Certification of a Hydrogen Transmission Network Operator

Lessons for Sweden

Report for Energimarknadsinspektionen

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Project description

The introduction of hydrogen requires the build-out of new infrastructure and/or the conversion of existing gas infrastructure, and a regulatory framework to that end. In this report, we describe the development of hydrogen infrastructure in European regulation and in selected countries. We also described the possible role of hydrogen in the Swedish energy system in the long run and assessed a set of options for organising the hydrogen transmission network operator function. Finally, we put forward a set of recommendations for the development of a Swedish hydrogen regulation and the role of the Ei in that respect.

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Executive summary

Background and purpose

Hydrogen is expected to play a crucial role in the future decarbonised energy systems. Sweden, like other European countries, has adopted strategies for the role and growth of hydrogen.

The introduction of hydrogen requires the build-out of new infrastructure and/or the conversion of existing gas infrastructure, and a regulatory framework to that end. In Sweden, the Swedish Energy Authority (SEA) has been tasked with a government assignment to coordinate work with hydrogen in Sweden in close dialogue with, inter alia, the Swedish Energy Market Inspectorate.

The EU is currently in the process of developing the regulatory framework for hydrogen, including rules for the certification of hydrogen transmission network operators (HTNOs). The purpose of this report is to give input to SEA's coordination work and to the Energy Market Inspectorate's future work with a possible certification process.

Sector coupling

Hydrogen is a gas with similar characteristics as other gases when it comes to transportation and storage, and hydrogen can, with certain adaptations, use existing methane gas infrastructure and replace methane gas in current uses. On the other hand, hydrogen can relieve the electricity network: Hydrogen can be produced from renewable power generation on-site (power-to gas, as green hydrogen) and transported to the user. Use cases include industry, transportation, and power generation (gas-to-power). Similarly, hydrogen can be produced from methane gas with carbon capture (blue hydrogen). As an energy carrier, hydrogen is also an alternative to electricity when it comes to the transportation of energy from suppliers to users.

Sweden has ambitious targets for the scaling up of hydrogen production and use. Initially, the hydrogen industry is expected to be developed within "hydrogen valleys" or clusters, where renewable generation and hydrogen production are located near industrial uses.[1] Whereas the Swedish methane gas network is limited to the southwest coast, the electricity grid extends across the entire country, and the initial hydrogen economy is expected to be established in the north.

European legislation

A Hydrogen and Gas Markets Decarbonisation Package is currently being legislated on in the EU, with a provisional agreement on the legal text reached in December 2023.

This defines important types of actors, notably hydrogen transmission and distribution network operators, as well as their formal legal roles. Among other things, it also establishes requirements for the unbundling of these actors and on the form of any hydrogen network tariff model.

[1] "A Hydrogen Valley is a geographical area – a city, a region, an island or an industrial cluster – where several hydrogen applications are combined into an integrated hydrogen ecosystem that consumes a significant amount of hydrogen, improving the economics behind the project. It should ideally cover the entire hydrogen value chain: production, storage, distribution and final use." https://ceenergynews.com/hydrogen/hydrogen-valleys-a-regional-and-very-promising-phenomenon/

The potential roles of hydrogen transmission network operators as foreseen by the legislation include:

- providing non-discriminatory access to transmission infrastructure,
- developing hydrogen infrastructure plans,
- ensuring gas quality,
- developing sufficient cross-border capacity,
- balancing the network,
- ensuring clear and efficient tariffs, and
- coordinating at a Union-wide level with other hydrogen transmission network operators.

ENNOH, the European Network of Network Operators for Hydrogen, will consist of all certified hydrogen transmission network operators in EU member states, and have a legal mandate to create network codes, publish 10-year network development plans, and cooperate with ENTSO-G and ENTSO-E to create an integrated market.

The certification process is set out in Chapter IX, Section 5 of the Directive and requires that HTNOs be certified by a National Energy Regulator (NRA). For hydrogen transmission network operators, the NRA must ensure compliance with the unbundling requirements contained in Article 62 of the Directive.

Hydrogen transmission network operators face both horizontal and vertical unbundling requirements. For horizontal unbundling, concerning integration with electricity and natural gas networks, legal unbundling is generally required. However, a derogation may be obtained where a cost-benefit analysis shows this to be beneficial.

For vertical unbundling, the general principles and approaches for natural gas TSOs apply. As such, the same set of actors should not control both a hydrogen transmission network and hydrogen supply or production activities. However, this requirement can be met in numerous ways ranging from full ownership unbundling to ensuring the independence of transmission network activities within a single vertically integrated organisation.

A time-limited derogation to the above unbundling requirements may be granted to certain named isolated regions, including Upper Norrland (NUTS 2 SE33).

If the organisation applying for certification is controlled by actors outside the EU, the certifying NRA must also consider the national and Union-wide security implications. In such cases, the opinion of the Commission on the actor's eligibility should be sought.

In addition, a Member State may empower the NRA to grant derogations from the unbundling and certification requirements for hydrogen transmission network operators if the concerned hydrogen network covers "a geographically confined, industrial or commercial area" and fulfils certain additional, legally defined criteria. This option may become relevant in the context of the envisaged hydrogen clusters (see below). If Sweden makes use of this option and a hydrogen transmission network operator requests a corresponding derogation, it is up to the NRA to determine whether these criteria are fulfilled.

Insights from international practices and experience

Other European countries are also in the process of implementing EU hydrogen regulation and national hydrogen strategies. We have surveyed the status of these efforts in Finland, Denmark, Germany, and the Netherlands, to look for lessons valuable for the Swedish process. We find that relevant lessons are few. There are some similarities among the countries, but the overall picture is quite diverse.

The current energy system, including the power generation mix and energy infrastructure, the potential for expansion of renewable power generation and the decarbonization options strongly affect the expected role of hydrogen in the future system.

All the countries have given the current gas TSOs central roles in the development of the hydrogen infrastructure and market. The main reasons are the similarities between natural gas transportation and hydrogen and the possibility to partly convert existing natural gas infrastructure to hydrogen. In Denmark, Energinet is the TSO for both electricity and gas. They emphasize the benefits of coordinated planning of different energy infrastructures.

Finland is the country most similar to Sweden both when it comes to the extent of the gas network, the electricity generation mix, and the industry structure. Even in Finland, the responsibility is so far placed with the gas TSO. Unlike in Sweden, however, the Finnish gas TSO is a state-owned company.

Although the responsibility for planning and development of a hydrogen infrastructure has been delegated, none of the countries have formally certified a national (or regional) HTNO yet. They are all waiting for the final EU regulation to the adopted.

Options for the organisation of an HTNO

The following options for unbundling exist:

Under the **Independent Transmission System Operator (ITO)** model, TSO tasks are performed by an ITO that may be owned by the vertically integrated company but must be independent from the group's commercial activities. This implies that the ITO must not control, be controlled by, hold participations, or be participated in by other companies belonging to a vertically integrated undertaking that are active in production or supply. The ITO must also comply with functional and accounting unbundling requirements.

Under the **Independent System Operator (ISO)** model, energy supply companies may still formally own gas or electricity transmission infrastructure. However, decisions regarding operation, maintenance and investment in the network are taken by an ISO, which is not owned by the vertically integrated undertaking. The ISO is a TSO and is subject to all the obligations this implies.

Management and accounting unbundling requires that the accounts of transmission and distribution activities must be separated from other activities.

Functional unbundling requires that network and competitive activities be separated into different, independent administrative units.

Legal unbundling requires that network activities be placed in a separate legal entity.

Insights from certification of electricity and gas TSOs

As for HTNOs, certification of electricity and gas TSOs is the responsibility of the NRAs. Before making a final decision, the NRA adopts a preliminary decision which is reviewed by the Commission. The Commission's practical guidance on the certification procedures, likely to be relevant to certification of HTNOs as well, gives an overview of the certification criteria relevant under different unbundling requirements. A key feature of the certification procedures is that the ITO model requires significantly more regulation and detailed documentation, most importantly to ensure compliance and neutrality of the TSO. The ISO model is also more complex than the TSO due to the need to document that the ISO has the necessary mandate and resources to carry out investment planning and make investment decisions.

Options for HTNO responsibility in Sweden

Provisions for the current Swedish electricity and gas TSOs

Sweden currently has separate certified TSOs for electricity and gas.

The Swedish electricity TSO, Svenska kraftnät (Svk), is a state-owned entity. Its general objective is to manage, operate, and develop a cost-effective, reliable, and environmentally adapted power transmission system. Its duties include

- Expansion of the transmission network
- Promotion of competition
- Promotion of R&D, and demonstration of new technologies
- Monitoring and providing information
- Consulting with and reporting to the Swedish government and providing ten-year investment plans biannually.

The natural gas TSO, Swedegas (a subsidiary of Nordion Energi), is privately owned and operates within the framework set out in the natural gas law. Its general objectives correspond to those of Svk. The law requires:

- Vertical unbundling from production and trade of natural gas
- Accounting unbundling from distribution of natural gas
- Obligation to connect third parties on reasonable terms
- Measure and report transmitted volumes
- Set reasonable fees, that are objective and non-discriminatory
- Adhere to revenue limits set in advance
- Build infrastructure provided government concession

Assessment of HTNO options

We have considered a set of feasible HTNO options that combine different models for sector integration and unbundling models according to table 1.

In line with the available models for TSO certification in the gas and electricity sectors, we assume that all of the above options can be made compliant with future EU rules for certification of HTNOs, including any requirements on horizontal unbundling in the integrated models.

In general, we find that a TSO model has some advantages over the other options. Full ownership unbundling makes it easier to achieve neutrality, compared to the ITO solution. An ITO requires extra regulation to be efficient. The TSO is also able to plan and finance investments without need for external coordination, compared to an ISO solution. Efficient coordination and financing can also be achieved with the ITO solution, but again more complex regulation is needed for the underlying objectives to be reached. One may also hypothesise that a hydrogen TSO is in line with a likely long-run European target model, as seen in the gas and electricity sector.

Table 1 Options for HTNO organization

	TSO	ISO	ITO
Separate HTNO(s)	Separate unbundled HTNO-TSO	Separate unbundled HTNO-ISO	Separate HTNO-TSO part of VIU
Integration gas TSO-HTNO	Gas TSO + unbundled HTNO-TSO	Gas ISO + separate unbundled HTNO-ISO	Gas TSO + HTNO-TSO part of VIU
Integration electricity TSO-HTNO	Electricity TSO + unbundled HTNO-TSO	N/A assuming electricity TSO remains	N/A assuming electricity TSO remains

In the long run, we also find that integration with the electricity TSO has more potential benefits than the other options. This stems from the expected increased role of sector coupling and the benefits from coordinated short-run dispatch and balancing and from long-term coordinated development of the physical infrastructures. However, it also makes regulation more complex in some respects.

Coordination can also be achieved through a designated entity with the necessary powers. This solution entails higher transaction costs and administrative resources and adds complexity, but avoids the need to integrate the TSO and the HTNO.

We have discussed the options in a long-term perspective. There is however also a need to consider the path to a desired long run model if this differs from the initial options available. Given the small role of natural gas in the current Swedish energy system, there is little to build on with existing infrastructures and stakeholders. Instead, there is a possibility that the first applicants for HTNO certification will be separate operators in different parts of the country. A model with several smaller HTNOs that are not physically integrated is likely to have drawbacks in the form of inefficient size, more costly coordination and too low security of supply due to a lack of integration of grids. This is particularly relevant if hydrogen is expected to play a significant part in the future. It is then important that Ei carefully assesses how the regulation can facilitate a smooth transition to the long-term solution.

State ownership may complement the regulation, national/EU ownership may be desirable from security criteria. Again, the importance of ownership restrictions depends on the role of hydrogen in the long run.

Concluding remarks

The development of a Swedish hydrogen infrastructure is still at an early stage, but an outline of the future European regulation is starting to emerge. This has several implications for Ei.

Firstly, Ei must prepare for an expanded role in regulating the hydrogen sector. The main legal and regulatory frameworks for certification processes and unbundling requirements are likely to be similar to what has become the standard for electricity and natural gas. The same applies to the connection and access regime based on non-discriminatory tariffs and third-party access. It is however likely that Ei will have a larger role in network planning and development compared to other energy infrastructures.

In the short run, Ei has flexibility with respect to the certification process and other parts of the evolving European regulation. The first hydrogen infrastructure players may be eligible for derogation decisions – i.e., as geographically confined networks. Also, key elements of the new directive and regulation do not come into force until 2032/2033.

On the substantial elements of the regulation, a key challenge is the relationship between the options in the short run versus a long-run efficient solution compliant with EU regulation. If hydrogen is expected to play a significant role in the future Swedish energy system, a transition to an efficient long-term solution should be planned for. This means that Ei needs to start thinking about several issues even at this early stage. Key issues include the preferred HNTO model (TSO/ISO/ITO) and the coordination between electricity and hydrogen TSOs. It is also necessary to consider a long-run target model for ownership and regulation.

Sammanfattning på svenska

Bakgrund och syfte

Vätgas förväntas spela en avgörande roll i framtidens koldioxidsnåla energisystem. Sverige liksom andra europeiska länder, har antagit strategier för vätgasens roll och tillväxt.

Introduktionen av vätgas kräver utbyggnad av ny infrastruktur och/eller konvertering av befintlig gasinfrastruktur samt ett regelverk för detta. I Sverige har Energimyndigheten fått ett regeringsuppdrag att samordna arbetet med vätgas i Sverige i nära dialog med bland annat Energimarknadsinspektionen.

EU håller för närvarande på att utveckla regelverket för vätgas, inklusive regler för certifiering av en systemansvarig enhet för vätgasöverföring (HTNO). Syftet med denna rapport är att ge information till Energimyndighetens samordningsarbete och till Energimarknadsinspektionens framtida arbete med en eventuell certifieringsprocess.

Sektorkoppling

Vätgas är en gas med liknande egenskaper som andra gaser när det gäller transport och lagring. Vätgas kan med vissa anpassningar använda befintlig infrastruktur för metangas och ersätta metangas i nuvarande användningsområden. Å andra sidan kan vätgas avlasta elnätet: Vätgas kan produceras från förnybar elproduktion på plats (från el til gas, som grön vätgas) och transporteras till användaren. Användningsområdena omfattar industri, transport och kraftproduktion (gas-till-kraft). På samma sätt kan vätgas produceras från metangas med koldioxidavskiljning (blå vätgas). Som energibärare är vätgas också ett alternativ till el när det gäller transport av energi från leverantörer till användare.

Sverige har ambitiösa mål för uppskalning av produktion och användning av vätgas. Inledningsvis förväntas vätgasindustrin utvecklas inom "vätgasdalar" eller kluster, där förnybar produktion och vätgasproduktion ligger nära industriell användning.[2] Medan det svenska metangasnätet är begränsat till sydvästkusten, sträcker sig elnätet över hela landet, och den inledande vätgasekonomin förväntas etableras i norra Sverige.

Europeisk lagstiftning

Ett paket för minskade koldioxidutsläpp på vätgas- och gasmarknaderna håller för närvarande på att lagstiftas i EU, med en preliminär överenskommelse om den rättsliga texten i december 2023.

Här definieras viktiga typer av aktörer, särskilt operatörer av överföring- och distributionsnät för vätgas, samt deras formella rättsliga roller. Bland annat fastställs också krav på åtskillnad av dessa aktörer och på utformningen av en tariffmodell för vätgasnät.

De potentiella rollerna för systemansvariga för vätgasöverföring enligt lagstiftningen omfattar följande

- tillhandahålla icke-diskriminerande tillgång till överföringsinfrastruktur,
- utveckling av planer för vätgasinfrastruktur,
- säkerställande av gaskvalitet,
- utveckla tillräcklig gränsöverskridande kapacitet,

[2] ”En vätgasdal eller Hydrogen Valley är ett geografiskt område - en stad, en region, en ö eller ett industriellt kluster - där flera vätgastillämpningar kombineras till ett integrerat vätgasekosystem som förbrukar en betydande mängd vätgas, vilket förbättrar ekonomin bakom projektet. Det bör helst täcka hela värdekedjan för vätgas: produktion, lagring, distribution och slutlig användning” https://ceenergynews.com/hydrogen/hydrogen-valleys-a-regional-and-very-promising-phenomenon/

- balansering av nätverket,
- säkerställa tydliga och effektiva tariffer, och
- samordning på unionsnivå med andra systemansvariga för vätgasöverföring.

ENNOH, European Network of Network Operators for Hydrogen, kommer att bestå av alla certifierade system-ansvariga för vätgasöverföring i EU:s medlemsstater och ha ett rättsligt mandat att skapa nätkoder, publicera 10-åriga nätutvecklingsplaner och samarbeta med ENTSO-G och ENTSO-E för att skapa en integrerad marknad.

Certifieringsprocessen fastställs i kapitel IX, avsnitt 5 i direktivet och kräver att HTNO certifieras av en nationell energitillsynsmyndighet (NRA). För systemansvariga för vätgas måste den nationella tillsynsmyndigheten se till att kraven på åtskillnad i artikel 62 i direktivet uppfylls.

Systemansvariga för vätgas ställs inför krav på både horisontell och vertikal åtskillnad. För horisontell åtskillnad, som rör integration med el- och naturgasnät, krävs i allmänhet rättslig åtskillnad. Ett undantag kan dock erhållas om en kostnads-nyttoanalys visar att detta är fördelaktigt.

För vertikal åtskillnad gäller de allmänna principerna och tillvägagångssätten för systemansvariga för naturgas. Samma aktörer skall därför inte kontrollera både ett vätgas-överföringsnät och vätgasförsörjning eller vätgasproduktion. Detta krav kan dock uppfyllas på många olika sätt, från fullständig åtskillnad av ägandet till säkerställande av oberoende för överföringsnätsverksamheter inom en vertikalt integrerad organisation.

Ett tidsbegränsat undantag från ovanstående krav på åtskillnad kan beviljas vissa namngivna isolerade regioner, däribland Övre Norrland (NUTS 2 SE33).

Om den organisation som ansöker om certifiering kontrolleras av aktörer utanför EU måste den certifierande nationella tillsynsmyndigheten också beakta de nationella och unionsomfattande säkerhetskonsekvenserna. I sådana fall skall man begära ett yttrande från kommissionen om aktörens behörighet.

Dessutom kan en medlemsstat ge den nationella tillsynsmyndigheten befogenhet att bevilja undantag från kraven på åtskillnad och certifiering för systemansvariga för vätgasöverföring om det berörda vätgasnätet täcker "ett geografiskt begränsat, industriellt eller kommersiellt område" och uppfyller vissa ytterligare, rättsligt definierade kriterier. Detta alternativ kan bli relevant i samband med de planerade vätgasklustren (se nedan). Om Sverige använder sig av detta alternativ och en nätoperatör för vätgas begär ett motsvarande undantag, är det upp till den nationella tillsynsmyndigheten att avgöra om dessa kriterier är uppfyllda.

Insikter från internationell praxis och erfarenhet

Andra europeiska länder är också i färd med att implementera EU:s vätgasförordning och nationella vätgasstrategier. Vi har kartlagt statusen för detta arbete i Finland, Danmark, Tyskland och Nederländerna för att se om det finns några lärdomar att dra för den svenska processen. Vi finner att relevanta lärdomar är få. Det finns vissa likheter mellan länderna, men den övergripande bilden är ganska splittrad.

Det nuvarande energisystemet, inklusive kraftproduktions-mixen och energiinfrastrukturen, potentialen för utbyggnad av förnybar kraftproduktion och alternativen för utfasning av fossila bränslen påverkar starkt vätgasens förväntade roll i det framtida systemet.

Alla länder har gett de nuvarande TSO:erna för gas en central roll i utvecklingen av infrastrukturen och marknaden för vätgas. De främsta skälen är likheterna mellan naturgastransport och vätgastransport samt möjligheten att delvis konvertera befintlig naturgasinfrastruktur till vätgas. I Danmark är Energinet TSO för både el och gas. De betonar fördelarna med samordnad planering av olika energiinfrastrukturer.

Finland är det land som mest liknar Sverige både när det gäller omfattningen av gasnätet, elproduktionsmixen och industristrukturen. Även i Finland ligger ansvaret än så länge hos den systemansvarige för gasöverföring. Till skillnad från i Sverige är dock den finska gas-TSO:n ett statligt ägt bolag.

Även om ansvaret för planering och utveckling av en vätgasinfrastruktur har delegerats, har inget av länderna ännu formellt certifierat en nationell (eller regional) HTNO. De väntar alla på att den slutliga EU-förordningen ska antas.

Alternativ för organisationen av en HTNO

Följande alternativ för åtskillnad finns:

Enligt modellen med en **oberoende systemansvarig för överföringssystemet (ITO)** utförs TSO-uppgifter av en ITO som kan ägas av det vertikalt integrerade företaget, men som måste vara oberoende av koncernens kommersiella verksamhet. Detta innebär att ITO:n inte får kontrollera, kontrolleras av, inneha andelar i eller vara delaktig i andra företag som tillhör ett vertikalt integrerat företag som är aktiva inom produktion eller leverans. ITO:n måste också uppfylla kraven på funktionell och redovisningsmässig åtskillnad.

Enligt modellen med en **oberoende systemoperatör (ISO)** kan energiförsörjningsföretag fortfarande formellt äga infrastruktur för överföring av gas eller el. Beslut om drift, underhåll och investeringar i nätet fattas dock av en ISO, som inte ägs av det vertikalt integrerade företaget. ISO är en systemansvarig för överföringssystem och omfattas av alla de skyldigheter som detta innebär.

Åtskillnad i fråga om förvaltning och redovisning kräver att räkenskaperna för överförings- och distributionsverksamhet måste separeras från annan verksamhet.

Funktionell åtskillnad kräver att nätverksamhet och konkurrensutsatt verksamhet separeras i olika, oberoende administrativa enheter.

Juridisk åtskillnad kräver att nätverksamheten placeras i en separat juridisk enhet.

Insikter från certifiering av systemansvariga för överföringssystem för el och gas

Liksom för HTNO ansvarar de nationella reglerings-myndigheterna för certifieringen av systemansvariga för överföringssystem för el och gas. Innan ett slutligt beslut fattas antar den nationella tillsynsmyndigheten ett preliminärt beslut som granskas av kommissionen. I kommissionens praktiska vägledning om certifieringsförfarandena, som sannolikt också är relevant för certifiering av HTNO, ges en översikt över de certifieringskriterier som är relevanta enligt olika krav på åtskillnad. En viktig aspekt av certifieringsförfarandena är att ITO-modellen kräver betydligt mer reglering och detaljerad dokumentation, framför allt för att säkerställa överens-stämmelse och neutralitet för den systemansvarige för överföringssystemet. ISO-modellen är också mer komplex än TSO-modellen på grund av behovet av att dokumentera att ISO har det mandat och de resurser som krävs för att genomföra investeringsplanering och fatta investeringsbeslut.

Alternativ för HTNO-ansvar i Sverige

Bestämmelser för de nuvarande svenska systemansvariga för överföringssystemen för el och gas

Sverige har för närvarande separata certifierade system-ansvariga för el och gas.

Svenska kraftnät (Svk) är en svensk stamnätsoperatör för el och är ett statligt ägt bolag. Det övergripande målet är att förvalta, driva och utveckla ett kostnadseffektivt, driftsäkert och miljöanpassat kraftöverföringssystem. I uppgifterna ingår

- Utbyggnad av överföringsnätet
- Främjande av konkurrens
- Främjande av FoU och demonstration av ny teknik
- Övervakning och tillhandahållande av information
- Samråd med och rapportering till den svenska regeringen samt tillhandahållande av tioåriga investeringsplaner vartannat år

Swedegas (ett dotterbolag till Nordion Energi) är en privatägd TSO för naturgas och bedriver sin verksamhet inom de ramar som anges i naturgaslagen. Dess allmänna mål motsvarar Svk:s. Lagen kräver:

- Vertikal åtskillnad från produktion av och handel med naturgas
- Redovisningsmässig åtskillnad från distribution av naturgas
- Skyldighet att ansluta tredje part på rimliga villkor
- Mäta och rapportera överförda volymer
- Fastställa rimliga avgifter, som är objektiva och icke-diskriminerande
- Hålla sig till i förväg fastställda intäktsgränser
- Bygga infrastruktur med statlig koncession

Bedömning av HTNO-alternativ

Vi har övervägt ett antal genomförbara HTNO-alternativ som kombinerar olika modeller för sektorsintegration och åtskillnadsmodeller enligt tabell 1.

Tabell 1 Alternativ för HTNO-organisation

	TSO	ISO	ITO
Separat HTNO(s)	Separat åtskild HTNO-TSO	Separat åtskild HTNO-ISO	Separat HTNO-TSO del av VIU
Integration gas TSO-HTNO	Gas TSO + åtskild HTNO-TSO	Gas ISO + Separat åtskild HTNO-ISO	Gas TSO + HTNO-TSO del av VIU
Integration el TSO-HTNO	Elektricitet TSO + åtskillnad HTNO-TSO	N/A förutsatt att TSO för el kvarstår	N/A förutsatt att TSO för el kvarstår

I linje med de tillgängliga modellerna för TSO-certifiering inom gas- och elsektorerna antar vi att alla ovanstående alternativ kan göras förenliga med framtida EU-regler för certifiering av HTNO, inklusive eventuella krav på horisontell åtskillnad i de integrerade modellerna.

Generellt sett anser vi att en TSO-modell har vissa fördelar jämfört med de andra alternativen. Full åtskillnad av ägandet gör det lättare att uppnå neutralitet, jämfört med ITO-lösningen. En ITO kräver extra reglering för att vara effektiv. TSO:n kan också planera och finansiera investeringar utan behov av extern samordning, jämfört med en ISO-lösning. Effektiv samordning och finansiering kan också uppnås med ITO-lösningen, men återigen krävs mer komplex reglering för att de underliggande målen ska uppnås. Man kan också anta att en TSO för vätgas är i linje med en trolig långsiktig europeisk målmodell, som man sett inom gas- och elsektorn.

På lång sikt finner vi också att integration med den systemansvarige för el har fler potentiella fördelar än de andra alternativen. Detta beror på den förväntade ökade betydelsen av sektorkoppling och fördelarna med samordnad kortsiktig inmatning och balansering och med en långsiktigt samordnad utveckling av de fysiska infrastrukturerna. Det gör dock också regleringen mer komplex i vissa avseenden.

Samordning kan också uppnås genom en utsedd enhet med nödvändiga befogenheter. Denna lösning medför högre transaktionskostnader och administrativa resurser och ökar komplexiteten, men undviker behovet av att integrera den systemansvarige för överföringssystemet och HTNO.

Vi har diskuterat alternativen i ett långsiktigt perspektiv. Det finns dock också ett behov av att överväga vägen till en önskad långsiktig modell om denna skiljer sig från de ursprungliga tillgängliga alternativen. Med tanke på naturgasens lilla roll i det nuvarande svenska energisystemet finns det inte mycket att bygga vidare på med befintliga infrastrukturer och intressenter. Istället finns det en möjlighet att de första som ansöker om HTNO-certifiering kommer att vara separata operatörer i olika delar av landet. En modell med flera mindre HTNO som inte är fysiskt integrerade kommer sannolikt att ha nackdelar i form av ineffektiv storlek, dyrare samordning och för låg försörjningstrygghet på grund av bristande integration av näten. Detta är särskilt relevant om vätgas förväntas spela en betydande roll i det svenska energisystemet på lång sikt. Det är då viktigt att Ei noggrant utvärderar hur regleringen kan underlätta en smidig övergång till den långsiktiga lösningen. Statligt ägande kan komplettera förordningen, nationellt/EU ägande kan vara önskvärt utifrån säkerhetskriterier. Återigen beror relevansen av ägarbegränsningar på vätgasens roll på lång sikt.

Avslutande anmärkningar

Utvecklingen av en svensk vätgasinfrastruktur är fortfarande i ett tidigt skede, men en skiss över den framtida europeiska regleringen börjar växa fram. Detta har flera implikationer för Ei.

För det första måste Ei förbereda sig för en utökad roll i regleringen av vätgassektorn. De huvudsakliga rättsliga och regleringsmässiga ramarna för certifieringsprocesser och krav på åtskillnad kommer sannolikt att likna det som har blivit standard för el och naturgas. Detsamma gäller för anslutnings- och tillträdessystemet som baseras på ickediskriminerande tariffer och tredjepartstillträde. Det är dock troligt att Ei kommer att ha en större roll i planering och utveckling av vätgasinfrastruktur jämfört med andra energiinfrastrukturer.

På kort sikt har Ei flexibilitet när det gäller certifierings-processen och andra delar av den framväxande europeiska förordningen. De första aktörerna inom vätgasinfrastruktur kan vara berättigade till undantagsbeslut - dvs. som geografiskt avgränsade nätverk. Dessutom träder viktiga delar av det nya direktivet och förordningen inte i kraft förrän 2032/2033.

När det gäller de väsentliga delarna av förordningen är en viktig utmaning förhållandet mellan alternativen på kort sikt och en effektiv lösning på lång sikt som överensstämmer med EU-förordningen. Om vätgas förväntas spela en betydande roll i det framtida svenska energisystemet bör en övergång till en effektiv långsiktig lösning planeras för. Det innebär att Ei redan i detta tidiga skede behöver ta ställning till flera frågor. Viktiga frågor är vilken HNTO-modell som föredras (TSO/ISO/ITO) och samordningen mellan TSO:er för el och vätgas. Det är också nödvändigt att överväga en långsiktig målmodell för ägande och reglering.

1 Introduction

1.1 Background

Hydrogen, in particular green hydrogen produced from renewable electricity, is expected to play a crucial role in the decarbonization of the energy use and to provide flexibility in a future power system dominated by intermittent renewable generation from wind and solar PV. The EU is currently in the process of developing the regulatory framework for the hydrogen market.

One of the new provisions is about rules for the certification of TSOs or a hydrogen transmission network operator (HTNO). Section 5 of the Directive requires that HTNOs be certified by the relevant NRA. As Ei is the NRA for Sweden it follows that Ei should be responsible for the certification process. The report is to provide a knowledge basis for Eis possible future work related to certification of an HTNO in Sweden.

This report presents current knowledge about the possible roles and responsibilities of such an HTNO function, and analyses to what extent the function should be organized separately, or jointly with the electricity TSO function or with a gas network operator.

1.2 Issues

The main elements of the assignment are to

1. Describe the responsibilities and duties of a hydrogen network operator (HTNO).

- Describe the differences and similarities of responsibilities of a hydrogen TSO, and an electricity and gas TSO, respectively.

2. International experiences and practices

- Describe how other countries intend to implement certification of a hydrogen network operator, including the allocation of responsibilities and tasks.
- Describe and discuss lessons learned from the process in other countries.

3. Options for the organization of a system operator for hydrogen

- Certification requirements

4. Allocate responsibility Svk or Nordion?

- Analyse advantages and disadvantages of allocating the responsibility for the development and operation of a hydrogen network to the established electricity transmission system operator, Svk.
- Analyse advantages and disadvantages of allocating the responsibility for the development and operation of the hydrogen network to the established gas transmission system operator, Nordion.

5. Should it be publicly owned?

- Assess whether there are specific considerations to take into account implying that certain tasks should be carried out by a government actor.

2 Physical characteristics of hydrogen and implications for the corresponding infrastructure

In order to assess the roles and requirements for a hydrogen network operator, it is useful to understand the similarities and differences between hydrogen networks and those of natural gas and electricity, and to draw on the practices of certification of these other energy network operators.

Hydrogen is poised to become a cornerstone of Europe´s energy transition. Its versatility as a carbon-free alternative to fossil fuels in transport, industry, and the power sector makes it very attractive. In some processes such as fertilizer and steel production it is virtually the only viable carbon-free alternative. In others it competes with other low-carbon solutions, especially electrification.

However, today's supply of hydrogen is based on steam methane reforming (SMR) and emits substantial amounts of CO_2 (grey hydrogen). In order to contribute to decarbonization, significant efforts are underway to switch to low-carbon or carbon-free means of hydrogen production, such as SMR with CCS (blue hydrogen) or water electrolysis using renewable energy (green hydrogen).

While forecasts differ, demand will certainly be substantial. By 2030 the EU aims at 10 Mt domestic hydrogen production and another 10 Mt of imports. Producing this much hydrogen through water electrolysis would require about 500 TWh renewable electricity, almost the equivalent of the total electricity production in Germany today.

Connecting production facilities and import hubs with demand centres will require new H_2 transport networks across the continent. The European Hydrogen Backbone initiative, a group of 33 infrastructure operators has formulated a vision of a pan-European hydrogen transport infrastructure. This vision is being used as a blueprint for concrete national plans, for example the German Kernnetz for hydrogen.

In order to assess the roles and requirements for a hydrogen network operator, it is useful to understand the similarities and differences between hydrogen networks and those of natural gas and electricity, to draw on the practices of certification of these other energy network operators. In addition, hydrogen transport competes with electricity and natural gas transport as ways of transporting energy and thus regulation for all three needs to be coordinated (see also Chapter 6).

As a background for the analysis, this chapter presents the physical characteristics of hydrogen and the implications on the requirements of the corresponding transmission and storage infrastructure.

2.1 The physical properties of hydrogen

Just like natural gas, hydrogen is gaseous at room temperature. Contrary to electric energy, physical gases can easily be stored in appropriate storage facilities and transported through pipelines.

However, there are also differences that need to be considered when transforming infrastructure from natural gas to hydrogen:

The boiling point of hydrogen lies at -253 °C, making liquefaction of H2, e.g., for efficient storage, much more energy intensive than for natural gas, with a boiling point at -162 °C (Terega, 2023). Liquifying H2 consumes almost a third of the energy stored within the hydrogen itself (US energy department, 2023).

Hydrogen has a low volumetric energy density. 3.5 times more hydrogen has to be transported to achieve the same energy throughput, compared with natural gas.

Hydrogen has a higher gravimetric energy density, however, almost 2.5 times that of natural gas. This, however, is less important for transport and storage purposes (THEMA, 2023a).

The hydrogen molecule (H_2) is ca. four times smaller than CH_4, the molecule making up natural gas, enabling it to slip through much smaller cracks than natural gas and showing a higher permeability rate through any material.

Finally, hydrogen requires much less energy for self-ignition, making it more flammable than natural gas, and shows a higher reactivity with steel, turning some steel grades used for pipelines brittle.

2.2 Implications for hydrogen transport and storage infrastructure

There are several technologies and paths to transport H_2. Depending on the distance, local circumstances and the final application, different solutions can be relevant. In most of Europe, however pipelines seem to be the preferred mode of transport and is for longer distances probably the most economical solution (JRC, 2021) (US energy department, 2023). Here, we will focus mainly on pipeline transport, before giving a brief overview over alternatives and their use cases at the end. Swedish hydrogen production is anticipated to cater primarily to the nation's own industry, initially related to hydrogen valleys, but with the added potential for exporting to continental Europe.

The different characteristics of hydrogen compared to natural gas pose different prerequisites for transport and storage infrastructure. This is important both for new investments and especially for retrofitting existing pipelines and storage facilities. The Hydrogen Backbone estimates that ca. 60% of hydrogen pipelines will consist of refurbished natural gas pipes (Include Source: Link). Refurbishing natural gas pipelines instead of installing new H_2 pipelines may save 60 to 90% of the investment needs (Lipiäinen et al, 2023).

As mentioned, the volumetric energy density of H_2 is lower than for natural gas. Transporting the same amount of energy would require much higher pressure in the pipelines (assuming identical pipeline diameters). Unfortunately, higher pressure puts more strain on the system, and increases hydrogen leakage.

Pipelines and storage sites must be much tighter for hydrogen than required for natural gas. Leakage control is especially important due to hydrogen´s high permeability through all materials and its high flammability. The standard solution to track leakage is odoring. However, some standard H_2 use cases (e.g., fuel cells) have high purity requirements and would require expensive removal of any odorants. Also, most currently used odorants do not work with H_2, as they are too heavy. The hydrogen would not carry them with it. Hence, operators need detectors to track leakage. This may be technically more challenging and more expensive than odorants, depending on the setup.

One of the key locations of H_2 slippage are compressors, which in turn are required to increase the pressure in the pipelines. The Netherlands, with its already far-reaching H_2 network plans (details in chapter 5), intends to operate the H_2 pipelines at a pressure of 30-50 bar, equal to the pressure coming out of electrolysers (Lipiäinen et al, 2023). This would reduce the need for leakage-prone compressors. (High-pressure natural gas pipes operate at up to 85 bar) but at the same time reduce the energy throughput even further.

As with natural gas pipelines, TSOs would be responsible to keep the pressure stable over time, as changing pressure causes stress on the system such as loosening of bolts, screws, and valves and making steel more brittle by constantly changing the forces working against it.

Another reason for corrosion is H_2´s high reactivity with steel. To protect the pipes, higher grade steel has to be used. Alternatively, coating the metal with another substance or mixing the H_2 with chemical inhibitors can be applied. All come with their own challenges and cost factors (Lipiäinen et al, 2023).

Some countries discuss blending hydrogen with natural gas in existing natural gas grids for a more gradual transition. This is proven to work until a volumetric H_2 share of ca. 20%, replacing ca. 7% of the energy transported by the natural gas. If the H_2 is to be used in its pure form after being blended into the gas grid, separating it again adds costs of €2-€4/kg of H_2. This amount is substantial, considering that cost estimates for low-carbon H_2 are between €3-€7/kg for 2030 (THEMA, 2023). Blending would also require cross-European alignment of blending regulations, otherwise the usage of cross-border gas grids will become almost impossible (Fraunhofer IEE, 2022).

For large-scale and long-term storage H_2, underground caverns can be used (e.g., salt caverns or depleted gas fields). However, this requires appropriate geological formations. Steel containers above ground are an alternative but are naturally smaller in scale. For a grid operator's needs, however, they are sufficient.

Some studies suggest pressures of up to 700 bar may be achievable for storage. This would reduce the volume of 1 kg of hydrogen from 11 000 litres under atmospheric pressure to 24 litres. Liquefying hydrogen would bring it to 14 litres. However, this again requires energy for liquification and low temperatures, reducing the energy losses (Terega, 2023).

2.3 Alternatives to pipeline transport

For small distances, the transport of gaseous H_2 stored in metal containers via truck or rail is possible. For longer distances, transport via ship in different chemical forms, e.g., as Liquid Organic Hydrogen Carriers (LOHC), liquefied H_2 or ammonia, may be cheaper than pipelines. This depends on the individual case.

In LOHCs, H_2 is bound to an organic molecule (usually carbon-based) which makes it easier to store and transport than in its pure form. The reason being that LOHCs are liquid and less prone to leakage. Basically, all existing oil transporters in the world could transport LOHCs. For direct usage, the H_2 again needs to be separated from the organic molecule, which consumes energy.

The transport of pure H_2 in liquefied form on the other hand has two important challenges: One is the large amount of energy needed to liquefy the gas, including cooling it down to extremely low temperatures. Second, the low temperatures require low and stable pressures at around 5 bar. Once some of the liquefied H_2 turns into gas, it expands and pressure increases, causing the need to vent the H_2. This "boil-off" causes considerable H_2 losses during transport (US Energy Department, 2022).

It should be noted that for a network catering many small points, compressed hydrogen is expensive due to the many needs for storage and small-scale transport: Even for small-scale networks H_2's low volumetric energy density requires large storage sites and many shuttles, driving up costs. In such cases, liquefied H_2 may be an option, because it achieves higher purity grades than LOHCs or other delivery paths. The downside is the high energy required in its production (JRC, 2021).

Table 1: Comparison of different hydrogen transport options

Mode of transport	***Compatible storage technologies***	***Economical travel distance***
Trucks	Compression, Liquefaction, Ammonia	< 1000 km
Rail	Compression, Liquefaction, Ammonia	800-1100 km
Pipeline	Compression	1000-4000 km
Shipping	Liquefaction, Ammonia, LOHCs	> 4000 km

Source: Structureinsider, 2022

3 The current and future Swedish energy system

3.1 Hydrogen strategy

Sweden initiated its work on a hydrogen strategy by tasking Fossil Free Sweden, a coordination initiative between industry and government, with formulating a development plan for hydrogen (Fossil Free Sweden, 2021). Their strategy was published in January 2021 and played a significant role in shaping a subsequent proposal for a national hydrogen strategy, released by the Swedish Energy Agency in November of the same year (Swedish Energy Agency, 2021). As there has been no official ratification of a national hydrogen strategy, the two aforementioned strategies currently serve as the primary foundation for Sweden's hydrogen development plans.

The Swedish Energy Agency set ambitious targets, proposing the installation of 5 GW of electrolysers by 2030, followed by an additional 10 GW by 2045. The 2030 target is considerable compared to the overall EU targets[3], which in large part reflects the Swedish industry's potential and growing interest in hydrogen.

3.2 Policy measures and financing

Government measures aimed at increasing the cost of emissions, like the national carbon tax and EU's emission trading scheme (ETS), indirectly encourage the adoption of fossil-free hydrogen. Such measures align with the principle of technology-neutrality, which prioritizes market-driven solutions for emissions reduction and leaves technology and investment decisions to the private sector. However, a recent discussion paper from the Research Institute for Sustainability (2023) emphasizes the need for the Swedish government to adopt a more proactive role in hydrogen development. It argues that the current, more passive strategy significantly increases uncertainty.

Direct government backing for hydrogen production and infrastructure is primarily channelled through two key programs: Climate Leap and Industrial Leap. Climate Leap supports investments in sectors not covered by EU ETS, whereas the Industrial Leap finances pilot projects and research aimed at reducing carbon emissions in the industry sector, typically operating within the ETS framework. Besides this direct funding from the Swedish government, the hydrogen value chain also benefits from various EU-specific support instruments.

3.3 Current energy system

Today, Sweden is a significant electricity exporter with a predominantly carbon-free electricity mix. As illustrated in Figure 1, renewables accounted for over half of its 2020 electricity production, and nuclear energy provided nearly a third. The remaining 8% of electricity came from combined heat and power plants, primarily fuelled by waste or biomass.

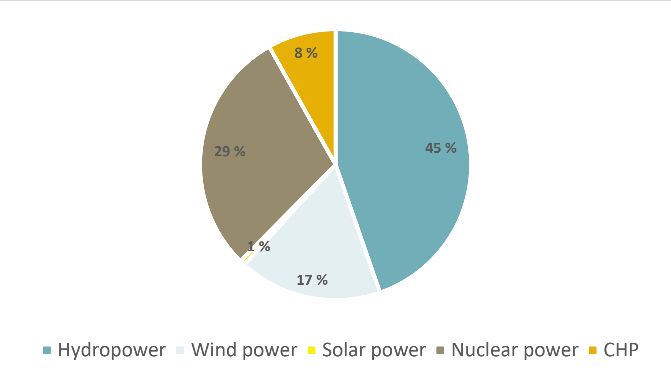
Natural gas, in contrast, only plays a minor role in Sweden's energy mix, constituting less than 2% of the country's total energy use (Swedish Energy Agency, 2022)[4]. This situation presents both opportunities and challenges for hydrogen development in Sweden. On the one hand, it boasts a substantial, clean electricity surplus, advantageous for hydrogen production. On the other hand, limited gas

[3] Production depends on the capacity factor. A factor of 70% gives Sweden a target of 600 kt of hydrogen in 2030, compared to EU targets producing 10 million tons.

[4] 6 TWh, 2020 numbers and excluding non-energy use of around 4.7 TWh.

infrastructure restricts the potential for retrofitting existing gas systems for hydrogen use.

Figure 1: Electricity mix in Sweden in 2020



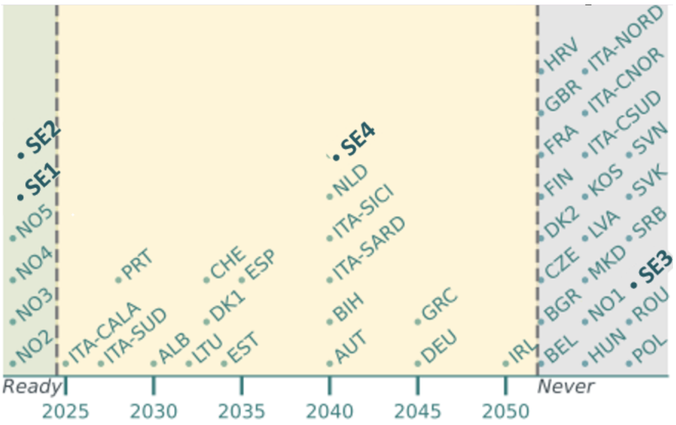
Source: Swedish Energy Agency, 2022

The shares of renewable power generation are particularly high in the northernmost bidding zones, SE1 and SE2, with RES shares expected to reach more than 90%. This constitutes a comparative advantage for hydrogen production according to newly adopted EU policies setting the conditions for defining hydrogen as renewable in the EU taxonomy (European Commission, 2023).

In order to be classified as renewable according to the taxonomy, hydrogen production must be based on new renewable power generation, documented by power purchase agreements, PPAs, that adhere to specific criteria of *additionality*, to ensure that new renewable energy capacity is added, and temporal and geographical *co-location*, meaning the production of hydrogen is closely aligned in time and location with renewable energy generation.

However, bidding zones with RES shares of 90% are exempt from these requirements. In these zones, hydrogen production may use grid electricity and still be classified as renewable. Consequently, SE1 and SE2 hold a comparative advantage in attracting hydrogen production. Figure 2 shows when various bidding zones are expected to reach the 90% RES share, according to THEMA's base scenario (2023b&c).

Figure 2: The first year in which each bidding zone reaches the 90% RES-share threshold in THEMA's Base scenario (2023b&c)



3.4 Expected role of hydrogen in the future energy system

Meeting Sweden's hydrogen targets will require significant increases in renewable and/or low-carbon electricity. For example, the 5 GW of electrolyser capacity targeted by 2030 could need between 20 and 40 TWh annually, depending on their capacity factor. That would consume the country's current power surplus, underscoring the need for additional emission-free power generation in Sweden. With the government now withholding subsidies for offshore wind, THEMA (2023c) expects most of the increase in production to come from onshore wind in the northern regions. These onshore projects are now economically viable without government subsidies and can therefore be financed on merchant terms.

A significant portion of Sweden's carbon emissions originates from sectors that are difficult to decarbonize, such as transport and industry. In this context, fossil-free hydrogen is gaining recognition as a key factor in reducing emissions, especially within Sweden's extensive steel industry and as a replacement for today's grey hydrogen.[5] Hydrogen and hydrogen-based synthetic fuels also hold potential for reducing carbon emissions in parts of the transport sector where battery use is not practical.

Hydrogen production may also help balance the volatility of Sweden's large share of intermittent power, depending on the economic viability of flexible hydrogen production and storage. Furthermore, power demand for hydrogen production is likely to be located near large power surpluses, for example in the north. By reducing the amount of excess power that cannot be effectively distributed due to transmission constraints, the hydrogen economy can thus help alleviate issues with interregional congestion and regional price disparities in Sweden's electricity market.

3.5 Planned hydrogen supply and demand

Fossil Free Sweden (2021) envisages the development of Sweden's hydrogen economy around 'hydrogen clusters.' These clusters are focused areas combining hydrogen production, storage, and usage facilities. By co-locating these elements, the aim is to maximize efficiency and minimize infrastructure expenses. Hydrogen clusters are also likely to be located in or near areas with large power surpluses, as well as near railways and ports, facilitating efficient transport of produced goods.

Citing the lack of gas infrastructure, Fossil Free Sweden deems the prospects of a national hydrogen network or pipelines for hydrogen export to the continent as unrealistic. Instead, they advocate for Sweden to focus on exporting products manufactured using fossil-free hydrogen.

However, there are also reasons for considering the development of hydrogen pipelines in Sweden, especially in the long term. Once Swedish hydrogen clusters have matured and hydrogen production has scaled up, connecting these clusters through pipelines could become economically viable. Moreover, hydrogen pipelines could offer a cost-effective solution for transporting surplus energy when compared to long-distance electricity transmission, both within Sweden and to energy-hungry regions in Europe. Svk supported this perspective in their latest grid development plan (2023). They highlighted that the current grid capacity is inadequate to meet expected hydrogen demand, and that hydrogen pipelines may be more cost-effective than additional electricity grid capacity.

While Fossil Free Sweden's views on pipelines largely reflect industry interests, Nordion Energy, owner of Swedegas, is one of the main advocates for an international hydrogen grid connecting Sweden with Finland and the rest of Europe. As a member of the European Hydrogen Backbone Initiative, Nordion Energy is already working on plans for cross-border pipelines in the Bothnian Bay (Nordic Hydrogen Route, 2023), as well as a pipeline system connecting Sweden and Finland with Baltic Sea offshore wind and with Germany (Baltic Sea Hydrogen Collector, 2023). Both these projects were recently recognized by the European Commissions as Projects of Common Interest (PCI).

Many of the announced hydrogen projects are located in Northern Sweden, a region with a significant energy surplus and lower electricity costs compared to the south. A notable example is the HYBRIT project in Luleå, a pilot initiative focused

[5] Total Swedish hydrogen demand was 175 kt in 2022, whereas 126 kt was from the refining industry (European Hydrogen Observatory, 2023)

on developing hydrogen-based steel production, which has secured funding from the Industrial Leap and the EU Innovation Fund. Similarly, H2 Green Steel targets Northern Sweden's coastal areas for another major project. It is likely that this region will host one or more major hydrogen clusters.

Southern Sweden's existing industry hubs are also possible sites for future hydrogen clusters, especially if they are integrated with infrastructure such as ports and railways. For example, the Fossil Free Sweden report (2021) identifies the Gothenburg area as a potential hydrogen cluster, partly due to its significant present use of grey hydrogen. Additionally, the report anticipates the formation of hydrogen clusters near Gävle and Helsingborg.

4 Overview of relevant legislation and regulations

4.1 Structure and status of European legislation

4.1.1 The Hydrogen Package

In December 2021, the European Commission published the Hydrogen and Gas Markets Decarbonisation Package, a series of legislative proposals to help reform the relevant markers. It consists of a recast Directive and Regulation on gas markets and hydrogen (COM/2021/803 and COM/2021/804). The primary aim of the Directive and Regulation is the creation of an optimal and dedicated infrastructure to help decarbonise European gas consumption and create EU-wide rules for the hydrogen market.

The proposals define in generic terms the entities responsible for operating future hydrogen networks and some of their responsibilities. They also establish requirements for the certification of the relevant bodies by National Regulatory Authorities.

A provisional agreement on the legal text was reached in December 2023, and now requires formal adoption by both the European Parliament and the Council.

Overview of contents

Among other things, the legislation:

- Aims to establish a market for hydrogen and provide for the legal separation of hydrogen production and supply from transport (unbundling);
- Sets out the conditions for non-discriminatory connection and access to hydrogen networks, including principles for congestion management and tariff-setting;
- Determines the responsibility for hydrogen quality management and provides for the blending of hydrogen into the natural gas system by up to 2% by volume;
- Allows for the formulation of potential rules for future TSOs and DSOs in the hydrogen market in the form of dedicated network codes depending on the development of a hydrogen market and infrastructure;
- Establishes a European Network of Network Operators for Hydrogen (ENNOH) that will facilitate cross-border coordination and interconnector construction as well as develop common technical rules in the form of network codes and guidelines on hydrogen for the EU;
- Plans to introduce a common system of terminology and certification for low-carbon hydrogen and low-carbon fuels across the EU;
- Establishes processes for integrated European network planning across electricity, gas and hydrogen networks, including the construction of hydrogen interconnectors to other Member States;
- Mandates national network development plans based on a joint scenario for electricity, gas and hydrogen, that are expected to be aligned with National Energy and Climate Plans as well as the EU-wide Ten-Year Network Development Plan.

4.1.2 The role of Hydrogen Network Operators

The draft EU legislation defines hydrogen transmission and distribution networks as follows.

A ‘hydrogen transmission network’ “means a network of pipe-lines for the transport of hydrogen of a high grade of purity, in particular, networks which include hydrogen interconnectors, or which are directly connected to hydrogen storage, hydrogen terminals or two or more hydrogen interconnectors or which primarily serve the purpose of transporting hydrogen to other hydrogen networks, hydrogen storages or hydrogen terminals. Such networks may serve the purpose of supplying directly connected customers”.

A 'hydrogen distribution network' "means a network of pipelines for the local or regional transport of hydrogen of a high grade of purity, which primarily serve the purpose of supplying directly connected customers, and do not include hydrogen interconnectors, and are not directly connected to hydrogen storage or to hydrogen terminals, unless the network in question was a natural gas distribution system on [entry into force of this Directive] and has been partially or fully repurposed for the transport of hydrogen, or to two or more hydrogen interconnectors."

It also sets out the roles and responsibilities of these entities, which we describe in the sections below. Since this report focuses on the implementation of one or several hydrogen transmission system operators in the Swedish energy landscape, hydrogen distribution network operators generally remain outside the scope. Note that the owners/operators of the envisaged hydrogen clusters (see section 3.5 above) may argue that these constitute hydrogen distribution networks rather than hydrogen transmission networks in order to benefit from the more relaxed legal requirements for hydrogen distribution networks. It will be up to the NRA to determine whether each hydrogen cluster constitutes a hydrogen transmission or distribution network. However, as per our mandate we do not cover the specific rules applicable to hydrogen distribution network operators in this report.

Connecting users and providing non-discriminatory access to capacity and services

The envisaged regime for connection and access to hydrogen networks is very similar to the rules for electricity and natural gas networks in existing EU energy legislation.[6] HTNOs may refuse the connection of new users to the hydrogen network and deny existing network users access for reasons of insufficient capacity, Article 34(1) of the Directive. However, this right is restricted in several ways. In general, Article 34(4) of the Directive obliges HTNOs to provide duly substantiated reasons whenever they refuse connection or access to their hydrogen network.

Concerning connection, according to Article 34(2) of the Directive, Member States shall take measures to ensure that the operators of hydrogen networks make the necessary enhancements to connect new network users where 'it is economic to do so'. Whereas the provisional agreement text for the Directive does not specify who is responsible for determining when it is economic to connect new users to the hydrogen network, we assume that this decision is part of the NRA's mandate to fix the terms and conditions for connection and access to national hydrogen networks (Article 72(7)(b) of the Directive).[7] This notwithstanding, HTNOs must reinforce their network if the connecting party is willing to pay for the necessary network enhancements.

With regard to access, Article 31(4) of the Directive allows a Member State to implement a system of negotiated third-party access up to 31 December 2032. Where this option is used, the

[6] On the difference between network connection and access, see Case C–239/07 *Julius Sabatauskas and Others* [2008] ECR I-7523.

[7] An additional ambiguity arises from Article 38(2) of the Directive, which states that hydrogen transmission network operators "shall not be entitled to refuse the connection of a new natural gas or hydrogen storage facility, LNG regasification facility, hydrogen terminal or industrial customer on the grounds of possible future limitations to available network capacities or additional costs linked with necessary capacity increase."
We assume that the obligation under Article 38(2) only applies to the point where the additional costs linked with a necessary capacity increase are no longer economic in the meaning of Article 34(2) of the Directive.

Member State shall ensure that negotiated third party access to hydrogen networks is provided in accordance with objective, transparent and non-discriminatory criteria and under the supervision of the national regulatory authority.

From 1 January 2033, Article 31(1) of the Directive obliges the Member States to ensure the implementation of a non-discriminatory third-party network access system based on published tariffs, such as is currently the case for electricity and gas. These tariffs must be approved by the national regulatory authority pursuant to Article 31(2), 72(1)(b), (7)(b) of the Directive (regulated third-party access).

The Gas Regulation further fleshes out the provisions on third-party access. Article 6 of the Regulation states that HTNOs are obligated to provide their capacity and services on a non-discriminatory basis to all network users. The maximum capacity of the hydrogen network must be made available to all market participants after due consideration of the demands of system integrity, efficiency and the safe operation of the network. This limits the scope for refusals of access, in particular in conjunction with the duty to provide reasons for each refusal. It is also hydrogen transmission network operators' responsibility to implement and publish non-discriminatory and transparent congestion management procedures to facilitate cross-border hydrogen exchange on a non-discriminatory basis. Network operators must regularly assess market demand and identify new investments, taking into consideration security of supply and the efficiency of end-use.

Hydrogen infrastructure development according to ten-year network development plans

The provisional agreement text of the Directive establishes a much tighter control over hydrogen transmission network operators' investment behaviour, especially when compared to the extant investment regime for electricity TSOs. Article 51 of the Directive states that HTNOs must submit a ten-year network development plan (TYNDP) to the relevant NRA every two years. This can take the form of a joint plan with the natural gas network, or be separate, provided that plans are developed based on close cooperation between the relevant operators. In any case, hydrogen transmission network operators must closely cooperate with electricity TSOs and DSOs in order to coordinate joint infrastructure requirements and take the utmost account of their views.

While the NRA does not approve the respective TYNDP, it scrutinises the plan and may require the TSO to amend it. The NRA also monitors and evaluates the implementation of the plan (Article 51(6) and 72(1)(n) of the Directive).

Of particular interest is the fact that Article 51(7) of the Directive obliges the Member States to ensure that where a project enumerated in the TYNDP is not executed according to plan, the NRA has a far-reaching duty (and corresponding powers) to enforce the execution of that project, provided it is still relevant. To that end, the NRA may take the following measures according to Art. 51(7) of the Directive:

> (a) to require the [hydrogen transmission network operator] to execute the investments in question;
>
> (b) to organise a tender procedure open to any investors for the investment in question;
>
> (c) to oblige the [hydrogen transmission network operator] to accept a capital increase to finance the necessary investments and allow independent investors to participate in the capital.

Ensuring gas quality

Article 46(3) of the Gas Directive states that where appropriate for system management and end-users, the NRA shall entrust a network operator with responsibility for ensuring efficient hydrogen quality management and stable hydrogen quality in their networks in accordance with the hydrogen quality standards.

Article 19 of the Regulation states that HTNOs must cooperate with HTNOs from other countries to avoid restrictions to cross-border flows due to gas quality differences at interconnection points between Union member states. In case there arises a restriction to cross-border flows due to gas quality differences, it is the responsibility of the HTNO to inform the NRA without delay. The NRA can request that the HTNO develop technically feasible options without changing uniform gas quality specifications, jointly carry out a cost-benefit analysis of options, produce an estimate of the implementation time for these options, conduct public consultations and based on these activities submit a joint proposal to the NRA to resolve the restrictions.

Creating sufficient cross-border capacity

According to Article 46 of the Gas Directive, Hydrogen transmission network operators shall aim to ensure sufficient cross-border capacity to integrate European hydrogen infrastructure. This should support market integration efforts identified in the hydrogen network operator's own TYNDP and the Union-wide ten-year network development plans where these are economically reasonable and technically feasible. NRAs may task one or more hydrogen transmission network operators with the responsibility for ensuring cross-border capacity.

Network balancing

Article 46(3a) of the Directive states that HTNOs will be required to balance their networks from 2033 or from an earlier date as provided by the NRA.

Ensuring clear and efficient tariffs

Article 6 of the Regulation states that HTNOs will be required to publish the contractual terms and tariffs charged for network access and balancing charges on their website.

HTNOs must also cooperate with the relevant NRA in pursuing the convergence of tariff structures across the transmission system according to Article 15 of the Regulation.

ENNOH membership

According to Article 40 of the Regulation, hydrogen transmission network operators must cooperate at the EU level through the European Network of Network Operators of Hydrogen (ENNOH). ENNOH will consist of all certified hydrogen transmission network operators in EU member states. Any hydrogen transmission network operators is eligible to join the ENNOH as soon as the certification process by the National Regulatory Authority (NRA) is initiated. The HTNO must have obtained its certification within 24 months of its joining ENNOH and take a final investment decision to develop a hydrogen infrastructure project, if does not already have hydrogen network infrastructure, within 4 years of joining ENNOH.

The costs of ENNOH will be borne by hydrogen transmission network operators and their tariff payers pursuant to Article 42 of the Regulation. HTNOs shall cooperate regionally within the ENNOH and in this context promote suitable operational arrangements to facilitate cross-border exchanges of hydrogen (Article 47 of the Regulation). In addition, hydrogen transmission network operators will need to support ENNOH in fulfilling the following legal mandates.

- **Creating network codes**
  As in electricity and gas, Article 54 of the Regulation states that hydrogen transmission network operators, as members of the ENNOH, are responsible for creating network codes, inter alia for providing/managing access to cross-border capacity and ensuring the coordinated development of the network in the Union (including the creation of interconnection capacities). The EC will establish a priority list for the development of network codes for hydrogen one year after ENNOH's establishment and every third year thereafter. ACER will review these network codes before submitting them to the EC for adoption. The NRA must ensure that HTNOs

operate their networks in accordance with these network codes (Article 72(1)(d) of the Directive).[8]

- **Publication of 10-year network development plans**
  Article 43 of the Regulation states that hydrogen transmission network operators, as members of the ENNOH, must publish and regularly update a Union-wide, 10-year network development plan for hydrogen. This plan will include the modelling of an integrated network, scenario development, the identification of investment gaps in hydrogen infrastructure, a review of barriers that jeopardize potential increases in cross-border capacity and an assessment of the resilience of the system. If ACER (European Union Agency for the Cooperation of Energy Regulators) identifies inconsistencies between a national hydrogen network development report and the Union-wide network development plan, it will recommend amending the national hydrogen development report or the Union-wide network development plan as deemed appropriate.
- **Cooperation with ENTSO-G and ENTSO-E and creation of an integrated market**
  Article 43a of the Regulation states that hydrogen transmission network operators, as members of the ENNOH, must cooperate with ENTSO-G and ENTSO-E to develop joint scenarios, coordinated infrastructure gap analyses, a methodology for energy-system-wide cost-benefit analysis and progressively integrated energy system modelling. The cooperation aims at integrating the separate sectoral TYNDPs to allow for EU-level integrated network planning.

4.1.3 Network tariffs

The detailed rules governing the setting of hydrogen network tariffs are set out in Articles 6 and 15 of the Regulation and impose a similar system of entry and exit charging as applies to natural gas networks.

Importantly, Member States may, until 31 December 2032, unilaterally determine the tariffs imposed at interconnection points between tariffing regimes, potentially allowing for tariffs to be levied at national borders. This simplifies the process for recouping the costs of investments in transmission infrastructure at the risk of introducing trade frictions within the internal market.

Article 6(7) of the Regulation requires that regulatory authorities consult the "regulatory authorities of directly connected Member States and relevant stakeholders" when deciding on the tariff-setting methodology applied at cross-border interconnection points. It also specifies that the approach needs to take into account the outcome of the consultations and "the impact of the chosen network access tariffs on cross-border trade and market functioning in the directly connected Member States". The concerned NRAs may request a factual opinion on the tariff-setting methodology from ACER.

When unilaterally deciding on a tariff-setting methodology to be applied at cross-border interconnection points, the competent NRA shall apply the tariff principles set out in Article 15(1), (2), (2b) and (2c) of the Regulation. These principles closely resemble the principles for electricity or gas transmission tariffs (i.e. transparency; taking into account the need for system integrity and its improvement, including investment incentives; cost-reflectivity; efficiency; non-

[8] Note that Article 69 of the Regulation allows the EC to adopt guidelines instead of network codes. While the procedure for the adoption of guidelines does not give formal tasks to hydrogen TSOs, it appears probable from previous experience in the electricity sector that the drafting of hydrogen guidelines will heavily involve hydrogen TSOs.

discrimination; no restriction of market liquidity; no distortion of cross-border trade). However, the NRA may decide to charge no network access tariffs or, when capacity is allocated via auctions, to set the reserve prices to zero. The last subparagraph of Article 6(7) of the Regulation stipulates that further details concerning the right to unilaterally set certain tariffs will be regulated in a future network code.

From 1 January 2033 (or from the moment a Member State implements regulated third-party access to hydrogen transmission systems according to Article 31 of the Directive), hydrogen transmission network operators must adhere to Article 15 of the Regulation when setting tariffs, subject to the approval of the NRA.

4.2 HTNO certification process

Chapter IX, Section 5 of the Directive requires that HTNOs be certified by the relevant NRA. The NRA must ensure compliance with the unbundling requirements established in the Directive. They may also consider the security implications of certifying organisations controlled by actors outside the Union. Both are discussed in further detail below.

To our understanding, only hydrogen transmission operators require certification according to Articles 65 and 66 of the Regulation. While the provisional agreement text speaks of HNOs—a term that comprises hydrogen transmission as well as distribution network operators—we consider this a drafting error. The certification serves to ensure compliance with the unbundling requirements enshrined in Article 62 of the Regulation, which only apply to hydrogen transmission network operators (i.e., not to hydrogen distribution system operators). We assume that the EU institutions forgot to update the wording of Article 65 when they introduced the distinction between hydrogen distribution and transmission operators and expect that this omission will be fixed when the Regulation is formally adopted.

Applying this reading, the Directive establishes considerably less onerous unbundling requirements for hydrogen distribution network operators (in particular no ownership unbundling and no horizontal unbundling). Again, depending on the infrastructure present in the envisaged hydrogen clusters (see above at section 3.5), the owners/operators of these clusters may thus strive for recognition as hydrogen distribution systems rather than hydrogen transmission systems. It will be up to the NRA to determine whether each respective hydrogen cluster fulfils the definition of a hydrogen transmission system, and whether the owners and/or operators of these clusters require certification as hydrogen transmission network operators. We focus on the rules applicable to hydrogen transmission network operators in the following and do not expand upon the situation of hydrogen distribution network operators.

4.2.1 Unbundling requirements

Types of unbundling

Before discussing the unbundling requirements set out in the Directive, it is worth briefly outlining the different forms of unbundling established in European energy market legislation. We describe each, from the least to the most restrictive, below.

Accounting unbundling requires that the accounts of transmission and distribution activities must be separated from other activities.

Functional unbundling requires that network and competitive activities be separated into different, independent administrative units.

Legal unbundling requires that network activities be placed in a separate legal entity.

Ownership unbundling requires that network assets and production and supply activities cannot share the same owner.

Under the **Independent Transmission System Operator (ITO)** model, TSO tasks are performed by an ITO that may be owned by the vertically integrated company but must be independent from the group's commercial activities. This implies that the ITO must not control, be controlled by, hold participations, or be participated in by other companies belonging to a vertically integrated undertaking that are active in production or supply. The ITO must also comply with functional and accounting unbundling requirements.

Under the **Independent System Operator (ISO)** model, energy supply companies may still formally own gas or electricity transmission infrastructure. However, decisions regarding operation, maintenance and investment in the network are taken by an ISO, which is not owned by the vertically integrated undertaking. The ISO is a TSO and is subject to all the obligations this implies.

Hydrogen transmission network operator unbundling requirements

Hydrogen transmission network operators face both horizontal unbundling requirements—which govern the scope for integration with electricity and natural gas networks—and vertical unbundling requirements—which govern the scope for integration with other elements of the hydrogen value chain including hydrogen production and storage.

Horizontal unbundling is covered by Article 63 of the Directive. This states that:

"Where a hydrogen transmission network operator is part of an undertaking active in transmission or distribution of natural gas or electricity, it shall be independent at least in terms of its legal form."

Member States may grant a derogation from this requirement on the basis of a publicly available positive cost-benefit analysis and the positive assessment of the NRA. An assessment of the derogation's impact on transparency, cross subsidies, network tariffs and cross-border trade must be published by the relevant regulatory authority at least every seven years and, if this assessment concludes that the derogation has a negative impact, it must be withdrawn.

The requirements on vertical unbundling are set out in Article 62 and provide considerable flexibility regarding the regulatory model. In general, the rules for hydrogen transmission network operators are aligned with those for natural gas TSOs. This implies that person or persons controlling a hydrogen transmission network may not exercise any control over an undertaking the produces or supplies hydrogen, and vice versa.

In addition to ownership unbundling, the text allows this requirement to be fulfilled through the creation of an independent hydrogen transmission network operator that is unbundled in accordance with the ISO model for natural gas.

The text also provides derogations to apply the ITO unbundling model in cases where the vertically integrated network already exists when the Directive enters into force or the hydrogen transmission network belongs to a certified natural gas TSO. In these cases, the vertically integrated entity cannot be active in hydrogen production and supply at the same time that it is active in the production or supply of natural gas or electricity.

Derogations for geographically confined hydrogen networks

According to Article 48 of the Directive, a Member State may empower the NRA to grant derogations from the unbundling and certification requirements if the concerned hydrogen network covers "a geographically confined, industrial or commercial area" and fulfils certain additional criteria. This option may become relevant in the context of the envisaged hydrogen clusters, cf. section 3.5 above. If Sweden makes use of this option and a hydrogen transmission network operator requests a derogation pursuant to Article 48, it is up to the NRA to determine whether these criteria are fulfilled.

It is worth quoting the wording of the Directive with regard to the criteria for granting a derogation:

> *"For the duration of the derogation, such network shall fulfil all following conditions:*

(a) it shall not include hydrogen interconnectors;

(b) it shall not have direct connections to hydrogen storage facilities or hydrogen terminals, unless such storage facilities or terminals are also connected to a hydrogen network which does not benefit from a derogation under this Article or Article 47;

(c) it shall primarily serve the purpose of supplying hydrogen to customers directly connected to this network; and

(d) it shall not be connected to any other hydrogen network, except to networks also benefiting from a derogation under this article which are operated by the same hydrogen network operator."

Furthermore, the NRA must withdraw the derogation once it concludes that the derogation "would carry the risk of impeding competition or adversely affecting the efficient deployment of hydrogen infrastructure or the development and functioning of the hydrogen market in the Member State or the Union, or where any of the conditions listed [above] is no longer fulfilled." In our view, this does not impose an active monitoring duty on the NRA, since the NRA is explicitly obliged to publish an assessment of the derogation's impact on competition, hydrogen infrastructure as well as the development and functioning of the hydrogen market in the Member State or the Union every seven years (similar to the rules for derogations from the horizontal unbundling requirement discussed in the previous section).

However, the Directive obliges Member States to ensure that access requests of hydrogen producers as well as connection requests of industrial customers are notified to the NRA and made public (subject to the confidentiality of commercially sensitive information). If these reveal negative effects on competition or the functioning of the hydrogen market, it appears that the NRA is generally required to withdraw the derogation.

Hydrogen network operator unbundling requirements

All hydrogen network operators, even those enjoying a derogation for geographically confined hydrogen networks pursuant to Article 48 of the Directive or those not at the transmission level, are required to keep unbundled accounts (Articles 64, 69 of the Directive).

4.2.2 Additional security considerations

Article 66 of the Directive states that where the HNO's[9] owner is controlled by a person or persons in a third country, additional certification requirements apply with a view to ensure that "granting certification will not put at risk the security of energy supply or the essential security interests of the Member State and the Union". The certification decision is taken by the concerned Member State via its NRA, however the NRA must request an opinion of the Commission on the HTNO's eligibility against the unbundling and security criteria beforehand. When adopting its certification decision, the NRA must "take utmost account of the Commission's opinion." Where the final decision and the EC's opinion diverge, the concerned Member State must publish its underlying reasoning together with the decision.

4.2.3 Potential derogations for Upper Norrland

Article 80b in the revised text of the Directive allows Member States to grant derogations covering the unbundling

[9] Note that we assume that the third-country rules only apply to hydrogen transmission network operators. However, we follow the wording of the provisional agreement text of the Directive.

requirements for hydrogen networks in named isolated regions. These include Upper Norrland (NUTS 2 SE33).

Specifically, the article allows Member States to grant derogations from those articles detailing the unbundling requirement for both hydrogen distribution and transmission networks, as well as the associated requirements related to the certification procedure. The relevant checks related to third-country ownership, explained in section 4.2.2, are not within the scope of the potential derogation.

Derogations granted in line with the relevant article expire 15 years after they are granted and, in any case, by 2045 at the latest. They must also be withdrawn if the relevant network extends beyond the isolated region or becomes connected to hydrogen networks located outside of the regions. The derogations must also be published and notified to the European Commission.

4.2.4 Insights from the certification of electricity and gas TSOs

For electricity and gas TSOs, a certification procedure has been in place since the implementation of the third Electricity and Gas directives in 2009 (Directive 2009/72/EC and Directive 2009/73/EC respectively). The certification procedure and the corresponding requirements have been carried over in the fourth directives.

Certification is the responsibility of the NRA. The process may be initiated by a prospective TSO notifying the NRA of its desire to be certified. The NRA may also be obliged to open a certification procedure on its own initiative where it has knowledge that an infringement of the unbundling rules may occur or may have occurred. Finally, the Commission can request an NRA to open a notification procedure. In any case, the NRA adopts a preliminary decision and the European Commission reviews this preliminary decision to issue an opinion. The final decision rests with the NRA, but the NRA is obliged to take utmost account of the Commission's opinion. The Commission may also request an opinion from ACER.

The European Commission has provided practical guidance on these certification procedures that are likely to be of relevance for HTNOs as well.[10] The guidance is aimed at NRAs and other stakeholders and is intended to enable an efficient, transparent and predictable process for certification. While the guidance itself is not legally binding and only sets out the Commission's understanding of the provisions in the relevant directives, this guidance gives an overview of the certification criteria that are relevant under different unbundling requirements.

The Commission guidance is separated into three distinctive sets of recommendations depending on the nature of the organisation to be certified and its associated unbundling requirements:

1. Transmission System Operator (TSO) – full ownership unbundling.
2. Independent System Operator (ISO) – no ownership of transmission assets but control over investment decisions and network planning in addition to system operation
3. Independent Transmission Operator (ITO) – TSO that is part of a Vertically Integrated Undertaking (VIU)

The process for certification of a TSO is the simplest and consists mainly of a requirement to document ownership unbundling and the independence of the TSO towards market actors active in generation, production or supply. This includes a detailed review of the persons controlling the TSO and any

[10] Commssion Staff Working Paper on certification of Transmission System Operators of networks for electricity and natural gas in the European Union, SEC(2011) 1095 Final.

undertakings active in the relevant market that are controlled by the TSO or the parties controlling the TSO. It also includes documenting the independence of public bodies exercising control or rights over transmission from public bodies with control over generation/production or supply activities. There are also requirements to ensure that commercially sensitive information held by the TSO and its staff are not transferred to competitive undertakings where these were previously part of a vertically integrated undertaking. Finally, the TSO must document that it has responsibility for carrying out the tasks required of TSOs in the Directives and that the NRA has the powers to ensure that the TSO fulfils its tasks and obligations.

For an ISO, the certification requirements are more complex. As for the TSO model, the ISO is required to document ownership unbundling, its independence towards market actors and the independence of public agencies involved separately in transmission and supply. The requirements regarding regulatory supervision and the transfer of information are also similar to the TSO model. The additional requirements include the following:

- The ISO must document that it has the required human, technical, financial and physical resources to fulfil its tasks and that it will comply with a ten-year network development plan and participate in ENTSO-E or ENTSO-G.
- There must be mechanisms in place for coordinating and exchanging information with the network owner (transmission system owner).
- The owner of the transmission system must be legally and functionally unbundled from the ISO and have a compliance programme in place to ensure that discriminatory conduct is excluded.

For an ITO, the certification requirements are even more detailed than for the ISO. These additional requirements include the following:

- The ITO must document that it has the necessary personnel to fulfil its obligations and that these are employed directly by the TSO, not leased from other parts of the VIU.
- The ITO must have sufficient financial resources to fulfil its mission.
- The ITO must have a corporate identity, IT systems, consultants, security access systems etc. that are separate from those of the VIU.
- The management structure and statutes must ensure the effective independence of the ITO from the VIU and enable the ITO to raise capital for its activities and investments.
- Commercial and financial relations between the ITO and the VIU must be on market terms.
- The ITO must have a Supervisory Body responsible for making decisions that meet specific requirements in the Electricity and Gas Directives, with the NRA confirming compliance.
- A compliance programme must be established, and a compliance officer appointed who is independent of the VIU.

The key elements of the three main models are summarised in the table below.

Table 2 Key elements of the main HTNO models

Certification model	*Key elements*	*Certification requirements and other requirements*
Transmission System Operator (TSO)	Ownership unbundled	• Document ownership and independence, including towards public bodies exercising control or rights over transmission activities, generation/production and/or supply • NRA has the power to, e.g., impose fines if the TSO does not fulfil the relevant tasks and obligations
Independent System Operator (ISO)	Ownership unbundled, does not own transmission assets, but has control over investment decisions and network planning as well as system operations	• Document ownership and independence, including towards public bodies exercising control or rights over transmission activities, generation/production and/or supply • Document that the ISO has required human, technical, financial and physical resources to fulfil its tasks and to comply with a 10-year network development plan, participation in ENTSO-E/ENTSO-G • Coordination and information exchange mechanisms with network owner • Transmission system owner: Legal and functional unbundling, compliance programme • NRA has the power to, e.g., impose fines if the ISO does not fulfil the relevant tasks and obligations
Independent Transmission Operator (ITO)	TSO that is part of a Vertically Integrated Undertaking (VIU)	• Document that the ITO has necessary personnel to fulfil its obligations and that these are employed directly by the ITO, not leased from other parts of VIU • ITO must have minimum financial resources required to fulfil its mission • ITO shall have corporate identity, IT systems, consultants, security access system etc. separate from VIU • Management structure and statutes ensure effective independence of VIU, able to raise capital • Commercial and financial relations between ITO and VIU on market terms • ITO shall have a Supervisory Body responsible for making decisions that meet specific requirements in the Electricity and Gas Directives, with the NRA confirming compliance • Establish compliance programme and appoint compliance officer independent of VIU • NRA has the power to, e.g., impose fines if the ITO does not fulfil the relevant tasks and obligations

4.3 Roles and responsibilities of current Swedish electricity and gas TSOs

Today, Sweden has separate electricity and gas TSOs who differ in terms of ownership structure and regulatory environment. State-owned Svenska kraftnät (Svk) is the TSO for the electricity grid, while the privately owned Swedegas is TSO for the gas grid in Sweden. This chapter outlines their responsibilities and details the Swedish regulations for certifying electricity and gas grid operators. Swedish laws and regulations are in this chapter referred to by their SFS numbers and can be accessed on the webpages of Sweden's parliament (Sveriges Riksdag, 2023).

Regulation of electricity TSO

As a state-owned enterprise, Svk's mandate and responsibilities are detailed by government regulation. Notably, the Swedish government issues annual regulatory letters that outline the focus areas for Svk. In addition, there is a specific regulation (2007:1119) stating Svk's mission. Overall, it tasks the enterprise with managing, operating, and developing a cost-effective, reliable, and environmentally adapted power transmission system, selling transmission capacity, and conducting other activities related to the power transmission system. The regulation further specifies duties such as:

- Expand an electricity transmission network in Sweden and connections with electrical networks in other countries based on socio-economic profitability assessments.

- Promote competition in the electricity market.
- Promote research and development, as well as demonstration of new technology.
- Monitor and provide information regarding power and capacity availability in the grid. The electricity act (1997:857) also states that the TSO must report production, transmission and consumption data to a transmission system authority.
- Regularly consult and report to the Swedish government, including a bi-annually ten-year investment plan.

The regulation (2007:1119) also outlines the management structure of Svk, detailing its key entities and the government's role in appointing the company's leadership. Since the company's funding comes from tariffs, the regulation permits Svk to levy charges for its commercial activities and manage revenues from statutory fees.

Alongside targeted regulations for Svenska kraftnät (Svk), Sweden's Electricity Act (1997:857) also imposes regulations on Svk and other grid operators. In chapter 3, containing regulation of grid operators, it includes requirements that mostly overlap with the requirements in the Svk-specific regulation (2007:1119). Most notably, it includes requirements for vertical unbundling, stating that a network operator shall not carry out any activities other than network activities.

Regulation of gas TSO

Swedegas (a subsidiary of Nordion Energi) is privately owned and therefore not regulated as directly as Svk. Instead, the company operates within a framework established by Sweden's natural gas law (2005:403). Similar to the responsibilities of the electrical TSO, the natural gas law outlines a gas SO's responsibilities of operating, maintaining and extending the pipeline system, as well as the connection to other systems. Among other things, the law requires gas system operators:

- Vertical unbundling: A company engaged in the transmission of natural gas is not allowed to trade in or produce natural gas.
- Activities related to transmission of natural gas must be accounted for separately from other activities, including the distribution of natural gas.
- Obligation to connect to other pipelines, storage facilities and gasification plants on reasonable terms[11].
- Obligation to measure and report the transmitted natural gas.
- Fees and other terms and conditions for connection shall be reasonable, objective, and non-discriminatory.
- Revenue limits shall be decided in advance for each regulatory period for undertakings engaged in the transmission of natural gas.
- The building of natural gas infrastructure needs a concession from the government.

Certification of transmission network companies

Certification of a transmission system operator for electricity is regulated through a distinct act (2011:710). It emphasizes that companies must comply with unbundling rules from the electricity act (1997:857) most notably that transmission system operators must be independent of companies producing or trading in electricity or natural gas. The law also places extra rules for companies controlled or linked to third countries.

[11] If the infrastructure is not exclusively used for the owners own account

Certification of natural gas companies is also governed under a distinct act, specifically the 2011:711 legislation. Similar to the act regarding electricity, this act primarily addresses the unbundling requirements outlined in the Natural Gas Act of 2005 (2005:403), as well as extra requirements for companies linked to third countries.

5 International Survey

As background for the Swedish regulator's certification of an HTNO and implementation of EU guidelines, it is relevant to investigate how other EU countries are approaching the certification process. We have thus performed a survey of four countries, namely Denmark, Finland, Germany, and the Netherlands.

Differences between the countries when it comes to current use of hydrogen, the future role of hydrogen, the structure of the energy system, and governance structures for energy infrastructure, naturally affect the choices. To draw lessons relevant for the situation in Sweden, we therefore also describe the context for the countries' hydrogen governance processes. The survey is based on public information and supplemented through interviews.

5.1 Denmark

5.1.1 Hydrogen strategy and policies

Denmark announced its power-to-X strategy in 2021, including a national target of between 4-6 GW of electrolyser capacity. This hydrogen strategy has four main objectives: reducing emissions, establishing an effective regulatory framework and hydrogen infrastructure, integrating power-to-X into the Danish energy system, and creating export value (Danish Ministry of Climate, Energy and Utilities, 2021a).

In 2023, Denmark also mandated Energinet, the national electricity and gas TSO, and Evida, a major gas distributor, to own and manage the country's upcoming hydrogen pipelines. Under this mandate, Energinet is set to oversee system planning and manage cross-border infrastructure, whereas Evida will handle the operation of distribution networks. Both companies are owned by the Danish state. To supplement this report, an interview was conducted with Energinet on December 13th, 2023. According to the interview, Energinet projected that Denmark would adopt the European hydrogen legislation by the second half of 2024.

Denmark is actively supporting the growth of a hydrogen economy by subsidizing several segments of the value chain. The government intends to announce financing for the hydrogen transmission network by the end of 2023, and it has already arranged a tender for hydrogen production, supporting projects totalling 280 MW of electrolyser capacity (Hydrogen Europe, 2023). The country also earmarks EU funds, particularly from the REACT-EU initiative and the Just Transition Fund to innovative green technologies like hydrogen (Danish Ministry of Climate, Energy and Utilities, 2021). Furthermore, Denmark participates in the IPCEI[12] schemes concerning hydrogen (IPCEI Hydrogen, 2023), and is home to Green Hydrogen Hub, a flagship project combining hydrogen production with storage in salt caverns.

5.1.2 Expected role of hydrogen in the energy system: Current status and outlook

Denmark has a significant share of renewables in its power mix and is actively pursuing further offshore wind development. The government increased the 2030 goal for offshore wind to 12.9 GW, from today's 2.7 GW, and the country has multiple projects underway. Most notably, Denmark plans to construct two energy islands, see Figure 3. The islands will facilitate electricity distribution from offshore wind, thus reducing costs, and connect with both Denmark and Germany.

[12] Important Projects of Common European Interest

Hydrogen production is seen as a suitable complement to the Danish energy system due to Denmark's large and increasing share of intermittent wind power. Primarily, flexible hydrogen production can help the energy balance, consuming power mainly when wind output is high, thereby mitigating price volatility. Secondly, hydrogen can be used to reduce the need for electricity grid reinforcement and grid operation costs, for example by locating hydrogen production close to where offshore wind power is transmitted to shore.

Offshore wind is expected to make Denmark an energy exporter in the 2030s, and transporting energy via hydrogen pipelines could be more cost-effective than investing in additional electricity grid capacity. In the interview, Energinet highlighted the potential synergy between electricity and hydrogen infrastructure and pointed to the advantages of having a single entity responsible for coordinated planning of both.

Figure 3: Visualization of the proposed Danish energy islands

Source: Danish Energy Agency

Like other countries in continental Europe, Denmark has a well-developed gas grid interlinking various regions within Denmark and extending to Germany and Sweden. The country's Green Gas Strategy (Danish Ministry of Climate, Energy and Utilities, 2021b) highlights the potential for retrofitting parts of this network for hydrogen transportation, leveraging the cost savings of retrofitted gas pipelines. However, Energinet pointed out that this potential is limited by the geographical misalignment of traditional gas demand and emerging hydrogen demand. For instance, the demand for gas in heating will not shift to hydrogen but will instead be met by heat pumps.

There is also potential in repurposing some of the gas infrastructure that connects Denmark and Germany. Energinet's most advanced initiative, the Danish Backbone West, which aims to link with Germany's Hyperlink 3 project, is currently exploring this option (Energinet, 2023). Considering Denmark's close proximity to the expected large hydrogen demand in central Europe, the country is well positioned to become a hydrogen exporter.

Given its initial conditions of large wind development and relatively cheap hydrogen infrastructure, Denmark is likely to base its hydrogen system on landing zones, where hydrogen is produced, stored, and then distributed and exported through pipelines. Typically, these landing zones will be located near points where large volumes of fluctuating offshore wind power is transmitted to shore. They can serve as a buffer between large scale renewable energy and the rest of the grid, producing hydrogen when power output is high (Energinet, 2019).

With its limited industrial base and minimal domestic demand for hydrogen, the Danish hydrogen strategy is focusing on exporting hydrogen and power-to-X products to Central Europe. The country's 2021 hydrogen strategy highlights the importance of building a hydrogen infrastructure, including pipelines and storage facilities. This infrastructure aims to facilitate export by creating direct connections between Denmark and the European continent, which is essential for establishing a demand for the eventual hydrogen production in Denmark.

5.1.3 Denmark Sweden comparison

Differences

- Denmark has a well-developed gas grid connecting different parts of the country. Their Green Gas Strategy (2021b) outline that some pipelines can be converted to transport hydrogen, lowering Denmark's expected expenses associated with hydrogen infrastructure compared to Sweden.
- Denmark's industrial sector is considerably smaller compared to Sweden's. Furthermore, Denmark has less experience in hydrogen technology, in contrast to Sweden, which currently has a substantial consumption of grey hydrogen as a part of its industrial sector.
- Denmark plans to export hydrogen and power-to-X products directly, while Sweden intends to export products produced using hydrogen.
- Denmark has come further in the planning of its hydrogen infrastructure and has already mandated Energinet and Evida to develop and operate hydrogen infrastructure.
- Denmark's proximity to the central European hydrogen market reduces the cost of exporting hydrogen compared to Sweden.
- The hydrogen landing zones envisioned in Denmark are different from the hydrogen clusters envisioned for Sweden. Mainly, the landing zones are expected to export hydrogen via pipelines, while the Swedish hydrogen clusters would consume the hydrogen locally instead.

Similarities

- Both countries have a large share of renewable power and are expected to expand their wind power capacity substantially. This expansion is likely to attract hydrogen production and enhance the countries' advantage of using hydrogen production to stabilize the variable output from renewable sources.
- DK1 is expected to reach the 90% RES share needed for hydrogen to be classified as green without a specialized PPA, according to THEMA's base scenario (2023c) and seen in figure 2 from Chapter 3.3. This will give the bidding zone the same competitive advantage as SE1 and SE2, although at a later stage.

5.2 Finland

5.2.1 Hydrogen strategy and policies

In early 2023, Finland adopted a national resolution outlining the country's objectives and policies related to hydrogen (Finnish Government, 2023). This resolution establishes Finland's ambition to become a leader in the European hydrogen value chain, targeting 10% of the EU's emissions-free hydrogen production by 2030. A key driver for this ambition is Finland's focus on energy security, a concern heightened by its geographical proximity to Russia and mentioned in the government's resolution,

Finland has adopted a relatively proactive approach to hydrogen, for example by granting hydrogen projects precedence in permit processes and accelerating the development of new onshore wind to ensure supply of energy (Finnish government, 2023).

Furthermore, the Finnish government has tasked Gasgrid Finland with establishing a national hydrogen infrastructure and developing a hydrogen market. This initiative also shows Finland's commitment to creating a stable operational environment for hydrogen stakeholders (Finnish government, 2023), a crucial step in addressing the 'chicken and egg' dilemma often associated with hydrogen adoption.

5.2.2 Expected future role of hydrogen in the energy system: Position and future outlook

Finland has historically been challenged by a substantial generation deficit and some of the highest power prices in the Nordics, but the country's energy system is now undergoing a transformative shift. The shift is marked by the recent commissioning of the country's latest nuclear reactor, coupled with substantial investments in onshore wind and solar power. The expansion of onshore wind capacity is particularly notable. 3.2 GW is currently under construction, with completion anticipated by the end of 2025, a significant increase when compared to the existing capacity of 6.1 GW.

Finland, with its robust nuclear power capacity and significant growth in renewable energy sources, is increasingly aligning its energy mix with that of Sweden, albeit with a lesser reliance on hydropower. According to the new EU taxonomy on green hydrogen, discussed in section 3.3, this makes Finland more attractive for hydrogen production. Although Finland is not expected to reach the 90% RES share due to its nuclear power, the carbon intensity of the electricity mix is expected to be low enough for Finnish producers to qualify for exemption from the stringent PPA requirements.

Finland's significant expansion of onshore wind power is strategically designed to meet the anticipated surge in the nation's power consumption, particularly due to the industrial sector's decarbonization. This transformation will heavily rely on electrical energy, notably through hydrogen utilization. Key industries such as steel, chemicals, and refineries are poised for a substantial increase in the demand for renewable hydrogen. Mirroring developments in Sweden, Finland is also progressing with major green steel projects, such as the initiatives from SSAB and Blastr, both in Raahe.

Finland's gas network is limited, predominantly serving only some southern regions. This limitation restricts the country's ability to transform existing gas infrastructure into a hydrogen-based system. Despite these challenges, Gasgrid Finland is actively pursuing the development of pipelines to connect prospective hydrogen clusters and is also exploring possibilities for international pipeline connections.

It is unclear what Finland’s hydrogen value chain will have as its end-product. A recent report by Fingrid and Gasgrid (2023) outlines three probable scenarios for Finland's hydrogen use, spanning from exporting goods manufactured with hydrogen to exporting the hydrogen itself. Notably, even in scenarios where hydrogen is exported, a significant portion is anticipated to be utilized by Finland's industrial sector.

5.2.3 Finland Sweden comparison

Differences

- Finland has already mandated Gasgrid Finland with the promotion of hydrogen infrastructure and a hydrogen market in the Baltic Sea region.
- Finland plans to interconnect the hydrogen clusters through a national grid of hydrogen pipelines. Sweden has no such plans yet, and Fossil Free Sweden (2021) is skeptical to such infrastructure in the short-to medium term.
- Gasgrid Finland is planning export pipelines through the Baltics. Sweden is not currently planning the export of hydrogen itself, at least not in the short term.

Similarities

- Both countries have significant steel industries that are seeking to decarbonize, as well as substantial industries that currently rely on grey hydrogen.
- Both Sweden and Finland hold significant potential for onshore wind power production. Conversely, the lack of subsidies for offshore wind makes such buildouts less probable in both countries.
- Like Sweden, Finland also faces the challenge of a limited gas pipeline network, increasing the costs associated with establishing a hydrogen network.
- The Finnish government wants to establish hydrogen clusters, similarly to what is expected for Sweden.
- EU taxonomy rules will probably allow for Finnish producers to produce green hydrogen without specialized PPA’s. This is because of the low carbon intensity expected.

5.3 Germany

5.3.1 Hydrogen strategy and policies

Targets

The German hydrogen strategy sets a target for domestic electrolysis capacity at 10 GW by 2030 (Bundesregierung, 2023). This may be enough to cater to the current H_2 demand in the country, depending on the electrolysers´ operating hours: Current demand for hydrogen in Germany is 55 TWh. It is expected to grow to around 95-130 TWh by 2030, according to Germany´s Hydrogen Strategy. According to the document, 50-70% of hydrogen demand will be covered by imports. Therefore, a dedicated import strategy will be published by the end of 2023 or early 2024.

Germany´s hydrogen infrastructure plans centre around the already existing individual H_2 hubs, which are to be connected by a transmission network. The strategy states that H_2 generation shall be located close to RES production to relieve the electricity grid.

The country´s hydrogen policies and regulations are currently undergoing regular updates. Changes are announced almost every week. But the underlying target is to achieve as much self-sufficiency as possible.

Status of implementation, including current governance

Following the hydrogen strategy and due to the hub-oriented structure of the medium-term hydrogen system, the organization of hydrogen transport is a very relevant issue. Germany plans to refurbish its existing natural gas pipeline network into an H_2 transport system.

To achieve this, the official hydrogen strategy foresees an important role of the gas TSOs in the future hydrogen system. In fact, the German Energy Act (EnWG) demanded that the natural gas TSOs submit a common hydrogen report. This report now provides the blueprint for the hydrogen transport infrastructure.

The gas TSOs have also jointly presented a plan for development of the so-called “core H_2 network”. The core network will have a length of ca. 9700 km, 60% of which are planned to be refurbished gas pipelines (ca. 5800 km). The German cabinet has approved the legal framework for this hydrogen core network. The plan is now (November 2023) under public consultation. It is expected that the grid will cost around EUR 20 bn.

To finalise the grid in 2032 as planned, construction must begin soon, according to the involved gas TSOs. Hence, the gas TSOs will shortly submit a joint application for approval of the core grid design to the German regulator (BNetzA). BNetzA will then have the possibility to either accept, change, or reject the proposals. (It may also accept only parts of the proposal).

As a second step, the periodic gas network development plan is to be expanded into an integrated gas and hydrogen network development plan. This plan will be renewed every two years. Hydrogen network modelling was already part of the Gas Network Development Plan 2022-2032 (BMWK, 2023).

The role of the gas TSOs was decided only this year. Before, a federal “Planning and Starting” organization was also discussed, which would have been responsible for planning and running the H_2 grid. However, the government has decided that setting up such an organization would take too much time and now grants a lot of initiative and responsibility to the gas TSOs (Bundesregierung, 2023).

Financing

Building the pipeline infrastructure will incur high costs. The core grid alone has a price tag of ca. EUR 20 bn. The plans for financing of the new H_2 grid are not yet entirely final, but a government “intermediary report” lays out several principles (Bundesregierung, 2023):

- The users shall finance the grid through network tariffs.

- The tariffs are to be similar across Germany, based on "aggregated network costs of all operators of grid infrastructures". It is not yet clear whether this will comply with EU legislation. This provision would also require a financial balancing mechanism between TSOs to settle extra or too low revenues.
- A governmental "amortisation account" shall balance payments between early and late users:
  - Early grid users need only pay a part of the grid costs, the rest comes from the governmental "amortisation account".
  - The German regulator decides how high this nearly-stage tariff is going to be. (A study will soon look into tariff levels.)
  - In the medium- to long-term, slightly higher grid tariffs than necessary are planned to re-fill the amortisation account.
  - The government may terminate the amortisation account in 2039, if the buildout of the H_2 infrastructure is failing. (This would mean that the amortisation payments in the beginning were actually subsidies).
  - If the amortisation account is not balanced out until 2055, TSOs are to cover up to 24% of the remaining costs, with the state covering the rest.
  - The government does not expect income from congestion fees before 2032.

Support for the envisaged electrolyser capacity consists of a mixture of EU support via IPCEIs, and national measures.

Certification

There are no concrete plans regarding the certification process of German Hydrogen TSOs as of now.

Currently, the natural gas TSOs are fulfilling some HTNO roles without any formal certification (e.g., network planning and likely also network building).

In an interview with THEMA on December 09th, 2023, BNetzA officials pointed to the unfinished EU regulation on HTNO certification. German regulation will follow as soon as the EU regulation is adopted.

5.3.2 Expected role of hydrogen in the energy system

Germany, with roughly 30 million gas consumers, has 16 gas TSOs, which operate throughout the country. The country also has four electricity TSOs. The availability of an extensive natural gas grid strongly influences the plans on the future hydrogen system. The German gas TSOs are putting in much effort to turn their gas into hydrogen assets and thus remain relevant.

Germany produced 571 TWh of electricity in 2022. This is expected to grow to anything between 680 and 750 TWh until 2030. Renewables produced 256 TWh in the same year (Destatis, 2023).

Meanwhile, Germany consumed 825 TWh of natural gas in 2022. Demand is expected to drop by 95% until 2050, but as of yet it is rather uncertain how quickly (Destatis, 2023) (Fraunhofer ISI, 2023).

Fossil fuel consumption in Germany is still large, but the country has set an emissions reduction target of at least 65% by 2030, and to achieve climate neutrality by 2045.

Hydrogen´s role in the country´s future energy system is still uncertain. The transport ministry would still like to see H_2-fueled cars, as would some state governments. Others point to the gas´s high cost and would favour its use to replace fossil energy and grey hydrogen in high-emission intensity processes, like steel production.

Depending on the outcome of the political processes, H_2 consumption may reach anything between 100 and 500 TWh per year by 2045, according to the German government´s long-term prognoses (Fraunhofer ISI, 2023). This would mean an annual increase of between 2 and 18 TWh; up from the current consumption of roughly 55 TWh of H_2.

- Of this, the electricity sector will account for between 20 and 150 TWh (for peak production during "Dunkelflauten").
- The prognoses expect general demand to consume the remaining 100/400 TWh (shipping, air travel, industry).

5.3.3 Planned hydrogen supply and demand

There is currently no nationwide hydrogen grid infrastructure, supply and demand are hence highly distributed. Several regional clusters with hydrogen infrastructure exist, for example:

- The Unterelbe/Weser/Ems cluster,
- the Ruhrgebiet cluster,
- and the Mitteldeutschland/Berlin Brandenburg cluster.

The hydrogen core network is to connect all these clusters, including import locations. Germany expects to import large volumes of H_2. Supply will hence come both from local production and from imports. Both importers and local producers are currently competing for government subsidies.

Meanwhile, smaller companies not directly connected to the hydrogen core grid, are deliberating to switch to H_2-fueled processes and are trying to gain access to the core network.

5.3.4 Outlook / uncertainties / concerns

Germany has not yet adopted legislation regarding the certification of HTNOs itself. The country still awaits the final EU regulation on the matter.

However, Germany seems to have achieved its goal of allowing HNOs to operate under the ITO status: The latest draft of the agreed new gas directive contains the ITO certification for HTNOs (cf. Chapter 4).

The interdependency of gas, hydrogen and electricity networks is a challenge. Germany intends to solve this by developing a joint network development plan for gas and hydrogen grids every two years. This plan is to consider the electricity network development plan, which is set to be developed simultaneously. Both gas/H_2 and electricity plans will base their modelling and detailed planning on previously developed high-level energy system strategies. The German energy agency (dena) is responsible for developing these strategies every four years, involving all relevant stakeholders. They should also always consider EU-level strategies, developed by ENTSO-E and ENTSO-G (and in the future, ENNOH).

Blending hydrogen into the gas grid might be a good starter for the H_2 economy, but will likely not be economical, as the German government does not allow for virtual netting of green H_2: Regulations do not allow feeding green H_2 into the grid and then take it out at another location "virtually", i.e., by buying green H_2 certificates from the H_2 producer. The government is wary of giving gas TSOs the option to continue running their current business models.

5.3.5 Germany Sweden Comparison

Differences

- Germany has an extensive natural gas grid that can be repurposed for hydrogen, hence, blending of H_2 into methane grids would be an option, if virtual netting were possible.
- Germany already has joint network planning procedures in place for hydrogen and natural gas.
- Germany already consumes large amounts of H_2, mainly produced from natural gas without CCS (grey hydrogen).

Similarities

- Both countries feature a North-South disconnect, with most of the available RES generation capacity for green H_2 production in the North.
- Over the next years, both countries´ hydrogen economy will consist of localized hubs.

5.4 The Netherlands

5.4.1 The Dutch hydrogen strategy

Targets

The Dutch National Climate Agreement includes an ambition to scale up electrolysis capacity to ca. 500 MW by 2025 and to 3-4 GW by 2030. A roadmap prepared for the Economic Ministry even demands 8 GW by 2032, which has been endorsed by some members of the government (NautaDuthil, 2023).

The country already consumes large amounts of hydrogen, in the same order of magnitude as Germany. (TNO, 2023) reports 27 TWh. Other sources offer somewhat higher or lower figures, but all are in the same order of magnitude. The country also expects hydrogen to play a larger role in future transport and industry applications.

As to grid targets, the government has appointed Gasunie to build the hydrogen backbone project, also known as "HyWay27". Hynetwork Services (a 100% subsidiary of Gasunie) has been tasked with the implementation. This project will have the form of a 1200 km country wide hydrogen grid network. It is targeted to become wholly operational already by 2030 (Gasunie, 2023).

Status of implementation, including current governance

The first 30km of the grid is planned to become operational by 2025 (Gasunie, 2023).

While the government is already setting up many programs and is even already letting Gasunie build the new hydrogen grid, there is as of now no specific legislation for hydrogen. Hydrogen is not covered by the current Gas Act. Hence, for the time being, the Ministry of Economic Affairs and Climate Policy of the Netherlands regulates hydrogen on an ad-hoc basis.

Meanwhile, everybody is waiting for the announced "Energy Act" which is supposed to set the Dutch H_2 regulation into stone: The Dutch Authority for Consumers and Markets (DACM) already promised such an act in 2021, in order to streamline electricity, gas and hydrogen regulations. But it is still with the DACM (ACM, 2021).

According to (CMS, 2022) the Energy Act is expected to ensure a step-by-step regulatory development, following the development of EU law:

1. Until 2025, the Dutch government expects no new EU legislation to become mandatory.
    a. Thus, the Ministry of Economic Affairs and Climate is likely to set conditions for third-party access to hydrogen infrastructure and tariffs (and organise trilateral negotiations between interim "de-facto" H_2 TSO Hynetwork Services, potential users and the ministry to set tariffs).
    b. Hynetwork Services will publish standard connections and transport contracts after conducting market consultations.
2. During the second phase (2025-2030), gradual implementation of EU hydrogen law into Dutch national law will take place. At first, the regulator ACM will provide guidelines for a hybrid negotiated third party access, which will then transition towards regulated third party access.
3. In the third phase (post-2031), the operational phase will start. Then, ACM will set or approve the tariffs, and formulate rules regarding third-party access, balancing, capacity allocation and congestion management.

According to our interview with ACM in January 2024, Hynetwork Services are already carrying out bilateral negotiations on grid access with potential users. ACM expects to become involved if there are any disputes following the negotiations. They also expect to have an advisory role on, e.g., investment decisions or the transfer of assets from the gas to the HTNO.

In general, ACM have so far had a limited role in the development of the hydrogen sector. However, they are preparing for a larger role and will start talks with the Ministry to this end this year. They expect to be responsible for regulating both tariffs and third-party access from 2032, in line with EU regulation. They expect that the development of these regulations must start some years prior to 2030, though.

Financing

The planned H_2 grid of 1200 km will cost around 1.5 billion EUR to build.

The Dutch government has earmarked 750 million EUR as subsidy for the start-up phase. This amount is expected to cover losses taking place due to possible vacancies (or lack of use) until the network is fully regulated and as long as the financing cannot be fully covered by grid user fees (Clifford Chance, 2022).

This money is hence intended to bridge the years when sufficient supply and demand for hydrogen have not arisen. At the end of the startup phase (in 2030), the subsidy actually needed will be determined and any excess subsidy that has been paid will be recovered.

Regarding regulations on grid user tariffs, the Netherlands is awaiting the outcome of discussions on EU level. However, estimates indicate that "acceptable" tariffs may be realistic already in 2031, under the assumption of a certain amount of usage (Interview with ACM, January 2024).

Gasunie has also issued green bonds worth 300 million EUR with a maturity of 9.5 years. A part of this money will go towards the construction of the national H_2 grid.

Certification

The Ministry for Climate and Energy is expected to set conditions for the designation of the company "Hynetwork Services" as the Hydrogen TSO, putting an emphasis on non-discriminatory access to the grid for third parties. Details are still unclear (Vandoorne, 2022). The reason for this expectation is a letter by the then-Minister of the Economy to Parliament in 2022, stating that HyNetwork Services would in the future operate such an H_2 transmission system.

5.4.2 Expected role of hydrogen in the energy system

The Netherlands features only one gas TSO, Gasunie. Gasunie's high pressure gas pipeline system has a total length of about 13 000 km. It is 100% owned by the Dutch state.

Dutch electricity generation was 122 TWh in 2022, with total electricity consumption at 108 TWh (Enerdata, 2023).

Meanwhile, the Netherlands produced 147 TWh of natural gas in 2022, while consumption was at 322 TWh (Enerdata, 2023).

Besides the high (and now shrinking) natural gas production, the Netherlands is also Europe's second largest grey hydrogen producer with an annual production of over 27 TWh (TNO, 2023).

Targeted energy system

With the 2019 Climate Act, the Netherlands has set legally binding targets to reduce greenhouse gas emissions by 49% by 2030 and by 95% by 2050 (compared to 1990 levels). It also aims for renewables to provide 100% of electricity by 2030 (Ember, 2022).

Offshore wind will be a crucial enabler of scaling up the hydrogen production. Planned projects in the Dutch sector of the North Sea add up to 11 GW of offshore wind capacity by 2030, with space for scaling up to 20-40 GW.

Under current government plans and buildout targets for offshore wind and electrolysers, THEMA finds electrolysis to consume about half of the large Dutch offshore wind power generation after 2030 (THEMA, 2023b).

5.4.3 Planned hydrogen supply and demand

The Dutch strategy centres around production and consumption hubs, connected by a refurbished version of the already existing natural gas grid.

- In Phase 1 (2025-2026) the hydrogen pipeline will focus on connecting the large industrial clusters on the Dutch coast.
- Phase 2 (2027-2028) will focus on connecting industrial clusters in the rest of Netherlands and expand connections with neighbouring countries.
- Phase 3 (tbd) will depend on the demand for transport and storage capacity of hydrogen (Clifford Chance, 2022).
- The estimated length of the core network already planned will be 1200 km. The plans account for 200 km of these pipelines to be new, the rest refurbished gas pipelines.

To ensure enough green hydrogen production within the Netherlands, the Minister of the Economy announced plans to spend EUR 7.5 bn on H_2 production projects in April 2023, (CSIRO, 2023).

The government also plans to mandate some demand obligations, to increase the share of green hydrogen in the currently already high consumption of the gas. This will follow the EU´s Renewable Energy Directive III (Argus Media, 2023).

5.4.4 Outlook / uncertainties / concerns

The Netherlands has already started developing plans for build up a hydrogen economy. However, the country at times still lacks concrete measures to realise its plans:

1. The hydrogen TSO certification system is not yet in place. Further, no hydrogen-specific law at the national level exists.
2. The Netherlands awaits pending EU regulation on how to implement the financing and grid tariff mechanism.

5.4.5 Netherlands Sweden comparison

Differences

- Sweden has little gas transmission infrastructure to be converted to H2 pipes while Netherlands expects above 80% of its future H2 network to consist of refurbished natural gas pipelines.
- Sweden has a large renewable power surplus in the north, which makes the region ideal for hydrogen production. Netherlands is a small country, so no such demarcation exists. Yet, northern Netherlands and even offshore regions are most suitable for RES generation. The Dutch offshore law even includes that H2 is a suitable transport option for bringing power from offshore hubs to shore.

Similarities

- Both countries have no blending plans for H2 and natural gas
- Both countries organise their future H2 economy around hubs, but the Netherlands already have plans to connect them from the get-go and have a large gas grid to use for this.

5.5 Key takeaways with relevance for Sweden

Table 3 below summarizes some key information from the international survey, including comparable features of the Swedish situation:

- The main targets of the hydrogen strategy
- Characteristics of the current energy system
- The future energy system and the expected role of hydrogen
- The current allocation of responsibilities for the development of the hydrogen infrastructure and market

There are some similarities among the countries, but the overall picture is quite diverse. All countries have adopted ambitious hydrogen strategies, but it is obvious that the status of the current energy system, including the generation mix and energy infrastructure, the potential for expansion of renewable power generation and the decarbonization options, i.e., path dependencies, affect the role that hydrogen is expected to play in the future system. In this context, Finland is the country that bears the most similarity to Sweden both when it comes to the extent of the gas network, the electricity generation mix, and the industry structure.

A crucial difference compared to Denmark, Germany and the Netherlands, is the extent of the gas infrastructure, which constitutes an important basis for the development of a hydrogen network, both in terms of converting gas pipelines to hydrogen pipelines and in terms of starting the hydrogen economy by mixing hydrogen into gas. This also makes it more natural that the development of the hydrogen infrastructure is placed with the gas TSO. However, even in Finland, the responsibility is so far placed with the gas TSO. Unlike in Sweden, however, the Finnish gas TSO is a state-owned company.

All the countries are however similar when it comes to the certification of an HTNO: Although the responsibility for planning and development of a hydrogen infrastructure has been delegated by authorities, none of the countries have formally certified a national (or regional) HTNO yet. They are all waiting for the final EU regulation to the adopted.

Table 3: Overview of the current status of hydrogen strategy adoption and regulation in the focus countries

	Sweden	Denmark	Finland	Germany	Netherlands
Hydrogen strategy	• Proposed target: 5 GW electrolyzer capacity by 2030, 10 GW 2045 • Expected high industry demand, plus e-fuels • Establishment of local/regional industry hubs/hydrogen valleys	• Target: 4-6 GW electrolyzer capacity • Some domestic use (industry, e-fuel) • Hydrogen infrastructure mainly for exports	• Target: Producer of 10% of EU emission-free hydrogen in 2030 • Combination of domestic (industry) use and exports • National H2 infrastructure connecting initial hydrogen valleys	• Target: 10 GW electrolyzer capacity by 2030 • National hydrogen infrastructure partly based on existing gas network (regional gas TSOs) • Import of green hydrogen to meet domestic demand (50-70%)	• Target: electrolyzer capacity from 500 MW to 3-4 GW by 2030 • Use in industry and transport • Country-wide hydrogen network, partly based on existing gas network
Energy system characteristics	• Limited gas network, minor role of natural gas • Substantial share of RES (onshore wind and hydropower) plus nuclear • Heat: DH based on waste and biomass	• High share of RES (onshore wind) • Gas for heating (DH) and in domestic use • Energinet TSO for both electricity and gas	• Focus on energy security • Limited gas network • Large share of nuclear power	• Extensive gas network and large share of gas in energy mix • Grey hydrogen used in industry • High RES-E plans, nuclear out • North-south el grid bottlenecks • Regional gas TSOs, four el TSOs	• Extensive gas network • Grey hydrogen used in industry • Separate national TSOs for gas and electricity
Expected future role of hydrogen	• Reduce existing industry emissions, decarbonize transport • Green industry expansion • Balancing energy system with high RES, north-south bottlenecks • Hydrogen hub/valley structure • Long-term: Alternative to power grid expansion	• Domestically: Balance power system • Hydrogen production mainly from offshore wind • Exports via pipelines to Germany • Alternative to electricity grid	• Reduction of industry emissions • Planned substantial expansion of onshore wind to provide energy for hydrogen • Hydrogen may be used in export industry or exported directly	• Replace grey hydrogen in industry • Replace natural gas in heating , initially through blending • Possibly decarbonize transport • Production close to RES-E production to relieve el grid, plus balance power system	• Decarbonize current hydrogen use • Offshore wind development to enable H2 production • Stepwise development: 1 connecting industrial hubs, 2 cross-border connection
Status of certification and regulation	• Current responsibility for hydrogen development rests with el TSO (Svk) • Energy market inspectorate expects to certify applications for HNOs, no applications yet	• No HTNO formally certifed yet • Energinet responsible for hydrogen transmission network development, gas distribution company Evida for hydrogen distribution	• No HTNO formally certifed yet • Gasgrid Finland tasked with establishment of national infrastructure and development of hydrogen market	• No HTNO formally certified yet • Regional gas TSOs currently act as HNOs • Common proposal for a core H2 network - legal framework approved • Bi-annual common integrated gas and H2 nework development plan	• No HTNOformally certified yet • Ad hoc regulation by Ministry • New energy act to set H2 regulation is pending • Gasunie (gas TSO) to build hydrogen backbone infrastructure via subsidiary Hynetwork Services

6 Analysis of options for a Swedish hydrogen transmission network operator

In this chapter, we analyse a set of options for a Swedish hydrogen transmission network operator in the long run. We start by defining the hydrogen transmission network operator's core tasks and responsibilities before describing the criteria we use for assessing the options. We then define the options to be considered before assessing each option according to the criteria. We also discuss the possible role of state and national/EU ownership. Finally, we provide some comments on the possible way forward for designing a suitable hydrogen transmission network operator solution for the Swedish energy system and discuss possible trade-offs between short- and long-term solutions.

6.1 Hydrogen transmission network operator tasks and responsibilities

As a starting point, we assume that the tasks and responsibilities of a hydrogen transmission network operator will mirror those of TSOs in the gas and electricity sectors. We also assume that the same basic models will be available, i.e. the TSO, ISO and ITO models are all viable options for the hydrogen transmission network operator. Table 4 summarises the tasks of the network operator in each of the models.

From the overview, we see that the core hydrogen transmission network operator's tasks and responsibilities will include the following:

- Balancing
- Data exchange
- Network planning
- Investment decisions
- EU coordination

In the ISO model, the network ownership is carried out by an external party. The network ownership task includes building and maintaining the physical grid infrastructure.

Table 4: Network operator tasks under different organisational models for the hydrogen transmission network operator

	TSO	ISO	ITO
Network operator tasks	Balancing Data exchange Network planning Investment decisions Network ownership EU coordination	Balancing Data exchange Network planning Investment decisions EU coordination	Balancing Data exchange Network planning Investment decisions Network ownership EU coordination
Other actors' tasks		Network ownership	

6.2 Criteria

Having established the core tasks and responsibilities of the hydrogen transmission network operator, we can now define the criteria we use for assessing the different options:

Economic efficiency. The hydrogen transmission network operator should operate in a manner that maximises economic efficiency in the sense that the net benefits to Swedish society are maximised. This is in line with the overall goals of the organisation of e.g. the Swedish electricity sector. In the short run, this means that the hydrogen transmission network operator should ensure optimal dispatch. The costs of balancing the physical system should also be minimised, and the operations of the hydrogen transmission network operator should be cost-efficient (e.g. personnel costs, costs of operating IT systems). In the long run, economic efficiency requires that hydrogen transmission network operator make optimal investments in the physical infrastructure (right location and correct dimensioning of assets) and that investments are carried out in a cost-efficient manner.

Security of supply. From a system perspective, the hydrogen transmission network operator should also maintain security of supply in the short and long run. In the short run, this requires that the hydrogen transmission network operator operate the system in a secure manner. In the long run, the hydrogen transmission network operator must add sufficient capacity to the system to keep the risk of outages and operational failures at an acceptable level.

Coordination nationally and internationally. The hydrogen transmission network operator must coordinate with other stakeholders within the hydrogen sector and other parts of the energy sector to enable sector coupling and realise synergies between electricity, gas and hydrogen in the short and long run. The hydrogen transmission network operator must also coordinate with international stakeholders to enable efficient cross-border operations and infrastructure development.

Transition costs. The costs of moving from a gas infrastructure to a hydrogen infrastructure should be as low as possible. This issue is however less important in Sweden than countries such as Germany and the Netherlands with a large existing gas infrastructure.

Access to financing. Assuming that hydrogen will play a significant role in the future Swedish energy system, it is vital that the hydrogen transmission network operator can raise the necessary capital and revenues for large investments in the physical grid.

Administrative costs. Finally, the administrative costs of the regulation for the Ei, the hydrogen transmission network operator and other stakeholders should be as low as possible.

Of the above criteria, we consider economic efficiency and security of supply to be the most important.

6.3 Set of options

To identify a set of options for the hydrogen transmission network operator function in the Swedish market, we have taken as our starting point the TSO, ISO and ITO models described previously. We have then considered the following three structural options:

1. the hydrogen transmission network operator is separate from other energy infrastructures
2. the hydrogen transmission network operator is integrated with the gas TSO
3. the hydrogen transmission network operator is integrated with the electricity TSO

A special case of the first model is to have several hydrogen transmission network operators for different regions. To simplify, we assume that the model with several hydrogen transmission network operators is not available when integrating with the gas or electricity TSO.

Integration of the hydrogen transmission network operator with the gas TSO is similar to the preliminary model in the German market, where gas TSOs play a key role in the planning of the hydrogen infrastructure.

In theory, it is of course also possible to have a fully integrated TSO for electricity, gas and hydrogen as in the Danish system. However, we have assumed that the electricity and gas TSOs will be separate entities in Sweden in the foreseeable future and disregarded that option for the purpose of this analysis.

With these assumptions, we arrive at a total of nine different options for the analysis, as shown in table 5. However, assuming that the electricity TSO will remain a TSO and not move to an ISO or ITO model, we are left with seven options that we consider feasible. For the integrated gas-hydrogen TSO we assume that the same regulatory model applies to both natural gas and hydrogen networks. For example., in the ISO model for the hydrogen transmission network operator we assume that the gas TSO shifts to an ISO model as well.

Table 5: Hydrogen transmission network operator (HTNO) options to be considered

	TSO	ISO	ITO
Separate HTNO(s)	Separate unbundled hydrogen TSO	Separate unbundled hydrogen ISO	Separate hydrogen TSO part of VIU
Integration gas TSO-HTNO	Gas TSO + unbundled hydrogen TSO	Gas ISO + separate unbundled hydrogen ISO	Gas TSO + hydrogen TSO part of VIU
Integration electricity TSO-HTNO	Electricity TSO + unbundled TSO	N/A assuming electricity TSO remains	N/A assuming electricity TSO remains

In line with the available models for TSO certification in the gas and electricity sectors, we assume that all of the above options can be made compliant with future EU rules for certification of hydrogen transmission network operators.

6.4 Analysis of the main options

Having identified a set of feasible options in the previous section, we now turn to the assessment. We describe the characteristics of the options separately for the two main criteria economic efficiency and security of supply before discussing the remaining criteria jointly.

6.4.1 Economic efficiency

The differences between the options are small at the outset. However, there are several caveats to this general conclusion.

Firstly, a single hydrogen transmission network operator is likely to be more efficient due to economies of scale. A single hydrogen transmission network operator is also better placed to minimise dispatch costs and balancing costs in an integrated national hydrogen grid compared to a situation with several smaller hydrogen transmission network operators that are not integrated, assuming a significant role for hydrogen in the long run. This applies regardless of whether the hydrogen transmission network operator is organised as a TSO, ISO or ITO, provided the regulation is efficient and the hydrogen transmission network operator acts in a neutral manner.

In a longer perspective, there may be significant short-run synergies between the electricity TSO and a national hydrogen transmission network operator with respect to dispatch and balancing costs, assuming that sector coupling and joint optimisation of the two infrastructures will play a key role in minimising total system costs. An integrated electricity-hydrogen TSO may also be more cost-efficient due to economies of scale and scope. Due to the limited historical role of gas in the Swedish system, the synergies between the gas TSO and a hydrogen transmission network operator are smaller, both with respect to dispatch and balancing and operations. While there may be synergies in the short run, we expect these to become less important over time.

When considering long-run coordination across energy carriers, we expect the synergies between the electricity and gas infrastructures to be even greater. Coordinated planning and development will play a key role in achieving a cost-efficient energy system in the long run. There are two options for achieving coordinated planning and development:

1. A joint electricity-hydrogen TSO
2. Mandatory coordination through a designated entity with powers to enforce coordination

The first option requires horizontal unbundling of the TSOs unless the derogation criteria are met. There is also a need to establish internal work processes and decision-making structures that enable coordination.

The second option requires that a coordinating entity is appointed. This could be one of the TSOs or a new entity. We consider that the electricity TSO is a suitable option as electricity will have a key role in the energy system in any future scenario, ant the electricity TSO has an established organisation and competence base. Existing governance structures and regulatory arrangements can also be leveraged.

However, the transaction costs and administrative requirements for Ei and the key stakeholders are likely to be higher than in the joint TSO option.

In table 6, we summarise our overall assessment of the different options with respect to economic efficiency. The assessment is qualitative and refers to the relative strengths of the options. A zero in the table means that the relevant options is ranked last.

Table 6: Assessment of hydrogen transmission network operator (HTNO) options with respect to economic efficiency

	TSO	ISO	ITO
Separate HTNO(s)	++ (+)	+ (0)	+ (+)
Integration gas TSO-HTNO	++	+	+
Integration electricity TSO-HTNO	+++	N/A	N/A

Note: Assessment in parentheses for separate HTNO refers to the special case of several smaller HTNOs.

Generally, we consider that the TSO model is superior to the other models, primarily due to the fact that the TSO has control of both network planning, system operations and ownership of the infrastructure. Furthermore, the integrated electricity-hydrogen TSO is considered superior due to the coordination benefits between the infrastructures in the short and long run, assuming a significant role for hydrogen in the Swedish energy system in the long run. Having several hydrogen transmission network operators is generally less efficient due to a lack of coordination and economies of scale.

6.4.2 Security of supply

On security of supply, we note that there are no significant differences between the options regarding short-run operational security. This again assumes that the hydrogen transmission network operator has the right competence and sufficient capacity and competence to operate the hydrogen infrastructure securely.

In the long run, the hydrogen transmission network operator must be able to add sufficient capacity to the system. This requires the hydrogen transmission network operator be able to carry out the necessary planning activities and make investment decisions, and also be able to finance the necessary investments. Financing may come from tariffs and connection charges, public support or payments by users of other infrastructures (cross-subsidisation).

In this respect, we consider the TSO and ITO models to be superior to the ISO model. The ISO does not own the grid assets and depends on other parties for financing. A TSO or ITO may have easier access to financing and does not need to coordinate with a transmission owner. Again, we consider that the integrated electricity-hydrogen TSO has an advantage through more efficient coordination. Finally, we consider that the lack of coordination and physical integration of grids makes the solution with several smaller hydrogen transmission network operators less advantageous than the single hydrogen transmission network operator models.

The key characteristics of the options with respect to security of supply are summarised in table 7, with the differences mainly stemming from the long-run aspects that we have discussed.

Table 7: Assessment of hydrogen transmission network operator (HTNO) options with respect to security of supply

	TSO	ISO	ITO
Separate HTNO(s)	++ (+)	+ (0)	++ (+)
Integration gas TSO-HTNO	++	+	++
Integration electricity TSO-HTNO	+++	N/A	N/A

Note: Assessment in parentheses for separate HTNO refers to the special case of several smaller HTNOs.

6.4.3 Other criteria

On coordination with other stakeholder nationally and across border, we note that the single hydrogen transmission network operator option is likely to be more efficient. With an integrated TSO, particularly between electricity and hydrogen, the benefits should be even greater due to the expected role of sector coupling and scale of the hydrogen infrastructure.

On the issue of transition costs, an integrated gas-hydrogen TSO will be the best option due to the fact that the necessary decisions and costs can be internalised in the hydrogen transmission network operator. The practical impact is however fairly small given the limited existing gas infrastructure compared to e.g. Germany and the Netherlands.

On the administrative costs of the regulation, the models perform differently:

- The administrative costs are likely to be lower with a single separate hydrogen transmission network operator as it is the most transparent model with only one hydrogen transmission network operator.
- With several hydrogen transmission network operators the administrative costs naturally increase.
- An integrated hydrogen transmission network operator with electricity or gas may have both positive and negative effects on costs. Regulating a single entity is easier in some respects, but on the other hand a more complicated company structure will be less transparent.
- The ISO model incurs extra costs as it is necessary to regulate both the system operator and the transmission owner.
- The ITO is likely to incur even more administrative costs as it is part of a VIU that requires special compliance measures.

On the issue of financing, a separate hydrogen transmission network operator (or several separate hydrogen transmission network operators) will need to earn revenue from selling transmission services and possibly from public support in addition. A single hydrogen transmission network operator should however be better placed due to economies of scale and a larger and more diversified customer base than with several smaller hydrogen transmission network operators.

An integrated HTNO under the TSO or ITO model can also in principle be able to use revenue from other activities (cross-subsidisation) to finance hydrogen infrastructure. While cross-subsidisation should not be a preferred option, EU regulation may open such a possibility and it may be useful in the absence of better alternatives. In any case an integrated HTNO should be able to achieve cheaper debt financing at group level due to company size and the diversified cash flows it has access to. This applies in particular to the integrated electricity-gas TSO due to the bigger size of the electricity TSO.[13] Of course, public support is an option in the integrated models also.

For the ISO, the financing issue is more complicated due to the need to coordinate with the transmission owner responsible for building the physical infrastructure. There will be a need for coordinating between the parties.

In table 8, we summarise our assessment of the hydrogen transmission network operator options according to the other criteria. In general, we consider the TSO option superior due to simpler regulatory arrangements and access to financing. We again consider the integration with the electricity TSO to be an advantage with respect to financing and coordination. The ITO model requires extra layers of regulation to be efficient, with the ISO somewhere in between. We also consider the solution with several hydrogen transmission network operators to have disadvantages with respect to coordination and financing in particular.

Table 8: Assessment of hydrogen transmission network operator (HTNO) options with respect to other criteria

	TSO	ISO	ITO
Separate HTNO(s)	++ (0)	+ (0)	0 (0)
Integration gas TSO-HTNO	++	+	0
Integration electricity TSO-HTNO	+++	N/A	N/A

Note: Assessment in parentheses for separate HTNO refers to the special case of several smaller HTNOs.

6.5 The role of state and national/EU ownership

We discuss the topics of state and national/EU ownership separately, as the motivation for particular ownership models are different.

State ownership of the hydrogen transmission network operator

The hydrogen transmission network operator will in effect be a TSO or an ISO. We know from other infrastructure sectors that regulating such entities efficiently can be challenging. For instance, benchmarking TSOs is inherently difficult as the practical option of international benchmarking may not be available due to inter alia differences in energy systems, market size and local cost levels. A possible exception here is the German market with several electricity and gas TSOs, but this must be viewed in a historical context and in light of the size of the German energy markets. In any case, the complex tasks of the TSO and the large consequences if the regulation fails to achieve objectives related to economic efficiency and security of supply means that it is difficult to design an appropriate regulatory model.

In this respect, state ownership can play a role as it gives the owner (the state) residual control over decisions that cannot be regulated efficiently. This has been an important consideration in the historical Norwegian debate on Statnett, in particular when the ownership and organisation of Statnett was discussed in the late 1990-ies/early 2000s. Statnett's articles of association reflect these considerations explicitly. Statnett is obliged to carry out investments and other measures according

[13] We have not considered here the special arrangements in place for Svenska kraftnät, with parliamentary approval of investment plans and financing, but make a general statement that is independent of the particular financing model in place for the TSO.

to economic efficiency criteria rather than maximising the company's profits subject to the regulation. We note that similar arrangements are used for Svenska kraftnät as well, and the Danish TSO Energinet. Furthermore, we observe that countries with private TSOs tend to spend large resources on detailed regulatory arrangements and monitoring of TSOs, such as in the UK.

This does not mean that state ownership automatically solves all regulatory shortcomings, but there is a trade-off between very detailed regulation and a more light-handed approach where state ownership supplements the regulation.

We also note that state ownership will be more relevant the more important hydrogen is in the Swedish energy system. The cost of regulatory failure may be small if hydrogen does not play a big part, but with a bigger role the combination of regulation and state ownership can be important in reaching the long-term goals in the Swedish system.

National or EU ownership

Requirements for national or EU ownership of the hydrogen transmission network operator can be used as an instrument to protect national security. Swedish state ownership is the strongest form.

Ownership restrictions according to security criteria will be more important the stronger the role of hydrogen in the Swedish energy system.

6.6 Final comments

In this chapter, we have assessed a set of feasible long-term hydrogen transmission network operator options against a set of criteria that include economic efficiency and security of supply as key criteria.

In general, we find that a TSO model has some advantages over the other options. Full ownership unbundling makes it easier to achieve neutrality, compared to ITO solution. An ITO requires extra regulation to be efficient. The TSO is also able to plan and finance investments without need for external coordination, compared to an ISO solution. Efficient coordination and financing can also be achieved in ITO solution, but again more complex regulation is needed for the underlying objectives to be reached. One may also hypothesise that a hydrogen TSO is in line with a likely long-run European target model, as seen in the gas and electricity sector.

In the long run, we also find that integration with the electricity TSO has more potential benefits than the other options. This stems from the expected increased role of sector coupling and the benefits from coordinated short-run dispatch and balancing and from long-term coordinated development of the physical infrastructures. However, it also makes regulation more complex in some respects.

We have discussed the options in a long-term perspective. There is however also a need to consider the path to a desired long run model if this differs from the initial options available. Given the small role of natural gas in the current Swedish energy system, there is little to build on with existing infrastructures and stakeholders. Instead, there is a possibility that the first applicants for HTNO certification will be separate operators in different parts of the country. A model with several smaller HNOs that are not physically integrated is likely to have drawbacks in the form of inefficient size, more costly coordination and too low security of supply due to a lack of integration of grids. This is particularly relevant if hydrogen is expected to play a significant part in the future Swedish energy system in the long run. It is then important that Ei carefully assesses how the regulation can facilitate a smooth transition to the long-term solution.

State ownership may complement the regulation, national/EU ownership may be desirable from security criteria. Again, the importance of ownership restrictions depends on the role of hydrogen in the long run.

7 Recommendations

In previous chapters we have described the development of hydrogen infrastructure in European regulation and in selected countries. We have also described the possible role of hydrogen in the Swedish energy system in the long run and assessed a set of options for organising the hydrogen transmission network operator function. In this final chapter, we summarise our findings in the form of a set of recommendations for the development of a Swedish hydrogen regulation and the role of the Ei in that respect.

7.1 Ei's tasks and responsibilities will change with the coming European regulation

Firstly, we note that the changes in the natural gas directive and underlying regulations will give Ei more tasks and responsibilities and a similar role to what Ei already has in the electricity and natural gas sectors. We have identified three key areas where Ei will need to develop detailed national regulation and regulatory practice.

Unbundling

Ei will be the responsible party for carrying out certification of hydrogen transmission network operators. According to the coming European regulation, the TSO/ISO/ITO models that are known from other energy infrastructure sectors will be available. Ei will then need to take a position on what model(s) should be applied for Swedish hydrogen transmission network operators.

At the distribution level, Ei's role will mainly be to enforce the legal and functional unbundling rules and possible exemptions for DSOs that meet the relevant criteria (e.g., less than 100 000 customers).

Ei will also need to consider whether to apply other available derogation rules. For instance, geographically confined hydrogen networks may be exempted from, inter alia, the unbundling requirements. Derogation may also be applied to specific isolated regions such as Upper Norrland. Finally, the horizontal unbundling requirement for TSOs operating several energy infrastructures may not need to be applied, subject to a positive cost-benefit analysis.

Tariff setting and third-party access conditions

The coming regulation foresees a connection and access regime that is very similar to the rules for electricity and natural gas networks in the existing EU legislation. As national energy regulator, Ei will have a similar role for hydrogen that, inter alia, entails a responsibility for approving tariffs in the hydrogen grid and/or the methodologies for setting tariffs and access conditions.

It should be noted that before 2033 an option with negotiated third-party access can be used. Ei will still have a role in such a regime, although the administrative burden can be expected to be smaller than in the long-term regime with standard third-party access rules.

Infrastructure development

On infrastructure development, hydrogen TSOs are obliged to submit ten-year network development plans at least every four years. This can be a joint plan with the natural gas network, or a separate plan provided that plans are based on close cooperation with natural gas planning. The hydrogen TSO(s) must also cooperate closely with electricity TSOs and DSOs.

The national regulatory authority's role with respect to hydrogen infrastructure planning and development is more extensive than for the electricity and natural gas sectors. Specifically, the regulator has a far-reaching duty and corresponding power to ensure that the ten-year network development plan is executed, providing that the planned projects are still deemed relevant. The regulator may task one or more TSOs with the responsibility for ensuring cross-border capacity.

For Ei, the role with respect to infrastructure planning and development is particularly important as it differs from its current role related to electricity and natural gas.

7.2 Close coordination between hydrogen and electricity TSOs gives benefits

We have argued that coordination between the electricity TSO and a hydrogen TSO has many advantages in a scenario where hydrogen plays a significant long-term role in the Swedish energy system. The coordination benefits arise both in the short-run dispatch and balancing of the system and in coordinated planning and development of electricity and hydrogen infrastructures.

While the EU regulation stipulates that hydrogen TSOs should cooperate with electricity TSOs and DSOs in network planning, this is likely to capture only part of the potential benefits with respect to infrastructure development, and none of the short-run benefits. Ei should consider two options for stronger coordination:

1. A joint hydrogen-electricity TSO
2. Mandatory coordination through a nominated entity with the necessary powers

The two options have different advantages and disadvantages and should be assessed further before deciding on a model.

7.3 The TSO model is preferable to an ISO or ITO model

The European regulation allows for different unbundling options for a hydrogen transmission network operator. Our conclusion is that the TSO model with full ownership unbundling and integrated network ownership and system operations is superior to the other models. The main reasons are the simpler certification procedure and a significantly simpler regulatory framework and compliance monitoring.

This does not preclude that Ei may choose to certify a Swedish hydrogen transmission network operator under an ISO or ITO model. However, Ei must then prepare a more complex certification procedure and develop the necessary measures to ensure compliance and efficient regulation.

7.4 Ownership restrictions can have advantages

Ownership restrictions are likely to have little positive impact in the event that hydrogen plays only a small role in the Swedish energy system. With a larger role for hydrogen, ownership restrictions may yield economic and security benefits.

We have found that state ownership can supplement the economic regulation and other direct regulations of a hydrogen TSO as a safeguard against inefficient regulation. This follows from the observation that designing an efficient regulation for a TSO is a difficult task. We note that electricity TSOs in the Nordic region are state-owned partly due to such considerations.

Furthermore, TSO ownership from outside the European Union may pose security challenges, which can motivate national or EU ownership. Again, this is particularly relevant with a significant role for hydrogen. The European regulation also specifies additional measures and a more complex certification procedure for TSOs controlled by third countries.

7.5 Ei should carefully consider the path to a desired long-term solution

In the short run, Ei has flexibility with respect to the certification process and other parts of the evolving European regulation. The first hydrogen infrastructure players may be eligible for derogation decisions – i.e., geographically confined networks.

Also, key elements of the new directive and regulation do not come into force until 2032/2033.

If hydrogen is expected to play a significant role in the future Swedish energy system, a transition to an efficient long-term solution should be planned for. This means that Ei needs to start thinking about several issues even at this early stage. Some key issues include:

- Preferred HTNO model (TSO/ISO/ITO)
- Coordination between electricity and hydrogen TSOs – what form?
- Transitional arrangements, e.g., infrastructure ownership
- Tariff principles
- Principles of income regulation
- Financing of early infrastructure investments
- Development of Ei's own competences and capacities

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