GREEN ELECTRICITY AND HYDROGEN

FOR A COMPETITIVE, RESILIENT AND CLEAN EUROPEAN ENERGY SYSTEM

CIP Copenhagen Infrastructure Partners

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Joint Industry Paper — April 2025

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Increasing cooperation between the electricity and hydrogen sectors will offer Europe the opportunity to strengthen its competitiveness through the supply of affordable energy and will allow it to become more energy resilient while decarbonising its industry and economy.

FOREWORD

Europe is facing several intersecting challenges: climate change; rising energy and supply chain costs; and geopolitical pressures. Europe's future energy supply lies at the very heart of the answer to all three. The future design of the continent's energy system will shape the competitiveness of its industries and determine its capacity to provide consumers with affordable and secure energy while addressing the need for a comprehensive transformation towards net-zero emissions by 2050.

Establishing a competitive, resilient and clean energy system in Europe by 2050 requires both investments in new renewable energy generation and transmission assets and new ways of designing and operating our energy system. Next to energy efficiency, the electrification of final energy demand will be the priority. However, not all sectors can be electrified, and for hard-to-abate sectors, hydrogen and its derivates will play an important role.

This paper is the product of a collaboration between three European energy infrastructure companies: Copenhagen Infrastructure Partners, Elia Group and GASCADE. Our close cooperation is mirrored in our joint message: we believe that the electricity and hydrogen sectors should be more tightly developed and linked, ultimately leading to economic and efficiency gains.

In this paper, we set out key focus areas for policymakers to consider as cornerstones of a competitive, resilient and clean energy transition in Europe. We intend to provide impetus for the discussion on how to utilise synergies and make the transformation to a climate-neutral energy system as efficient as possible, thereby also contributing to the implementation of the European Union's Clean Industrial Deal in a cost-effective and timely manner.

Enjoy the read!

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EXECUTIVE SUMMARY

To establish a European competitive, resilient and clean energy system by 2050, it is crucial to unlock the expansion of renewable energy, electricity grids and hydrogen infrastructure across Europe and to unlock synergies between the electricity and hydrogen sectors. In this joint paper, we describe how this requires new ways of designing and operating our energy system, and outline recommendations on how to effectively achieve this.

1. Unlock the expansion of renewable energy, electricity grids and hydrogen infrastructure across Europe

Europe's renewable electricity generation needs to grow by a factor of 4-5 by 2050. To make efficient use of the electricity produced from renewable energy sources, Europe's final energy demand needs to be electrified as much as possible. However, electrification alone is not sufficient as it is neither technically nor economically feasible to electrify all sectors.

Therefore, green electrons must be supplemented by green molecules. An expansion of both electricity grids and hydrogen infrastructure is needed to transport electrons and molecules across Europe in a cost-efficient manner.

2. Unlock synergies between the electricity and hydrogen sectors

- This includes enhancing sector coupling between renewable energy sources and hydrogen production in regions with a structural surplus of renewable energy, making better use of the renewable energy potential in Europe while reducing the need for electrical grid expansion. This can also include offshore hydrogen production based on offshore wind resources, which can in some cases be a cost-competitive alternative to onshore hydrogen production.
- Additionally, enabling a flexible operation of electrolysers to adjust production in line with the fluctuation of electricity prices and regional renewable electricity generation will result in more cost-competitive hydrogen production and a higher utilisation of renewable generation assets.

3. Recommendations

- This paper recommends that in order to establish a competitive, resilient and clean energy system in Europe by 2050, it is essential to mobilise more private investment to realise the necessary buildout of renewable energy generation and transport infrastructure.
- Moreover, to unlock synergies between the electricity and hydrogen sectors, a smarter regulatory framework which promotes a system-friendly location and flexible operation of electrolysers for green hydrogen production is needed.
- This also includes the close alignment of planning processes for electricity grids and hydrogen infrastructure at the European level, within each Member State, as well as per sea basin, based on a joint vision for the future energy system.

ACCELERATED BUILDOUT OF RENEWABLE ENERGY, ELECTRICITY GRIDS AND HYDROGEN INFRASTRUCTURE

For Europe to strengthen its competitiveness and become more energy resilient while it decarbonises, a rethink and overhaul of the energy system is required. Although the expansion of renewable energy technologies is gaining pace in many European countries, the buildout of renewable energy must be further accelerated[1]. To make efficient use of the electricity produced from renewable energy sources, Europe's final energy demand needs to be electrified as much as possible.

Given the rising amounts of electricity production and consumption, the timely buildout of the electricity grid will be of pivotal importance.

Given the rising amounts of electricity production and consumption (see Figure 1), the timely buildout of the electricity grid will be of pivotal importance for ensuring the success of Europe's energy transition and for safeguarding the competitiveness of Europe's industries, as outlined in the Mario Draghi report, which was published in September 2024[2].

In addition to green electrons, Europe will need green molecules to decarbonise its hard-to-abate sectors and applications, where electrification is neither technically nor economically feasible[3]. As the European market for green hydrogen is still maturing, uncertainties regarding the future demand for hydrogen remain (see Figure 2). On the demand side, industry is likely to be the biggest consumer of green hydrogen and its derivatives, including the steel manufacturing, chemical production and heavy transportation (aviation and shipping) industries.

FIGURE 1: EU27 ELECTRICITY GENERATION IN 2023 AND EXPECTED ELECTRICITY GENERATION IN 2050 (TWH).

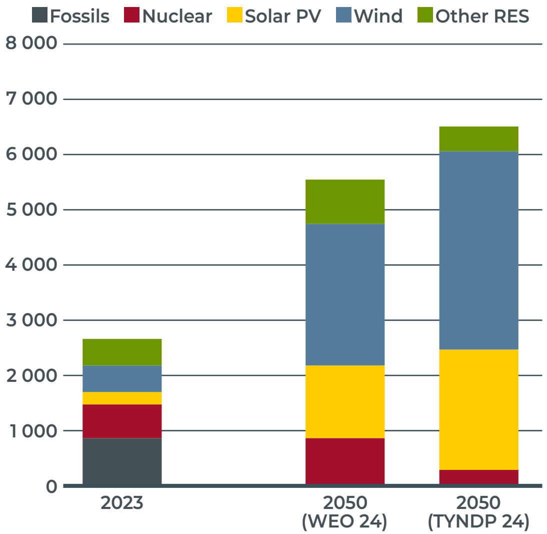
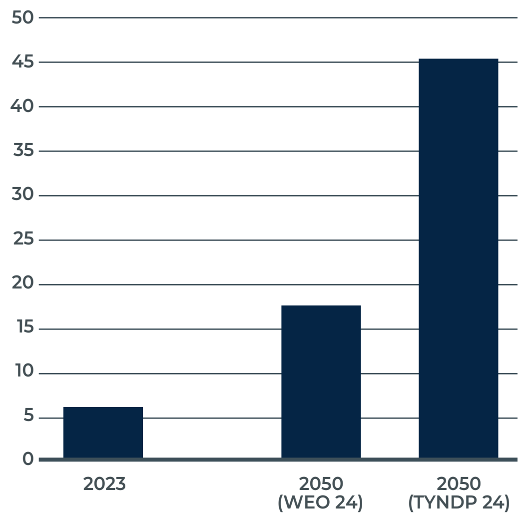


FIGURE 2: EU27 HYDROGEN DEMAND IN 2023 AND EXPECTED DEMAND IN 2050 (MTH$_2$), NOT INCLUDING HYDROGEN DERIVATIVES.



Sources: Eurostat, IEA World Energy Outlook (WEO) 2024 Announced Pledges Scenario, ENTSOs TYNDP 2024 Distributed Energy Scenario.[4]

1. Next to renewable energy, nuclear power and carbon capture & storage technologies may also play an important role on the way to carbon neutrality. However, this paper focuses on the characteristics of renewable energy generation and its synergies with green hydrogen production
2. European Commission (2024), 'The Future of European Competitiveness', (last accessed on 10/01/25)
3. European Commission (2020). 'A hydrogen strategy for a climate-neutral Europe', (last accessed on 10/01/25)
4. Eurostat, IEA World Energy Outlook 2024, ENTSOs TYNDP 2024

The future demand for green hydrogen will depend on regulatory frameworks and decarbonisation targets set out at the European and national levels, as well as their ability to maintain their competitiveness in the global market[5]. Therefore, unlocking the potential for a cost-efficient decarbonisation path is critical for Europe to remain competitive in a global economy.

On the supply side, Europe has sufficient renewable energy potential to meet a substantial share of its demand for green hydrogen[6] via domestic production.

The share of Europe's future production of domestic green hydrogen will depend, amongst other factors, on its ability to provide cheap renewable electricity to enable the production of cost-competitive green hydrogen (compared with import opportunities from North Africa, for example) and will also depend on the political priority given to European energy independence.

The European Union has set itself the goal of producing 10 million tonnes of green hydrogen and importing 10 million tonnes of hydrogen per year by 2030[7]. However, the European Union's impact assessment report from June 2024 expects only around 2 million tonnes of domestic production of green hydrogen by 2030[8].

Despite the uncertainties, it is generally expected that Europe will rely on a mix of both European green hydrogen production and global imports of green molecules to reach climate neutrality by 2050.

BOX 1

In the lead-up to 2050...

- **total electricity generation to increase by a factor of 2-2.5.**
- **renewable electricity generation to increase by a factor of 4-5.**
- **electricity generation from wind and solar PV to increase by a factor of 5-8.**
- **hydrogen demand to increase by a factor of 3-8 (not including hydrogen derivatives)**

Based on IEA's World Energy Outlook 2024 Announced Pledges Scenario (WEO24) and ENTSOs TYNDP 2024 Distributed Energy Scenario (TYNDP24).

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In addition to green electricity, Europe will need green molecules to decarbonise its hard-to-abate sectors and applications.

5. The RED III legal framework for the development of clean energy across all sectors of the EU economy has taken critical steps for the formation of a European hydrogen market. This includes the industry target requirements for green hydrogen along with the definition of renewable fuels of non-biological origin (RNFBO), laying down the principles for the buildout of green hydrogen and renewable energy.

6. Fleiter, T., et al (2024). 'Hydrogen Infrastructure in the Future CO_2-Neutral European Energy System—How Does the Demand for Hydrogen Affect the Need for Infrastructure?', Energy Technology 2300981, (last accessed on 10/01/25)

7. European Commission (2022). 'REPowerEU: Affordable, secure and sustainable energy for Europe', (last accessed on 1/01/25)

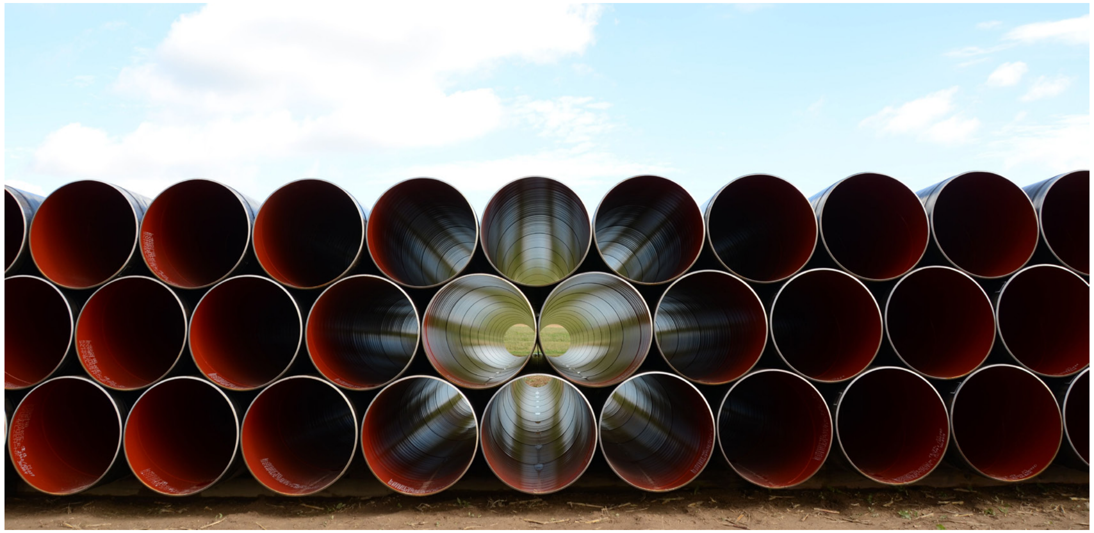
8. European Commission (2024). 'Impact Assessment Report, Securing our future – Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society', (last accessed on 1/01/25)

A core hydrogen pipeline network, or 'backbone', will enable the cost-efficient on- and offshore transportation of hydrogen across Europe.

Most of Europe's green hydrogen is expected to be produced in countries that have a disproportionately high renewable energy potential compared with their levels of national electricity demand, such as the Iberian Peninsula and countries centred around the North and Baltic Seas. Moreover, Germany, which is expected to be a net importer of electricity in the future[9], and at the same time enjoys high wind resource potential that can be translated into green energy, has set ambitious goals regarding its domestic production of hydrogen: it wishes to install 10 GW of electrolysis capacity by 2030, which is, amongst other things, a solution for coping with the fluctuating nature of Germany's domestic renewable energy supply.

For Europe to keep pursuing its decarbonisation goals and remain competitive, it is crucial for industry and other major green hydrogen consumers to be connected with green hydrogen production centres, import hubs and storage sites via a timely and reliable pipeline network.

A core hydrogen pipeline network, or 'backbone', will enable the cost-efficient on- and offshore transportation of hydrogen across Europe, connecting the areas where hydrogen is produced with areas where it is consumed. Moreover, the network will provide flexibility in terms of the location of electrolysers, allowing them to be located close to renewable electricity generation assets rather than near consumers, so reducing transportation needs across the electricity grid. Furthermore, an efficient hydrogen infrastructure network will be a prerequisite for creating a more liquid hydrogen market, which in turn will enable a more flexible and more cost-efficient way to produce green hydrogen that is focused on moments when there is an oversupply of renewable electricity.



In this context, the German Federal Network Agency's approval of the German Hydrogen Core Grid ('Kernnetz') in October 2024 was an important step forward. Such anticipatory investments in hydrogen infrastructure are crucial in order to provide certainty to future producers and consumers of hydrogen in order to ramp up the hydrogen market.

Given the expected buildout of renewable energy sources in the run-up to 2050, the energy system will need technologies that support and address more variable levels of electricity production. This includes electrolysers and other technologies – such as large-scale batteries and flexible power-to-heat applications – that are all expected to gain importance in Europe's future energy system.

Each of these technologies carry their own particular benefits.

- Power-to-heat solutions are a good option when there is a heat demand nearby.
- Batteries are ideal for storing excess supply for a few hours.
- Electrolysers to produce green hydrogen can also utilise surplus electricity for longer time periods (depending on the development of adequate hydrogen storage).

9. German Electricity Network Development Plan 2037/2045 (2023), (last accessed on 10/02/25)

REALISATION OF SYNERGIES BETWEEN THE ELECTRICITY AND HYDROGEN SECTORS FOR A COST-EFFICIENT TRANSITION

Synergies exist between the production of electricity and the production of hydrogen through the system-friendly location and flexible operation of electrolysers. The benefits include cost savings generated by an optimised transportation of energy and a more efficient use of renewable energy assets. Therefore, it is crucial to create frameworks that enable the positioning of electrolysers in regions which carry a structural surplus of renewable energy[10] and enable their connection to the European electricity grid in order to be operated in a flexible way.

Location of electrolysers

The location of electrolysers is highly relevant for establishing a cost-efficient energy system. When electrolysers are installed close to the renewable electricity generation instead of near hydrogen demand centres, the electricity for running these electrolysers does not need to be transported across long distances via the electricity grid.

To supply high volumes of hydrogen to its distant consumption centres, the buildout of core hydrogen pipelines is typically more cost efficient than expanding the electricity grid. Placing electrolysers close to the renewable energy source in regions where there is a surplus production of renewable electricity will contribute to establishing a more cost-efficient energy transportation system[11].

Producing green hydrogen close to renewable electricity generation assets may also entail offshore hydrogen production. For example, Germany has announced the development of 1 GW of offshore electrolysis by 2030 to support the technological development and testing of offshore electrolysis. For the offshore production of hydrogen to be part of Europe's future energy system, the development of solutions that reduce the cost of infrastructure and enable scalability is necessary. Given these solutions, the offshore production of hydrogen can in some areas be a cost-competitive alternative to the onshore production of hydrogen.

The offshore production of hydrogen is of particular interest in cases where: a) wind sites are far from the coast; and b) when there are substantial wind resources in a region that exceed the region's electricity demand. Combined configurations of offshore hydrogen production with a limited onshore electricity grid connection will allow for an optimised use of electrolyser flexibility and enable offshore wind energy to be directly used in the electricity system during moments when there is a low overall supply of renewable electricity. In addition, the design of the grid connection affects the efficiency of the system.

When renewable energy generators and electrolysers share the same grid connection, this reduces the total amount of required transformer capacity and the need for connection equipment. The flexibility therefore allows for a higher grid load factor.

Positioning electrolysers in regions which carry a structural surplus of renewable energy will contribute to establishing a more cost-efficient energy transportation system.

10. This implies that a hydrogen backbone in which electrolysers feed in the produced hydrogen needs to travel through regions which have an oversupply of electricity in order to enable the 'harvesting' of the renewable electricity surplus.

11. This should not be understood as the hydrogen network being a substitute for the electricity grid if the final demand is electricity. In general, electricity is to be transported via the electricity grid, as both the conversion of electricity into hydrogen and the reconversion back into electricity involves significant efficiency losses.

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The flexible operation of electrolysers offers several benefits with regard to the efficiency of the energy system and a more cost-competitive production of hydrogen.

Flexible operation of electrolysers

In addition to the location of electrolysers, their flexible operation for the production of hydrogen offers several benefits with regard to the efficiency of the energy system and a more cost-competitive production of hydrogen. The production of green hydrogen can be optimised if it takes place when electricity prices are low, which typically occurs when the generation of renewable electricity is high and the demand for electricity is low.

From a system perspective, the production of green hydrogen is not desirable at times when the level of renewable electricity is low compared with the demand for electricity; when renewable electricity surpluses occur, electrolysers can utilise the surpluses and so reduce the curtailment of renewable energy sources. In this context, it is important for electrolyser flexibility to not just be focused on a single renewable electricity generation asset, but on regional surpluses.

A surplus of renewable electricity and the subsequent curtailment can be caused by a market-wide oversupply of renewable electricity generation or by a local oversupply due to grid constraints. If, in the latter case, electricity prices do not reflect this surplus, other signals are needed to incentivise the operation of flexible demand assets.

Only electrolysers that are connected to the electricity grid and operated flexibly can adjust their production in line with moments when there is a surplus of renewable electricity or when there are low prices. This benefits the utilisation of renewable generation assets, as the electricity is utilised for the production of hydrogen during moments when there is a surplus of electricity generation.

RECOMMENDATIONS FOR ACHIEVING A COMPETITIVE, RESILIENT AND CLEAN EUROPEAN ENERGY SYSTEM

Europe can establish a competitive, resilient and clean energy system by 2050. This requires large investments to be made in new renewable energy generation and transmission assets and also new ways of designing and operating our energy system. Two key elements are required to achieve this. Firstly, the expansion of renewable energy, electricity grids and hydrogen infrastructure needs to be unlocked; secondly, a smarter system design is needed to enable synergies between the electricity and hydrogen sectors.

1. Unlock the expansion of renewable energy, electricity grids and hydrogen infrastructure across Europe

For Europe to utilise its full potential of cheap renewable energy, it must:

- **unlock the buildout of renewable energy sources in countries which carry more renewable energy potential than they need to meet their domestic electricity demand;**
- **expand its energy infrastructure for electricity and hydrogen.**

For Europe to unlock renewable energy sources in countries which carry more renewable energy potential than they need, this requires incentives to enable the buildout of renewable generation assets that will benefit European competitiveness and the green transition – rather than just those which are matched to each country's domestic needs.

Moreover, in order for Europe to utilise its full renewable energy potential, Europe must expand its energy infrastructure for electricity and hydrogen. This includes the need to increase the interconnection capacity between countries, as interconnectors are vital for enabling the cross-border trade of electricity and hydrogen, and so facilitate the effective use of Europe's renewable energy potential.

As public budgets are increasingly constrained and the balance sheets of TSOs and energy companies are increasingly stretched, greater levels of private capital need to be mobilised. Policymakers should explore ways to attract private capital in order to expand the buildout of renewable energy sources and Europe's energy infrastructure.

This can include:

- developing new financing models that include a fair cost and risk allocation that can help to finance infrastructure investments by unlocking more private capital;
- involving relevant actors, including governments, TSOs and private developers;
- developing clear guidance on a pan-European regulatory framework for cross-border energy infrastructure. Embracing the concept of anticipatory infrastructure investments could contribute to improving investment certainty for renewable generation asset investors.

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2. Unlock synergies between the electricity and hydrogen sectors

BUILD A SMARTER FRAMEWORK TO ENABLE THE SYSTEM FRIENDLINESS OF ELECTROLYSERS FOR THE PRODUCTION OF GREEN HYDROGEN.

The cost-efficient buildout of renewable energy requires a smarter framework to unlock the synergies between the electricity and hydrogen sectors. A key element of this should be the enabling of the system-friendly location and flexible operation of electrolysers.

System-friendly locations and the flexible operation of electrolysers can reduce electricity transport needs, making the entire energy system more cost efficient. To incentivise this, the resulting cost savings for the energy system should be reflected in developers' business cases. This should be achieved via market-based initiatives for strengthening price signals related to the location and the flexible operation of electrolysers.

Several regulatory frameworks and policies are being implemented to foster and support the system-friendly location and operation of electrolysers, as shown in Box 2. The applicability and effect of each specific measure depends on the regulatory environments that apply in different markets and areas.

Regulations and policies for a system-friendly location and operation of electrolysers across specific countries should be complemented by uniform standards at the European level (e.g. standardised definitions, safety and environmental regulations) in order to facilitate cross-border cooperation and enable a cost-efficient allocation of electrolysers across Europe.

System-friendly locations and the flexible operation of electrolysers can reduce electricity transport needs, making the entire energy system more cost efficient.

BOX 2

Initiatives to build a framework for the system friendliness of electrolysers

- Dedicated tendering schemes for electrolysers in system-friendly locations.
- Geographically differentiated grid tariffs and time-variable grid charges.
- Location-specific pre-auctioning of otherwise curtailed electricity generation assets during moments when grid congestions occur.
- Establishment of criteria for green hydrogen based on the technology, location and temporality of its production.
- Encouragement of a temporary or permanent limited grid connection, such that hydrogen producers are only guaranteed a limited or flexible electricity supply (as opposed to a standard grid connection that carries a high level of security of supply); this temporary or limited connection would carry lower connection fees and tariffs.

ALIGN THE PLANNING PROCESSES FOR ELECTRICITY AND HYDROGEN GRIDS AT THE EUROPEAN LEVEL, PER SEA BASIN AND WITHIN EACH MEMBER STATE, BASED ON A JOINT VISION FOR THE FUTURE ENERGY SYSTEM.

To make best use of Europe's renewable energy potential and enable a cost-efficient and resilient European energy system, a consistent and holistic approach to the planning of electricity and hydrogen infrastructure is required. To this end, the planning processes for electricity and hydrogen networks need to be sufficiently aligned at the European level, per sea basin and within each Member State.

The future deployment of gigawatt-scale electrolysers exemplifies this need. Depending on their location and manner of operation, these assets may have a significant impact on grid needs. Therefore, electricity and hydrogen transmission system operators (including their European associations ENNOH and ENTSO-E) need to closely cooperate in their planning. Onshore and offshore network planning processes should explicitly account for synergies at the interface between the electricity and hydrogen sectors and their needs. This will serve to enable a cost-efficient buildout of European energy infrastructure and provide the market with relevant signals (regarding the optimal location of electrolysers, for example), complementing appropriate policy measures, as described above.

A first relevant step in this context is an alignment of the process steps and timelines (including draft scenario publications, stakeholder consultation windows and regulatory approval procedures as well as planning horizons, or 'target years') for electricity and hydrogen network planning. Secondly, a harmonisation of scenario assumptions is vital. To adequately assess future grid needs, network planning processes should therefore be based on a joint vision and understanding of the future energy system. This includes a holistic approach to maritime spatial planning, considering all assets of the future offshore energy system. A full integration of the planning processes for electricity and hydrogen grids into one process is not advisable, as this would generate more complexity than benefits.

Ideally, grid planning scenarios reflect society's common understanding of the main characteristics and uncertainties regarding Europe's future energy system. To this end, TSOs need to consider the input of a variety of stakeholders when developing these scenarios.

Engaging with relevant stakeholders – such as industrial consumers and consumer representatives, project developers, nature protection associations, public authorities, and scientific institutions – is therefore common practice in most network planning processes. Facilitating the involvement of a broad range of stakeholders is becoming even more important given the significant changes that the energy system is undergoing. Both the frequency and methods of stakeholder engagement should be regularly reviewed and adapted in line with the changing energy landscape.

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Ideally, grid planning scenarios reflect society's common understanding of the main characteristics and uncertainties regarding Europe's future energy system. To this end, TSOs need to consider the input of a variety of stakeholders when developing these scenarios.

Founded in 2012, Copenhagen Infrastructure Partners P/S (CIP) is today the world's largest dedicated fund manager within greenfield renewable energy investments and a global leader in offshore wind.

The funds managed by CIP focus on investments in offshore and onshore wind, solar PV, biomass and energy-from-waste, transmission and distribution, reserve capacity, storage, advanced bioenergy, and Power-to-X.

CIP manages 12 funds and has to date raised approximately €30 billion for investments in energy and associated infrastructure from more than 180 international institutional investors.

As the owner of two electricity transmission system operators in Belgium (Elia) and Germany (50Hertz), we at Elia Group are fully committed to accelerating the energy transition.

We are strengthening Europe's energy security, the competitiveness of its businesses, and its climate work by building a sustainable, low-carbon electricity system for its citizens.

Our strategic locations near the North and Baltic seas – Europe's prime hubs for renewable energy – put us in an excellent position for long-term, sustainable growth in the decades ahead.

We are further enhancing our growth potential by leveraging our unique technical expertise in electricity transmission to expand into new markets through value-creating, lower-CAPEX activities.

Decarbonisation goes hand in hand with electrification: it requires the timely readiness of extensive new grid infrastructure. To achieve this, we are undertaking an unprecedented €26.8 billion investment programme over the next three years, which will see €7.5 billion being allocated to our activities in Belgium and €19.3 billion being allocated to our activities in Germany.

GASCADE is a transmission system operator for natural gas and soon also hydrogen. Set in the heart of Europe, our 3,700-kilometre-long pipeline network connects supply sources with the major consumption centres in Germany and Europe. We transport energy over long distances to exactly where it is needed.

By building and expanding a hydrogen network, GASCADE is driving forward a secure and sustainable energy future for Germany and Europe. Hydrogen produced on a climate-neutral basis is a key component of the energy transition and future supply security. That is why we are pressing rapidly ahead with expanding the infrastructure: Until the end of the decade, we are preparing our powerful pipeline network for hydrogen transport in the gigawatt range. And even before then, by the end of 2025, the first pipeline sections should already be transporting hydrogen. GASCADE is therefore driving the development of the European energy infrastructure forward.

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