydrogen: offshore at integrated areas vs onshore



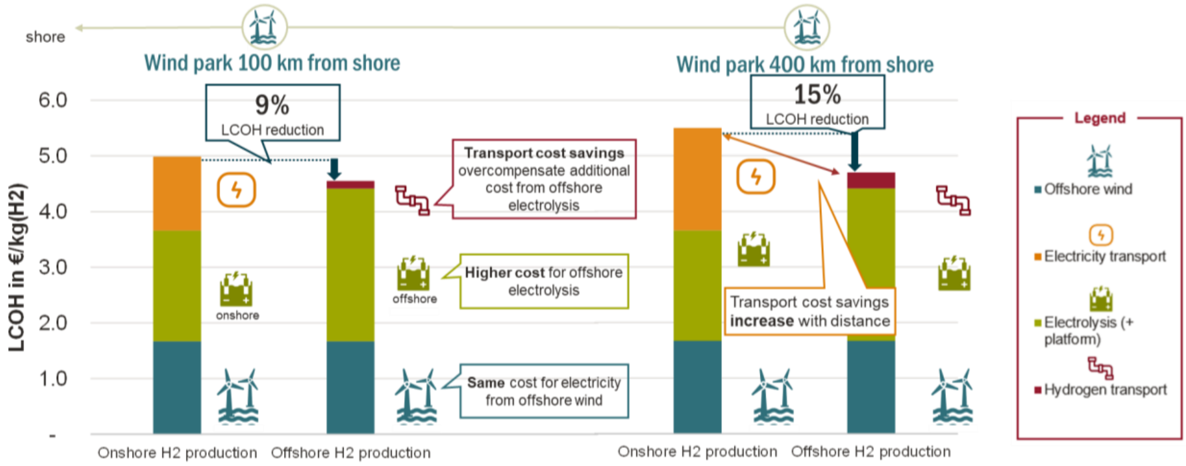
Source: Singlitico et al (2021).

Note: LCOH is median across technologies and for hydrogen-driven operation, giving priority to electrolysers in the use of offshore wind power..

Building on DNV (2023), we estimate similar cost savings of 9–15% when comparing offshore and onshore hydrogen production, assuming stand-alone hydrogen and electricity infrastructure configurations at 100 and 400 km from shore, respectively. These results align with Singlitico et al. (2021) for integrated areas, indicating that hydrogen pipeline cost savings persist even in an integrated infrastructure setup, particularly when offshore wind energy is prioritised for electrolysis rather than direct electricity use.

These findings further suggest that transport cost savings offset the higher capital costs of marine electrolysers (compared to onshore electrolysers) and increase with the distance between wind parks and the shore, as shown in Figure 4.

Figure 4 Comparison of LCOH for hydrogen from offshore wind in 2030



Source: Frontier replication of DNV (2023), based on the assumptions in the appendix of their study (See page 68).

Note: We hold offshore wind and electrolyser costs constant across distance from shore as a simplifying assumption. In practice, factors such as LCOE, full-load hours, and sea depth do not consistently increase with distance, but instead vary depending on specific location.[15]

4 Offshore hydrogen production in integrated areas helps maximise the capacity of offshore wind farms

The studies reviewed indicate that cost efficiencies—or the savings enabled by integrated areas compared to stand-alone electricity configurations—support the deployment of more offshore wind farms in optimal system designs.

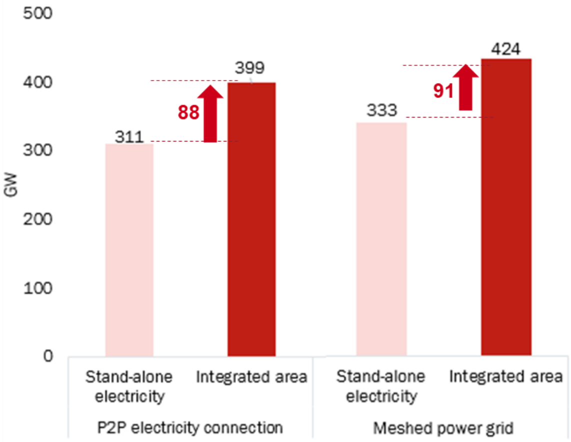
By 2050, offshore wind capacity in the North Sea could be 88 –121 GW higher with integrated areas (see Figure 5), compared to stand-alone electricity connections. This increase would make a valuable contribution towards the 300 GW target for the Northern Seas set out in the Ostend Declaration.

Integrated areas reduce transmission costs and improve operational flexibility, making offshore wind expansion more cost-effective. This allows better use of offshore wind's higher full load hours compared to onshore renewables, maximising energy generation and system efficiency.

15 See the heatmaps at the Danish Energy Agency. 'Offshore Wind Potential in the North Sea. Long-run supply curves and cross-country competitiveness' (2022) https://ens.dk/media/2414/download

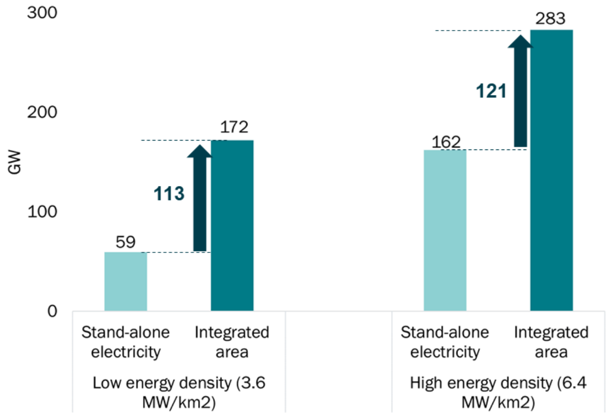
Figure 5 Offshore wind capacity in the North Sea by 2050

a) All North Sea



Source: *Glaum et al (2024) page 16.*

b) Far North Sea (over 80 km from shore)



Source: *Martínez-Gordon et al (2022) pages 15,16 and 19.*

5 International interconnection of integrated areas enables additional cost savings

International interconnection of integrated areas enables **additional cost savings of €1–4 billion per year** (0.2–0.5% of total system costs) in Europe, with expected higher savings observed when both power lines and hydrogen pipelines are internationally interconnected rather than power lines alone.[16,17] International power connections of integrated areas reduce overall costs by:

- **Optimising resource utilisation** – variations in wind patterns and demand across the North Seas can be exploited, allowing electricity to be directed to areas where it is most valuable.
- **Improving transmission infrastructure utilisation** – greater flexibility through interconnections reduces the need for redundancies onshore, thereby increasing the efficiency of transmission lines that deliver offshore electricity to shore.

These advantages promote the development of offshore wind farms further from shore. While such sites are more costly to integrate into a single country's grid, they are less expensive to incorporate into an internationally connected system. For instance, NSWPH (2024) estimates

16 NSWPH (2024) The study finds that integrating offshore energy hubs via power lines (in the reference scenario) reduces system costs by 1 bn € in 2050 relative to a situation where these hubs have radial power connections. See page 20.

17 Glaum et al. (2024) estimate cost savings of 15 bn €/y with a meshed power and hydrogen grids, where "meshed" refers to internationally interconnection. This is compared to a reference scenario with point-to-point power connections and no offshore hydrogen grid. They also identify 11 bn €/y savings from integrated areas with point-to-point power and hydrogen connections. This implies that 4 bn €/y cost savings are specifically attributable to international interconnection (see page 14).

that offshore wind capacity is 31 GW higher with international power line interconnections than with power radial connections alone.[18]

The expanded deployment of offshore wind power also supports domestic hydrogen production, reducing reliance on hydrogen imports from outside Europe, which would otherwise be the next cheapest source. In this way, international connections contribute to greater energy independence within Europe.

6 Enabling offshore hydrogen production at internationally interconnected integrated areas requires addressing regulatory and market challenges

This meta study confirms the cost savings of offshore hydrogen production in integrated areas to support Europe's climate goals. To realise these savings and further benefits such increased energy independency in Europe, challenges related to **regulation**, infrastructure **investment**, and **incentives** for **supply and demand** need to be addressed. While this study focuses on the role of offshore hydrogen production rather than the regulatory framework, a number of recommendations can be outlined to unlock the cost efficiency and energy security benefits of internationally interconnected integrated areas.

Regulatory fragmentation and the **absence of harmonised standards** across Northern Seas countries hinder coordinated planning and the development of international interconnections. Addressing these barriers requires harmonising regulations and technical standards to ensure compatibility and streamline development. A coordinated long-term strategy with clear targets is needed to guide infrastructure planning and investment. Additionally, establishing a policy framework for international connections - including rules for investment models, ownership structures, and market operation (e.g., bidding zones) - would further support the development of international interconnections.[19]

Market failures also create **barriers to investment** in **hydrogen transport and storage infrastructure**. These include the first-mover disadvantage, where early investments carry risks due to learning and scale externalities, and coordination failures, as infrastructure must be developed ahead of supply and demand growth. To overcome these obstacles, de-risking mechanisms can be introduced, including Regulated Asset Base (RAB) models with subsidies to address early-phase revenue gaps, intertemporal cost allocation to spread costs over time by delaying depreciation, and cross-subsidisation between natural gas and hydrogen infrastructure, although the latter approach is discouraged by the EU.

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18 NSWPH (2024), Pathway study 2.0, page 155

19 North Sea Wind Power Hub (2024), *Pathway Study 2.0*, p. 21. Available at: https://northseawindpowerhub.eu/files/media/document/2024.06.24_NSWPH%20Pathway%20Study%202.0.pdf

Further challenges arise from market failures that hinder the growth of hydrogen **supply and demand**. Supply faces learning and innovation externalities that keep private investment below socially optimal levels. Demand is weakened by negative externalities from unpriced carbon emissions and information gaps, such as limited familiarity with hydrogen technologies. Policies to bridge the cost gap between hydrogen and conventional energy sources can help stimulate both. Options include support mechanisms or setting hydrogen production and consumption targets to drive market growth and investor confidence.

By implementing these policy measures, governments can address the challenges to offshore hydrogen production at internationally interconnected integrated areas. This approach will help unlock the cost efficiencies of this infrastructure configuration and its contribution to energy security.

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