Paris Agreement Compatible Scenarios for Energy Infrastructure

The role of hydrogen in a future, low-carbon, and secure European energy system

Discussion Paper

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DISCLAIMER

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Introduction

In a world of enduring scarcity – scarcity of space, materials, workforce, political will, and public support, to name just a few – optimisation of processes and utilisation of available resources across the entire energy system are essential. The full carbon neutrality of an energy supply, especially one largely based on variable renewable energy sources (RES), is crucial to fight climate change and increase energy security within European borders. The need for speed and scale in energy infrastructure deployment to reduce dependencies and enhance European energy security has attracted increased attention, particularly on the feasibility of policy targets in view of the scarce resources at our disposal.

Hydrogen is considered an important component of the decarbonisation process. Indeed, in the REPowerEU Plan published in May 2022, the European Commission set ambitious targets for the demand and production of green hydrogen by 2030. The short time frame to implement REPowerEU's targets raises multiple concerns, as it appears to shift attention away from electrification as the most efficient way to decarbonise and ignore scarcity issues within supply chains, space, and infrastructure. In this paper, we argue that the EU's 2030 hydrogen targets are exceeding expected demand and are dependent on a very fast and unprecedented increase of renewable capacity, grid connections, and electrolysers. The prioritisation of hydrogen production over direct electrification means Europe will have to use significant amounts of electricity based on wind and solar (578 TWh/year) in an inefficient way, which will generate energy loses and will not serve to optimise the system. With missing renewable capacity for green hydrogen production, electricity from fossil sources will have to be used to create hydrogen and subsequently increase overall emissions across the European Union. Moreover, if hydrogen is not channelled towards sectors which can only be decarbonised with green hydrogen, these sectors risk missing their decarbonisation targets.

1. European targets and related concerns

With the REPowerEU Plan[1], the European Commission has responded to turbulence in energy markets caused by Russia's invasion of Ukraine, which impacted energy imports into the European Union. While addressing the energy crisis, the European Commission also outlined their targets for Europe's future low-carbon, secure, and affordable energy system. An important building block of the comprehensive REPowerEU Plan is hydrogen, called *green hydrogen* when produced via water electrolysis supplied by electricity generated from renewable energy sources.

[1] European Commission, 2022, *Implementing the REPower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets*, European Commission.

The new targets for green hydrogen are substantially higher than in previous EU policy files (2020 EU Hydrogen Strategy[2] and the Fit for 55 Package[3] published in 2021) and foresee 10 million tons (Mt) of domestic production and 10 Mt of imports by 2030. These are ambitious targets, which, if realised, will fundamentally impact electricity generation and the transmission infrastructure required for electrolysers in both Europe and countries exporting to the EU, as well as electricity markets and (future) hydrogen markets. Therefore, it is essential to ask if such high quantities of hydrogen, both imported and produced within the European Union, are needed and realistic. These political targets should be carefully considered, especially whether they are the best choice in view of expected scarcity constraints from now until 2030 as well as their implications for the entire energy system. As of today, there is neither clarity nor transparency about the technical feasibility of producing such large amounts of green hydrogen, particularly in the short time frame envisaged. Furthermore, the impacts of such a pathway on decarbonisation, energy security, and energy affordability objectives are equally unclear for both 2030 and beyond. It is therefore relevant to scrutinise and understand the possible impacts of this massive push towards hydrogen.

In the next sections, we discuss the current hydrogen demand and supply in Europe, including expected development of hydrogen demand by 2030 and by 2050 – when Europe should achieve full decarbonisation at the latest. Moreover, we assess the implications of the target for 20 Mt of green hydrogen in the EU's energy system. In that context, we derive recommendations for the needed optimisation of the future European energy system, without discussing in detail how the hydrogen market should develop.

2. Present situation – hydrogen usage and supply

Today's annual consumption of hydrogen in Europe is about 8.32 Mt, which is mainly used at refineries (more than 50%) and ammonia plants (around 30%)[4], as shown in Figure 1. The current hydrogen demand is mainly sourced from natural gas via a steam methane reforming process (SMR), resulting in 9 kg of CO_2 emissions per 1 kg of hydrogen produced[5], excluding upstream methane emissions during production and transport.

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[2] European Commission, 2020, *A hydrogen strategy for a climate-neutral Europe*, European Commission.

[3] European Commission, 2021, *'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality*, European Commission.

[4] Fuel Cells and Hydrogen Observatory, 2023, *Hydrogen Demand*, Fuel Cells and Hydrogen Observatory, (25 May 2023).

[5] This is an average value, assumed that depending on the specific process, the amount of the CO_2 emissions may vary between 8-12 kg of CO_2 per 1 kg of hydrogen; See: Hydrogen Council, 2021, *Hydrogen decarbonization pathways. A life-cycle assessment*, Hydrogen Council.

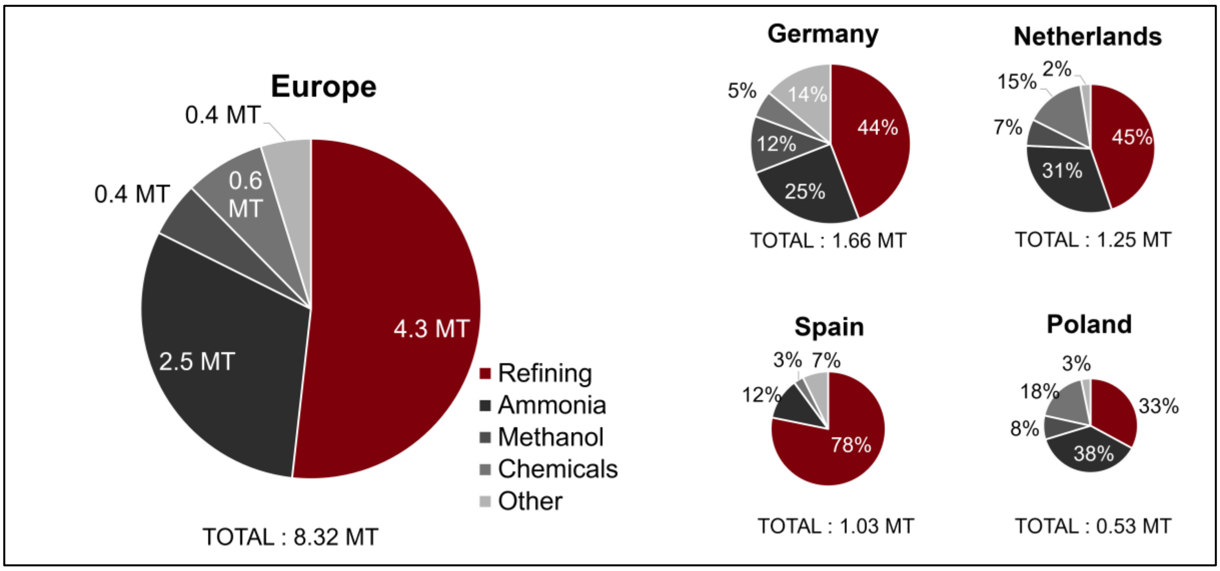

Figure 1: Hydrogen consumption in Europe in 2020, by sector, with examples of differences among the end use sectors in selected European countries.

European hydrogen demand per country is characterised by substantial differences, with Germany accounting for the largest European hydrogen market. Germany, together with the Netherlands, Poland, and Spain, represent more than 50% of European hydrogen demand[6]. Currently, almost all hydrogen is produced near its end-use sites, with a small amount of hydrogen transported over relatively short distances by dedicated pipelines or trucks. Figure 2 indicates differentiated hydrogen demand per country, the selected main industrial centres of hydrogen production, the planned hydrogen production sites, and the few existing hydrogen pipelines.

[6] Fuel Cells and Hydrogen Observatory, 2022, *Chapter 2: 2022 Hydrogen Supply Capacity and Demand*, Fuel Cells and Hydrogen Observatory.

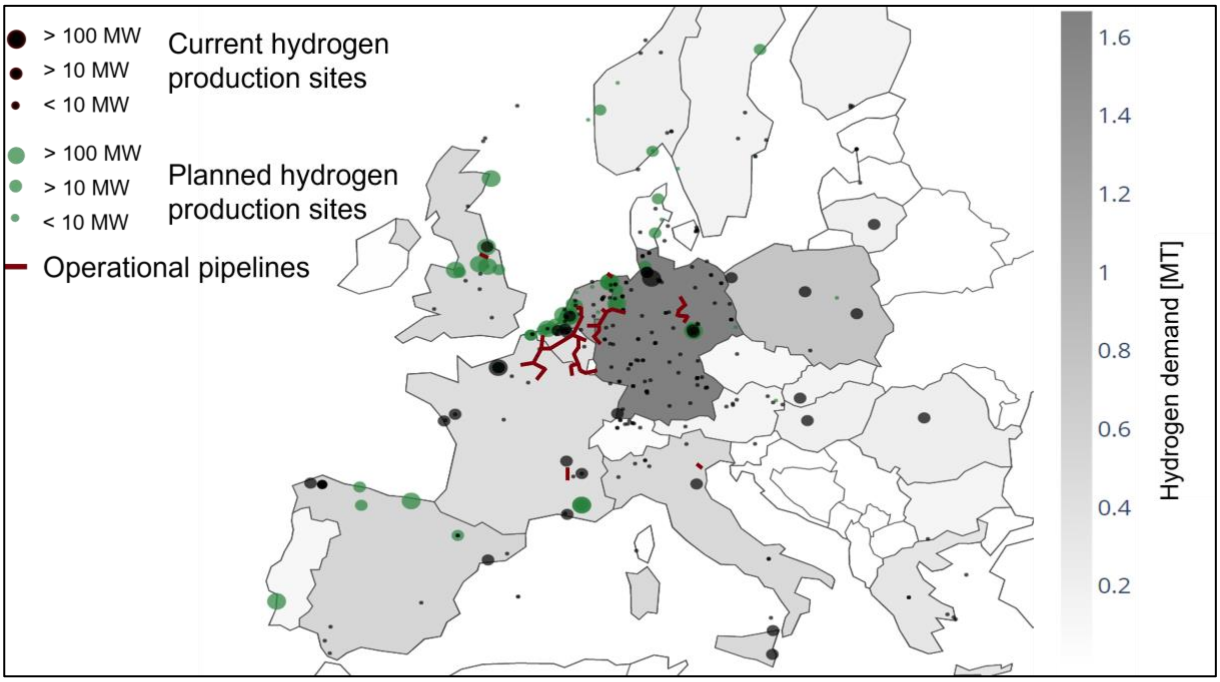

Figure 2: The selected locations of the current and planned centres of hydrogen production in Europe and existing pipelines (Source: own visualisation, based on IEA (2021)[7], FCHObservatory (2022)[8], FCHObservatory (2022).[9]

3. Future projection of hydrogen demand

REPowerEU's hydrogen targets exclusively refer to green hydrogen and assume that no production and no imports of other types of hydrogen will be present within Europe. However, deals for delivery of blue hydrogen[10] by 2030 are emerging, as in the case of Germany and Norway[11]. Additionally, in the largest chemical cluster of Europe, Antwerp, a major investment is planned to produce blue hydrogen[12]. This acceleration in hydrogen production is meant to replace natural gas, coal, and oil. According to modelling results presented by the European Commission, this should be achieved through an increasing use of non-biological renewable fuels (75% for industry and 5% for transport) by 2030[13]. The anticipated change in hydrogen demand in the REPowerEU Plan compared to previously published targets in the Fit for 55 Package is illustrated in Figure 3. The various red components in this figure represent different sectoral uses where hydrogen is needed as a feedstock. The grey colours represent sectors where other forms of energy supply

[7] IEA, 2022, Hydrogen Projects Database, (25 May 2023).
[8] Fuel Cells and Hydrogen Observatory, 2022, Hydrogen Demand, Fuel Cells and Hydrogen Observatory, (25 May 2023).
[9] Fuel Cells and Hydrogen Observatory, 2022, Hydrogen Supply Capacity, Fuel Cells and Hydrogen Observatory, (25 May 2023).
[10] Blue hydrogen is produced by using fossil gas where CO2 is captured and stored.
[11] Hydrogen Central, 2023, Germany And Norway Reach Blue Hydrogen Agreement, Hydrogen Central, (25 May 2023).
[12] Air Liquide, 2023, Air Liquide, Fluxys Belgium and Port of Antwerp-Bruges awarded EU funding for building the Antwerp@C CO2 Export Hub, Air Liquide, (4 July 2023).
[13] European Commission, 2022, Implementing the REPower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets, European Commission.

could be provided (e.g., direct electrification). It should be noted that this figure also includes blending, which is not a final sectoral use but should be understood as a possible energy carrier.

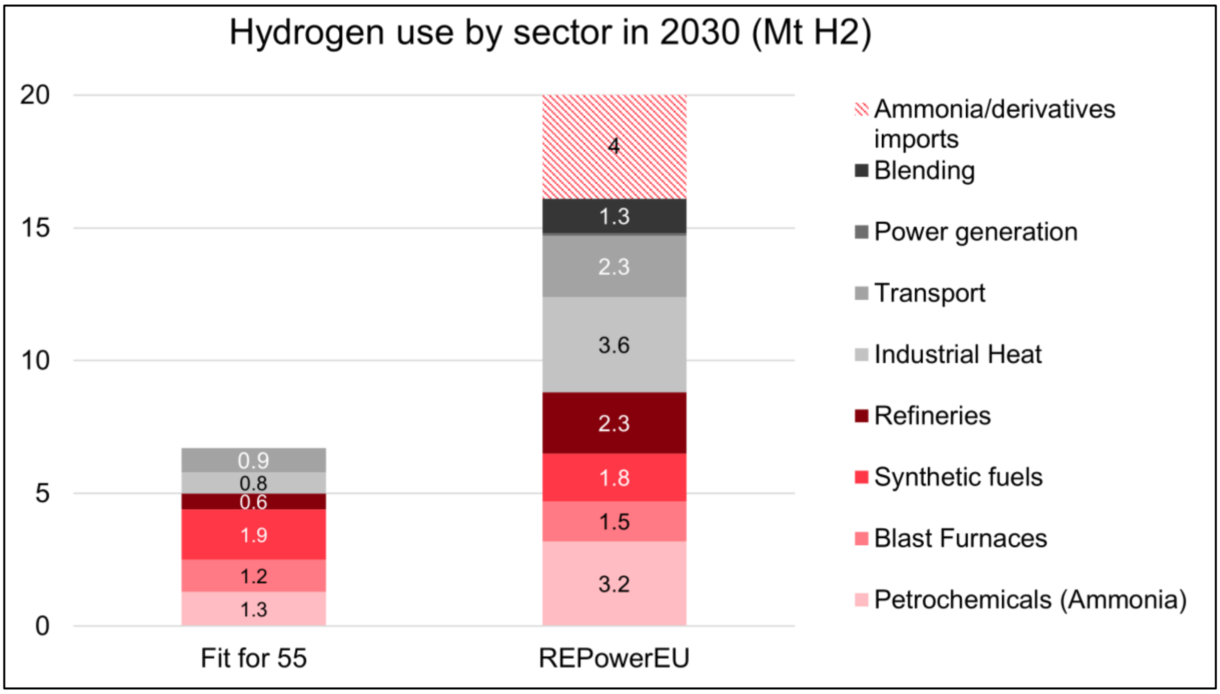

Figure 3: Comparison of hydrogen use (million tons) by sector in 2030 in EU-27 as presented in Fit for 55 and REPowerEU (Source: own visualisation, based on European Commission, (2022)[14]).

The need for the increased target of 20 Mt green hydrogen by 2030 foreseen in REPowerEU remains unclear, as it would assume an exponential growth of hydrogen demand from the 8.2 Mt currently used.

Additionally, it should be noted that the hydrogen use presented in REPowerEU mixes fuels and carriers, as in the case of blending and ammonia imports (hydrogen derived via ammonia cracking), as represented in Figure 3. This increases confusion on the perception of overall hydrogen demand and requirements across the European Union.

A detailed analysis of different end-use sectors of green hydrogen as presented in REPowerEU is elaborated below in Table 1.

[14] European Commission, 2022, *Implementing the REPower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets*, European Commission.

Sector	Hydrogen target by 2030	Comments, including explanations and related considerations
Petrochemicals (ammonia)	3.2 Mt	Use of grey hydrogen for local ammonia production in EU in 2020 was 2.5 Mt[15], which resulted in 14.6 Mt of ammonia. As provided by Hydrogen Europe, the EU's ammonia production capacity is 17.7 Mt[16], which requires 3 Mt of hydrogen. Therefore, the 3.2 Mt target by 2030 implies that all existing production capacity will be converted to produce 100% green ammonia.
Blast furnaces	1.5 Mt	The European steel sector currently produces 153 million tons of steel. The most common use of hydrogen in steelmaking is in a DRI-EAF[17] plant. In a decarbonised steel production cycle, hydrogen would be used directly to replace coke and reduce iron oxide in a DRI plant, which would then be melted in an EAF. 60% of steel is produced by the integrated route (primary steelmaking) and the remaining 40% is secondary, which does not need hydrogen for iron reduction. REPowerEU estimates that primary steel production could be decarbonised by 30% by 2030. This means that within 60% of primary steel, 30% will use green hydrogen by 2030, what results in 18% of the total steel production. This corresponds with a total number of 27 million tons of green steel produced. Given that it takes more than 50 kg of H2 to produce one ton of steel, the H2 demand for the green steel sector would be about 1.4 million tons, what is close to the number presented by REPowerEU. If one would assume that 100% of the primary steel production can be decarbonised, then the demand for green hydrogen for green steel production would result in 4.2 million tons.
Synthetic fuels	1.8 Mt	Hydrogen would be required for bio-kerosene upgrading as well as to produce synthetic kerosene for aviation and shipping. This is in line with the study of the European Hydrogen Backbone, which estimated the demand for synthetic kerosene at 50 TWh for a 7% integration of synthetic fuels in aviation by 2030[18]. Producing this synthetic fuel would require an additional 1.8 million tons of green hydrogen.
Refineries	2.3 Mt	This number is lower than the current demand from refineries for hydrogen (4.3 Mt; see Figure 1), assuming that by 2030 the sectors using the refined products will shrink (e.g., due to electrified road transport).

[15] Fuel Cells and Hydrogen Observatory, 2022, *Chapter 2: 2022 Hydrogen Supply Capacity and Demand*, Fuel Cells and Hydrogen Observatory.

[16] Bonnet-Cantalloube, B., Espitalier-Noël, M., Ferrari de Carvalho, P., Pawelec, G., 2023, Clean Ammonia in the Future Energy System. Hydrogen Europe.

[17] DRI-EAF: Direct Reduction Iron in an Electric Arc Furnace.

[18] Wang, A., Jens, J., Mavins, D., Moultak, M., Schimmel, M., van der Leun, K., Peters, D., Buseman, M., 2021, *European Hydrogen Backbone: Analysing future demand, supply, and transport of hydrogen*, Gas For Climate. A path to 2050.

Industrial heat	3.6 Mt	According to REPowerEU almost all industrial heat needs can be electrified in 3 stages: stages 1 and 2 use mature technologies for low- and high-grade heat accounting for almost 80% of heat electrification. Stage 3 brings this up to 99%. A large part of overall industrial heat demand is to make steam or process heat below 100°C in chemical, food, and paper industries – which can be effectively provided by industrial heat pumps with significant gains in efficiency. Some studies[19] estimate that almost 100% of industrial heat demand can be electrified by 2050. However, some technologies required for this currently have a low Technology Readiness Level (TRL) and might not be available by 2030.
Transport	2.3 Mt	REPowerEU mentions that renewable hydrogen should be used to fuel some segments of the transport sector, namely: heavy-duty trucks, aviation, and waterborne transport, but does not specify how much hydrogen would be needed by each of these segments.
Power generation	0.1 Mt	Assuming hydrogen's energy density is 33.6 kWh per kg, 0.1 Mt of hydrogen corresponds to 3.36 TWh. Considering the energy conversion losses of gas to power (fuel cell or combined cycle gas turbine (CCGT)) of about 50% will correspond to 1.68 TWh of electric energy.
Blending	1.3 Mt	REPowerEU suggests its careful consideration, because of the inefficiencies and the risks of overall increase of system costs as well as the increase of heating costs for the residential sector. Additionally, it could lead to lock-ins of fossil fuel infrastructure.
Ammonia/ derivatives imports	4 Mt	This number corresponds with 23.5 Mt of ammonia imported, as 1 kg of ammonia contains 0.17 kg of hydrogen. This number is much higher than the existing EU ammonia production capacity. Since it is hard to imagine a doubling of ammonia needs in the EU, we believe that the underlying assumption is to extract 4 Mt of hydrogen from the imported ammonia via the ammonia cracking process, which has energy losses of about 30%[20].

Table 1: Projection of European demand for green hydrogen as per REPowerEU, including explanations and considerations for each sector and carrier.

[19] Madeddu, S., Ueckerdt, F., Pehl, M., Peterseim, J., Lord, M., Kumar, K. A., Krüger, Ch., Luderer, G., 2020, 'The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat)', *Environmental Research Letters*, vol. 15, n. 12, DOI: 10.1088/1748-9326/abbd02.

[20] Chatterjee, S., Parsapur, R. K., Huang, K.-W., 2021, 'Limitations of Ammonia as a Hydrogen Energy Carrier for the Transportation Sector', *ACS Energy Letters*, vol. 6, n. 12, pp. 4390–4394, DOI: https://doi.org/10.1021/acsenergylett.1c02189.

In applications where hydrogen will replace fossil fuels due to a lack of realistic alternatives (petrochemicals, steel production, synthetic fuels, and refineries), the amount of hydrogen foreseen in REPowerEU is close to the current consumption (8.8 Mt as presented in REPowerEU vs. 8.2 Mt today). An additional 7.2 Mt of green hydrogen included in the REPowerEU calculations is represented by applications such as: heating, industrial heat, transport, blending, and power generation, where in each case fossil fuels are simply replaced by hydrogen without analysing the availability of more efficient alternatives[21]. The remaining 4 Mt of green hydrogen should be imported to the European Union in the form of ammonia and other hydrogen carriers and derivatives. However, there is no clarity on which end-use sectors should be used for hydrogen extracted by cracking ammonia. Plans and investments for cracking ammonia are already underway (e.g., in Germany[22]), most likely without a clear understanding of the need, costs, or losses of such processes.

4. Implications of green hydrogen production on the power system

Hydrogen production based on water electrolysis is attracting significant attention, since it has the potential to produce hydrogen without carbon emissions if the process is fed only by renewable electricity. However, currently there is not a 100% carbon-free electricity supply in any European country or most parts of the world. Considering the annual electricity mix of different countries and their carbon intensity, carbon emissions for the production of 1 kg of hydrogen using water electrolysis at continuous full load can be estimated. For example, the carbon intensity of Germany's energy generation mix in 2022 was 386 g CO_2/kWh, which would imply that the production of 1kg of hydrogen would result in 20 kg of CO_2 emissions – equalling more than twice the emissions from the Steam Methane Reforming (SMR) process. In that context, replacing coal with renewable generation remains the fastest way to reduce carbon emissions in the power sector. Moreover, a recent study published by researchers from the University of Cambridge, National Centre for Atmospheric Science, and the University of Reading[23] have assessed the risks of hydrogen leakages during transport, production, and storage to be much higher and damaging than previously estimated, with the global warming potential of leaked hydrogen at least 100% larger than previously calculated.

[21] For a discussion about the inefficiencies of using hydrogen for heating and cooling purposes see: Rosenow, J., 2022, 'Is heating homes with hydrogen all but a pipe dream? An evidence review', *Joule*, vol. 6, n. 10, pp. 2225-2228, DOI: https://doi.org/10.1016/j.joule.2022.08.015.

[22] Burridge, E., 2023, *ADNOC Explores Ammonia Opportunities in Germany*, CHEManager, (25 May 2023); Cozier, M., 2023, *BP studies feasibility of new ammonia cracker in Germany to provide green hydrogen*, Sci News, (25 May 2023).

[23] Warwick, N., Griffiths, P., Keeble, J., Archibald, A., Pyle, J., Shine, K., 2022, *Atmospheric implications of increased Hydrogen use*, University of Cambridge, National Centre for Atmospheric Science, University of Reading.

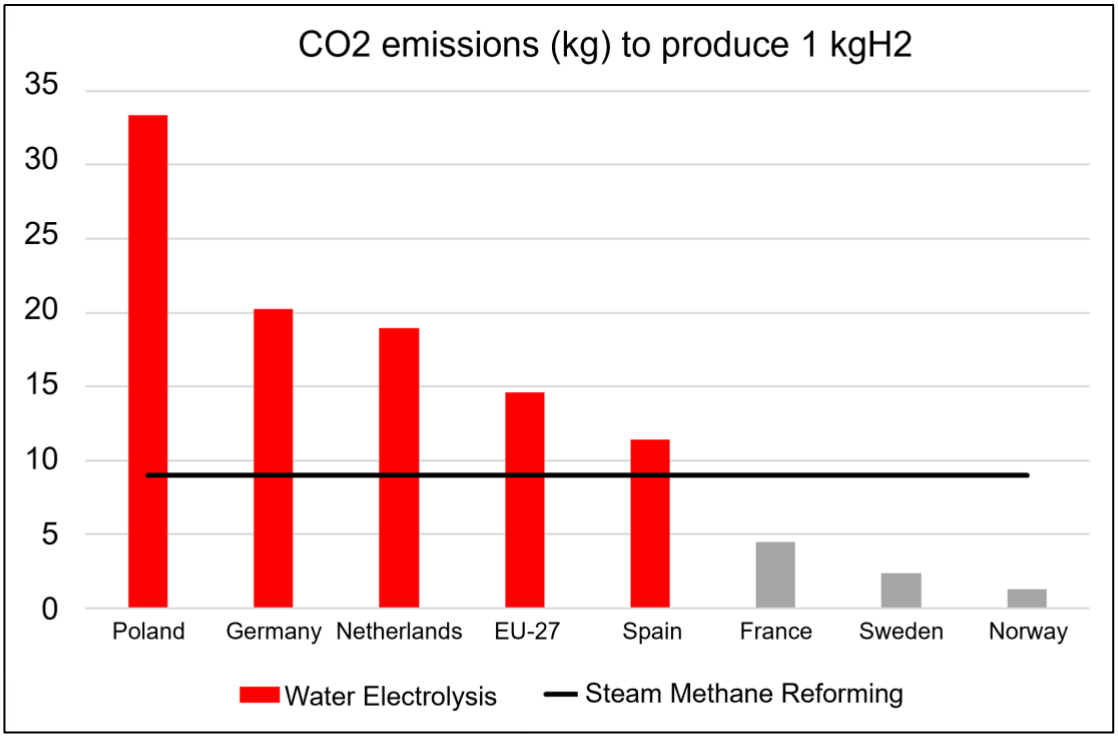

Figure 4: Carbon dioxide emissions associated with the production of one kilogram of hydrogen via water electrolysis or Steam Methane Reforming (SMR). Water electrolysis is using a regional carbon intensity of an annual electricity mix. The value of carbon inten during the SMR-based hydrogen production is stable and does not depend on the regional carbon intensity of the annual electricity mix. Source: Our World in Data (2022)[24].

In order to address this challenge and to avoid the cannibalisation of renewables generation, which is primarily meant to meet growing electricity demand and enable direct electrification, the European Commission adopted two Delegated Acts[25] in line with the Renewable Energy Directive[26]. These Delegated Acts set rules on the production requirements of renewable hydrogen and, in particular, define the principle of additionality. Both legislative files have been scrutinised by the European Parliament and the Council[27] and apply for renewable hydrogen produced within and beyond EU borders. Their importance lies in the fact that binding additionality rules, alongside effective geographical and temporal correlation, ensure that electrolysers connected to the grid do not operate on an electricity mix that includes fossil fuels and that

[24] Our World in Data, 2022, *Carbon intensity of electricity*, Our World in Data, (25 May 2023).

[25] European Commission, 2023, Commission Delegated Regulation (EU) 2023/1185 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a minimum threshold for greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels, *OJ L 157, 20.6.2023, p. 20–33, and* Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin, *OJ L 157, 20.6.2023, p. 11–19.*

[26] 'Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources' (2018) OJ L 328, pp. 82–209.

[27] For more details see: Register of delegated and implementing acts (I) and Register of delegated and implementing acts (II) (31 May 2023).

green hydrogen is indeed produced from renewable electricity[28]. In the absence of these measures, the production of green hydrogen could potentially take place using electricity not from renewable energy sources, but from carbon-intensive generation sources such as coal, gas, and oil, thereby increasing overall emissions. Moreover, due to the limited renewable energy generation capacity within Europe, the amount of imported hydrogen may have to be increased to meet the set targets. Without additionality rules and stringent certificates of origin, imports of hydrogen produced by different energy sources may increase overtime, leading to higher emissions and overall external costs[29]. Therefore, considering the huge amounts of imported hydrogen foreseen by REPowerEU and to guarantee that hydrogen brought to Europe is really green, it is imperative that the countries of origin have measures with the same effects foreseen by the Delegated Acts and the additionality principle is in place. A transparent, reliable, and tracible reporting scheme should complement imports.

Green hydrogen production by electrolysis consumes a significant amount of electricity: between 50 (as assumed by REPowerEU) and 55 kWh per 1 kg of hydrogen using Proton Exchange Membrane (PEM) electrolysers (66% efficiency). Hence, a production of 10 Mt of domestic hydrogen in EU requires 500-550 TWh of clean electricity generation (excluding additional transmission and distribution losses). This amount corresponds to today's annual electricity consumption in all of Germany[30]. Considering additional transmission and distribution losses associated with electricity delivery to electrolyser plants, these numbers can increase by 3-5% and result in an additional need for 578 TWh of renewable electricity generation to produce green hydrogen[31].

In 2022, the annual solar PV production in EU-27 was 202 TWh and 421 TWh was generated by wind power[32], giving a total of 623 TWh of renewable electricity. Thus, more than 92% of the renewable electricity generated in Europe in 2022 would be needed to cover the green hydrogen demand assumed by REPowerEU. The additional renewable capacity foreseen in REPowerEU targets (592 GW of solar PV and 510 GW of wind), which should generate 622 TWh of solar and 1340 TWh of wind[33], should be enough to cover 10 Mt of domestic green hydrogen production in 2030. However, it would mean that almost 30% of total renewable electricity production in the EU (578 TWh out of 1962 TWh) will be consumed by electrolysers for hydrogen's production.

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28 Ricks, W., Xu, Q., Jenkins, J. D., 2023, Minimizing emissions from grid-based hydrogen production in the United States, *Environmental Research Letters,* vol. 18, n. 1, DOI 10.1088/1748-9326/acacb5.

29 Thiele, L., 2022, *Hydrogen and Climate Justice*, Konzeptwerk Neue Ökonomie, (25 May 2023).

30 Statista Research Department, 2023, *Electricity net consumption in Germany from 2000 to 2021*, Statista, (25 May 2023).

31 This number depends on the efficiencies of electrolyser technology and transmission and distribution grids.

32 EMBER, 2023, *Electricity Data Explorer*, (4 July 2023).

33 To simplify the calculations, we assumed the capacity factor of 12% for solar and 30% for wind, which does not take into account the (lower) efficiency of currently existing assets, potential repowering and does not differentiate between offshore and onshore wind.

This is a significant amount which seriously questions the "energy efficiency first" principle, as this additional renewable energy capacity could feed more electric vehicles (instead of using hydrogen for transport) and heat pumps (instead of blending outlined in REPowerEU). Directing additional renewables proposed by REPowerEU towards more efficient electrification options for transport and heating would contribute to significant savings and system optimisation. This is especially true for hydrogen intended for the transport sector (excluding synthetic fuels) and blending (for heating), which in REPowerEU accounts for 3.6 Mt. This amount is almost equal to the additional quantity of local green hydrogen production assumed by REPowerEU in comparison to Fit for 55 (3.3 Mt).

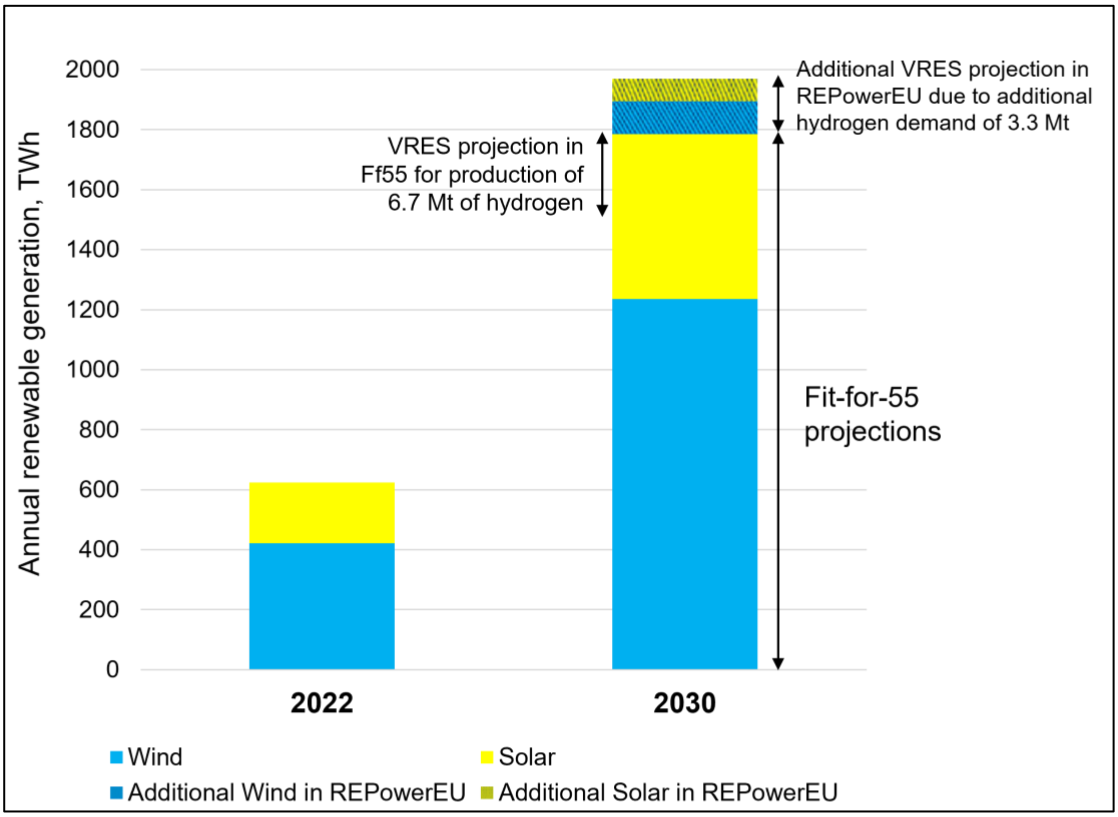

Figure 5: Wind and solar PV energy production in 2022 and future projections for 2030. Source: own visualisation, based on European Commission (2022)[34].

Additional concerns about the feasibility of producing domestic green hydrogen in the EU by 2030 arise regarding the availability of electrolysers. REPowerEU assumes 65 GW of installed electrolyser capacity to meet the 2030 objectives. However, if these electrolysers use only renewable energy, their best-case capacity factor would be around 50-60%. This means that at least 40% of the primary energy would be lost during hydrogen production. To meet the objectives, the EU would actually need 95-115 GW of electrolyser capacity,

[34] European Commission, 2022, *Implementing the REPower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets*, European Commission.

which is closer to the estimates of 120 GW suggested by the European hydrogen industry[35]. Yet, some studies present reservations about constraints related to supply chains and external dependencies, raising serious doubts about whether the European industry can meet internal demand and produce enough electrolysers to produce 10 Mt of green hydrogen domestically by 2030[36]. If the implementation of the additional electrolyser capacity in Europe does not materialise, there is a risk that the missing demand will be covered with fossil fuel-based hydrogen to meet the internal EU hydrogen targets. This may lead to over-generation and low market prices, as well as very high risks for the entire hydrogen industry.

5. Conclusions and outlook

REPowerEU's targets for the growth of renewable energy and green hydrogen in the European Union by 2030 are presented as a coherent development path in which generation and demand are fully matched. However, the presented targets, and the division of hydrogen consumption across end-use sectors in particular, do not provide a critical reflection on the expected hydrogen demand by 2030 nor acknowledge the challenges and risks of delivering them.

The growth scenarios included in REPowerEU assume ambitious RES deployment targets within the European Union. They are built on assumptions about the ability to accelerate deployment of RES – and the corresponding adaptation of electricity grids – at a scale multiple times larger than the cumulated installed capacity of the past two decades. Measures to accelerate and scale the deployment foreseen in REPowerEU may indeed not be sufficient to realise planned growth, especially in the given time frames.

The risk that RES and electricity grid deployment targets will be missed is considerably higher when taking into account the strong emphasis on, and support provided for, ramping up hydrogen demand and production capacity. This may result in: 1) a decreased push and support for electrification, thus failing to reduce overall energy demand (due to potential support mechanisms); 2) higher emissions due to the use of carbon-intense electricity for electrolysers and leakages from hydrogen production and transport; 3) shortages of hydrogen for those consumers that cannot electrify, as hydrogen may be channelled towards sectors that do not really need them; and, finally 4) massive public opposition related to higher energy costs, increasing conflicts on the ground due to the larger space requirements for infrastructure and related local

[35] European Academies Science Advisory Council, 2023, *The Future of Gas*, European Academies Science Advisory Council.
[36] See for example: Ansari, D., Grinschgl, J., Pepe, J., M., 2022, *Electrolysers for the Hydrogen Revolution*, German Institute for International and Security Affairs.

impacts, deployment of controversial assets (such as underground hydrogen storage), support for carbon-intensive solutions, and continuous cost externalisation from huge import targets.

Thus, the feasibility of delivering the REPowerEU hydrogen targets and their implications require a careful consideration of the constraints, which can negatively impact the EU's pathway to climate neutrality. These constraints include the availability of space, supply chains becoming increasingly insufficient, and global competition intensifying. Similarly, conflicts on the ground, competing interests, public opposition, and access to cheap capital are all aspects that cannot and should not be ignored. Broadening the scope of energy system modelling with these constraints in mind and embedding them in energy scenarios would draw a more realistic picture of the future decarbonised energy system. Similarly, developing energy system models driven by principles aimed at reduction of energy losses and waste would lead to system optimisation, which will deliver benefits across the entire economy.

This discussion paper addressed some key points related to hydrogen demand and supply as outlined by REPowerEU and their implications for the power system. Nevertheless, the uncertainties related to the potential pathways for implementing the REPowerEU hydrogen targets must be addressed, including: 1) the costs and geopolitical consequences of importing a larger amount of hydrogen compared to the development of local production (cost, logistics of transport and distribution, emissions); 2) where hydrogen production should be optimally located; 3) how much space hydrogen infrastructure requires compared to direct electrification; and, 4) what the consequences are if domestic green hydrogen production is not feasible with given investments in the entire energy sector, including manufacturing capacities.

If indeed the EU's objective is to curb emissions, reach climate neutrality, and guarantee energy security, the given green hydrogen targets should be re-assessed in view of the current and anticipated constraints. Efficiency of the entire energy system should be taken as a key driver for energy planning as well as reducing import dependencies. Assuming that the main source of energy in a net-zero energy system will be electricity from renewable sources (mainly solar and wind), the aim must be to minimise demand for this primary source of energy by striving for maximum system efficiency and therefore increase electrification. The difference between aiming for 20 Mt versus only 10 Mt of green hydrogen by 2030 is significant. If the green hydrogen targets for 2030 aim at creating a large hydrogen market which includes all forms of hydrogen (from fossil sources – with or without CCS – and nuclear), as is the interest of some EU Member States and neighbouring countries, clarity and transparency on targeted technologies, their locations, and expected costs should be outlined and publicly shared by the European Commission. This will also lead to an appropriate reassessment of RES and electricity grid requirements.

Finally, the authors of this discussion paper tend to believe that these high green hydrogen targets may come from the desire to build overcapacity – with the expectation that this will lead to cheaper hydrogen market prices, protect European industries, and create potential export opportunities. In view of the scarcity constraints described above, we consider this a very risky strategy, especially because it will further increase the real cost of energy for all consumers. European industries may therefore face higher uncertainties than in a smaller, but optimised hydrogen market.

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