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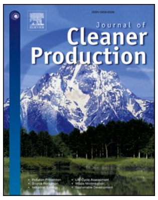

Unveiling complexity of hydrogen integration: A multi-faceted exploration of challenges in the Dutch context

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ABSTRACT

As the transition to sustainable energy intensifies, hydrogen emerges as a pivotal medium in mitigating climate change and improving energy security. While its applicability across various sectors is undeniable, its integration into established energy systems presents multifaceted challenges. This study investigates the complexities of integrating hydrogen into the Netherlands' energy systems. Beyond technological advancements, the successful design and rollout of a hydrogen supply chain require coordination and collaboration among a myriad of stakeholders. Through a mixed-methods approach, this study combines findings from a broad literature review, policy document analyses, evaluation of 59 field projects, and engaging dialogues with 33 key stakeholders from different sectors. This investigation led to the identification and categorization of key players in the Dutch hydrogen sector, revealing their interconnected roles and the challenges encountered in the hydrogen integration process. The study further categorized the identified challenges faced by stakeholders into five core domains: technical, infrastructural (including supply chain), socioeconomic, environmental, and institutional, with associated factors. Prominent challenges include transportation infrastructure upgrades, high initial costs and scalability, effective storage methods, safety and cybersecurity measures, storage and distribution infrastructure, security of supply, and public acceptance. This study contributes to the hydrogen integration discourse, offering insights for academics, industry, and policymakers. Its detailed stakeholder analysis, holistic categorization of challenges across five domains, and a stakeholder-centric approach grounded in real-world dialogues offer applicable frameworks beyond its primary context. In this vein, it guides future research and decisions, and its approach is adaptable for different regions or sectors, emphasizing comprehensive transition strategies.

1. Introduction

The changing energy landscape, driven by climate change and energy security concerns, highlights the need for a global shift toward sustainable energy resources (Parra et al., 2019). The European Council's 2030 Climate and Energy Policy Framework aspires to cut domestic greenhouse gas (GHG) emissions by 55% and augment the role of hydrogen and renewables (European Commission, 2022). Hydrogen stands out as a potential solution for decarbonizing hard-to-abate sectors.

Hydrogen, predominantly used in the chemical and petrochemical industries, has localized consumption due to storage and transportation challenges. This has often led to bilateral contracts wherein producers and consumers are located in the same or nearby industrial hubs (Abdalla et al., 2018). The growth of green hydrogen, produced via renewable electrolysis, has expanded its utility across different energy sectors, signaling the need for revamped infrastructure and cross-sectoral coordination (Smit et al., 2007).

However, integration of hydrogen into existing energy systems introduces complex challenges, necessitating substantial investments in technological innovation and infrastructure for production, storage, transport, and distribution. This paradigm shift in energy systems incurs uncertainties for stakeholders, particularly concerning design and implementation of an emergent hydrogen supply chain (Schlund et al., 2022).

The literature has explored various facets of the hydrogen economy, such as production strategies, transportation, distribution logistics, and the technologies underpinning its cross-sectoral integration (da Silva César et al., 2019; Haghi et al., 2018; Murray et al., 2008). However, comprehensive analyses of hydrogen integration, considering inherent

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interdependencies and stakeholder roles in shaping decision-making, are still limited. This oversight can lead to fragmented strategies and missed collaboration opportunities.

This study primarily aims to explore the complexities involved in integration of hydrogen into existing energy systems in the Netherlands. Recognizing that successful hydrogen integration extends beyond technological solutions, it mandates the coordination of stakeholders across various sectors. The first objective is to identify key stakeholders in the Dutch hydrogen sector, understand their interrelated roles, and establish a detailed stakeholder taxonomy. The second objective is to pinpoint and categorize the challenges of hydrogen integration, as perceived by the stakeholders.

The Netherlands presents an intriguing case study for hydrogen integration due to its strategic geographic positioning and well-established infrastructure (Rentier et al., 2023; Schenk et al., 2007). This progress is fueled by multi-level regulatory initiatives, which have led the country to adopt a decentralized approach, putting an emphasis on sector-specific solutions, bottom-up decision-making, and fostering innovative partnerships (Netherlands Enterprise Agency, 2023). This multifaceted strategy, underpinned by shared knowledge, collective projects, and strategic investments, aims to balance financial and developmental risks. Such an approach is crucial in maintaining a consistent trajectory of innovation and in guiding these innovations across the challenging phases often referred to as the ‘valley of death’ (Odenweller et al., 2022).

Stakeholder dynamics within the Dutch context, involving government entities, industries, research institutions, and financial and environmental organizations, have been insufficiently explored in existing literature. These stakeholders form a complex network within both competitive and regulated realms and their mutual reliance fosters a vibrant ecosystem at the crossroads of policy, technology, finance, and implementation (Hasankhani et al., 2023). Within this sphere, relationships are dynamic, evolving with shifts in interests, priorities, technological innovations, and market fluctuations. The dynamism highlights that successful adoption and integration go beyond linear decision-making processes, relying instead on dynamic stakeholder coordination and collaboration.

The study began with a comprehensive literature review that highlighted the challenges in supply chain logistics, infrastructure, and stakeholder coordination in the broader context. Building on this groundwork, Dutch policy frameworks and the emerging hydrogen projects were analyzed. This exploration led to the identification of key stakeholders in the Dutch hydrogen sector, and their interconnected roles, and resulted in a detailed stakeholder taxonomy. Dialogues with selected stakeholders were initiated to gain first-hand insights into the challenges of hydrogen integration. These insights were then systematically analyzed, categorizing challenges into five key areas: technical, infrastructural (with a focus on supply chain complexities), socioeconomic, environmental, and institutional. Each domain was further dissected to understand the factors influencing the hydrogen landscape in the Netherlands.

This exploration contributes to the existing academic discourse on hydrogen integration, providing insights beneficial for academics, industry stakeholders, and policymakers. While its primary focus is the Netherlands, its detailed stakeholder taxonomy, holistic categorization of challenges across five domains, and a stakeholder-centric approach grounded in real-world dialogues present applicable frameworks. The identified challenges and insights promise to inform future research and drive informed decision-making across industries and policy domains. Other regions or sectors can customize these frameworks to their specific contexts during technological integration, it is important to have strategies that are both flexible and consider all aspects of the transition process.

Following this introduction, Section 2 outlines study design, data collection, and analysis methods. Results are delineated in Section 3 followed by a discussion in Section 4. Concluding remarks and avenues for future research are encapsulated in Section 5.

2. Material and methods

This study explores the complexities of integrating hydrogen into the Netherlands' energy systems, emphasizing the coordination of stakeholders across various sectors. The approach is based on a systematic three-stage exploration, as illustrated in Fig. 1. The primary objective is to identify and categorize key stakeholders in the Dutch hydrogen sector. This leads to a comprehensive taxonomy that clarifies their interconnected roles. This objective is accomplished in the first two stages. The secondary objective centers on understanding the challenges of hydrogen integration by analyzing them through the perspective of the identified stakeholders in the third stage.

In the initial stage, a review of the academic literature was conducted by searching Scopus for terms such as “hydrogen supply chain,” “hydrogen infrastructure,” and “stakeholder” or “stakeholder analysis.” Of the 122 articles and grey literature items identified from 2003 to 2023, 100 were particularly relevant. The analysis of these studies provided insight into the main themes surrounding hydrogen integration as detailed in Section 3.1 which then guided the following stages of the study.

In the second stage, a deeper dive into the stakeholder dynamics within the Dutch hydrogen sector was undertaken. Guided by the International Energy Agency's database (IEA, 2022), 59 distinct real-world projects were selected from an initial 81. These ranged from hydrogen-powered residential areas to large-scale offshore wind power collaborations. Among the 420 stakeholders identified, 264 were distinct, and their validation involved cross-referencing with project websites and official announcements. Using a selection of policy documents (Ministry of Economic Affairs and Climate Policy, 2020; Netherlands Enterprise Agency, 2023), insights into stakeholders' roles, as well as strategies, and the regulations shaping the sector were extracted.

Stakeholders range from government entities, regulatory bodies, and local municipalities managing policy and compliance, to industry players such as energy producers, suppliers, and technology providers, as well as research and environmental institutions. While government bodies mainly focus on compliance, safety, and macroeconomic benefits, industry players are driven by profitability, market expansion, and technological advancement. These differing interests create a dynamic landscape of cooperation, competition, and negotiation, necessitating a detailed analysis to understand challenges and pathways to hydrogen integration.

The development of stakeholder taxonomies was grounded in the comprehensive analysis of previous literature, notably studies of introducing new energy solutions in Germany (Schlund et al., 2022) and blending energy modalities in Denmark (Enevoldsen et al., 2014). Their frameworks provided a foundational analytical structure, which was adapted to the specific context of the Dutch hydrogen sector. This adaptation involved several iterative processes, including cross-referencing gathered data with the existing frameworks, customizing parameters to reflect the unique Dutch context, and validating these categories through expert consultations, ultimately resulting in the creation of Table 1 in Section 3.2. In instances where a stakeholder's specific role within a project was ambiguous, such as a company both producing electricity and offering energy services, they were classified based on their primary activity.

In the third stage, dialogues with stakeholders and experts from select projects took place. The rationale behind these dialogues rested on two main research principles. Firstly, there was an aim to include a variety of decision-makers from different sectors to encapsulate the multifaceted challenges of hydrogen integration. To achieve this, the project dataset was analyzed to identify involved organizations. From this analysis, the most active participants from each sector were chosen for engagement. To further diversify the perspectives and insights, a

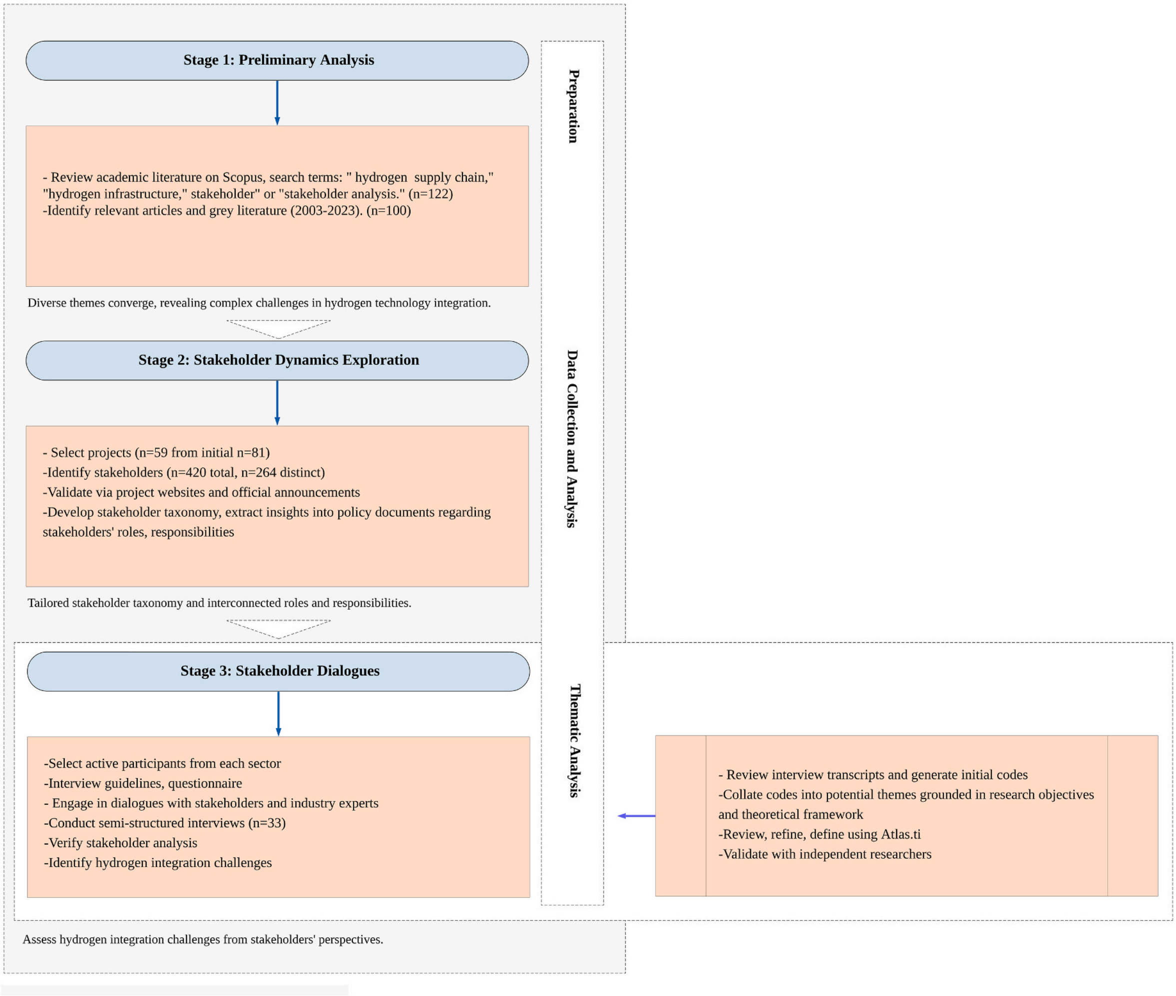

Fig. 1. Procedure for application of a three-stage systematic approach.

snowball sampling method was implemented. This method started with primary contacts and expanded based on their recommendations, encompassing a range of stakeholders from government representatives to industry experts. Secondly, the study adhered to the 'data saturation' principle (Marshall et al., 2013), recognizing that after a specific threshold, additional interviews would no longer yield new insights. In this case, that threshold was met after 33 interviews. The method employed was semi-structured interviews, designed to validate the preliminary stakeholder analysis and pinpoint challenges within the Dutch hydrogen sectors.

A thematic analysis of interview transcripts began by generating initial codes inductively. Drawing on insights from prior analyses, especially a comprehensive literature review, these codes—reflecting the fundamental elements of the raw data—were grouped into potential themes. An iterative process of reviewing, refining, and defining themes was followed, ensuring they accurately represented the dataset. Using Atlas. ti for analysis, themes were validated by two researchers for improved validity. Upon the systematic dissection of the challenges identified through thematic analysis, these findings were synthesized into a visual format to offer a concise representation of the data. Fig. 2, presented in Section 3.3, illustrates the frequency at which each challenge was cited by stakeholders, thereby spotlighting the most prevalent concerns within the sector (see Fig. 3).

Findings spotlighted five key areas: technical, infrastructural (including supply chain), socioeconomic, environmental, and institutional along with their related factors. It becomes clear challenges are not solely technological; they extend to decision-making entities influenced by societal norms, or what is referred to as 'institutions' (Lukszo and Farahani, 2021). Thus, the effective integration of hydrogen into current systems requires not only the modular design of technical components but also advanced infrastructure technologies and a coordinated supply chain (Reuβ et al., 2019). This process of integration has the potential to disrupt existing businesses, introducing new stakeholders while necessitating new collaborations, thus creating decision-making uncertainties and potential conflicts. Refer to Appendices A-C for a detailed version of the material and methods.

3. Results

In this section, the findings from the multi-stage study are presented, and divided into three main parts, each corresponding to the stages of the study approach. After establishing a broad understanding of the hydrogen landscape through the literature review (Section 3.1.) the study pivoted to collecting data from real-world projects, concluding with a tailored taxonomy of stakeholders and interconnected roles (Section 3.2.). Section 3.3. outlines the hydrogen integration challenges in the Dutch sector, as perceived by stakeholders, in line with the secondary objective of exploring the intricacies of hydrogen integration.

3.1. *Explorative literature analysis*

In the study of research papers, six overarching themes emerged. First, there is a marked shift towards more sustainable forms of energy, driven by the imperative to cut CO2 emissions and this trend aligns with

Table 1
A holistic view of the stakeholders, presenting their categories and roles.

Number	Stakeholder Categories	Stakeholder Name	Stakeholder Role
1	Primary Producers and Suppliers	Petrochemical Industries	Produce hydrogen as a byproduct in large-scale chemical processes such as fertilizer or polymer production.
		Chemical Industries	Involved in various hydrogen production methods, including electrolysis and steam methane reforming.
		Energy Utilities (Gas, Power)	Incorporate hydrogen into their energy portfolios for electricity generation or energy storage.
		Renewable Energy Provider	Utilize renewable energy sources like on and offshore wind, solar, biomass, and geothermal to produce green hydrogen through electrolysis.
		Oil and Gas Suppliers	Produce hydrogen as a byproduct of operations like steam methane reforming.
2	Technology and Service Providers	Hydrogen Technology Providers	Develop crucial technologies (electrolyzers, fuel cells, storage systems, storage tanks, hydrogen compressors, and other necessary equipment) for the production, distribution, and use of hydrogen.
		Public and Private Research and Development Institutions	Conduct essential R&D to advance hydrogen technology.
		Equipment and Component Manufacturers	Specialize in the design and manufacturing of hydrogen-specific equipment, components, and systems.
		Engineering, and Technical Service Providers	Provide expertise and services to design, plan, install, and maintain hydrogen technologies and infrastructures.
		Startups and Small Enterprises	Develop innovative technologies and solutions for the hydrogen industry.
		Information and Communications Technology (ICT) and Automation providers	Providing ICT solutions for hydrogen supply chain control and automation.
3	Infrastructure Providers for Storage and Distribution	Power and Gas Network Operators	Manage the infrastructure for delivering energy supplies, including hydrogen.
		Supply Chain Logistics	Manage the entire supply chain, ensuring efficient and timely delivery of hydrogen from producers to end users.
		Storage Providers (material based, physical)	Manage the large-scale storage of hydrogen using a variety of methods such as salt caverns, depleted oil & gas reservoirs.
		Seaport Authorities	Supervise port activities, crucial for importing and exporting hydrogen.
		Transportation Companies	Handle the logistics for long-distance hydrogen transport.
		Hydrogen Infrastructure Accelerators (HIA)	Provide strategic support, funding, and expertise to expedite the implementation of hydrogen infrastructure projects.
		Construction Companies, Housing Associations	Build the physical infrastructure necessary for hydrogen production, storage, and distribution.
		Project Developers	Plan and manage hydrogen-related projects.
		Energy Aggregators (Energy Hub Operators)	Aggregate the demand or supply of hydrogen energy among customers, playing a role in balancing and optimizing energy markets.
		Fuel Station Operators (Mobile, Stationary)	Run stations where hydrogen can be dispensed for use in fuel cell vehicles and other applications.
		Regional fuel suppliers	Distribute hydrogen within specific geographical regions.
		Hydrogen Retailers	Sell hydrogen to end users.
		Energy Retailers	Distribute hydrogen to end users
4	End-Use	Mobility sector (Heavy-light duty vehicles buses, shipping, aviation)	Employs hydrogen as a fuel source in vehicles, ships, aircraft, trucks, and heavy machinery.
		Petroleum Refining	Utilizes hydrogen to remove impurities from crude oil.
		Industries (Steel, cement, glass, industrial gas)	Employs hydrogen as a feedstock or energy source in their processes.
		Semiconductor	Uses hydrogen in manufacturing processes to provide ultra-clean environments and for etching.
		Pharmaceutical Industry	Employs hydrogen in various stages of drug production and research, including synthesis of chemical compounds and powering manufacturing plants.
		Agriculture	Uses hydrogen for energy needs, potentially for

(continued on next page)

Table 1 (*continued*)

Number	Stakeholder Categories	Stakeholder Name	Stakeholder Role
			producing fertilizers, or powering machinery.
		Food Industry	Uses hydrogen for energy generation or in waste-to-energy solutions using organic waste.
		Water Treatment	Produces hydrogen from wastewater through electrolysis, providing a clean energy source.
		Waste Management	Uses hydrogen for energy needs or produces it from organic waste via waste-to-energy solutions.
		Built Environment	Utilizes hydrogen for heating and power generation in historical, residential, and commercial buildings, local communities, and islands.
		Energy Cooperatives	Use hydrogen as a power source or feedstock.
		Private Consumers	Could use hydrogen for various energy needs.
5	Intermediaries	Industry Associations	Represent the interests of various groups within the hydrogen industry.
		Consultancy and advisory firms	Provide expert advice and guidance on various aspects of hydrogen infrastructure integration and management.
		Safety and Regulatory Service Providers	Ensuring safe and compliant hydrogen technology operation.
		Certification Organizations for Hydrogen Facilities	Validate and certify the safety, performance, and quality of hydrogen technologies and facilities.
		Environmental and Resource Management	Assess and manage the environmental impact of hydrogen technologies.
		Water Management	Involved in managing water resources.
		Partnership Initiatives	Collaborative stakeholders pursuing shared hydrogen goals.
		Banks and Financial Institutions	Provide financial support for hydrogen projects, such as loans or investment.
		Institutional Investors (Pension Funds, Insurance Companies, etc.)	Pool money to purchase securities, real property, and other investment assets, potentially including stakes in hydrogen-related companies or projects.
		Legal Firms	Handle legal aspects like contracts, permits, patents, compliance with regulations, etc.
		Social Impact and Advocacy, NGOs	Advocating, educating, recommending policies, and researching hydrogen energy promotion.
6	Policy and Regulatory Authorities	Policy Makers, Regulators, and Government on Different Scales	Shape the hydrogen industry through policies, regulations, and incentives.
7	Research and Education	Research and development -Training and Skills Development	Advancing hydrogen tech and training professionals.

the increasing interest in the hydrogen production (Chandran and Purayil, 2022; Hammerstrom et al., 2022; Saffron, 2022). The second theme delved into the technological advances that are expanding hydrogen's potential most notably in these studies, a clear focus on Fuel Cell Electric Vehicles (FCEVs) (Keles et al., 2008; Küffner, 2022; Saxena and Yadav, 2023) and hydrogen as a storage medium for renewables exits (Hassan et al., 2023; Huang et al., 2022). An emerging market for mobile fuel cells suggests their use in off-grid solutions (Li and Ogden, 2011; Maestre et al., 2022; Zhou and Zhou, 2023). Yet, challenges are around the costs of production itself and technology, storage, infrastructure, and efficiency, along with concerns about safety, environmental impact, and competition from other technologies (Egyedi and Spirco, 2011; Köhler et al., 2010; Lopez Jaramillo et al., 2021; Viesi et al., 2017). Third, regarding the infrastructure and supply chain challenges; consisting of production, transportation, distribution, and end-use subsystems, existing setups might support large-scale hydrogen integration and be less optimal for smaller-scale projects in the immediate future (Kumar et al., 2023; Yang et al., 2020). Different regions are launching pilot projects and forming collaborations to strengthen their strategic placement of both technology and infrastructure in sectors pushing for decarbonization. This underscores the technology and infrastructure's crucial role on both the local and international levels (Han and Kim, 2019; Madsen and Andersen, 2010; Stiller et al., 2008).

Fourth, there is a strong emphasis on the socioeconomic implications of hydrogen adoption. Notably, key sectors such as grid operators, heavy vehicle manufacturers, and industries like aviation and shipping, have displayed keen interest in integrating hydrogen at a grand scale. Yet, its embrace for domestic purposes and personal transportation lags behind (Murray et al., 2008; Palies, 2022; Schlund et al., 2022; Shardeo and Sarkar, 2023; Vergragt, 2006). While primary market players are centered on the core market dynamics, external entities like Non-Governmental Organizations (NGOs) and public institutions wield considerable influence over the market's trajectory. These bodies highlight the myriad factors that shape public opinion on hydrogen adoption (Emodi et al., 2021; Gordon et al., 2022; Harichandan and Kar, 2023; Schönauer and Glanz, 2022). In this vein, coordination among multiple stakeholder groups necessitates transparent communication to prevent disparities in the cost-benefit distribution. The fifth, environmental implications of hydrogen such as CO2 reduction potential, and broader resource utilization considerations are coming to the forefront (Gray et al., 2022; Ocko and Hamburg, 2022; Swennenhuis et al., 2022). Lastly, the emerging hydrogen sector is further shaped by dynamic policy decisions and regional and sectoral transition strategies aimed at realizing ambitious objectives (Bataille, 2020; Haghi et al., 2018; Hisschemöller and Bode, 2011).

The diverse themes emerging from literature analysis converge to form a complex landscape that cannot be navigated in isolation. The urgency of sustainable energy drives hydrogen technology advances, yet this is gated by cost and infrastructure challenges that stem from and exacerbate supply chain limitations. While technological advances show promise, their true potential is bottlenecked by supply chain constraints

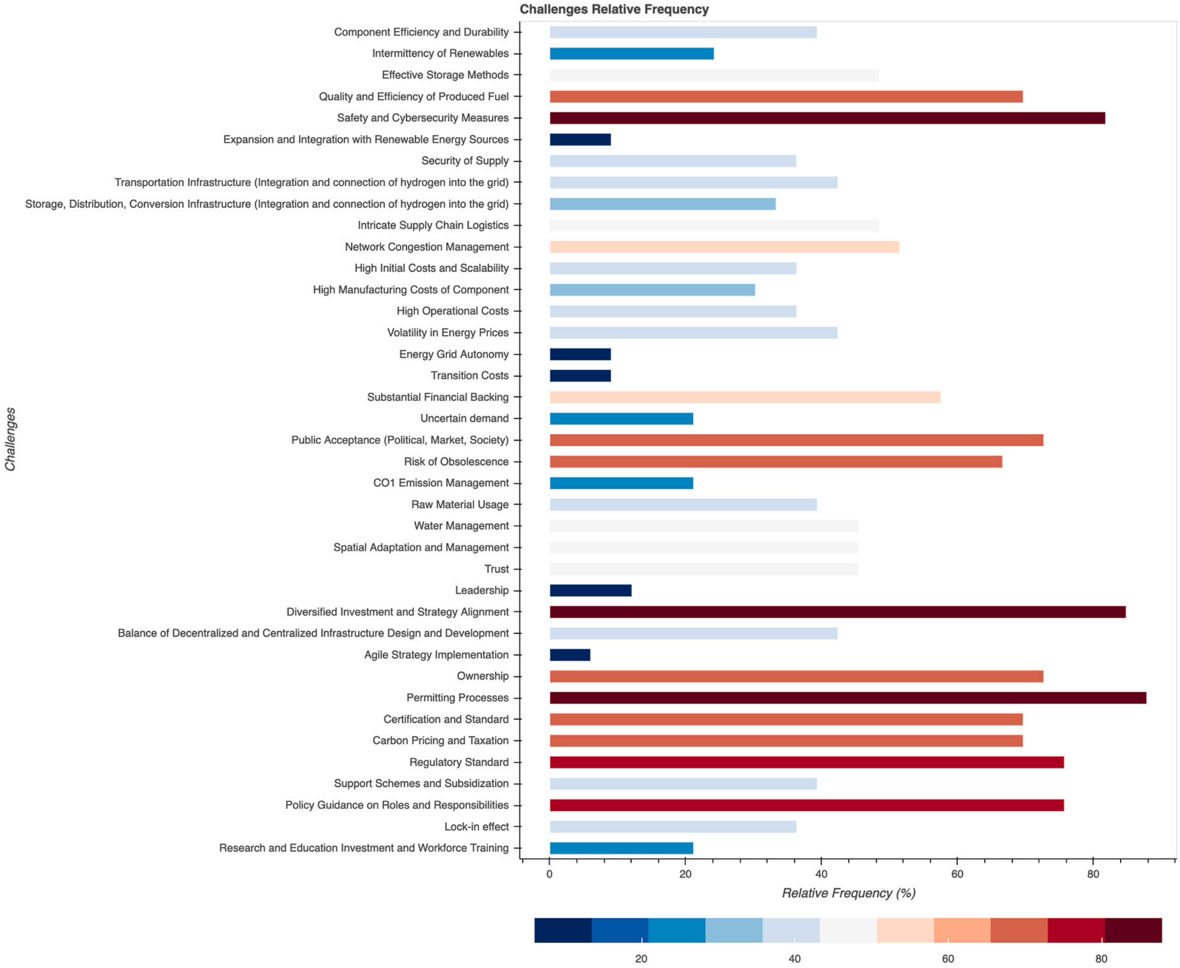

Fig. 2. Relative frequency of challenges based on interviews.

that are currently too rigid to adapt to smaller, more localized needs. Meanwhile, the active participation of a broad array of stakeholders adds another layer of complexity, shaping market dynamics, public perception, and policy frameworks. This vast, interrelated ecosystem reveals a tension between macro-level ambitions for hydrogen and the micro-level realities of its integration across sectors and stakeholder groups.

3.2. Stakeholder identification and categorization in the Dutch hydrogen sector

Building on the objective to comprehensively map the key stakeholders in the Dutch hydrogen sector, the analysis identified 264 distinct entities, categorized into seven main groups as detailed in Table 1. These categories include: “Primary Producers and Suppliers,” “Infrastructure, Storage and Distribution,” “Intermediaries,” “Technology and Service Providers,” “End-Use,” “Policy Makers and Regulators,” and “Research and Education.” Emerging roles within these categories see the energy industry stepping up as a significant hydrogen producer and supplier. Technology and R&D institutions lead the way with innovations in hydrogen production, storage, and transportation, while manufacturers cater to specific industry requirements. Network operators, seaports, and storage providers lay down the foundation of the hydrogen infrastructure, and distributors such as fuel stations drive the growth in distribution. Partnership initiatives act as vital intermediaries, bridging the gaps between different entities like producers, consumers, and regulators, and stimulating collaborations in the hydrogen ecosystem that cater to areas like mobility, heavy industry, and agriculture.

3.3. Analysis of stakeholder challenges in hydrogen integration

Engaging in dialogues with selected stakeholders provided first-hand insights into contextual challenges, aligning with the objective of understanding the intricacies of hydrogen integration. The thematic analysis of challenges drew upon data obtained through semi-structured interviews and focus groups that originated from these dialogues. This approach contributed significantly to the systemic understanding of these challenges. Occasionally, stakeholder inputs posed ambiguities, requiring the use of technological infrastructure and supply chain logistics structure to clarify relations.

Primary Hydrogen Producers and Suppliers (Category 1), primarily operate within traditional sectors like petrochemical and oil industries, relying heavily on Steam Methane Reforming (SMR) for hydrogen production. However, regulatory shifts are increasingly nudging these industries towards adopting cleaner alternatives, such as green hydrogen and Carbon Capture and Storage (CCS) (Flamme et al., 2019). As efforts to verify and monitor the sustainability of energy sources grow, there is a notable move towards green hydrogen certificates, mirroring the model of Renewable Energy Certificates (RECs) (Van de Graaf et al., 2020). However, in the absence of governmental support mechanisms or proper CO2 abatement costs, there is a risk of reduced investment in clean production and a lock-in effect. As highlighted in interview 25, *“Without addressing transition costs, industries might shut down or relocate where costs are cheaper.”*

Green hydrogen’s progress relies on the expansion of large-scale renewables, including onshore and offshore wind energy yet faces challenges related to underdeveloped regulatory frameworks and public

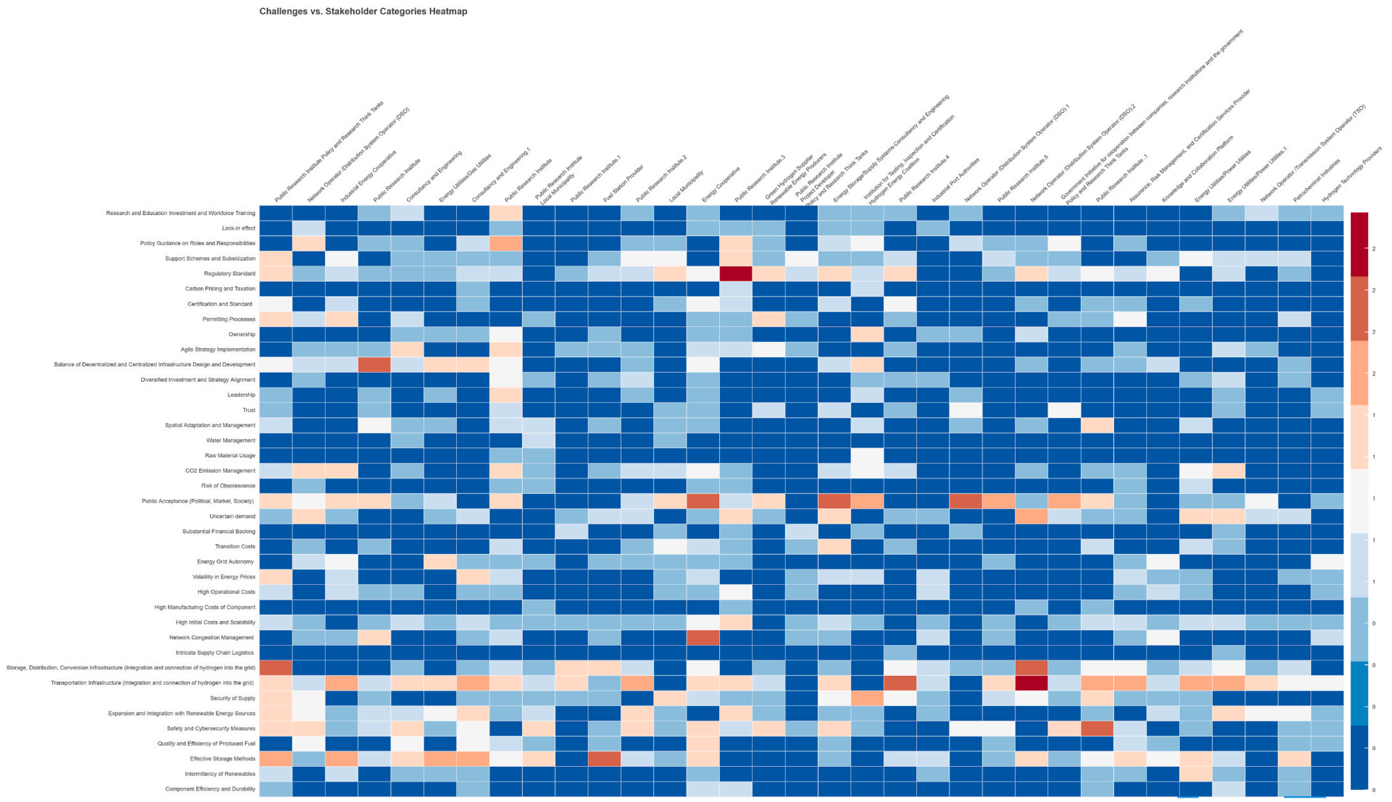

Fig. 3. Challenges vs. Stakeholder categories Heatmap (Based on Interviews).

acceptance. As noted in interview 16, *"The Netherlands' permitting process can inflate costs and extended timelines."* The regulatory frameworks promote local green hydrogen production as a means of ensuring long-term acceptability and supply security. However, this approach presents challenges in terms of import capacity requirements, local production expenses, and the demand for substantial infrastructure investments (interview 1). In the hydrogen supply, four main electricity methods exist direct renewable energy connection, supply from electricity firms, wholesale electricity market, and hybrids (Parra et al., 2017). As stakeholders lean towards greener methods, challenges like intermittent renewable energy, limited capacity (Agnolucci, 2007), effective storage solutions (Hassan et al., 2023), and supply security, all contribute to high initial costs and scalability dilemmas. Analyzing the costs of hydrogen energy systems requires a comprehensive assessment of both Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). The selection of an electricity supply source is a critical factor influencing the economic feasibility of these systems, and this decision is further complicated by the volatile electricity cost.

Hydrogen technology and service providers (Category 2), include a diverse group, from tech providers, manufacturers, research institutions, and start-ups, to engineering and ICT firms. Through incentives and strategic partnerships, they advance hydrogen technologies, such as various electrolysis methods, storage solutions, and fuel cell systems. Scaling of hydrogen technologies from laboratory to commercial scale presents challenges including high equipment and infrastructure costs, efficiency and durability of multiple components under intense operating conditions, and the need for raw materials like precious metals for catalysts and membranes leading to higher manufacturing costs (Wang, 2015). Further, securing a reliable and cost-effective supply chain for raw materials, components, and equipment is vulnerable to disruptions. As hydrogen applications diversify, an all-encompassing optimization approach—combining software, hardware, and connectivity changes—becomes vital to enhance fuel purity, operational efficiency, and safety (Baraldi et al., 2017; Kashkarov et al., 2020). Considering the flammability of hydrogen, it is imperative to reach a consensus on safety and cybersecurity measures and establish certificates and standards for its handling, storage, and transportation during the integration process (López et al., 2006). As pointed out in interview 27, *"Despite the minor technical differences when switching from gas to hydrogen, safety is crucial, we need to ensure reliability by collecting and sharing data."*

Establishing a hydrogen network demands the collaboration of diverse infrastructure providers responsible for transport, storage, and distribution systems (Category 3). These stakeholders include power and gas operators, logistics entities, storage providers, and port authorities. Additionally, Hydrogen Infrastructure Accelerators (HIA), and emerging distributors play critical roles in the expansion of this network. The network's complexity lies in syncing production locales with demand and storage hubs and integrating hydrogen into the existing energy grids, with challenges like network congestion and demanded energy autonomy (Scorzelli et al., 2023). A notable trend is the drive to strike a balance between centralized and decentralized infrastructure deployment. This shift stems from pipeline development delays, the need to establish connection points, revenue generation, and optimizing asset use (Hisschemöller and Bode, 2011). Communication gaps with network operators have led to use of trucks for deliveries as stated in interview 3 "*Our site produces 10 MW of hydrogen, but with pipeline development lagging, we cannot rely on network operators and are forced to use trucks for deliveries.*" Ensuring seamless hydrogen transfers, supply chain logistics, and port authorities are refining transportation routes, schedules, and methods. Effective transit solutions rely on proximity between production and consumption, safe storage, and adherence to hydrogen's unique safety norms. Transportation primarily relies on trucks and ships, with storage options ranging from gaseous to liquid forms.

Debates surrounding energy infrastructure ownership, whether offshore, onshore, or in distributed setups, underscore the importance of a coherent government strategy. This strategy should serve the dual purpose of ensuring that hydrogen development projects are in line with climate goals, (interview 6), and of explicitly defining the roles and shared responsibilities of both conventional industry participants and emerging players (interview 25) particularly given the integration complexities associated with bundling.

HIA advocates for regulations, safety, and environmental standards, and on the Distribution landscape, Energy Aggregators (Energy Hub Operators), Fuel Station Operators (Mobile and Stationary), Regional Fuel Suppliers, and Hydrogen and Energy Retailers streamline the hydrogen flow from producers to local consumers on the regional level. Energy Hub Operators and/or Distribution System Operators (DSOs) centralize this distribution, optimizing both long-distance and local channels. Fuel station operators predominantly serve hydrogen-powered vehicles and off-grid demands, capitalizing on nearby energy hubs. Meanwhile, Hydrogen and Energy Retailers maintain market balance, adjusting to demand shifts and regulatory challenges.

Hydrogen's versatility allows it to produce a spectrum of products, from hydrogen gas and synthetic natural gas to electricity and heat, presenting numerous revenue opportunities. This adaptability appeals to end-user sectors (Category 4), notably in sectors where electrification falls short, like heavy industries and mobility which are emerging as early adopters (Ueckerdt et al., 2021). In the medium to long term, hydrogen systems have the potential for adoption in sectors like high-tech manufacturing, agriculture, the food industry, water treatment, waste management, and the built environment (commercial and residential, cooperatives, and individual users). As quoted in interview 31, *"The electrification revolution is reshaping transportation and industry, manufacturing high tech, with isolated networks harnessing surplus energy in the form of hydrogen."* Yet, the demand for hydrogen remains uncertain largely due to its elevated costs and inadequate infrastructure, especially in comparison to direct electrification. A diverse investment strategy is key for providing consistent financial support to sectors and areas where hydrogen has potential appeal.

Intermediaries (Category 5) often termed innovation intermediaries (Kivimaa et al., 2019) act as crucial connectors among producers, consumers, and regulatory bodies. Both industrial associations and regional alliances advocate for favorable policies. Through fostering collaboration among stakeholders, they attract financial investments and shape a receptive regulatory backdrop, crucial for facilitating joint ventures and disseminating expertise. Additionally, consultancy and advisory firms contribute by providing strategic insights, enhancing these collaborative endeavors. Regulatory service providers and certification bodies, from an operational stance, set benchmarks for hydrogen facilities, ensuring they adhere to top-tier practices and safety regulations. Environmental and resource management stakeholders, including water management entities, along with advocacy organizations ensure ecological responsibility including water and CO2 management (Luderer et al., 2022). These entities play a pivotal role in influencing public perception and guiding spatial adaptation strategies for sustainable hydrogen development. However, challenges specific to the Netherlands, such as limited available space and public mistrust towards the fossil fuel sector, impact the spatial integration of hydrogen infrastructure, as noted in interview 28.

Policymakers and regulatory authorities (Category 6) from national down to provincial and local levels, shape the policies and regulatory frameworks as well as financial incentives and coordination of multiple stakeholders. Stakeholders noted the importance of coherent policies, stating *"Incomplete hydrogen policies throughout the whole chain obstruct growth, definitive government guidelines are indispensable for rapid advancement in the hydrogen sector"* (interview 28). Sustainable growth in this emerging sector extends beyond short-term financial mechanisms, it necessitates an agile long-term market strategy that prioritizes transparent resource allocation and coordination. As this strategy matures, the sector's dependence on subsidies and tax incentives should gradually diminish, leading to financial independence. Provincial and local governments are positioned to lead the advancement of hydrogen technology projects. Yet, their efforts are often hindered by a clear lack of knowledge in creating detailed hydrogen strategies, personal biases, and voids in specific hydrogen sector investment and infrastructure guidelines. The scarcity of a skilled workforce, a deficiency within both governance structures and the industry, leads to production delays and underlines the urgent need for focused education and training initiatives in this sector. While the research and education stakeholders (Category 7) are pushing R&D and educational initiatives, a comprehensive strategy is crucial to foster wider acceptance of hydrogen technologies.

Five main challenge areas: technical, infrastructural (including supply chain), socioeconomic, environmental, and institutional, with associated factors are pinpointed as detailed in Table 2. The frequency of mentions for each factor by stakeholders is shown in Fig. 2. Topping the list was the pressing need for upgrades in Transportation Infrastructure at 87.88%. Financial challenges were apparent, with High Initial Costs and Scalability concerns at 84.85%. Other crucial aspects included Effective Storage Methods and Safety and Cybersecurity Measures, both at 75.76%. Storage and Distribution Infrastructure, Security of Supply, and Public Acceptance all garnered a score of 72.73%, emphasizing the multifaceted nature of the integration. Some challenges, like Intricate Supply Chain Logistics, were less emphasized.

Table 2
Key Challenges related to the Integration of hydrogen infrastructure network.

Key Challenges	Sub-Challenges
Technical Challenges	Component Efficiency and Durability Intermittency of Renewables and Low-capacity Effective Storage Methods Quality and Efficiency of Produced Fuel Safety and Cybersecurity Measures
Infrastructure and Logistics Challenges	Expansion and Integration with Renewable Energy Sources Security of Supply Transportation Infrastructure (Integration and connection of hydrogen into the grid) Storage, Distribution, Conversion Infrastructure (Integration and connection of hydrogen into the grid) Intricate Supply Chain Logistics Network Congestion Management
Socio-economic Challenges	High Initial Costs and Scalability (CAPEX) High Manufacturing Costs of Components (Equipment, Infrastructure) High Operational Costs (Energy consumption, Maintenance, safety, conversion) (OPEX) Volatility in Energy Prices Energy Grid Autonomy Transition Costs Substantial Financial Backing Uncertain demand Public Acceptance (Political, Market, Society) Risk of Obsolescence
Environmental Challenges	CO2 Emission Management Raw Material Usage Water Management Spatial Adaptation and Management
Institutional Challenges	Trust Leadership Diversified Investment and Strategy Alignment Balance of Decentralized and Centralized Infrastructure Design and Development Agile Strategy Implementation Ownership Permitting Processes Certification and Standard Carbon Pricing and Taxation Regulatory Standard Support Schemes and Subsidization Policy Guidance on Roles and Responsibilities Lock-in effect Research and Education Investment and Workforce Training

4. Discussion

Integrating hydrogen into the energy system is crucial for a sustainable future. The Netherlands, with its emphasis on a decentralized approach, is laying the foundation for pioneering initiatives and partnerships. Transitioning to green hydrogen requires a coordinated blend of strategies, policies, and infrastructural advancements. A significant challenge is the transformation of the transportation infrastructure, an issue underscored by 87.88% of stakeholders. This shows the urgent need for strategic investments in research and development and public-private projects to forge a hydrogen transit network bridging production and consumption locales. Centralized hydrogen production, while economically favorable due to its economies of scale, encounters logistical challenges, primarily distribution inefficiencies that are accentuated by geographical complexities. Alternatively, decentralized production, although fostering energy resilience and autonomy, might be associated with elevated operational costs.

The integration of these production models necessitates infrastructural adaptability, particularly the architecture should include multifaceted storage systems that efficiently transport hydrogen across scales. This encompasses stationary repositories designed for major centralized hubs to dynamic, modular systems tailored for heterogeneous transport needs. Further development in diverse storage forms, ranging from compressed and liquid hydrogen to solid-state storage holds importance. Simultaneously, it is important to utilize and adapt existing assets such as geological reservoirs and gas pipelines. As these developments proceed, prioritizing safety over standardized protocols, worker training, regular safety audits, and public awareness is essential, this comprehensive approach ensures safe and effective scaling of the hydrogen industry. A continuous dialogue and partnership between governmental safety bodies and the hydrogen industry are vital for regularly revisiting and refining these safety procedures.

A consensus of 84.85% underscores the financial challenges posed by steep initial costs and scalability issues, suggesting that the current Capital Expenditure (CAPEX) subsidies might not be sufficient to both offset operational costs and attract private investments. Feed-in Tariffs (FITs), tax incentives, and Carbon Contracts for Differences emerge as possible motivators for industries. The potential role of fossil hydrogen could also serve as a transitional mechanism to develop the hydrogen infrastructure (Odenweller et al., 2022) and draw venture capital for tech advancements. Yet, rigorous assessment of GHG emissions, considering carbon pricing and evolving regulatory frameworks, is paramount. As private entities begin to see the vast potential of green hydrogen, Public-Private Partnerships (PPPs) should be solidified to distribute operational and financial responsibilities.

A holistic strategy for successful hydrogen integration necessitates a forward-thinking approach that not only addresses the present but also anticipates the challenges and opportunities of the future (Harichandan et al., 2023). At its core, early planning and coordination are essential, laying out a proactive roadmap that charts the course of adoption, resource allocation, and potential challenges, thereby providing clarity and direction to all involved parties. Integral to this approach is fostering collaboration and coordination across all sectors - government, industry, academia, and the public. By harnessing the collective expertise and insights of these diverse groups, and by coordinating their efforts, solutions can be both innovative and representative of the wider community's needs and aspirations. In this dynamic landscape, a responsive and flexible governance system is crucial to be capable of adapting to new technological breakthroughs and market shifts. To achieve this, regulatory frameworks that are easily updateable to new conditions are essential, alongside mechanisms for ongoing monitoring and swift policy adjustments. Coordination at both strategic and operational levels is key in unlocking hydrogen's potential, particularly in areas where electrification is less feasible, thereby advancing sustainable energy adoption.

5. Limitations and recommendations for future research

The study acknowledges the limitations posed by its specific focus on the Dutch context. To mitigate this, future research should embrace a global perspective, engaging with a diverse array of countries and energy contexts. This broader approach can yield a richer, more universally applicable understanding of the hydrogen sector. In addition, the study's limited stakeholder engagement could lead to biases. Future research should adopt a more inclusive approach, incorporating diverse stakeholder perspectives through comprehensive stakeholder analyses, focus groups, and public consultations. This would not only enrich the data but also ensure that the insights are reflective of a wider array of interests and concerns.

A full-spectrum understanding of the hydrogen sector is crucial. Future research endeavors should investigate the entire hydrogen supply chain to understand its technological and infrastructural advancements, socio-economic implications, environmental considerations, and institutional dynamics that might affect its adoption. Emphasis should also be placed on identifying challenges and proposing innovative solutions, ensuring the sector's viability and sustainability. In conclusion, this study underscores the complex challenges of integrating hydrogen into the Netherlands' energy system. Hydrogen represents a nexus of technological advancement and environmental commitment, paving the way toward a greener, more sustainable energy paradigm. Given the intensifying global environmental and energy crises, hydrogen's flexibility and adaptability emerge as crucial assets in striving for a sustainable energy horizon. This research emphasizes the pressing need for ongoing exploration and collaborative efforts in this field.

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CRediT authorship contribution statement

Mahshid Hasankhani: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Jo van Engelen:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing, Supervision, Project administration. **Sine Celik:** Validation, Visualization. **Jan carel Diehl:** Methodology, Validation, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Data Gathering and Analysis.

A: Overview of Selected Projects

Table 3
Overview of selected projects

Projects	Location
H2GO - 1st phase H2GO - 2nd phase	Goeree-overflakkee
NortH21, NortH2, phase 2, NortH2, phase 3	Eemshaven
Power-To-Gas (P2G) Phase II "Rozenburg Power2Gas Phase 2 DNV Kema/DNV GL/Rozenburg Power2Gas Phase 1″	Rozenburg
Hystock (EnergyStock)-A8 - HyStock Demonstration project	Zuidwending
Hydrogen Delta	Zeeland
HyNetherlands	Groningen
Port of Rotterdam BP refinery - H2.50	Rotterdam
Eemshydrogen -Hydrogen Plant for Westereems Wind Farm (RWE Eemshaven)	Groingen
Hy4Am	Amsterdam
Yara Sluiskil (Deltaurus 2) - Haddock	Sluiskil
GreenH2UB (10 hubs of 3–10 MW, the first one Ref786)-GreenH2UB (1st hub, Noord Brabant)	Eindhoven
Hemweg hub Amsterdam	Amsterdam
AVR e-thor	Rotterdam
H_2 Air Base Leeuwarden	Leeuwarden
Multiphly	Rotterdam
PosHYdon	North Sea
H2Watt	Ameland
GldH2	Zutphen
Enowatts-Energy Demo Field-P2P IPKW	Arnhem
Cyrus Smith-hymatters	Arnhem
Alliander Oosterwolde - solar park of GroenLeven-Sinnewetterstof-Hydrogenpilot Oosterwolde	Oosterwolde (Friesland)
Holland Hydrogen - phase 1 Holland Hydrogen - phase 2	Rotterdam
Duwaal	Wieringermeer
Hysolar Green on Road - Nieuwegein	Nieuwegeen
H-Vision (phase 1),H-Vision (phase 2)	Rotterdam
GZI Next	Emmen
DJEWELS Chemiepark - Delfzijl, Phase 1	Delfzijl
DJEWELS Chemiepark - Delfzijl, Phase 2-DJEWELS Chemiepark - Delfzijl, Phase 3 (h2eron)	Delfzijl
H2ermes	Amsterdam
H2M	Noord-Holland
Shell heavy residue gasification CCU - Pernis refinery (in 2024, the CCU project will become CCUS - ref1323 - once Porhtos project is available) Shell heavy residue gasification CCUS - Pernis refinery	Rotterdam
Bio Energy Netherlands	Amsterdam, Delfzijl, Groningen
H2-Gateway/Blue Hydrogen Den Helder	Den Helder
H2-based residential area in Van der Veen-Hydrogen Neighbourhood Hoogeveen	Hoogeveen
GH2	North Holland -Utrecht -South Holland
VoltH2 - Delfzijl	Delfzijl
Terneuzen - VoltH2 - phase I,Terneuzen - VoltH2 - phase II	Terneuzen
Vlissingen - VoltH2 - phase IVlissingen - VoltH2 - phase II	Vlissingen
Curthyl	Maasvlakte
Deltaurus 1-Hydrogen Delta program-Deltaurus 3-Hydrogen Delta program	Zeeland
Uniper Maasvlakte, phase I-Uniper Maasvlakte, phase II	Rotterdam
Synkero synfuels project	Amsterdam
SeaH2Land	Zeeland
North Sea Wind Power Hub	North-sea
Energiepark Eemshaven West (phase I)-Energiepark Eemshaven West (phase II)	Eemshaven
ELYgator	Terneuzen
Zeeland Refinery-Zeeland Refinery CCS	Zeeland
FUREC	Limburg
BrigH2	Limburg
Hydrogen Mill	MULTIPLE
H2-gateway	Den Helder
H2opZee	North Sea
Air Liquide Botlek Rotterdam refinery (Porthos CCS)Port of Rotterdam CO2 Transport Hub and Offshore Storage.	Rotterdam
Air Products Botlek Rotterdam refinery (Porthos CCS)Port of Rotterdam CO2 Transport Hub and Offshore Storage.	Rotterdam
Exxonmobil Benelux Botlek Rotterdam refinery (Porthos CCS)Port of Rotterdam CO2 Transport Hub and Offshore Storage.	Rotterdam
AMpHytrite demonstrator, Port of Rotterdam, phase 1, AMpHytrite demonstrator, Port of Rotterdam, phase 2	Rotterdam
H2er	Amsterdam
WAviatER	Groningen
MoU Shell - Mitsubishi, phase1	

B: Overview of Interview and Focus Groups.

Adhering to ethical guidelines, we ensured participant anonymity, obtained informed consent, and explicitly outlined the objectives of our interviews.

Table 4
Overview of interviews and focus groups.

Interview Number	Interview Duration	Interview Type	Project Location	Participant's Role	Organization
1	54	Individual	Multiple -Goeree-Overflakkee- South Holland	Senior Research and development (R&D) lead - Policymaker	Public Research Institute Policy and Research Think Tanks
2	55	Individual	Multiple	Senior Hydrogen Project Manager	Network Operator/Distribution System Operator (DSO)
3	58	Individual	Zutphen-Gelderland	Junior Project Manager	Industrial Energy Cooperative
4	50	Individual	Groningen -Groningen	Senior Researcher	Public Research Institute
5	40	Individual	Multiple	Senior Hydrogen Project Manager	Consultancy and Engineering
6	65	Individual	Multiple	Senior Hydrogen Project Manager	Energy Utilities/Gas Utilities
7	35	Focus Group	Multiple	Senior Hydrogen Project Manager	Consultancy and Engineering
8	60	Individual	Multiple	Senior Electrical Engineer and Renewable Energy Specialist	Public Research Institute
9	60	Focus Group	Leeuwarden-Groningen	Senior Research and development (R&D) lead – Local Policymaker	Public Research Institute Local Municipality
10	40	Individual	Delft	Senior Hydrogen Project Manager/ Project Developer	Public Research Institute
11	30	Individual	Multiple	Senior Project Developer	Fuel Station Provider
12	40	Focus Group	Leeuwarden-Groningen	Senior Research and development (R&D) lead	Public Research Institute
13	44	Individual	Hoogeveen-Drenthe	Local Policymaker	Local Municipality
14	60	Individual	Goeree-Overflakkee- South Holland	Senior Stakeholders Manager	Energy Cooperative
15	60	Focus Group	Groningen	Senior Research and Development (R&D) lead	Public Research Institute
16	52	Individual	Multiple	Director of Business Development	Green Hydrogen Supplier Renewable Energy Producers
17	45	Individual	Multiple	Senior Hydrogen Project Manager	Public Research Institute Project Developer Policy and Research Think Tanks
18	45	Individual	Hospital	Director of Business Development	Energy Storage/Supply Systems-Consultancy and Engineering
19	70	Individual	Multiple -Notrh-International	Senior Hydrogen Project Manager	Institution for Testing, Inspection and Certification Hydrogen Energy Coalition
20	55	Focus Group	Groningen	Senior Research and development (R&D) lead	Public Research Institute
21	49	Individual	Rotterdam- South Holland	Junior Hydrogen Project Manager	Industrial Port Authorities
22	40	Individual	Multiple	Senior Hydrogen Project Manager	Network Operator/Distribution System Operator (DSO)
23	65	Individual	Multiple	Senior Hydrogen Project Manager	Public Research Institute
24	40	Individual	Rotterdam- South Holland	Senior Hydrogen Project Manager	Network Operator/Distribution System Operator (DSO)
25	55	Focus Group	Multiple	Senior Hydrogen Project Manager	Government Initiative for cooperation between companies, research institutions and the government Policy and Research Think Tanks
26	43	Focus Group	Multiple	Senior Risk Strategist	Public Research Institute
27	53	Individual	Multiple	Senior Risk Strategist	Assurance, Risk Management, and Certification Services Provider
28	40	Individual	Multiple	Senior Electrical Engineer and Renewable Energy Specialist	Knowledge and Collaboration Platform
29	31	Individual	Multiple	Senior Hydrogen Project Manager	Energy Utilities/Power Utilities
30	30	Individual	Multiple	Senior Hydrogen Project Manager	Energy Utilities/Power Utilities
31	40	Individual	Multiple	Senior Hydrogen Project Manager	Network Operator/Transmission System Operator (TSO)
32	41	Individual	Multiple	Senior Electrical Engineer	Petrochemical Industries
33	30	Individual	Multiple	Director of Business Development	Hydrogen Technology Providers

C: The Interviews Guide and Questions Themes

Table 5
Overview of questions themes and examples

Questions Themes	Example of Questions
Theme 1: Explore interdependencies	Who do you identify as the main stakeholders in the hydrogen integration process in the Netherlands, considering both technological and supply chain aspects? How do stakeholders perceive the potential disruptions caused by integrating hydrogen into the existing energy landscape? Could you share insights on technical and logistical obstacles encountered during the implementation of hydrogen infrastructure projects?
Theme 2: Understand the evolving stakeholder dynamics	Are there any unexpected stakeholders involved in this process? Can you explain their roles and motivations? Have there been any shifts in stakeholder roles within the Dutch hydrogen sector? How have these shifts affected the hydrogen integration process? Can you provide examples of how stakeholders have adapted to these changes, particularly in terms of technological and supply chain aspects?
Theme 3: Identify integration challenges	What do you see as the main challenges in developing a hydrogen infrastructure in the Netherlands? Are there conflicting interests among stakeholders regarding the development of hydrogen infrastructure? Can you provide

(*continued on next page*)

Table 5 (*continued*)

Questions Themes	Example of Questions
	examples? How do government regulations and initiatives affect the challenges faced by stakeholders in the development of hydrogen infrastructure? What are the stakeholders’ views on the financial and economic viability of hydrogen projects in the Netherlands? Can you discuss any environmental or social concerns raised by stakeholders regarding hydrogen infrastructure development? How do stakeholders assess the market readiness for hydrogen adoption in the Netherlands? What barriers do they identify in terms of consumer acceptance and demand?

Table 6
Frequency of integration challenges among interviewed stakeholders

Challenges	Relative Frequency
Component Efficiency and Durability	21.21212121
Intermittency of Renewables	36.36363636
Effective Storage Methods	75.75757576
Quality and Efficiency of Produced Fuel	39.39393939
Safety and Cybersecurity Measures	75.75757576
Expansion and Integration with Renewable Energy Sources	69.6969697
Security of Supply	69.6969697
Transportation Infrastructure (Integration and connection of hydrogen into the grid)	87.87878788
Storage, Distribution, Conversion Infrastructure (Integration and connection of hydrogen into the grid)	72.72727273
Intricate Supply Chain Logistics	6.060606061
Network Congestion Management	42.42424242
High Initial Costs and Scalability	84.84848485
High Manufacturing Costs of Component	12.12121212
High Operational Costs	45.45454545
Volatility in Energy Prices	45.45454545
Energy Grid Autonomy	45.45454545
Transition Costs	39.39393939
Substantial Financial Backing	21.21212121
Uncertain demand	66.66666667
Public Acceptance (Political, Market, Society)	72.72727273
Risk of Obsolescence	21.21212121
CO1 Emission Management	57.57575758
Raw Material Usage	9.090909091
Water Management	9.090909091
Spatial Adaptation and Management	42.42424242
Trust	36.36363636
Leadership	30.3030303
Diversified Investment and Strategy Alignment	36.36363636
Balance of Decentralized and Centralized Infrastructure Design and Development	51.51515152
Agile Strategy Implementation	48.48484848
Ownership	33.33333333
Permitting Processes	42.42424242
Certification and Standard	36.36363636
Carbon Pricing and Taxation	9.090909091
Regulatory Standard	81.81818182
Support Schemes and Subsidization	69.6969697
Policy Guidance on Roles and Responsibilities	48.48484848
Lock-in effect	24.24242424
Research and Education Investment and Workforce Training	39.39393939

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