

# Positioning Germany in an international hydrogen economy: A policy review

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## ABSTRACT

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. 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 comprehensive assessment of hydrogen policy instruments, which have been systematically analyzed and coded. This was complemented by a detailed analysis of policy documents and 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 strategies in other major economies. The article closes with a reflection on the key features of the strategy compared to other important countries, identifies gaps of the strategy and discusses important avenues for future research.

## 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 2021 major climate legislation followed, increasing Germany's national emissions reduction targets [1]. The country now aims to reduce GHG emissions by at least 65 percent by 2030 compared to 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 [2,3].

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. Moreover, Germany has rapidly emerged as one of the most active players on the global hydrogen stage. It currently has active engagements in over 40 countries. The US and China, in contrast, have remained largely focused on the promotion of their domestic hydrogen sectors, while the EU is only beginning to launch its international hydrogen strategy. Japan and South Korea – both major potential hydrogen importers – have devised strategies that are more regional in their outlook, focusing on bilateral relationships in the Asia-Pacific and the Middle East.

Arguably, this makes Germany the most prominent actor currently shaping an international hydrogen economy. Indeed, past research has found that government policy plays a crucial role in shaping early stages

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of development in emerging green industries [4]. In this vein, Germany's international hydrogen strategy has implications that go far beyond securing hydrogen for the decarbonization of the German economy. Rather, it represents one of the crucial drivers of development in the sector.

Against this background, this article provides a detailed review of German hydrogen policy, characterizing the strategy in terms of its main priorities, features and remaining gaps and exploring its impact on the global hydrogen sector. It begins with a brief review of the literature on the development of global green industries, highlighting the important role of government policy in this context. Based on this literature review, we briefly define our analytical approach and methodology, which draws on a mix of qualitative and quantitative data. After this, the paper provides a brief overview of the strategy's central goals and its main areas of intervention, followed by an in-depth review of its international dimension. The latter consists of a general review of Germany's international policy approach, followed by short case studies of its implementation in six partner countries. On this basis, the article discusses the key characteristics of the strategy and their implications for positioning Germany within an emerging hydrogen economy. It closes with a consideration of important avenues for future research.

## 2. The role of policy in shaping emerging green sectors

The literature on green innovation and industrial development has pointed out the central role of policy in shaping the formation of emerging green industries and their international development trajectories [5]. Moreover, scholars have pointed out the importance of these early stages of innovation and industrial development in laying the foundation for industrial leadership. These so-called windows of opportunity are critical in determining the geography of green industrial supply chains and the related distribution of resources and bargaining power [6].

Past experiences in the formation of green industries, such as wind and solar energy and battery-electric vehicles, have been largely shaped by domestic support policies as well as their interplay within global innovation systems [7–9]. More active international strategies to shape emerging green sectors have been relatively slow to emerge. Nevertheless, Germany has been at the forefront of developing such an international approach, building a network of so-called energy partnerships over the course of the past two decades [10]. Originally, these partnerships served the primary aim of promoting the German *Energiewende* concept in major emerging economies, both as a vehicle to promote its climate and energy policy and to support German exports. In the context of growing geoeconomic rivalry, they are increasingly being viewed as a vehicle for actively shaping global supply chains within strategic sectors, of which hydrogen is a prominent case [11].

Against this background, this paper analyzes the German strategy as a vehicle for shaping an international hydrogen economy. While it includes a brief review of Germany's domestic policy approach, it mainly focuses on its international policy strategy. The analysis builds on a set of analytical categories inspired by the extensive literature on technological innovation systems [12,13] as well as related applications to the field of policy [14,15]. According to this body of literature, the development of emerging technologies is dependent on a number of system functions, most prominently the legitimization of the respective technologies, the development and diffusion of knowledge, formation of markets, the mobilization of resources and, finally, guidance to give a common direction to these processes [12]. As indicated above, at early stages of green industrial development, policy is critical for supporting all these functions. Moreover, it is increasingly recognized that via their role in catalyzing and steering investments these policies shape the formation of global markets and supply chains [16].

Building on these concepts, we propose the following five analytical categories for reviewing how the German policy strategy is shaping the emergence of an international hydrogen economy: i.) 'international

partnerships and dialogue' are vehicles for building the international legitimacy of the sector; ii.) 'research and innovation' refers to activities in support of knowledge development and diffusion; iii.) 'international market and supply chain development' refers to interventions for promoting international markets and mobilizing financial resources along the hydrogen value chain, iv.) 'capacity and skill development' refers to the mobilization of human and institutional resources and for raising awareness, and v.) 'promotion of sustainability' are activities aimed explicitly at guiding hydrogen development, both regarding its form of production as well as its end-uses. Given the role of the current hydrogen economy as a vehicle for decarbonization, questions of sustainability are central to this.

These five analytical categories serve as a heuristic for the analysis of Germany's international policy strategy in the hydrogen sector, for characterizing its main features and identifying gaps. It represents and adaptation of the policy assessment framework proposed in Quizow (2015) [15] and Imbert et al. (2017) [16], tailored to the context of the outward-oriented policy approach under consideration. The aim is to analyze to what extent the policy approach addresses the different dimensions of the emerging hydrogen sector as represented by the categories that have been proposed. The paper does not attempt to assess the outcome or impacts of these policies, as this would be beyond the scope of the paper and would require extensive data collection at the program or instrument-level. Rather the aim is to take stock of the full spectrum of policies and placing this in the context of the emerging hydrogen innovation and industrial system. The paper also does not attempt to provide a systematic comparison to other major economies and hydrogen frontrunner countries. However, it does provide references to other major actors to help contextualize the analysis, focusing on the US and China as the largest global economies, France as the second largest actor in Europe and Japan as the other major economy with a strongly import-oriented hydrogen strategy.

This qualitative review is supported by a comprehensive review of policy documents, complemented by six interviews with German government representatives responsible for hydrogen policy in all the key ministries and two central implementing agencies.<sup>1</sup> These interviews served the purpose of gathering additional insights on policy developments as well as validating key findings from the document review. In addition, a preliminary version of the paper was sent to all interview partners to ensure the accuracy of any factual statements.

The qualitative review is complemented by a quantitative review, which builds on a comprehensive database of German hydrogen policy instruments, which have been coded based on two sets of categories. Firstly, policy instruments are distinguished on the basis of the segment of the hydrogen value chain that they address, i.e. production, usage or transport and storage. Where applicable, interventions are also coded as spanning multiple segments of the value chain. Secondly, policy interventions are distinguished in terms of the instrument type that they represent, inspired by the generic scheme proposed by Schaffrin et al. (2015) [17]. Based on this scheme, instruments are categorized based on the type of activity within the hydrogen sector that they promote, i.e. R&D; investment; network and cluster development; education and information. In addition, economy-wide instruments, voluntary agreements and international activities are identified as additional instrument types.<sup>2</sup> This coding of policy instruments provides an additional entry-point in the effort to provide a comprehensive review of Germany's approach to promoting the hydrogen sector.<sup>3</sup>

<sup>1</sup> See methodological note for more details.

<sup>2</sup> An exception to this is the category of economy-wide instruments, which are by definition limited to the national level.

<sup>3</sup> See methodological note for more details.

### 3. 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-friendly economy [18]. 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 viable domestic and an international green hydrogen markets and supply chains, including production, usage, storage and transport ("ramping up the market"); developing German technology and industrial leadership in the sector ("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.

The strategy originally targeted 5 gigawatts (GW) of domestic electrolyser capacity by 2030 and 10 GW by 2040, which translates into approximately 14 and 28 terawatt hours (TWh) of hydrogen, respectively. A strategy revision has increased the 2030 target to 10 GW, which the government intends to realize via a mix of instruments (see Fig. 1). At the same time, the government expects domestic demand for hydrogen to reach 95 to 130 TWh by 2030, signaling a large gap between the expected demand for hydrogen and the targeted domestic supply of green hydrogen. For this reason, the development of hydrogen imports has taken a very prominent role in the strategy, and the government has announced the development of a separate import strategy [18,19].

In contrast to other leading countries, like China [20], Japan, France [21] or the US [22],<sup>4</sup> Germany initially focused policy support exclusively on the promotion of green hydrogen. While its first strategy document did not rule out imports of other forms of so-called "carbon-free" hydrogen, it limited public support to green hydrogen. In the revision of the strategy, this has been adapted. The government no longer rules out limited support for fossil-based hydrogen coupled with carbon capture and storage (blue hydrogen) in the context of its demand-side support schemes, and it proposes the definition of a policy framework for defining the specific parameters for this. Nonetheless, the focus remains strongly on the promotion of green hydrogen. Similarly, 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 articulated a focus 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 [19].

The strategy's relatively narrow focus on green hydrogen and priority end-uses is less apparent when considering the policy instruments that have been put in place for its implementation. Rather, a large number of policy instruments is designed to target multiple stages of the value chain. As illustrated in Fig. 2, around 46 percent 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, 75 percent either target multiple usage types or leave open the particular type of usage. Fifteen percent target the mobility sector and 7

<sup>4</sup> The US, China and Japan also support hydrogen production from fossil-fuels as well as electrolysis powered by nuclear energy. France promotes only the latter.

percent target the industrial sector, as detailed in Fig. 3. It should be noted, however, that some of the largest programs in terms of funding volume are two programs targeting development and deployment of industrial applications, accounting for approximately €3,5 billion in funding commitments. 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 Fig. 4).

### 4. Germany's outward-oriented strategy

As indicated above, the strong outward orientation of Germany's hydrogen strategy is a key characteristic of its approach to the sector. In the following, we discuss the most important interventions in this sphere. We begin with a general overview of international interventions, drawing on the systematically coded data to provide a quantitative summary of policy interventions. This is followed by a qualitative review, based on the analytical framework detailed in section 2.

#### 4.1. Overview

Like the domestic strategy, Germany's international policy strategy involves a host of interventions spanning multiple segments of the value chain. However, compared to the domestic strategy, it focuses more strongly on hydrogen production. Dedicated support for hydrogen usage plays only a comparatively minor role in the international sphere, clearly reflecting German's import-oriented approach to international cooperation (see Fig. 5). This contrasts strongly with French overseas cooperation on hydrogen, for instance, which is not only smaller in terms of total funding volumes but also clearly focused on local application of hydrogen in partner countries. This reflects the French government's ambition to promote domestic renewable and nuclear-based hydrogen and a strong skepticism regarding hydrogen imports [21]. Indeed, among major economies, only Japan and Korea have shown a similar determination to pursue a hydrogen strategy with a strong import-oriented dimension.

In terms of instrument-type, R&D promotion along with international partnerships and dialogue dominate Germany's international interventions, closely followed by education and information (see Fig. 6). The latter are predominantly capacity building efforts in developing and emerging countries, as will be discussed in greater detail below.

#### 4.2. International partnerships and dialogue

Germany's international policy dialogue in the hydrogen sector can build on a well-developed set of bilateral energy partnerships, which have been launched 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 provide an official forum for policy dialogue and exchange among relevant experts and stakeholders. They are rather unique in that they build almost exclusively on exchange in the sphere of renewables and energy transition, owing to Germany's very limited presence in the international fossil fuel economy and pioneering role in the field of renewables [10]. This sets Germany apart from other major economies, like the US, China but also France or Japan whose energy relations have been shaped more strongly by relations related to fossil fuels and nuclear energy. 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 of the H2 Diplo initiative. Led by Germany's 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

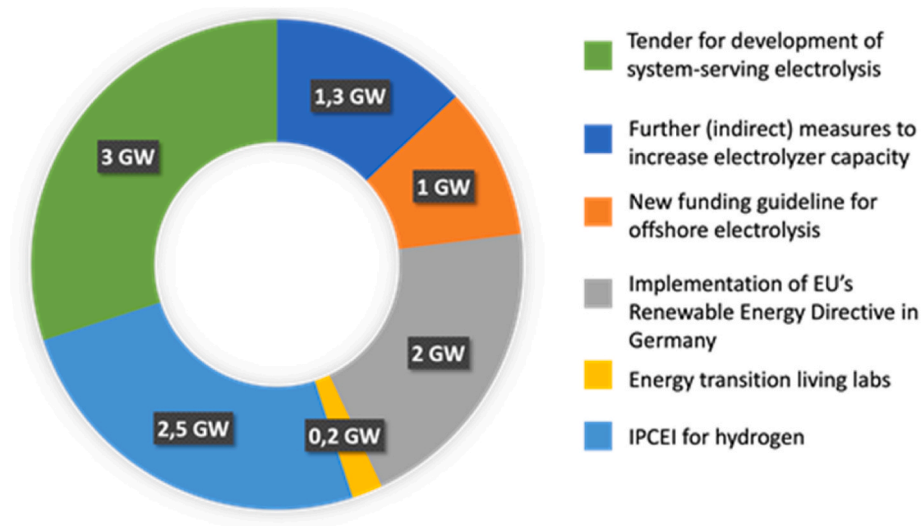


Fig. 1. Overview of instruments for achieving Germany's domestic target of 10 GW of electrolyzer capacity by 2030. Source: Federal Government of Germany (2023) National Hydrogen Strategy Update [19].

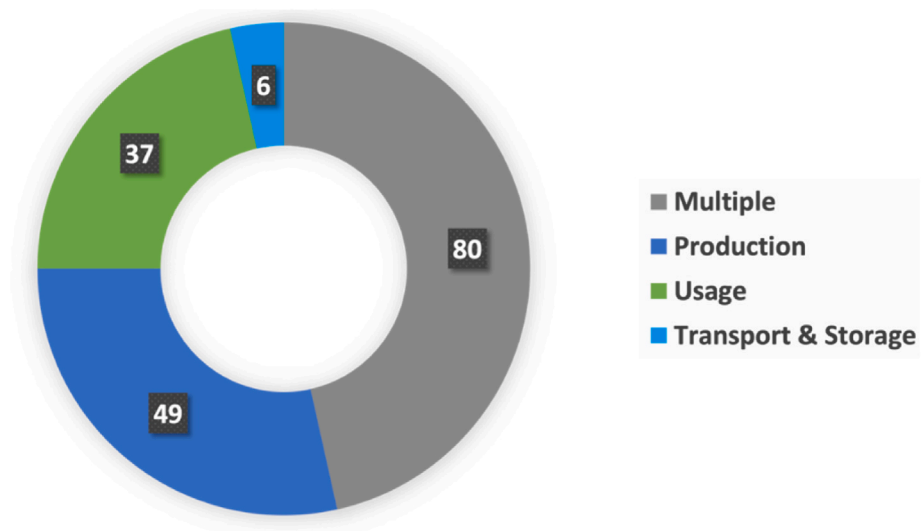


Fig. 2. Number of policy instruments by segment of the hydrogen value chain (own representation). \* Multiple refers to interventions targeting more than one segment of the value chain, see methodological note for details.

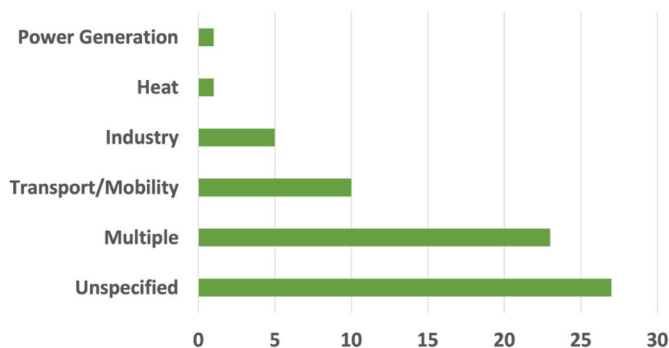


Fig. 3. Number of policy instruments targeting different types of hydrogen usage (own representation). \* Multiple refers to instruments targeting more than one usage category; unspecified refers to interventions targeting hydrogen usage that do not specify any specific usage category.

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<sup>5</sup> 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)<sup>6</sup> 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

<sup>5</sup> For more details, see <https://greenhydrogencatalogue.com/>.

<sup>6</sup> 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 fulfill a number of eligibility criteria, including the participation of at least four EU member states.

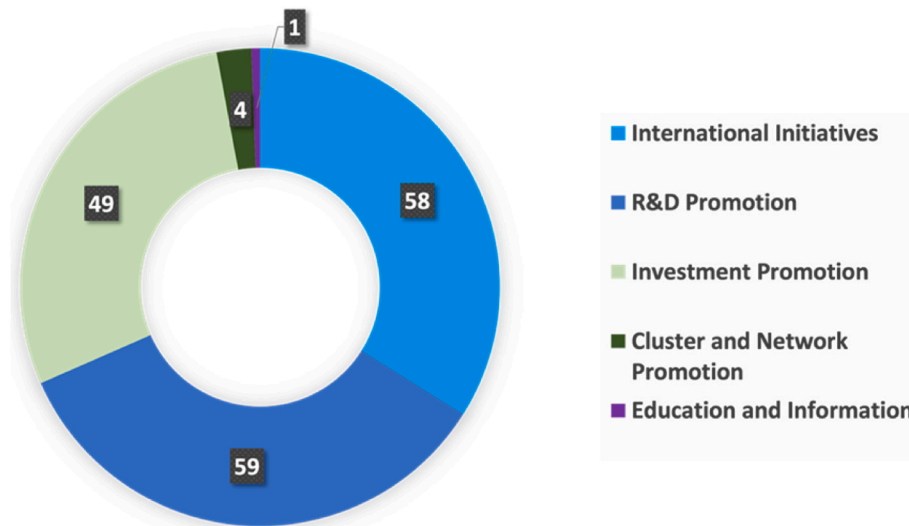


Fig. 4. Number of policy instruments in the hydrogen sector by instrument type (own representation).

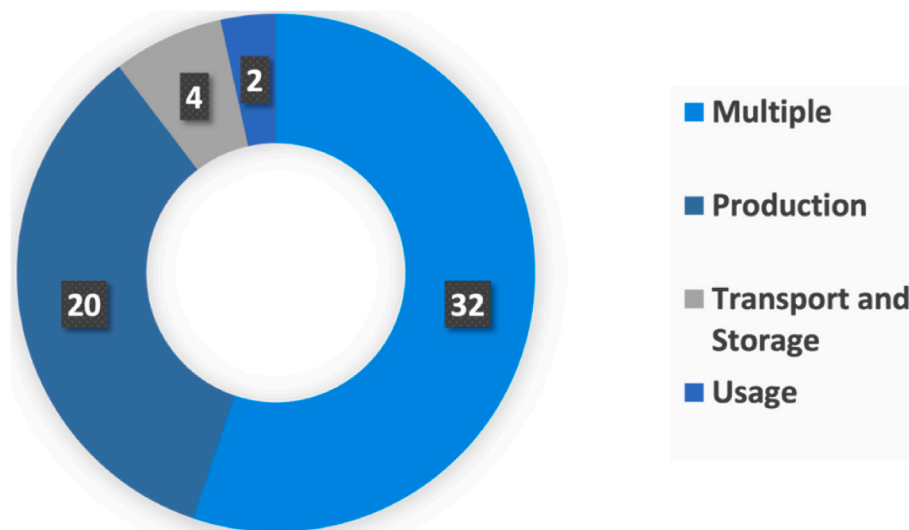


Fig. 5. Number of policy instruments with an international scope by segment of the hydrogen value chain (own representation).  
 \* This graph displays only policy interventions with an international scope, distinguishing between the same categories as Fig. 1.

countries to support regional hydrogen development. With Belgium, Denmark and the Netherlands, it signed the “Esbjerg Declaration on the North Sea as a Green Power Plant of Europe” in May 2022, jointly committing to develop 65 GW of offshore wind and 20 GW of green hydrogen production in the North Sea by 2030.<sup>7</sup> Moreover, Germany joined the Benelux countries, France, Austria and Switzerland in signing a joint declaration by the Pentilateral Energy Forum calling for accelerated hydrogen development.<sup>8</sup>

#### 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

<sup>7</sup> Find the declaration here [https://kefm.dk/Media/637884617580584404/The%20Esbjerg%20Declaration%20\(002\).pdf](https://kefm.dk/Media/637884617580584404/The%20Esbjerg%20Declaration%20(002).pdf).

<sup>8</sup> Find the declaration here <https://www.permanentrepresentations.nl/binaries/nlatio/documenten/publications/2020/06/12/penta-declaration-on-hydrogen/Penta+Declaration+Signed.pdf>.

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 [23] and 50 [24] 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 with Ukraine and Central Asian countries, Canada, New Zealand, South Korea, Japan, and Namibia.

Germany stands out compared to other major actors in that it has actively promoted R&D cooperation not only in industrialized countries but also a range of low and middle-income countries in Africa and Central Asia. The partnership with Namibia is particularly extensive and is based on a funding commitment of €40 million 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 [25]. The funding program “Internationale

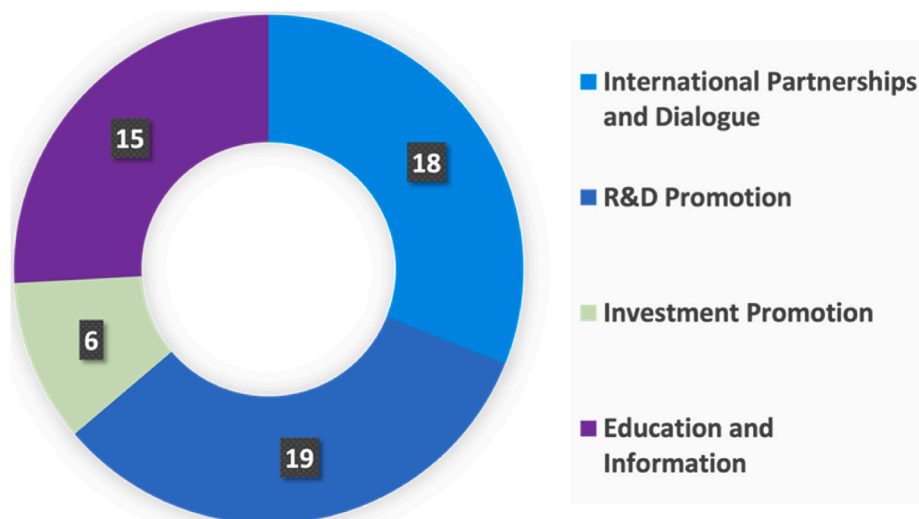


Fig. 6. International initiatives in the hydrogen sector by instrument type (own representation).

\*The graph displays all international initiatives pursued by the German government, classified according to the same categories as in Fig. 3 with the added category of international partnerships and dialogue.

*Wasserstoffprojekte*” (International Hydrogen Projects) supplies grants of up to 15 million euros for international research and innovation projects [26]. Complementing these activities, Germany has funded large-scale R&D projects, including ThyssenKrupp’s project “Element One” in Saudi Arabia for the development of electrolyzer technology [27] 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. In both these countries, Germany is competing with similar efforts from the US, Japan and China.

#### 4.4. International market and supply chain development

Germany is also playing an active role in supporting the development of European and international hydrogen supply chains. Within the EU, investments of approximately €11 billion are being channeled through the IPCEI initiative. Germany has supported 62 IPCEIs in collaboration with other member states, including a total of 2,5 GW electrolyzer capacity (NWS 2023). Outside of the EU, the German government is promoting production capacities in potential export countries via its initiative and the International Hydrogen Ramp Up program (H2Uppp). The latter supports smaller projects in developing and emerging countries sponsored by SMEs, providing technical advice for the identification, preparation and implementation of hydrogen projects [28]. The flagship H2 Global initiative consists of an auction mechanism to provide subsidies for the supply of hydrogen and its derivatives as well as 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 government. Supply contracts under the scheme are awarded for the delivery of hydrogen or its derivatives to ports in the Netherlands, Belgium or Germany. In a first phase, H2 Global is targeting hydrogen supply outside the EU with an initial funding volume of €900 million [29] Additional funding of €3,5 billion has been announced for future auctions [2].

The scheme aims to catalyze the development of required supply chains by private actors. While it offers differing funding windows for hydrogen and various hydrogen carriers, such as ammonia, methanol or jet fuel, it does not seek directly influence or promote specific transport routes or technologies. This contrasts with the approach taken by Japan,

the other major actor seeking to develop hydrogen imports. The Japanese government has directly funded demonstration projects for developing and testing specific transport options and the related technologies, such as liquid-organic hydrogen carrier technology (LOHC), synthetic methane and ammonia [22].

#### 4.5. Capacity and skill development

In developing and emerging economies, the German government has also supported capacity and skill development, clearly outpacing other major economies in this sphere. This includes activities within the portfolio of energy-related development cooperation in Tunisia, Morocco, Brazil and South Africa as well as additional capacity building sponsored by the Federal Ministry of Economic Affairs and Climate Protection (BMWK), which is channeled through the International PtX Hub.<sup>9</sup> The latter represents a knowledge and training center on Power-to-X technologies with activities in 13 countries. In addition, Germany’s Ministry of Education and Research supports capacity building with €8 million (2021–2025) 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 [30] and a large-scale assessment of hydrogen production potentials in Africa, the H2 Atlas Africa.

#### 4.6. 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

<sup>9</sup> The PtX Hub was originally created under the previous administration by the Federal Ministry of Environment, but was transferred to the BMWK along with the overall climate change portfolio.

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 international dialogue on the definition of sustainability standards. It also did not engage in an international process sponsored by the International Partnership on the Hydrogen Economy (IPHE) for developing a methodology for measuring the carbon footprint of different forms of hydrogen production, including fossil-based hydrogen. Relative to Germany's strong engagement in the hydrogen economy overall, this represents an important gap in Germany's international hydrogen policy. That said, apart from the process sponsored by IPHE, there have not been any other major initiatives from other governments in this area. Moreover, Germany's revised strategy now explicitly states that the government will place a stronger emphasis on promoting the development of sustainability certification schemes along with the development of criteria and standards for use of blue hydrogen when promoting hydrogen use.

## 5. Country-level engagement

The multi-dimensional international policy approach described in the previous section has translated into engagement in the EU and a total of 51 non-EU countries, as highlighted in Fig. 7 on the following page. As the map reveals, the government has initiated cooperation with partners across the five continents, with a particular emphasis on African countries. Here again, Germany stands out among other frontrunners in terms of the broad range of partner countries it is engaging on hydrogen-related cooperation. Japan, for instance, has focused much more strongly on potential trading partners in its more immediate vicinity, most notably Australia. Germany's partnerships include countries both in its immediate neighborhood 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 (see table in the annex for a summary of results).

### 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 CO<sub>2</sub> from Germany for storage in Norway [31]. Norway's keen interest in developing exports of fossil-based hydrogen combined with CCS has been one of the reasons for Germany's decision to reconsider its exclusive focus on green hydrogen in its strategy update. To date, a joint feasibility study has been launched to assess the potential for large-scale transport of hydrogen and CO<sub>2</sub> [32]. In January 2023, the countries declared a German-Norwegian Partnership on Climate, Renewable Energy and Green Industry, covering hydrogen, carbon capture and storage (CCS) and green shipping [33]. 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 [34]. The government has also launched a working group on hydrogen under the auspices of the German-Norwegian Chamber of Commerce.

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 has focused more strongly 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

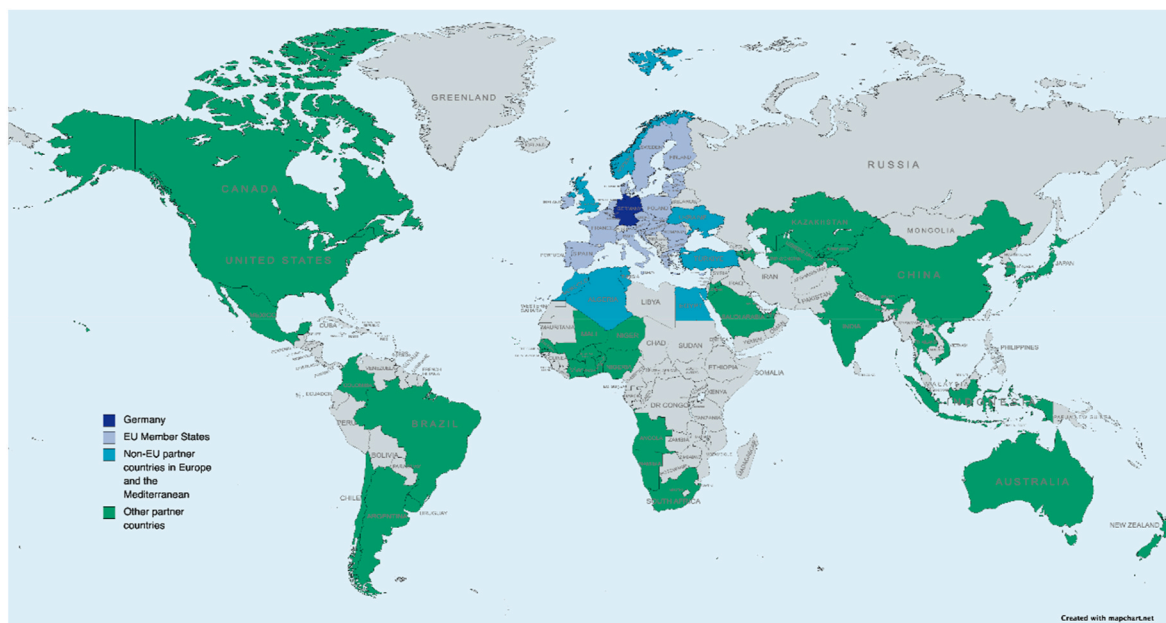


Fig. 7. Germany's engagement with partner countries for the promotion of green hydrogen. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Source: Official government documents and media sources.

Australia [24]. Since then, research collaboration has been established via the prominent research projects HySupply (1,7 million euros) [23] and HyGate (50 million euros) [24]. It has brought 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 green hydrogen. Cooperation builds on a long-standing energy partnership and a major program in support of renewable energy development. Building on this, Germany's Ministry of Economic Cooperation and Development has established a Hydrogen Alliance with Morocco. The alliance counts on close to 90 million euros of funding and aims at establishing 100 MW in electrolysis capacity [35]. In addition, the government has supported joint research on green ammonia synthesis and work by the PtX-Hub to establish a Power-to-Liquid demonstration project, the development of regulatory frameworks for Power-to-X and modelling exercises on Power-to-X 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, supported with 8,23 million euros [36] and 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, both via the existing Program for Renewable Energy and Energy Efficiency [37] and more recently via the work of PtX-Hub. The latter has also included dialogue and analysis on questions related to sustainability of green hydrogen in the country.

### 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. Germany and Namibia established a hydrogen partnership, the first such partnership for Namibia, in August 2021. Against this background, the German Federal Ministry of Education and Research (BMBF) has committed up to 40 million euros for cooperation [38]. It has supported the development of the national hydrogen strategy, a program to develop quality and standardization infrastructure by Germany's Bundesanstalt für Materialforschung und -prüfung (BAM), and scholarship programs for Namibian students. It has also provided funding for four large-scale research and demonstration projects with a total of 30 million euros [39]. In addition, the PtX-Hub has supported 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 have also remained largely at a scoping stage. The German government has funded a study to assess the potential for the production of green hydrogen [40] 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 [41]. Algeria's state-owned oil company, Sonatrach, has signed an MoU with German gas trading company VNG to develop hydrogen-related projects [42].

## 6. Discussion

The review reveals that Germany's international hydrogen strategy spans the whole range of dimensions identified in the analytical framework introduced in section 2 of the paper. Its extensive international cooperation with multiple research and development partnerships has placed Germany at the forefront of the emerging global innovation system. With its focus on green hydrogen, the government has made a major effort to promote a hydrogen economy based on renewable energy, which aligns closely with its previous renewable energy diplomacy but contrasts strongly with all other major frontrunner countries. No other major economy, including neighboring France, have placed such a strong emphasis on green hydrogen. Instead, countries like China [20] and Japan [22] have relegated an explicit prioritization of hydrogen production pathways to a later stage of hydrogen development. The US has chosen to explicitly support all low-carbon production pathways, linking the level of investment support to the CO<sub>2</sub> footprint of chosen projects [43], while France is focusing on electricity-based hydrogen fueled by both renewable and nuclear power [21] (see Table 1 for an overview).

The country-level cases also reveal Germany's consistent engagement at the political level in support of its aim to promote the development of green hydrogen supply chains. In all of the chosen countries (see table in the annex), political dialogue in support of a green hydrogen economy have played an important role. In other words, a major component of Germany's international hydrogen strategy has been the promotion of the political legitimacy of the sector and support among political stakeholders in potential partner countries.

Similarly, in all but Algeria, the German government has supported activities within the fields of research and innovation and international market and supply chain development, albeit with differing levels of intensity. It indicates Germany's willingness to invest resources in broader international market and supply chain development rather than specific supply routes or transport technologies. Moreover, at the country-level, German support for market and supply chain development has consisted of investments in feasibility studies and demonstration projects in partner countries to pave the way for the eventual development of international hydrogen supply chains by the private sector. Larger-scale subsidies for hydrogen imports, however, are channeled through H<sub>2</sub> Global and are thus subject to competitive bidding among project developers throughout the world, albeit with delivery to a major Northern European port. This contrasts with Japan who has prioritized bilateral cooperation with Australia and the Middle East. Its largest engagement involves \$1,5 billion in subsidies for a single demonstration project for the production and transport of hydrogen from Victoria in Australia to Kawasaki, Japan [44]. The US and China have both not launched extensive international activities to date, while France has explicitly focused on domestic applications in partner countries rather than the development of international supply systems [21,22,43,45] (see overview in Table 1).

Germany is the only major government actor in the emerging hydrogen economy whose strategy has targeted such a broad spectrum of countries that are not likely to represent major trading partners in the short-to medium-term. This may signal both a belief in the importance of a liquid international market as well as a strong interest in developing a range of production hubs to support diversification in the long run. It may also indicate that German policy makers have operated on the assumption that the cost of green hydrogen will be dominated by the cost of renewable electricity, discounting other cost factors like mode and distance of transport or cost of capital. This appears to be reflected in its engagement in countries like Australia, Chile and Namibia, all at a

**Table 1**

Role of different types of hydrogen production and the importance of international supply chain development in hydrogen strategies of major economies.

	Germany	Japan	France	USA	China
<b>Prioritized production pathways</b>	Focus on green hydrogen, openness to blue hydrogen	All production pathways, including unabated fossil-based hydrogen production, in the short term	Focus on electricity-based hydrogen fueled by renewable and nuclear power	Focus on all forms of low-carbon hydrogen, prioritized according to their carbon footprint	No short-term prioritization, but long-term priority on green hydrogen
<b>Importance of international supply chain development</b>	High	High	Low	Low	Low

Source: Author.

significant distance from Germany but with exceptional renewable resources at their disposal. Indeed, Germany's very active engagement with these partners may contribute to the emergence of a global system of hydrogen trade, which may co-exist with more regionalized markets, similar to the LNG market. Germany's broad-based, global engagement combined with its auction-based approach also signal a commitment to market forces as a central determinant of import routes. An important downside to Germany's approach is that it has proven to be slower than the bilateral approach pursued by Japan whose government has already developed infrastructure and awarded substantial funding to a specific import project.

In the same vein, it is notable that outside of formal EU processes, Germany has primarily focused its international engagement on non-EU countries. Most importantly, H2 Global, its flagship instrument for stimulating the development of international hydrogen supply chains, was designed to target imports from non-EU countries and did not allow bidders from within the EU. Meanwhile, similar schemes have been announced but have not yet been launched at the EU-level. In other words, to date, Germany's reliance on EU-level schemes for investment promotion within Europe has translated into a *de facto* prioritization of non-EU imports and supply chains. This may change with the decision to channel EU-level auctions by the so-called European Hydrogen Bank through the German H2 Global Foundation. This would provide the German government with a favorable position for influencing the rollout of this major European subsidy scheme. This development could also increase the willingness of the German government to commit funding to the scheme.

Another significant finding is that not only capacity building and skill development, but also sustainability-related efforts are focused primarily on countries with lower levels of renewable energy capacities that are still at an early stage of their decarbonization efforts. Engagement with more advanced countries has not prioritized sustainability-related issues. Moreover, Germany's cooperation with Norway has explicitly included cooperation on blue hydrogen. Although the government has not provided financial support to the import of blue hydrogen, it has provided active political support, a key to legitimizing the efforts. In spite of this, Germany has not engaged actively in processes to determine standards for the assessment of CO<sub>2</sub> emissions across production methods. This gap in Germany's engagement on sustainability-related issues contradicts its strong emphasis on green hydrogen and on the deployment of hydrogen in hard-to-electrify end-uses articulated in its domestic strategy. This same ambiguity is also demonstrated by the quantitative assessment of policy instruments, revealing a significant degree of flexibility when it comes to hydrogen usage.

Rather than engaging actively in sustainability-related issues with other frontrunners or at the multilateral level, the German government has initially chosen to largely limit its engagement on sustainability-related questions to processes at the EU-level (not discussed in detail in this paper), where it has come out strongly in support of green hydrogen. Its active global engagement provides it with a potential entry-point for promoting sustainability-related criteria in line with national and EU-level priorities. While capacity-building efforts play an important role in preparing the ground in potential partner countries in

the Global South, the development of internationally recognized sustainability certification schemes will be decisive in shaping a future hydrogen market. Cooperation with other frontrunner countries in developing such standards would not only provide an entry-point for promoting Germany's priorities in international markets but also support the harmonization of standards across key countries. The revised strategy indicates that the government has recognized this and may increase this dimension of its engagement.

## 7. Conclusion

This review of Germany's outward-oriented hydrogen strategy provides a detailed characterization and discussion of how the German government is 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 neighbor France but also the US and China. For varying reasons, these countries have all largely pursued inward-oriented strategies. Japan, facing similar resource constraints as Germany, has also taken up a more outward-oriented strategy. In contrast to Germany, however, this strategy is more focused on supply relationships with countries closer to it geographically. Moreover, in contrast to all these countries, Germany – despite its pragmatism – strongly promotes the use of green hydrogen based on renewable energy.

It is clear that Germany is a leader in terms of the geographical scope of its activities, with the ambition to shape a global hydrogen market rather than merely establish a domestic hydrogen economy with regional supply relationships. At the same time, Germany's focus on green hydrogen coupled with its relative lack of political engagement so far on addressing sustainability issues (outside its capacity building efforts) reduces its ability to actively shape the broader rules of engagement in the sector. Given its limited capacity for domestic green hydrogen production, it may also constrain its access to hydrogen in the early stages of the market and thus place it at a disadvantage in establishing downstream segments of the supply chain. In the longer term, it may prove to be an advantage, as blue hydrogen investments may prove to be liabilities as countries seek to achieve climate neutrality targets by mid-century.

From a broader system perspective, the diversity of government strategies – with Germany representing one prominent example – increases uncertainty for investors and may discourage investment needed for a more rapid ramp-up of hydrogen supply. On the other hand, it offers space for innovation and experimentation along different possible pathways for a clean hydrogen economy. Moreover, as Germany's evolving stance on blue hydrogen shows, its policies are also responding to developments in the broader hydrogen policy landscape, signaling steps towards policy convergence.

Further systematic analysis of the evolving hydrogen policy landscape, including its international components, 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. An important entry-point for additional research would be the comparison of hydrogen strategies across countries as well as the analysis of their interplay within the evolving hydrogen sector. While this article provides a systematic assessment of a single country, future research should explore differences between countries as well as the causes and implications of these differing approaches. Insights from this research could provide important lessons for fostering better alignment of policies, both between major hydrogen frontrunners and between potential importing and exporting countries.

7.1. Methodological note

Over 170 policy instruments by the German federal government targeting the hydrogen sector were collected and systematically coded according to guidelines established in a codebook. The collection of policy instruments is comprehensive and updated until July 2023. For an intervention to be accounted as a policy instrument we followed the definition of Hettiarachchi & Kshourad (2019) [36] 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 counted as a policy instrument it should be a part of an official government document that includes an action or set of actions. As indicated above, the coding of policy instrument types builds on the approach outlined in Schaffrin et al. (2015) [16]. Building on this, policy instruments were coded according to instrument type, distinguishing

Annex

Dimensions of cooperation between Germany and selected partner countries.

Country	Political Dialogue and Diplomacy	Research and Innovation	International Market and Supply Chain Development	Capacity Building and Skill Development	Promotion of Sustainability
Norway	German-Norwegian Partnership on Climate, Renewable Energy and Green Industry	Joint feasibility study on large-scale transport of hydrogen and CO2	Hydrogen Working Group at German-Norwegian Chamber of Commerce		
Australia	Australia-Germany Hydrogen Accord	HySupply and HyGate projects	HySupply and HyGate projects		
Morocco	Hydrogen Alliance	Green Ammonia project; modelling exercises	100 GW green hydrogen & Power-to-Liquid demonstration projects	Capacity building by PtX Hub	
Chile	Task force on hydrogen within Energy Partnership	Haru Oni project	Haru Oni project	Program for Renewable Energy and Energy Efficiency & PtX Hub	Dialogue and analysis on sustainability of hydrogen within work of PtX hub
Algeria	Series of studies workshops and study tours on hydrogen within Energy Partnership			Capacity building by PtX Hub	Trainings on sustainability of green hydrogen and sustainability certification by PtX Hub
Namibia	Hydrogen Partnership	Large-scale research and demonstration projects	Development of laboratory capacities as well as a quality and standardization infrastructure for hydrogen by BAM; Large-scale research and demonstration projects	Capacity building and skill development financed by BMBF & work of PtX Hub	Advisory work on sustainability by PtX Hub

international initiatives, R&D promotion, investment promotion, cluster and network promotion, education and information. Furthermore, international initiatives comprise international partnerships and dialogue as well as the other basic instrument types. International partnerships and dialogue refer to any activities at the political level, such as partnership agreements, high-level dialogue or other diplomatic activities targeting the hydrogen sector. In addition, policy instruments were coded according to segment of the hydrogen value chain that they address (i.e. production; usage; storage and transport), including sub-categories like different types of hydrogen usage.

Interviews were conducted with representatives of the Federal Foreign Office, the Federal Ministries of Economic Affairs and Climate Protection, Economic Cooperation and Development, and Education and Research as well as the International PtX Hub and the H2 Global Foundation.

### CRedit authorship contribution statement

**Rainer Quitzow:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Almudena Nunez:** Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Adela Marian:** Investigation, Methodology, Writing – original draft.

### Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rainer Quitzow reports financial support was provided by Federal Ministry of Education and Research.

### Data availability

Data will be made available on request.

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