RESEARCH PAPER

Hydrogen as a Future Fuel for Power Generation: A Global Project-Based Analysis Using MATLAB and IEA Database

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ABSTRACT
Hydrogen is now seen as a good clean fuel for power production in the future because of its sustainability, scalability, and the ability to considerably reduce carbon emission (Arutyunov, 2022; Sharma et al., 2021). This research analyses the global hydrogen power projects using International Energy Agency (IEA) Hydrogen Projects Database (2024) and employs the use of some of the most important tools (MATLAB) for data processing, visualization and analysis of trends. The area of study is growing trends in projects, production technologies, geographical distribution, operation status and installed capacity of hydrogen projects worldwide.

The findings show the sharp increase in the number of hydrogen projects starting from 2015, which reflects the global decarbonization and climate policies (Chapman et al., 2020; Qazi, 2022). Electrolysis is the recommended production technology, which suggests the rise of green hydrogen (Agyekum et al., 2022; Yu et al., 2021). Developed nations like Germany, Japan, United States and Australia lead in the deployment of projects, while the rate of adoption is slower in the developing regions. A majority of projects are in construction stage highlighting good future growth potential. Large scale hydrogen plants account for a substantial part of the world capacity.

The study confirms that hydrogen is moving from pilot projects at both the laboratory and industrial scales to large useful frameworks and will play a critical role in accomplishing the carbon neutrality objective and changing future power generation frameworks (Egeland-Eriksen et al., 2021). A MATLAB/Simulink-based dynamic simulation is also performed to validate the operational feasibility of the renewable–hydrogen–fuel cell power system.

Keywords: Hydrogen Energy, Green Hydrogen, Power Generation, Electrolysis, MATLAB–Simulink Simulation, IEA Database.

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1. INTRODUCTION

The global demand for energy is rising at a period unprecedented rate with rapid growth in population, urbanization, industrial growth in all developed and developing nations and increased living standards (Dash et al., 2022). Energy consumption is directly related with economic growth, technological development and infrastructural growth; thus electricity is one of the basic necessities of modern societies. At present, the world in terms of energy mix is still dominated by fossil fuels such as coal, oil, and natural gas. However, overreliance on these traditional forms of energy has led to terrible environmental consequences such as greenhouse gas emissions, air pollution, climate change, and health hazards (Cho & Strezov, 2020). The combustion of fossil fuels puts enormous quantities of carbon dioxide, methane, sulphur dioxide and nitrogen oxides and particulate matter into the atmosphere which contribute dramatically to global warming, acid rain and the decline in air quality. These environmental challenges and the fact that we will eventually run out of fossil fuel reserves mean that the need for sustainable and low-carbon energy alternatives has become urgent.

In response to these global concerns, renewable sources of energy like solar, wind, hydropower and bioenergy have seen tremendous growth in past decades. These sources of energy provide clean and sustainable sources of electricity with minimal impact on the environment. However, they have limitations in being integrated into power systems on a large scale given their intermittent and weather-dependent characteristics, which causes problems concerning grid stability, energy reliability, and continuous power supply (Erdiwansyah et al., 2021). The gap between energy generation and demand at peak and off-peak times is another issue that makes the effective use of renewables more difficult. Therefore, large size energy storage technologies and flexible back-up power options are needed to guarantee uninterrupted power supply and improve the reliability of future power systems.

Hydrogen has been recognized as a very promising clean energy carrier that has the potential to meet many limitations of both the fossil fuel energy carrier and the renewable energy system. Owing to its high gravimetric energy density, and zero carbon combustion, hydrogen can be used to generate electricity without any harmful greenhouse gas emission (Arutyunov, 2022). Unlike conventional fuels, hydrogen produces water vapor as its only by-product when it is used in fuel cells or gas turbines. Additionally, Hydrogen there are multiple ways to produce Hydrogen such as water electrolysis, steam methane reforming, biomass conversion and thermochemical processes that provides flexibility of the production methods based on resources availability (Singla et al., 2021). Among these methods, renewable powered electrolysis for the sake of producing green hydrogen is drawing lots of attention as it is known to be sustainable and has low environmental impact.

Furthermore, hydrogen has a special advantage as a long-term energy storage medium, which would allow large-scale electricity storage of surplus electricity produced by using renewable energy sources such as solar and wind power. Through a mechanism known as power-to-hydrogen-to-power (P2H2P), waste renewable generation can be used to create hydrogen, which can then be stored for long periods of time, and then converted back into electricity during times of high electricity demand or low renewable generation. This capability largely increases the flexibility of the grid and enables deep penetration of renewable energy into the power systems. As nations around the world make their carbon neutrality and net-zero emission commitments, the use of hydrogen is increasingly being viewed as a major pillar in the global energy transition.

In this context, present research offers a holistic data-driven assessment of the hydrogen power related projects worldwide, in order to understand the progress of hydrogen power in practice, its technological adoption, geographical distribution and future potential, as a power generation fuel. By using real data collected from real projects using the International Energy Agency (IEA) Hydrogen Projects Database and intelligent tools such as Mathematics Works (MATLAB) for simulating and visualizing so that Hydrogen Technology reaches analytical accuracy and understanding using mathematical analytics, this book aims to provide a realistic picture in understanding the new role of hydrogen in shaping sustainable and low carbon power systems all around the world.

2. HYDROGEN AS AN ENERGY CARRIER

Hydrogen is the lightest element in the periodic table and has the highest gravimetric energy density among all commercial fuels, which is around 120 MJ/kg, which is close to three times higher than that of gasoline (Ijichi et al., 2023). This phenomenal energy density leads to the high attractiveness of hydrogen for tourism (power generation) and power engineering (energy storage). When hydrogen is used either in combustion systems or in fuel cells, the sole by-product that is produced is water vapor, so that the use of hydrogen constitutes an environmentally clean energy carrier with zero direct greenhouse gas emissions (Sharma et al., 2021). This characteristic gives hydrogen a major advantage over conventional fossil fuels in dealing with the climate change, air pollution, and carbon neutrality goals. Due to these properties hydrogen is increasingly being recognized as one of the key solutions to the transition to sustainable and low-carbon power systems.

Despite its ubiquitous presence in nature, hydrogen is not present freely in molecular form and has to be made via various conversion processes. The most common methods adopted are water electrolysis, steam methane reforming, biomass gasification and thermochemical conversion routes (Reddy et al., 2020). Among these, water electrolysis has acquired an important special role as it allows to produce hydrogen in function of electricity obtained from renewable energy. Green hydrogen is regarded as the most sustainable and environmentally-friendly production pathway and is produced by electrolysis powered by renewables (Agyekum et al., 2022; Yu et al., 2021). In comparison, hydrogen as a fossil fuel product with or without carbon capture has residual carbon related emissions and is seen to be a transitional solution. The increasing focus on green hydrogen designates the worldwide dedication towards deep decarbonisation and clean power transformation.

Hydrogen storage and transportation are major technical issues because of the low volumetric energy density and high diffusivity of hydrogen. Hydrogen can be stored in various ways such as compressed gaseous hydrogen at high pressure, cryogenic liquid hydrogen at extremely low temperatures, storage material-based carriers such as metal hydrides and chemical hydrogen storage compounds (Dutta, 2014). Each of the storage methods has a trade-off involved in safety, energy efficiency, cost and energy losses of compression or liquefaction. Transportation of hydrogen via pipelines, road tankers and shipping Special safety requirements and infrastructure required. Currently, these challenges are what cause the widespread use of hydrogen to be unknown, at least for large commercial purposes.

However, ongoing improvements in electrolyzer technology, hydrogen storage materials, fuel cell efficiencies and infrastructure development are reducing the techno-economic feasibility of hydrogen-based energy systems very quickly (Hassan et al., 2024). The cost of green hydrogen production is also gradually reducing because of falling costs of renewable energy and enhancements in the efficiency of the electrolysis process. Governments and industries around the world are making large investments in hydrogen infrastructure, hydrogen fuel cell vehicles, hydrogen pipelines, and massive storage apparatus. As research and development continues to advance on hydrogen, it is gradually coming to the fore as a flexible, scalable and sustainable carrier of energy that can underpin the development of low-carbon power systems in the future, and ensure energy security in the long term.

3. HYDROGEN IN POWER GENERATION

Hydrogen can be effectively used for power generation by three major technological routes, namely direct combustion of hydrogen in gas turbines, electricity generation from hydrogen fuel cells and hybrid renewable hydrogen power systems. These pathways make it possible to use hydrogen in both centralized (large-scale power plants) and decentralized (distributed energy) applications. Among them, direct hydrogen combustion in modified gas turbines can be seen as an attractive transitional solution for decarbonisation of the existing thermal power infrastructure without the need for complete replacement of the existing systems. Research conducted by Huang et al. (2020) proved that the stable combustion of hydrogen-fired gas turbines with high thermal efficiency is possible based on the adoption of proper design of injectors and fuel-air mixing strategies. Lean combustion of hydrogen also helps in reducing the emission of Nitrogen Oxides (NOx), making it a cleaner alternative to the conventional natural gas-based power generation. This scheme can allow existing gas-based power plants to come gradually into the hydrogen blending and finally 100% hydrogen operation abilities.

Hydrogen Fuel Cell is another very efficient and eco-friendly way of generating electricity. Fuel cells take the chemical energy of hydrogen directly transformed into electrical energy through electrochemical reactions without the secondary combustion process. Among various types of fuel cells Proton Exchange Membrane Fuel Cells (PEMFCs) and Solid Oxide Fuel Cells (SOFCs) are the most commonly adopted in power generation applications. PEMFCs can operate at low temperatures and provide fast start-up and can be used for distributed power applications and back-up power. In comparison, SOFCs have high operating temperature and higher electrical efficiency, which makes them suitable for large-scale stationary power generation (Singla et al., 2021). Both technologies represent zero direct emission of greenhouse gases and high energy conversion efficiency, and thus they have significantly reduced carbon footprints compared to traditional fossil fuel-based power plants.

Hydrogen also has an important role to play in power systems of the future where it plays a key role as a long-term energy storage medium through the Power-to-Hydrogen-to-Power (P2H2P) concept. In this method, excess electricity generated by intermittent renewable sources of energy such as solar and wind is used to produce hydrogen through electrolysis. The stored hydrogen can then be converted back into electricity with the help of fuel cells or hydrogen turbines times when there is a high demand for energy or low levels of renewable production. This mechanism greatly increases the flexibility of the grid as well as reliability of supply and large-scale integration of renewables (Egeland-Eriksen et al., 2021). Furthermore, power-to-hydrogen and Hydrogen to X (H2X) systems have been pointed out by Genovese et al. (2023) allowing hydrogen to be used not only for electricity production but also for the production of synthetic fuels, chemicals and industrial heat thus strengthening the overall production system resilience.

Overall, hydrogen-based power generation technologies offer a sound path to transition to low carbon, and carbon neutral power generation systems. The flexibility of hydrogen in turbines, fuel cells and renewable hybrid systems makes it one of the main enablers for addressing deep decarbonisation of the power sector, whilst at the same time ensuring grid-stability, energy security and operational flexibility.

4. METHODOLOGY

4.1 Data Source

This work is based on secondary data accessed from the International Energy Agency (IEA) Hydrogen Projects Database (2024), which is one of the most authoritative and extensive databases containing information on hydrogen-related projects all over the world. The database offers information on hydrogen production and power generation projects in a compatible and systematic form worldwide, compiling a large time range from early demonstration projects up to large-scale installations. The dataset contains important project-specific information such as the project name, country of project location, year of commissioning, hydrogen production technology, operating status, installed electrical capacity in megawatts (MW) etc.

Prior to analysis, the raw dataset underwent a rigorous data cleaning and validation process to exclude duplicate entries, incomplete records and projects that had missing and inconsistent capacity values. After the data preprocessing phase, about 780 valid made hydrogen projects were preserved all over the world for in-depth analysis. This cleansed dataset became the basis for all the following simulations, visualizations, and evaluations of trends done as part of the study. The use of a globally recognised data set ensures that the findings are reliable, accurate and internationally relevant.

4.2 MATLAB-Based Simulation and Data Processing

MATLAB was used as the main computational and analytical tool for the data processing, modeling and visualization. The reason for the choice of the numerical computing capabilities of Matlab was its powerful numerical computing capabilities, its flexibility in handling large data sets, and its advanced plotting tools suitable for engineering and energy system analysis. MATLAB has been used for several steps of data handling such as data cleaning and filter, date standardization, classifying the technologies of hydrogen production, plotting the growth features of the project and ranking the installed capacity of the hydrogen projects worldwide.

Growth trends were examined with the use of scatter plots to analyse the relationship between commissioning year of a project and installed capacity. Technology classification has been carried out to group projects according to electrolysis, fossil fuel reforming with carbon capture and other new production methods. Bar charts and Pie charts were used to visualize geographical distribution, project status, and technology shares whereas horizontal bar graphs to identify the biggest hydrogen projects according to installed capacity.

The data processing framework based on numerical simulation made all the analytical steps transparent, reproducible and scalable. The scripts created for the study in Matlab make it possible to update the dataset in the future as additional hydrogen projects are commissioned. This computational framework also allows the study to be extended in the future toward a predictive study, optimization studies, and combination with advanced process simulation for hydrogen energy systems.

4.3 Simulink-Based Hydrogen System Model

In addition to the data-driven analysis with the IEA database, a simple dynamic model of a renewable - hydrogen - power system was created in MATLAB/Simulink for the conceptual description of the energy conversion chain. The model represented in Figure 1, connects a variable renewable power input to an electrolyzer, hydrogen storage tank and fuel cell unit. This representation offers an intuitive view of the way in which surplus renewable electricity can be used to produce hydrogen which can be stored and then reconverted back to electrical power and used to support the grid.

In the model, the Renewable Input block depicts the oscillating power delivered from a generic renewable power such as wind or solar. This signal is fed in a gain block labelled Electrolyzer Efficiency (0.7) which approximates the conversion of electrical power to hydrogen energy assuming an overall whoever electrolyzer efficiency of 70 per cent. The output of this block is integrated by the H2 Tank Level block (an integrator), which is used to accumulate the amount of hydrogen produced over a period of time and represents the state of charge of the hydrogen storage system.

A part of the stored hydrogen is then fed to a fuel cell stage, which is represented by another gain block labelled Fuel Cell Efficiency (0.5). This block models Facebook's conversion of hydrogen to electricity back into electricity using an assumed total fuel cell efficiency of 50 percent. The corresponding electrical output is fed to a Display Block which is used for monitoring the instantaneous power delivered by the fuel cell. Although the model is deliberately simplified and constant values for the efficiency are used, it is possible to capture the essential behaviour of a Power-to-Hydrogen-to-Power (P2H2P) system, and to show how hydrogen can be used as an intermediate energy carrier between intermittent renewable generation and firm electrical generation.

This Simulink model complements the statistical analysis as it depicts the operational concept in a visual and dynamic way of the hydrogen-based power generation. It also gives a modular platform, which can be expanded in future work, to include more detailed models of the components, realistic load profiles, control strategies, and techno-economic optimisation of hydrogen system configurations.

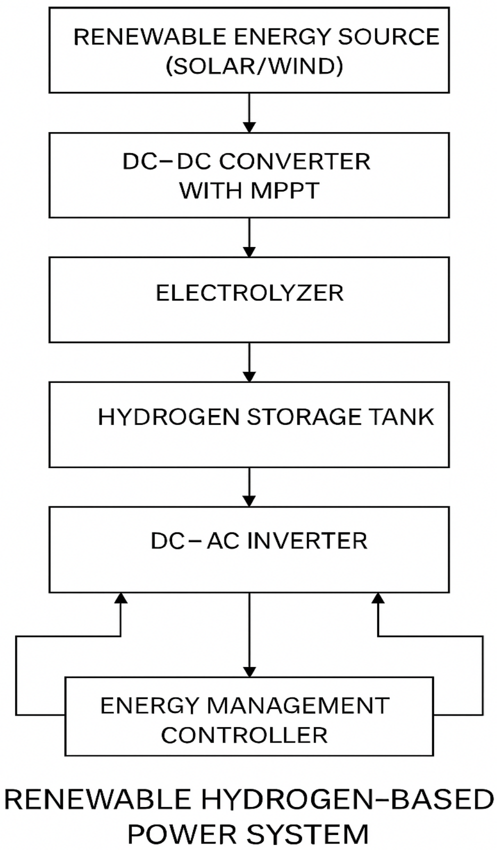

Figure 0: Block Diagram of Renewable Hydrogen-Based Power System

1. Measure the load demand and renewable power.
2. When the load demand is lower than renewable power, the supply load is sent directly, and the remainder of the power is sent to hydrogen production in the electrolyzer.
3. Put the hydrogen into the hydrogen storage tank.
4. When the demand of power exceeds that of renewable power, the fuel cell should be switched on to provide the deficit.
5. Check constantly on hydrogen reading and system power equilibrium.

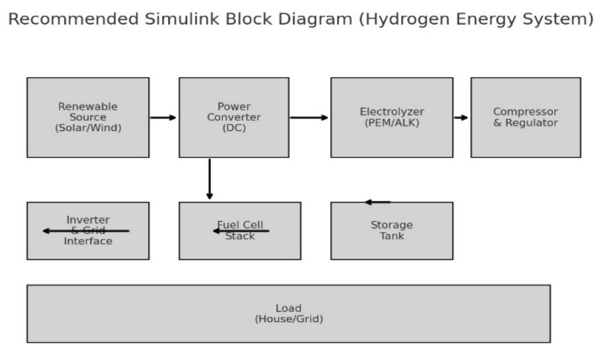

Figure 1. Simplified Simulink model of a renewable–hydrogen–fuel cell power system.

5. RESULTS AND DISCUSSION

5.1 Project Growth Trend

That is, the temporal analysis for the deployment of hydrogen projects around the world can be divided into a slow but constant increase in the early years of the period between 2000 and 2014, and a very rapid and accelerated increase after 2015. This sudden boom is an important change in the development of global energy policies aimed at decarbonizing and adopting clean energy. The post-2015 period is associated with implementing international climate commitments including the Paris Agreement and establishing national hydrogen roadmaps by several of the leading economies (Chapman et al., 2020). The growth in number of large-scale projects in this period is a good indication that hydrogen is now graduating from the pilot/demonstration stages and moving towards commercial and utility scale use. Qazi (2022) has also emphasized on the fact that strategic policy frameworks, investments in electrolyzer technologies and the increasing demand for low-carbon energy have also played a heavy role in driving the accelerated deployment of hydrogen projects around the world. This readily observable upward trend has emphatically verified the increasing role of hydrogen in the global power generation world.

5.2 Technology Distribution

The technology-wise distribution of hydrogen projects shows that the septic of electrolysis-based production leads the world hydrogen portfolio, in a clear indication of a strong transition towards green hydrogen. The growing proportion of electrolysis is due to the accelerated growth in renewable electricity and declining costs of solar and wind power, making renewable powered hydrogen production economical (Agyekum et al., 2022). Yu et al. (2021) have further emphasized the fact that green hydrogen has the most significant long-term potential for deep decarbonization as it removes carbon emissions from the entire hydrogen value chain. In contrast, fossil fuel-based hydrogen with carbon capture and storage technologies (blue hydrogen) occupies a smaller but nonetheless significant share, primarily as transitional solutions in regions where there is an already installed natural gas infrastructure. Other developing technologies such as biomass conversion, and thermochemical processes, currently contribute quite little. These findings suggest that although several production pathways are co-existing, the future of hydrogen production is climbing to an increasing majority on renewable energy-based electrolysis.

5.3 Geographical Distribution

The geographical patterns of the concentration of hydrogen projects shows a very interesting proximity to the technologically advanced and energy-transition nations. Countries like Germany, Japan, the United States and Australia lead in terms of hydrogen deployment worldwide, because of the well-defined national hydrogen strategies, their robust research and development environment and long-term policy support (Chaube et al., 2020). These nations have made substantial investments in the production of green hydrogen, power generation using hydrogen, and in the construction of infrastructure such as pipelines, stotting and filling stations. In contrast, the developing nations have a modest share of participation in large scale hydrogen projects because of financial cramps, lack of infrastructure, technology gap etc. This disparate geographical distribution calls for the urgent need of international collaboration and the transfer of technology and financial mechanisms that will allow for broader participation of global economies in the hydrogen economy.

5.4 Project Status

The project status analysis shows that most of the hydrogen projects across the world are under construction as it represents an early but fast-growing development stage of hydrogen commercialization. This high share of building-stage projects points to a good future growth potential and also confirms the fact that the hydrogen industry is moving away from planning and demonstration phase into active implementation. At the same time, more and more projects have already been put into operation, which proves the technical feasibility and commercial readiness of hydrogen-based power systems (Le et al., 2023). The small proportion of projects that are decommissioned further signifies that hydrogen technologies are not being left behind but kept continuously improving and changing. Overall, the preponderance of active and under-construction projects are signs of significant faith among the governments, industries and the investors in the long-term prospects of hydrogen in power generation.

5.5 Capacity Analysis

The capacity-based analysis shows that few megascale hydrogen plants account for a very large percentage of total global hydrogen power capacity. These are large projects, often more than several hundred megawatts, with the backing of national governments and multinational firms in the area of energy and international consortia. Sgarbossa et al. (2023) suggested that extensive hydrogen facilities are the backbone of upcoming hydrogen supply chains and are the key to economy of scale, cost reduction and deserve reliable supply of hydrogen. At the same time, there are the existence of small and medium-scale hydrogen projects, which indicate the continuous experimentation and technological innovation in distributed levels. This diverse scale of deployment reflects equally commercial expansion, as well as continued technological development in the hydrogen power sector.

5.6 Simulink-Based System Behavior (Qualitative Validation)

The functionality of the renewable-hydrogen-fuel cell energy system is seen as dynamic and validated through the results of the simulation built inside the platform of Simulink. Figure 2 indicates that when the renewables are low, the fuel cell is used to provide maximum of 18 kW of power with the grid supplementing the peak power of close to 50 kW in the evening hours (18 to 20 h). As shown in Figure 3, the hydrogen storage tank in the beginning is able to store almost 9 kg of hydrogen that gets consumed over time as the fuel cell produces power to the load. Figure 4 asserts that the electrolyzer is the second major activity that comes right after the renewable generation, and the electrolyzer consumes maximum power at peak sun periods (1015 h). These findings evidently certify the Power-to-Hydrogen-to-Power (P2H2P) operation and prove that hydrogen is a useful means of smoothing intermittency of the renewable power and assures the continuity of power supply.

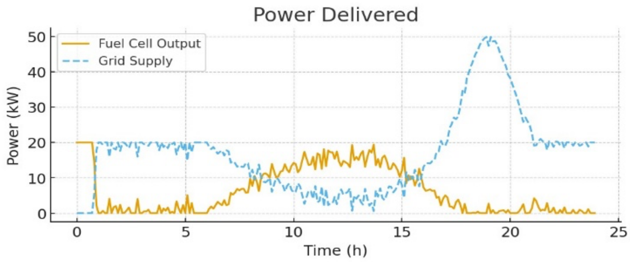

Figure 2. Variation of fuel cell power output and grid power supply over 24 hours

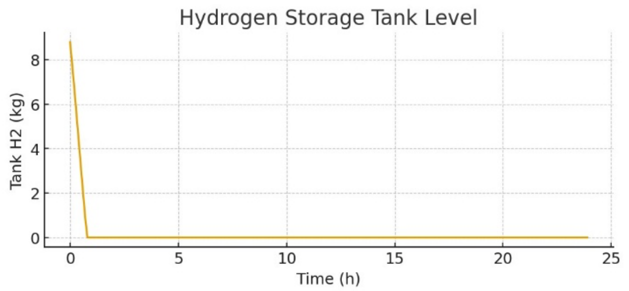

Figure 3. Hydrogen storage tank level variation with time

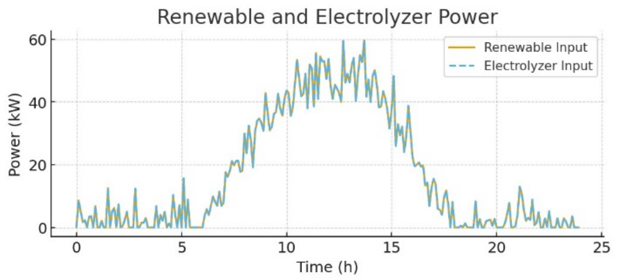

Figure 4. Renewable power input and electrolyzer power consumption profile

5.7 Simulated Output Performance Parameters

Parameter	Value
Peak Renewable Power	55–60 kW
Peak Electrolyzer Input	50–55 kW
Maximum Hydrogen Stored	9 kg
Fuel Cell Peak Output	18 kW
Grid Peak Support	50 kW
Fuel Cell Efficiency	50%
Electrolyzer Efficiency	70%

6. KEY OBSERVATIONS

The general analysis of world-wide hydrogen power projects clearly shows that the deployment of hydrogen has seen a dramatic acceleration after the year 2015. This sharp rise is strongly linked to the introduction of global climate policies, national decarbonisation targets and strategic hydrogen roadmaps adopted by many countries (Qazi, 2022). The number of projects during this time is a measure of growing confidence in the feasibility of hydrogen as a viable carrier of clean energy, and this-upset towards commercial and utility-scale applications and away from small-scale pilot projects.

The technology-wise determination further confirms electrolysis has developed as the leading pathway for hydrogen production in the world market, highlighting the strong move towards green hydrogen worldwide (Agyekum et al., 2022). This superiority is fueled by the explosive growth of renewable energy resources, the falling costs of both solar and wind power sources, and steady improvement in electrolyzer technologies. The preference for the electrolysis-based production of electricity proves a clear commitment to long-term sustainability and carbon-free hydrogen production.

Another key observation is that it is currently developed nations that lead with regard to the global hydrogen deployment landscape. Countries such as Germany, Japan, the United States and Australia are seen at the forefront in terms of project numbers, installed capacities and infrastructure development due to the robust policy support, research investments and long-term energy transition strategies (Chaube et al., 2020). In comparison, developing nations are still at the start of adoption to the use of hydrogen, primarily because of financial constraints, inadequate infrastructure, and overall technological barriers. This disparity underscores the need for international co-operation, technology transfer in the interest of more global participation in the hydrogen economy.

The status evaluation of the project shows a large proportion of hydrogen projects are being constructed at the time of writing, which indicates a good growth pipeline and continued momentum in the sector (Le et al., 2023). This indicates that hydrogen is no longer stuck in conceptual planning, but is suddenly moving on to large-scale physical implementation. The growing number of running projects gives further validity to the technical reliability and commercial viability of hydrogen-based power systems.

Finally, the capacity analysis shows that globally, the hydrogen production capacity is highly concentrated in a small number of megaprojects. These large-scale facilities, which are often supported by national governments and international energy consortia, are providing a large part of the overall hydrogen production, and are instrumental in building up large hydrogen supply chains (Sgarbossa et al., 2023). At the same time, the coexistence of small and medium scale projects represents on-going innovation and decentralized deployment. Together, these observations make an offer that hydrogen is rapidly being transformed into an important pillar of the low-carbon power generation systems of the future.

7. CONCLUSION

This study confirms hydrogen is quickly emerging as a scalable, versatile and sustainable fuel for the future production of power. The in-depth analysis of the global hydrogen projects shows a definite shift from pilot-scale demonstrations towards large-scale commercial projects, especially since 2015. The preponderance of electrolysis-based hydrogen generation shows a significant overlap of hydrogen development with the worldwide growth of renewable energy sources (Yu et al., 2021; Sharma et al., 2021). This trend reflects the growing preference for green hydrogen as the environmentally sustainable solution pathway that can be used for deep decarbonization of the power sector.

Despite this great momentum, the study also points to some major challenges which are still shaping the large-scale introduction of hydrogen technologies. High infrastructure costs, storage and transportation challenges and geographically imbalanced distribution of hydrogen projects are some of the great hurdles for universal implementation (Mittal et al., 2021). Developed countries lead currently with regard to adoption of hydrogen because of robust support behind the policy, financial capability and technology being able to catch up to it while developing regions lag behind because of economic and infrastructural limitations. Addressing these disparities through international collaboration, policy harmonization, and technology transfer is going to prove key for creating a truly global hydrogen economy.

Nevertheless, the growing number of megascale hydrogen projects being built and commissioned is an important validation of the growing commercial viability of hydrogen as a power generation fuel. Hydrogen is uniquely placed to reinforce future low-carbon power systems in terms of allowing large-scale integration of renewable energy, long-term storage of energy, and flexibility of the power grid. Through mechanisms such as Power-to-Hydrogen-to-Power and Hydrogen-to-X systems, hydrogen can help fill the gap between intermittent renewable electricity production and continuous electricity demand (Egeland-Eriksen et al., 2021; Genovese et al., 2023).

Overall, the results from this research are a clear indication that hydrogen is no longer a distant energy concept but a fast materializing energy reality in the global energy transition. With the continued improvement in the technology used in electrolyzers and with the opportunity for low cost renewable energy sources and government support, hydrogen stands to play a central and pivotal role in achieving carbon neutrality, stability in the grid and the future of sustainable power production.

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