HYPAT

H_2 Potential

Global Atlas of H_2 Potential

Sustainable locations in the world for the green hydrogen economy of tomorrow: technical, economic and social analyses of the development of a global sustainable hydrogen atlas

HYPAT Working Paper 03/2023

Positioning Germany in an International Hydrogen Economy: A Policy Review

Authors:
Rainer Quitzow (RIFS Potsdam)
Almudena Nunez (RIFS Potsdam)
Adela Marian (RIFS Potsdam)

RIFS POTSDAM

HYPAT Working Paper 03/2023

Positioning Germany in an International Hydrogen Economy: A Policy Review

The paper has been submitted to *Energy Strategy Reviews*.

Funding

The HYPAT – H_2 POTENTIAL ATLAS – project is funded by the German Federal Ministry of Education and Research BMBF as part of the "Hydrogen Republic of Germany" ideas competition in the basic research module on green hydrogen. The project runs for a period of three years, March 2021 - February 2024.

Project lead

Prof. Dr. Martin Wietschel
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Str. 48, 76139 Karlsruhe, Germany
martin.wietschel@isi.fraunhofer.de

Project website

www.hypat.de/hypat-en/

Recommended citation

Quitzow, R.; Nunez, A.; Marian, A. (2023): Positioning Germany in an International Hydrogen Economy: A Policy Review. HYPAT Working Paper 03/2023. Potsdam: RIFS (ed.).

Published

Date	Version	Amendment
May 2023	01	

Table of Contents

Executive Summary

Germany, the European Union member state with the largest fiscal space and its leading manufacturer of industrial goods, is pursuing an ambitious hydrogen strategy aiming at establishing itself as a major technology provider and importer of green hydrogen. The success of its hydrogen strategy represents not only a key element in realizing the European vision of climate neutrality but also a central driver of an emerging global hydrogen economy. This article provides a detailed review of German policy, highlighting its prominent international dimension and its implications for the development of a global renewable hydrogen economy. It provides an overview of the strategy's central goals and how these have evolved since the launch of the strategy in 2020. It then highlights the strategy's institutional underpinning and discusses its implications for strategy implementation. Next, it moves on to provide an overview of the strategy's main areas of intervention and highlights corresponding policy instruments. For this, we draw on a detailed assessment of 160 hydrogen policy instruments, which have been systematically analyzed and coded. This was complemented by information gathered in six interviews with government officials and staff of key implementing agencies. The article places particular emphasis on the strategy's international dimension. While less significant in financial terms than domestic hydrogen-related spending, it represents a defining feature of the German hydrogen strategy, setting it apart from other strategies in the EU. The article closes with a reflection on the key implications of the German approach for the development of a hydrogen economy in Europe and globally. It emphasizes the importance of systematic policy assessment as a basis for understanding of how policies are driving not only decarbonization but also the sustainability and resilience of a hydrogen economy.

1 Introduction

Following the example of Japan, France, South Korea, Australia, the Netherlands, and Norway, which had already launched hydrogen strategies, Germany set in motion its own National Hydrogen Strategy (NHS) in the summer of 2020 to accelerate the deployment of green hydrogen (i.e. hydrogen produced via electrolysis with renewable energy) in the country. In 2021 major climate legislation followed, increasing Germany's national emissions reduction targets (BMF, 2021). The country now aims to reduce GHG emissions by at least 65 percent by 2030 compared to the 1990 levels and by at least 88 percent by 2040. By 2045, the country plans to achieve climate neutrality, assigning green hydrogen additional prominence as a vehicle to reduce GHG emissions in so-called hard-to-abate sectors, like industry, aviation and shipping. Moreover, Russia's invasion of Ukraine and the resulting gas crisis in Europe have laid bare Germany's high level of dependence on Russian natural gas, offering an additional energy-security rationale and further impetus to its hydrogen development plans (Quitzow, et.al, 2022) (HYPAT, 2022). Indeed, as the largest producer of industrial goods in the European Union (EU) and the member state with the largest fiscal space, the success of its hydrogen strategy will play a key role in paving the way towards the EU's vision of climate neutrality and shaping the role of green hydrogen in this context.

In this vein, this article provides a review of the German hydrogen strategy and related policy developments to date. It provides a brief overview of the strategy's central goals and how these have evolved since the launch of the strategy in 2020. It then highlights the strategy's institutional underpinning and discusses its implications for strategy implementation. It then moves on to provide an overview of the strategy's main areas of intervention and highlights corresponding policy instruments. For this, we draw on a detailed assessment of 160 hydrogen policy instruments, which have been systematically analyzed and coded[1]. This was complemented by information gathered in 6 interviews with government officials and staff of key implementing agencies. The article places particular emphasis on the strategy's international dimension. While less significant in financial terms than domestic hydrogen-related spending, it represents a defining feature of the German hydrogen strategy, setting it apart from other strategies in the EU. The article closes with a brief reflection on the key implications of the German approach for the development of a hydrogen economy in Europe and beyond.

[1] See methodological note at the end of the paper for details.

2 Germany's green hydrogen vision: securing industrial leadership through technology and imports

Germany's hydrogen strategy is rooted in its strong tradition as Europe's largest industrial economy and its successful export-oriented economic model. Against this background, hydrogen represents a key to reducing GHG emissions in the steel and chemical sectors and thereby sustaining value creation and employment in these industries within a future climate-neutral economy (dena, 2022). In addition, it offers an attractive prospect for its strong production equipment and machine tool industry to develop a leadership position in hydrogen-related technologies and supply chains.

In this vein, the strategy's core objectives can be roughly sub-divided into three categories: to establish a viable domestic and an international green hydrogen market ("ramping up the market"); developing German technology and industrial leadership in this market ("building a competitive hydrogen industry") and securing a future supply of green hydrogen for German industry ("securing hydrogen supply"). Moreover, these objectives are pursued against the background of the broader climate objectives outlined above. In support of these broader objectives, the strategy articulates twelve areas of intervention as shown in Box 1.

Box 1: Areas of intervention as articulated in Germany's hydrogen strategy (The Federal Government of Germany, 2020)

(i) Assuming global responsibility;
(ii) Making hydrogen competitive;
(iii) Developing a domestic market for hydrogen and paving the way for imports;
(iv) Establishing hydrogen as an alternative to other energy sources;
(v) Making hydrogen a sustainable feedstock for industry;
(vi) Enhancing transportation and distribution infrastructure;
(vii) Fostering science, mobilizing skilled labor;
(viii) Shaping and fostering transformation processes;
(ix) Strengthening German industry and securing global markets for German firms;
(x) Regarding global cooperation as an opportunity;
(xi) Building up and securing the quality assurance infrastructure for hydrogen;
(xii) Improving the policy environment

Source: The Federal Government of Germany, The National Hydrogen Strategy, 2020, 1-32.

Furthermore, the strategy originally targeted 5 GW of domestic electrolyser capacity by 2030 and 10 GW by 2040, which translates into 14 and 28 TWh of hydrogen, respectively. At the same time, the government expects domestic demand for hydrogen to reach 90 to 110 TWh by 2030, signaling a large gap between the expected demand for hydrogen and the targeted domestic supply of green hydrogen (The Federal Government of Germany, 2020). For this reason, the development of hydrogen imports has taken a very prominent role in the strategy. In contrast to other leading countries, like China, Japan or the US, Germany is focusing policy support exclusively on the promotion of green hydrogen. While it does not rule out imports of other forms of so-called "carbon-free" hydrogen, it is aiming to meet its hydrogen demand with green hydrogen. Finally, the strategy clearly prioritizes so-called hard-to-abate sectors but does leave open the possibility of supporting other "niche applications", for instance in the

transport sectors. In sum, Germany has chosen to strongly focus its strategy on the use of green hydrogen for reducing GHG emissions in hard-to-electrify sectors, while leaving space for accommodating pragmatic arrangements with international partners as well as domestic industry groups (The Federal Government of Germany, 2020).

3 Delivering its hydrogen vision

When analyzing the concrete policy instruments, the relatively narrow focus articulated in the strategy is less apparent. Rather, a large number of policy instruments is designed to target multiple stages of the value chains. As illustrated in Figure 1, around 42 % of policy instruments have targeted more than one stage of the value chain, i.e., production, usage, transport and storage (referred to as "Multiple Sectors" in the graph). Among those instruments that promote hydrogen usage, the largest share of measures – approximately one half - leaves open the particular type of usage. Another fifth targets the mobility sector, while about ten percent target the industrial sector, as detailed in Figure 2. Regarding the type of intervention, R&D promotion still dominates the instrument landscape, while a large number of international initiatives signal the importance of the strategy's international outlook (see Figure 3).

Figure 1: Number of policy instruments by sector of intervention along the hydrogen value chain

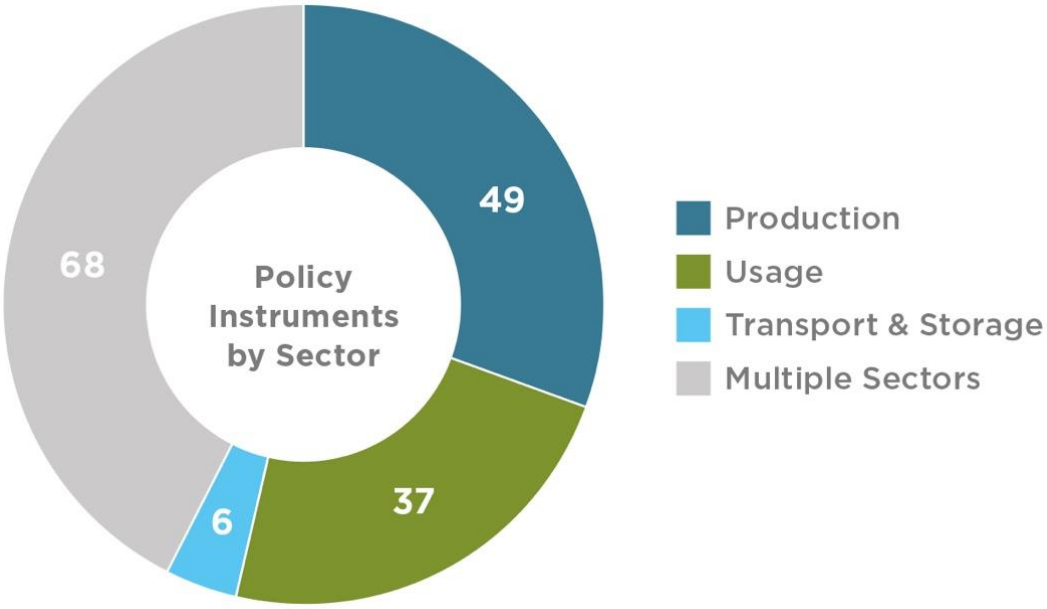

Figure 1: Number of policy instruments by sector of intervention along the hydrogen value chain (own representation). Shown here are only those interventions that were coded as policy instruments and later classified in the following sector categories: multiple, production, usage, and transport and storage. Here multiple refers to the policy instruments that directly impact two or more sectors, while the remaining areas of production, usage, transport and storage exclusively impact the respective sectors.

Figure 2: Number of policy instruments targeting different types of hydrogen usage

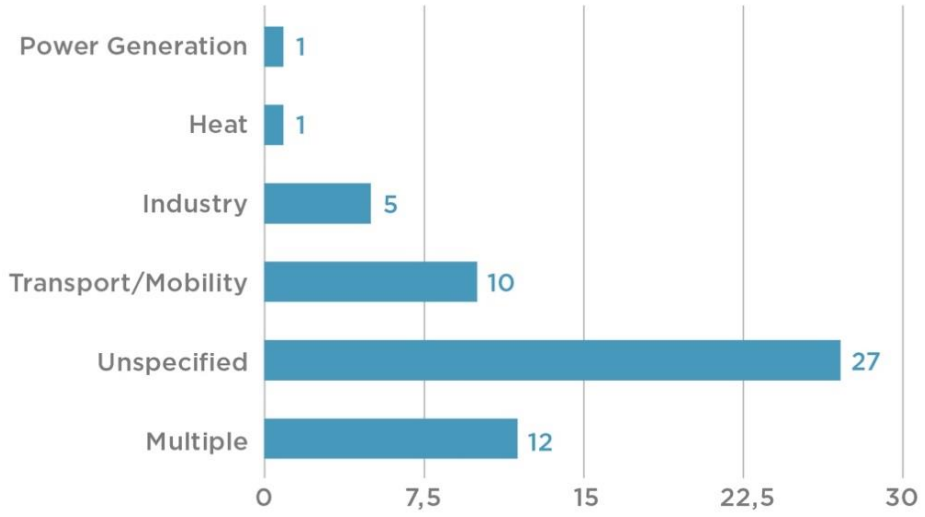

Figure 2: Number of policy instruments targeting different types of hydrogen usage (own representation). These policy instruments are further divided into six subcategories: power generation, heat, industry (i.e., steel, chemical, cement, other), transport/mobility (i.e., automobile, bus, train, trucks, aviation and maritime), unspecified (usage focus not specified), and multiple (touching on two or more subcategories within usage). The six subcategories encompass not only the 37 instruments directly affecting usage in Fig. 1, but also the usage-relevant policy instruments that are accounted under the category "Multiple" of the previous figure i.e., that also touch on different parts of the hydrogen value chain in addition to usage. The latter need to be included here for an accurate representation of the policy instruments targeting hydrogen usage.

Figure 3: Number of policy instruments in the hydrogen sector by instrument type

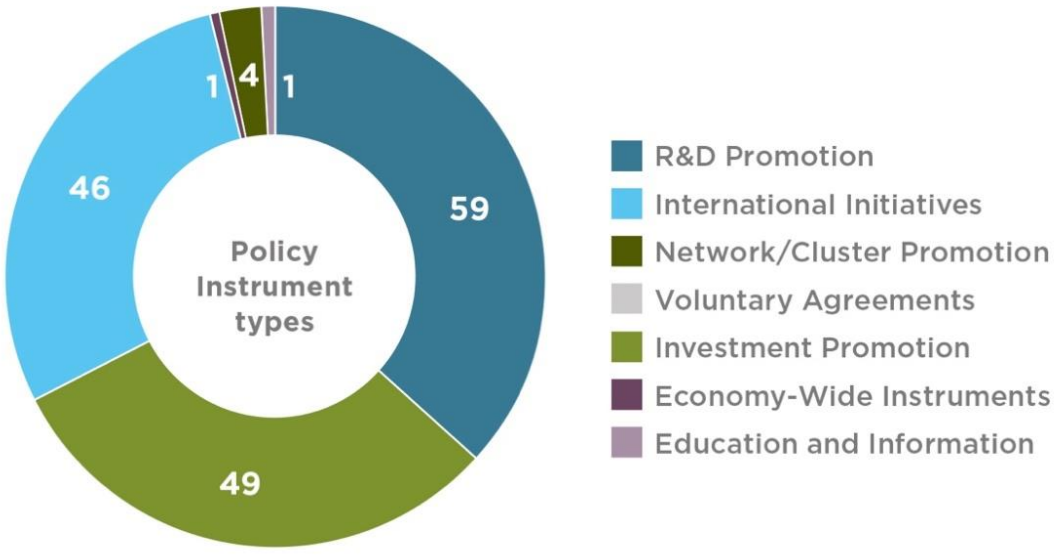

Figure 3: Number of policy instruments in the hydrogen sector by instrument type (own representation). Here the R&D category entails those instruments promoting hydrogen research and development either through tax incentives or grants/subsidies; the Investment category comprehends those instruments promoting the investment in hydrogen production, usage, and/or transport and storage infrastructure; International Initiatives entail the instruments that have an international component i.e. treaties, accords, diplomatic activities, investments made by the Government abroad; Economy-wide instruments refer to non-sector-specific policies that provide a relative advantage to climate-friendly products and economic activities; Network/cluster promotion encompasses those policy instruments focused on building regional clusters and/or networks; Education and information entails the instruments to increase public awareness related to hydrogen; Voluntary agreements refer to those agreements made with private entities to take certain actions without an enforcement mechanism by the government.

The strategy's broad approach is also reflected in the range of ministries involved in Germany's hydrogen strategy process. As Figure 4 on the following page indicates, currently six government ministries are actively involved in the implementation of hydrogen-related policy measures with the bulk of interventions being carried forward by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economic Affairs and Climate Protection (BMWK). Moreover, the strategy has put in place a formalized mechanism for the coordination of strategy implementation across all relevant ministries at the level of State Secretary (vice minister), including the Federal Ministry of Environment (BMUV, former BMU) and the Federal Foreign Office (AA).

Figure 4: Number of hydrogen-related interventions by federal ministry

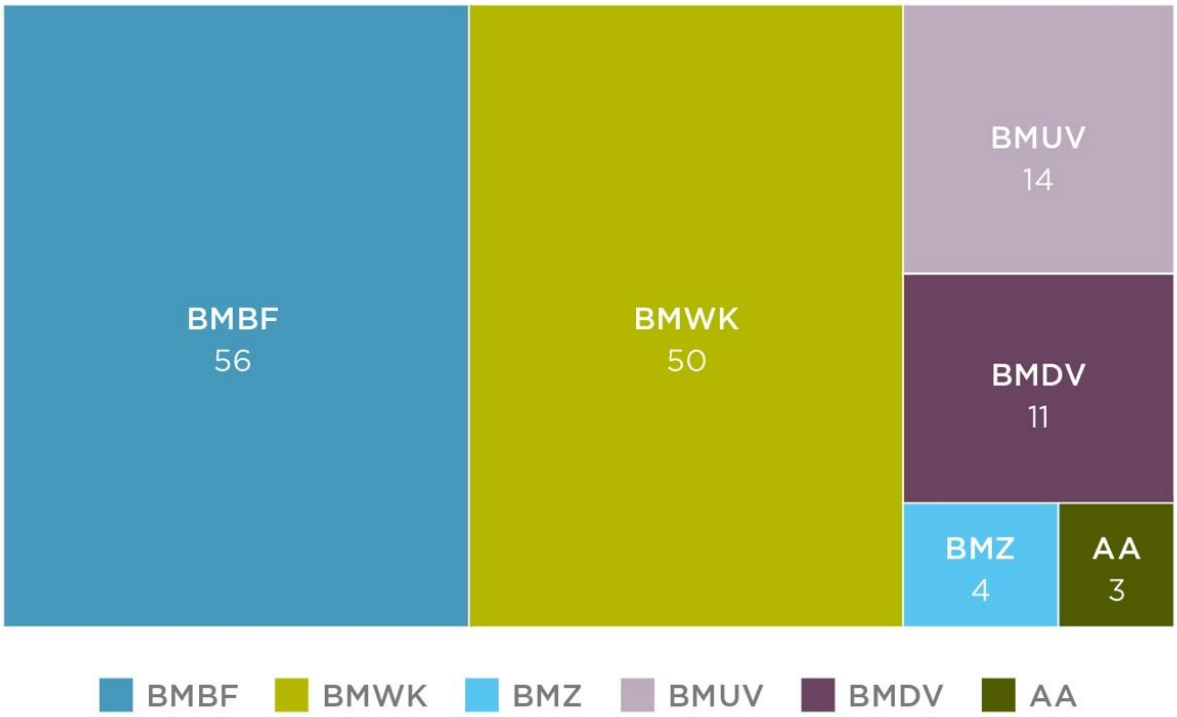

Figure 4: Number of hydrogen-related interventions by federal ministry (own representation). Shown here is the distribution of policy interventions among the six federal ministries involved. The number of interventions per ministry takes into account all hydrogen-related activities, both individual as well as inter-ministerial collaborations. As seen in the graph, the ministry with most interventions is the BMBF with 56, followed by the BMWK with 50, then the BMUV with 14, the BMDV with 11, the BMZ with 4, and lastly the AA with 3.

4 Germany's outward-oriented strategy

As indicated above, the strong outward orientation of Germany's hydrogen strategy represents a key characteristic of its approach to the sector. The various federal ministries have a large portfolio of international activities, spanning both multi- and bilateral activities. In the following, we review the most important interventions in this sphere, drawing on a framework consisting of the following five categories: i.) policy dialogue and diplomacy; ii.) international market and supply chain development, iii.) research and innovation, iv.) capacity and skill development, and v.) promotion of sustainability.

4.1 Policy dialogue and diplomacy

Germany's policy dialogue in the hydrogen sector can build on a well-developed set of bilateral energy partnerships, which have been developed over the past twenty years with major industrialized and emerging economies and a number of countries in the Middle East and North Africa. These partnerships, which are led by BMWK[2] in most cases, provide an official forum for policy dialogue and exchange among relevant experts and stakeholders (Quitzow & Thielges, 2022). Since the launch of Germany's hydrogen strategy, many existing partnerships have integrated hydrogen, and new partnerships have been formed with a strong focus on hydrogen cooperation. In addition, the government has opened so-called hydrogen offices in Saudi Arabia, Angola, Nigeria, Kazakhstan and Ukraine as part the new H2 Diplo initiative. Led by the Federal Foreign Office, this effort places an explicit focus on utilizing hydrogen-related issues to strengthen political dialogue with these fossil-fuel exporting countries.

The German government has also engaged at the multilateral level to strengthen dialogue and political coordination on hydrogen. It utilized its G7 presidency to launch the G7 Hydrogen Action Pact and is a founding member of the Green Hydrogen Catalogue. The latter represents an initiative launched within the UN High-level Dialogue on Energy[3] and aims to motivate countries and other stakeholders to support the green hydrogen market by publishing their commitments in the catalogue. During its European Council Presidency, Germany launched an initiative to support so-called Important Projects of Common European Interests (IPCEI)[4] on Hydrogen Technologies and Systems as well as an Agenda Process Green Hydrogen for the development of a Strategic Research and Innovation Agenda (SRIA). Complementing these processes at the EU-level, Germany has engaged with a number of neighboring countries to support regional hydrogen development. With Belgium, Denmark and the Netherlands, it signed the "Esjberg Declaration on the North Sea as a Green Power Plant of Europe" in May

[2] The only exceptions are the partnerships with Angola and Nigeria, which are led by the Federal Foreign Office, and the partnership with Namibia, led by the BMBF.

[3] For more details, see https://greenhydrogencatalogue.com/

[4] IPCEI projects represent large-scale investment projects in support of EU objectives that are exempt from certain restrictions within EU State Aid rules. To receive the exemption, the projects need to fullfill a number of eligibility criteria, including the participation of at least four EU member states.

2022, jointly committing to develop 65 GW of offshore wind and 20 GW of green hydrogen production in the North Sea by 2030[5]. Moreover, Germany joined the Benelux countries, France, Austria and Switzerland in signing a joint declaration by the Pentalateral Energy Forum calling for accelerated hydrogen development[6].

4.2 International market and supply chain development

Building on the political efforts outlined above, Germany is playing an active role in supporting the development of European and international hydrogen supply chains. Within the EU, investments have been channeled through the IPCEI initiative. Germany has supported 62 IPCEIs in collaboration with other member states. Outside of the EU, the BMWK is promoting production capacities in potential export countries via its initiative H2 Global. Implemented by the H2 Global Foundation, it consists of an auction mechanism to provide subsidies for both the supply of hydrogen (and its derivatives) and their use. Based on a competitive tendering process, the so-called Hydrogen Intermediary Network Company (HINT.CO) awards long-term (10-year) contracts for the purchase of hydrogen or hydrogen derivatives as well as short-term (2-year) contracts for its sale to users. Both function on the basis of Contracts for Difference (CfD's) scheme, where HINT.CO finances the difference between prices offered by producers and users with funds provided by the BMWK. Supply contracts under the scheme are awarded for the delivery of hydrogen or its derivates to ports in the Netherlands, Belgium or Germany, aiming to catalyze the development of the required supply chains. In a first phase, H2 Global is targeting hydrogen supply outside the EU (Bollerhey et.al, 2022) although an announced expansion is likely to address EU countries as well (Quitzow et.al, 2022). H2 Global was born from a public-private dialogue under the umbrella of the Business Alliance Energy (Unternehmensallianz Energie). Other important initiatives include the funding programs "Internationale Wasserstoffprojekte" (International Hydrogen Projects), which supplies grants of up to 15 million euros for research and innovation projects (BMWK & BMBF, 2022), the International Hydrogen Ramp Up program (H2Uppp), which supports project preparation by SMEs in developing and emerging countries providing technical advice for the identification, preparation and implementation of hydrogen projects.

4.3 Research and innovation

Germany's engagement in the field of research and innovation includes support for international cooperation in the sphere of technology development and broader analysis of the sector. An important focus lies on research collaborations with other European technology leaders and Australia. The latter has received high-profile support via the HySupply and HyGate projects, with 1,7 (BMWK, 2021) and 50 (BMWK a, 2022) million euros in funding, respectively. Within the EU, the German government has launched a joint call for proposals with the Netherlands and a multi-country call under the EUREKA umbrella, a public network for research collaboration. Germany has also launched hydrogen-related research cooperation initiatives

5 Find the declaration here https://kefm.dk/Media/637884617580584404/The%20Esbjerg%20Declaration%20(002).pdf

6 Find the declaration here https://www.permanentrepresentations.nl/binaries/nlatio/documenten/publications/2020/06/12/penta-declaration-on-hydrogen/Penta+Declaration+Signed.pdf

with Ukraine and Central Asian countries, Canada, New Zealand, South Korea, Japan, and Namibia. The partnership with Namibia is particularly ambitious and is based on a funding commitment of 40 million euros from the German government. Within Germany, the International Future Labs initiative funds scholars from around the world to conduct research visits on hydrogen-related topics, and the Redefine H2 Economy project brings international researchers to Germany to conduct research on selected technological challenges (TUM, 2021). Complementing these activities, the BMWK has funded large-scale R&D projects, including ThyssenKrupp's project "Element One" in Saudi Arabia for the development of electrolyzer technology (The Federal Government, 2023) and a project for the development of liquid-organic hydrogen carriers (LOHC). The latter involves Uniper, the Abu Dhabi National Oil Company and Jera, Japan's largest electricity utility.

4.4 Capacity and skill development

In developing and emerging economies, the German government has also supported capacity and skill development. This includes activities within the portfolio of energy-related development cooperation in Tunisia, Morocco, Brazil and South Africa, led by BMZ, as well as activities sponsored by BMBF and BMWK. A central channel is the International PtX Hub[7], funded by BMWK. It represents a knowledge and training center on Power-to-X technologies with activities in 13 countries. In addition, BMBF supports capacity building in a number of African countries, including a Master's Graduate Program on green hydrogen technologies in collaboration with the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) graduate schools (BMBF b, 2021) and a large-scale assessment of hydrogen production potentials in Africa, the H2 Atlas Africa.

4.5 Promotion of climate protection and sustainability

As already mentioned above, the German government has come out strongly in support of green hydrogen, while leaving open the option of importing fossil-based hydrogen. Despite the latter caveat, it is almost exclusively engaging on questions related to the sustainability of green hydrogen. The International PtX Hub plays an important role in this context. It has developed a sustainability framework, which distinguishes Environmental, Economic, Governance, and Social issues. The framework represents an important element of its training programs. Also, the H2 Global scheme includes requirements to ensure that hydrogen production supported by the scheme is exclusively from renewable sources as well as requirements pertaining to other sustainability dimensions, including biodiversity, water and land use, the use of environmental management systems, labor standards and local skill development. The German government has not actively engaged in the definition of standards for the production of fossil-based hydrogen, despite the fact that it has officially announced plans to import blue hydrogen, i.e. fossil-based hydrogen with CCS, from UAE, Canada and Norway.

[7] The PtX Hub was originally created under the previous administration by the Ministry of Environment, but was transferred to the BMWK along with the overall climate change portfolio.

5 Country-level engagement

The multi-dimensional international policy approach described in the previous section has translated into country-level engagement in the EU and a total of 43 non-EU countries, as highlighted in Figure 5. As the map reveals, the government has initiated cooperation with partners across the five continents, with a particular emphasis on African countries. These partnerships include countries in its immediate vicinity and countries further afield with differing levels of pre-existing capacity for renewable energy development. In the following, we apply these dimensions to distinguish the following country types: a.) high-capacity hydrogen frontrunners; b.) emerging and developing countries with significant pre-existing capacity for renewable energy; c.) countries with little pre-existing capacity for renewable energy development. For each of these three country types, we briefly review Germany's interventions for one example within the European Neighborhood and one country located at a greater distance from Europe.

Figure 5: Engagement of the main four German federal ministries in partner countries outside Europe

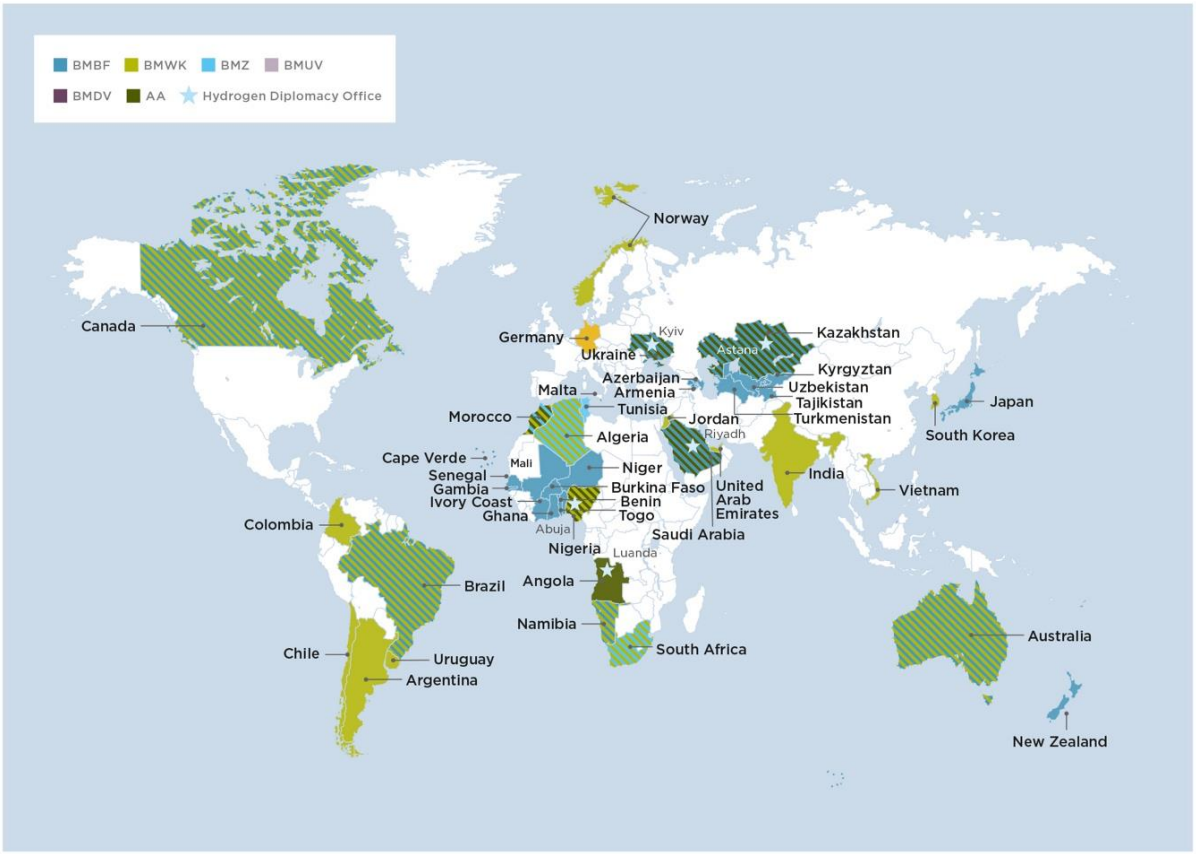

Figure 5: Engagement of the main four German federal ministries in partner countries outside Europe (own representation). The presence of a ministry in a country indicates one or several hydrogen-related activities with/in that specific country. In total, there are 43 non-European countries with hydrogen activities driven by German ministries, either individually or jointly. As seen on the map, in some countries two or more ministries are present with either joint activities or individual ones.

5.1 Hydrogen frontrunners

Norway and Australia represent two important frontrunner countries that Germany is engaging with actively. As North Sea neighbors, Germany and Norway have stated a willingness to enhance their cooperation in the renewable energy sector by building on the North Seas Energy Cooperation (NSEC), a collaboration within the framework of the EU to improve the expansion of the offshore grid development and the large renewable energy potential in the region. The two countries signed a joint statement on energy collaboration in March 2022, which establishes close cooperation to facilitate large-scale hydrogen imports from Norway to Germany, including blue and green hydrogen, as well as transport of CO2 from Germany for storage in Norway (BMWK b, 2022). A joint feasibility study was subsequently launched to assess the potential for large-scale transport of hydrogen and CO2 (Office of the Prime Minister and Ministry of Petroleum and Energy, 2023). In January 2023, the countries declared a German-Norwegian Partnership on Climate, Renewable Energy and Green Industry, covering among other areas hydrogen, carbon capture and storage (CCS) (Office of the Prime minister and Ministry of Trade and Fisheries, 2023) and green shipping. This was accompanied by an announcement by the Norwegian state-owned oil company Equinor and German energy supplier RWE to develop jointly owned power plants, based on natural gas and later hydrogen, along with a corresponding pipeline project (RWE & Equinor, 2023).

Despite the long distance from each other, Australia and Germany have also built cooperation on hydrogen-related topics. Compared to Norwegian-German engagement, however, cooperation is more strongly focused on research and innovation. The foundation of this collaboration was established in 2021 through the Australia-Germany Hydrogen Accord, where the BMBF committed 50 million euros over a three-year period to foster joint research and innovation activities with Australia (BMWK a, 2022). Since then, research collaboration has been established via the prominent research projects HySupply (1,7 million euros) (BMWK, 2021) and HyGate (50 million euros) (BMWK a, 2022). They bring together research and industry partners from both countries, for the assessment of potential hydrogen supply chains and trade between Australia and Germany.

5.2 Emerging and developing countries with established capacities for renewable energy development

Chile and Morocco are examples of potential hydrogen exporters with significant pre-existing renewable energy capacities and important ambitions to play an active role in the emerging hydrogen economy. Morocco has a long history of engagement with Germany in the energy sector and was the first country to partner with Germany to develop its green hydrogen sector. Cooperation builds on a long-standing energy partnership and a major program in support of renewable energy development. Building on this, the BMZ has established a Hydrogen Alliance with Morocco. The alliance counts on close to 90 million euros of funding and aims at establishing 100 megawatts in electrolysis capacity (KFW, 2021). In addition, with funding from BMWK the PtX-Hub is supporting a Power-to-Liquid demonstration project as well as the development of regulatory frameworks for Power-to-X and for incorporating Power-to-X in modelling exercises for its National Determined Contribution.

Cooperation with Chile also builds on an existing energy partnership, which has been supplemented by an agreement to develop cooperation projects on green hydrogen. This has yielded

the Haru Oni project for the integrated production of hydrogen-based synthetic fuels, which the BMWK has supported with 8,23 million euros (BMWK, 2020) and which was placed into operation in December 2022. The German government has also supported Chile's process for the development of a hydrogen strategy and promoted capacity building in the hydrogen sector via the Program for Renewable Energy and Energy Efficiency (4E, 2023) in Chile.

5.3 Emerging and developing countries with low levels of renewable energy capacity

Engagement with Namibia and Algeria builds not only on a low level of renewable energy capacity in the two countries but also on relatively undeveloped bilateral energy relations. These relations are now being reinforced in light of the emerging prospect for cooperation in the hydrogen sector. This is particularly visible in Namibia. Initiated by the BMBF, Germany and Namibia established a hydrogen partnership, the first such partnership for Namibia, in August 2021. Against this background, the BMBF has committed to provide up to 40 million euros for cooperation (BMBF a, 2021). Currently, it is supporting the development of the national hydrogen strategy, capacity building and training of skilled professionals, scholarship programs for Namibian students, and it is funding four large-scale research and demonstration projects with a total of 30 million euros (Nangara, 2022). In addition, the PtX-Hub is supporting capacity building and dialogue involving policy makers and professionals. This includes a component on sustainability-related questions related to Power-to-X technologies.

Although Germany has formally entertained an energy partnership with Algeria since 2015, cooperation has been limited compared to other countries in the region. Hydrogen-related activities also remain largely at a scoping stage. The German government has funded a study to assess the potential for the production of green hydrogen (GIZ, 2021) and conducted seminars and study tours. In addition, the PtX-Hub has advised the government on the development of its hydrogen roadmap and conducted trainings, which have also addressed sustainability-related issues (International PtX Hub, 2023). Algeria's state-owned oil company, Sonatrach, has signed an MoU with German gas trading company VNG to develop hydrogen-related projects (Nhede, 2023).

6 Discussion

Germany's hydrogen import strategy signals that policy makers are not only seeking to explore a range of possible trade routes and transport infrastructures but are also explicitly aiming to develop a diversified hydrogen supply.

Moreover, cooperation seeks to place Germany at the forefront of the emerging global innovation system, with multiple research and development partnerships. In particular, Australia has emerged as an important partner. As a large industrialized country with strong innovation capabilities and large-scale renewable energy resources, Australia offers important complementarities for Germany's import dependent energy system and highly-specialized export sector. It is also notable that German cooperation is clearly aimed at activities across the entire hydrogen value chain. Germany's H2 Global mechanism represents an innovative subsidy scheme in this regard, providing incentives for the development of supply chains from production sites outside Europe to import terminals on the North Sea.

Moreover, Germany has come out strongly in support of green hydrogen production as well as application in hard-to-abate industrial and transport sectors. In line with this principled approach, it is also incorporating sustainability-related aspects in subsidy schemes and capacity building efforts. At the same time, this is not preventing the German government from working with partners like Norway who are pursuing alternative production pathways and from supporting technology development in non-priority uses, such as automotive sector. Interestingly, however, its sustainability-related activities focus exclusively on green hydrogen. As a result, Germany's strategy is playing a central role in shaping a green hydrogen economy but has not actively engaged with questions regarding the production and use of fossil-based hydrogen. This appears to be at odds with its ambition to shape the broader hydrogen sector.

Finally, Germany has pursued a truly global approach, engaging with countries across the globe. And although Germany has also launched important initiatives at the EU-level, it is noticeable that its import strategy has placed more emphasis on non-EU countries. Most importantly, H2 Global, its flagship instrument for stimulating hydrogen supply chains, did not initially target EU member states. While previous international efforts aimed at promoting Germany's policies and technologies abroad, its hydrogen strategy includes an import-oriented dimension. Germany positioned itself early in this field, seeking to secure green hydrogen to decarbonize its domestic industry and to promote its electrolyzer industry.

7 Conclusion

This review of Germany's outward-oriented hydrogen strategy reveals the key role that government policy plays in shaping an emerging international hydrogen economy. The German government is actively engaging with partners around the world, seeking to position its private sector as central player in green hydrogen supply chains and innovation systems. It is notable that Germany, a country characterized by low levels of renewable energy potential, is taking such an activist approach to hydrogen. It is exploiting its weakness in terms of renewable energy resources to develop a large international hydrogen footprint. This is in stark contrast not only to its European neighbors France and Poland but also the US and China. For varying reasons, these countries have all largely pursued inward-oriented strategies. Similarly, Germany is unique among these countries in its focus on green hydrogen based on renewable energy.

Systematic analysis of this evolving hydrogen policy landscape is critical for understanding not only the emerging hydrogen sector but the broader global energy transition and how this is reshaping energy landscapes and relations. This article represents a first contribution to such a systematic mapping of international hydrogen policies. More research will be needed not only to complete and continuously update this changing policy landscape but to begin linking it to economic and technological developments in the hydrogen sector. Central to this endeavor is the assessment of how policies are driving not only decarbonization but also the sustainability and resilience of a hydrogen economy.

Methodological note

Over 200 policy instruments on hydrogen in Germany were collected and systematically coded according to guidelines established in a codebook. For an intervention to be accounted as a policy instrument we followed the definition of Hettiarachchi & Kshourad (2019) who explain that policy instruments are the methods used by the government and/or public entities to promote certain actions to achieve a defined set of objectives. Moreover, we established that for an intervention to be accounted as a policy instrument it should be a part of an official government document that includes an action or set of actions.

Conflict of Interest statement

There are no conflicts of interest to report.

References

4E. (2023): The Program for Renewable Energies and Energy Efficiency (4E), https://4echile.cl/program-for-renewable-energies-and-energy-efficiency/, (accessed 16.03.2023)

BMBF a. (2021): German Research Minister Karliczek: Germany and Namibia form partnership for green hydrogen, https://www.bmbf.de/bmbf/shareddocs/kurzmeldungen/en/Karliczek-Germany-and-Namibia.html, (accessed 27.03.2023)

BMBF b. (2021): Young Specialists for Green Hydrogen, https://www.fona.de/en/young-specialists-for-green-hydrogen, (accessed 27.03.2023)

BMF. (2021): Climate action for everyone. https://www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Priority-Issues/Climate-Action/climate-action-for-everyone.html, (accessed 30.03.2023)

BMWK & BMBF. (2022): Funding guideline for international hydrogen projects 5 Within the scope of the National Hydrogen Strategy and the Economic Recovery Plan: 6 to combat the effects of the coronavirus pandemic, secure prosperity and strengthen future viability , 2022, 1-15, available at https://www.ptj.de/lw_resource/datapool/systemfiles/cbox/8088/live/lw_bekdoc/preliminary_translation_funding_guideline_international_hydrogen_projects.pdf., (accessed 27.03.2023)

BMWK. (2020): "Haru Oni PtX project Minister Altmaier hands over first approval notice for international green hydrogen project, https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2020/12/20201202-haru-oni-ptx-project-minister-altmaier-hands-over-first-approval-notice-for-international-green-hydrogen-project.html, (accessed 27.03.2023)

BMWK. (2021): Federal Government Report on Energy Research, Public Relations Report, Germany, available at https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/federal-government-report-on-energy-research-2021.pdf?__blob=publicationFile&v=6, (accessed 27.03.2023)

BMWK a. (2022): German Research Minister Stark-Watzinger: German-Australian supply chain for Green Hydrogen an important step towards climate neutrality and greater independence, https://www.bmbf.de/bmbf/en/home/_documents/german-australian-supply-chain-for-green-hydrogen.html, (accessed 27.03.2023)

BMWK b. (2022): Germany and Norway sign joint statement on cooperation on hydrogen imports, https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/03/20220316-germany-and-norway-sign-joint-statement-on-cooperation-on-hydrogen-imports.html , (accessed 27.03.2023, 2022)

Bollerhey, T., Exenberger,M., Geyer,F. & Westphal, K. (2022): H2Global - Idea, Instrument and Intentions, 2022, 3-20, available at http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-01_2022-EN.pdf, (accessed 25.03.2023)

dena. (2022): Auf dem Weg zur Klimaneutralität – Neustrukturierung industrieller Wertschöpfungsketten, 2022, 6-25, available in German at https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2022/DISKUSSIONSPAPIER_Auf_dem_Weg_zur_Klimaneutralitaet.pdf (accessed 27.03.2023)

GIZ. (2021): Étude exploratoire sur le potentiel du Power-to-X (hydrogène vert) pour l'Algérie, Partenariat Energétique Algéro-Allemand Bonn, 2021, available in French at https://www.energypartnership-algeria.org/fileadmin/user_upload/algeria/21_12_07_Hydrog%C3%A8ne_vert_en_Alg%C3%A9rie_-_Rapport_PE.pdf, (accessed 16.03.2023)

Hettiarachchi,H. & Kshourad,C. (2019): Promoting waste-to-energy: nexus thinking, policy instruments, and implications for the environment. Current Developments in Biotechnology and Bioengineering, 2019, 163-184, https://doi.org/10.1016/B978-0-444-64083-3.00009-9 (accessed 05.03.2023)

HYPAT. (2022): War in Ukraine: Implications for the European and German strategies for importing hydrogen and synthesis products, 2022, 3-17, available at https://www.hypat.de/hypat-wAssets/docs/new/publications/2022-03-21_HyPAT_Impulspapier_Ukraine-english.pdf (accessed 27.03.2023)

International PtX Hub. (2023): PtX Hub in Algeria Leveraging existing infrastructure and vantage points to build up PtX potential, https://ptx-hub.org/algeria/, (accessed 16.03.2023)

KFW. (2021): Energy transition 2.0-with green hydrogen, https://www.kfw-entwicklungsbank.de/International-financing/KfW-Development-Bank/Our-topics/SDGs/SDG-7/Interview-PtX/index-2.html, (accessed 27.03.2023)

Nangara, A. (2022): Germany to fund four green hydrogen projects in Namibia, https://theexchange.africa/industry-and-trade/germany-to-fund-four-green-hydrogen-projects-in-namibia/, (accessed 27.03.2023)

Nhede,N. (2023): Sonatrach to Explore Green Hydrogen and Downstream Projects with German Firms, https://energycapitalpower.com/sonatrach-green-hydrogen-german-firms/ , (accessed 17.03.2023)

Office of the Prime Minister and Ministry of Petroleum and Energy. (2023): Joint Statement-Germany-Norway-Hydrogen, https://www.regjeringen.no/en/whatsnew/dep/smk/press-releases/2023/closer-cooperation-between-norway-and-germany-to-develop-green-industry/joint-statement-germany-norway-hydrogen/id2958105/, (accessed 23.03.2023)

Office of the Prime Minister and Ministry of Trade and Fisheries. (2023): Joint Declaration-German-Norwegian Partnership on Climate, Renewable Energy and Green In-

dustry, https://www.regjeringen.no/en/whatsnew/dep/smk/press-releases/2023/closer-cooperation-between-norway-and-germany-to-develop-green-industry/joint-declaration-german-norwegian-partnership-on-climate-renewable-energy-and-green-industry/id2958104/, (accessed 27.03.2023)

Quitzow, R. & Thielges,S. (2022): The German energy transition as soft power. Review of International Political Economy, 2022, 29(2), 598-623, https://doi.org/10.1080/09692290.2020.1813190 (accessed 24.03.2023)

Quitzow, R., Renn, O. & Zabanova,Y. (2022): The crisis in Ukraine: another missed opportunity for building a more sustainable economic paradigm. GAIA-Ecological Perspectives for Science and Society (Heidelberg, Germany), 2022, 31(3), 135-138, https://doi.org/10.14512/gaia.31.3.2 (accessed 05.03.2023)

RWE & Equinor. (2023): Hydrogen pipeline in the North Sea, RWE and Equinor secure the supply of hydrogen-capable gas-fired power plants, https://www.rwe.com/en/research-and-development/project-plans/hydrogen-pipeline-in-the-north-sea/, (accessed 16.03.2023)

The Federal Government of Germany. (2020): The National Hydrogen Strategy, 1-32, available at https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6 (accessed 27.03.2023)

The Federal Government of Germany. (2023): "Element One" project in the Saudi Arabian model region "NEOM", https://www.bmwk.de/Redaktion/EN/Hydrogen/Examples/element-one.html, (accessed 30.03.2023)

TUM. (2021): TUM to coordinate Future Labs for Green Hydrogen, https://www.tum.de/en/news-and-events/all-news/press-releases/details/tum-koordiniert-zukunftslabor-fuer-gruenen-wasserstoff, (accessed 27.03.2023)

List of figures