Ariadne-Analysis

Securing hydrogen imports for Germany: Import needs, risks and strategies on the way to climate neutrality

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Content

Preface to the English translation

This paper is a slight adaptation of the German-language analysis "Wasserstoffimportsicherheit für Deutschland – Zeitliche Entwicklung, Risiken und Strategien auf dem Weg zur Klimaneutralität", published in December 2021. The analysis takes a close look at Germany's future need for hydrogen imports, hydrogen import-related risks as well as strategies to secure hydrogen imports.

The original version targets the German energy and foreign policy community as well as the broader public in Germany. Accordingly, it is written from a German point of view and based on data on Germany. By showcasing Germany, this English translation has the aim to provide relevant insights for other future hydrogen-importing countries on the way to climate neutrality. Most qualitative arguments concerning import risks and the strategies to manage them could also largely be applied to these countries. Further, the insights on the German debate provided in this paper may prove interesting to readers from abroad.

Under this premise, the Germany-focused scenarios have not been adapted in this English translation. Rather, the adaptations are limited to a few explanations aiming at explaining the context for certain assumptions or facts to a non-German public and, in certain cases, at discussing to which extent they might be applicable also to the EU or other future hydrogen-importing countries.

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Executive Summary

The objective of this analysis is to outline how Germany's need for hydrogen imports will develop over time, to define various risks associated with the import of hydrogen, and to develop strategic approaches to manage these risks. In this document, the term "hydrogen" will also refer to its derivative products.

Four simple scenarios are used to predict how **Germany's need for hydrogen imports will develop over time**. It is shown that Germany's overall need for energy imports will decline both proportionally and in absolute terms as the country progresses towards climate neutrality. The very large quantities of fossil fuels and uranium imported today will have to be replaced by significantly smaller quantities of climate-neutral energy, mostly consisting of hydrogen. How much energy countries such as Germany will have to import largely depends on their success in reducing energy demand, promoting direct electrification and deploying domestic renewables.

With time, the context for securing hydrogen imports will change considerably. Over the next few years, the hydrogen option will mostly be developed on the grounds of climate policy. For this purpose, initial supply channels will probably be established for the most part through bilateral agreements. At the same time, first hydrogen infrastructures will be built and preparations will be made for the development of a hydrogen market.

After 2030, when demand for hydrogen increases and the range of applications broadens, both the economy and society will become more vulnerable to possible hydrogen import shocks. On the other hand, the much greater vulnerability associated with fossil fuel imports will decrease. At the same time, with the successive dismantling of the fossil fuel infrastructure, the latter will be losing its function as a back-up in the case of hydrogen import disruptions. Meanwhile, the ramp-up of the international hydrogen economy will result in a more diversified import infrastructure and more liquid markets, which in turn will make hydrogen import risks easier to manage.

Hydrogen import security can be jeopardised by various **risks**. Besides the three overarching areas of *availability, affordability* and *sustainability* of imported hydrogen, further risks arise along the import chain. Risks associated with exporting countries include an insufficient *number of hydrogen-exporting countries and companies*, *political instability in exporting countries*, and *exporters becoming non-substitutable* due to an insufficiently diversified transport infrastructure or an inflexible hydrogen market. During transport, *transit risks* caused by domestic or international conflicts along the supply route as well as *transport risks* caused by technical or physical issues can arise. There is also a growing risk that hydrogen-importing countries such as Germany will be *unable to fully compensate for shortages of hydrogen imports*. Three factors determine the replaceability of hydrogen in the event of shortages: the availability of hydrogen storage, the options available for switching energy carriers at short notice, and the short-term scalability of domestic hydrogen production.

Strategic measures for securing imports divided into three categories are presented. Firstly, import risks could be reduced by *limiting demand for hydrogen imports*. This can be achieved by the reduction of overall energy demand through energy sufficiency (e.g. reducing motorised individual transport), energy efficiency (e.g. refurbishing buildings) and direct electrification (e.g. switching to electric mobility). Further means to limit the demand for hydrogen imports are the expansion of the domestic production of green hydrogen and the associated expansion of renewables. Secondly, the ramp-up of the hydrogen market must be boosted by setting ambitious, reliable climate and energy targets, offering investment incentives, establishing R&D programmes and making sufficient investments in hydrogen infrastructure, with the goal to secure the *availability, affordability and sustainability of hydrogen imports*. Additionally, foundations must be laid for the diversification of hydrogen import sources and transport routes; in terms of infrastructure (pipelines, ports of entry), market structures and trading relations. Appropriate standards and certification procedures must be developed to safeguard the sustainability of imports. Thirdly, preventive measures against import shortages, price shocks and critical situations, could include early import risk detection, the development of a strategic hydrogen reserve and holding domestic hydrogen production capacities on standby. Emergency plans must be developed for severe supply shortages.

In the end, this analysis tries striking a **balance between cooperation and competition between various countries** when it comes to securing hydrogen imports. If all future hydroge-importing countries implement the strategy outlined here, positive synergies will arise when ramping up the market, preparing for crisis situations, and dealing with many aspects of securing imports. Conversely, the implementation of other strategic measures could give rise to competition between hydrogen-importing countries for the most affordable hydrogen sources. Given the urgent need for global decarbonisation, the success of a hydrogen-importing country which secures these scarce resources for itself and prevents access for others would be questionable if it meant that other countries had to continue to rely on emission-intensive energy. Rather than relying on international energy policy approaches from the oil age, then, Germany should – in the spirit of climate mitigation – pursue a cooperative approach to securing hydrogen imports, coordinating its activities with other importing countries and especially with EU member states.

List of abbreviations

BECCS	*Bioenergy with carbon capture and storage*
CCS	C*arbon capture and storage*
CO_2	Carbon dioxide
DAC	D*irect Air Carbon Capture*
DACCS	D*irect air carbon capture and storage*
GHG	Greenhouse gases
H_2	Hydrogen
IEA	International Energy Agency
LOHC	L*iquid Organic Hydrogen Carriers*
PEC	Primary Energy Consumption
PtX	Power-to-X
R&D	Research and Development
TWh	Terawatthours

Introduction and central question

In its coalition treaty, Germany's new government has laid out comprehensive measures for accelerating the energy transition and putting Germany on the path to climate neutrality by 2045. As a result, the importance of low-carbon hydrogen as an energy carrier and feedstock will increase more rapidly than previously planned. In this text, references to hydrogen also include hydrogen derivatives such as synthetic energy carriers and ammonia.

Hydrogen is sometimes referred to in public debate as the "oil of the 21st century". This analogy can create the impression that the geopolitics in a climate-neutral world will be similar to that of the twentieth century, dominated by risks and conflicts surrounding access to and the distribution of oil and natural gas. However, this is only partly to be expected.

Although hydrogen is set to become a key energy carrier and feedstock[1], which will account for a large part of internationally traded energy, the oil analogy is in other respects misleading: As a new primary energy carrier, oil conquered global energy markets in the 20th century because of its technical superiority, which in many cases outclassed all of the alternatives. This is not directly applicable to hydrogen, since its development is required and driven by *climate policy.* Unlike oil, future demand for hydrogen imports will depend on the stability of the climate policy framework, and countries will be able to rely on fossil alternatives for quite some time if need be. In a world striving for climate neutrality, the principles and strategies for securing imports will therefore be subject to change.

Another striking geopolitical difference is the possibility that international trade of hydrogen in a climate-neutral world may be less asymmetrical than has so far been the case with oil and natural gas. One reason for this is that more countries will be able to cover their energy needs with domestic (renewable) energies.[2] Because of their high population density and high demand for energy, other countries will have to rely on hydrogen imports to supplement their domestic renewables potential; along with Germany, these will include numerous EU member states, China, Japan, Korea, and presumably India and

[1] In most cases, our use of "energy carriers" also incorporates the material use of hydrogen and hydrocarbons as feedstocks.
[2] Van de Graaf et al. (2020). Cf. also the remarks made by Pflugmann and De Blasio (2020) on this debate.

others. However, these energy import needs can be reduced by pursuing energy efficiency and expanding the production and use of domestic renewables. Moreover, future hydrogen-exporting countries are geographically more evenly distributed than today's energy-exporting countries. This could reduce the vulnerability of the European and global economy to disruptions on individual transport routes. By minimising the access and distribution risks associated with fossil fuels and by resolving the conflicts caused by climate change, the energy transition could create a "global security dividend".[3]

The term "dependence" is often used in connection with imports. This term has negative connotations and suggests that a country's reliance on imports in specific areas is as such problematic. The logical consequence would be the notion that complete autarky is an economy's ideal state. There are many economic, political, social and geographic arguments against this notion, none of which can be elaborated on here. We would merely like to note that efforts to achieve energy autarky would be of little benefit to large trading countries like Germany, which have comparatively few energy resources and raw materials of their own and whose prosperity mainly comes from exports of high-value industrial products and services. This argument is valid also for other energy importing countries. This is why we refer to "import needs" rather than "import dependence" in this analysis.

As we progress towards climate neutrality, the requirements for energy import security will continue to change. Hydrogen imports will be especially important for Germany and other energy-importing countries, if they are to be successful with their energy transitions. The goal of this analysis is to showcase the role of hydrogen imports in Germany, describe the risks associated with the import of hydrogen and develop strategies for securing these imports.

[3] Goldthau et al. (2018).

Development of hydrogen import needs

Next, we will discuss the framework conditions in which Germany will have to secure its energy imports in the future. These include the development of hydrogen import demand, the progress made in expanding the infrastructure, and the availability of alternative energy supply options. While this analysis and its data focus on Germany, many of the lessons drawn from this analysis can be applied to other industrialised countries that are expected to become net hydrogen importers in the future.

Fig. 1 shows four possible scenarios for Germany's primary energy consumption (PEC) on the way to climate neutrality; divided into domestically produced energy and net energy imports. These developments are based on the scenarios of the Ariadne scenario report but have been simplified and generalised.[4] In general, most current studies with ambitious climate protection targets take a similar course with regard to the key parameters, since the scope of transformation pathways is limited by the status quo and the challenging nature of the targets. The Ariadne policy brief "Cornerstones of an Adaptable Hydrogen Strategy" synthesises bandwidths for the use of hydrogen and its derivatives from five scenario studies on Germany and describes the technical and economic uncertainties that determine the viability of the different pathways.[5] The specific assumptions behind each scenario are described in this footnote[6].

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[4] See: Ariadne (2021): Deutschland auf dem Weg zur Klimaneutralität 2045. Szenarien und Pfade im Modellvergleich. Ariadne-Report.

[5] See: Ariadne (2021b): Eckpunkte einer adaptiven Wasserstoffstrategie. Ariadne-Kurzdossier.

[6] According to the simplified logic used in these diagrams, the difference between energy consumption and domestic renewable energy production yields the amount of energy that will have to be imported. In reality, this one-sided chain of effects is not realistic, since these three variables will interact with each other.

The diagram does not show net electricity exports (approx. 35 TWh or 126 PJ in 2019). In 2020, they declined by about half. It is generally assumed that they will fall to zero in the near future and that Germany will become a net electricity importer in the medium term.

Energy consumption: scenarios 1 and 2 assume that PEC will fall from 12,800 PJ in 2019 to 7,200 PJ in 2045. This corresponds to the target set by the federal government in 2010 for the year 2050, when the goal of an 80% reduction in emissions by 2050 still applied. Scenarios 3 and 4 are based on studies which anticipate that PEC will fall more sharply when climate neutrality is achieved; these assume that PEC will drop to 9,000 PJ by 2030 and to 6,500 PJ by 2045. All four scenarios indicate that PEC will only fall slightly between 2045 and 2060, either to 7,000 or 6,300 PJ.

Domestic renewables production: scenarios 1 and 3 assume that Germany will be generating 1,500 TWh (5,400 PJ) from its own renewable resources (including renewable heat) by 2045. This figure is based on Agora Energiewende et al. (2021). Scenarios 2 and 4 assume that the production of renewables will only have risen to 1,200 TWh (4,320 PJ) by 2045. This rough estimate reflects the constraints that may arise due to competing land use claims, lack of acceptance, or the fact that producing renewables may be less economically efficient than importing them. All of these scenarios use linear interpolation to calculate the expansion of renewables by 2045; this will decrease slightly after 2045 since energy demand will continue to decline.

Domestic production of fossil fuels: it is assumed that this will fall to zero by 2030. This could also happen somewhat earlier or later, depending on how quickly lignite is phased out and the already greatly reduced extraction of oil and natural gas ends completely. Even without the domestic production of fossil fuels and despite the completion of the nuclear phase-out, energy imports from fossil fuels will decline by 15% to 38% (depending on the scenario) between 2019 and 2030 as a result of reduced consumption and the increased use of renewables.

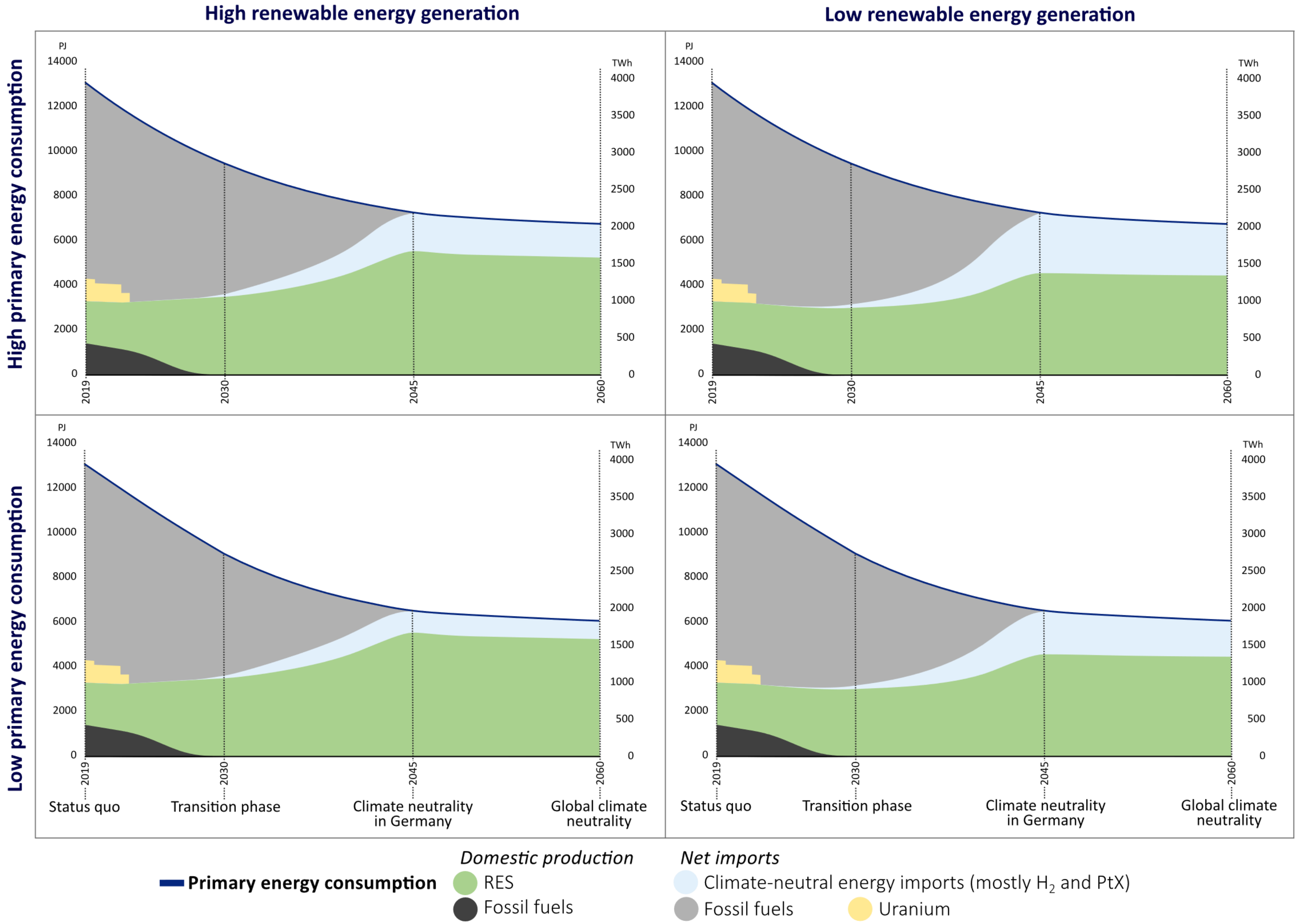

Fig. 1: Development of German energy import needs depending on energy consumption and domestic renewables generation

Germany's energy import needs depend primarily on two variables in the scenarios: primary energy consumption and domestic generation of renewable energy. The less energy is consumed and the more energy is produced domestically, the smaller the demand for imported energy. This means that energy efficiency and the expansion of renewables can also be understood as measures aimed at minimising import risks.

Next, we will discuss what the scenarios have in common in terms of hydrogen import risks and strategies in four stages of transformation.

1. Status quo (2019)
2. Transition phase (2030):
3. Climate neutrality in Germany (2045)
4. Global climate neutrality (2060)

The actual years stated are not of critical importance. Although the scenarios assume that Germany will meet its climate mitigation targets, for the sake of the issues discussed in this paper nothing much would change if any of these phases were to last longer than anticipated. Moreover, we assume that fossil energy imports will in the long-term only be compatible with climate neutrality for negligible amounts, since the availability of CCS for CO2 originating from the for further use of fossil raw materials is not certain.[7]

A climate-neutral Germany could import energy in three forms: electricity, biomass and hydrogen and its derivatives. However, for all three, production would have to be climate-neutral.[8] As these are partly interchangeable and a variety of "import mixes" are possible, all are jointly classified as "climate-neutral energy imports" in the light blue area of the diagram.

[7] This assumption refers to Germany and is based above all on the uncertainty as to whether suitable storage sites will have to be partly or wholly reserved for the negative emissions generated. Moreover, the geological storage of CO2 finds little acceptance in Germany, different geological and political conditions might exist in other countries. CCS always raises the question of whether other measures can be used to compensate for methane leakages and remaining CO2 emissions. The potential of CCS for use in various situations will be investigated and discussed in greater depth in future Ariadne reports and scenarios.

[8] After the end of 2022, the use of nuclear energy in Germany is excluded by a law supported by an overwhelming majority of the population and by nearly all political parties in Parliament. It is certain or very likely that nuclear energy will be absent from or only play a very small role in the energy mix of many other energy-importing countries.

Electricity imports[9] from European countries will be subject to constraints due to area constraints, the limited acceptance of renewable plants and the need for grid expansion. For large-scale biomass imports, there are significant concerns regarding their actual GHG emission intensity and the conflicts of interest between bioenergy, biodiversity, food security and other forms of land use. We therefore assume that in the long term, the majority of Germany's climate-neutral imports will consist of hydrogen produced by electrolysis.

Status quo (2019)

As in many other countries, Germany's current energy system still strongly relies on fossil fuel imports. In 2019, Germany imported 75% of its primary energy consumption. Net imports of crude oil (35%) accounted for the majority of PEC, followed by natural gas (25%), coal (9%) and uranium (6%)[10]. Domestic extraction of fossil fuels is declining; climate-neutral hydrogen does not yet play a significant role.

Transition phase (2030)

2030 will be an important milestone on the way to climate neutrality. Rising CO_2 prices will have at least caused lignite-fired electricity generation to decline sharply or end completely – even without pulling forward the end date specified in the Coal Exit Act. In the scenarios mentioned, fossil fuel imports fall by 15% to 38% between 2019 and 2030 due to reduced energy consumption, brought about by energy efficiency and electrification, and the increased use of renewables.[11]

Until 2030, hydrogen imports will account only for a relatively small proportion of overall energy consumption. All four scenarios in fig. 1 assume that Germany will be importing 100 PJ (28 TWh) of climate-neutral energy in 2030, most of which will consist of hydrogen. During this phase, the main limiting factors for imports will be the still rather scarce supply of hydrogen from abroad and, until 2030, the limited availability of hydrogen

[9] Current studies take differing views of the long-term demand for imported electricity: Agora (2021) assumes that electricity imports will amount to 10 TWh, while the long-term scenarios set out by the Federal Ministry for Economic Affairs (BMWi) anticipate imports of up to 130 TWh (cf. www.langfristszenarien.de).

[10] AGEB (2020a)

[11] The scenarios in the Ariadne scenario report's REMIND model (Ariadne, 2021) anticipate that imports of fossil primary energy will decline by 25-32% between 2020 and 2030, depending on the scenario.

pipelines from countries in which large quantities of green or blue hydrogen can be produced at low prices. Without pipelines, hydrogen will have to be transported to Germany by ship, road or rail, which comes at high costs.

The hydrogen infrastructure is expected to undergo massive expansion during this transition phase. First hydrogen clusters can be expected to emerge in certain areas of Germany (e.g. in the Ruhr region), with their hydrogen needs being covered by first import pipelines, e.g. from the Netherlands, as well as by first import terminals at German ports. Large-scale geological hydrogen storage sites will be under construction in Germany during that time.

During this phase, most hydrogen trade will likely be on the basis of bilateral contracts, since a dynamic, liquid hydrogen market cannot be expected to emerge in this short period of time. As most of the fossil energy infrastructure will probably still be operational at this time, fossil fuels could still serve as a back-up if hydrogen imports are disrupted. Many of the first industrial users (refineries, the chemical industry, steel works) will have alternative, fossil-fuelled hydrogen production plants on site or will have no difficulty integrating them.

During this phase, hydrogen supply will be secured through hydrogen bulk storage in salt caverns, but mainly by alternative, fossil-fuelled hydrogen production facilities. Although this is less than ideal in terms of climate mitigation, it can hardly be avoided from a technical and economic viewpoint. The establishment of a system based entirely on green hydrogen at this early stage would require vast storage volumes as well as electrolysis capacities that would be all but impossible to obtain in this short time. However, this will not be necessary: The goal of the first phase must be the diffusion of hydrogen applications, which contribute to climate mitigation, as well as the production of the necessary quantities of green hydrogen. Supply security based solely on renewables can and must be achieved at a later date when the hydrogen system has reached appropriate dimensions.

Second stage: climate neutrality in Germany and the EU (2045)

The key milestone in fig. 1 is Germany reaching climate neutrality in 2045. From this point in time at the last, Germany’s entire energy needs will be covered by domestic or imported climate-neutral energy. The same is valid for all countries aiming for climate neutrality. However, the volume of energy produced domestically will be subject to restrictions. The most critical constraint is likely to be the availability of suitable area, limited by competing land use claims, nature conservation regulations and a lack of social acceptance. These obstacles make it difficult to estimate the realisable renewables potential. Since the majority of scenario analyses estimate that Germany's renewables potential does not suffice to cover all its energy needs through domestic production, it is expected that there will be a substantial need for energy imports.[12] Countries that have a significantly better ratio of renewables potential to population and energy demand, i.e. sparsely populated regions with better renewables resources, are particularly suitable as import sources.

All the scenarios in fig. 1 and all the recently published scenario analyses on climate neutrality in 2045 indicate that Germany's long-term demand for climate-neutral energy imports will be substantial. These analyses see a role for hydrogen as a feedstock and heat source for many industrial processes as well as in the energy sector during times of low renewables production. Hydrogen's role in the transport sector is still the subject of intensive discussion. With the increase in hydrogen imports after 2030, it can be expected that a robust hydrogen infrastructure in Germany, the EU and for imports will be available until 2045. Along with pipelines between the EU, North Africa, Eastern Europe (including Russia) and possibly the Middle East, this will include sizeable geological hydrogen storage sites in Germany as well as the required terminals at ports.

However, unlike in 2030, long-term disruptions to hydrogen imports would affect not only individual consumers but also the economy as a whole as well as sensitive areas of society. Sustained hydrogen shortages on a scale that exceeds hydrogen storage capacities and short-term fuel switching option would jeopardise hydrogen-dependent industries as well as security of supply of electricity and district heating.

It is possible that liquid international markets for climate-neutral hydrogen and its derivatives will have formed by 2045. These would be better able to absorb production shortfalls in individual countries or regions than an import market dominated by a few bilateral contracts. Imports by sea could play an important role in this context since they

[12] cf. for example Ariadne (2021); dena (2021); Prognos, Öko-Institut, Wuppertal Institut (2021).

would diversify the available import sources and routes, thus facilitating the development of less fragmented or even global markets for hydrogen-based, climate-neutral energy carriers.

By the time Germany achieves climate neutrality, the fossil fuel infrastructure in Germany and the EU may not have been completely dismantled or repurposed, but it will be significantly less powerful than in 2030. Many gas distribution networks as well as pipelines of the gas transmission network will likely have been decommissioned. Filling stations will no longer offer fossil fuels; all fossil-fuelled power plants will have at least been shut down, while many will have been dismantled or repurposed for hydrogen use. Other parts of the infrastructure will still exist, but considering the drastic decline in demand in the preceding years, it is likely that increasingly high capacity payments will be necessary to keep them operational. After climate neutrality is achieved, very few consumers can be assumed to still have technology at hand, which allows to switch to oil or natural gas if hydrogen imports are disrupted.

Progress towards climate neutrality entails a rapid dismantling of the fossil fuel supply infrastructure from 2030 on, which means that fossil fuels will be able to serve as back-up in fewer and fewer areas. Security of energy supply, not only in the electricity sector but also in sectors that are not to be electrified, must therefore be guaranteed by climate-neutral energy carriers.

Third stage: global climate neutrality (2060)

Fig. 1 shows the global achievement of climate neutrality by 2060 as the final stage. The actual year in which this milestone will be reached is not critical to the argument. The figure shows that little will change in Germany's energy mix between 2045 and 2060. At the same time, the global context for Germany's hydrogen import security will change significantly during the same period. In order to achieve global climate neutrality, major energy consumers such as China, India, Russia and Saudi Arabia would have to massively transform their energy sectors just like Germany and EU did in the decades before. Most of the world will then have little or no access to fossil energy infrastructures, thus largely ruling out the possibility of "relapsing" into fossil fuel use. However, this will also mean losing the potential back-up function for securing energy supply, which the physical fossil energy infrastructure still partially available in Germany and the EU in 2045 may have in emergency. In this fully climate-neutral world, security of energy supply will essentially be guaranteed by renewables. Compared to 2045, when only a few countries are climate-neutral, the world's plentiful but not unlimited renewables resources and its equally restricted CO_2 storage capacities will probably come under increasing pressure for offsetting unavoidable process emissions and achieving negative emissions. This could alter the balance between international cooperation and competition, discussed in the last chapter of this analysis.

Preliminary conclusion

For Germany as a whole, an important side effect of consistent climate policy will be a falling demand for energy imports, and thus a general decrease in the vulnerabilities associated with these imports. The rapidly growing demand for climate-neutral energy imports will be offset by an even faster decline in the demand for fossil fuel imports. Depending on the scenario, the remaining energy import demand falls to between 17% and 40% of primary energy consumption by 2045, compared to 75% in 2019.

Risks associated with hydrogen imports

The import security in countries reliant on hydrogen imports such as Germany could be jeopardised by a variety of risks. Based on research of the general scientific literature on energy security and energy import dependence[13] and in particular a study carried out by the Fraunhofer ISI into the opportunities and challenges of importing hydrogen, this analysis presents several of these risks.[14] After considering three overarching risks (availability, affordability and sustainability of hydrogen imports), this chapter analyses risks associated with hydrogen-exporting countries, risks encountered when transporting hydrogen, and risks which are largely within the control of Germany and the EU.

What is hydrogen import security?

The extensive body of literature on energy security provides widely varying definitions of this term. In this analysis, we follow a broad definition which describes energy security as a state in which a country's entire energy system, from generation and distribution to end use, shows low vulnerability on several levels (resources, economy, geopolitics, society)[15]. This definition of security primarily refers to the reduction and prevention of risks. Energy import security can be understood as a subcategory of energy security. With regard to hydrogen, it describes a state in which a country's or region's need for hydrogen imports is secured by a reliable, affordable and sustainable hydrogen supply from abroad.

Overarching risks

Until around 2030, the **availability of hydrogen imports** in importing countries will probably be secured predominantly if not entirely by bilateral supply contracts, which can also be concluded by intermediaries as in the case of the funding programme H2Global[16]. Since neither large-scale domestic hydrogen storage facilities nor a liquid international hydrogen market are expected during this phase, possible import disruptions would for the most part have to be compensated by fossil alternatives, either on the consumer's side (e.g. dual systems that could also operate using natural gas) or through potential reserve capacities for the production of grey hydrogen in the importing country. From

[13] Elbassoussy (2019); Vivoda (2009); Energy Charter Secretariat (2015); Ikenberry (1986) etc.
[14] Wietschel et al. (2020)
[15] Based on Cherp and Jewell (2014). See Gracceva and Zenjewski (2014); Azzuni and Breyer (2018); Ang et al. (2015) for other definitions.
[16] https://h2-global.de/

about 2030, we can expect the gradual development of international markets for climate-neutral hydrogen. If this is to happen, there must be adequate numbers of suppliers and customers and a physical infrastructure that offers greater flexibility for importers and domestic consumers.

Multilateral hydrogen trade would reduce the probability of shortages and bottlenecks but give rise to price risks. Particularly during the initial phase, consumers will potentially be exposed to fluctuating market prices, which could impact the **affordability of hydrogen imports.** As the market volume increases, the market will become more liquid and prices less volatile. As with other commodities, it is conceivable that import needs could be covered by a mixture of long-term contracts with stable prices and short-term trading on spot markets. On the way to climate neutrality, supply and demand may at times be out of balance. The stronger the international commitment to climate policy, the more likely it is that a liquid, competitive global hydrogen market will develop quickly. Hydrogen will become more available and affordable as the infrastructure expands. Especially once various pipeline projects have been concluded (probably after 2030), hydrogen supply is likely to stabilise.

From today's perspective, only assumptions can be made regarding the risk of a structural undersupply of hydrogen. However, one key difference to the dynamics on the fossil energy markets is already foreseeable. Global crude oil and natural gas production can fluctuate considerably, also in the short term, depending on the state of the economy and the strategic measures implemented by producers. When market prices are high, even the most expensive production sites step in. Less is produced when prices are low; some producers slow down their production for strategic reasons. In this situation, they forgo income, while their reserves stay in the ground and can possibly be sold off later at a higher price. From a business perspective, this behaviour is rational: when prices are low, the producers not only have to bear the marginal production costs (including the costs of the energy required for production) but also the opportunity costs that arise when commodities are sold at low market prices. Importers of blue hydrogen may experience a similar situation in the future – with the additional constraint that the need for more CCS infrastructures and systems will reduce the flexibility for supply regulation.

This dynamic may be somewhat different in the case of green hydrogen from wind and solar power. This is not only because the marginal costs of renewable energy generation are practically zero, but also because there are no opportunity costs. Wind which is not converted into usable energy today will not be available tomorrow. It is difficult to assess what this will mean for importers. On the one hand, price fluctuations could be absorbed by hydrogen storage facilities, which would enable importers (and also producers) to store hydrogen when prices are low and use it when prices are higher. Countries like Germany, where there are good geological conditions for large-scale hydrogen storage[17], would clearly be at an advantage here. On the other hand, hydrogen storage facilities will presumably always be more expensive than the "natural storage" of fossil fuels in the ground. Compared to the fossil fuel age, a climate-neutral world could therefore require stronger political and regulatory incentives to develop reserve capacities, since these will only rarely be required to cover unexpectedly high demand peaks or compensate for sudden supply disruptions at important production facilities or on major transport routes. This means that high-volume hydrogen storage facilities may well become all the more important in the future.

Since green hydrogen production facilities and the necessary renewable energy plants still have to be set up in all parts of the world and are likely to be in short supply over the next two decades, the question arises to what extent countries with favourable conditions will use these for export purposes. For countries like the USA, with a very high renewables potential and high energy demand, it is conceivable that domestic renewable energy resources will be used primarily to meet their own needs (including for green hydrogen). Other countries may decide to use their low-cost renewable energy resources to build up their own energy-intensive industries rather than exporting hydrogen. Potential hydrogen-exporting countries could for example work towards exporting green steel instead of hydrogen.[18]

Insufficiently **sustainable hydrogen imports** can also be viewed as an overarching risk to import security. After all, in countries with climate neutrality targets, hydrogen imports can only be considered to have been effectively secured if they actually contribute to achieving this target and overall to sustainable energy supply. The criteria to be applied

[17] Caglayan et al. (2020).
[18] Westphal et al. (2020)

and the methods by which sustainable hydrogen can be certified will have to be discussed extensively and elaborated in detail. It is expected that these criteria will gradually become stricter. Initial sustainability criteria will probably be deliberately less stringent in order to promote pilot plants (e.g. to allow for longer hours of full-load electrolysis). In the medium term, transition technologies that supplement the scarce supply of green hydrogen could be used to gain time for the development of hydrogen markets. These transition technologies (blue hydrogen, hydrogen derived from grey electricity or natural gas during steel production) cause higher emissions than green hydrogen. More stringent sustainability requirements will gradually be imposed on both domestic hydrogen production and hydrogen imports, including transportation. The development of a global hydrogen market will increase the attention paid to other aspects of sustainability, e.g. the availability of fresh water in the exporting country.

Risks relating to export countries

When the **number of hydrogen-exporting countries and companies** initially is still low, the risk of disruptions to hydrogen imports tends to be higher. This inevitably higher risk during the first phase will be counteracted by the overall lower vulnerability to hydrogen import shocks (see above). Another risk would arise for hydrogen-importing countries if exceptionally inexpensive and/or high-yield sources of climate-neutral hydrogen were to remain in the hands of just a few companies or be controlled by the governments of rival countries. In the longer term, the number of hydrogen exporters is likely to increase significantly. If liquid international markets with lively competition among exporters form, importing countries would be able to access a diversified hydrogen supply pool and to minimise excessive dependencies on individual exporters. If international competition remains weak or a handful of exporters form an oligopoly, import security would be more at risk in the event of fluctuating prices or production shutdowns.

The **substitutability of hydrogen exporters** will be a crucial factor if there are short-term supply disruptions or longer-term delivery stops by key exporting countries or companies. In these situations, it will be important to not only have a large number of hydrogen supply sources, but also a diversified transport infrastructure – e.g. a combination of multilateral pipeline networks and shipping routes – and an adaptable international hydrogen market structure that flexibly connects hydrogen suppliers and customers. Inflexible transport routes (e.g. heavy reliance on a few bilateral pipelines) and rigid market structures (e.g. a lack of liquid spot markets) could mean that import deficits cannot be replaced in good time. In the ramp-up phase, in which bilateral supply contracts will probably play a key role and the transport structure is not yet fully developed, this short-term substitutability is impaired. In the long term, however, this risk is easier to manage thanks to increasingly diversified transport routes and flexible market models.

Another risk is the **political stability of the exporting countries**. Domestic or foreign-policy conflicts could significantly disrupt international energy trade. Overall, this risk should gradually decrease with increasing hydrogen imports and domestic renewables expansion. This is suggested not only by the increasing diversification of Germany's energy-supplying countries but also, from today's perspective, by the comparatively higher stability and lower foreign policy tension with potential hydrogen exporting countries such as Iceland, Chile, Canada and Australia – when compared to some countries from which Germany import fossil fuels. Even in the longer term, Germany is likely to be less exposed to this risk than was the case with oil and gas imports. Firstly, because green hydrogen can be produced in significantly more countries than fossil fuels, making hydrogen less suitable for use as a geopolitical weapon than oil[19], and secondly, because energy import demand will decrease (see above).

Risks relating to transport

The hydrogen supply chain may be exposed to **transit risks**. These include domestic and international political conflicts along the transport route. Ukraine is one example of a geopolitically high-risk transit route. Unlike transit risks, **transport risks** are technical rather than political in nature. Examples include the breakdown of a pipeline or regasification plant at a terminal as a result of technical failure or a natural disaster. These risks are particularly pronounced when there are only a few transport routes (e.g. single pipelines) and import locations (e.g. only one import terminal), when large import volumes depend on individual routes, when the import infrastructure is outdated, prone to breakdown or susceptible to climate change, and when alternative import routes are difficult

[19] Van de Graaf et al. (2020)

to mobilise in the event of supply disruptions.

Risks in Germany and the EU

The lower the domestic capacities available to **compensate for hydrogen import shortages,** the more vulnerable the country will be to possible import disruptions. The substitutability of hydrogen imports will predominantly be determined by three factors, all of which are largely within the control of the importing country:

1. Low or insufficient storage capacities
2. Lack of options for fuel switching at short notice, and
3. Insufficient scalability of domestic hydrogen production.

Strategies for hydrogen import security

As described in the previous chapter, the import of hydrogen entails certain risks. However, hydrogen imports are also associated with significant advantages, since a climate-neutral economy without them would be practically inconceivable without expending very high costs and accepting other disadvantages. This is why risk management is a core element of any import security strategy. As a rule, risk management does not mean avoiding all risks. Even in cases where that would be possible, it would usually be far too expensive and not very practical. This general principle also applies to energy-importing countries as they progress towards climate neutrality.

In the following, various strategies aimed at managing risks and strengthening hydrogen import security for energy-importing countries are presented. These are divided into three areas: reducing the hydrogen import needs; securing available, affordable and sustainable hydrogen imports; and taking measures to reduce vulnerability to import disruptions.

Reducing hydrogen import needs

The import share of a country's energy consumption is regularly categorised as a risk-increasing factor in international energy security rankings.[20] In this analysis, too, we assume that the risks associated with energy imports in terms of availability and accessibility are higher than those associated with domestic supply chains. Reducing the need for hydrogen imports can therefore be seen as the first element of a strategy for securing hydrogen imports. There are three main approaches that could conceivably decrease demand for hydrogen imports: reducing energy demand, increasing domestic production of hydrogen and renewables, and increasing imports of non-hydrogen-based energy (e.g. electricity, biomass).

<u>Future energy demand could be reduced</u> through energy sufficiency, energy efficiency and direct electrification – clearly "no regret" strategies, also from the perspective of cli-

[20] World Energy Council (2020), Global Energy Institute (2020), Azzuni and Breyer (2020), Hughes and Shupe (2010).

mate policy. More economical or efficient forms of energy should be used whenever possible and expedient (e.g. reducing motorised individual transport, switching to electric mobility) in order to ensure that sufficient affordable climate-neutral hydrogen is available for use in sectors that are difficult to decarbonise.

A second approach to reducing hydrogen import needs would be to increase domestic production of hydrogen, which would require greater deployment of domestic renewable energy. In Germany, however, this strategy would come up against obstacles in terms of political acceptance, nature conservation, alternative land use requirements and economic viability. In principle, domestic hydrogen production could also be supplemented by hydrogen from fossil energy with CCS (blue hydrogen). However, the CO_2 storage facilities available in Germany and Europe are limited. Moreover, this scarce resource will be needed to offset emissions from non-energetic activities (e.g. cement production, agriculture).

The third approach to reducing hydrogen import needs would be to increase imports of other non-hydrogen-based forms of energy (electricity or biomass). However, since the potential for climate-neutral electricity imports to Germany is limited and there are significant concerns about biomass imports in terms of sustainability and competition for land, the first two approaches appear to be much more promising.

Securing hydrogen imports

A strategy for securing hydrogen imports can be inferred from the three overarching risks (availability, affordability and sustainability). To some extent, availability and affordability are two sides of the same coin, meaning that the associated strategies are closely interlinked and will be considered together in this analysis.

Safeguarding availability and affordability

One key strategic element of this first phase, in which we already find ourselves, is to support the ramp-up of national and international hydrogen markets. The interdependence of supply, demand, infrastructure and competitiveness can be resolved through different strategies, which accelerate the market ramp-up and promote economies of scale, technological advancements and thus affordability. These include:

- Ambitious, credible climate targets in Germany, the EU and worldwide – only then will hydrogen become really relevant.
- A regulatory framework commensurate with climate targets, with climate policy instruments such as sharply rising CO_2 prices which cover all sectors in which hydrogen is used – including international aviation and shipping.
- Some hydrogen technologies will also require technology-specific instruments to trigger innovation and the market ramp-up. These include targeted funding programmes, at both international (e.g. H2Global) and national level (e.g. Carbon Contracts for Difference).
- The integration and alignment of the European and global markets for hydrogen and hydrogen technologies, e.g. by harmonising safety standards and creating a reliable regulatory framework for infrastructure operations.
- Securing favourable long-term concessions and/or supply agreements for the majority of hydrogen imports, and purposefully developing liquid international markets for the remainder. In principle, there is an area of conflict between these two goals in which both hydrogen-importing companies as well as policymakers will have to strike a good balance, e.g. when making decisions about infrastructure expansion.
- Adequately funded R&D programmes, which are aligned with climate targets and the hydrogen strategy and will promote the learning effects necessary for medium and long-term cost reductions and resource efficiency gains.

Another key strategic measure for securing the availability and affordability of hydrogen imports involves diversifying supply sources and strengthening trading relations. The faster and more extensively the initially unavoidable dependence on just one or a very few suppliers and possibly transit routes can be supplemented by trading relations with several exporting countries and companies, the lower the hydrogen import risks tend to be. Hydrogen trade cannot be considered separately in this context. The stronger the hydrogen-importing country's economic, political and cultural relations with the key export and transit countries, the lower the risk of import disruptions or shocks. The following strategic measures could be adopted to minimise these risks:

- The creation of a market for ship transport as a basis for multilateral trading relations, both as a supplement and – in emergencies – as an alternative to future hydrogen or ammonia pipelines.
- When planning international pipelines: attention to potential economic and foreign policy conflicts and agreements, which mitigate these conflicts and thus the risk of supply disruptions.
- When defining criteria for distributing subsidies and – for private companies – when selecting suppliers: in addition to other criteria, importance must be attached to the diversification of suppliers and transport routes.
- Promoting bilateral and multilateral cooperation and partnerships in the hydrogen space (e.g. through the IEA and IRENA) and establishing international import chains with close cooperation between companies in the importing, transit and exporting countries.
- Long-term cooperation (also outside the energy sector) with exporting and transit countries and efforts to achieve (balanced) interdependencies between importing countries and exporting/transit countries.
- Cooperation, coordination and joint action to secure international hydrogen demand with other future hydrogen importers (example: origin of the IEA).

Another strategic measure would be the <u>development of a robust, diversified import infrastructure</u> for hydrogen. This includes the entire infrastructure along the import chain, including pipelines, import and export terminals for liquid hydrogen or ammonia, and hydrogen storage facilities. This following strategic measures could support such expansion:

- Securing adequate, i.e. timely and sufficient investments[21] in the hydrogen import infrastructure prior to the ramp-up of the hydrogen import market.

[21] Gracceva and Zeniewski (2014)

- Bearing the diversification of supply channels in mind when planning infrastructure expansion.
- Focusing on the robustness and climate adaptability of the infrastructure in order to ensure its resilience in the event of future disasters.

Safeguarding the sustainability of hydrogen imports

Due to its climate neutrality targets, all of Germany's energy imports must be climate-neutral by 2045.[22] As most countries aim for climate neutrality by 2050 or shortly afterwards, their energy imports will have to be climate neutral, too. Other sustainability considerations – e.g. water consumption and land use when producing green hydrogen and the effects of fracking on groundwater when producing blue hydrogen – must also be taken into account.

However, in the short term, it may be expedient to define less ambitious emission intensity standards and sustainability criteria for hydrogen imports. Firstly because the emission intensity of hydrogen imports used in 2030, e.g. in German steel mills, should be compared with an actual alternative (e.g. steel produced using coal) rather than a climate-neutral alternative that is not yet feasible. Secondly, because the market ramp-up of hydrogen production and its applications in hard-to-abate sectors is essential for achieving climate neutrality in the long term. However, due to the long lifetime of many plants, the market ramp-up must begin early on – a task made significantly more difficult by initially too strict emissions standards. The closer Germany gets to climate neutrality, the stricter the emission standards for hydrogen consumption and consequently for hydrogen imports will have to become.

The following strategic measures could ensure that hydrogen imports are sustainable:

- Analysing the life-cycle emission intensity of various imports of hydrogen and hydrogen derivatives.

[22] In principle, the climate neutrality of imports (and naturally also of domestic fossil-fuelled energy production if this still exists) could also be guaranteed by offsetting emissions through BECCS or DACCS. However, BECCS requires significant amounts of land and consequently raises concerns regarding competition with other forms of land use such as nature conservation, food production, agriculture and forestry. DACCS will be energy-intensive and very expensive in the foreseeable future. Both require social acceptance and access to CO_2 storage facilities which are otherwise of limited use. BECCS and DACCS will be needed to offset unavoidable emissions such as those that arise from agriculture and cement production. Unless the costs of DACCS fall significantly, it should be assumed as a matter of precaution that all energy imports will have to be net zero once Germany achieves climate neutrality.

- Strengthening the (satellite-supported) monitoring of methane leakages along the entire upstream production chain (production sites, pipelines, LNG terminals, distribution grids) and at (future) blue hydrogen production sites.
- Development of standards and certification procedures for the GHG emission intensity of green and blue hydrogen and for the transport of hydrogen and its derivatives.
- Cooperation with other hydrogen-importing countries committed to climate policy with the aim of establishing common criteria for reviewing and gradually improving the emission intensity of hydrogen imports and preventing a "race to the bottom" in the exporting countries.
- Consistent CO_2 pricing of upstream emissions from energy imports, e.g. through integration into a CO_2 border adjustment at the EU's external borders or multilateral alliances with a coordinated rise in CO_2 prices.

Reducing vulnerability to import shortages

Additional strategic measures could lessen the vulnerability of hydrogen-importing countries to possible hydrogen import disruptions. These include structural measures to **improve the substitutability of missing hydrogen imports** and **emergency plans** to mitigate the impact of hydrogen import shocks should these arise. The following strategies could be considered:

- Targeted political support for the expansion of hydrogen storage capacities and corresponding investments in the hydrogen-importing country. Geologically, large quantities of hydrogen can be stored at relatively low costs. A number of EU countries – Germany in particular – have especially good conditions for this. Hydrogen storage facilities are in any case required on a large scale in a system in which most hydrogen is produced via electrolysis. Even if imports are completely secured, they will be needed to balance seasonal fluctuations in production and demand. Their function is in many respects similar to that of today's natural gas storage facilities; however, hydrogen production is prone to still greater fluctuation and cannot be ramped up as quickly at short notice. Besides securing supplies against the standard fluctuations of hydrogen production based on variable renewables, storage facilities should also function as strategic reserves, like natural gas storage facilities do today. In the event of import shortages, consumers would have short-term access to hydrogen reserves, to be replenished when the situation returns to normal. The existence of extensive storage capacities would reduce the vulnerability of the importing country, and with it the likelihood of exporting or transit countries disrupting imports deliberately. Strategic stockpiling is one of the most important instruments to protect against import disruptions.

- Investments in the scalability of domestic hydrogen production: in emergencies, domestic electrolysers, which under normal circumstances will probably only run at part load, could operate around the clock and thus significantly increase their hydrogen production. Secondly, domestic reserve capacities for producing hydrogen from natural gas could be kept available for emergencies. These approaches assume that there will be sufficient (fossil) reserve capacities available, whether it be power plants, pipelines or energy resources; however, which would entail additional GHG emissions. In terms of climate policy, the main area of concern with regard to fossil-based solutions for the strategic reserve would not be the emissions caused on very rare occasions when emergency operations are required, but rather the risk of locking in the fossil fuel infrastructure. From the perspective of climate policy, a reserve consisting of fossil-based hydrogen production capacities would be more acceptable in the short term, while large-scale hydrogen storage facilities would be preferable in the long term.
  If hydrogen imports were to be disrupted for lengthy periods, there might be sufficient time for measures such as creating additional production capacities for green hydrogen. This approach would be of limited use for importing countries like Germany with less generous renewables resources, since renewables expansion will have to be stepped up considerably in these countries in any case, presumably leaving little additional area available for emergencies.
- Where technically and economically feasible, vulnerability to import shocks could also be mitigated by the option of fuel switching. Individual consumers will be able to make such a switch if they have alternative, non-hydrogen-based application systems. With the exception of possible individual cases, however, the practicability and economic viability of large-scale fuel-switching is questionable, since this would require parallel and under normal conditions redundant application systems as well as the necessary energy infrastructure. In the case of synthetic hydrocarbons, it is possibly switch back to fossil energy carriers at short nice. A systemic switch to another energy

carrier would be possible as long as only a relatively small portion of a fleet (e.g. of ships, peak load power/heating plants or city buses) has previously switched to hydrogen and sufficient alternative electric or fossil fuel capacities are available.

- As has been the case for fossil fuels, government-prescribed emergency plans, which can be implemented quickly and without red tape, must be put in place for times when a hydrogen supply crisis would have a serious impact on society and the economy. Plans of this kind must define the responsibilities and obligations of authorities and businesses as well the consumers who will have to be given priority if supply runs short. In a climate-neutral Germany, these would probably consist first and foremost of hydrogen-based peak load power and heating plants which guarantee security of electricity and heating supply, and possibly also strategically important industrial sectors. These emergency plans must also define the special rules under which ordinary market activities can be supplemented or replaced by sovereign intervention in response to a crisis.
- Finally, the early detection of impending import risks or supply shortages could be achieved by, if necessary, government-guaranteed access to relevant market and geopolitical information (e.g. development of supply and demand, storage levels, relevant political framework conditions, prices) for companies involved in the import of hydrogen.

Balancing cooperation and competition when securing imports

Although this analysis adopts a German perspective, many elements can be applied to other countries that are pursuing climate neutrality and are dependent on energy imports. Along with a number of EU member states, these include China, Japan, Korea and other countries in Asia and elsewhere.

If all future hydrogen-importing countries were to implement the strategic measures described in this analysis, this would lead to positive synergies in many respects, but not in all.

The synergies are likely to predominate over the next few years. The measures taken by various countries to drive the ramp-up of the hydrogen market will be mutually beneficial, thus providing investment security for producers and accelerating technological advancement and economies of scale. Structural shortages of climate-neutral hydrogen will be problematic from the perspective of climate policy, but not yet in terms of energy security, since the remaining fossil fuel infrastructure will still allow hydrogen to be produced conventionally in emergencies.

After 2030, when many countries will become increasingly reliant on hydrogen, measures taken to limit Germany's or another importer's need for hydrogen imports could help make hydrogen imports more available and affordable for other countries. If an importing country has good crisis prevention measures in place, enabling it to deal with import disruptions with relative ease, its direct and indirect trading partners would also benefit. In the light of economic ties, this is particularly relevant for Germany with regard to its EU partners. Moreover, a number of strategic measures for securing hydrogen imports would have positive synergistic effects if implemented in several hydrogen-importing countries simultaneously. This applies above all to ambitious climate targets and policies as well as to the harmonisation of safety standards.

However, there are also individual areas in which the implementation of the import security measures described above could lead to political competition between hydrogen-importing countries. Access to particularly inexpensive, high-yield sources of climate-neutral hydrogen could, for example, be seen as a zero-sum game. If a government were to attempt to obtain privileged access to such sources for its own hydrogen producers or customers, this would place other countries at a disadvantage. Privileged access could be favoured by various government actions such as guarantees, subsidies, privileged licensing procedures or trade or foreign policy exchange deals. This kind of government action can help enabling long-term supply agreements or concessions for the use of certain resources or for the construction of pipelines along certain routes.

It appears that the majority of these strategic measures would create positive synergies between import countries, while a dynamic of geopolitical competition might only arise with a few of these measures. Even if particular importance were attached to these few rather competitive elements, it is doubtful whether the categories of the oil age still make sense in a world striving to achieve climate neutrality. According to the oil age's logic, the success of a hydrogen-importing country would depend on it securing a comparatively large share of the scarce hydrogen resources for itself. In light of global climate change, however, this would be a disadvantage if it resulted in other countries continuing relying on high-emission energy because they did not have sufficient access to affordable climate-neutral hydrogen.[23]

If other potential hydrogen-importing countries were to gain the impression that Germany or the EU wanted to secure their own hydrogen imports by making access more difficult for other countries, this could adversely affect these countries' climate policy commitments. Approaches to securing hydrogen imports that are based on tough international competition would therefore not be conducive to the efforts of achieving global climate neutrality. Close cooperation within the EU is particularly important for Germany. A purely or predominantly national consideration of hydrogen import security would in any case be unrealistic, given the synchronous electricity grid linking continental Europe, the partially shared responsibilities for oil and natural gas supply security, the common climate targets and the high degree of economic, political and social integration. If a hydrogen import crisis were to hit other EU countries, Germany would inevitably be affected as well, be it through the impact on security of electricity supply, industrial production or general economic integration.

[23] Piria (2020).

Moreover, Germany will depend on the goodwill of several EU member states, which act as source or transit countries, to secure its future hydrogen imports via pipeline and its renewable electricity imports. As the largest energy consumer in the middle of the EU, with an above-average population density, comparatively unfavourable renewable energy resources and a strong industrial sector, Germany can benefit more than many other countries from a stronger integration of energy systems in the EU. Taking an EU-wide view of hydrogen import security could prevent redundancies when setting up the import and storage infrastructure and achieve positive synergistic effects in foreign hydrogen policy, e.g. when developing international sustainability standards and certification procedures.

Summing up: those hydrogen import security strategies, which are likely to create positive synergies between hydrogen-importing countries, predominate. Germany's foreign hydrogen policy should therefore not only focus on (potential) hydrogen-exporting countries but also reach out to other (potential) hydrogen-importing countries, e.g. by cooperating on the development of hydrogen transport technologies, the establishment of supply chains and the roll-out of hydrogen applications that make sense for climate policy.

When it comes to ensuring the sustainability of hydrogen imports, diverging preferences could arise among hydrogen-importing countries as a result of more or less ambitious climate goals and sustainability concepts or of differing views on the potential of CCS or on the risks of nuclear energy. Germany could therefore work together in particular with importing countries and regions with similar energy policy objectives and with potential exporting countries with low-cost renewable energy resources.

References

AGEB (AG Energiebilanzen e.V.) (2020a): Auswertungstabellen 1990 - 2019 (Datenstand September 2020). https://ag-energiebilanzen.de/#awt_2019_d

Ang, B.W., Choong, W.L, Ng, T.S. (2015): Energy security: Definitions, dimensions and indexes. Renewable and Sustainable Energy Reviews, 42, 1077-1093. https://ideas.repec.org/a/eee/rensus/v42y2015icp1077-1093.html

Ariadne (2021): Deutschland auf dem Weg zur Klimaneutralität 2045. Szenarien und Pfade im Modellvergleich. Ariadne-Report. https://ariadneprojekt.de/publikation/deutschland-auf-dem-weg-zur-klimaneutralitat-2045-szenarienreport/

Ariadne (2021b): Eckpunkte einer adaptiven Wasserstoffstrategie. Ariadne-Kurzdossier

Azzuni, A., Breyer, C. (2018), Definitions and dimensions of energy security: a literature review. WIREs Energy Environ, 7: e268. https://doi.org/10.1002/wene.268

Azzuni, A., Breyer, C. (2020): Global Energy Security Index and Its Application on National Level, Energies 2020, 13(10), 2502. https://doi.org/10.3390/en13102502

Caglayan, D.C., Weber, N., Heinrichs, H.U., Linßen, J., Robinius, M., Kukla, P., Sollten, D. (2020): Technical potential of salt caverns for hydrogen storage in Europe. International Journal of Hydrogen Energy, 45, Issue 11, 6793-6805. https://doi.org/10.1016/j.ijhydene.2019.12.161

Cherp, A., Jewell, J. (2014): The concept of energy security: Beyond the four As. Energy Policy, 75, 415-421. https://doi.org/10.1016/j.enpol.2014.09.005

dena (2021): dena-Leitstudie Aufbruch Klimaneutralität. https://www.dena.de/newsroom/meldungen/dena-leitstudie-aufbruch-klimaneutralitaet/

Elbassoussy, A. (2019): European energy security dilemma: major challenges and confrontation strategies, Review of Economics and Political Science, 4, 321-343. https://doi.org/10.1108/REPS-02-2019-0019

Energy Charter Secretariat (2015): International Energy Security. Common Concept for Energy Producing, Consuming and Transit Countries. https://www.energycharter.org/fileadmin/DocumentsMedia/Thematic/International_Energy_Security_2015_en.pdf

Global Energy Institute (2020): Energy Security Risk Index. https://www.globalenergyinstitute.org/energy-security-risk-index

Goldthau, A., Keim, M., Westphal, K. (2018): Die Energiewende und ihre geopolitischen Konsequenzen, in: Stiftung Wissenschaft und Politik, SWP-Aktuell 2018/A 51, 22.09.2018.

Gracceva, F., Zeniewski, P. (2014): A systemic approach to assessing energy security in a low-carbon EU energy system. Applied Energy, 123, 335-348 https://ideas.repec.org/a/eee/appene/v123y2014icp335-348.html

Hughes, L., Shupe, D. (2010): Applying the Four 'A's of Energy Security as Criteria in an Energy Security Ranking Method. The Routledge Handbook of Energy Security. https://www.routledgehandbooks.com/doi/10.4324/9780203834602.ch18

Ikenberry, G.J. (1986): The irony of state strength: comparative responses to the oil shocks in the 1970s. International Organization, 40 (1), 105-137. http://www.jstor.org/stable/2706744

Pflugmann, F., De Blasio, N.D. (2020): The Geopolitics of Renewable Hydrogen in Low-Carbon Energy Markets. Geopolitics History and International Relations 12 (1): 2374-4383. https://www.researchgate.net/publication/341251092_The_Geopolitics_of_Renewable_Hydrogen_in_Low-Carbon_Energy_Markets

Piria, R. (2020): Wasserstoffstrategie: Auch mit Importländern ist eine Partnerschaft essenziell. Tagesspiegel Background Energie, 10.1.2020. https://background.tagesspiegel.de/energie-klima/wasserstoffstrategie-auch-mit-importlaendern-ist-eine-partnerschaft-essenziell

Prognos, Öko-Institut, Wuppertal Institut (2021): Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann. Zusammenfassung im Auftrag von Stiftung Klimaneutralität, Agora Energiewende und Agora Verkehrswende. https://www.agora-energiewende.de/veroeffentlichungen/klimaneutrales-deutschland-2045/

Van de Graaf, T., Overland, I., Scholten, D., Westphal K. (2020): The new oil? The geopolitics and international governance of hydrogen. Energy Research & Social Science, 70. https://www.sciencedirect.com/science/article/pii/S2214629620302425

Vivoda, V. (2009): Diversification of oil import sources and energy security: A key strategy or an elusive objective? Energy Policy, 37 (11), 4615-4623. https://doi.org/10.1016/j.enpol.2009.06.007

Westphal, K., Dröge, S., Geden, O. (2020): Die internationalen Dimensionen deutscher Wasserstoffpolitik. SWP-Aktuell 2020/A 37, 19.05.2020. https://www.swp-berlin.org/10.18449/2020A37/

Wietschel, M., Bekk, A., Breitschopf, B., Boie, I., Edler, J., Eichhammer, W., Klobasa, M., Marscheider-Weidemann, F., Plötz, P., Sensfuß, F., Thorpe, D., Walz, R. (2020): Chancen und Herausforderungen beim Import von grünem Wasserstoff und Syntheseprodukten. Fraunhofer ISI. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2020/policy_brief_wasserstoff.pdf

World Energy Council (2020): Energy Trilemma Index. https://trilemma.worldenergy.org/

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