Advancing a green hydrogen agenda in the G20

Challenges and opportunities of the G20 as a green hydrogen forum

Policy Brief

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Main findings and recommendations

The G20 should build on previous efforts to shape the emerging global market for green hydrogen by:

- **Establishing common standards to determine greenhouse gas emissions from hydrogen production** to appropriately assess all types of hydrogen. The G20 should establish a working group to standardize and coordinate monitoring and certification procedures that include key environmental and social sustainability aspects.

- **Creating lead markets for green hydrogen and the associated equipment and infrastructure** to reduce investment risks and promote the global build-up of production capacities. All countries meeting the required conditions should have access to these lead markets.

- **Supporting the production and use of green hydrogen in other countries** by granting preferential market access for green hydrogen, its derivates and green basic materials or incentivizing its uptake in the producing country.

Introduction

This policy brief aims to support the work of NGOs and think tanks by developing elements of a green hydrogen agenda for the G20. Based on an analysis of the heterogeneous interests and agenda of the G20 countries, the first part discusses the challenges and opportunities of the G20 as a forum for shaping the emerging markets for hydrogen and hydrogen-based products into a direction that is compatible with climate neutrality. The second section outlines the governance challenge of ensuring the environmental and social sustainability of hydrogen production and use. Finally, it develops options on how to advance a green hydrogen agenda in the G20.

Different shades of hydrogen – from green to blue to grey

For the sake of simplicity, this paper applies the color codes widely used in the hydrogen debate: 'green' hydrogen refers to hydrogen produced via electrolysis based on renewable electricity (RE); 'grey' refers to hydrogen produced with unabated fossil fuels (e.g. natural gas or coal); 'blue' to the production with fossil fuels in combination with carbon capture, utilization and storage (CCUS); 'pink' to the production with electrolysis based on nuclear energy, 'turquoise' with pyrolysis.

However, these color codes suggest clear-cut distinctions that do not reflect complex realities. For instance, 'blue' hydrogen is frequently presented by fossil energy advocates and several G20 country governments as 'zero carbon'. However, depending on the level of methane leakages and on the share of CO_2 that is permanently stored, the actual GHG emissions intensity may be substantial. In most cases, what is presented as 'blue', is in fact some shade of 'blue-grey' with varying, possibly high GHG emission intensity. The GHG emission intensity of hydrogen produced by electrolysers connected to the electricity grid depends on the power mix, which varies between countries and over time. This is the main reason why there are complex debates on how to define and certify renewable hydrogen.

The G20 as a forum for green hydrogen policy?

To achieve the goals of the Paris Agreement and prevent catastrophic climate change, the international community must achieve net-zero greenhouse gas emissions globally by mid-century (IPCC 2022). The G20 countries are crucial to achieving this transformation: they accounted for 62% of global population, 83% of GDP and 76% of GHG emissions in 2019 (Minx et al. 2021; World Bank 2022b; 2022a). They also have emitted almost 80% of the CO_2 released into the atmosphere since 1850, totaling more than 2.500 $GtCO_2$. This is about five times more than the remaining carbon budget, i.e. the amount of CO_2 that can still be emitted until the end of the century for a 50% chance to keep global warming below 1.5°C (IPCC 2022).

The G20 is an informal forum for debates and exchange without a permanent secretariat. Besides being a venue for multilateral exchange, its main output consists of the yearly Leaders' Declaration signed by the Prime Ministers, and of the yearly Communiqué of the Finance Ministers and Central Bank Governors. Additional meetings of specific ministers may be held. The last communiqué of energy ministers was in 2018, under the Argentinian presidency (G20, 2018).

The G20 works on a consensual basis and the declarations are not legally binding. Given the very diverse interests within the G20 group, the space for shared positions is limited, especially in contentious fields such as energy and climate, which often leads to rather generic declarations. The energy section of the Bali Leaders' Declaration, for instance, states that "we will accelerate transitions and achieve our climate objectives by strengthening energy supply chain and energy security, and diversifying energy mixes and systems". It does "recognize the importance to accelerate the development, deployment and dissemination of technologies, and the adoption of policies, to transition towards low-emission energy systems, including by rapidly scaling up the deployment of clean power generation, including renewable energy (…) and including accelerating efforts towards the phasedown of unabated coal power, in line with national circumstances" (G20, 2022). However, it does not mention the need of reducing fossil fuel consumption, let alone of phasing it out.

The G20 countries' diverse interests on hydrogen

Concerning (green) hydrogen market ramp-up and regulations, the G20 is a group of countries with very heterogeneous conditions, interests, and preferences. A short glance at them helps to understand what kind of goals can be best pursued in the G20 and those that might be best brought forward in other venues.

- **Climate policy commitments**: The G20 includes countries with extremely different climate policy ambitions, ranging from global frontrunners to countries lacking ambitious climate targets or only non-binding ones, and weak or non-existing review and planning processes (Climate Transparency 2022).
- **Traditional energy trade balance**: The G20 includes some of the countries with very large fossil energy reserves and the largest fossil energy exporters, such as Australia, Canada, Russia and Saudi Arabia, as well as some of the largest energy importers, such as China, the EU, Japan and South Korea.
- **Renewables potential**: The G20 includes countries with limited renewables potential, such as Germany, Italy and Japan, as well as countries with the potential to meet their entire energy demand with domestic renewable sources and, additionally, export significant amounts of renewable energy in form of electricity, hydrogen or hydrogen derivatives (e.g. Australia, Canada, Saudi Arabia, potentially Brazil and the USA).
- **Energy balance under climate neutrality**: In a future global climate-neutral economy based on renewables, some of the G20 countries are very likely to remain energy importers (e.g. France, Germany, Italy, probably the EU as a whole, Japan, South Korea), while other countries could remain (Australia, Canada, Saudi Arabia) or become (e.g. possibly UK with its huge offshore wind resource) net energy exporters.

However, the G20 does not include any **energy export newcomers** – countries with little or no domestic fossil energy extraction, but high potential for renewable energy deployment. Some non-G20 countries, such as Chile, Iceland, Jordan, Morocco, Namibia, and Tunisia, are particularly important in terms of the upcoming green hydrogen geopolitics, as they have a specific interest in developing a green hydrogen economy, but no strong vested interests in fossil extraction. When it comes to the competition between fossil-based and renewable-based hydrogen, these countries are likely to take a strong position in favor of green hydrogen. This distinguishes them from several of the G20 countries that have both strong renewable potential but also large-scale fossil energy resources, and thus have a vested interest in developing fossil-based hydrogen, such as Australia, Canada, Mexico, Saudi Arabia and the USA.

Heterogeneous agendas with some common denominators

Most G20 members have formulated hydrogen strategies or roadmaps (see Table 1 for an overview) and have begun to implement policies to develop their hydrogen sectors[1]. For our analysis of the G20 as a venue for green hydrogen debates, it is important to highlight both the common denominators and the areas where the G20 countries have diverging interests and positions.

Common denominators among all or most G20 countries are:

- A strong interest in developing hydrogen from electrolysis. This also applies toG20 countries with strong vested interests in fossil energy extraction, as all of them have a strong renewable energy potential and even the most conservative leaders who are closest to the fossil extraction sector acknowledge that, at least in the long term, green hydrogen will play a major role.
- The vision of using carbon-neutral or at least low-carbon hydrogen to reduce the GHG emission intensity of hard-to-abate sectors, such as aviation, long-distance shipping, steelmaking, ammonia production, and methanol production.
- The awareness that, as the global economy progresses towards climate neutrality, the global energy trade flow will significantly change, with declining trade in fossil fuels and increasing trade in hydrogen and hydrogen derivatives.
- The awareness that this process is likely to produce significant geopolitical and geo-economic change, both in terms of energy flows and probably also in terms of relocation of elements of industrial value chains currently based on fossil feedstock and energy sources.

Concerning the green hydrogen agenda, some **key points of divergence** among G20 countries are:

- The preferences and prioritization of energy sources to produce hydrogen: The EU as a whole, and Germany in particular, prioritize green hydrogen; blue and purple hydrogen are not excluded, but receive less political backing. G20 countries outside the EU take a different stance, in that they also consider fossil-based hydrogen as an important future option; several of them are open to nuclear-based hydrogen as well.
- G20 countries are in different geopolitical positions in terms of their future role as exporters or importers of hydrogen or derivatives and in terms of their potential economic loss or gains within the context of the relocation of industrial activity.
- Their engagement for and specific interests concerning the sustainability of future (fossil and renewable) hydrogen production.

[1] For instance, the US Inflation Reduction Act includes tax break of up tu US$ 3 per kg for the production of low-carbon hydrogen. The EU is expected to also include substantial financial support for hydrogen in its forthcoming Net-Zero Industry Act.

Country	H_2 strategy, roadmap or policy discussions	Objectives	Energy sources in focus	Sectoral usage of H_2	Investments
Argentina	Policy discussions				
Australia	Hydrogen Strategy (2019)		Fossil and renewables	Heating, industry, transport, export	$14 billion by 2030
Brazil	Strategy in preparation				
China	Hydrogen plan (2022)	Production of 0.1-0.2 million tons H_2 per year with RE by 2025. 50% of H_2 will stem from RE by 2030	Fossil and renewables	Industry, mobility	
Germany	Hydrogen Strategy (2020)	5 GW electrolysis capacity by 2030, leading to 90-110 TWh H_2, i.e. 4% of final energy consumption (FEC)	Renewables	Industry, transport	$22.83 billion by 2026
France	National strategy (2020)	6.5 GW electrolysis capacity by 2030	Nuclear, renewables and fossil	Industry, mobility	
United Kingdom	Hydrogen strategy (2021)	5 GW electrolysis capacity by 2030. 20-35% H_2 in FEC by 2050		Power generation, heating, industry, mobility	
India	Hydrogen roadmap (2022)	Production of 5 million tons of green H_2 by 2030		Industry, mobility, heating, power generation	
Indonesia	-				
Italy	Hydrogen Strategy (2020)	5 GW electrolysis capacity, leading to 2% H_2 in FEC by 2030 and 20% in 2050			
Japan	Hydrogen Roadmap (2019)	H_2 consumption of 3 million tons by 2030. Domestically produced H_2 should be carbon-free by 2030	Fossil and renewables	Heating, power generation, transport	$18.2 billion by 2030
Canada	Hydrogen Strategy (2020)	Production of 4 million tons H_2 per year and H_2 share of 6,2% in FEC by 2030	Fossil, nuclear and renewables	Industry, transport	$1.937 billion by 2030
Mexico	Policy discussions				

Russia	Hydrogen Roadmap (2021) (*)	Production of 2 million tons H_2 by 2030	Fossil, nuclear and renewables	Export	$1.7 billion by 2030
Saudi-Arabia	Strategy in preparation				
South Africa	Hydrogen roadmap (2021)	Production of 500.000 tons H_2 per year and electrolysis capacity of 12 GW by 2030; 15 GW by 2040	Fossil and renewables	Mobility, industry, power generation, export	
South Korea	Hydrogen Roadmap (2019)	Production of 5.26 million tons H_2 per year. by 2040, 5.9 million fuel cell electric vehicles and 1.200 H_2 refueling stations	Fossil and renewables	Power generation, mobility	$16.26 billion in 2025
Turkey	Roadmap for hydrogen in preparation				
USA	Plans for hydrogen, infrastructure and employment (**)	17 million tons H_2 demand by 2030, 1.5 million fuel cell electric vehicles and 4.300 H_2 refueling stations by 2030	Renewables, fossil and nuclear	Power generation, industry, mobility	
EU	Hydrogen Strategy (2020)	Production of 10 million tons H_2 per year and 40 GW electrolysis capacity by 2030	Renewables and fossil	Industry, mobility	$155 billion by 2030

Table 1: Hydrogen strategies of G20 Member States

Sources: Zhu and Wei 2022; World Energy Council, EPRI, and PwC 2021; Garcia-Herrero, Tagliapietra, and Vorsatz 2021; Government of India 2022; Department of Science and Innovation 2021; Daily Sabah 2022; Note: (*) = Information from “Russia’s hydrogen Energy Development Plan for 2024” has been included as well; (**) = The “Hydrogen Energy Development Plan” (2019) and “Infrastructure Investment and Jobs Act” (2021) have been considered.

Green hydrogen in a climate-neutral energy system

One key element of the transformation to climate neutrality will be to replace fossil energy with energy from renewable sources – including through the expansion of renewable electricity, and the electrification of energy uses e.g. in industry, transport and heating. This part of the transformation is picking up speed rapidly, driven by dramatically declining costs of wind and solar energy. According to the International Renewable Energy Agency (IRENA), renewable power is now 'the cheapest energy in human history' (IRENA 2021), pushing fossil energy sources out of electricity markets around the globe. Sales of electric vehicles are soaring, and in some countries new registrations have already overtaken those of cars with internal combustion engines (IEA 2021a). Likewise, heat pumps are being widely adopted as an efficient solution to produce low-temperature heat, in space and water heating or in industrial applications.

Yet there are some activities and processes for which direct electrification is not (yet) an option – for instance long-distance aviation and shipping, as well as certain industrial processes, particularly steelmaking and chemicals (IEA 2021b) – either because fossil resources are used as a feedstock or reaction agent, because they require large amounts of high-temperature heat, or because of the weight or lacking energy density of batteries. For these activities, hydrogen (or hydrogen-based synthetic fuels) can serve as a substitute for fossil energy carriers (see Figure 1).

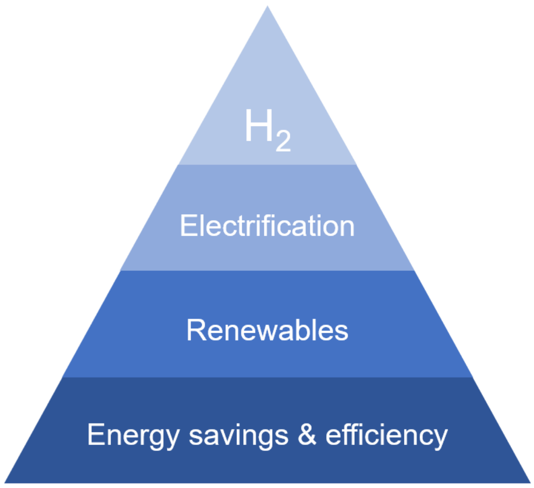

Figure 1: Hierarchy of emission reduction options – including green hydrogen.

Source: own depiction.

If the hydrogen is green, i.e. generated with renewable electricity, it is a climate-neutral energy carrier. However, since the production, handling and processing of hydrogen inevitably involves energy losses, direct electrification – wherever possible – will be the cheaper and easier alternative. Green hydrogen, as an expensive and scarce resource, should be reserved for those sectors and applications for which no other viable alternatives exist. Net-zero scenarios project that, by 2050, the share of hydrogen in global final energy consumption would likely amount to more than 10% and might even exceed 20% (IEA 2021b; IRENA 2022; Agora Energiewende and Agora Industry 2021).

An emerging international market for (green) hydrogen?

At present, hydrogen is predominantly used in the fertilizer industry to produce ammonia and in the petro-chemical industry to reduce the sulfur content of diesel fuels. The international supply of hydrogen is still limited. In 2020, 90 Mt of hydrogen were produced globally.

Most of the current hydrogen supply is produced from fossil fuels (IEA 2021b). Green hydrogen produced from electrolysis using renewable electricity so far accounted for a negligible amount. In 2020, the international electrolysis capacity amounted to 0.3 GW (Clarke et al. 2022), producing around 0.03% of the global hydrogen, with most capacity located in Europe (40%), followed by Canada (9%) and China (8%) (IEA 2021b). However, the cumulated installed electrolysis capacity is growing exponentially: after more than doubling in just two years from 2019 to 2021 (from 242 MW to 513 MW), in September 2022 it was projected to almost triple (1,398 MW) within only one year by the end of 2023 (IEA 2022b). By 2050, the IEA's global net zero-scenarios see global hydrogen production increase at least five-fold (IEA 2021b).

To accelerate its diffusion, green hydrogen needs to become cost-competitive with hydrogen produced from fossil sources. Economies of scale and technological learning will likely further decrease both the costs of electrolysers and that of electricity generation from renewable sources. At the same time, the steep rise of natural gas prices has pushed up the costs of grey hydrogen to levels comparable to – or even above – those of green hydrogen (IEA 2022). For this reason, green hydrogen could conceivably dominate the global hydrogen market (Clarke et al. 2022). How quickly this point arrives, however, will depend not only on technological advances, but also on the regulatory environment. Policies can advance the production and use of green hydrogen above all by closing the price gap between green and non-green hydrogen, including through carbon pricing, direct payments or contracts-for-difference, by banning fossil alternatives, or by using quota obligations or public procurement to create stable and predictable future demand.

Production costs for green hydrogen differ considerably between regions – depending on the locally available renewable energy potential, available infrastructure and costs of capital. Regions with abundant and cheap renewable energy potential may turn into exporters of green hydrogen, selling to the regions with the highest demand. However, transporting pure hydrogen over longer distances is both expensive and energy intensive, which explains why currently about 85% of the produced hydrogen is consumed on-site and not traded over longer distances (IRENA 2022). The costs of shipping pure hydrogen amount to about 2-3 US$/kg, whereas future generation costs are projected to decline to about 1 US$/kg in some regions. Where production and consumption are not too far removed, pipelines can offer a more feasible solution to transporting hydrogen. In many circumstances, existing natural gas pipelines could be repurposed at low costs (IRENA 2022). Where hydrogen needs to be transported over larger distances, a more promising option is to trade green hydrogen derivatives, such as ammonia, methanol and synthetic fuels. IRENA (2022) estimates that pipelines will likely account for at most half of international hydrogen trade, whereas the majority of international trade will be in the form of shipments of derivatives.

Given the expected production and transport costs, markets for pure green hydrogen might remain regional, with a more closely integrated global market for green hydrogen derivatives. Some projections see between one fifth and one third of globally produced hydrogen traded across national borders by 2050 (Clarke et al. 2022; IEA 2021; IRENA 2022). Since international market(s) for green hydrogen and derivatives are only beginning to emerge, this is a decisive time to make the right choices for the governance of these emerging markets – and the G20, combining much of both the supply and demand for green hydrogen and derivatives, is in a unique position to help shape these markets from the outset.

Sustainable governance of international hydrogen trade

Unlike the well-established global markets for fossil fuels, the international market for (green) hydrogen is still in its infancy, and few dedicated regulatory frameworks exist. How this market will further develop is highly path dependent. That is, the future structure of the international market for green hydrogen (and/or hydrogen derivatives) will be crucially determined by decisions taken in early stages of its development. The G20 can shape this market early on and avoid lock-ins in an environmentally or socially unsustainable hydrogen economy.

Figure 1 illustrates the multiple path-dependencies involved in the process: at the outset, the new emerging energy system that involves a substantial role for hydrogen must compete with the incumbent, fossil-based energy system, in which hydrogen (of any variety) plays only a niche role. Within the different varieties of hydrogen, there is again competition between fossil-based varieties (in particular the current standard production method, unabated "grey" hydrogen from natural gas), and options involving electrolysis to produce hydrogen. Where this is fueled with renewable electricity, it counts as green – but even within green hydrogen, there are different shades of green, depending on the (environmental and social) criteria applied to the electricity used. These are not binary choices: in practice, all these different approaches will co-exist and compete. At the same time, however, there are learning costs and economies of scale involved in following the different routes, and hydrogen production needs to co-evolve with the supporting infrastructure: the more investment flows into either option, the more competitive this option becomes. However, there is also a risk of wanting too much too soon: focusing only on the different shades of green hydrogen (and raising the bar too high too fast), entails the risk that this deep-green hydrogen remains uncompetitive with fossil options scaled up elsewhere.

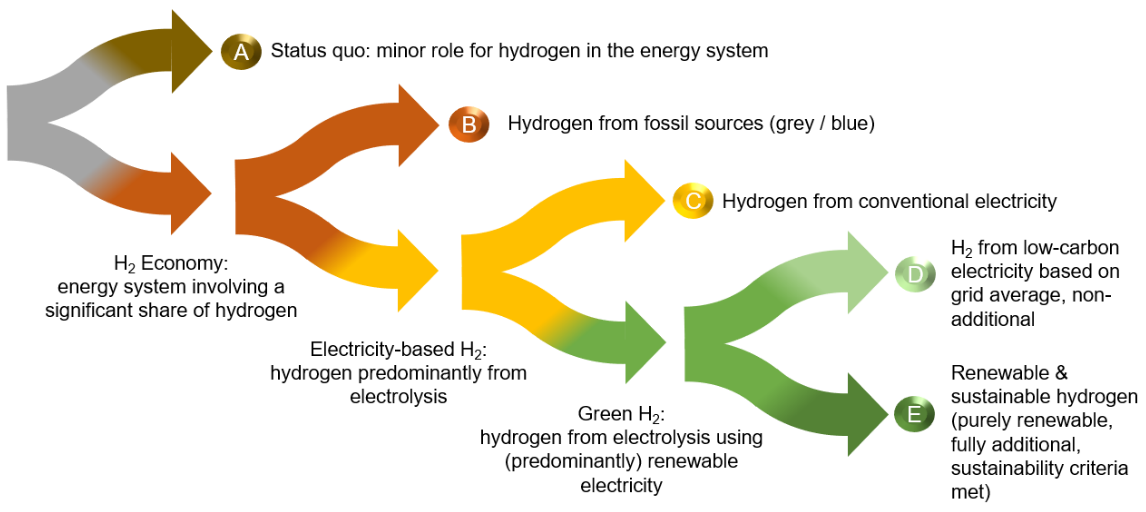

Figure 2: Path dependencies in the hydrogen market.

Source: own depiction.

The regulation of the emerging international market(s) for green hydrogen and derivatives needs to consider the implications for both importing and exporting countries. Hydrogen production from renewable energy can also have numerous benefits for producing countries, for instance by creating economic opportunities and employment. However, there are also important risks attached to the production of hydrogen, for instance if it exacerbates scarcity of land and water, or intensifies conflicts over such resources. Whether or not the production of green hydrogen supports the energy transition in the producing country is a matter of debate: on the one hand, the expansion of renewables that is required to scale up production of green hydrogen can accelerate the transformation by adding further demand and stimulating investment into new capacities. On the other hand, it can be argued that hydrogen production diverts the existing renewable electricity away from other domestic uses: by adding demand, it drives up prices and can thus make domestic uses of renewable electricity less attractive.

A key feature of green hydrogen is that it will not be produced in a pure commodity market, such as the markets for other energy resources. Rather, it will – at least partly – be a politically created market, driven by regulation and requiring public oversight. Hence, trade in green hydrogen must be based on clear and sufficiently ambitious sustainability criteria and must be accompanied by the necessary institutions and mechanisms to ensure monitoring and compliance. Table 2 below lists challenges and potential governance options for green hydrogen exports.

		Challenges for Sustainable Development	Governance Options
Ecological	Energy systems	If limited renewable capacities are used to produce hydrogen, energy demand will migrate to additional fossil capacities, with a potentially negative impact on climate. In exporting countries with limited renewable resources or capacity to invest, hydrogen produced from 100% renewables could delay the decarbonisation in the producing country, if renewables are prioritised for export instead of the most effective domestic use.	Renewable energy for green hydrogen could be deemed additional only if it comes from sources not connected to the nation's power grid or a power-purchasing-agreement with renewable electricity suppliers Grid electricity could also be permitted if its carbon intensity is below a certain benchmark. This benchmark could be defined in absolute terms (CO_2 per kWh) and should be based on a complete life-cycle analysis.
	Water	Water use for electrolysis is limited and would only be a concern for very water scarce countries. If renewable power is generated with concentrated solar power, water use could be an order of magnitude higher. In water-scarce regions, sea water would need to be desalinated. Additional desalination capacities could expand water access to the local population. The resulting sludge needs to be treated.	Tracking water use for green hydrogen from the source through the entire production chain to the final product, i.e. the green hydrogen, on the regional level where the project takes place.. Establishing a comprehensive monitoring system for water scarcity based on appropriate indicators that is able to assess the impacts of green hydrogen production. Ensuring that desalination plants are installed and operated in an environmentally friendly manner.
	Land use	Renewable energy requires extensive land areas. For countries with large land areas, land requirements as such are not problematic. Green hydrogen produced in certain vulnerable areas, such as biodiversity hotspots or arable land, could have adverse sustainable development implications.	Environmental impact assessments to ensure that renewable energy production does not have adverse ecological impacts. Some vulnerable areas, such as biodiversity hotspots, should be excluded. Combined use, e.g. with agriculture, could in turn receive preferential treatment.
	Hydrogen leakage	If hydrogen leaks into the atmosphere, it could increase the lifetime of methane and increasing climate forcing. The potential climate effect of hydrogen leakage is still unclear. Establishing supply chains that are prone to leakage could result in a lock-in into a system that is harmful for the climate.	Monitoring requirements for hydrogen leaks, security standards to prevent leakage and a clear commitment to exclude any hydrogen imports that involve major leaks.

	Resource use	Solar panels, wind turbines and electrolysers use scarce materials. This could lead to dependence on imports from a limited number of suppliers and entails the risk of disruptions of supply chains. Mining of these materials could also have harmful effects on the environment and human well-being in producing countries.	Demonstrate that hydrogen is produced with materials that have been sourced under well-defined environmental and human rights standards. Renewable energy sources and hydrolyser could need to include a certain minimum share of materials from signatories to the Extractive Industries Transparency Initiative.
Social	**Human rights**	Hydrogen production could affect human rights if people are forcefully displaced or if areas of cultural or religious significance are used.	Different forms of participation starting from information to decision making including the local population should be analyzed and conducted. Prior and informed consent by the affected communities can be regarded as indicating a project's integrity with human rights standards. Jurisprudence and media reports could serve as warning signals, requiring exporters to show that no human rights have been violated.
	Socio-economic development	If hydrogen production fails to spur the development of additional industries, it will have little – or even negative – effects for socio-economic development. Figures of direct employment in hydrogen are insufficient as an indicator, as they do not consider economy-wide job effects.	Track distribution of income and aggregate employment to assess the impact of hydrogen production on socio-economic development. For high-quality employment in the producing country, ensure that the skills are developed among the domestic labour force and new industries fomented.

Table 2: Key challenges and potential governance options for green hydrogen exports.

Advancing a green hydrogen agenda in the G20

Amid the divergent interests of G20 members, efforts to further the green hydrogen agenda may well stall, or worse, result in unambitious compromises or greenwashing. Bearing these caveats and constraints in mind, the following chapter develops some options for advancing an agenda for green hydrogen in the G20:

1. First, the G20 could work **towards leveling the playing field between hydrogen based on fossil sources** (grey, blue and all shades between them), **and green hydrogen**. This entails avoiding any underestimation of methane and CO_2 emissions for fossil hydrogen and proper accounting of the emission intensity of electricity from power systems with significant fossil shares.
2. Second, the G20 can contribute to **creating lead markets for those elements of the hydrogen value chain that support the ramp up of green hydrogen** and on which there may be wide consensus in the G20. Besides green hydrogen itself, green ammonia and possibly other hydrogen derivatives, these also include electrolysers and transport infrastructure, including hydrogen pipelines as well as harbors and ships for shipping hydrogen and its derivatives.
3. Third, G20 members can **support the production and use of green hydrogen in other countries** to ramp up global supply chains.

A level playing field for hydrogen sustainability

A key issue where action at the G20 level could be helpful is establishing a level playing field for GHG emission accounting and sustainability criteria for hydrogen produced from renewables and from fossil sources.

Definition of renewable/green hydrogen

Under which conditions can hydrogen be considered as green, i.e. produced from renewable energy sources? In this debate, the EU as a global frontrunner has set the agenda, driven by its legally binding renewable energy targets that require a detailed, legally enforceable definition of hydrogen and derivatives of renewable origin. Criteria for renewable hydrogen have been developed in the second and third revision of the EU Renewable Energy Directive (RED II and III). The main criteria in discussion are:

- The additionality of the renewable energy capacities producing the electricity consumed for the electrolysis: Is the hydrogen produced with additional renewable electricity generated for this purpose, or is existing renewable electricity simply re-allocated towards green hydrogen production?
- In case of electrolysers connected to the grid, the time and spatial correlation between the operational time and location of electrolysers and of the electricity generated by (additional) renewable capacities. If the electrolysers also produce at times of low renewable shares and thus higher emission intensity, the electricity demand is likely to be met by additional fossil generation. The same applies if there are physical bottlenecks between them.
- The criteria are relaxed in case of (national/regional) power systems that have already achieved very high shares of renewables.

The underlying questions and concerns are relevant for any country that seeks to incorporate green hydrogen in a clean energy system. Furthermore, the EU definition of renewable hydrogen will be immediately relevant for project developers and non-EU countries intending to export green hydrogen or derivatives to the EU.

Whether a joint approach to classifying green hydrogen is attainable at the G20 level, however, is another matter – given that most G20 countries outside the EU do not prioritize renewable hydrogen as such, but instead rather opt for a classification based on the GHG intensity of different pathways of hydrogen production.

Greenhouse Gas Emission Intensity of hydrogen production

A key venue for this debate is the International Partnership for a Hydrogen Economy (IPHE), which has developed a *Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen* (IPHE 2022). A previous draft of this IPHE methodology had been criticized for underestimating the fugitive methane emissions linked to hydrogen production from natural gas and coal. Moreover, the draft methodology underestimates the GHG emissions from electrolysers connected to the grid. Unfortunately, most of these issues have not been addressed in the new version of the IPHE methodology.

An overly narrow focus on green hydrogen may run the risk of overlooking such deficiencies in the calculation of non-green production methods, as it leaves the control of the debate on the GHG emission accounting of fossil-based hydrogen in the hands of countries with vested interests in fossil energy assets. Since several countries plan significant investments in 'blue' hydrogen production, it is crucial that the remaining CO_2 emissions, as well as fugitive methane emissions, are properly accounted for. By underestimating fugitive methane emissions, the proposed IPHE methodology would further tilt the playing field between fossil and renewable hydrogen in favor of fossil-based varieties.

In order to avoid favoring non-green fossil hydrogen by underestimating methane leakage, common standards should be developed for determining greenhouse gas emissions associated with hydrogen production. These must adequately account for fugitive methane emissions in particular. The G20 should establish a working group to standardize and coordinate monitoring and certification procedures that include key environmental and social sustainability aspects of (green as well as non-green) hydrogen. The G20 can be a relevant venue to discuss how to create a level playing field between green and fossil hydrogen, based on a seamless monitoring - including via satellites - of methane emissions caused by the gas infrastructure related to hydrogen production sites. Bringing these issues on the agenda will help create an incentive to reduce methane and CO_2 emissions from fossil-based hydrogen and avoid that "grey-bluish" hydrogen is sold as zero-carbon blue.

Lead markets for green hydrogen

Predictable demand for green hydrogen reduces the risks for investors and accelerates the build-up of production capacities. G20 members can create such demand by establishing lead markets for green hydrogen and its derivatives.

It is crucial to identify no-regret options in the hydrogen value chain on which wide consensus in the G20 might be achievable. The focus is therefore on green hydrogen, as it is supported by all G20 members and a priority for many of them, while fossil and nuclear-based hydrogen are not supported by all G20 members.

On the supply side, some of the crucial elements for the market ramp-up of green hydrogen production are:

- A massive expansion of the global industrial capacities to produce electrolysers as well as a further expansion of production capacities for wind, solar and other relevant equipment,
- Securing the availability and the sustainability of the critical materials needed for this equipment, and promoting R&D aiming at substituting them with less critical materials,
- Securing the availability of land and water surfaces to deploy massive amounts of additional renewable energy capacities, mainly wind and solar, privileging areas with low levels of impact on biodiversity and on other key environmental and social standards,
- Creating the necessary transport infrastructure, including hydrogen and possibly ammonia pipelines, as well as the infrastructure necessary to handle the increasing volumes of hydrogen derivatives and, possibly, of liquid hydrogen shipping.

Some of these elements, especially infrastructure and research, require supportive policy frameworks that could be coordinated in the G20 to achieve synergies. Lead markets also require stable and predictable demand, be it from the private or public sector.

- Carbon pricing instruments setting a sufficiently high future price on GHG emissions can be a main driver for green hydrogen investments, for instance by steel plants or refineries.
- Private sector demand can also be stimulated by requiring an increasing share of current hydrogen demand (e.g. for fertilizer production or petrochemical applications)[2] to be met with green and sustainable hydrogen. Alternatively, fossil energy uses where hydrogen-based alternatives exist (e.g. fuels for aviation and shipping, or steelmaking) can be required to meet a certain share of their energy use with green hydrogen or derivatives. However, such policies must not discourage the use of alternatives with a lower carbon footprint, such as direct electrification of industrial processes.
- It is also conceivable to extend this approach to lead markets for green basic materials, such as steel or chemicals, which could benefit from preferential treatment or be subject to a quota requirement (Åhman, Arens, and Vogl 2022).
- Public demand can be created through a commitment to procure basic materials that were produced with green hydrogen, public infrastructure and building projects using green steel. Efforts to advance could build on the Clean Energy Ministerial's Green Public Procurement Principles.[3]
- Involving large financial institutions in the process of creating sustainability standards could help to facilitate access to attractive financing opportunities, as investments carry lower risks.

An expression of the joint commitment to advance toward an international green hydrogen economy, based on joint standards, would be an important signal for market actors. The G20 could also provide an important forum for exchange on planned production and consumption of green hydrogen, possibly accompanied by a common reporting framework.

Support the production of green hydrogen in non-G20 countries

Efforts to expand the production of green hydrogen should not be restricted to G20 members. Rather, G20 members could support the build-up of a green hydrogen economy in other countries by granting preferential market access for green hydrogen, its derivatives and green basic

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[2] As long as petrochemical applications are needed. If the global economy progresses towards a climate neutral economy, the usage of petrochemical products should start shrinking massively during the next two decades.

[3] See https://www.cleanenergyministerial.org/iddi-drives-global-green-procurement-with-global-pledge-to-procure-green-steel-and-cement/?cn-reloaded=1.

materials. They could also support the build-up of infrastructure for the production and transport of green hydrogen and derivatives. Such efforts could build on (existing or newly established) energy and climate partnerships for technology transfer and capacity building.[4] Bi- and multilateral financial mechanisms could be used to de-risk investments in green hydrogen in non-G20 countries, for instance by providing credit risk guarantees (Steckel and Jakob 2018).

Instead of trading green hydrogen (or derivatives) internationally, it may be preferable from a climate perspective to use the green hydrogen where it is produced. Lead markets for green basic materials (such as steel or chemicals) would pose an incentive to use green hydrogen in the country of production. Other options include financial support, possibly funded by bi- and multilateral development cooperation. The recent Just Energy Transition Partnerships with South Africa, Indonesia and Vietnam demonstrate how energy policies can be linked to a broader discourse of social transformation, identifying measures that simultaneously advance environmental and social sustainability. Similar approaches – e.g. strategically building up related industries – could spur the production and use of green hydrogen in these countries.

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[4] The South Africa Just Energy Transition Investment Plan covers green hydrogen as one of three priority areas for finance. See https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_22_6664.

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