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Hydrogen Policy Environment in the European Union, Current Status of Policy Uptake

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Hydrogen (H_2) can become a crucial technology in building an independent and resilient energy infrastructure. The production and utilisation of green hydrogen will play a crucial role in the energy environment of the European Union in the future. Several strategies were defined, and policy actions were taken. H_2 has a comparably high lower heating value and no direct harmful emission during use, so it presents a viable alternative for conventional energy carriers. Independently from the final form of usage, H_2 will play a key role in integrating green electricity into the grid, as according to the state-of-the-art, large-scale, long-term energy storage is only feasible in molecules containing H_2. H_2-based mobility solutions could offer a viable technology for sustainable transportation. This article investigates H_2 production and demand in the EU, as well as the directives and incentives of the EU to accelerate H_2 production and H_2 technologies in general. Based on the existing policies and applications, it reviews the up-to-date status of policy uptake within the EU and gives insights into the different preparedness for the transition to a H_2-based energy system of the Member States.

1. Introduction

With a comparably high lower heating value of 119.96 MJ/kg (Linstrom and Mallard, 2021) and no direct harmful emissions during use, H_2 presents a viable alternative for conventional energy sources or fossil fuels. H_2 can play a key role in integrating green electricity into the grid, as according to the state-of-the-art, large-scale, long-term energy storage is only feasible in molecules containing H_2 (Bothe, 2018). The International Energy Agency (IEA) Statistics show that the contribution of CO_2 emissions of transport to total fuel combustion was between 19 % and 22 % over the last 50 y (1960-2014) (IEA, 2014). By 2030, the European Commission (EC) envisions at least 30 million zero-emission vehicles on European roads, 100 climate-neutral European cities, doubled high-speed rail traffic, carbon-neutral collective travel of under 500 km, and market-ready zero-emission vessels (European Commission, 2020b). By 2050, the EU has set out that nearly all transport utilisation should be zero-emission. In mobility, H_2 has multiple pathways to reduce greenhouse gas emissions. Besides its usage in fuel cells, H_2 can produce synthetic methane and other e-fuels, and it can directly fuel thermal and internal combustion engines. However, the applicability of H_2 for specific industries must be analysed through a comprehensive Life Cycle Assessment (LCA) to assess the environmental impact objectively. The proposed complex methodology should incorporate several factors: the energy balance of the various H_2 production methods, the effect of different use cases or further environmental and social topics. Recent research in H_2 LCA focuses on different production and utilisation options. Tabrizi et al. (2023) focus on the CF of green H_2 production based on photovoltaics, Arfan et al. (2023) evaluate the LCA and LCC of H_2 production from biowaste, the same topic is addressed by Buffi et al. (2022) supplemented with the energy footprint of the H_2 production. Grazieschi et al. (2023) analysed the energy and greenhouse gas LCA of electric and H_2-driven buses in Italy. The biomass can also be utilised for producing hydrogen in a renewable way (Peres et al., 2013). Adopting a Systems Engineering approach for LCA could improve the overall accuracy of the CF of H_2 technologies, and a holistic LCA method with an enhanced Life Cycle Inventory (LCI) can be set up. The different policy initiatives of the EU and its member states are targeting the energy transition from widespread fossil-based solutions to more sustainable, partly H_2-based solutions. These policy initiatives have a clear influence on the CF of H_2. There are at least two focus areas to analyse: the uptake of the proposed and already adopted

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policies, the development of different KPIs regarding goals, and how sustainable is the planned transition? To answer this research question, a more complex and holistic lifecycle-based analysing method should be introduced. There is a lack of comprehensive scientific research which analyses the H_2 policy background and its influence on LCA results. In this article, a short insight will be given into the first topic, focusing on the H_2-related policies of the EU and policy uptake in two member states (Germany as a forerunner in H_2 utilisation and Hungary). The focus of the investigation is achieving targets in the field of green H_2 production. Analysis of the scientific literature and policy documents was used to reach the research goals. Future research will investigate how state-of-the-art policy results can be involved in LCA methodology.

2. Hydrogen policy environment in the European Union

Review of H_2-oriented goals (Lagioia et al., 2023) and strategical trends (Liu et al., 2023) towards green H_2-based society can be found in scientific research (Asiegbu et al., 2023), but the topic is evolving quickly, necessitating a regular update on policy uptake. The following chapter investigates the current status of H_2 policy environment in the EU. The most cited definition of sustainable development was laid down in the Brundtland Report (Our Common Future) in 1987 (United Nations, 1987). In 2015, the United Nations (UN) adopted its 2030 Agenda for Sustainable Development and defined the 17 Sustainable Development Goals (SDGs) (United Nations, 2015a). The most recent emergence of sustainability is linked with the environmental, social, and governance (ESG) framework. As one of the main goals of an H_2-based economy is to reduce CF, the related environmental policies should also be assessed. The Paris Agreement, adopted in 2015, is a legally binding international treaty which provides a comprehensive framework for future goals (setting the 2 °C target) and activities (United Nations, 2015b). Reducing CF means reducing primary energy use and converting processes to more energy-efficient ones. It also means a massive investment need in renewable energy production solutions. These international targets also set the framework for the environmental strategies of the EU (to establish a greener and more sustainable Europe within a limited period). The time horizon of the environmental strategies of the EU ends in 2050. The most important initiative is the European Green Deal (EGD), a set of policy initiatives to transform the EU into a resource-efficient, climate-neutral continent. The EGD covers many topics, such as tackling climate change, sustainable agriculture, environmentally friendly transport solutions, clean energy transition, and uptake of renewable energy (European Commission, 2021a). Strategies and programs with similar aims are – among others – the EU Sustainable Development Strategy (European Commission, 2001), the 8th Environmental Action Programme (European Commission, 2022a), the Circular Economy Action Plan (European Commission, 2020a), the Zero Pollution Action Plan (European Commission, 2021b). Within the United Nations 2030 Agenda frames, the EU committed to the UN SDGs (United Nations, 2015a). The transition to a more effective and climate-friendly energy system incorporates several topics, among others, using renewable energy sources. It can be stated regarding the EU H_2 landscape that the use of H_2 for energy production was not significant (under 2 % on an annual basis) in 2020. However, it is a key technology in the EU's energy and sustainability strategies (European Commission, 2020c). Getting appropriate data about H_2 production and demand in the European Union is challenging due to the lack of official H_2 statistics. According to the Clean Hydrogen Monitor 2022, the total H_2 production capacity in Europe (EU; EFTA and United Kingdom) was 11.5 Mt/y in 2020, produced by 504 H_2 production sites (Allsop and Bortolotti, 2022). Despite activities in clean H_2 production methods, 99.3 % of the produced amount was generated by conventional technologies, i.e., captive reforming (80.4 %), merchant reforming (10.4 %), ethylene and styrene production by-products (4.8 %) (Allsop and Bortolotti, 2022). The average capacity utilisation was 76 % (8.6 Mt) (FCHO, 2022a), whereas the total H_2 demand in 2020 was approximately 8.7 Mt (Franklin-Mann and Kutka, 2022). It has to be highlighted that approximately 91 % of the demand stems from the refinery industry, ammonia production, and the production of methanol and other chemicals, whereas only approximately 4 % can be accounted to the energy industry and approximately 1 % to the transport (Allsop and Bortolotti, 2022). For reference, Europe was the fourth largest H_2 consumer in 2021, with 8 Mt total consumption (IEA, 2022a). The IEA's Stated Policies Scenario (STEPS) forecasts a global H_2 demand increase of approximately 22 % by 2030 compared to 2021, whereas the Announced Pledges Scenario (APS) forecasts a rise of 38 % till 2030 to the level of 2021 (IEA, 2022a). Similar growth can be expected in the European H_2 market based on the ambitious goal of the EU's RePowerEU strategy, which plans a target of 10 Mt of clean H_2 production within the EU in 2030, along with an additional 10 Mt of imported clean H_2 (European Commission, 2022c). Green H_2 is mainly produced by electrolysis using power from renewable energy sources. The installed clean H_2 production capacity of Europe has almost doubled between 2019 (85 MW) and 2022 (162 MW) (Franklin-Mann and Kutka, 2022). There were 114 operational H_2 production sites using water electrolysis (power-to-gas) on a European level in 2020, with a total capacity of 99 MW, equalling a production rate of 44 t/day (FCHO, 2022a). The most widespread electrolyser technology was PEM (Polymer electrolyte membrane) (FCHO, 2022b). The overall electrolysis capacity in Europe reached approximately 162 MW in 2022, which highlights 63.6 % increase compared to 2021 (Franklin-Mann and Kutka, 2022). In 2022, 77 % of EU Power-to-Hydrogen (PtH) capacity and 75 % of PtH projects were powered by renewable sources (Allsop and Bortolotti, 2022). The EU attached great importance to clean H_2, defined its strategy toward the H_2 economy, and incorporated this topic into several strategic documents. Due to the length of this article, it is not possible to give an in-depth analysis of all EU strategies and legislation on H_2. The base document of the EU's H_2 strategy is the EU Strategy on Hydrogen (COM/2020/301) (European Commission, 2020c). It appoints the frames of the EU's activities. The planned activities are grouped into five main categories: investment support, support production and demand, creation of an H_2 market and infrastructure, research and cooperation in H_2 production, and establishment of international collaborations. The main categories were specified in 20 key action points, implemented by the first quarter of 2022. The action points and the strategy have been linked with other strategies of the EU to support the EGD and the more rapid transition to an H_2 economy. The H_2 strategy will also play a significant role in achieving the targets of the Fit-for-55 policy package and support the sector integration of the EU's energy system (EU strategy on energy system integration) (European Commission, 2020d). H_2 uptake as an energy carrier was accelerated by accepting the new RePowerEU plan (RPP) in May 2022. The main goal of the RPP is to reduce the dependence on foreign energy and to speed up the green transition of the EU energy system. One part of RPP is to achieve massive growth in using renewable energies, with H_2 being a crucial part of it. The EU has set an ambitious goal: producing 10 Mt of green H_2 in 2030 and importing 10 Mt to replace conventional energy sources. These targets were laid down in the Staff Working Document Nr. 230 (SWD/2022/230) as a "Hydrogen Accelerator" concept. It also defined the priority sectors that can consume more H_2 in 2030 (e.g., industrial heat production, petrochemical production (ammonia production), refineries, and transport sector) (European Commission, 2022c). The H_2 Accelerator concept includes several different measures to boost the uptake of H_2, such as raising the targets of the revised Renewable Energy Directive (RED II – 2018/2001/EU), doubling the number of H_2 valleys in Europe, speeding up the assessment and approval of H_2-related Important Projects of Common European Interest (IPCEI) and the development of H_2 standards (Franklin-Mann and Kutka, 2022). The EC proposed a revised target for renewable energies, which affects the updated Renewable Energy Directive (RED II – 2018/2001/EU). In the field of H_2 use, the targets for 2030 were raised from 50 % to 75 % in the industry sector and from 2.6 % to 5 % in the transport sector, which means a significant growth of H_2 demand estimated on a level of 6.2 Mt for the industry and 4.2 – 4.8 Mt for the transport sector (Franklin-Mann and Kutka, 2022). One key issue is Renewable Fuels of Non-Biological Origins (RFNBO). The EC adopted two delegated acts in February 2023 that describe the rules and definitions regarding RFNBOs. The first (C(2023) 1087) defines the criteria which should be applied to decide whether H_2 or H_2-based fuel can be considered as an RFNBO or not (European Commission, 2023). The second describes the methodology to calculate the greenhouse gas emissions from RFNBOs on a total life cycle base (European Commission, 2023). Both detailed regulations are important to understand and implement the actions defined in the EU strategy on H_2 and the RePowerEU plan. Other relevant policy documents include the Alternative Fuels Infrastructure Regulation (AFIR), the Regulation on trans-European energy Infrastructure (TEN-E), the Regulation on the trans-European transport network (TEN-T) (European Commission, 2013), the H_2 and Decarbonized Gas Package of the Commission and the EU Emissions Trading System (ETS) regulation (European Commission, 2022b) and the new Carbon Border Adjustment Mechanism (CBAM) proposal (European Commission, 2021c) which will be in operation since the October of 2023. The EU supports the implementation of policy measures with several steps. One crucial tool implemented is the formation of IPCEIs. These are cross-border projects contributing to reaching the common European policy goals. The IPCEI Hy2Tech supports the R&D&I activities for H_2 production in different sectors. It incorporates 41 projects, realised by 35 different companies and financed by the 15 signing member states with up to 5.4 billion EUR (European Commission, 2022e). Another relevant IPCEI called IPCEI Hy2Use was launched in September 2022 to support activities on a vast part of the H_2 value chain (infrastructure, storage, and technics) to integrate H_2 into industrial processes. This was prepared and funded by 13 member states and will provide public funding of 5.2 billion EUR (European Commission, 2022d). Both IPCEIs try to cover the whole H_2 value chain to provide a comprehensive perspective and solutions. Institutional activities and solutions such as the European Clean Hydrogen Alliance, the Clean Hydrogen Partnership, and the Hydrogen Energy Network also support the H_2-related activities of the EU. Besides the EC, most EU member states have already adopted or developed national H_2 strategies. Each member state's national strategy is on a different level of maturity, but progress is ongoing and accelerating. As of February 2022, fourteen EU member and EEA states (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Luxembourg, Norway, the Netherlands, Poland, Portugal, Slovakia, Spain, and Sweden) and the United Kingdom had a relatively developed H_2 policy (FleishmanHillard, 2022). Other countries do not have a developed H_2 strategy, but they are running several H_2-related projects and partially have H_2-related goals (Austria, Bulgaria, Croatia, Estonia, Finland, Greece, Ireland, Italy, Lithuania, and Romania) (FleishmanHillard, 2022). Cyprus, Latvia, Malta, and Slovenia did not develop H_2 strategies until February 2022 (FleishmanHillard, 2022).

3. Current status of policy uptake in selected countries

This article investigates the uptake of adopted H_2 policies in Germany and Hungary, focusing on H_2 production. Germany is a forerunner in H_2 issues within the EU. H_2 plays a crucial role in the energy sector transition goals. The National Hydrogen Strategy (NHS) of Germany was adopted in June 2020. Other provinces of Germany have adopted their own H_2 strategy, too. As of that NHS, the domestic H_2 consumption is about 55 TWh annually (FMEAE, 2020). Most of this amount is covered by using grey H_2. Only approximately 5 % of the total amount is green H_2 (Merten et al., 2020). The future H_2 demand in Germany will grow exponentially. As to the study by the Fraunhofer Institute, the annual demand for H_2 will be at 80 TWh in 2030 and between 400 – 800 TWh in 2050, with great uncertainty (Wietschel et al., 2021). The NHS presumes a bit higher demand in 2030, a range between 90 – 110 TWh, but gives no foresight for 2050 (FMEAE, 2020). The forecast of the National H_2 Council is slightly higher, with an estimate of 964 – 1,364 TWh between 2040 and 2050, including the amount of grey H_2 (TGNHC, 2023). The NHS laid down the main strategic directions and defined the targets for 2030 and 2050 in different categories. The strategy covers all the relevant fields of action, from the production of green H_2 through market development, international cooperation and import-related topics to the scientific and educational background of H_2 value chain with 38 defined action fields. The NHS is targeting a massive improvement in the green H_2 production capacities. Till 2030, the overall installed production capacity should reach 5 GW, with an expected annual production of 14 TWh green H_2. The strategy also plans for an additional 5 GW by 2035 and no later than 2040. The total capacity of 10 GW should cover approximately 28 TWh H_2, which is only 35 % of the expected demand. This means that Germany should have a significant grey H_2 production and/or a huge amount of green H_2 import. The update of the NHS is just running, and there are more ambitious goals defined. One of them is that the installed green H_2 production capacity should reach 10 GW by 2030 (BMWK, 2023). The installed green H_2 production capacity of Germany was 1,15 GW in October 2022, according to the H_2 project database of the International Energy Agency (IEA, 2022b). An additional 0,914 GW capacity had a final investment decision, and 0,0011 GW was under construction (IEA, 2022b). This means a slight delay in the policy uptake and some risk of reaching the targets. Hungary also focuses on H_2 as a future energy source and as an energy vector. Hungary adopted its national H_2 strategy in May of 2021. Green H_2 production stands at the focal point. Targets are set to 2030. The main action fields are the improvement of green H_2 production capacity, decarbonisation of industrial processes by using green H_2, greening the transport sector and sectoral integration with other energy sectors. Focusing on the production issues, the targeted value for 2030 is 20.000 t of low carbon H_2 and 16.000 t of carbon-neutral H_2 with a total of 240 MW electrolyser capacity. Another strategic source is the National Energy Strategy of Hungary, which also defines goals for H_2 utilisation. The first H_2 production power plant in Hungary was handed over in May 2023. The 2,5 MW capacity device in Kardoskút produces 400 m^3/h grey H_2 by using grid energy. The forecasted H_2 demand of Hungary will be approximately 162.000 t in 2030, which will rise to 249.000 t by 2050 (Government of Hungary, 2021). Both in Germany and Hungary, the strategic background for H_2 was laid down, and mostly all the necessary institutional funds and processes were established. Both analysed countries have targeted the improvement of green H_2 production capacities till 2030. The process has already begun, but there is a significant gap between targeted values and already realised capacities in both states. It is necessary to accelerate the processes in that field both in Germany and Hungary.

4. Conclusions

In conclusion, this scientific paper provides insights into the H_2 policy landscape, including use cases and its current adoption in both Germany and Hungary. The results highlight the pivotal role of well-defined H_2 policies and regulations in promoting the widespread use and development of this energy carrier. Germany's proactive stance on H_2 policy has positioned it as a leader in the global H_2 economy. The nation's strategic investments in research, infrastructure, and international collaborations have led to significant advancements in H_2 technologies. The exploration of H_2 applications in mobility and stationary contexts showcases its potential to revolutionise the transportation and energy sectors. H_2-powered vehicles (utilising fuel cells or internal combustion engines), offer low-emission transportation with fast refuelling capabilities, addressing range concerns and contributing to cleaner air while reducing reliance on fossil fuels. In stationary utilisation, H_2's ability to store surplus renewable energy serves as a crucial tool for grid stability and energy storage.

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