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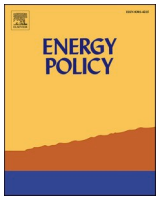

Hydrogen distribution in the Netherlands: Addressing Ambiguities in the regulatory framework

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ABSTRACT

Hydrogen is increasingly recognized as a key solution for decarbonizing the Dutch energy system, particularly within the industrial sector. A national hydrogen network is under development to serve the five major industrial clusters in the Netherlands. However, meeting the hydrogen needs of the industries outside these clusters, which are collectively known as "Cluster 6", remains difficult. Regulatory unclarity and ambiguity around the hydrogen distribution infrastructure, including restrictions on distribution system operators (DSOs), compound these challenges. This study investigates the complex and evolving regulatory landscape for hydrogen distribution across Cluster 6 in the Netherlands using a two-step approach of Institutional Network Analysis (INA) and stakeholder interviews. Findings outline possible pathways for delegating distribution responsibilities in current and future regulatory frameworks while stakeholders report structural and outcome uncertainty, limiting their willingness to invest in hydrogen distribution initiatives. The research findings highlight the need for a more coherent regulatory and technical framework to support more effective development of physical hydrogen systems. Policy recommendations include clarification of distributor roles, targeted support mechanisms, and flexible regulations that can adapt to the rapidly developing hydrogen market.

1. Introduction

The urgency of the Paris Agreement, coupled with recent geopolitical events like Russia's invasion of Ukraine, has accelerated research into hydrogen as a promising solution for decarbonizing hard-to-abate sectors and enabling large-scale renewable energy storage (Alverà, 2021; Machado et al., 2022). In this context, the Netherlands, Europe's second-largest hydrogen consumer, is actively developing a nationwide hydrogen infrastructure (CMS, 2022; Gasunie, 2023; Nationaal Waterstof Programma, 2022). This initiative aims to connect major industrial clusters, particularly in the refinery and chemical sectors, by retrofitting existing gas pipelines to form a secure, cost-effective network (Gasunie, 2024).

While these major clusters drive the primary demand, numerous smaller industrial activities, often situated near urban areas and other clusters (Huneman and Koopman, 2022), collectively known as Cluster 6 or regional industries, contribute approximately 30 % of the nation's industrial CO_2 emissions (Het Zesde Cluster, 2020). These regional industries face significant uncertainties regarding hydrogen pricing, connection options, and network capacity (Huneman and Koopman, 2022; VNCI, 2022). Although the long-term vision is to link these regional industries to the national hydrogen backbone, fueled by large-scale hydrogen production and imports, the dispersed nature of these industries means that substantial new infrastructure will be required (de Flart, 2024; Het Zesde Cluster, 2020). Regional hydrogen production might reduce initial dependency on the national network, yet it also raises challenges for local and provincial authorities, including unclear investment regulations and limited strategic planning expertise (Hasankhani et al., 2024). Additionally, existing regulations do not clearly define the roles and responsibilities in hydrogen distribution. This structural uncertainty leaves stakeholders unsure about their permissible activities (van der Spek et al., 2022).

To address these challenges, this research investigates how the

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Abbreviations

ACM	Autoriteit Consument & Markt (Netherlands Authority for Consumers and Markets)
CO_2	Carbon Dioxide
DSO	Distribution System Operator
EA	Electricity Act (Elektriciteitswet)
EU	European Union
EU-package	*Hydrogen and Decarbonised Gas Market Package*
ENA	Energy Act (Energiewet)
EPA	Environment and Planning Act (Omgevingswet)
GA	Gas Act (Gaswet)
H2	Hydrogen
HDNO	Hydrogen Distribution Network Operator
HNO	Hydrogen Network Operator
HNS	HyNetwork Services
HTNO	Hydrogen Transmission Network Operator
IG	Institutional Grammar
INA	Institutional Network Analysis
LLM	Large Language Model
LNG	Liquefied Natural Gas
OECD	Organization for Economic Co-operation and Development
TPA	Third-Party Access
TSO	Transmission System Operator

complex and evolving regulatory landscape[1] for hydrogen distribution in the Netherlands affects stakeholders' operations and decision-making, particularly among regional industries. Previous studies have primarily focused on the techno-economic potential of hydrogen technologies or value chains (Durakovic et al., 2023; Jesse et al., 2024; Steinbach and Bunk, 2024). Policy interventions and market design for hydrogen deployment have been analyzed (Chapman et al., 2020; Farrell, 2023; van der Spek et al., 2022) alongside examinations of legal structures in regions such as Mexico (Ávalos Rodríguez et al., 2022), the US (Bade et al., 2023), the EU (Barnes, 2023; Baumgart and Lavrijssen, 2023), and the Netherlands (Broersma et al., 2024; van Ahee et al., 2022; Van Oorschot and Jacobs, 2021). Additionally, stakeholder analyses along the hydrogen value chain have provided insights into their relationships and perceptions (Asna Ashari et al., 2023; Hasankhani, 2023; Schlund et al., 2022; Steinbach and Bunk, 2024). However, there is a notable gap in the literature regarding specific regulatory frameworks for hydrogen distribution and their practical implications, especially in terms of ambiguity regarding stakeholders' roles, financial support, and regulatory inflexibility.

To this end, the study first comprehensively analyzes the regulatory framework governing hydrogen distribution by systematically coding regulatory statements from European and Dutch policy documents. Using Institutional Network Analysis and Institutional Grammar (Crawford and Ostrom, 1995; Mesdaghi et al., 2022), the study visualizes the interconnections among stakeholders, regulatory components, and contextual factors. The analysis moves from a broad contextualization of the evolving regulatory landscape to a detailed breakdown of specific regulatory components affecting hydrogen distribution in the Netherlands, considering the pending national regulatory reforms prompted by decisions at the European level. Secondly, semi-structured interviews with key professionals from municipal authorities, DSOs, commercial enterprises, and government bodies provide qualitative insights into the practical challenges. Integrating the empirical findings, the research formulates and further explores propositions regarding the challenges in the regulatory framework, hurdles faced by stakeholders, and potential policy reforms, thereby contributing valuable insights to both academic debates and practical policymaking in the hydrogen sector.

The remainder of this research is structured as follows: Section 2 outlines the research approach, materials, and methods. Section 3 examines the evolving regulatory framework for hydrogen distribution in Europe and the Netherlands. Section 4 presents a detailed discussion of the regulations and emerging opportunities for Dutch hydrogen distributors, supported by network diagrams. Section 5 explores stakeholder perspectives on the barriers and enablers to hydrogen deployment in regional industries. Finally, Section 6 concludes with a discussion of the implications, unresolved questions, and suggestions for future research.

2. Materials and methods

This research conducted a two-step approach to examine the regulatory structure and its implications for hydrogen distribution in the Netherlands. The first step involved institutional analysis to map the formal rules shaping hydrogen distribution in the Netherlands, focusing on roles, responsibilities, and regulatory mechanisms (Siddiki and Frantz, 2024). In the second step, semi-structured interviews were held with key stakeholders to capture practical perspectives on perceived barriers, enablers, and potential pathways for enhancing regional hydrogen distribution. Fig. 1 provides an overview of these sequential steps.

2.1. Institutional analysis

Institutional analysis provides insight into how formal and informal rules ("institutions") govern interactions and decision-making among stakeholders (Ostrom, 1986; Siddiki and Frantz, 2022). Desk research, including document analysis, provided insight into the economic and regulatory context of the regional industries in the Netherlands. As this research analyses the influence of the regulatory landscape for hydrogen distribution on stakeholders' operations and decision-making, we focus on the formal European and Dutch regulations related to hydrogen, gas, and electricity markets. Rules relevant to regional hydrogen distribution were extracted using search criteria, such as hydrogen infrastructure, development and operation of infrastructure, infrastructure planning, and network operators' role. Table 1 lists the legal or policy documents and their scope included in the institutional analysis. The focus is on general hydrogen distribution policies, while location-specific documents established on a lower governmental level (such as permits) are not considered. Such location-specific subnational policy documents have been omitted from this research, because the regional industries in the Netherlands are geographically scattered throughout the Netherlands, therefore requiring the analysis and coding of a large quantity of subnational documents or limiting the research to a specific geographic area. This fell outside the scope of this research.

Institutional Grammar (IG), introduced by Crawford and Ostrom (1995), was employed to code the extracted rules systematically. IG is an effective method for thoroughly, structurally and systematically examining the regulatory framework governing a certain action situation (Siddiki and Frantz, 2022). An action situation is a decision situation, shaped by institutions, where two or more actors interact and are faced with a set of potential actions that jointly produce outcomes (McGinnis, 2011; Montes et al., 2022). The present study applies IG 2.0 to code the rules extracted from the selected policy documents. The focus is on regulative statements that specify the behaviors expected of

[1] With regulatory landscape, regulatory framework or regulations, we refer to the formal rules regarding the hydrogen market, e.g. attribution of tasks, setting boundaries or attributing roles and responsibilities.

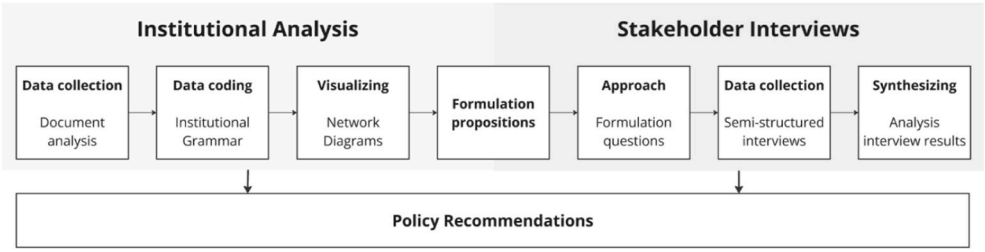

Fig. 1. Research steps.

Table 1
List of key policy documents on hydrogen distribution in the Netherlands.

Policy document	Policy scope
Environment and Planning Act (Omgevingswet, 2016)	Defines requirements for spatial planning and zoning of production and pipeline transport.
Gas Act (Gaswet, 2000)	Defines rules and requirements for gas infrastructure, market and activities.
Electricity Act (Elektriciteitswet, 1998, 1998, 1998)	Defines rules and requirements for electricity infrastructure.
Governmental letter National Hydrogen Network (Jetten, 2022)	Defines the role of the HyNetwork Services and goals of the national hydrogen transportation network.
Tolerance Policy Hydrogen Pilots (ACM, 2022)	Describes requirements to support hydrogen pilot projects.
Generic guidelines Hydrogen Safety (RVO, 2022b)	Defines safety guidelines for hydrogen projects to substitute missing legislation.
Supplementary guidelines hydrogen pilots in the built environment (RVO, 2022a)	Supplementary guidelines for the hydrogen pilots in the built environment.
Energy Act (Energiewet - Voorstel, 2024)	Revision of regulations that govern the energy system. Combines GA and EA and add several definitions for hydrogen.
EU Hydrogen and Decarbonised Gas Market Package – Regulation (Regulation 2024/1789, 2024)	Contains detailed articles on the hydrogen market and network development.
EU Hydrogen and Decarbonised Gas Market Package - Directive (Directive 2024/1788, 2024)	Contains detailed articles on the hydrogen market and network development.

stakeholders when certain constraints are in place (Frantz and Siddiki, 2021). Constitutive statements, which parametrize the features of the system in which actors interact (Frantz and Siddiki, 2021), are not considered in this research as the focus is on how stakeholders' behaviour is affected by the regulatory framework. Fig. 2 illustrates the IG 2.0 syntax for regulative statements, referencing Article 46.1 of the Directive in the Decarbonized Gas and Hydrogen Package (Directive 2024/1788, 2024). The statements were coded following the coding protocol proposed by Siddiki et al. (2011) based on IG 2.0.

Each regulative statement in IG 2.0 must include at least three components: an Attribute (A) indicating the stakeholder or entity responsible, an Aim (I) describing the required action or outcome, and a Context (Cac and Cex) defining the conditions under which the statement applies. If any context element is absent, the statement applies by default in all circumstances. As the Or Else (O) component is the consequence of noncompliance with the regulative statement, it can be expressed as an institutional statement in itself (Frantz and Siddiki, 2021; Siddiki and Frantz, 2024).

Next, Institutional Network Analysis (INA) (Mesdaghi et al., 2022) was employed to visualize the coded statements. INA utilizes network diagrams to display how syntactic components in IG, such as stakeholders, objects, and contexts, are interconnected within the regulatory framework. It also illustrates whether relationships between statements are actor-, sanction- or outcome-driven, showing how compliance depends on specific contextual elements (Ghorbani et al., 2024). To create the network diagrams, IG syntactic components are assigned specific shapes and connected to visualize the relationships among the institutions within the regulatory framework. Fig. 3 illustrates how a network diagram is developed based on the IG syntax in Fig. 2. The approach creates a holistic landscape of the existing regulations and helps in understanding the institutional linkages and context dependency (Ghorbani et al., 2024). In this research, INA helps create a comprehensive overview of regulations regarding hydrogen distribution in the Netherlands, revealing complexities, future pathways, and possible overlaps or voids. Additional details on the relationship between INA and IG can be found in Appendix A.

As coding with IG is primarily a manual process, four researchers experienced with IG extracted and coded statements independently. The results were then compared to check the consistency and accuracy in applying the IG 2.0 syntax to the extracted statements. Differences between the coding were critically assessed using literature and digital resources on the IG 2.0 syntax, and the coding was adapted accordingly. In other words, the coded rules were compared at component-level, providing a standard basis to judge similarities and differences.

2.2. Stakeholder interviews

To complement the institutional analysis and address the research gaps related to practical challenges in the regulatory framework, semi-structured interviews (n = 6) were conducted with stakeholders actively engaged in the Dutch hydrogen market. These interviews aimed

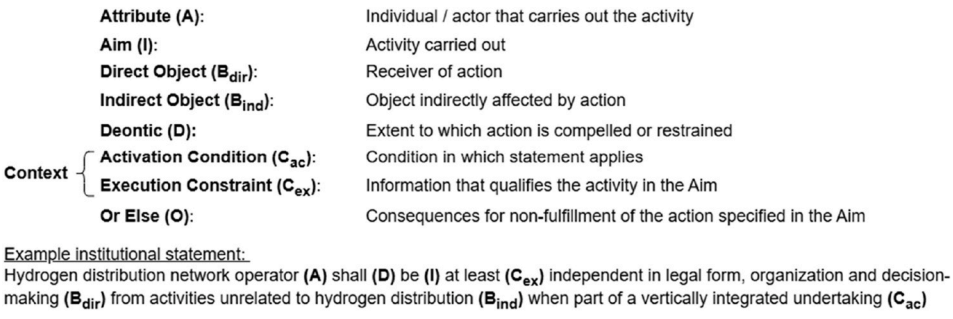

Fig. 2. IG 2.0 syntax for regulative statements.

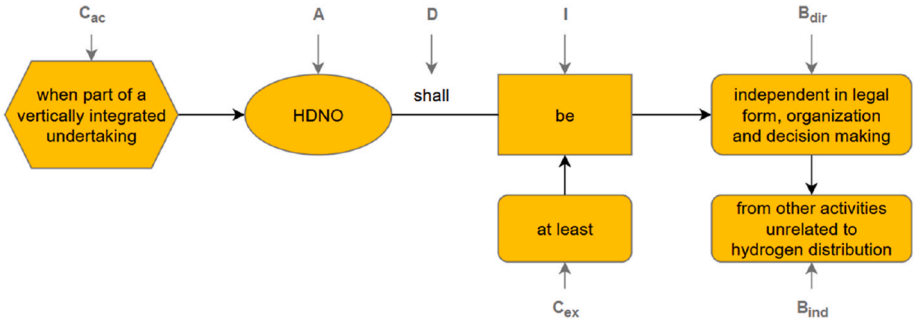

Fig. 3. Institutional statement represented in network format using IG 2.0.

to capture diverse perspectives on the regulatory framework's suitability, perceived regulatory barriers, and potential strategies to support hydrogen distribution. Semi-structured interviews were used as they allow for gaining insight into an actor's personal, unique perspective (Adeoye-Olatunde and Olenik, 2021).

Six professionals from various work domains (one municipal, two DSO, two commercial and one governmental) were selected for interviews based on their active involvement in regional hydrogen distribution projects. Although limited, the sample reflects several of the key stakeholders typically engaged in current, cross-sectoral regional hydrogen initiatives in the Netherlands. This captures a broad range of expertise with the regional hydrogen transition and provides valuable insight into its practical and institutional dynamics. These interviewees were identified through the network of a DSO actively working with regional industries and their shift to hydrogen. The interview guide was developed based on preliminary propositions derived from the INA. The propositions are detailed in section 4.5, addressing topics such as ambiguous regulatory responsibilities, market uncertainty, insufficient financial support, and inflexible regulations. Appendix B details the interviews and the interview guide.

Before the interviews, the interviewees received an informed consent form that detailed the research goal, how the obtained data would be handled, and their rights. Upon giving informed consent, the interviews were conducted via Microsoft Teams, recorded, transcribed, and anonymized. Each transcript was shared with the respective interviewee to verify accuracy and secure approval for its use in the analysis. The resulting transcripts were systematically analyzed to identify recurring themes, which were then synthesized and integrated with the broader findings from the institutional analysis. The qualitative data from these interviews were essential for deepening the understanding of how the regulations operate in real-world settings and for pinpointing specific areas where the current regulatory framework could be improved.

3. Hydrogen distribution in the Netherlands

To foster the growth of the hydrogen sector, new regulations are needed to promote the development and adoption of low-carbon hydrogen technologies (CMS, 2021). Since current technologies alone cannot overcome the cost and pricing challenges inherent in hydrogen production, regulatory reform and institutional support play a pivotal role in building a sustainable hydrogen economy (Lee et al., 2024). Due to hydrogen's relative infancy in the energy market, existing rules are lacking or ambiguous, offering limited support in driving progress. In some cases, they may even impede development despite ongoing political debates on support mechanisms (Nuñez-Jimenez and De Blasio, 2022; OECD, 2023; Bleischwitz and Bader, 2010).

The Netherlands has taken significant steps to build a national hydrogen backbone. The operation and maintenance of this backbone have been entrusted to HyNetwork Services (HNS), a subsidiary of the nation's gas transmission system operator (TSO), following an appointment by the Minister of Climate and Energy using a Service of General Economic Interest (Broersma et al., 2024; Jetten, 2022). On the regional distribution level, however, network operators and companies had limited opportunities to engage in green hydrogen activities until recently (Van Oorschot and Jacobs, 2021).

Historically, the Dutch hydrogen regulation was framed by the Gas Act, Electricity Act, and Environment and Planning Act. The latter of which came into force on January 1, 2024. In June 2023, the new Energy Act was proposed and approved by parliament at the end of 2024. However, it has not yet been implemented. This forthcoming Act is expected to replace both the Gas Act and Electricity Act and to introduce specific regulations for hydrogen-related activities (Broersma et al., 2024; Van Oorschot and Jacobs, 2021). In the meantime, to enable hydrogen-related activities before the adoption of new regulations, the Dutch regulatory authority ACM introduced a tolerance policy allowing DSOs to participate in the hydrogen pilots in the built environment (ACM, 2022).

The Netherlands is also subject to European regulations as an EU member state. Until recently, there was no harmonized EU legal framework for hydrogen (Baumgart and Lavrijssen, 2023). Since December 2021, the Hydrogen and Decarbonised Gas Market Package (hereafter the EU-package) has been in development and was officially adopted on June 13, 2024. The package reforms the laws governing the internal markets for natural and renewable gases, addresses barriers like the lack of a competitive hydrogen market, and aims to create a unified legal framework for hydrogen (Heidecke et al., 2022). The package comprises a Regulation that entered into force on July 15, 2024 (Hancher and Suciu, 2024), and a Directive, which must be transposed into national law by August 5, 2026 (European Commission, 2024).

The Dutch Energy Act is expected to be updated in the coming years to incorporate the provisions of the EU-Package Directive. Since the Energy Act is to come into effect before the Directive is fully integrated, ongoing adaptations will likely be necessary to align national regulations with EU requirements (Broersma et al., 2024; Jetten, 2022). Fig. 4 shows the timeline of the Dutch hydrogen regulatory framework. The timeline uses color coding to indicate the status of each regulation, with lighter shades denoting regulations that are still under development or partially dependent on EU rules. Darker shades indicate when the regulation is, or will be, formally adopted.

Given the ongoing evolution of regional hydrogen distribution regulations, assessing each regulatory phase in advance is crucial to identify potential inconsistencies and hurdles. This proactive approach is vital for establishing an efficient and cohesive regulatory environment for hydrogen, especially considering the persistent uncertainty Dutch regional industries face. Accordingly, this research aims to align the different phases of the Dutch hydrogen regulatory framework and to pinpoint potential implementation issues with both EU and Dutch regulations before their materialization. This enables the timely adaptation of the regulatory framework rather than waiting for the regulatory framework to materialize and then encountering issues. In the context of the hydrogen market, this is especially relevant given the increasing pressure of climate change on society.

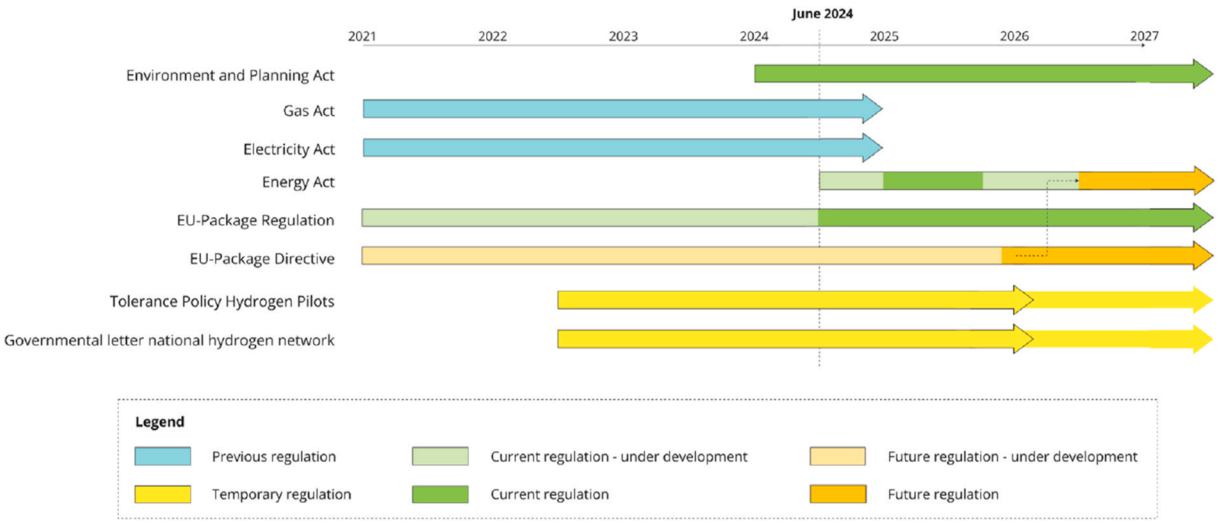

Fig. 4. Expected timeline of the regulations on hydrogen distribution network development and operation in the Netherlands.

4. Regulatory landscape on hydrogen in the Netherlands

The preceding section outlined the historical evolution, current challenges, and EU influences shaping the regulatory framework on hydrogen distribution in the Netherlands. This section presents the results from the detailed analysis of this regulatory framework, achieved through systematic coding of regulatory documents and visualization of the coding.

The policy documents listed in Table 1 were examined, resulting in 106 coded[2] rules relevant for hydrogen distribution visualized in the network diagrams. The comprehensive network diagram in Appendix C shows the regulatory structure based on the previously discussed timeline, outlining the potential roles and responsibilities in hydrogen distribution. Several key topics covered by the regulatory framework are identified from the network diagram, as outlined in the statement level diagram in Fig. 5. These include unbundling requirements for operators, the designation and responsibilities of network operators, Third-Party Access (TPA) to the network, and government support mechanisms. Additionally, some rules specify circumstances under which exemptions (or derogations) may apply, particularly concerning the tasks permitted for operators and the conditions for TPA.

The diagram presented in Fig. 5 employs a color scheme to indicate the status of each regulation, in line with the timeline presented in Fig. 4: blue are the regulations that previously structured the gas and electricity market but will be replaced in the short term, yellow depict the temporary regulations that at the time of writing shape the distribution of hydrogen, but will be retired in the near future. Green regulations are currently applicable (EU-package regulations) or will be in the short term (Energy Act); orange are future, to-be-implemented regulations. Each rule is numbered and labelled with the letter according to its status: Previous (P), Temporary (T), Current (C); Forthcoming (F). Aside from the rule-type connections (sanction-, actor-, outcome-), the diagram contains dotted arrows and solid lines between rules. The dotted arrows indicate references to other articles within a rule and the solid lines connect rules with similar content across previous, current and future regulations.

The rules in the diagram distinguish between operators of the gas and electricity system (DSOs and TSOs) and Hydrogen (Distribution) Network Operators (HDNOs and HNOs). Although the EU-package Directive distinguishes among hydrogen network operators (HNOs), hydrogen distribution network operators (HDNOs) and hydrogen transmission network operators (HTNOs), the analysis focuses on the HDNO and HNO categories. Since an HNO is defined as an entity or legal person responsible for the transmission or distribution of hydrogen via onshore and offshore pipelines used for the transport of hydrogen,[3] this category effectively encompasses both hydrogen distributors and transmitters and is therefore included in the analysis.

Overall, the diagram reveals the inherent complexity of the regulatory framework for hydrogen distribution, especially as it applies to regional industries. Many regulations are interconnected, evidenced by the multiple references between rules (indicated by dotted arrows). The diagram also highlights areas that remain unclear or underdeveloped and contribute to overall regulatory uncertainty. With the national government still finalizing decisions to implement the Directive regulations, stakeholders continue to face structural and outcome uncertainty, particularly regional industries that already contend with challenges related to their size, location, and financial constraints. In the analysis, categorizing rule types (as outcome-, actor- or sanction-driven) helps illustrate the interconnectedness and complexity of the regulatory environment rather than specifying the precise nature of the connections between individual statements.

4.1. *Vertical unbundling requirements*

The regulatory frameworks for gas and electricity in the EU have enforced vertical unbundling, which is the separation of competitive market activities (production and supply) from monopolistic network functions (transmission and distribution) (Hancher and Suciu, 2024). This subsection examines how these principles are adapted for the hydrogen market. Fig. 6 portrays these rules identified from the regulatory framework for hydrogen distribution.

Vertical unbundling is central to the regulatory landscape for hydrogen distribution. According to the forthcoming regulations, in the designation of a hydrogen distributor (F12 & F13), compliance with vertical unbundling must be ensured (F14). This means that, when the designated hydrogen distributor is part of a vertically integrated undertaking, the distributors shall, at a minimum, be legally independent of any activities other than distribution (F15). In a vertically integrated undertaking, at least one activity related to transport, terminal, or storage operation for LNG, natural gas, or hydrogen is combined with an activity related to the production or supply of natural gas or hydrogen (Hancher and Suciu, 2024). Accordingly, an existing DSO in the

[2] The coded statements can be found in Appendix D.

[3] Art. 2 (25) of (Directive 2024/1788, 2024).

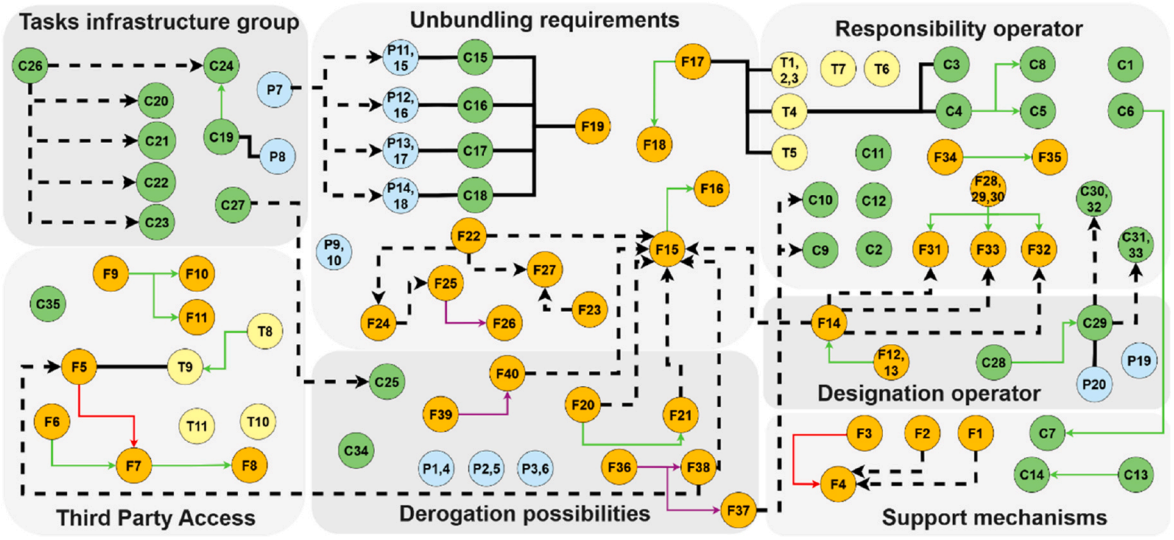

Fig. 5. Regulatory landscape for hydrogen distribution in the Netherlands.
Statement C14 and C35 are according to IG 2.0 syntax constitutive statements. As this research focused on regulative statements that describe the actions to be taken by the involved stakeholders, the syntax for constitutive statements has not been included. As the two respective statements are of relevance for our analysis, the regulative syntax has been applied, but the authors acknowledge that this is not entirely correct and do not recommend other studies that include more constative statements to copy this approach.

Netherlands can take the role of hydrogen distributor, if this branch is legally separated from the other activities in the DSO organization.

The solid lines between the Forthcoming vertical unbundling rules (F15, F16, F19), Current rules (C15 – C18), Previous rules (P9 – P18) and Temporary rules (T1 – T5) in the diagram illustrate alignment of the forthcoming regulations on vertical unbundling with the previous and current Dutch regulatory framework for the natural gas and electricity system. Also, in the hydrogen pilot projects, the DSOs handling hydrogen distribution are prohibited from engaging in commercial activities (T5). The vertical unbundling rules in the preceding regulatory framework on gas and electricity distribution implemented the maximum extent of unbundling where involvement in a group active or part of production, supply or trade activities is prohibited (P11-P18). The rules that currently shape hydrogen activities (C15-C18) also apply to ownership unbundling, but are limited to electricity and gas network operators. Interestingly, the network diagram reveals that hydrogen distributors are not required to separate the ownership of the distribution network from the vertically integrated undertaking to which they belong (F16).

Current regulations on unbundling that do apply to hydrogen specify account unbundling (C3) and the separation of a regulatory asset base (C4). In the future, Member States may choose to relax vertical unbundling requirements under certain conditions. For instance, exemptions may be granted if a hydrogen network is situated within a geographically confined industrial or commercial area (F40) or if a DSO serves fewer than 100,000 connected customers (F20). Additionally, if a derogated DSO has an HDNO within the same undertaking and their collective connected customers remain below 100,000, the HDNO may also be exempted from unbundling requirements (F21). A similar derogation may apply to an existing hydrogen network that is part of a vertically integrated undertaking on August 4, 2024 (F36).

4.2. Delegating hydrogen distribution

Building on the exploration of vertical unbundling, this subsection focuses on the delegation of hydrogen distribution responsibilities (Fig. 7), evaluating how operational roles are assigned and how legacy practices are being reinterpreted.

Under existing regulations, a DSO is required to operate only within a designated geographical zone. Both previous and current regulations stipulate that an operator may manage the gas network solely within the area assigned to it (P20), with network operators collectively having the opportunity to submit proposals to define these zones (P19). Administrative orders determine the precise allocation of zones.

The network diagram demonstrates a clear connection between the earlier regulation (P20) and the current regulation (C28 – C33), indicating that geographical allocation remains a key principle for DSOs. However, because these regulations currently apply only to TSOs and DSOs, it is uncertain whether this zoning requirement will be extended to cover hydrogen distribution. Consequently, uncertainty persists regarding whether the designation of a HDNO, as a subsidiary of an existing DSO, will be confined to the same area assigned to the respective DSO. In the absence of forthcoming regulations addressing the zoning of HDNOs' activities, the operational territory of hydrogen distributors remains unclear until a comprehensive national-scale framework is established.

Simultaneously, forthcoming regulations appear to allow for the designation of an independent entity, one that is not part of an existing vertically integrated group as a HDNO (F12, F13 & F14). An independent HDNO would inherently satisfy unbundling requirements, potentially enhancing efficiency by reducing the administrative burdens associated with legally separating activities and maintaining separate bookkeeping. Alternatively, another delegation model is the Combined Operator (F22), where a single entity manages transmission networks, terminals, storage, and distribution facilities for hydrogen. This model is contingent upon the entity complying with the unbundling of hydrogen distribution from other activities (F15), transmission from other activities (F24) and the separation from the distribution or transmission of gas or electricity (F27).

Both a vertically integrated HDNO and an independent HDNO could evolve into a Combined Operator. If an entity is legally independent from the transmission or distribution activities of gas or electricity (F27), it may even be authorized to operate across both natural gas and hydrogen systems (F23). Such an approach to horizontal integration between hydrogen and other carriers could foster synergies and prevent the inefficient duplication of infrastructure, risks that might otherwise result from strict horizontal unbundling (Baumgart and Lavrijssen, 2023; Fleming, 2024).

It is important to note that the delegation models for hydrogen distribution remain subject to future regulatory decisions. At present,

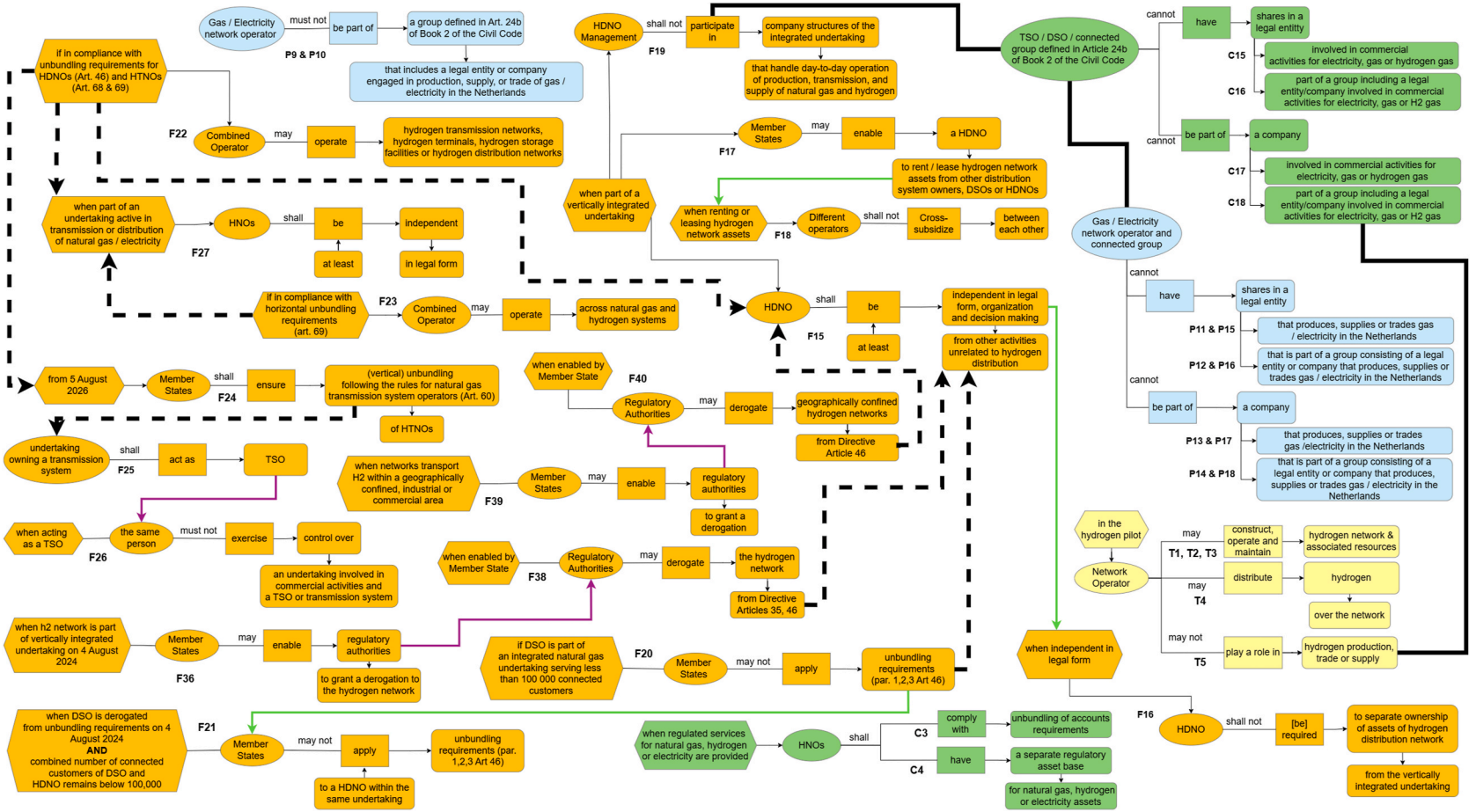

Fig. 6. Rules regarding vertical unbundling.

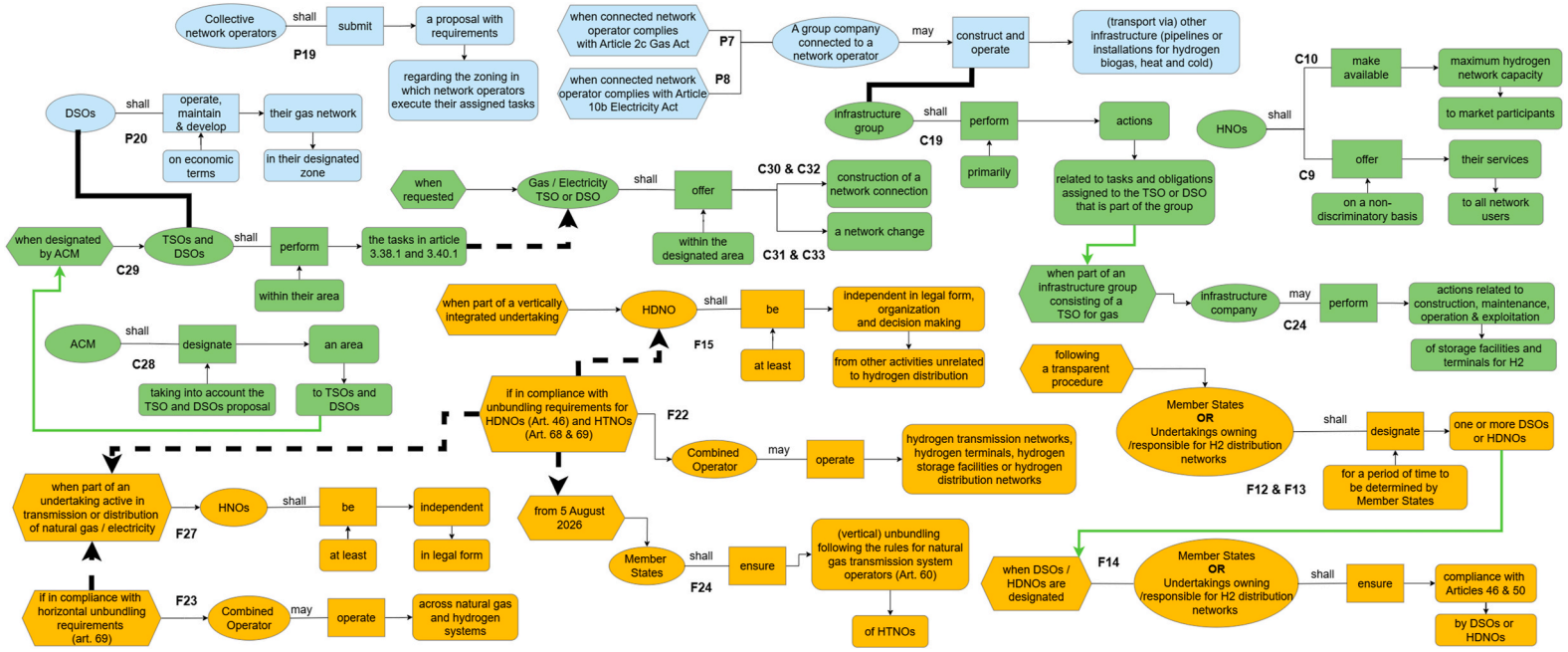

Fig. 7. Rules regarding the delegation of hydrogen distribution.

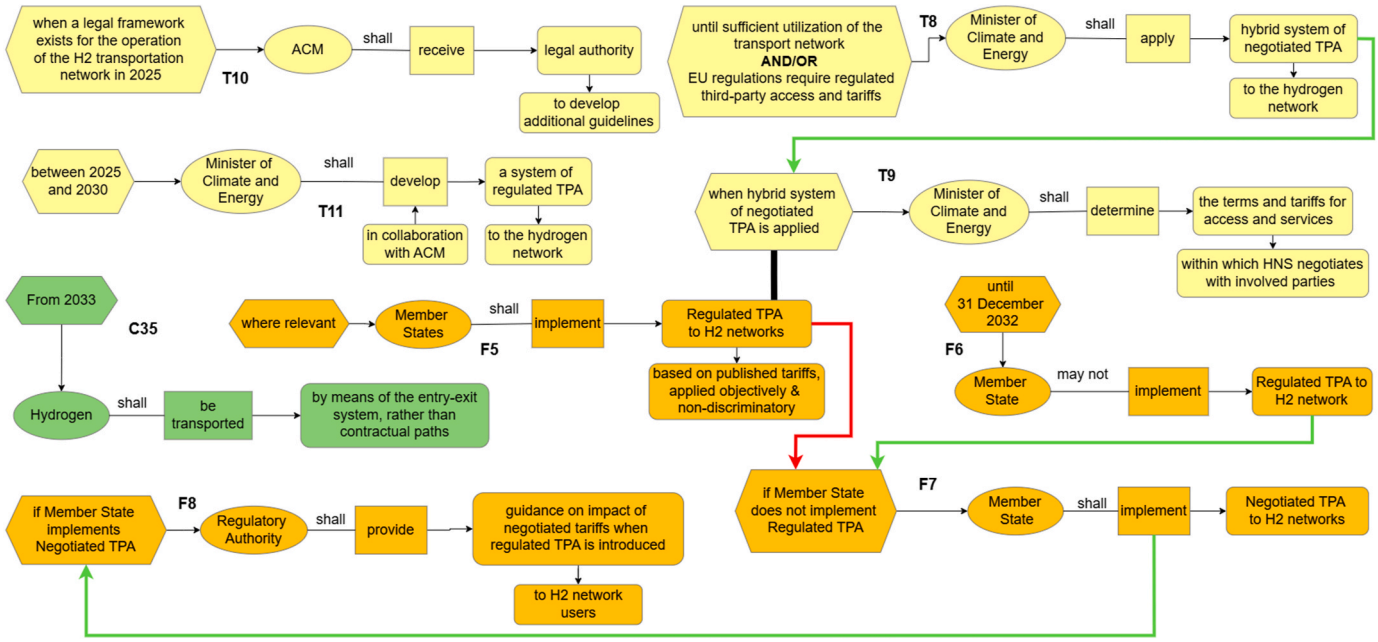

Fig. 8. Rules regarding third-party access.

hydrogen infrastructure development and operation are confined to an infrastructure group or a company within such a group (C19 & C24), mirroring the previous regulatory structure applied to the gas and electricity sectors (P7 & P8). As a result, options for hydrogen distributors outside the scope of pilot projects are limited, and responsibilities specific to hydrogen distributors are incomplete. Current regulations define the role of a HNO by the obligation to maximize network capacity and provide services to market participants (C9 & C10). Without detailed guidelines on the designation and responsibilities of HNOs, the practical impact of these provisions remains limited, thereby perpetuating structural uncertainty for stakeholders.

4.3. Third-Party Access regimes

Following the examination of operator roles, the focus shifts to the interaction between network operators and external market participants (Fig. 8). TPA refers to the provision of infrastructure access to parties that do not control that infrastructure (Broersma et al., 2024) and is critical for fostering competition and ensuring the efficient utilization of network infrastructure.

The network diagrams show that, with the construction of the national hydrogen network, the Dutch government has implemented a hybrid TPA model (T8), wherein the responsible minister sets the terms and tariffs for access and related services (T9). The condition is maintained until the transport network reaches sufficient utilization or until regulated TPA is mandated at the European level (T8).

Between 2025 and 2033, the responsible minister will, in collaboration with the regulatory authority, develop a system of regulated TPA (T11), at which point a national regulator will establish the tariffs and access conditions (Broersma et al., 2024). Current regulations only dictate that hydrogen be transported using an entry-exit system, rather than contractually, from 2033 onwards (C35).

Forthcoming regulations, by default, mandate regulated TPA (F5). However, Member States may not enforce such a system until the end of 2032 (F6) and instead opt for a negotiated TPA system (F7), allowing network operators and customers to establish tariffs and access conditions through commercial negotiations (Broersma et al., 2024). In both the temporary (T10) and future circumstances (F8), the regulatory authority is assigned the task of providing guidance and developing further guidelines.

4.4. Operator responsibilities & support mechanisms

After outlining TPA regimes, the focus turns to the operational obligations imposed on HNOs. This section examines the specific responsibilities and support mechanisms embedded within the regulatory framework shown Fig. 9.

Key operational topics for hydrogen distributors in the Netherlands include the duty to balance the hydrogen network in response to connection or change requests and the adoption of objective, transparent and non-discriminatory rules when balancing the network, under the forthcoming regulations (F34, F35). Aside from the required compliance with unbundling (C3, C4), current regulations require hydrogen distributors to make available the maximum network capacity and the offering of services to all network users. Additionally, the role of Member States in the development of the hydrogen market are addressed (C1, C5-C8) for instance by prohibiting financial transfers between regulated services (C5). However, such transfers may be permitted when the regulatory authority determines that network access tariffs are insufficient to cover network establishment costs (C8).

Additional regulatory provisions support cooperation among network operators. For example, rules encourage collaboration among HNOs (F32) as well as between HDNOs and HTNOs (C2). Regulation on EU level also mandates that DSOs cooperate through an EU DSO entity (C11), while providing HDNOs with the option to collaborate (C12). These measures may help foster synergies for the emerging hydrogen market alongside the established gas and electricity sectors.

Another significant aspect of the regulatory landscape is the option to derogate from the standard framework. Current regulations only allow infrastructure companies to execute additional energy-infrastructure projects by executive order for up to 10 years (C25), or an entitled party may be assigned a tolerance obligation for a Work of General Interest (C34). In contrast, the previous framework allowed electricity and gas network operators to engage in activities beyond those permitted by the Gas and Electricity Act (P1–P6). Aside from the exemptions from unbundling requirements discussed in section 4.1 (F39, F20, F36), the forthcoming regulations, however, do not include a comparable general derogation rule. Given that the hydrogen market and its regulations are still in early development, a flexible derogation mechanism could prove essential to facilitate market advancement.

Lastly, the framework incorporates several support mechanisms

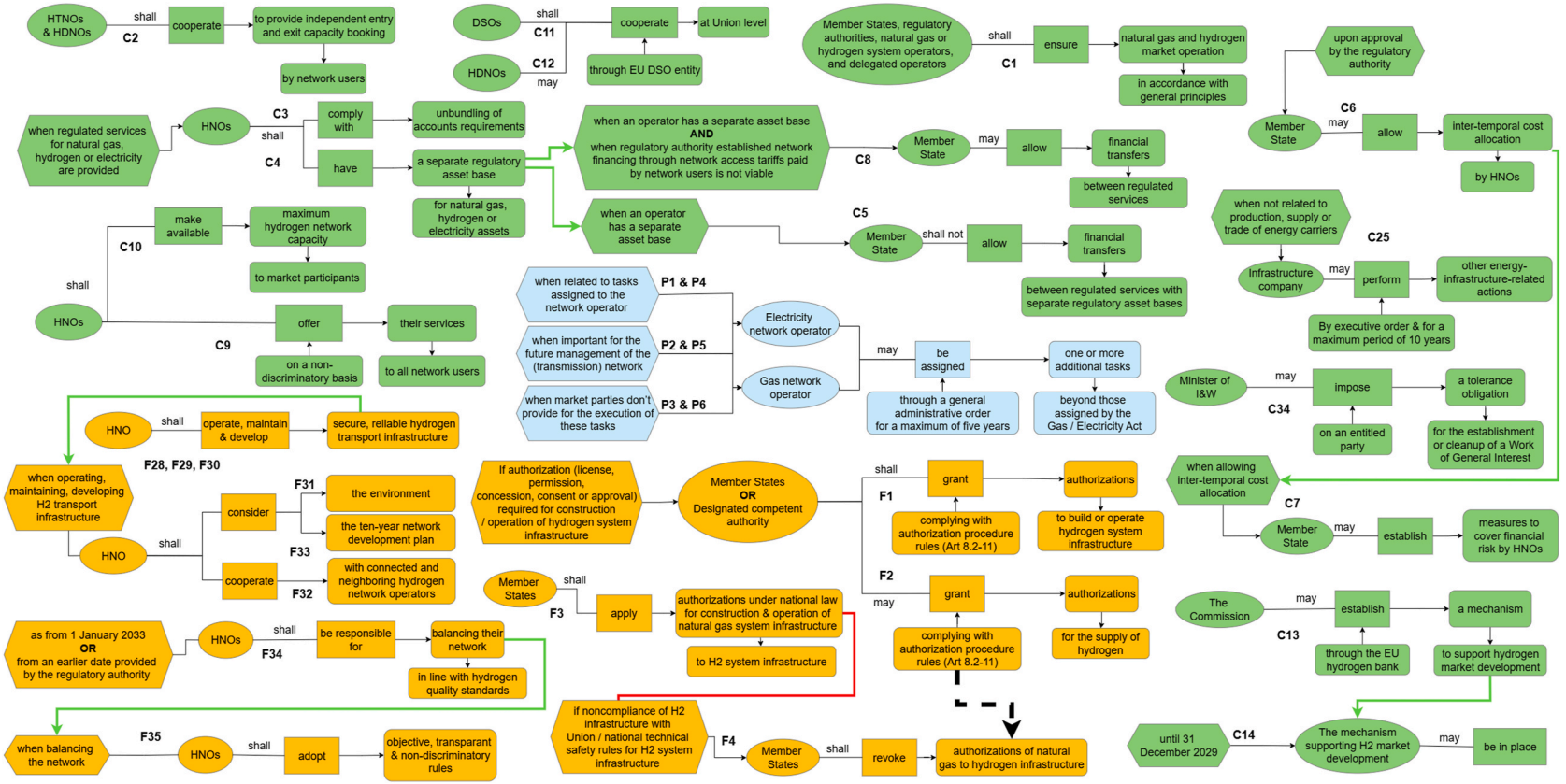

Fig. 9. Rules regarding operator responsibilities and support mechanisms.

Table 2
The propositions formulated based on the network diagrams.

	Topic	Proposition
1	Network Development	Ambiguities in the assignment of responsibilities within regional hydrogen distribution networks slow down or stagnate their development
2	Network Development	The absence of a comprehensive hydrogen market regulatory framework creates market uncertainty, thereby slowing hydrogen distribution network development
3	Finance	The lack of a clearly defined subsidy scheme slows the development of regional hydrogen distribution networks
4	Regulatory Certainty	Limited flexibility in the regulatory framework, beyond existing derogations, undermines the progress of regional hydrogen distribution network development
5	Regulatory Certainty	Stakeholders require additional, region-specific regulations to support the development of regional hydrogen distribution networks adequately

aimed at promoting hydrogen market development. The European Commission may establish an EU hydrogen bank (C13) which may operate until the end of 2029 (C14). However, the specific scope and areas of market development covered by this mechanism remain unclear. Forthcoming regulations will enable Member States or competent regulatory authorities to grant authorizations for the supply of hydrogen (F1), the construction or operation of hydrogen system infrastructure (F2). Member States may also extend existing authorizations under national law that apply to natural gas infrastructure to cover hydrogen infrastructure (F3).

4.5. Emerging propositions

The analysis of the regulatory landscape indicates that although several aspects of hydrogen distribution have been addressed through new regulations, numerous critical issues remain unresolved. The network diagrams served as the basis for formulating a set of propositions to be explored regarding the suitability and effectiveness of the regulatory framework for hydrogen distribution in the Netherlands. These propositions are summarized in Table 2 and are discussed below.

The network diagrams illustrate that the delegation of hydrogen distribution responsibilities in the Netherlands can take multiple forms. As these rules come from the EU-package Directive, their national implementation remains pending. This pending implementation leaves stakeholders in a state of ambiguity, a factor that is likely to hamper hydrogen distribution development (Propositions 1 and 2).

Although the regulations incorporate support mechanisms for hydrogen network development, they do not provide a clearly defined subsidizing scheme. Therefore, proposition 3 states that this negatively affects the development of regional hydrogen distribution networks. Proposition 4 posits that the inherent rigidity of the regulatory framework beyond the few existing derogations significantly stifles the development of regional hydrogen distribution networks. Finally, the diagrams reveal a scarcity of regulations specifically tailored to regional hydrogen practices. Since such rules are often established by lower-level governmental bodies (e.g., provincial or municipal authorities), proposition 5 questions whether additional region-specific regulations are necessary to foster the development of a regional hydrogen distribution network.

5. Stakeholder perspectives: outlooks for hydrogen developments in the Netherlands

This section integrates insights from stakeholder interviews structured around the five propositions. For each proposition, empirical evidence is evaluated and regulatory reform proposals by the interviewees are addressed.

5.1. Proposition 1: ambiguous distribution responsibilities delay development (Network development)

Stakeholders unanimously identify ambiguity in role allocation within regional hydrogen distribution networks as a significant impediment. Interviewees noted that unclear responsibilities lead to project delays, inefficient planning, and reduced investment. For example, Stakeholder 5 remarked that although consensus exists on the desired market structure, the absence of concrete national guidelines hinders decisive action. Similarly, Stakeholder 2 stressed that clearly assigning local network management is crucial to avoid costly future retrofits. Stakeholder 6 observed that without a defined role for grid operators in the regulatory framework, branches of the national hydrogen backbone are neglected in network planning. Even though their integration would yield notable economic and operational benefits.

Complicating matters, current European regulations permit any company to act as a hydrogen distributor (see Section 4.2). Stakeholder 5 argued that established grid operators, with their experience and capacity to repurpose existing gas networks, are best suited for the role. In contrast, regions developing independent networks, without the involvement of existing grid operators, risk creating isolated systems with inconsistent technical and operational standards. In summary, the absence of formalized guidelines creates ambiguity, hindering DSOs and other stakeholders from planning and investing with confidence. Early role clarification is essential to prevent costly retrofits, maintain strategic consistency as projects scale, and foster a unified, interconnected hydrogen network.

5.2. Proposition 2: regulatory gaps create market uncertainty (Network development)

Outdated and non-specific regulations were widely cited as factors that exacerbate market uncertainty and delay the development of hydrogen distribution networks. Stakeholder 1 pointed out that regulatory evolution lags technological advancements and market demands. In contrast, Stakeholder 2 highlighted that adjustments to the Dutch Environment and Planning Act have introduced transitional delays as companies, operators, and authorities require time to adapt to the Act. Stakeholder 3 emphasized that the lack of hydrogen-specific safety and control standards complicates project approvals, creating extra hurdles for compliance with diverse municipal and emergency service requirements. Together with lengthy and uncertain processes in receiving permits, which are also often not hydrogen-specific, this contributes to project hesitancy among stakeholders.

Stakeholders further stressed the importance of ensuring TPA and balanced tariffs. Stakeholder 4 argued that robust regulatory oversight on costs, access, safety, and maintenance should take precedence over debates about ownership. To address these challenges, proposals include

clearer market organization, strategic amendments to the Energy Act to alleviate grid congestion, and an integrated development approach that synchronizes market structures, infrastructure, and regulatory frameworks. For instance, attributing the ability to a regulatory authority to prioritize projects that meet specific strategic goals or increased governmental guidance to enable simultaneous development of the various nodes in the hydrogen value chain.

5.3. Proposition 3: the lack of a clearly defined subsidy scheme impedes progress (finance)

Subsidies emerged in the interviews as a double-edged sword: both a driver and a barrier to hydrogen projects. Both Stakeholders 1 and 6 consider subsidies vital for economic feasibility and Stakeholder 2 considers them essential in creating a safety net. Joint subsidy schemes, where regional and national network operators collaborate in network development, would streamline investments and address broader societal needs, as emphasized by Stakeholder 3.

However, concerns persist regarding the current subsidy system in the Netherlands. Interviewees criticized its lengthy and uncertain approval process, as well as insufficient overall funding. These factors heighten the investment risk, consequently impeding the likelihood of such investments. Recommendations call for establishing a more transparent and structured subsidy framework, potentially including governmental guarantees, regionally focused funding, prioritization of regional areas with high potential hydrogen demand, alternative financing options such as loans, and even participation from pension funds to provide the certainty necessary for large-scale investments.

5.4. Proposition 4: rigid regulations stifle Network growth (regulatory certainty)

The interviewees widely view the current regulatory framework for hydrogen infrastructure as overly rigid, limiting both scalability and innovation. Stakeholder 4 observed that inflexible regulations, particularly those governing hydrogen integration into existing gas networks, hinder the scalability of hydrogen deployment. Similarly, Stakeholder 1 criticized the Environmental and Planning Act for failing to provide clear relief for projects of local or national significance. Although the regulatory framework permits geographically confined hydrogen networks to bypass certain unbundling requirements (Section 4.1), Stakeholder 5 noted a key limitation: these networks cannot be connected to a regulated network like a transmission network. Once the confined networks grow, connection to the regulated system is likely, necessitating full compliance and corresponding operational and regulatory alterations for the confined network. Simultaneously, Stakeholder 4 warned that public ownership of hydrogen assets could stifle innovation.

In response, stakeholders call for more flexible, demand-driven regulatory frameworks rather than the current focus on large hydrogen users. Proposed measures include encouraging small entrepreneurial clusters and fostering collaborative investments among regional industries, authorities, and network operators. According to the stakeholders interviewed, such regulatory approaches can stimulate shared investments and balance costs and benefits, effectively reducing societal costs.

5.5. Proposition 5: Need for tailored regional regulations (regulatory certainty)

Interview responses indicate that, despite recent updates with the Environment and Planning Act and the EU-package, additional clarity and comprehensiveness are needed at the regional level. Stakeholder 5 noted a decline in hydrogen interest compared to previous years, linking this trend partly to insufficient financial support and market clarity. Similarly, Stakeholder 6 stressed the importance of further regulations to drive the regional energy transition, while Stakeholder 2 emphasized the need for clear guidelines regarding hydrogen blending, standards, and local network management. Overall, consensus exists that more tailored market regulations would better prepare the industry for future changes in the hydrogen market and its regulatory framework.

Guided by the INA-derived propositions, the interview insights reveal a multifaceted landscape of ambiguous responsibilities, regulatory gaps, uncertainty in subsidy schemes, and rigid frameworks impeding the advancement of hydrogen distribution infrastructure in the Netherlands. Addressing these challenges through more straightforward guidelines, more flexible and integrated regulatory frameworks, and structured financial support is essential to foster a unified, efficient, and resilient hydrogen network, particularly at the distribution level. The findings also carry broader implications for EU-national alignment as the propositions reflect regulatory gaps or hurdles that currently exist between the existing national and emerging EU-level regulatory landscapes. For example, the ongoing structural uncertainty surrounding distributors' roles and the extent of regulatory flexibility in forthcoming regulations highlight critical areas for future policy reform to support the effective deployment of hydrogen among regional industries.

6. Conclusions and policy implications

Despite the potential of hydrogen in the decarbonization of the Dutch regional industry, its deployment has been progressing slowly, with regulatory barriers identified as a contributing factor. This research has therefore investigated the evolving regulatory landscape for hydrogen distribution in the Netherlands through an institutional analysis of the previous, current, and forthcoming regulations and garnered insights on the experience of stakeholders with the regulatory framework through stakeholder interviews. IG and INA enabled a systematic and detailed breakdown of the specific regulatory components affecting hydrogen distribution in the Netherlands, thereby identifying voids, gaps, or overlaps in the regulatory framework. Stakeholder interviews allowed for further exploration of the propositions derived from the institutional analysis, ultimately garnering insight into potential regulatory reforms to further advance the deployment of hydrogen in the Dutch regional industry.

The findings indicate significant progress in addressing regulatory uncertainty when comparing past, present, and future frameworks. Initially, limited domestic regulations hindered the transition of regional industries to hydrogen. The EU initiatives have provided a foundational regulatory framework. Despite this progress, structural uncertainty remains at the national level, particularly concerning market organization and the delineation of roles and responsibilities. Given that key decisions, such as the incorporation of the EU-package Directive into the Energy Act, are still pending. Stakeholder interviews further reveal a strong demand for clearer guidelines on roles, responsibilities, market organization, and support mechanisms to advance hydrogen distribution. These insights are consistent with Broersma et al. (2024) who addressed the significant structural uncertainty in the TPA approach to hydrogen transmission infrastructure in the Netherlands.

Based on the analysis of the regulatory structure and stakeholder interviews, several recommendations for reform emerge. First, it is essential to clarify the roles and responsibilities for operating the hydrogen distribution infrastructure as soon as possible. The findings indicate that stakeholders remain hesitant to act due to a lack of regulatory certainty. The delegation of hydrogen distribution operators depends on the national governmental decisions regarding the assignment,

geographical location, and scope of responsibilities. Additionally, the continuously evolving regulatory framework, as highlighted by Broersma et al. (2024), adds further legal, governance, and operational uncertainty. Timely clarification of Dutch regulation would give stakeholders the confidence to take concrete, long-term steps toward hydrogen implementation.

A second critical area is financial support. The research shows that stakeholders are uncertain about governmental support, which they deem essential yet insufficient. The combination of financial and regulatory uncertainty leads to investor hesitation for hydrogen infrastructure and equipment, which constrains strategic infrastructure planning necessary for the long-term development of the hydrogen sector. In line with Steinbach and Bunk (2024), stakeholders recommend that regulations governing financial support for hydrogen projects be clarified and strengthened. This is particularly important for regional industries, which may have fewer financial resources to transition to hydrogen despite the potential benefits to both their operations and the overall decarbonization of the energy system.

Balancing is the third critical area. Renewable hydrogen's dependency on renewable energy sources creates significant challenges for regional (decentral) industries. The diagram on hydrogen distribution and stakeholder interviews reveals a lack of regulatory support for balancing. Therefore, the third policy recommendation is to allow for prioritization measures in the regulatory framework, where certain pressing issues can be prioritized in regulatory support and development.

Additionally, it is recommended that flexibility in the regulatory framework for hydrogen distribution be increased. The research finds that regulatory flexibility is limited to the unbundling requirements and authorizations for developing and operating system infrastructure and TPA. Another example is the permits and granting processes that cause considerable delays according to the interviewed stakeholders, aligning with findings from (Jesse et al., 2024) on stakeholder perspectives in Germany and the Netherlands. The flexibility for authorizations allowed by the EU-package is potentially a considerable step forward in making the authorization procedure less confusing and burdensome. Still, the results show that stakeholders perceive limited flexibility in the regulatory framework as a hurdle and recommend establishing more flexibility mechanisms within the regulatory framework. Additionally, flexibility in the regulatory framework might increase the adaptiveness and resilience of the framework to future changes in the market. As stated by van der Spek et al. (2022), given that the hydrogen market is still in its infancy, applying mature gas market designs, such as strict ownership unbundling, could hinder private investment by restricting risk-sharing between producers and consumers (Barnes, 2023). A proposed reform, therefore, is to further enhance the allowance of regulatory flexibility to enable more effective responses and adaptation to unforeseen market changes.

Finally, regional industries not directly linked to the national network should receive greater attention in policymaking. Regulatory structural and outcome uncertainty will likely persist in the short term, despite their shared need for decarbonization. To prevent these industries from relocating outside the Netherlands, it is essential to address the regulatory needs and challenges they face. According to interviewed stakeholders, collaboration among these regional companies and decentralized initiatives can stimulate the development of hydrogen distribution networks. Comprehensive regulations supporting these initiatives can provide the necessary certainty for companies to remain in the country, thereby contributing to market developments through small-scale production and demand developments. Overall, the research findings highlight the need for a coherent institutional and technical framework to support more effective development of physical hydrogen systems.

This research differentiates itself as one of the emerging studies on hydrogen regulations that structurally analyzed and visualized the regulatory landscape, complemented by qualitative insights from stakeholders. Its relevance lies in addressing a gap in the academic body of knowledge on the implications of the regulatory framework for hydrogen distributors in the Netherlands, particularly from an institutional perspective as opposed to from a purely legal or societal perspective. Socially, the research offers clarity on the possibilities available to hydrogen distributors within the regulatory framework. The network diagram provides a comprehensive overview of the regulations relevant to hydrogen distribution in the Netherlands, which can guide regional industrial players in understanding the complex and dynamic nature of the regulatory environment. Furthermore, guided by the propositions derived from the network analysis, the interview findings shed light on stakeholders' experience with the regulatory framework, indicating the areas where measures can or should be taken to support hydrogen deployment on the distribution level. Thereby, this research highlights unresolved questions within the current and anticipated regulatory framework that must be addressed to establish a robust hydrogen distribution network. Given the timeliness of this analysis, it can therefore contribute to the implementation of the EU-package Directive within the Dutch legal framework.

The research focuses on national and EU-level regulatory documents, providing a structured analysis of the overarching regulatory framework and implications for hydrogen deployment. By concentrating on these higher-level regulations, the study highlights regulatory dynamics that shape national policymaking, offering insights into the broader European regulatory landscape. It identifies barriers within the EU-framework and its national translation, thereby informing future regulatory decision-making at both the European Union level and that of Member States. Given that the Netherlands has implemented one of the strictest forms of regulatory unbundling in the EU, future comparative studies could help determine whether the observed challenges are unique to this context or indicative of a more systematic trend across Europe. The focus on regional industries within the Netherlands serves as a relevant case study for examining the regulatory structure and impact for innovation-driven contexts. Concurrently, this research presents a valuable foundation for future research exploring other segments of the hydrogen value chain or subnational policymaking. While this study focused on national-level regulations, interviewees frequently referred to local permitting and governance challenges. These were not formally coded due to the heterogeneity of subnational texts, but they highlight important areas for future research. Such research could delve into the finer operational details, such as coordination mechanisms, price setting, and safety regulations, that fell outside the research scope but can be crucial for developing targeted measures to stimulate hydrogen deployment. Furthermore, the ongoing implementation of the EU-package on a national scale is expected to instigate further analysis of the role allocation among HDNOs, DSOs, TSOs and HTNOs. Such developments offer timely opportunities for future research to obtain additional insights into regulatory gaps and best practices for uniform governance for hydrogen distribution within and beyond the Netherlands.

Although the research approach was designed to be rigorous, several limitations may affect the study's outcomes. One significant constraint is the evolving regulatory landscape in the Netherlands. Many key documents, such as the new Energy Act and the EU-package Directive, are either temporary, forthcoming, or pending full implementation. Given the rapid pace of policy evolution and the ongoing process of aligning national regulations with EU requirements, the findings provide a provisional snapshot of a dynamic regulatory landscape, which may affect their ability to fully anticipate future regulatory developments and their implications for long-term policy design. Additionally, once implemented, the regulatory framework is likely to present stakeholders with new barriers and enablers that may reshape their roles and decision-making capacities. A follow-up study is therefore envisioned to assess future regulatory changes to re-evaluate the conclusions drawn in this research. Additionally, future work is advised to explore future potential scenarios through complementary quantitative methods, such as

simulation.

The methodological approach introduces further challenges. The use of IG 2.0 as a syntactic tool for coding institutional statements has been valuable for assessing the content and interconnections within the regulatory framework. However, this method requires extensive manual coding, which carries an inherent risk of misinterpretation or misunderstanding of regulatory statements. Even though validation was performed through the manual coding of multiple researchers familiar with IG 2.0, the subjective nature of interpreting these statements may have influenced the results. Future research should continue to refine and validate these coding and visualization methods to better understand and mitigate these limitations. Additionally, future research is recommended to also consider constitutive statements in the analysis, rather than only regulative statements, as it could provide additional insight into the regulatory structure on hydrogen distribution in the Netherlands.

In addition, while the stakeholder interviews provided valuable qualitative insights, they reflect individual viewpoints that introduce potential subjective bias. With only six stakeholders participating, drawn from municipal authorities, DSOs, commercial enterprises, and governmental bodies, the sample may not capture the full diversity of experiences and opinions present in the broader hydrogen sector. The data has likely been shaped by the stakeholders' personal experiences, roles, and interests and by using a DSO's network, whose services are geographically concentrated. Additionally, different researchers might categorize or interpret these perspectives in various ways. A recommendation for future research is therefore to extend the number and variety of interviewees to gain a greater understanding of the regulatory challenges and enablers for the Dutch regional industries.

In summary, while the study provides important insights into the regulatory framework for hydrogen distribution in the Netherlands, its outcomes are influenced by the dynamic nature of policy, the narrow focus on regional industries and higher-level regulatory documents, the challenges associated with manual coding and subjective interpretation, the limited and potentially biased stakeholder sample, and the absence of an in-depth analysis of specific operational issues. Future research that addresses these limitations will help to validate and extend the findings of this study.

CRediT authorship contribution statement

Renske van 't Veer: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hidde Meijer:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zofia Lukszo:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Mahshid Hasankhani:** Writing – review & editing, Writing – original draft. **Amineh Ghorbani:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to assist in writing some sections of the article. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of competing interest

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Appendices.

This section provides details regarding the methodologies employed, data gathering and the collected data. Appendix A provides complementary information regarding Institutional Network Analysis, followed by details regarding the interview approach in Appendix B. The resulting network diagram is presented in Appendix C. The rules coded and visualized in this network diagram are provided in the tables in Appendix D, presenting the previously in force regulations (Table 5), the currently in force regulations (Table 6) and the forthcoming regulations (Table 7).

Appendix A. Institutional Network Analysis

When the receiver of an action (object) is the actor carrying out the activity (attribute) in another statement, an actor-driven connection exists. An outcome-driven connection exists when one statement initiates a discrete context that activates a second statement. Lastly, when a statement describes what happens when the opposite of the activity in another statement is carried out, a sanction-driven connection is present.[4]

Fig. 10 below is an example of a network diagram where each IG-coded statement is represented in a graphical form. The Attributes, Context, Aim, and Objects are the nodes, while the Deontic is presented as link between nodes. Whether an outcome-, actor- or sanction-driven connection exists between statements is indicated with coloured lines, respectively purple, green and red[5].

[4] See (Ghorbani et al., 2024) for a detailed description of the protocols for identifying connections and building diagrams

[5] A tool to create the INA diagrams is available at https://ina-editor.tpm.tudelft.nl/#/network/comp.

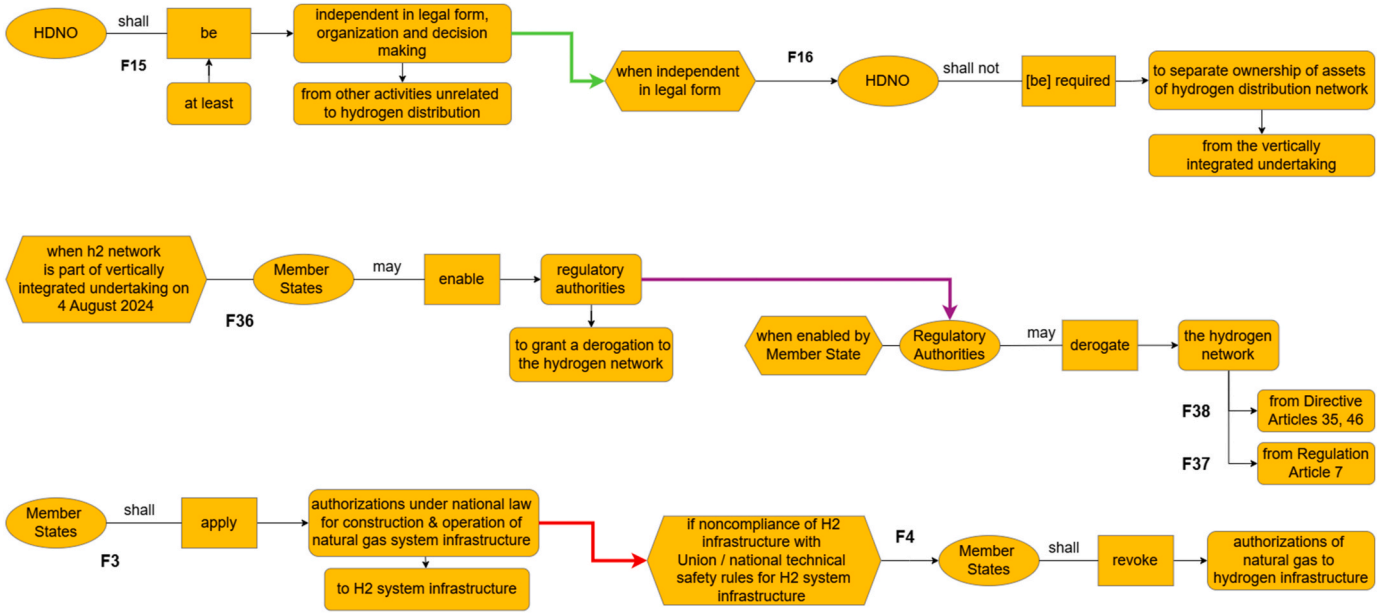

Fig. 10. Example institutional statements and statement connections

Appendix B. Interview approach and questions

Interviews were conducted with the stakeholders listed in Table 3 in compliance with ethical guidelines, ensuring both anonymity and informed consent. Each interview followed a set of predefined objectives, and the questions, themes, and examples outlined in Table 4 were explored during the discussions.

Table 3
Overview of conducted interviews

Interview	Approx. Duration	Interview Type	Description
1	~30 min	Semi-structured	Hydrogen project developer
2	~30 min	Semi-structured	Developer innovative energy solutions
3	~30 min	Semi-structured	Employee Distribution System Operator
4	~40 min	Semi-structured	Employee Governmental Institution supporting innovation
5	~30 min	Semi-structured	Employee Distribution System Operator
6	~35 min	Semi-structured	Employee Municipality orientating hydrogen deployment

Table 4
Interview guide

Discussion topic	Questions
Background and role	1. Can you describe your role and experience in the Dutch hydrogen sector?
	2. How does your organization fit into the hydrogen value chain in the Netherlands?
	3. What are the drivers for the projects you do in the Dutch Hydrogen sector?
Understanding of current regulations	4. What are the key regulations governing hydrogen transportation and distribution according to you?
	5. Can you explain if and how these regulations have evolved over recent years?
	6. What are the infrastructure requirements mandated by the regulatory framework for hydrogen transport and distribution?
Regulatory impact	7. Have you encountered any significant challenges due to these regulations?
	8. What measures does your organization take to comply with the existing hydrogen regulations?
	9. Are there any regulations that you find particularly difficult to comply with? If so, why?
Network development	10. How do planning and zoning regulations affect your actions in the hydrogen sector?
	11. Can hydrogen market regulations influence the development of hydrogen transportation networks? If so, how should these be implemented?
Financial regulations	12. How do regulatory frameworks impact the economic viability of hydrogen projects in your experience?
	13. Are there financial incentives or subsidies available for supporting hydrogen projects? How can these be implemented to accelerate the development of hydrogen networks?
Operation	14. How should the operations of hydrogen transportation networks be regulated?
Barriers & Enablers	15. What regulations have you perceived as enables for hydrogen development in the Netherlands?
	16. What are the biggest regulatory barriers currently facing the hydrogen distribution networks in the Netherlands?
Future of the Regulatory framework	17. Are there upcoming regulatory changes that you are preparing for and how?
	18. In what ways could the regulatory framework be improved to accelerate the development of hydrogen distribution networks?
Generic ending topic/question	19. What else should be done to accelerate the development of hydrogen transportation and distribution networks besides regulatory changes?

Appendix C. Network Diagram

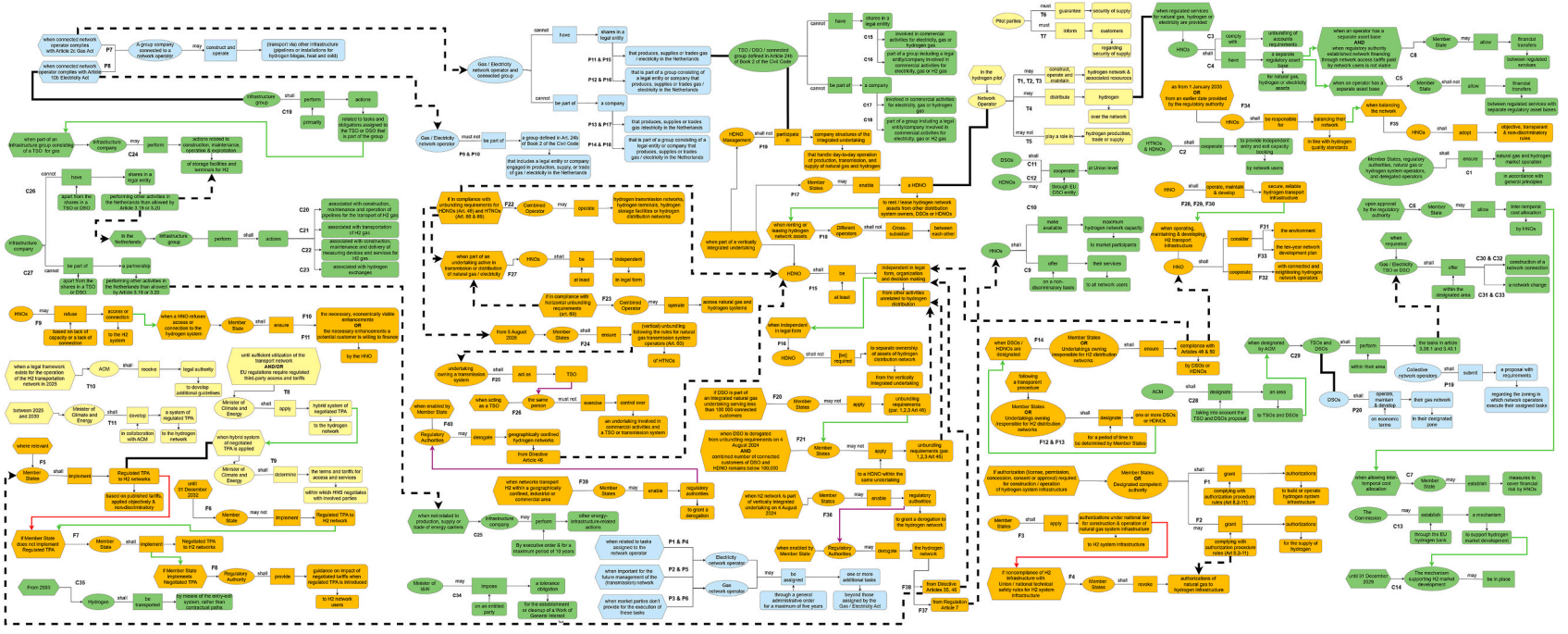

Fig. 11. Complete Network Diagram

Appendix D. Extracted institutional statements

The tables below contain the rules (institutional statements) relevant to hydrogen distribution in the Netherlands that were extracted from the policy documents. The first column provides the statement ID used in the network diagrams, followed by the Article number and legislative document from which the rule was extracted. The last column contains the statements with the components of the IG 2.0 syntax.

Table 5
Rules from the previous regulatory framework (up to mid-2024)

ID	Art.	Source[a]	Statement
P1	10b.1a	GA	A gas network operator (A) may (D) be assigned (I) one or more additional tasks (Bdir) beyond those assigned by the Gas/Electricity Act (Bind) when the tasks are related to the tasks assigned to the network operator under this law (Cac) through general administrative order for a maximum of five years (Cex)
P2	10b.1a	GA	A gas network operator (A) may (D) be assigned (I) one or more additional tasks (Bdir) beyond those assigned by the Gas/Electricity Act (Bind) when the tasks are important for the future management of the gas transmission network, (Cac) through general administrative order for a maximum of five years (Cex)
P3	10b.1a	GA	A gas network operator (A) may (D) be assigned (I) one or more additional tasks (Bdir) beyond those assigned by the Gas/Electricity Act (Bind) when market parties do not, or only to a limited extent, provide for the execution of these tasks (Cac) through general administrative order for a maximum of five years (Cex)
P4	17a.1	EA	An electricity network operator (A) may (D) be assigned (I) one or more additional tasks (Bdir) beyond those assigned by the Gas/Electricity Act (Bind) when the tasks are related to the tasks assigned to the network operator under this law (Cac) through general administrative order for a maximum of five years (Cex)
P5	17a.1	EA	An electricity network operator (A) may (D) be assigned (I) one or more additional tasks (Bdir) beyond those assigned by the Gas/Electricity Act (Bind) when the tasks are important for the future management of the network, (Cac) through general administrative order for a maximum of five years (Cex)
P6	17a.1	EA	An electricity network operator (A) may (D) be assigned (I) one or more additional tasks (Bdir) beyond those assigned by the Gas/Electricity Act (Bind) when market parties do not, or only to a limited extent, provide for the execution of these tasks (Cac) through general administrative order for a maximum of five years (Cex)
P7	10D.2e	GA	A group company connected to a network operator (A) may (D) construct and operate (I) (transport via) other infrastructure (pipelines or installations for hydrogen, biogas, heat and cold) (Bdir) when the connected network operator remains in compliance with Article 2c of the Gas Act (Cac)
P8	17c.2e	EA	A group company connected to a network operator (A) may (D) construct and operate (I) (transport via) other infrastructure (pipelines or installations for hydrogen, biogas, heat and cold) (Bdir) when the connected network operator remains in compliance with Article 10b of the Electricity Act (Cac)
P9	2c.1	GA	A gas network operator (A) must not (D) be part of (I) a group defined in Art. 24b of Book 2 of the Civil code (Bdir) that includes a legal entity or company engaged in production, supply, or trade of gas in the Netherlands (Bind)
P10	10b.1	EA	An electricity network operator (A) must not (D) be part of (I) a group defined in Art. 24b of Book 2 of the Civil code (Bdir) that includes a legal entity or company engaged in production, supply, or trade of electricity in the Netherlands (Bind)
P11	2c.3a	GA	A gas network operator and connected group (A) cannot (D) have (I) shares in a legal entity (Bdir) that produces, supplies or trades gas in the Netherlands (Bind)
P12	2c.3a	GA	A gas network operator and connected group (A) cannot (D) have (I) shares in a legal entity (Bdir) that is part of a group consisting of a legal entity or company that produces, supplies or trades gas in the Netherlands s (Bind)
P13	2c.3b	GA	A gas network operator and connected group (A) cannot (D) be part of (I) a company (Bdir) that produces, supplies or trades gas in the Netherlands (Bind)
P14	2c.3b	GA	A gas network operator and connected group (A) cannot (D) be part of (I) a company (Bdir) that is part of a group consisting of a legal entity or company that produces, supplies or trades gas in the Netherland (Bind)
P15	10b.3a	EA	An electricity network operator and connected group (A) cannot (D) have (I) shares in a legal entity (Bdir) that produces, supplies or trades electricity in the Netherlands (Bind)
P16	10b.3a	EA	An electricity network operator and connected group (A) cannot (D) have (I) shares in a legal entity (Bdir) that is part of a group consisting of a legal entity or company that produces, supplies or trades electricity in the Netherlands s (Bind)
P17	10b.3b	EA	An electricity network operator and connected group (A) cannot (D) be part of (I) a company (Bdir) that produces, supplies or trades electricity in the Netherlands (Bind)
P18	10b.3b	EA	An electricity network operator and connected group (A) cannot (D) be part of (I) a company (Bdir) that is part of a group consisting of a legal entity or company that produces, supplies or trades electricity in the Netherland (Bind)
P19	12b.1.f	GA	The collective network operators (A) shall (D) submit (I) a proposal with requirements (Bdir) regarding the zoning in which network operators execute their assigned tasks (Bind)
P20	10.1/6	GA	DSOs (A) shall (D) operate, maintain and develop (I) their gas network (Bdir) in [a]heir designated zone (Bind) on economic terms (Cex)

[a] GA: Gas Act, EA: Electricity[b]Act.

Table 6
Rules from the current regulatory framework (mid-2024 – 2026)

ID	Art.	Source[a]	Statement
T1		TPP	A Network Operator (A) may (D) construct or reuse of (I) the hydrogen or gas network and associated resources (Bdir) in the pilot for hydrogen in the built environment (Cac)
T2		TPP	A Network Operator (A) may (D) operate (I) the hydrogen network and associated resources (Bdir) in the pilot for hydrogen in the built environment (Cac)
T3		TPP	A Network Operator (A) may (D) maintain (I) the hydrogen network and associated resources (Bdir) in the pilot for hydrogen in the built environment (Cac)
T4		TPP	A Network Operator (A) may (D) distribute (I) hydrogen (Bdir) over the network (Bind) in the pilot for hydrogen in the built environment (Cac)
T5		TPP	A Network Operator (A) may not (D) play a role in (I) hydrogen production, trade and supply (Bdir) in the pilot for hydrogen in the built environment (Cac)
T6		TPP	Pilot parties (A) must (D) guarantee (I) security of supply (Bdir)
T7		TPP	Pilot parties (A) must (D) inform (I) customer (Bdir) regarding security of supply (Bind)
T8		GLH2	The minister of Climate and Energy (A) shall (D) apply (I) a hybrid system of negotiated TPA (Bdir) to the hydrogen network (Bind) until sufficient utilization of the transport network and/or EU regulations require regulated third-party access and tariffs (Cac)
T9		GLH2	The minister of Climate and Energy (A) shall (D) determine (I) the framework of the terms and tariffs for access and services (Bdir) within which HNS negotiates with involved parties (Bind) when hybrid system of negotiated third party access is applied (Cac)

(*continued on next page*)

Table 6 (*continued*)

ID	Art.	Source[a]	Statement
T10		GLH2	The ACM (A) shall (D) receive (I) legal authority (Bdir) to develop additional guidelines (Bind) when a legal framework exists for operation of the hydrogen transportation network in 2025 (Cac)
T11		GLH2	The minister of Climate and Energy (A) shall (D) develop (I) a system of regulated TPA (Bdir) to the hydrogen network (Bind) between 2025 and 2030 (Cac) in collaboration with ACM (Cex)
C1	3.1	EU-R	Member States, regulatory authorities, natural gas or hydrogen system operators, and delegated operators (A) shall (D) ensure (I) natural gas and hydrogen market operation (Bdir) in accordance with general principles (Bind)
C2	3.1.b	EU-R	hydrogen transmission network operators and hydrogen distribution network operators (A) shall (D) cooperate (I) to provide independent entry and exit capacity booking (Bdir) by network users (Bind)
C3	5.1	EU-R	hydrogen network operator (A) shall (D) comply with (I) requirement for unbundling of accounts (Article 75 of Directive (EU) 2024/1788 & Article 56 of Directive (EU) 2019/944) (Bdir) when regulated services for natural gas, hydrogen or electricity are provided (Cac)
C4	5.1	EU-R	hydrogen network operator (A) shall (D) have (I) a separate regulatory asset base (Bdir) for natural gas, hydrogen or electricity assets (Bind) when regulated services for natural gas, hydrogen or electricity are provided (Cac)
C5	5.2	EU-R	A Member State (A) shall not (D) allow (I) financial transfers between regulated services with separate regulatory asset bases (Bdir) when an operator has a separate asset base (Cac)
C6	5.3	EU-R	Member states (A) May (D) allow (I) Inter-temporal cost allocation (Bdir) by HNOs (Bind) upon approval by the regulatory authority (Cac) by hydrogen network operators (Cex)
C7	5.3	EU-R	Member States (A) may (D) establish (I) measures to cover financial risk of HNOs (Bdir) when allowing inter-temporal cost allocation (Cac) to cover the financial risk of hydrogen network operators associated with the initial cost recovery gap of inter-temporal cost allocation (Cex)
C8	5.4	EU-R	a Member State (A) may (D) allow (I) financial transfers (Bdir) between regulated services (Bind) when an operator has a separate asset base AND when regulatory authority established network financing through network access tariffs paid by network users is not viable (Cac)
C9	7.1	EU-R	Hydrogen network operators (A) shall (D) offer (I) their services (Bdir) to all network users (Bind) on a non-discriminatory basis (Cex)
C10	7.2	EU-R	Hydrogen network operators (A) shall (D) make available (I) the maximum capacity of a hydrogen network (Bdir) to market participants (Bind)
C11	39	EU-R	Distribution system operators (A) shall (D) cooperate (I) at Union level (Bdir) through the EU DSO entity (Cex)
C12	39	EU-R	hydrogen distribution network operators of a hydrogen network (A) may (D) cooperate (I) at Union level (Bdir) through the EU DSO entity (Cex)
C13	52	EU-R	The commission (A) may (D) establish (I) a mechanism (Bdir) to support market development of hydrogen (Bind) through the EU Hydrogen Bank (Cex)
C14	52	EU-R	The mechanism supporting hydrogen market development (A) may (D) be in place (I) until December 31, 2029 (Cac)
C15	3.10.2	ENA	A TSO or DSO or connected group as stated in article 24b of Book 2 of Civil Code (A) cannot (D) have (I) shares in a legal entity (Bdir) that produces, supplies or trades electricity, gas or hydrogen gas (Bind)
C16	3.10.2	ENA	A TSO or DSO or connected group as stated in article 24b of Book 2 of Civil Code (A) cannot (D) have (I) shares in a legal entity (Bdir) that is part of a group consisting of a legal entity or company that produces, supplies or trades electricity, gas or hydrogen gas (Bind)
C17	3.10.2	ENA	A TSO or DSO or connected group as stated in article 24b of Book 2 of Civil Code (A) cannot (D) be part of (I) a company (Bdir) that produces, supplies or trades electricity, gas or hydrogen gas (Bind)
C18	3.10.2	ENA	A TSO or DSO or connected group as stated in article 24b of Book 2 of Civil Code (A) cannot (D) be part of (I) a company (Bdir) that is part of a group consisting of a legal entity or company that produces, supplies or trades electricity, gas or hydrogen gas (Bind)
C19	3.19.1	ENA	An infrastructure group (A) shall (D) perform (I) actions (Bdir) related to tasks and obligations assigned to the TSO or DSO that is part of the group (Bind) primarily (Cex)
C20	3.19.2b	ENA	An infrastructure company (A) shall (D) perform (I) actions (Bdir) associated with construction, maintenance and operation of pipelines for the transport of hydrogen gas, gas from renewable sources and other gaseous substances from renewable source (Bind) in the Netherlands (Cac)
C21	3.19.2b	ENA	An infrastructure company (A) shall (D) perform (I) actions (Bdir) associated with transportation of hydrogen gas, gas from renewable sources and other gaseous substances from renewable sources through the network (Bind) in the Netherlands (Cac)
C22	3.19.2b	ENA	An infrastructure company (A) shall (D) perform (I) actions (Bdir) associated with construction, maintenance and delivery of measuring devices and measurement services for hydrogen gas or other gaseous substances from renewable source (Bind) in the Netherlands (Cac)
C23	3.19.2b	ENA	An infrastructure company (A) shall (D) perform (I) actions (Bdir) associated with hydrogen exchanges (Bind) in the Netherlands (Cac)
C24	3.19.4e	ENA	An infrastructure company (A) may (D) perform (I) actions related to construction, maintenance, operation and exploitation (Bdir) of storage facilities and terminals for H2 and other infrastructure for import, export, conversion, and transshipment of hydrogen gas and hydrogen carriers (Bind) when part of an infrastructure group consisting of a TSO for gas (Cac)
C25	3.20.1	ENA	An infrastructure company (A) may (D) perform (I) other energy-infrastructure-related actions (Bdir) when not related to production, supply or trade of energy carriers (Cac) by executive order and for a maximum period of 10 years (Cex)
C26	3.21.1	ENA	An infrastructure company (A) cannot (D) have (I) shares in a legal entity (Bdir) performing other activities in the Netherlands than allowed by Article 3.19 or 3.20 (Bind) apart from the shares in a TSO or DSO (Cex)
C27	3.21.2	ENA	An infrastructure company (A) cannot (D) be part of (I) a partnership (Bdir) performing other activities in the Netherlands than allowed by Article 3.19 or 3.20 (Bind) apart from participation in a TSO or DSO (Cex)
C28	3.37	ENA	The ACM (A) shall (D) designate (I) an area (Bdir) to TSOs and DSO to perform their tasks in article 3.38.1 (Bind) taking into account the TSO and DSOs proposal (Cex)
C29	3.37	ENA	TSOs and DSOs (A) shall (D) perform (I) the tasks in article 3.38.1 and 3.40.1 (Bdir) when designated by ACM (Cac) within that area (Cex)
C30	3.38.1	ENA	Electricity TSO or DSO (A) shall (D) offer (I) construction of a network connection (Bdir) when requested (Cac) within the designated area (Cex)
C31	3.38.1	ENA	Electricity TSO or DSO (A) shall (D) offer (I) a network change (Bdir) when requested (Cac) within the designated area (Cex)
C32	3.40.1	ENA	Gas TSO or DSO (A) shall (D) offer (I) construction of a network connection (Bdir) when requested (Cac) within the designated area (Cex)
C33	3.40.1	ENA	Gas TSO or DSO (A) shall (D) offer (I) a network change (Bdir) when requested (Cac) within the designated area (Cex)
C34	10.21.1	EPA	The Minister of Infrastructure and Water Management (A) may (D) impose (I) a tolerance obligation (Bdir) for the establishment or cleanup of a work of general interest not mentioned by the EPA (Bind) on an entit[b]ed party (Cex)
C35	3.1.b	EU-R	hydrogen (A) shall (D) be transported (I) by means of the entry-exit system, rather than contractual paths (Bdir) from 2033 (Cac)

[a] TPP: Temporary Pilot [c]olicy, GLH2: Guidelines Hydrogen, EU-R: EU package Regulation, ENA: Energy Act; EPA: Environment and Planning Act.

Table 7
Rules from the forthcoming regulatory framework (from 2026)

ID	Art.	Source[a]	Statement
F1	8.1	EU-D	the Member States or a designated competent authority (A) shall (D) grant (I) authorisations (Bdir) to build or operate hydrogen system infrastructure (Bind) if an authorisation (licence, permission, concession, consent or approval) is required for the construction or operation of hydrogen system infrastructure (Cac) complying with authorisation procedure rules (Art. 8.2–11) (Cex)
F2	8.1	EU-D	the Member States or a designated competent authority (A) may (D) grant (I) authorisations (Bdir) for the supply of hydrogen (Bind) if an authorisation (licence, permission, concession, consent or approval) is required for the construction or operation of hydrogen system infrastructure (Cac) complying with authorisation procedure rules (Art. 8.2–11) (Cex)

(*continued on next page*)

Table 7 (*continued*)

ID	Art.	Source[a]	Statement
F3	8.9	EU-D	Member States (A) shall (D) apply (I) authorisations under national law for the construction & operation of natural gas system infrastructure (Bdir) to hydrogen system infrastructure (Bind)
F4	8.9	EU-D	Member States (A) shall (D) revoke (I) authorisations of natural gas to hydrogen infrastructure (Bdir) if noncompliance of hydrogen infrastructure with Union/national technical safety rules for hydrogen system infrastructure (Cac)
F5	35.1	EU-D	Member States (A) shall (D) implement (I) Regulated third-party access to hydrogen networks (Bdir) based on published tariffs applied objectively & non-discriminatory (Bind)
F6	35.4	EU-D	Member State (A) may not (D) implement (I) a system of regulated third-party access (Bdir) Until December 31, 2032 (Cac)
F7	35.4	EU-D	The Member State (A) shall (D) implement (I) a system of negotiated third-party access to hydrogen networks (Bdir) if a Member State does not implement a system of regulated third-party access (Cac)
F8	35.5	EU-D	The regulatory authorities (A) shall (D) provide (I) guidance on the impact on negotiated tariffs when regulated third-party access is introduced (Bdir) to hydrogen network users (Bind) if Member State implements negotiated third-party access (Cac)
F9	38.1	EU-D	hydrogen network operators (A) may (D) refuse (I) access or connection (Bdir) to the hydrogen system (Bind) based on lack of capacity or a lack of connection (Cex)
F10	38.2	EU-D	Member States (A) shall (D) ensure (I) the necessary, economically viable enhancements (Bdir) by the HNO (Bind) when a HNO refuses access or connection to the hydrogen system (Cac)
F11	38.2	EU-D	Member States (A) shall (D) ensure (I) the necessary enhancements a potential customer is willing to finance (Bdir) by the HNO (Bind) when a HNO refuses access or connection to the hydrogen system (Cac)
F12	43	EU-D	Member States or undertakings that own or are responsible for distribution systems or hydrogen distribution network (A) shall (D) designate (I) one or more DSOs (Bdir) for a period of time to be determined by Member States (Cac) following a transparent procedure (Cex)
F13	43	EU-D	Member States or undertakings that own or are responsible for distribution systems or hydrogen distribution network (A) shall (D) designate (I) one or more HDNOs (Bdir) for a period of time to be determined by Member States (Cac) following a transparent procedure (Cex)
F14	43	EU-D	Member States (A) shall (D) ensure (I) acting in accordance with Articles 44, 46, 47 and 50. (Bdir) by the designated distribution operators (Bind) when DSOs/HDNOs are designated (Cac)
F15	46.1	EU-D	a HDNO (A) shall (D) be (I) independent in legal form, organisation and decision making (Bdir) from other activities unrelated to hydrogen distribution (Bind) when part of a vertically integrated undertaking (Cac) at least (Cex)
F16	46.1	EU-D	Independence of HDNO in legal form (A) shall not (D) [be] required (I) to separate ownership of assets of hydrogen distribution network (Bdir) from the vertically integrated undertaking (Bind) when independent in legal form (Cac)
F17	46.1	EU-D	Member States (A) may (D) enable (I) a hydrogen distribution network operator (Bdir) to rent or lease hydrogen network assets from other distribution system owner, DSOs or HDNOs (Bind) when in the same undertaking (Cac) by HDNOs (Cex)
F18	46.1	EU-D	different operators (A) shall not (D) cross-subsidize (I) between each other (Bdir) when renting or leasing hydrogen network assets (Cac)
F19	46.2a	EU-D	Management of the HDNO (A) shall not (D) participate in (I) company structures of the integrated undertaking (Bdir) that handle day-to-day operation of production, transmission, and supply of natural gas and hydrogen (Bind)
F20	46.4	EU-D	Member States (A) may not (D) apply (I) unbundling requirements (par. 1,2,3 art 46) (Bdir) if DSO is part of an integrated natural gas undertaking serving less than 100,000 connected customers. (Cac)
F21	46.4	EU-D	Member States (A) may not (D) apply (I) unbundling requirements (par. 1,2,3 art 46) (Bdir) to a HDNO within the same undertaking (Bind) when the DSO is derogated from the unbundling requirements on August 4, 2024 & the combined number of connected customers of the DSO and HDNO remains below 100,000 (Cac)
F22	49.2	EU-D	A combined operator (A) may (D) operate (I) hydrogen transmission networks, hydrogen terminals, hydrogen storage facilities or hydrogen distribution network (Bdir) if in compliance with unbundling requirements for HDNOs (Art. 46) and HTNOs (Art. 68 & 69) (Cac)
F23	49.3	EU-D	A combined operator (A) may (D) operate (I) across natural gas and hydrogen systems (Bdir) if in compliance with horizontal unbundling requirements (Art. 69) (Cac)
F24	68.1	EU-D	Member States (A) shall (D) ensure (I) (vertical) unbundling following the rules for natural gas transmission system operators (Art. 60) (Bdir) of hydrogen transmission network operators (Bind) from August 5, 2026 (Cac)
F25	60.0	EU-D	an undertaking owning a transmission system (A) shall (D) act as (I) transmission system operator (Bdir)
F26	60.1	EU-D	The same person (A) must not (D) exercise (I) control over (Bdir) an undertaking involved with commercial activities & a TSO or transmission system (Bind) when acting as a TSO (Cac)
F27	69.1	EU-D	a hydrogen transmission network operator (A) shall (D) be (I) independent (Bdir) in legal form (Bind) when part of an undertaking active in transmission or distribution of natural gas or electricity (Cac) at least (Cex)
F28	50.1a	EU-D	An operator of a hydrogen network, storage or terminal (A) shall (D) operate (I) a secure and reliable infrastructure for hydrogen transport or storage (Bdir)
F29	50.1a	EU-D	An operator of a hydrogen network, storage or terminal (A) shall (D) maintain (I) a secure and reliable infrastructure for hydrogen transport or storage (Bdir)
F30	50.1a	EU-D	An operator of a hydrogen network, storage or terminal (A) shall (D) develop, including repurposing (I) a secure and reliable infrastructure for hydrogen transport or storage (Bdir)
F31	50.1a	EU-D	An operator of a hydrogen network, storage or terminal (A) shall (D) consider (I) the environment (Bdir) when operating, maintaining and developing infrastructure for hydrogen transport or storage (Cac)
F32	50.1a	EU-D	An operator of a hydrogen network, storage or terminal (A) shall (D) cooperate (I) with connected and neighboring hydrogen network operators (Bdir) when operating, maintaining and developing infrastructure for hydrogen transport or storage (Cac)
F33	50.1a	EU-D	An operator of a hydrogen network, storage or terminal (A) shall (D) consider (I) the ten-year network development plan (Bdir) when operating, maintaining and developing infrastructure for hydrogen transport or storage (Cac)
F34	50.4	EU-D	Hydrogen network operators (A) shall (D) be responsible for (I) balancing their network (Bdir) as from January 1, 2033, or as from an earlier date provided by the regulatory authority (Cex)
F35	50.4	EU-D	Hydrogen network operators (A) shall (D) adopt (I) objective, transparent and non-discriminatory rules (Bdir) when balancing the network (Cex)
F36	51.1	EU-D	Member States (A) may (D) enable (I) regulatory authorities (Bdir) to grant derogation to the hydrogen network (Bind) when a hydrogen network belonged to a vertically integrated undertaking on August 4, 2024 (existing hydrogen network) (Cac)
F37	51.1	EU-D	Regulatory authorities (A) may (D) derogate (I) the hydrogen network (Bdir) from Article 7 (third-party access concerning HNOs) of Regulation (EU) 2024/1789 (Bind) when enabled by the Member State (Cac) through regulatory authorities (Cex)
F38	51.1	EU-D	Regulatory authorities (A) may (D) derogate (I) the hydrogen network (Bdir) from Articles 35 (third-party access to hydrogen networks), 46 (unbundling DSOs and HDNOs) (Bind) when enabled by the Member State (Cac) through regulatory authorities (Cex)
F39	52.1	EU-D	Member States (A) may (D) enable (I) regulatory authorities (Bdir) to grant a derogation (Bind) when hydrogen netw[c]rks transport hydrogen within a geographically confined, industrial or commercial area. (Cac)
F40	52.1	EU-D	Regulatory authorities (A) may (D) derogate (I) a geographically confined hydrogen network (Bdir) from Article 46 (Bind) when enabled by the Member State (Cac)

[a] EU-D: EU package Directive.

Data availability

Anonymized interview data will be made available upon request.

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