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End of previous Forum article

André Wolf and Nils Zander

Green Hydrogen in Europe: Do Strategies Meet Expectations?

The possibility of producing hydrogen as an energy carrier or raw material through electrolysis of water, so-called green hydrogen, has been on the table as a technological option for a long time. However, low conversion efficiency and a dubious climate balance have stood in the way of large-scale application ever since. Within the last three to four years, however, this view has changed significantly. In addition to technological improvements, the increasing speed of the expansion of volatile renewable energies in Europe has also contributed to this, since in principle a nearly climate-neutral utilisation of excess generation is possible through the use of hydrogen as an energy carrier in electrolysis. In addition, hydrogen or products derived from it can be used in a variety of ways as a final energy carrier in all energy-intensive activities: industry, heating and transport. For this reason, green hydrogen production could play a key role in interconnecting all energy consuming sectors (sector coupling), a long-term goal necessary for achieving the decarbonisation of the European economy.

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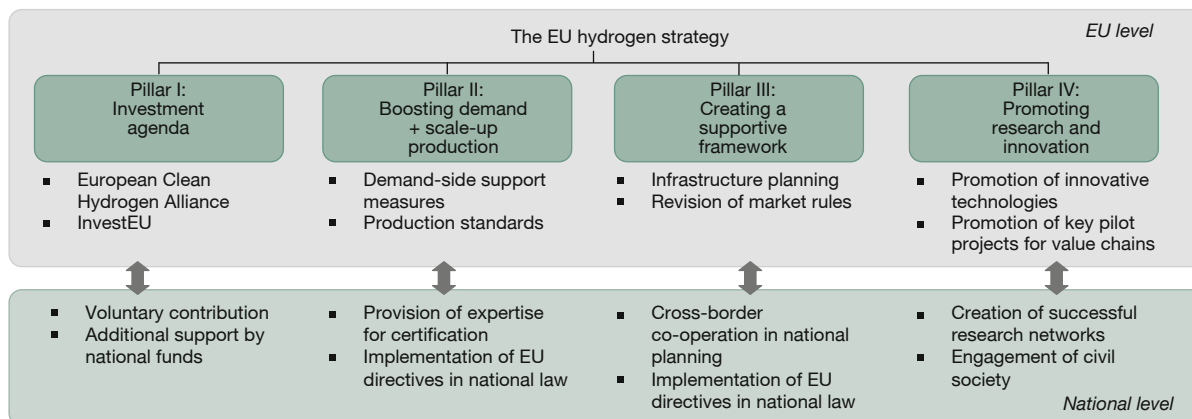
The European Commission has recognised this potential in its recent policy plans. The European Green Deal identifies hydrogen as key to a clean and circular economy. Furthermore, the European Union (EU) has issued a specific hydrogen strategy in 2020, bundling measures to promote a fast and targeted development of production capacities for green hydrogen. Nevertheless, successful implementation requires a sufficient degree of initiative at the national level. In view of the differences in economic structure and natural conditions, the EU countries understandably set different investment priorities. Despite this drawback, it is crucial that the national ambitions will eventually develop into a uniform strategy at the European level, making the continent's hydrogen economy more tangible.

This paper examines the current state of policymaking in EU countries concerning the roll out of a hydrogen infrastructure. As legislation in this area is still in its infancy, this takes the form of an examination of strategic long-term plans rather than an assessment of specific laws. In order to be able to assess the ambition of the political plans, the formulated goals are viewed through the lens of existing projections on the utilisation potentials of green hydrogen in individual countries.

The EU hydrogen strategy

In July 2020, the European Commission (2020) published its “Hydrogen strategy for a climate-neutral Europe”. It consists of a roadmap for the establishment and scale up of value chains based on the production of “green” hydro-

Figure 1
Pillars of the EU hydrogen strategy



Source: Author's own representation.

gen. According to the EU definition, hydrogen is labelled “green” if it is produced through the electrolysis of water, provided that the electric energy used as input is generated from renewable sources. The roadmap sketches a path consisting of three phases. In the short-term phase until 2024, the focus is on producing green hydrogen for existing applications. These are mostly limited to the chemical industry, where hydrogen is currently being used as feedstock in the manufacturing of fertilisers. At the same time, new applications should be promoted. To this end, electrolyzers with a total capacity of 6 GW are built up, producing up to one million tonnes of green hydrogen per year. In the medium term (2025-2030), the roll-out of electrolyzers is supposed to increase its pace, with hydrogen conquering new application fields including the role of energy carriers in energy-intensive industries (e.g. steel) and diverse transport applications. The total capacity of electrolyzers is envisaged to reach 40 GW in 2030, coupled with an effective annual production of up to 10 million tonnes of hydrogen. Finally, in the long term, from 2030 onwards, the use of green hydrogen will spread to all application areas where it is technically feasible and exhibits cost advantages compared to alternative green technologies.

To promote a timely rollout, several measures at the EU level have been designed and grouped into four pillars. The first pillar consists of fostering investments with funds from InvestEU as financial support and the European Clean Hydrogen Alliance as a stakeholder platform to coordinate an investment agenda. The second pillar consists of measures supporting the growth of hydrogen supply and demand for hydrogen-based applications, including fiscal incentives such as the Carbon Contracts for

Difference programme. The third pillar comprises measures creating a supportive framework for market growth, including the planning of physical infrastructure for hydrogen-based value chains and the revision of market rules to facilitate access to hydrogen for end users. The fourth pillar seeks to promote innovation by means of financing pilot projects and demonstrators through the EU regional funds. Finally, domestic measures are complemented by plans to increase cooperation with partners outside the EU on issues like regulation and infrastructure.

While these measures are designed at the EU level, their implementation requires the active involvement of legislators and private stakeholders in all member states. Figure 1 illustrates the relationships between actions at the European and national levels. This concerns all four pillars of the EU strategy. The actual extent of investment support for hydrogen projects will depend on the member states' willingness to contribute parts of their shared management funds to InvestEU (“Member State compartment”) as well as on the implementation of own financial instruments at the national level. The EU-wide effectiveness of regulatory support measures for a rollout of hydrogen production requires timely transmission of related EU directives into national laws. The build-up of an EU-wide hydrogen infrastructure requires sufficient prioritisation in national infrastructure planning. The success of pilot projects hinges on the strength of networks between public and private stakeholders in member states as well as on the willingness for cross-border cooperation. Against this background, some EU members have already issued own national hydrogen strategies or at least hydrogen-related goals within overarching action plans. They reveal discrepancies both in focus and overall ambitiousness. This deserves further examination.

Table 1
Indicators for hydrogen usage potential in EU member states

Country	Final electricity consumption / Capacity electricity storage (2018)	Share of variable renewable energy in electricity production (% , 2018)	Household heat consumption per capita (kWh, 2018)	Share of chemical industry in total domestic value added (% , 2018)	Share of basic metals in total domestic value added (% , 2018)	Share of road transport in total inland freight transport (% , 2019)
Austria	0.32	10.91	1013.13	1.44	2.64	66.70
Belgium	0.54	15.24	16.58	3.82	1.52	76.60
Bulgaria	0.33	5.68	511.00	1.35	1.65	47.10
Croatia	0.42	10.35	312.77	0.51	0.17	70.70
Cyprus	0.31	8.31	-	0.32	0.26	100.00
Czechia	0.34	3.38	1060.62	1.59	1.37	73.80
Denmark	0.27	48.92	3239.39	1.25	0.23	88.50
Estonia	0.33	5.39	2868.31	0.91	0.17	58.00
Finland	0.63	8.47	3355.73	2.37	1.26	72.80
France	0.39	6.88	222.89	2.09	0.55	87.90
Germany	0.27	24.28	555.75	2.42	1.29	73.40
Greece	0.30	18.95	57.06	1.20	1.79	97.50
Hungary	0.53	3.87	541.47	1.68	1.23	68.50
Ireland	0.30	27.80	-	0.00	-	99.40
Italy	0.31	13.96	172.63	1.74	1.27	88.10
Latvia	0.26	1.83	2224.87	0.60	0.09	26.40
Lithuania	0.42	37.53	1854.95	2.24	0.05	32.60
Luxembourg	0.47	17.01	-	0.30	-	85.00
Malta	0.48	9.63	-	0.20	0.01	100.00
Netherlands	0.53	12.56	194.18	2.75	0.57	50.90
Poland	0.45	7.71	1111.90	1.54	1.13	76.00
Portugal	0.29	22.84	0.97	0.83	0.55	87.00
Romania	0.30	12.47	421.87	0.67	1.09	45.00
Slovakia	0.46	2.20	861.96	0.71	2.74	65.50
Slovenia	0.46	1.60	413.00	1.56	2.02	64.50
Spain	0.27	23.20	-	1.68	0.96	95.20
Sweden	0.35	10.42	2918.51	1.34	1.96	69.30
EU average	0.38	13.76	1087.71	1.37	1.06	72.83

Note: Values clearly above (>10%) EU country average are highlighted.

Sources: Authors' own calculations based on Eurostat (2021).

Current usage potentials across Europe

In principle, the wide range of potential application fields for hydrogen would allow EU countries to formulate tailor-made strategies for the rollout of green hydrogen. Given the current differences in economic structure and thus in sector-specific energy needs between member states, this approach would be intuitive. However, diversity in national focus complicates the implementation of an EU-wide infrastructure. Assessing the perspectives for a European hydrogen economy should thus start with an ex-

amination of existing demand potentials across member states.

Table 1 lists a selection of relevant demand-related indicators, distinguishing between the four major application areas: electricity storage, heating (buildings), industry and transport. Regarding the potential use of green hydrogen as a storage option for electricity, the current magnitude of total electricity demand in relation to storage capacity is an insightful indicator. In this respect, country differences are quite pronounced in Europe. Finland, Belgium, Hun-

gary and the Netherlands currently exhibit particularly high consumption levels in relation to their domestic storage capacities, stressing the benefits of hydrogen as a complementary storage option. More specifically, future storage requirements will also depend on the relative importance of electricity stemming from volatile renewable sources (wind, solar, hydrothermal). In this regard, Denmark, Lithuania and Ireland stand out in EU comparison with especially high shares of volatile renewables in their electricity production.

A different picture is obtained for further usage areas. Concerning the use of hydrogen-based products as a heating source in buildings, household heat consumption per capita is a basic indicator. Here it is quite evident that the greatest demand-side potential is concentrated in the Nordic countries. Regarding the use of hydrogen in industrial production, a distinction can be made between the role as feedstock in the chemical industry (fertiliser production) and as an energy carrier, in particular for energy-intensive industries such as basic metals. Shares of these sectors in the countries' domestic value added are supposed to indicate the relative size of these industries. For this channel, usage potentials seem to focus primarily on Germany, the Netherlands, Finland or Austria. Finally, by implementing the fuel cell technology, many application opportunities arise for the transport sector. However, even though technical feasibility has by now been demonstrated for almost all modes of transport (including shipping and aviation), economic competition with battery-powered vehicles will most likely limit the scope of fuel cell drive to large vehicles like trucks within the foreseeable future (Morrison et al., 2018). Therefore, the relative importance of road transport in inland freight transport is an insightful indicator for the medium-term potential of hydrogen use in domestic transport. To this end, the small island states Cyprus and Malta with their pure reliance on road traffic, as well as significantly larger countries like Spain and Greece, exhibit a greater than average potential.

Hence, while usage potentials seem in some countries to be generally more pronounced than in others, relative differences in sector-specific needs could provide motivation for a diverse pattern of hydrogen use in Europe. However, whether this will actually materialise in terms of country-specific value chains will also depend on the priorities set by national policymaking.

Current state of national hydrogen policies

The state of hydrogen-related policies at the country level is similar in its degree of diversity to the demand-side potentials. At the time of writing this article, less than half (13) of EU countries had issued their own national hydro-

gen plans. Other countries (e.g. Austria, Sweden) explicitly announced the publication of hydrogen strategies for 2021. Independent of that, almost all EU countries mention green hydrogen in their 2030 National Energy and Climate Plans (NECP), the mandatory framework for member states to outline their energy and climate policies until 2030. While no country denies the long-term opportunities associated with the Power-to-Gas technology, the laid-out plans differ in ambition, scope and level of concreteness. To start with, 11 countries have set explicit targets for the evolution of hydrogen production capacities or consumption levels, including all major economies. The individual targets differ in their temporal division but share the year 2030 as a medium-term reference. France sets the most ambitious absolute target for 2030 with a capacity of 6.5 GW. Regarding hydrogen consumption, seven countries have declared explicit goals. In three countries (Bulgaria, Croatia, Slovenia), these are limited to the transport sector. Almost all countries specify their goals in absolute consumption levels, with Portugal's defined targets as percentages of total consumption being an exception. Moreover, some countries have defined more specific targets linked to production volumes or rates of fuel cell vehicles (Belgium, Czechia), shares in fuel consumption (Germany, Hungary, Italy, Slovakia, Slovenia) or number of refuelling stations (Czechia, France). In general, the specificity implies a low degree of comparability.

Existing national plans also differ in their sectoral priorities. In sketching a future vision of a hydrogen economy, not all technically feasible usage options are equally articulated. Table 2 lists the application fields that are explicitly pointed out by countries as potentially suitable either in the NECPs or the national hydrogen strategies (if available). The pattern clearly reflects the overall focus on the transport sector in the current hydrogen debate. Almost all countries are assigning green hydrogen a relevant role in decarbonising fuel use, predominantly in the context of the fuel cell technology. However, not all countries explicitly define the transport segments for which this technology is likely to become suitable. Among those that do, all see specific potentials for road freight transport in the form of fuel cell-powered trucks. Most countries also identify fuel cell-driven cars as an opportunity for the passenger traffic segment, even though the competition with battery-driven electric cars is frequently emphasised as a barrier to growth. Far less frequently mentioned is the application of hydrogen in other transport modes (aviation, shipping, trains). It is generally seen as a long-term perspective, stressing the need for further research. Regarding usage opportunities outside transport, the benefits of using green hydrogen as a new storage solution for electricity are pointed out by almost all countries. In light of future plans for an expansion of renewable ener-

Table 2
Hydrogen application areas mentioned in national policy plans of EU member states

Country	Sector	Heat- ing	Energy	Indus- try	Transport				
					General	Pas- senger	Truck		
Austria		x	x	x	x	x	x		
Belgium			x	x	x	x	x		
Bulgaria			x		x				
Croatia			x		x				
Cyprus									
Czechia		x	x		x	x	x		
Denmark			x		x				
Estonia		x	x		x				
Finland				x	x				
France			x	x	x	x	x		
Germany		x	x	x	x	x	x	x	x
Greece			x		x				x
Hungary		x	x	x	x				
Ireland			x	x	x				
Italy				x	x	x	x		x
Latvia					x				
Lithuania			x	x	x				
Luxem- bourg			x	x	x	x	x		
Malta		x	x		x	x	x		
Nether- lands		x	x	x	x		x		
Poland		x	x		x	x	x	x	x
Portugal			x	x	x	x	x	x	x
Romania			x	x	x				
Slovakia				x	x				
Slovenia			x		x		x		
Spain			x		x				
Sweden				x	x		x		

Sources: Bretagne Développement Innovation (2021); European Commission (2019); Federal Ministry for Economic Affairs and Energy (2020); Government of Portugal (2020); Government of the Netherlands (2020); Ministerio para la Transición Ecológica y el Reto Demográfico (2020); Ministero dello sviluppo economico (2020); Ministry of Climate and Environment (2021); Ministry of Innovation and Technology (2021); Streitner (2020).

gies, this solution is almost unanimously viewed as an important contributing factor to the stabilisation of the grids. Most countries also intend to promote the use of green hydrogen in industrial production – partly as a substitute for brown hydrogen in existing applications, and partly as a substitute for natural gas as an energy carrier. Finally, the use of hydrogen or hydrogen-derived products

for heating in buildings is also propagated, but in explicit form only by a minority of countries. Implicitly, additional countries are signalling interest by announcing a revision of rules regarding the access for these products to the existing gas infrastructure.

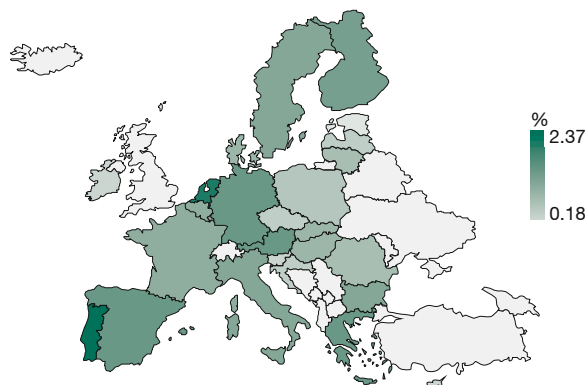
A comparison to Table 1 indicates some connection between country-specific usage potentials and national policy focus. This specifically holds for ambitions concerning the industry sector. Countries featuring high shares of domestic value added in chemical products and/or basic metals are more likely to put emphasis on this application field. Regarding the potentials of hydrogen as electricity storage, it is striking to see that all countries that do not refer to this opportunity in their national plans exhibited shares of volatile renewables clearly lower than average. The relationship of electricity consumption to current storage capacities seems to be less relevant for policymakers in comparison. This reflects the importance that policymakers attach to the need for the system integration of renewables for the future architecture of power systems in EU countries. Plans and potentials in other areas are less consistent. For instance, the use of green hydrogen as an energy source in residential heating currently plays a surprisingly small role in the plans of the Nordic countries, in view of their high heat demand.

Future relevance of green hydrogen

To discuss the future perspectives for green hydrogen across Europe, long-term energy needs and country-specific expansion goals for renewable energy carriers should be accounted for as well. In general, based on what has been said, countries with more ambitious expansion paths for renewables and/or higher growth of energy consumption are, *ceteris paribus*, expected to have greater incentives to turn to hydrogen as an additional energy source. Regarding the future evolution of energy demand at the national level, the EU Reference Scenario 2020, an energy outlook published by the European Commission (2020) based on the policy framework, provides the best overview for comparison. Accordingly, changes in consumption patterns are governed by significant country discrepancies. Comparing the situation in 2030 with the base year 2020, seven of 27 EU member states are expected to reduce their total energy consumption, including France and Germany. Conversely, data predicts that a number of large Central and Eastern European countries (Hungary, Poland, Bulgaria, Romania) may experience quite sharp increases where consumption levels are expected to increase by more than 10% by 2030 (European Commission, 2021a). At the same time, however, these countries are comparatively less ambitious regarding their expansion goals for renewable energies. Assess-

Figure 2
Potential future hydrogen coverage in the EU

Hydrogen consumption / Final energy consumption 2030 (%)

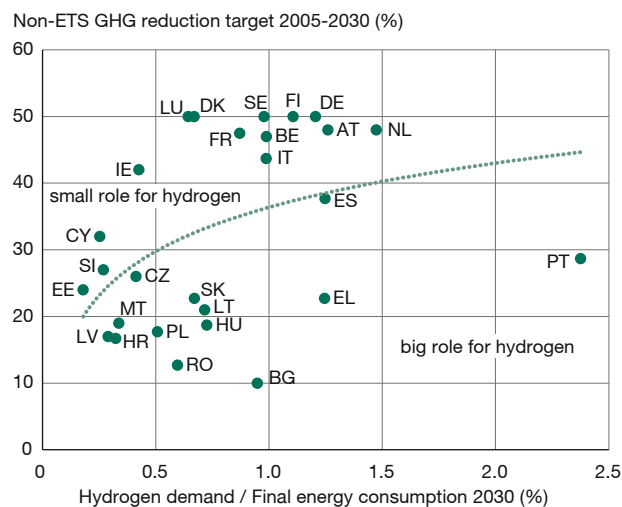


Sources: European Commission (2021a); Trinomics and LBST (2020); author's own calculations.

ing the future role of hydrogen in country comparison thus requires careful investigation of both policy goals and demand-based requirements.

Against this background, a recent study commissioned by the European public private partnership Fuel Cells and Hydrogen Joint Undertaking has developed demand and production scenarios for green hydrogen in EU countries based on their infrastructure, economic structure and policy environment. They have estimated low and high scenarios for production capacities of electrolyzers and required inputs of renewable energies for the year 2030. While the range opened up by the two scenarios reveals a high degree of uncertainty, average differences between countries are still significant. Due to its high demand potential, Germany is expected to have the highest production capacities by far. On scenario average, projected capacities for Germany (8.35 GW) are more than twice as high as those of the second largest producer France (3.25 GW). Spain (2.55 GW) and the Netherlands (2.2 GW) are also predicted to become relevant producers in absolute terms (Trinomics and LBST, 2020). However, to assess the future relevance of hydrogen at the national scale, the projected expansion paths must be viewed in relation to the evolution of total energy demand. Seen from this angle, the pattern changes quite substantially. Figure 2 maps the relation of projected national hydrogen consumption by Trinomics and LBST (2020) to the EU forecasts of total energy consumption discussed above. The total span of hydrogen coverage ranges from less than 1% to more than 2%. While Austria, Finland, Germany, Greece, the Netherlands and Spain exhibit higher than average cover-

Figure 3
Relationship between emission reduction goals and hydrogen potential in EU member states



Sources: European Commission (2021a); European Commission (2021b); Trinomics and LBST (2020); author's own calculations.

age rates, the highest rate by far is observed for Portugal, where 2.37% of total final energy consumption in 2030 is projected to be satisfied by hydrogen.

The strategic relevance of hydrogen becomes even clearer when the demand potential is contrasted with the level of ambition in pursuing climate targets. This applies above all to the decarbonisation of the transport sector and heating in buildings, as these are currently not yet subject to Europe-wide regulation via EU emissions certificate trading (EU-ETS). As defined in the Effort Sharing Regulation (ESR), individual targets for GHG emission reduction in non-ETS sectors have been assigned by the EU Commission to member states, taking differences in adjustment capacities into account. As part of its Fit for 55 package, the Commission recently made proposals for adjusting these targets to meet the new EU-wide objective of reducing emissions by at least 55% by 2030 compared to 1990. Total reductions in ESR-sectors over the time span 2005-2030 would have to amount to 40% instead of the 30% underlying the current regulation. At the same time, the Commission maintains the practice of setting the expected national contributions at very different levels.

Figure 3 plots the proposed adjusted national targets together with the rates of hydrogen coverage discussed above. In general, it shows an intuitive positive correlation: Countries with more ambitious requirements regarding emission reductions exhibit a bigger potential for green hydrogen in their future energy consumption. However, some country clusters are visible. Northern and Western European countries are facing by far the most ambitious

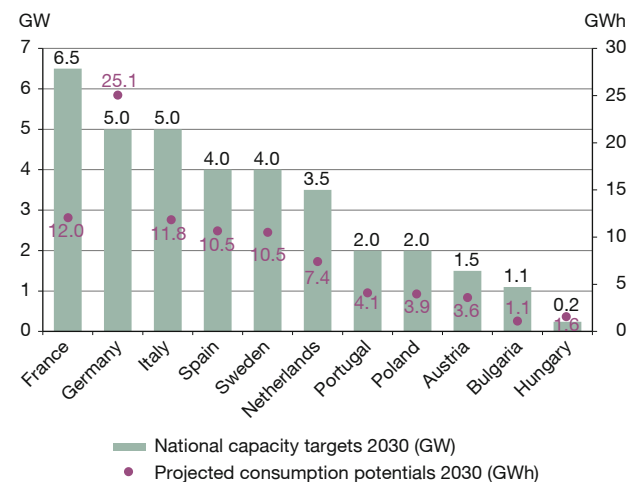
emission goals but, in relation to their energy demand, are not located at the absolute forefront of green hydrogen potential in Europe. In comparison, a group of Eastern European countries is assessed to have similar levels of hydrogen potentials, albeit with significantly weaker climate obligations. Moreover, the large hydrogen potentials expected for some Mediterranean countries, in particular for Portugal, stand out even more when viewed in relation to their only medium overall reduction targets. In parts, this reflects geographical conditions. These countries exhibit the highest potentials for solar-based electricity generation in Europe. The large coastal areas also represent significant opportunities for offshore wind power. At the same time, their spatial proximity to Northern Africa as one of the regions with the best natural conditions for volatile renewables worldwide (DTU, 2021; Solargis, 2021) also suggests considerable long-term potential for green hydrogen import.

Realising the identified potential requires tailor-made strategies at the country level, with proper focus on country-specific usage potentials and plans for capacity rollout. As discussed above, the level of concreteness in member states' current plans can be considered insufficient in this regard. When writing this article, 11 of 27 EU countries had published concrete targets for capacity building of electrolyzers. Among those, the relationship to consumption potentials is not always coherent (see Figure 4). Germany has set itself a lower capacity target than France, even though its projected consumption potential is more than twice as high. Spain possesses almost the same potential as France but is currently considerably less ambitious in its policy goals. Hungary has published the most modest plans for the future enrolment of electrolyzers, even though its usage potential lies in the range of countries of comparable economic size. For other countries, including potential major consumers like Italy, Sweden and the Netherlands, plans are more in line with mid-term consumption opportunities.

Conclusion

Against the backdrop of the EU's more ambitious climate targets, the technology of green hydrogen production has gained increasing importance in national plans to implement the energy transition. Currently, hydrogen strategies are published or are under way in almost all EU countries. However, plans differ both in concreteness and level of ambition. Viewed in relation to the expected national consumption potentials, different groups of countries can be relatively clearly distinguished from one another. For example, green hydrogen can play a particularly important role in decarbonisation in the Mediterranean countries. But hydrogen can also make a

Figure 4
Green hydrogen: Capacity targets and consumption potentials in the EU



Sources: Bretagne Développement Innovation (2021); European Commission (2019); Federal Ministry for Economic Affairs and Energy (2020); Government of Portugal (2020); Government of the Netherlands (2020); Ministerio para la Transición Ecológica y el Reto Demográfico (2020); Ministero dello sviluppo economico (2020); Ministry of Climate and Environment (2021); Ministry of Innovation and Technology (2021); Streitner (2020); Trinomics and LBST (2020).

major contribution in the Eastern European region in relative terms, given the less stringent emission reduction targets. For a successful implementation of the hydrogen economy, it is important not to restrict the planning to a race for electrolysis capacities. The development of infrastructure and value chains should be geared to the utilisation potentials and the country-specific differences that exist in this context. The structural differences between EU countries offer potential for a new European division of labour within a common hydrogen network, both in terms of production and consumption. This stresses the need for cross-country collaboration in planning a European hydrogen infrastructure. National plans in the medium term should be harmonised based on EU-wide consultation under the umbrella of the EU hydrogen strategy. Investment support as part of the European Green Deal will be crucial in this regard, assigning the European Commission a leading role for the steering of investments.

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