한독 에너지 파트너십 팀
Energiepartnerschaft - Team
DEUTSCHLAND – KOREA

Overview Study

Policy instruments for the market ramp-up of low-carbon hydrogen in Korea and Germany

adelphi

Imprint

Publisher:
Korean-German Energy Partnership Team

Implementing Organization:
adelphi consult GmbH
Alt-Moabit 91
10559 Berlin
T +49 (30) 8900068-0
F +49 (30) 8900068-10
office@adelphi.de
www.adelphi.de

Authors:
Adak, Beyza; Jensterle, Miha; Sperling, Fabian; Schuster, Bianca; Borghardt, Sören; Sieler, Roman Eric; Meißner, Daniel; Narita, Jana

Cite as:
Adak, Beyza; Jensterle, Miha; Sperling, Fabian; Schuster, Bianca; Borghardt, Sören; Sieler, Roman Eric; Meißner, Daniel; Narita, Jana (2023): Policy instruments for the market ramp-up of low-carbon hydrogen in Korea and Germany. Berlin: adelphi.

Supported by:
Saerok Jong (NEXT group) and Prof. Peter Radgen (University of Stuttgart) and the Korean-German Chamber of Commerce and Industry.
We express our thanks all experts for the successful cooperation. Your feedback and additional information enriched and improved the study.

Version:
08/2023

Federal Ministry
for Economic Affairs
and Climate Action

This publication is commissioned on behalf of the Federal Ministry for Economic Affairs and Climate Action. adelphi supports the Federal Government in various projects to implement the energy and climate policy goals within the framework of the energy transition.

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Content

1 Executive Summary

Korea and Germany, both long-time partners as well as leaders regarding the establishment of a global hydrogen economy, are united in their need to ramp-up low-carbon hydrogen production to reach their respective net zero goals. The following study analyses their respective circumstances, needs and policy approaches regarding the support of hydrogen market development. It then continues to identify similarities, differences as well as opportunities for mutual learning and cooperation within their joint Korean-German Energy Partnership.

The German approach, which also needs to be considered in the context of EU regulation, can generally be described as a production- and industry-focused combination of carrot as well as stick measures to advance the development of a national and global hydrogen market. On one hand, Germany seeks to heavily support future users of low-carbon hydrogen through programs designed to supply them with both domestic and international low-cost green hydrogen as well as to help the industry to successfully transition and to develop regional hydrogen clusters. At the same time, policy measures like the EU emission trading scheme, which puts a price of currently around 100 Euros on each ton of emitted carbon, the German emission trading scheme, the currently considered introduction of low-carbon hydrogen requirements in green lead markets and specific sectorial emission reduction targets are intended to push heavy emitters towards cleaner alternatives, such as green hydrogen. Compared to Korea, Germany is further on its path towards a successful energy transition, putting a strong focus on renewables and green hydrogen produced from renewable energy sources and planning on phasing out coal until 2038 at the latest.

The Korean approach is somewhat similar to Germany's in many ways, but with some noteworthy differences. The first of these differences is the focus on a wider range of end use sectors, including mobility and energy production, with industry not being as prioritized as in Germany. At the same time, this use-centred approach also leans more heavily towards the carrot compared to the stick. Korea's carbon price is for example significantly lower, while the government emphasises a range of subsidies and industry support measures as ways to advance the Korean hydrogen economy. It also focuses on supporting the establishment of required infrastructure, such as hydrogen refuelling stations, receiving terminals for future hydrogen imports as well as on regional development through the support of hydrogen clusters. Another noteworthy difference concerns the overall direction of Korea's energy transition. The current Korean government decided to favour a faster build-up of nuclear capacity as opposed to more renewable ambition. This approach also translates to its hydrogen production approach, which is wider than Germany's focus on green hydrogen and also includes hydrogen produced from nuclear energy as well as from fossil sources using carbon capture.

In direct comparison, in becomes apparent that each country leads the drive for low-carbon hydrogen production ramp-up in different ways. While Korea has a broader approach covering more sectors, which could present learnings regarding the support of hydrogen usage in sectors not currently prioritized by Germany, Germany's more focused approach could result in faster emission reductions, something that Korea might be able to learn and benefit from. More important than these approaches might be the establishment of instruments to enable the build-up of production capacity, both domestically and abroad, an area where the joint need for a strong global low-carbon hydrogen market offers many potential synergies. At the same time, there are a range of more technical details concerning shared or similar policy approaches which could be discussed to enable mutual learning, such as approaches to regional development, carbon pricing, the support of small and medium enterprises or green finance. Lastly, both countries share some structures when it comes to the discussion of hydrogen policies and an exchange between the respective hydrogen councils and commissions could, considering the special role of both countries in the advancement of the global hydrogen market, present an additional opportunity.

To summarize, both Korea and Germany have made considerable progress in the advancement of their respective hydrogen economies. Considering the multitude of potential areas for cooperation and mutual learning as well as the importance of a timely low-carbon hydrogen market ramp up, the good working relationship and the long-standing Energy Partnership between both countries offer significant opportunities waiting to be seized – both for the countries themselves and the establishment of a global low-carbon hydrogen market more broadly.

2 Introduction

With the Paris Agreement, on December 2nd, 2015, 195 countries committed to limiting climate change and to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. Both Germany and Korea have joined the Paris Climate Agreement and are aiming for climate neutrality by 2045 and 2050, respectively. A prerequisite for achieving these goals is a successful energy transition away from fossil fuels like coal, oil, and gas to renewable sources of energy. Depending on the use case, there are a range of different options to achieve such a transition and while electrification using renewables might be the best approach for most sectors, renewable or low-carbon hydrogen presents a viable alternative for sectors that are difficult to electrify.

The use of low-carbon hydrogen will be vital in the decarbonisation of heavy industrial applications, such as steelmaking, while its nature as a flexible energy carrier means that it can also be used in other contexts. By storing energy and providing flexible and peak power production, it can for instance contribute to balancing power systems based on variable renewable energy sources such as wind and solar. Hydrogen might also be useful for heating, mobility, or as a basis for producing synthetic fuels such as kerosene to power air transport. In each of these scenarios, it is, however, important to keep in mind that hydrogen is better used as a measure of last resort due to conversion losses making it significantly less efficient than direct electrification.

Another important detail to keep in mind is that the discussion around clean or low-carbon hydrogen often uses somewhat ambiguous terminology, while the actual carbon content of hydrogen can vary considerably, which greatly impacts its ability to be used for decarbonisation. Most of hydrogen already available is so-called grey hydrogen, meaning hydrogen produced from fossil fuels without carbon sequestration, which has considerable associated emissions. Less emission intensive alternatives include blue hydrogen, which is typically produced using gas, while also employing carbon capture and storage (CCS), as well as turquoise hydrogen, which uses a different process resulting in solid carbon instead of CO2 as a by-product. The lowest emissions are, however, associated with green hydrogen, which uses electrolysis and renewable energy for its production, as well as pink hydrogen using nuclear power. The latter, however, results in nuclear waste, which is why green hydrogen is generally seen as the cleanest option for hydrogen production. Low-carbon hydrogen summarizes all production methods with comparatively low emissions, including green, blue, turquoise and pink hydrogen. For an understanding of the terminology of the different colours of hydrogen, please also see Figure 1 in the Appendix that contains the respective definitions.

Low-carbon hydrogen is seen as a key piece in the decarbonisation strategies of both, Korea and Germany. Therefore, a fast ramp-up of the low-carbon hydrogen economy is necessary and both countries drafted strategic documents outlining their respective hydrogen policies for supporting this development; Korea with its Hydrogen Economy Roadmap in 2019, and Germany with its Hydrogen Strategy published a year later and updated in 2023.

Considering the current geopolitical developments, especially the post-pandemic rebound and the Russian attack on Ukraine with the resulting energy crisis, the pressure to transform the energy system has been increasing further. The EU response, the REPowerEU strategy, sees hydrogen as central to overcoming the current energy crunch and replacing Russian natural gas imports in the mid- to long term.

However, this necessary ramp-up of hydrogen production does present a challenge, not least because of the large amounts of hydrogen and the green electricity needed for its production. PwC estimates that under an ambitious climate scenario, which is at least somewhat aligned with the Paris agreement, the global demand for low-carbon hydrogen could reach up to 600 Mt or more than 22.500 TWh by 2050. Right now, less than 80 Mt or 2.500 TWh are produced, with most of it being grey hydrogen, meaning that it, too, will need to be replaced (PricewaterhouseCoopers 2023).

This study provides an overview of the status and goals of hydrogen ramp-up efforts in Germany and Korea and compares the policy instruments and measures in both countries aiming to facilitate the required steep low-carbon hydrogen ramp-up. It aims to derive valuable insights for policymakers and identify possibilities for bilateral cooperation.

3 Overview of hydrogen policy in Germany

3.1 The role of hydrogen in Germany's Energiewende

Today, Germany's yearly hydrogen demand stands at 55 TWh (1.65 Mt)[1], and is distributed roughly equally between the production of basic chemicals (ammonia, methanol, etc.) and the petrochemicals sector (conventional fuels). The majority of the hydrogen is produced from natural gas by steam methane reforming (SMR), while some is a by-product of chlor-alkali electrolysis and oil refining (catalytic reforming) (BMWK 2020b).

In recent years, numerous scenario studies on pathways to (near) climate neutrality by 2050 or 2045 respectively, have been published in Germany (Prognos, Öko-Institut, Wuppertal-Institut 2021; Deutsche Energie-Agentur GmbH 2021; Consentec GmbH et al. 2021; BCG 2021; Kopernikus-Projekt Ariadne 2021). In 2021, a metastudy investigating the role of hydrogen in Germany's energy transition was elaborated by Fraunhofer institutes IEG, ISE and ISI for the National Hydrogen Council (Wietschel et al. 2021)[2]. For the sectors industry, transport and buildings, the different scenarios reviewed in the metastudy predict an overall hydrogen demand of up to 80 TWh (2.40 Mt), with the majority of scenarios between 10 (0.3 Mt) and 50 TWh (1.5 Mt) by 2030. One study, however, estimates a significantly higher demand of around 350 (10.5 Mt) TWh. By 2030, most scenarios also see limited demand for hydrogen downstream products (energy carriers produced from hydrogen: ammonia, methanol, methane, naphtha, gasoline, diesel, kerosene etc.) mainly in the industry and transport sectors. The updated National Hydrogen Strategy (NWS) assumes a total hydrogen demand for 2030 between 95 (2.85 Mt) and 130 (3.9 Mt) TWh[3], an increase between 40 (1.2 Mt) and 75 (2.25 Mt) TWh compared to the current 55 (1.65 Mt) TWh (BMWK 2023c). Excluding, extreme outliers the demand for hydrogen and its downstream products starts to take off after 2030 and reaches a range of 100 (3.0 Mt) to 300 (9 Mt) TWh by 2040, and 200 (6.0 Mt) to 700 TWh (21 Mt) by 2050 across industry, mobility, and buildings. The demand in the conversion sector – that is power, district heating and refineries – is lower, reaching between 50 TWh (1.50 Mt) and 150 TWh (4.50 Mt) in 2050. The overall 2050 demand for hydrogen and its downstream products is estimated between 300 TWh (9.0 Mt) and 800 TWh (24 Mt), not considering the more extreme outlier scenarios.

For context, the scenarios forecast Germany's total final energy demand for 2030 to be between 2000 and 2050 TWh, for 2040 to be between 1700 and 2250 TWh, and for 2050 to be between 1350 and 2100 TWh (Wietschel et al. 2021).

The metastudy also indicates the sectoral hydrogen requirements which tend to vary significantly between the studies. For example, a demand of between 15 TWh (0.45 Mt) and 25 TWh (0.75 Mt) is assumed for the industrial sector for 2030 and between 70 TWh (2.10 Mt) and 330 TWh (9,90 Mt) for 2050. The long-term scenarios of the BMWK predict a demand for hydrogen of between 290 (8.7 Mt) and 440 (13.2 Mt) TWh for the industry in 2045 (BMWK 2023c). In the building sector, the demand is between 0 TWh and 150 TWh (4.50 Mt) in 2030 and between 0 TWh and 180 TWh (5.40 Mt) in 2050. In the conversion sector, the demand is assumed to be between 0 TWh and 60 TWh (1.80 Mt) in 2030 and between 50 (1.5 Mt) TWh and 150 (4.5 Mt) TWh (4.50 Mt) in 2050. A demand between 80 (2.4 Mt) and 100 (3.0 Mt) TWh in the conversion sector is predicted for 2045 by the BMWK long-term scenarios (BMWK 2023c). The transport sector is assumed to require between 0 TWh and 35 TWh (1.05 Mt) in 2030 and between 0 TWh and 220 TWh (6.60 Mt) in 2050.

While up to 2030, demand is focused on hydrogen, afterwards hydrogen's downstream products play an important – or even dominant – role in some scenarios. The authors of the scenario metastudy point out that there is a degree of substitutability between hydrogen and its downstream products (Wietschel et al. 2021). In 2030, the studies show a range between 43% and 70% imports for hydrogen. The share of imports increases in 2040, when the import ratio in the scenarios exceeds 50%. The range in 2050 is between 53% and 80%. In the updated NWS similarly, an import ratio between 50% and 70% is expected for 2030, which is expected to further increase in the years after (BMWK 2023c).

In terms of hydrogen's role in different sectors, the scenarios typically see demand for green hydrogen and its downstream products first materialising in the industry for direct reduction of iron, ammonia, and ethylene production. Some also see hydrogen use for process heat production. After that, demand for green hydrogen and its downstream products starts to pick up in the transport sector – especially for international air and sea transport. A heterogenous picture emerges across the scenarios with regard to demand in road transport; some studies see significant use in heavy trucks. Later still, demand for green hydrogen and its downstream products starts to emerge in the building sector, but generally remains lower than for the other two consumption sectors. Here, the authors of the metastudy point out that some assumptions leading to

[1] The lower heating value (LHV) of 33.33 kWh/kg, which this conversion is based on, expresses the energy content of one kilogram of hydrogen.

[2] Since the scenario studies referenced here predate the decision of the German government to move climate neutrality target ahead to 2045, their estimates of demand for hydrogen and its downstream products are in line with climate neutrality by 2050. Notwithstanding, they offer relevant reference ranges for hydrogen demand.

[3] In the original strategy document from 2020, a total hydrogen demand between 90 and 110 TWh was assumed. Accordingly, the expectation has been revised upwards.

significant hydrogen demand in buildings are hard to comprehend or are based on non-economic considerations. In the conversion sector, peak load power production, sometimes peak load district heat production, as well as (in the case of significantly reduced hydrogen costs) combined heat and power (CHP) are the most relevant demand drivers. Generally, the metastudy authors note that a higher degree of electrification and lower direct demand for hydrogen and its downstream products in the consumption sectors tend to lead to higher demand in the conversion sector, especially for power generation, as well as to a higher demand for flexibility in the consumption sectors (Wietschel et al. 2021).

In order for green hydrogen to provide GHG emissions reductions from a systemic perspective, it is imperative that its production must not consume renewable electricity that could have been used directly. Depending on sources, system configuration, grid restrictions and potential capping of the electrolyser full load hours, an additional 1 to 4 GW of renewable power generation must be installed for each GW of electrolysis (Agora Energiewende 2021). The original national target of 5 GW of installed electrolyser capacity by 2030, and 10 GW by 2035 or 2040 (BMWK 2020b), meant adding 5 to 20 GW of renewable power generation capacity at first by 2030 and then again by 2035 or 2040. Since Germany doubled its installed electrolyser capacity target to 10 GW by 2030 the required renewable energy increases accordingly (BMWK 2023c).

For context, Germany's currently installed capacities of renewable energy generation amount to about 57 GW for onshore wind, 8 GW for offshore wind and 61 GW for solar PV (Fraunhofer-Institut für Solare Energiesysteme ISE 2022). Due to sector coupling by electrification and hydrogen production, the electricity demand in Germany will increase to about 1000 TWh by 2045 (Agora Energiewende 2021). Therefore, the total renewable power generation capacity required in 2030 is estimated at 270 to 350 GW for 2030 and between 400 and 650 GW for 2045 (McKinsey 2019).

The phase out of coal and nuclear power together with the increased use of hydrogen requires a substantial increase in the pace of renewable energy deployment in Germany. Apart from that, a wide consensus has been reached that a significant share of the required hydrogen and derived energy products will have to be imported. The metastudy of energy transition scenarios reports that in 2040 and 2050, and in some scenarios already in 2030, around 40-70% of the demand for hydrogen and its downstream products are predicted to be covered by imports. Higher total demand for hydrogen and derived energy products tends to correlate with higher import shares. Hydrogen derived energy products have a higher import share than hydrogen as such, in some scenarios up to 100%, as they are easier to transport than hydrogen in molecular form (Wietschel et al. 2021). In order to meet the demands for hydrogen imports in the future, the hydrogen strategy is to be supplemented by an import strategy for hydrogen and hydrogen derivatives (BMWK 2023c).International cooperation and partnerships must be established and intensified in Germany for the import of hydrogen. To this end, cooperation with other EU member states is being intensified, especially in the North Sea and Baltic Sea regions, but also in southern Europe. Germany is also focusing on international cooperation with potential hydrogen exporting countries such as Australia, New Zealand, Canada, Chile, and different countries in Africa.

Especially when hydrogen and its downstream products are not produced domestically or near where they are needed, but instead arrive in Germany or other EU MS at seaports, they require an adequate transport and distribution infrastructure. Generally, the cheaper option is to repurpose the existing, well developed natural gas infrastructure. Where this is not possible, new hydrogen networks must be developed, requiring significant upfront investment. The authors of the meta-scenario study regard the development of an EU-wide hydrogen pipeline network a no-regret measure, but point out that in general terms, many questions pertaining to hydrogen imports remain unanswered at this point. Apart from hydrogen in molecular form, import in the form of its derived energy products seems even more promising for Germany. RWE, one of Germany's major energy companies, has announced its plans to build an ammonia import terminal in Brünsbuttel and start importing 0.3 Mt (1.56 TWh) of green ammonia per year in 2026 which is to be converted back to green hydrogen (RWE 2022). Another major player, Uniper, plans a similar but bigger project in Wilhelmshaven by 2030 (Uniper 2022).

Germany has an extensive natural gas network and underground gas storage facilities. Some of those are most likely suitable to be converted to store up to 32 TWh of hydrogen. Cavern storage facilities, large cavities in underground salt formations such as salt domes, are better suited for this then pore storage facilities, in which gas is pressed into porous rock (DBI 2022). The long-term scenarios published in 2021 by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) identified a capacity requirement for hydrogen storage of between 47 TWh and 73 TWh to achieve greenhouse gas neutrality in 2050 (DBI 2022). Due to lower volumetric energy density of hydrogen compared to natural gas, this means most of the current roughly 250 TWh of natural gas storage capacity in Germany would have to be converted to hydrogen.

According to the German national hydrogen strategy, only green hydrogen is sustainable in the long term. The strategy envisions using green hydrogen, supporting a rapid market ramp-up for it and establishing corresponding value chains. However, the German government assumes that CO_2-neutral[4] (e.g. blue or turquoise) hydrogen will also be traded on the global and European hydrogen market in the coming years.

[4] Low-CO2 hydrogen includes fossil hydrogen with CO2 capture and electricity-based hydrogen, for which the greenhouse gas emissions generated over the entire life cycle are significantly lower than for current hydrogen production. This therefore includes blue (CCS-Reforming; CCS Power) and turquoise hydrogen (Methane pyrolysis).

Due to Germany's close integration into the European energy supply infrastructure, CO_2-neutral hydrogen will therefore also play a role in Germany (BMWK 2020b).

For the EU, green hydrogen is the option that is most compatible with the EU's climate neutrality target in the long term. By 2050, green hydrogen is to be used on an increasingly large scale. However, other types of CO_2-neutral hydrogen will also be needed in the short and medium term, mainly to rapidly reduce emissions from existing hydrogen production facilities and to support the deployment of renewable hydrogen (European Commission 2020).

3.2 Policy goals and instruments

3.2.1 Background of Germany´s energy policy

In November 2016, Germany adopted the Climate Protection Plan 2050 *(Klimaschutzplan 2050)* which lays out for all sectors the emission reduction pathways necessary to achieve the national climate protection targets under the Paris Climate Agreement (BMUV 2022).

In October 2019, the Climate Protection Program 2030 *(Klimaschutzprogramm 2030)* was adopted specifying the climate protection measures. Importantly, the programme introduced a national CO_2 levy for the transport and heating sectors which started in 2021 with a price of 25 Euro/t CO_2 and will transition into an emission trading system after 2026 (Federal Ministry of Finance 2019). (The EU is currently also working on a new ETS for covering emissions from the buildings and transport sectors; it remains to be seen how exactly this will affect the German national emissions trading system).

The Climate Protection Act *(Klimaschutzgesetz)*, passed in December 2019, anchors the most important elements of the Climate Action Programme 2030, including its reduction targets, into law. The Climate Protection Act was updated in May 2021 and the climate protection targets were increased in ambition. Germany now intends to become climate neutral by 2045, and compared with 1990, greenhouse gas emissions will be reduced by at least 65 percent by 2030 and by at least 88 percent by 2040 (BMUV 2021a).

Germany is also subject to the European Commission's European Green Deal which aims for the entire EU to be climate neutral by 2050.

The impacts of both, the post lockdown economic recovery and the Russian war against Ukraine on energy prices and security of supply forced the EU and Germany to adapt their energy policies to these developments. Apart from the overarching strategies of reducing demand for fossil fuels, accelerating the rollout of renewables and diversifying energy suppliers, the REPowerEU includes several measures to specifically accelerate the deployment of hydrogen. In line with this, Germany is now striving all the more to expand the existing hydrogen partnerships and to establish new partnerships with further countries (BMWK 2022a).

3.2.2 Strategy documents and hydrogen-related policy goals in Germany

With the **National Hydrogen Strategy** (NWS) *(Nationale Wasserstoffstrategie)*, published in 2020, and updated in July 2023, the German government has created a framework for action for the future production, transport, and utilisation of hydrogen. It defines the steps necessary to achieve Germany's climate targets, create new value chains for the German industry and further develop international energy policy cooperation. Against this background, the following overarching goals are formulated in the NWS (BMWK 2020b) and in the **Update ("*Fortschreibung*") of the National Hydrogen Strategy** (BMWK 2023c):

- Assuming global responsibility for reducing greenhouse gas (GHG) emissions.
- Making hydrogen cost-competitive.
- Developing a lead market for hydrogen supply and technology in Germany, paving the way for imports.
- Establishing hydrogen as an alternative for other energy sources.
- Shaping and accompanying transformation processes.
- Strengthening German industry and securing global market opportunities for German firms.
- Establishing international markets and cooperation for hydrogen.
- Considering global cooperation on hydrogen projects as an opportunity.
- Building up trust and securing quality of the infrastructure for hydrogen production, transport, storage and use.
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- Ensuring sufficient supply of hydrogen by increasing imports and accelerating the expansion of hydrogen production and its derivatives in Germany.
- Establishing efficient, high-performance hydrogen infrastructure including national infrastructure, a European Hydrogen Backbone and the infrastructure for imports from third countries.
- Establishing the use of hydrogen applications in industry, transport and the energy sector to replace fossil fuels especially in hard-to-electrify applications (such as high-temperature heat, heavy industrial vehicles, aviation, shipping, military applications) and to provide flexibility in the power system (e.g. through grid-supporting electrolysers and H2-ready combined cycle power plants).
- Establishing effective policy framework both nationally and in the international context (e.g. within G7 framework), especially with regard to planning and approval procedures, sustainability standards and certifications, as well as for the promotion of research, innovation and training of specialists.

In concrete terms, the updated National Hydrogen Strategy targets at least 10GW of domestic hydrogen electrolyser capacity by 2030.. The strategy assumes an overall hydrogen demand of 95-130 TWh by 2050. A majority of the hydrogen demand that cannot be served by domestic production is to be covered by imports (45-90 TWh) from EU member states and international partner countries.

The import is set to be facilitated through an upcoming dedicated **Import Strategy for Hydrogen**. Hydrogen is firstly supposed to be imported by ship, gradually giving way to more and more pipeline-based imports. By 2027/2028, a hydrogen grid with more than 1,800 km of (converted and newly built) pipelines is to be established in Germany via IPCEI funding. At the European level, an additional 4500 km of hydrogen pipelines will form the so-called "European Hydrogen Backbone (EHB)" by 2030 – including pipelines for import of hydrogen, e.g. from Norway. At the same time, Germany aims to facilitate the construction of hydrogen receiving terminals through a **Hydrogen Acceleration Law**, while all new LNG terminals need to be H2-ready, and establish a concept for hydrogen storage infrastructure. An important clarification of the updated NWS is that while Germany will only directly support the generation of green hydrogen, the use of other forms of low carbon hydrogen during the transition phase is acknowledged.

The **Steel Action Plan**, which was drawn up by the German government together with the steel industry, identifies measures to achieve the goals of a climate-neutral steel industry. The document focuses on the development of a market for hydrogen technologies to secure the production of competitive low-carbon steel. The central goals are European and internationally competitive hydrogen prices and market conditions as well as ensuring that the steel industry's hydrogen requirements are met (BMWK 2020a).

The **chemical and pharmaceutical industries** have also formulated their action plan. Here, hydrogen is identified as one of the keys to the transformation of the chemical industry to climate neutrality, but plays a somewhat less central role compared to the steel action plan. It lists general objectives to design the regulatory framework for hydrogen production (VCI 2021). It has to be noted that hydrogen alone cannot fully replace the natural gas in the chemical industry, as the latter not only acts as a source of energy, but sometimes as a source of carbon as well.

3.2.3 Policy instruments on EU level

As member of the European Union, a wide range of EU policy instruments for the ramp-up of hydrogen production are of great significance to Germany. The following paragraphs summarize these instruments as well as EU-level regulation adapted in Germany.

The EU Emissions Trading System (EU-ETS) is the cornerstone of the EU climate policy. It was the first international and – before the launch of China's ETS – the world's largest emissions trading scheme. It addresses the power sector as well as parts of the industry and mobility sectors and covers around 40% of the EU's and 44% of Germany's total GHG emissions (Bundesrechnungshof 2022). During its 4th trading phase (2021 – 2030), the price per tonne of CO_2 equivalent has risen sharply, reaching nearly 100 EUR in 2022 (European Commission 2022a). This carbon price generally impacts a range of economic decisions in favour of low-carbon alternatives, such as green hydrogen. In the case of natural gas, for example, a carbon price increase of 100 €/tCO_2 results in a price increase of 2cent/kWh, therefore making hydrogen more competitive.

The **EU Renewable Energy Directive** (RED II) required the German government to raise the target share of renewable energies in the transport sector to 28% by 2030. Germany aims to fulfil these EU requirements by obligating the distributors to meet a GHG reduction quota. This allows the use of green hydrogen in the production of fuels to be counted toward the greenhouse gas reduction quota (BMUV 2021b). The updated hydrogen strategy assumes that about 2 GW of electrolysis capacity will be created from the implementation of the REDII directive in Germany by 2030.

To reduce emissions in the mobility sector, the EU **Clean Vehicles Directive** (CVD) was established to promote clean and energy-efficient road vehicles. It sets binding minimum public procurement (purchase, lease, rent, hire and service contracts) targets for low- and zero-emission passenger cars as well as light and heavy-duty vehicles (BMVI 2022). Hydrogen vehicles are considered clean. Germany's target for clean public procurement stands at 38.5% for the entire period up to 2030. Furthermore, the EU has ruled, that by 2035, new cars need to reduce their emissions by 100%. Vehicles with combustion engines can then only be licensed if they are operated exclusively with CO2-neutral e-fuels (Sims and Abnett 2023).

Another important aspect are financial flows. To direct them towards achieving the climate and energy targets, the **EU taxonomy** was introduced. It provides a definition of the economic activities that can be considered sustainable. This is intended to protect private investors from greenwashing and help companies to become more climate friendly by shifting investments to where they are most needed (European Commission 2022b). Among many other things, the EU Taxonomy stipulates the carbon intensity threshold for hydrogen to be considered sustainable. Thus, at the EU level, blue or turquoise hydrogen can also qualify as sustainable (but not as renewable as defined by the RED II).

Important Projects of Common European Interest (IPCEI) provides funding for integrated projects along the hydrogen value chain, from generation and infrastructure to end- use in industry and mobility. The IPCEI process networking of the hydrogen industry in Germany and Europe. In July 2022, the European Commission approved 41 projects in 15 EU countries and in September 2022 another 35 projects in 13 EU countries, accounting for a total of 76 approved projects so far (European Commission 2023). The updated hydrogen strategy assumes that about 2.5 GW of electrolysis capacity will be created through IPCEI projects in Germany by 2030.

3.2.4 National policy instruments for hydrogen production ramp-up

In addition to EU-level regulation, Germany also serves as a trailblazer in Europe, advancing novel and ambitious national initiatives and laws to ramp-up hydrogen production.

The German government provides a range of subsidy programmes intended to support the national and international hydrogen production capacity build up. The most innovative of these programmes with a focus on supporting the market ramp-up for hydrogen imports is **H2Global**. Its goal is to create sufficient planning and investment security for the private sector before a fully functioning market for green hydrogen and its downstream products comes into existence. This is achieved by a two-sided auctioning system, which is aimed at providing cost-effective support for hydrogen producers as well as end users. Through auctions, which are set to achieve the lowest possible green hydrogen cost, 10-year contracts will be awarded to projects outside of the EU that will supply hydrogen and its downstream products to industrial users in Germany and the EU. The tender for the first supply-side auction was launched in December of 2022 (Hydrogen Europe 2022), the first deliveries in the form of ammonia, methanol or kerosene (rather than hydrogen in molecular form) are expected in 2024 (BMWK 2022d).

On the demand side, a similar auctions-based mechanism is planned to award short-term contracts to industrial hydrogen end-users, aiming to achieve the highest possible sales price, while also allowing firms to procure green hydrogen at prices below production costs to allow the ramp-up of demand alongside supply. So-called **Carbon Contracts for Difference** *(Klimaschutzverträge)* will compensate via a variable subsidy the difference in operating costs between conventional and low or zero CO_2 processes (BMWK 2022d, 2020b). The baseline price for conventional production is determined on the basis of a tender process with automatic adjustment over time. The compensation is reversed into a state revenue once the climate-friendly production becomes cheaper than conventional production methods. The first contracts are expected to be awarded in the course of 2023 (BMWK 2023e).

In the long term, so-called **Green Lead Markets** (*Grüne Leitmärkte)* should have priority over Contracts for Difference (BMWK 2023a; Wissenschaftlicher Beirat beim Bundesministerium für Wirtschaft und Klimaschutz 2023). When the green products have become price-setting, the contracts can be terminated. However, in the short term, the contracts will be necessary to guarantee investment security and to incentivize investments in clean technologies at an early stage. The introduction of Green Lead Markets for key technologies is in planning, with green steel often mentioned as one of the priority areas. The aim would be to establish markets for green products, e.g. through public procurement or required green product quotas in specific industries (Federal Ministry of Finance 2022). The BMWK will present a concept in the first half of 2023 that identifies the measures relevant to the development of these markets. The fundamental requirements for this are recognized definitions and labelling in order to be able to distinguish "green" products from conventional products. Preparations for this are also being made at European level (for example, within the framework of the EU Ecodesign for Sustainable Products Regulation) and at international level (for example, within the framework of the G7 or the Industrial Deep Decarbonization Initiative, IDDI) (BMWK 2023a).

The **Offshore Wind Energy Act** ("Windenergie-auf-See-Gesetz") stipulates, following §96 Nr. 9, that from 2023 to 2028, 500 MW of green hydrogen production capacity will be tendered and installed annually using so-called system-serving electrolysis powered by wind energy. Accordingly, this will create a total electrolysis capacity of 3 GW. (BMWK 2023c)

Funding instruments from Germany for international hydrogen projects and market ramp-up abroad also include the **FRL** (*Föderrichtlinie für internationale Wasserstoffprojekte*), **H2-Uppp** and the **International PtX Hub** (BMWK 2022e, 9/23/2022). The funding guideline for international hydrogen cooperation projects, short **FRL**, is a joint initiative of the BMWK and the Federal Ministry of Education and Research (BMBF) to strengthen international cooperation and the build-up of a green hydrogen market. The initiative allows for non-repayable grants up to 25-45% of fundable costs with a maximum of funding at 15 Mio. EUR (module 1) or 5 Mio. EUR (module 2) per applicant and project (BMWK 2023b). **H2-Uppp** is a funding scheme based on a public-private partnership (PPP) approach that is implemented by GIZ and directed predominantly at pilot projects in developing and emerging countries with funding up to 200,000 EUR (for in-cash services) and 2,000,000 EUR (for in-kind services) (BMWK 2023d). The **International PtX Hub** is a platform and network implemented by GIZ on behalf of BMWK that aims to contribute to the development and implementation of PtX projects globally. The fields of action of the initiative include among others project assessment and consulting services (PtX Hub 2023).

The second phase of the **National Hydrogen and Fuel Cell Technology Market Activation Program** focuses on sustainable modes of transport. Eligible for subsidies are public hydrogen refuelling stations (PTJ 2022). Currently, Germany has just under a 100 publicly available hydrogen refuelling stations (H2.live 2022).

The subsidy programme **Decarbonisation in the Industry** *(Dekarbonisierung in der Industrie)* targets energy-intensive industries such as basic materials, steel, and cement. It covers different technology maturity levels from research and development to industrial-scale applications of innovative climate protection technologies, including (but not limited to) hydrogen-based processes and aims to provide investment support for innovative technologies (BMWK 2022d).

A central piece of legislation for climate action in Germany is the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, EEG) which also contains provision addressing hydrogen. As part of the revision of the act (§39p), **government support for green hydrogen power plants** is planned for 2023. At the end of 2023, 800 megawatts of capacity are to be auctioned by the Federal Network Agency. In 2024, 2025 and 2026, there are to be two auction dates with initially 1000, then 1200 and finally 1400 megawatts of power plant capacity per year. The plants are to be connected to the hydrogen grid planning (Tagesspiegel Background Energie & Klima 2022a).

In parallel, there are **bids for innovative concepts with hydrogen-based electricity storage** (EEG §39) (combined units of electricity generation, electrolysis, storage, and reconversion of hydrogen to electricity). Over the next six years a total of 4400 Megawatts of capacity will be offered for bidding, starting with 400 megawatts in 2023 and ending with 1000 MW in 2028 (Tagesspiegel Background Energie & Klima 2022b).

Germany's overall climate goals are also furthered through the German national **Fuel Emissions Trading Act** *(Brennstoffemissionshandelsgesetz)* for the heat and transport sectors. The program, which was introduced in 2021, complements the EU ETS and covers 40% of German emissions (BMUV 2019; Bundesrechnungshof 2022). It thereby contributes to an increased attractiveness of low-carbon alternatives, e.g., green hydrogen.

To provide a legal basis for the gradual development of a hydrogen infrastructure in Germany, the **Energy Industry Act** *(Energiewirtschaftsgesetz*) has been amended to include transitional arrangements for the joint regulation and financing of hydrogen and gas networks (Posch 2021).

3.2.5 National policy instruments for research and innovation

The **Research Offensive Hydrogen Technologies 2030** *(Forschungsoffensive Wasserstofftechnologien 2030)* strategically bundles research activities on key hydrogen technologies. These include (BMWK 2020b):

- Regulatory Sandboxes for the Energy Transition
- Large-scale research projects "Hydrogen in the Steel and Chemical Industry"
- Projects in the transport sector
- Feasibility studies and potential maps
- International networks and R&D cooperations
- Establishment of a new research network "Hydrogen Technologies"

In the **Regulatory Sandboxes for the Energy Transition** *(Reallabore der Energiewende)* funding program, innovative technologies are tested in practical application under real conditions and on an industrial scale. Within this funding program, an incentive is created for the development of a hydrogen infrastructure. 5 of 10 real labs focusing on sector coupling and hydrogen solutions are already in the implementation phase (BMWK 2022d). The updated hydrogen strategy expects that about 0.2 GW of electrolysis capacity will be created through projects that are implemented within the framework of the regulatory sandboxes in Germany by 2030.

A further research initiative is the **H2 Compass** *(H2-Kompass*) which aims to provide top-level orientation to achieving the ramp-up of the German hydrogen economy. To this end, metastudies of relevant publications are conducted, and possible development paths are described with their requirements, potentials and consequences (Deutsche Akademie der Technikwissenschaften 2021; BMWK 2021a).

The funding program **National Hydrogen and Fuel Cell Technology Innovation Program** *(Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (NIP))* aims to establish hydrogen and fuel cell technology competitively in the transport sector. Funding is provided for projects (demonstration, innovation and market preparation) in the field of hydrogen and fuel cell technology, particularly in road, rail, water and air transport and in special applications (BMWK 2021b). The updated hydrogen strategy assumes that around 0.1 GW of electrolysis capacity will be created through NIP funding in Germany in the medium-term.

The program **Hydrogen Lead Projects** under the funding call Ideas Competition Hydrogen Republic of Germany *(Wasserstoff-Leitprojekte (Förderaufruf Ideenwettbewerb Wasserstoffrepublik Deutschland))* includes technologies and solutions for (BMWK 2022d):

- Series production and upscaling of established and future electrolyser types (H_2Giga),
- Hydrogen transport in pressure vessels, liquefied, as ammonia and LOHC (TransHyDE),
- Offshore production of hydrogen and P2X products (H_2Mare),
- Cross-cutting issues such as safety, recycling, and system integration.

The aim of the Hydrogen Innovation and Technology Center (ITZ) *(Innovations- und Technologiezentrums Wasserstoff)* is to support small and medium-sized companies. The ITZ is intended to create a testing, inspection and development platform. The services offered by the ITZ are to contribute to increasing the product availability of fuel cell applications (components, vehicles, tank infrastructure) (BMWK 2022d).

Within the **WIR! program line** (*WIR!-Programmlinie)*, projects for the conversion of diesel multiple units to hydrogen and natural gas operation are funded (BMWK 2022d).

"**HyLand** – Hydrogen Regions in Germany" is an initiative by the Federal Ministry for Digital and Transport (BMDV) that was launched in 2019 to support and incentivise hydrogen-related concepts within a competition. The most promising regional concepts are selected and awarded technical, organisational and financial support for the implementation (NOW GmbH 2023).

3.3 Coordination bodies

The **National Hydrogen Council** *(Nationaler Wasserstoffrat)* was appointed by the German government and acts as an independent, non-partisan advisory body. The objective of the National Hydrogen Council is to assist and advise the State Secretary's Committee for Hydrogen in the further development and implementation of the National Hydrogen Strategy (Nationaler Wasserstoffrat 2022b). The **Hydrogen Coordination Office** *(Leitstelle Wasserstoff)* supports the implementation and further development of the National Hydrogen Strategy. In this context, the Coordination Office supports the ministries in the implementation of the NWS and the National Hydrogen Council in the coordination and formulation of recommendations for action and takes over the monitoring of the NWS (Nationaler Wasserstoffrat 2022a).

The **National Organization for Hydrogen and Fuel Cell Technology** (NOW) *(Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie)* is a research funding program company that coordinates funding programs in the field of sustainable mobility for the Federal Ministry of Transport and the Federal Ministry for the Environment (NOW GmbH 2022).

3.4 Engagement in hydrogen-relevant multilateral formats and international cooperation

Germany is a member of the **International Partnership for Hydrogen and Fuel Cells in the Economy** (IPHE), an international collaborative initiative for the development and deployment of hydrogen and fuel cell technologies. Germany is also a member of the hydrogen initiative of the **Clean Energy Ministerial**, the **International Renewable Energy Agency** and the **Internationale Energy Agency.**

Furthermore, Germany holds numerous **bilateral partnerships,** e.g. in form of formalised energy partnerships, many of which also deal with the topic of hydrogen. In addition to large-scale pilot projects and regular exchanges on political framework conditions and funding opportunities, also the preparation of studies on this topic, are part of the energy partnerships (BMWK 2022b). In addition, **H2Diplo**, the Global Hydrogen Diplomacy project implemented by the GIZ on behalf of the Federal Foreign Office similarly focuses on strengthening diplomatic relations and exchange in the area of hydrogen especially with export and transit countries for fossil fuels to discuss and point out alternative energy policy strategies and measures (GIZ 2023).

4 Overview of hydrogen policy in Korea

4.1 The role of hydrogen in Korea's energy transition

The Korean government attributes a key role to hydrogen in achieving the 2050 CO_2 neutrality target. The country intends to become a global leader in the application of hydrogen fuel cells for mobility, power generation and in the household sector, and sees this as a major future growth market (MOTIE 2019; Intralink 2022).

In contrast to Germany, Korea currently imports most of its ammonia and its demand for hydrogen predominantly results from crude oil refining. Korea processes more petroleum than it consumes and oil products represent an important share of its export revenues (The Korea Economic Daily 2022). Korea's present hydrogen demand is predominantly covered by grey hydrogen (Lim and Lee 2021) and stands at 1.8 Mt (60 TWh) (IEA 2021). However, the Korean accounting methodology typically omits hydrogen demand for refineries, and lists it much lower at between 0.22 Mt (7.3 TWh) and 0.45 Mt (15 TWh) (MOTIE 2021; Intralink 2022).

Overall hydrogen demand is expected to more than triple from 1.8 Mt (60 TWh) in 2020 to 3.9 Mt (130 TWh) in 2030, the latter excluding refineries, and to then further increase about seven-fold by 2050 (27.9 Mt, 929.9 TWh) (Lim and Lee 2021; MOTIE 2022a; IEA 2021). In 2030, 3.5 Mt (116.6 TWh) are to be used in the power sector and 370,000 tons (12.3 TWh) in the mobility sector. For 2050, the values are estimated at 13.5 Mt (450 TWh) and 2.2 Mt (73.3 TWh), respectively. In addition, 12.2 Mt (406.6 TWh) are to be used in industry by 2050.

Domestic production of hydrogen in 2030 is targeted to be grey (940,000 t, 31.3 TWh), blue (750,000 t, 25 TWh) and green (250,000 t, 8.3 TWh). In addition, 2.0 Mt (66.6 TWh), or around half of the total 2030 hydrogen demand, is to be covered by imported green hydrogen (Lee 2021). A key milestone of the 1st Basic Plan for Implementing the Hydrogen Economy is the increase of the share of clean hydrogen from currently 0% to 75% in 2030 and eventually 100% in 2050 (MOTIE 2021).

The amendment to the Hydrogen Act passed in May 2022 has not established a clear definition of "clean hydrogen", which is the phrasing that is most commonly used in Korean policies and discussion. Currently, Korea usually refers to both blue and green hydrogen as clean. With the current government's renewed focus on nuclear energy, it is likely that pink hydrogen will also be classified as clean (Song 2022). As foreseen in the hydrogen act (Park 2022), the Korean government is currently working on a clean hydrogen certification scheme based on specific emission thresholds. The methodology is currently under review. As of late 2022, the certification system is set to account for well-to-gate emissions and the threshold is discussed to be around 5 kgCO2eq/kgH2 (or 41.67 gCO2eq/MJ), reflective of the carbon intensity of domestic blue hydrogen with a capture rate of 95%. The scheme itself is set to be announced in 2023 (Yoon-seo 2022). For comparison, under the Delegated Acts on Renewable Hydrogen as part of the revision of the RED (Renewable Energy Directive), the EU is aiming for a clean hydrogen threshold of 28.2 gCO2eq/MJ or the equivalent of 3.38 kgCO2eq/kgH2 (International PtX Hub 2023).

Apart from the government's 1st Basic Plan for Implementing the Hydrogen Economy, numerous secondary sources such as newspaper articles and industry bulletins refer to a 2018 Mckinsey report titled Korea Hydrogen Industry Roadmap, commissioned by the Korean industry (Nam 2018; Lee 2018). In general terms, the McKinsey report sees a lower overall hydrogen demand in 2050 compared to the government's vision on the one hand, but also a substantial hydrogen demand in the buildings sector on the other.

Currently, the self-sufficiency of clean hydrogen (excluding grey hydrogen) in Korea stands at 0% and is to be increased to 34% by 2030 and to 60% by 2050. Next to nationally produced hydrogen, green hydrogen imports from projects owned by Korean companies are also considered in the self-sufficiency calculation. By 2050, the Korean government intends to produce 2.0 Mt (66.6 TWh) of blue hydrogen, 3.0 Mt of green hydrogen (100 TWh) and import 22.9 Mt (763.3 TWh) of hydrogen per year, and aims at establishing CCUS demonstration projects in GHG intensive industries (MOTIE 2022a).

As potential hydrogen supplier countries, Korea sees the USA, Canada, New Zealand, Chile, and Australia (Korea Energy Economics Institute 2021b). Korea aims at establishing 40 supply routes for clean hydrogen by 2050. So far, government-to-government hydrogen agreements have been formed with Norway, Saudi Arabia, Israel, Australia and New Zealand. Moreover, Memorandums of Understanding have been signed with Norway to develop hydrogen shipbuilding; with Chile and with Denmark. H2KOREA, a public-private consultative organisation, is a principal actor in the formulation of international partnerships (H2Korea 2021).

Since the Russian invasion of Ukraine, the relationship between Korea and Russia has declined. Korea has joined other countries in condemning the aggression, and Russia has retaliated by including Korea on its list of "unfriendly states". The cooperation between the two countries in the area of hydrogen is uncertain (Kallanish 2022). Another consequence of these events were energy supply chain perturbations and increased volatility of energy prices. This led the Korean government to renew its focus on energy security as a key policy goal next to carbon neutrality (Kim 2022a).

Korea has secured competitiveness in the field of hydrogen utilization technologies such as hydrogen vehicles and fuel cell power generation, but generally lags behind the global leaders in hydrogen production. Like most countries, Korea also still lacks infrastructure such as sufficient filling stations; the buildout of the public hydrogen supply infrastructure has experienced delays (FKI 2020; The JoongAng 2021). Korea has seen some success in the development of storage technologies. In March 2020, KEPCO developed the liquid organic hydrogen carriers technology (LOHC) (KEEI & MOTIE 2019). LOHCs are organic compounds that can absorb and release hydrogen through chemical reactions and can be used to store and transport hydrogen.

The scale-up of green hydrogen production will depend on the production of renewable electricity in Korea, which is likely to be a bottleneck. Currently, Korea's installed renewable capacity amounts to 23.6 GW consisting of 22 GW solar PV, 1.5 GW onshore wind and 1.14 GW offshore wind (en-former.com 2022; PV Magazine 2022). The current expansion targets, according to the 10th Basic Plan on Electricity Demand and Supply, amount to 46.5 GW solar, and 19 GW for wind . Reflecting a policy shift under the new Korean government, renewable capacity targets that were announced together with Korea's updated NDC in 2021 (Cha 2021) have been strongly modified under the new 10th Basic Electricity Plan presented in January of 2023. The targeted share of renewables by 2030 was reduced from 32.2% to 21.6%, while the target share of nuclear power was increased from 23.9% to 32.4%. Hydrogen and ammonia are set to make up 2.1% of the electricity mix (Kim & Chang 2023). The targets for 2036 are 30.6% renewable, 34.6% nuclear and 7.1% hydrogen/ammonia, respectively. This shows an overall shift towards nuclear energy in the medium run. At the same time, the targeted share for coal power in the electricity mix was further decreased, from 21.8% to 19.7% by 2030 and to 14.4% by 2036.

From 2016 to 2020, the electric power generated by renewable energy in Korea has increased from 22.94 to 32.65 TWh (+42.33%) (Statista 2022a) which accounts for a share in electricity production that increased moderately from 3.5% (2016) to 8.6% (2021) in the past years (Enerdata 2022). The share of renewable energy in terms of the total final energy consumption has at the same time increased only slightly from 3.2% (2016) to 4.3% (2020) (Statista 2022b). Given the current pace of renewable energy expansion, it appears uncertain that the production level of 250,000 tons of green hydrogen aimed for by 2030 can be achieved. This would likely require a rapid and significant expansion of offshore wind energy, while the current government's focus is on nuclear power (NEXT Group 2022), which makes the usage of pink hydrogen more likely.

4.2 Policy goals and instruments

4.2.1 Background of Korea´s energy policy

In October 2020, Korea announced the goal of achieving carbon neutrality by 2050 and to end their coal dependency (Bechauf 2020). While maintaining the goal for carbon neutrality, Yoon Suk-yeol, the president elected in 2022, questions the strong role for renewables in the previous plan and the new government has generally shifted attention towards nuclear energy, essentially pushing back renewable targets in favour of more nuclear expansion, as discussed previously. To achieve the increased capacity targets, projects for the construction of new nuclear power plants halted under the Moon government are to be resumed (MOTIE 2022c). The government is also planning to label nuclear power as green within the K-taxonomy (Ho-Jeong 2022).

In line with the increased focus on nuclear energy, the Yoon government intends to revive nuclear exports after projects to build such plants abroad were wound down significantly under the Moon government (Jung 2022). The planned Nuclear Energy Exports Strategy Task Force has been promoted to the Nuclear Power Plant Export Committee that will work towards increasing the export volumes of the Korean nuclear energy sector (KITA 2022). The Czech Republic and Poland are named as potential nuclear technology importers (MOTIE 2022d).

Despite the reduction in the overall target, renewable expansion will remain an important part of the Korean energy policy under the 10th Basic Electricity Plan. It is expected that 72.7 GW of renewable capacity will need to be installed by 2030, and the government plans to introduce a wind power bidding market. At the same time, requirements and standards regarding grid access for renewable power generation will be reinforced and changes to the overall electricity market are expected (Kim & Chang 2023).

Importantly, the massive expansion of the hydrogen economy planned under Moon is to be maintained under the new government. Korea already has extensive know-how and experience in the areas of fuel cells and fuel cell vehicles and considers the transformation to a hydrogen economy to play a key role in achieving the CO2 neutrality target by 2050. Regarding hydrogen production, the role of pink hydrogen, next to green and blue hydrogen, is expected to gain importance under the new government (Kwon 2022).

4.2.2 Strategy documents and hydrogen-related policy goals in Korea

In January 2019, Korea presented its **Hydrogen Economy Roadmap**, a strategic plan to promote the hydrogen industry with the participation of a total of six ministries, among them MOTIE. The roadmap addresses the timeframe until 2040 and sets a 2040 hydrogen supply target of 5.26 Mt (175.3 TWh). In the Roadmap, electrolysis appears as a hydrogen supply method from 2022 onwards. Hydrogen supply, as well as the proportion of green hydrogen, is to be increased by 2040 through domestic electrolytic hydrogen production, own overseas production, and imports (MOTIE 2019). The goal is to gradually bring down the costs of green hydrogen from KRW 6,000 per kg (4.4 €/kg) at the early market stage to KRW 3,000 per kg (2.2 €/kg) in 2040 (Korea Energy Economics Institute 2021a)[5].

[5] KRW 1 = EUR 0,00074 as of October 10 2022

The 1st **Basic Plan for Implementing the Hydrogen Economy** from November 2021 states four main pillars for implementing the Hydrogen Economy. First, Korea is to become a leader in domestic and overseas clean – i.e. green and blue – hydrogen production. Second, a nationwide infrastructure is to be built, consisting of distribution networks as well as refuelling stations. 14 sites for hydrogen import and distribution infrastructure in naval ports are to be established by 2040. For the use of existing natural gas pipelines, safety analysis and demonstration projects are to be carried out in the early 2020s for blending hydrogen into the gas network. Third, hydrogen is to be used broadly in power generation, mobility, buildings and industrial use. Hydrogen power generation should also include co-firing of ammonia in coal power plants from 2027, with the goal of reaching a 20% share by 2030 and the commercialization of hydrogen-powered gas turbines by 2050. Hydrogen use in the power sector is to reach 3.5 Mt (116.7 TWh) in 2030 and 13.5 Mt (450 TWh) in 2050. Within industry, the steelmaking and the petrochemical sectors as well as the cement industry are expected to account for most of the demand for hydrogen due to their energy intensiveness. Last but not least, the whole hydrogen ecosystem is to be strengthened by investing into R&D, human resources, standardization, safety management, international cooperation, private companies, hydrogen cities and clusters, institutions, as well as by increasing public acceptance (MOTIE 2021).

4.2.3 National policy instruments for hydrogen production ramp-up

In order to support the Hydrogen Economy Roadmap, the National Assembly has passed the **Hydrogen Economy Promotion and Hydrogen Safety Management Law**, also referred to as the **Hydrogen Act**. This law, initially enacted in February 2020, provides the legal framework for policy instruments in the field of hydrogen, and aims to guarantee a stable demand for clean hydrogen and to provide government support to hydrogen producers. With an amendment of the hydrogen act in 2022 the targets for clean hydrogen power generation were increased and a requirement for implementing a clean hydrogen certification system was added (Kim 2022b; Park 2022). Specific standards of clean hydrogen classification are to be prepared through Presidential Decree in 2023. In addition, **Clean Hydrogen Energy Portfolio Standards** (CHPS), which are similar to renewable portfolio standards, were included in the Hydrogen Act.

In order to bridge the gap between the production cost of hydrogen and the current willingness to pay, the Korean Ministry of Environment (MOE) announced the **K-Taxonomy** in December 2021. This Korean green classification system consists of a total of 69 distinct economic activities (MOE 2021). The taxonomy is intended to serve as a point of reference enabling the steering investments away from CO_2-intensive industries toward sustainable ones and to prevent greenwashing (Financial Services Commission 2021). In contrast to the EU taxonomy, the K-taxonomy is a non-legally binding directive. Nevertheless, it must be considered a central instrument in the reorientation of capital flows, including with regards to investments in the hydrogen sector (Lim et al. 2021). For instance, core technologies for reducing greenhouse gases in industrial sector such as DRI steel and hydrogen-powered vehicles are included in the taxonomy (MOE 2021). In 2023, it was announced that the Korean government intends to financially support companies with up to 300 million KRW (205,000 Euro) per company for the issuing of green bonds (MOE 2023).

The **Korean ETS** (K-ETS), launched in 2015, covers industry, power, buildings, domestic aviation and waste. With the participation of 684 of the country's largest emitters, it accounts for 74% of total GHG emissions. The average price of a certificate allowing for one tonne of CO2 emissions was at 23,243 KRW in 2022, which corresponds to approximately 16 EUR/tCO2 (International Carbon Action Partnership 2022b). This is likely to make clean alternatives, such as low-carbon hydrogen, more price competitive.

Korea currently plans to identify and promote large-scale overseas projects for hydrogen production to support the market ramp-up until 2030. To this end, Korea plans to establish a **domestic platform for international joint project planning**, including feasibility studies on overseas hydrogen production and business model development. To facilitate private investments, Korea plans to establish a joint promotion system with participation of domestic companies which were part of the initial feasibility studies (KPMG 2021). To enable the import of hydrogen, Korea also intends to establish hydrogen and ammonia receiving and storage facilities with 100kt/year and 4Mt/year capacity, respectively (Kim 12/7/2022).

Additionally, Korea has supported hydrogen technology scale-up since the establishment of the Hydrogen Roadmap. For 2023, the government allocated KRW 633 billion (EUR 466 million) to **subsidies for hydrogen vehicles** and KRW 190 billion (EUR 139 million) to **subsidies for refuelling stations** (H2Korea 2023). The government also announced KRW 330 billion (EUR 462 million) as the **hydrogen economy budget (R&D, subsidies, etc.)** in 2023. In 2023, the government also declared its intention to increase the number of hydrogen refuelling stations to 320 by the end of the year (MOE 2023). Additionally, the existing subsidies for hydrogen buses and trucks are set to increase and Korea plans to build the world's largest hydrogen liquefaction plant.

At the same time, Korea also plans to open the **bidding market for hydrogen-based electricity** in the first half of 2023, in order to support energy production from fuel cells, ammonia-coal co-firing, hydrogen turbines and related technologies. It is furthermore planned to enact the Hydrogen Business Act, to define operators as well as to establish supply and demand plans for each sector. It is Korea's goal to establish a hydrogen and ammonia co-firing demonstration project by 2027, with the medium-term goal to develop more than 50% hydrogen or 20% ammonia co-firing in LNG or coal plants, respectively (Kim 12/7/2022).

In response to the Covid-19 pandemic, the Korean government launched the Korean **Green New Deal** which includes measures to accelerate the implementation of the hydrogen economy (MOTIE 2020a). It provides a budget of

KRW 66.6 billion (EUR 49 million) for building a hydrogen production base. The funds available for building a hydrogen distribution base stand at KRW 3.6 billion (EUR 2.7 million) and the budget for developing green hydrogen technology that uses renewable energy instead of fossil fuels to produce hydrogen at KRW 10 billion (EUR 7.4 million). In addition, funding of approximately KRW 20 trillion (EUR 14.8 billion) is available for promoting projects in the field of environmentally friendly mobility (MOTIE 2020a; KITA 2020).

The goal of **fostering regional development** is pursued by projects such as the Promoting Gyeongnam-type Hydrogen Specialty Complex Initiative that supports hydrogen energy industry in the Gangwon region and focuses on green hydrogen production using offshore wind power (Kwon 2022). In total, the Korean government is aiming at establishing **five hydrogen clusters** with different hydrogen technology and value chain focus: Incheon for blue hydrogen production; Jeonbuk for green hydrogen production; Gangwon for hydrogen storage and transport; Gyeongbuk for hydrogen fuel cells; and Ulsan for hydrogen mobility. Further, **three hydrogen citie**s in Ulsan, Ansan, and Jeonju/Wanju are to be established to demonstrate hydrogen heating, cooling, power and transport applications in large scale real-life environments (Erneuerbare Energien Hamburg 2021; Kim 2021; FuellCellsWorks 2019).

4.2.4 National policy instruments for research and innovation

The Korean **Green New Deal** also includes a budget of around EUR 8.3 billion (EUR 6.1 million) to promote R&D and pilot projects in the field of renewable energy (Jones 2021), including hydrogen.

Industry transformation is also supported the **New Energy Industry Fund**, implemented by MOTIE. The fund's size amounts to KRW 500 billion (EUR 370 million), of which KRW 34 billion (EUR 25 million) are part of the dedicated **Hydrogen Economy Fund**. The fund aims to support companies in entering the hydrogen market, and in doing so to foster the generation and use of hydrogen along the entire hydrogen value chain (hydrogen production, distribution and storage) (Jung 2020).

MOTIE also plans to use a **regulatory sandbox approach** that will allow regulatory exemptions from certain current laws for individual projects in order to improve the regulatory environment in all areas relevant for the hydrogen industry (MOTIE 2022b; Korea.net 2019). One example is the first hydrogen self-charging station to be installed and operated in Seoul soon (Biogradlija 2022).

In November 2022, Korea unveiled a new **hydrogen R&D strategy** that will focus on clean hydrogen production, transport and storage technologies, and application in industry. Alkaline and PEM electrolysers are specifically mentioned as one area of focus, as is hydrogen transport in the form of ammonia, and fuel cells for transport applications (Business Korea 2022).

4.3 Coordination bodies

The Korean government has also established a supporting infrastructure for the build-up of the hydrogen economy. The **Hydrogen Economy Council** consists of 8 government ministries, including MOTIE, The Ministry of Economy and Finance (MOEF), The Ministry of Science, Technology and ICT (MSIT), The Ministry of Environment (MOE), The Ministry of Land, Infrastructure and Trade (MOLIT), The Ministry of Oceans and Fisheries (MOF) and The Ministry of SMEs and Start-ups (MSS). Further, **five expert committees** have been formed with the aim of encouraging R&D collaboration amongst academic institutes and businesses with the following focuses along the hydrogen value chain: Production; Storage/Transportation; Utilization for Transportation; Utilization for Energy; and Safety/Infrastructure (Lee and Kim 2021).

Additionally, the **Hydrogen Economy Committee,** which was established based on the Hydrogen Economy Promotion and Hydrogen Safety Management Law (see section 4.2.3), is chaired by the Prime Minister and oversees topics concerning hydrogen industry promotion, distribution and safety (HyResource 2021).

4.4 Engagement in hydrogen-relevant multilateral formats and international cooperation

Korea is participating in various multilateral formats: The **International Partnership for Hydrogen and Fuel Cells in the Economy** (IPHE), the hydrogen initiative of the **Clean Energy Ministerial**, the **International Renewable Energy Agency** and the **International Energy Agency**. A number of bilateral memorandums of understanding for cooperation on diverse hydrogen-related projects have been signed with various countries as well (see section 4.1). Further, in May 2022, the **Global Hydrogen Industry Association Alliance** (GHIAA) was inaugurated, led by H2Korea, comprising 18 hydrogen industry associations representing their respective countries (including the German Hydrogen and Fuel Cell Association (DWV)). This alliance acts as a platform for sharing information regarding hydrogen industry trends, supporting the international hydrogen industry cooperation, and promoting private investment in the market (Hydrogen and Fuel Cell Association of Singapore 2021; Ghiaa 2017).

5 Comparison

After providing an overview of the low-carbon hydrogen support policies implemented and planned in Germany and Korea in sections 3 and 4, this section identifies the main similarities and differences between them, and concludes with potential areas for cooperation.

The general context provides a range of similarities between the two countries. Importantly, both have set themselves the goal of achieving climate neutrality; Germany by 2045 and Korea in 2050 and both see hydrogen playing a key role in their decarbonisation. In a more general sense, both are high income countries with diversified economies and highly developed industrial manufacturing sectors as one of the main drivers of their prosperity. Their place among global leaders in various major industries ensures demand for their products and has allowed them to achieve trade surplus throughout the last decade. At the same time, both countries are resource-poor as well as highly dependent on energy imports and have suffered under recent global energy price volatilities.

Relevant differences relate to their respective geographical and (geo)political realities. While Germany is the strongest economy in the world's largest single market and surrounded by geopolitical allies, the only country which South Korea shares a land border with represents an acute and longstanding security threat. On the other hand, Germany as part of a closely integrated block of 27 countries must comply with its single market, state aid, environmental and fiscal rules and is not able to set its own monetary policy, while Korea enjoys more freedom in these respects. In terms of power and natural gas infrastructure, Germany is well integrated with its neighbours, while Korea's energy system is essentially an island. Lastly, while both countries belong to high-income countries, the total size of the two economies differs as well with Germany's GDP being more than twice as large as Korea's in 2021 (4.2 trillion US$ compared to 1.80 trillion US$) (World Bank 2022) and Germany's GDP per capita being around 1/4 higher than Korea's in purchasing power terms (World Bank 2023). Any comparisons between the two countries should be viewed in light of these differences.

While both countries joined the Paris Climate Agreement in 2016 and committed themselves to achieving climate neutrality, their visions vary to great extent. An important difference relates to the role of nuclear energy on the way to net zero. While Germany is phasing out nuclear energy alongside fossil fuels, the new Korean government sees a more prominent role for nuclear energy going forward. Apart from that, Germany's Federal Climate Change Act (*Klimaschutzgesetz*) as a key piece of national climate legislation spells out binding, long-term targets, sets up a monitoring mechanism and defines an implementation framework. Given the fact that Germany started its energy transition earlier and builds its current reduction pathways on these experiences, it should also be noted that reaching their respective climate neutrality goals might require a higher degree of policy ambition in Korea.

5.1 Hydrogen status, targets and projections

Currently, both countries rely almost exclusively on grey hydrogen. Germany consumes about 55 TWh (1.65 Mt) of hydrogen yearly for both ammonia production and in petrochemical industry. Korea consumes around 59 TWh (1.77 Mt) of hydrogen yearly, predominantly in refining processes and the petrochemical industry, while covering most of its ammonia demand through imports.

The expected ramp-up of hydrogen demand laid out in the relevant strategy documents and scenario studies differs between the two countries. Korea, which focuses more strongly on hydrogen usage in mobility, electricity, and heating, expects its demand to increase much faster and earlier. Most estimates for Germany see a 2030 hydrogen demand that is roughly equal to the current demand, with only a few studies seeing an increase, while the necessary conversion of existing grey hydrogen production capacity should also be noted. However, the most recent strategy update, predicts a considerable increase in the hydrogen demand until 2030 (approximately a doubling), which can be attributed to the fact that developments and expectations with regard to the hydrogen sector are accelerating quickly. Generally, estimates see hydrogen usage in Germany mostly limited to industry, with some scenarios seeing an increased demand in buildings as well – the latter however appears unlikely today due to the increasingly wide consensus that low-carbon hydrogen can be expected to remain too scarce and expensive to be used for heating in the mid- to long-term. Demand from the energy conversion sector typically remains low as well in 2030. In contrast, Korea sees its hydrogen demand increase by more than threefold by 2030, mostly due to a substantial demand of 3.5 Mt (116.7 TWh) materialising in the power sector, as well as some in the transport sector.

After 2030, the total demand for hydrogen (including, for Germany, its downstream products) starts to converge for Germany's high-demand scenarios and Korean government's vision. Germany's demand for hydrogen and its downstream products reaches a range of between 300 TWh (9.0 Mt) and 800 TWh (24.0 Mt) in 2045 / 2050. Again, the industry and transportation sectors provide the biggest demand, with buildings still playing a marginal role. The demand from the energy conversion sector – mostly power – increases between 2030 and 2045 / 2050 to between 100 TWh (3.0 Mt) and 200 TWh (6.0 Mt).

For Korea, the 1st Basic Plan for Implementing the Hydrogen Economy expects the total hydrogen demand to reach 27.9 Mt (929.9 TWh), with power at 13.5 Mt (450 TWh), industry at 12.2 Mt (406.6 TWh) and transport at 2.2 Mt (73.3 TWh). For the comparison of current and expected demand of hydrogen of both countries please also refer to Table 1.

Germany, as well as the EU more broadly, defines green hydrogen as the only long-term sustainable option. Blue and turquoise hydrogen are only to be used during the transition phase in the short and medium term and will not be targeted by government support policies. Korea, on the other hand, uses the term clean hydrogen to designate green and blue hydrogen as compatible with its decarbonisation strategy, with pink hydrogen potentially joining them under the current government's renewed focus on nuclear energy. By the time they have reached climate neutrality, both countries intend to use exclusively green and clean hydrogen, respectively.

In Germany, according to the original NWS 14 TWh (0.42 Mt) of green hydrogen were to be produced by 2030 with an electrolysis capacity of 5 GW. Reaching the updated target of 10 GW domestic hydrogen capacity from electrolysis, would thus result in around 28 TWh[6] (0.84 Mt) green hydrogen production by 2030. Assuming in line with most of the scenarios that the overall hydrogen demand does not increase substantially, this will displace some of the grey hydrogen used today. In contrast, the 8 TWh (0.24 Mt) of green hydrogen and 25 TWh (0.75 Mt) of blue hydrogen that the Korean government envisions to produce by 2030 will go towards covering the vastly increased demand, as will additional 31 TWh (0.93 Mt) of grey hydrogen. Focusing narrowly on GHG emissions stemming from hydrogen production, Germany will thus be able to achieve emissions reductions in the timeframe up to 2030, while hydrogen production-related emissions will increase in Korea.

Germany and Korea both assume that a significant amount of hydrogen demand has to be covered by imports. The import rate in Germany is assumed to be between 43 and 70% in 2030 and between 50 and 80% in 2050. Korea plans to import 2.0 Mt (66.7 TWh) of green hydrogen in 2030, resulting in an import rate of 51%. In 2050, Korea intends to import 22.9 Mt (763.3 TWh), or 82% of the hydrogen it consumes, partly from overseas projects in Korean ownership. Germany plans to import its demand from EU member states, especially in the North Sea and Baltic Sea regions, but also from southern Europe and from regions with larger distances such as Africa, Canada, Australia and New Zealand. Korea currently has plans to import from the U.S., Canada, New Zealand, Chile and Australia. Table 2 summarizes the hydrogen production targets and expected import shares for both countries. Table 3 summarizes the current status and targets for renewable energy sources.

For the import and usage of hydrogen, both countries need an adequate transport and distribution infrastructure. For Germany and other EU members states, the most cost-effective option is to use the existing gas infrastructure where possible. Besides hydrogen in molecular form, Germany is actively pursuing imports of hydrogen downstream products. Ammonia import terminals are already in planning stage. For the storage of hydrogen in Germany, the underground gas storage facilities can be refitted. Korea, which appears like an island when energy infrastructure is concerned, will need to rely more on maritime transport, with the construction of a hydrogen pipeline network for distribution in some parts within the country being planned.

For both countries, business opportunities stemming from potential mainstreaming of hydrogen technologies are of high interest. Germany is especially interested in establishing itself as a leader in power-to-x technologies such as electrolysers and integrated green hydrogen production systems. Korea's focus so far has been on transportation and fuel cell power generation to stimulate its economy. Currently, a focus is set on building hydrogen supply chains for the import of green and blue hydrogen as well as hydrogen power generation via co-firing hydrogen and natural gas and ammonia and coal.

Table 1: Hydrogen Demand in Germany and Korea

	Germany	Korea
Current demand:	~55 TWh ~1.65 Mt	~59 TWh ~1.77 Mt
Expected hydrogen demand by 2030:		
Total	10 – 130 TWh 0.30 – 3.9 Mt	130 TWh 3.90 Mt
Industry	15 – 25 TWh 0.45 – 0.75 Mt	- *
Buildings	0 – 150 TWh 0 – 4.50 Mt	-
Power	0 – 60 TWh 0 – 1.80 Mt	116 TWh 3.48 Mt
Transport	0 – 35 TWh 0 – 1.05 Mt	12 TWh 0.36 Mt
Expected hydrogen demand by 2045/2050:		
Total	300 – 800 TWh 9.0 – 24.0 Mt	929 TWh 27.9 Mt
Industry	70 – 440 TWh 2.10 – 13.2 Mt	403 TWh 12.1 Mt
Buildings	0-180 TWh 0 – 5.40 Mt	-
Power	50 – 150 TWh 1.50 – 4.50 Mt	446 TWh 13.4 Mt
Transport	0 – 220 TWh 0 – 6.60 Mt	73 TWh 2.19 Mt

** not included in the targets but nevertheless to be expected*
Data sources: BMWK (2020b), Wietschel et al. (2021), IEA (2021), MOTIE (2022a), MOTIE (2021), Lim and Lee (2021), (BMWK 2023c)

Table 2: Hydrogen Production Targets and Imports

	Germany	Korea
Hydrogen production targets by 2030:		
Grey hydrogen	- *	31 TWh 0.93 Mt
Green hydrogen	28 TWh 0.84 Mt	8 TWh 0.24 Mt

[6] This calculation assumes that the electrolysers run 4000h per year at 70% efficiency (Lübcke et al. 2022).

Blue Hydrogen	- *	25 TWh 0.75 Mt
Expected share of hydrogen imports:		
By 2030	43 – 70%	51%
By 2050	50 – 80%	82%

** not included in the targets but nevertheless to be expected*
Data sources: (BMWK 2023c), BMWK (2020b), Wietschel et al. (2021), Lee (2021)

Table 3: Renewable Energy in Germany and Korea

	Germany	Korea
Currently installed renewable energy capacity:		
Total	126 GW	23.6 GW
Share in electricity	46.2% (2022)	8.1% (2021)
Onshore wind	57 GW	1.5 GW
Offshore wind	8 GW	0.136 GW
Solar	61 GW	22 GW
Renewable energy targets by 2030:		
Total	270 – 350 GW	72.2 GW
Share in electricity	80.0%	21.6%
Onshore wind	115 GW	19.3 GW
Offshore wind	30 GW	
Solar	215 GW	46.5 GW
Renewable energy targets by 2050:		
Total	400 – 650 GW	-
Share in electricity	100%	-
Onshore wind	160 GW (2040)	-
Offshore wind	70 GW (2045)	-
Solar	-	-

Data sources: Enerdata (2023), MOTIE (2023), UBA (2023b), Bundesregierung (2023), UBA (2023a), KOSIS (2022), PV Magazine (2022), en-former.com (2022)

5.2 Hydrogen policy

Germany and Korea both have a central document for their respective hydrogen policies with Germany's 2020 Hydrogen Strategy and the relevant 2023 update and Korea's 2019 Hydrogen Roadmap. In addition to the hydrogen strategy, Germany also has action plans for the steel and chemical industries, both of which declare hydrogen to be central to their transformation.

A key difference between both countries can be identified in the structure of regulatory policy instruments, as Germany is subject to EU regulations, including REDII and CVD. On the national side, Germany´s EnWG determines the transitional arrangements for the joint regulation and financing of hydrogen and gas networks, while in Korea the Hydrogen Act regulates the strategic plan for the promotion of the hydrogen industry and the gas and hydrogen transport in the country.

Parallels in both countries' approaches to market-based instruments are apparent. Both Germany and Korea have emissions trading systems in place. Germany's European and national emission trading systems combine to cover energy conversion, industry transport (including aviation) and heating, and 84% of all national emissions. Korea's K-ETS covers industry, power, buildings, domestic aviation and waste and 74% of all national emissions. Perhaps the most material difference between the two countries is the price for emitting emissions equivalent to a tonne of CO_2: While the price of certificates in Korea is around half as high as in the German national ETS (around 16 EUR / 23,243 KRW in Korea compared to 30 EUR / 43,500 KRW in Germany in 2022), German power and industry sector which fall under the EU-ETS have been faced with prices of almost 100 EUR (145,000 KRW) per tonne of CO_2 equivalent this year (International Carbon Action Partnership 2022b, 2022a; Ember 2023). Whereas emission prices in this range do not yet merit replacing natural gas with green hydrogen in industrial processes on their own, they send a strong signal to the private sector. While emissions trading is not the only driver of transformation, many European energy intensive companies have entered partnerships to invest in hydrogen projects (IEA 2022).

A further parallel can be found in the taxonomies: the EU taxonomy, that applies to Germany, and the Korean taxonomy. Both contain references specific to hydrogen and go beyond defining green hydrogen as the only sustainable type of hydrogen. While blue and turquoise hydrogen are not considered renewable in the EU, they can be considered sustainable under the EU taxonomy if they stay below its GHG intensity threshold. The targeted thresholds for characterizing clean hydrogen are different between Korea and the EU. While the threshold currently discussed in Korea lies at around 5 kgCO2eq/H2 (41.67 gCO2eq/MJ) which reflects the carbon intensity of blue hydrogen, the EU aims at establishing a somewhat lower threshold of 3.38 kgCO2eq/kgH2 (28.2 gCO2eq/MJ).

Both countries have introduced various hydrogen support programs addressing a wide range of hydrogen technologies along different stages of the value chain and technology maturity levels. In general terms, the hydrogen subsidies available in both countries reflect their respective hydrogen strategies and the stage they currently find themselves in.

Germany is primarily focusing on ramping up green hydrogen production within Germany and abroad and on hydrogen use in industry, but also supports hydrogen use in the power and transport sectors.

For the market-ramp for hydrogen imports, the support instruments H2Global stands out as innovative instruments that works as a two-sided auction system and aims to create sufficient planning and investment security until a fully functioning market for green hydrogen is established. Germany is also in the process of setting up an auction scheme, the Carbon Contracts for Difference, for the demand side, which aims to compensate via a variable subsidy the difference in operating costs between conventional and climate-friendly processes. The German *Dekarbonisierung in der Industrie* programme focuses on the investment side of low-carbon applications, including those using hydrogen. Additionally, on the EU-level hydrogen production within Europe as well as infrastructure and end-use applications are also supported by the IPCEI. The power sector has also been a target for German subsidies, with green hydrogen power plants as well as power systems using hydrogen storage having been included in the EEG. Hydrogen refuelling stations as well as small stationary fuel cell applications for residential and non-residential buildings are also eligible for subsidies.

For Korea, pursuing the hydrogen economy means that subsidies are applied somewhat more broadly and aimed more at downstream value chains, i.e. distribution and consumption, especially fuel cell applications. Large funding has been earmarked for subsidies for hydrogen vehicles, stationary fuel cell applications and refuelling stations. At the same time, the New Energy Industry Fund and the Green New Deal are targeting investment in hydrogen production, storage, and distribution base, focusing on green hydrogen. While Germany also supports hydrogen clusters through its HyLand programme, the cluster approach with five hydrogen industry clusters and three hydrogen cities in Korea is more pronounced.

Parallels and differences in approaches can also be observed in R&D. Germany R&D funding covers the whole hydrogen value chain from production, transport and storage to distribution and consumption, and a wide range of domains spanning technology development, potential analyses, regulatory sandboxes, metastudies aimed at coordinating individual R&D activities, and combines a big-picture approach with focus on specific sectors, e.g. on industry. It also has a component explicitly targeting small and medium companies.

Korean R&D efforts are aligned with its strategy to establish itself as the global leader in mobile and stationary fuel cell applications, but also encompass electrolytic hydrogen production, transport and storage, and hydrogen power production. Similar to Germany, Korea also deploys regulatory sandbox approaches. In general terms, R&D efforts are more concentrated in the private sector, i.e. in big Korean corporations, and therefore harder to distinguish from subsidies than in Germany. At the same time, Korea also steers some of its funds away from corporations and towards small and medium companies.

In both Germany and Korea, different coordination bodies complement the respective governments and ministries. The German National Hydrogen Council is an independent advisory body that also features macroeconomists and scientists along with industry representatives and NGOs. It assists and advises the State Secretary's Committee for Hydrogen in the further development and implementation of the National Hydrogen Strategy. The Hydrogen Coordination Office, also an independent body, supports the implementation and further development of the National Hydrogen Strategy.

In Korea, the Hydrogen Economy Council consists of eight Korean ministries and is supported by five different topic-focused expert committees which aim for R&D collaboration between research and businesses. Another top-level coordination body, The Hydrogen Economy Committee, is chaired by the Korean Prime Minister and oversees topics regarding hydrogen industry promotion, distribution and safety.

The engagement of both countries in multilateral formats is very similar. Both countries are members of the International Partnership for Hydrogen and Fuel Cells in the Economy, Clean Energy Ministerial, International Renewable Energy Agency and International Energy Agency. Both countries have also signed numerous bilateral memorandums of understanding focusing on cooperation in the field of hydrogen. Additionally, on the industry level, associations of both countries are members of the GHIAA.

6 Conclusion and topics for Korean-German Cooperation

In a nutshell, it can be said that Korea and Germany are united in their goal to use low-carbon hydrogen as a foundation for the decarbonisation of their respective economies. In this quest, both also face similar challenges, such as finding solutions for the decarbonisation of heavy industry, a fossil-fuel reliant energy system as well as a prominent automotive industry.

There are, however, some key differences that need to be noted. While some of these differences come down to political preference and circumstances, such as the importance of nuclear power in both countries' decarbonisation plans, others could open room for mutual exchange and learning, e.g. in the framework of the Korean-German Energy Partnership (EP). In this regard, it is important to identify each country's individual strengths and policy experiences and to determine in how far these cold hold potentially important learnings for the other.

The ramp-up of low-carbon hydrogen production has two important sides – supply and demand. Starting with the supply side, it is striking that both countries are aiming at the establishment of low-carbon hydrogen supply chains and related policy instruments. In this context, Germany has become a trailblazer through the establishment of its H2Global program. At the same time, Korea, motivated by its geographic situation, has invested more in the question of hydrogen transportation and the build-up of receiving capacity. While Germany, in principle, has better opportunities for transportation by pipeline, the current geopolitical situation shows that seaborne transportation of hydrogen or – which seems more likely – hydrogen derivatives might also become relevant as a supplement and for diversification. These individual strengths mean that there is room for mutual learning, while the overall need to establish low-carbon hydrogen supply chains also presents unique opportunities for both countries to collaborate with respect to the establishment of overseas production facilities, standards, and international certification. This also ties together with Germany's more pronounced experience with green hydrogen production generally, which could support Korea in its domestic capacity ramp-up. In more concrete terms, the following cooperation formats could be meaningful:

- Exchange regarding the establishment of support schemes for international low-carbon hydrogen production and/or the development of an H2Global system adapted to Korea.
- Increased cooperation regarding standardization and certification.
- Korean-German cooperation project in a third country for green hydrogen production and transportation.
- Expert workshop on shipping of hydrogen and it's derivates and on the import-infrastructure and terminals and ports.
- Expert exchange on the distribution of hydrogen within the country via pipelines, trailers, storage.
- Expert workshop on the timely build-up of domestic green hydrogen production capacity.
- Expert trip with focus on policies and implementation of green hydrogen production for Korean stakeholders to Germany.

On the other side, approaches concerning the usage of hydrogen are somewhat different between Korea and Germany. While Germany sees low-carbon hydrogen used first and foremost as a way to decarbonise hard-to-electrify industrial applications and other sectors, it also started to carefully consider other use cases, such as energy production and energy storage in specific circumstances. Korea, on the other hand, has put a stronger emphasis on energy production, e.g. through co-firing, mobility and heating early on, with industrial applications representing only one of many use cases. Considering that ramp-up of low-carbon hydrogen production might be a long-term process, it might, nevertheless be relevant to clearly prioritise use cases. In this decision to prioritise, Germany's experience might be helpful for Korea. At the same time, Korea has more experience in some use cases Germany has put towards the end of its priority list, which opens opportunities for learning in the other direction as well as for potential industry cooperation projects. Therefore, it could be interesting to address the following topics within the energy partnership:

- Exchange on the prioritization and timeline of individual low-carbon hydrogen use cases.
- Exchange on the role of hydrogen power in the energy transition as well as related technologies.

Another area of common interest is the advancement of low-carbon hydrogen markets more generally, which Germany intends to support through the establishment of green lead markets based on procurement quotas. Korea uses a similar approach in a more limited sense, namely its Clean Hydrogen Energy Portfolio Standards, which require the usage of clean hydrogen in some sectors. Even though these strategies are somewhat different, the joint challenge could be a good foundation for mutual exchange:

- Exchange on the usage of regulatory policies to increase low-carbon hydrogen demand.

Another interesting aspect is Korea's focus on the establishment of hydrogen clusters as a means to foster regional development. While Korea's approach is more advanced in this regard, Germany has the HyLand program, which intends to achieve similar goals. This could offer an interesting opportunity for the EP, namely for

- Bilateral exchange on policy framework and practical perspectives between hydrogen clusters on sub-national level to foster cooperation and mutual learning.

Since both Germany and Korea are leaders in the establishment of a global hydrogen economy and the policy choices both may have considerable implications for the global market and technology pathways, it might also be sensible to empower crucial decision-makers in both countries to get in direct contact with each other. Through the energy partnership, one could for example:

- Establish a bilateral exchange between the relevant advisory bodies in Korea and Germany, such as the relevant hydrogen councils and committees.

Additionally, it is also noteworthy that both countries specifically intend to support small and medium enterprises. This, first of all, could mean that the experiences each country has made regarding the effective targeting of funds to such companies could present interesting learnings for the other partner. At the same time, such companies might find it more difficult to expand to other markets and find international partners as well as to communicate their needs to policymakers. Considering the unique strengths of each country's respective hydrogen economies, it might therefore be sensible to enable cooperation between such companies and get them in touch with relevant policymakers. The Energy Partnership could address these opportunities through:

- An expert workshop in the support of small and medium enterprises in the hydrogen economy.
- The organisation of mutual visits by small and medium enterprise delegations.
- Virtual B2B and B2G meetings with small and medium sized enterprises.

Green finance is another topic that especially Korea intends to use to support the ramp-up of hydrogen production. Considering the importance of securing sufficient financing for large-scale hydrogen production projects, this represents an opportunity for exchange, e.g. through:

- A joint Korean-German Expert Workshop on green finance as a tool to support the build-up of low-carbon hydrogen production capacity.

Lastly, an exchange on the effectiveness of a carbon price as a driver of low-carbon hydrogen take up could also present an important opportunity for learning. This could take place through:

- A joint Korean-German study exploring the role of carbon pricing in driving future demand for low-carbon hydrogen.

The long list of potential projects shows the significant promise that cooperation between two leading hydrogen economy trailblazers, Korea and Germany, holds. In order to seize these opportunities, increased cooperation through the joint Energy Partnership is vital to advance each other's hydrogen economies, considering both the need to achieve a timely ramp-up of hydrogen production as well as the need to keep an edge to other competitors unaligned with joint Korean-German values.

Appendix

Brown / black hydrogen
Brown and black hydrogen are produced by gasification from lignite and hard coal, respectively. Brown / black hydrogen is associated with high greenhouse gas (GHG) emissions.

Grey hydrogen
Grey hydrogen is produced from fossil fuels, typically by steam reforming of natural gas without CO2 abatement. Grey hydrogen is associated with high GHG emissions.

Green hydrogen
Green hydrogen is produced by water electrolysis using electricity from renewable power sources. Green hydrogen is associated with very low GHG emissions, depending on the exact requirements for the input power and electrolyser operation.

Blue hydrogen
Blue hydrogen is typically produced by steam reforming of natural gas, but its CO2 is captured and stored during production (CCS). The GHG intensity of blue hydrogen depends primarily on the share of CO2 captured and upstream methane leakages.

Turquoise hydrogen
Turquoise hydrogen is produced by methane pyrolysis from natural gas. Instead of CO2, solid carbon is produced in the process. The GHG intensity of turquoise hydrogen depends primarily on the energy source of the used heat, the carbon capture and the methane leakages.

Pink / red hydrogen
Pink (sometimes also referred to as red) hydrogen is typically produced by water electrolysis using power from nuclear energy. Pink / red hydrogen is associated with very low greenhouse gas (GHG) emissions.

Low-carbon hydrogen
Low carbon hydrogen includes all types of hydrogen with low or very low GHG emissions: green, blue, turquoise, pink/red.

Hydrogen downstream products
Energy carriers produced from hydrogen: ammonia, methanol, methane, naphtha, gasoline, diesel, kerosene etc.

Synthetic fuels (e-fuels)
Electrolytic hydrogen (green, pink/red) downstream products used as fuels, typically gasoline, diesel, kerosene etc.

Figure 1: The different colours of hydrogen

List of abbreviations

B2B	Business-to-Business
B2G	Business-to-Government
BMBF	Federal Ministry of Education and Research (Germany)
BMF	Federal Ministry of Finance (Germany)
BMDV	Federal Ministry for Digital and Transport (Germany)
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Germany)
BMWK	Federal Ministry for Economic Affairs and Climate Action (Germany)
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CHP	Combined heat and power
CHPS	Clean Hydrogen Energy Portfolio Standards
DRI	Direct reduced iron
DWV	German Hydrogen and Fuel Cell Association
EEG	Renewable Energy Sources Act
EP	Energy Partnership
EU-ETS	European Union Emissions Trading System
EU MS	European Union Member States
EU-RED	European Union Renewable Energy Directive
EU-CVD	European Union Clean Vehicles Directive
FRL	Funding guideline for international hydrogen cooperation projects
GIZ	German Agency for International Cooperation
GDP	Gross Domestic Product
GHG	Greenhouse gas
GHIAA	Global Hydrogen Industrial Association Alliance
IDDI	Industrial Deep Decarbonization Initiative
IPCEI	Important Projects of Common European Interest
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
ITZ	Hydrogen Innovation and Technology Center
K-ETS	Korean Emissions Trading Scheme
KRW	South Korean Won
LOHC	Liquid organic hydrogen carriers
MOE	Ministry of Environment (Korea)
MOEF	Ministry of Economy and Finance (Korea)
MOF	Ministry of Oceans and Fisheries (Korea)
MOLIT	Ministry of Land, Infrastructure and Trade (Korea)
MOTIE	Ministry of Trade, Industry and Energy (Korea)MSS Ministry of SMEs and Start-ups
MS	Member state
NDC	Nationally Determined Contribution
NIP	National Hydrogen and Fuel Cell Technology Innovation Program
NOW	National Organization for Hydrogen and Fuel Cell Technology
NWS	National hydrogen strategy of Germany
PEM	Proton exchange membrane (electrolysis)
PPP	Public-private Partnership
SMR	Steam methane reforming

List of figures

List of tables

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