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Trends in Hydrogen Production Projects for Energy and Climate Purposes – A Descriptive Analysis of the IEA Database

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Abstract: *This paper analyses the global project database on hydrogen production from the International Energy Agency (IEA), comprising 1477 projects for energy and climate purposes. Through quantitative analysis and data visualization, the research centers on renewable-powered hydrogen projects, encompassing various production methods. Across 80 countries, Germany, Australia, and the United States exhibit the most projects (182, 118, 114). Most of the projects are in developmental stages, with 35% undergoing feasibility studies, 23% in concept stages, and 15% operational. Notably, 66 operational projects are renewable-powered, Germany leading with 19, followed by China (8), Great Britain, and Spain (4 each). Technologies include proton exchange membrane electrolysis, alkaline electrolysis, and others. This work underscores global hydrogen production efforts, spotlighting countries pioneering renewable-driven facilities for this energy carrier.*

1. INTRODUCTION

There is momentum building around the hydrogen production technologies for several reasons, including the development of several national and regional hydrogen strategies around the globe, technological enhancement observed in recent years, important cost reduction (especially regarding the input renewable electricity generation technologies), more derivative products of hydrogen available at large scale (e.g. ammonia), its importance for climate change mitigation, as well as the acknowledgment that so-called clean energy (understood often as power or electricity) is not sufficient to meet the Paris Agreement (United Nations, 2015).

Based on previous work of the author (Ocenic & Tantau, 2023), this paper focuses on the hydrogen produced thanks to renewable energy sources, i.e., „green" hydrogen, with the purpose of decarbonizing economies and contributing to the overarching global climate agenda. In this context, „green" hydrogen plays a key role in the decarbonisation of so-called „hard-to-decarbonize" sectors of the global economy, like iron and steelmaking, cement, chemicals and petrochemicals, transport, as well as heating and cooling in buildings (IRENA, 2020).

2. LITERATURE REVIEW

Previous research has looked into the hydrogen project database put together by the International Energy Agency (IEA) (James & Menzies, 2022; Pleshivtseva et al., 2023), but with a different scope, and the database has evolved since their analysis was performed. For example, fewer projects were included in these analyses, compared to the present one.

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Regarding the method chosen, descriptive statistics are recommended for researchers to understand the data they are analysing, before conducting a more thorough analysis, for example performing inferential statistics (Grech, 2018). More precisely, exploratory analyses have been performed before in infrastructure projects, such as transport (Mathur et al., 2021) and other socio-economic topics, like household savings (Cuomo et al., 2023).

Moreover, Excel has been used in scientific research before and it is not necessarily a novelty, although it was seen as a *key tool for future research in improving the utilization of information across organizations*, given the capabilities of Pivot Tables, Pivot Charts (Palocsay et al., 2010, p. 191).

3. RESEARCH METHODOLOGY

The research objective of the present paper is to analyze the international project database on hydrogen production facilities which is collected by the IEA and made available publicly after registering on their dedicated website (IEA, 2022). The full database was downloaded on 12 May 2023, so this is considered the cutting point, after which any other updates of the database are not taken into consideration for consistency and accuracy of the analysis throughout the publication process of the present paper.

The quantitative analysis performed on the data available is focused on projects dedicated to hydrogen production powered by renewable energy. As such, descriptive statistics for data analysis are employed, as well as quantitative methods to examine key trends and emerging leaders in hydrogen project development around the globe. Moreover, data visualisation is being employed for a global mapping of projects, which helps understand the project distribution around the world.

Overall, the IEA database contains approximately 1500 projects from around the world. The projects have various categories listed, of which the most relevant for the present analysis are the development stage of the projects (e.g., feasibility study, concept stage, operational, demonstration, etc.), as well as the technology employed (e.g. alkaline electrolysis, proton exchange membrane electrolysis, solid oxide electrolysis cells and other/unknown) and the energy source used in the hydrogen production process.

Additionally, a country analysis is being performed by looking at the distribution of projects per country, which provides insights into whether there are any existing and/or emerging leaders when it comes to hydrogen production facilities (either planned or already operational). In addition to the energy used in the process, the technology employed both for operational and under-development projects is being analyzed to understand the key market trends concerning „green" hydrogen production.

The analytical steps taken are the following:

Step 1: Download the data (Microsoft Excel).
Step 2: Format the headings in the database.
Step 3: Create Pivot Tables of the entire database.
Step 4: Analyse the data for selected variables (e.g., country, count of projects, status, type of electricity, count of projects, etc.) via Pivot Tables.
Step 5: Visualize results using Pivot Charts and embedded maps.

4. FINDINGS

4.1. Leading countries today are likely to be leaders tomorrow

Table 1 shows the leading countries with the highest number of hydrogen projects included in the database. Germany, Australia, and the United States of America have the highest number of operational and planned projects, 182, 118, and 114 respectively.

Table 1. Countries with the most hydrogen projects in the IEA database

Country	Number of projects
Germany	182
Australia	118
United States of America	114

Source: Own calculations based on IEA, 2022

Figure 1 illustrates the distribution of projects existent in the database, based on their development stage, indicating that most projects are in a development stage, i.e., 35% are undergoing a feasibility study, 23% are in a conceptual stage, with 15% being operational. The remaining 13% are in a demonstration phase (DEMO), with 8% pending the final investment decision (FID), 5% under construction, and the rest either being decommissioned, or their status is unknown.

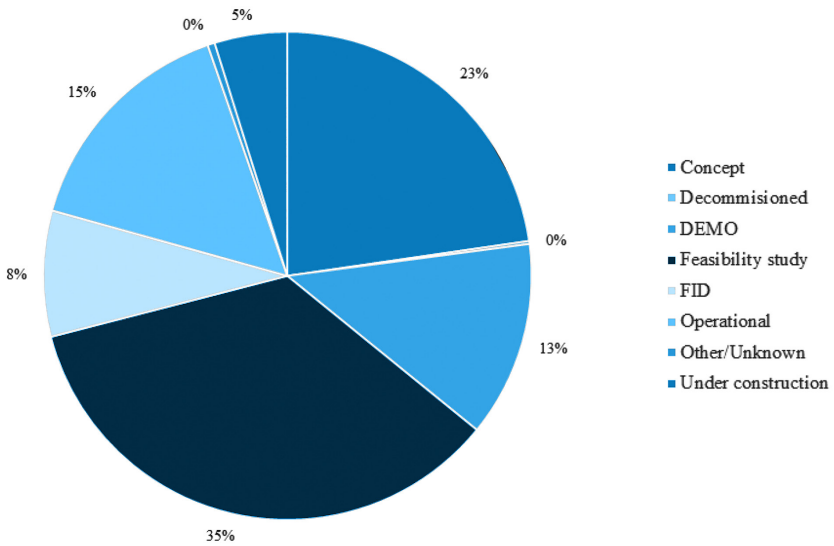

Figure 1. The development stage of all projects included in the IEA database

Source: Own calculations based on IEA, 2022

If the geographical distribution is assessed thanks to a global mapping, it is clear from Figure 2 that most projects that are operational and included in this database are located in Europe, with Germany leading the way in terms of the highest number of operational projects included in the database, irrespective of technology or energy source input.

However, the same global mapping looks more diverse if all projects included in the database are considered, since more countries have planned projects, i.e., under various development stages, compared to those that are today already operational. Figure 3 supports visually the findings presented in Table 1.

Diving deeper into the already operational „green" projects, the database contains two types of renewable electricity supply for hydrogen production: a) either dedicated renewable power supply for the hydrogen facility or b) the hydrogen facility is using or plans to use the excess renewable electricity from the grid, in times of renewable energy abundance.

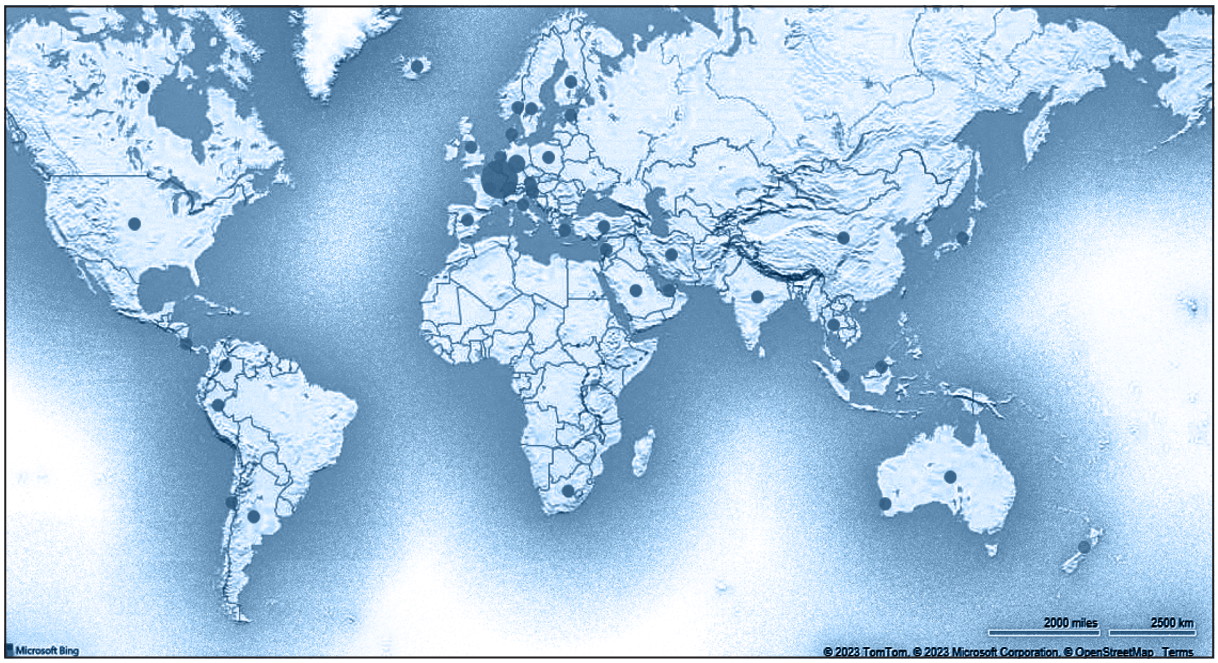

Figure 2. Geographical distribution of operational hydrogen projects

Source: Own calculations based on IEA, 2022

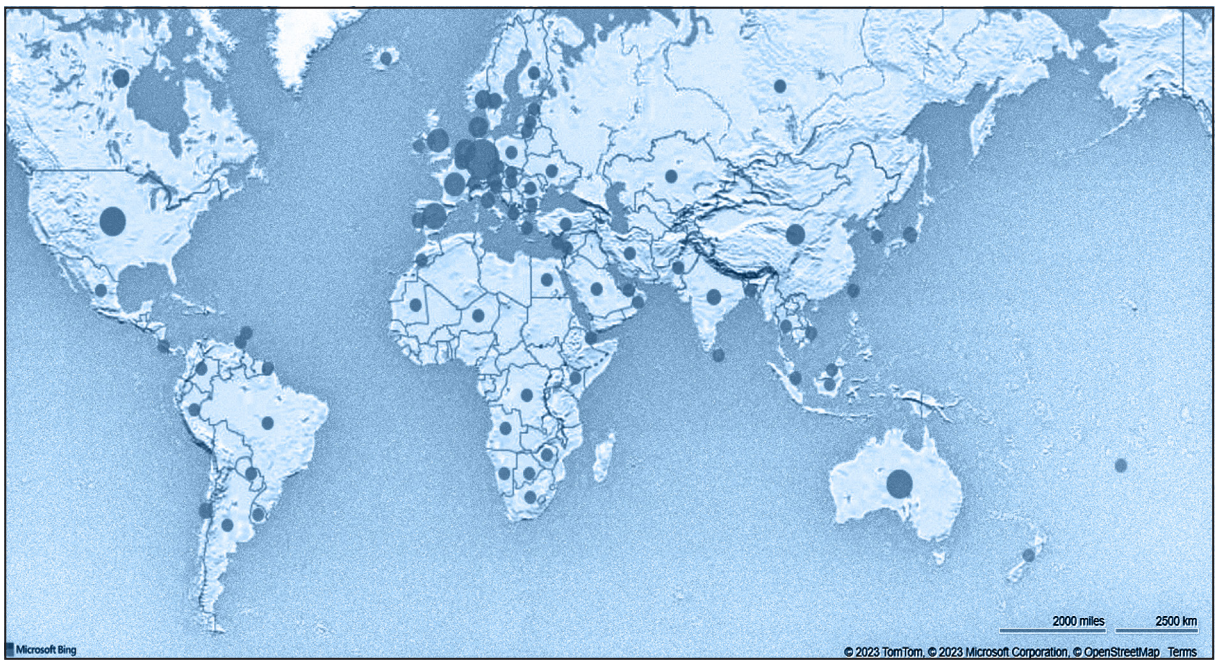

Figure 3. Geographical distribution of all hydrogen projects (planned/operational)

Source: Own calculations based on IEA, 2022

When it comes to the 227 operational projects included in the IEA database, there are 66 facilities with dedicated renewable electricity supply while 33 are using the electricity from the grid in periods of excess renewable electricity production.

Irrespective of the type of „green" hydrogen facility analyzed, Germany is leading with the highest number of projects, as shown in Table 2 and Table 3. However, which type of energy supply other countries are providing to the existing hydrogen production facilities seems to be different. As such, Germany has 19 operational hydrogen facilities with dedicated renewable power supply, followed by China with 8, and Spain and Great Britain with 4 each, respectively (Table 2). At the same time, Germany has 16 operational hydrogen facilities using the excess renewable electricity from the grid, followed by Denmark with 6 facilities, and Austria and Australia with 2 each, respectively (Table 3).

Table 2. Countries with the highest number of operational projects using renewable electricity supply

Country	Number of projects
Germany	19
China	8
Spain	4
Great Britain	4

Source: Own calculations based on IEA, 2022

Table 3. Countries with the highest number of operational projects using excess renewable electricity from the grid

Country	Number of projects
Germany	16
Denmark	6
Australia	2
Austria	2

Source: Own calculations based on IEA, 2022

Analyzing the renewable energy source is not possible for those projects that are relying on the grid for the available excess renewable energy, since the data is not available in the database, and the energy source may change rapidly depending on the power system analyzed.

However, the projects that have a dedicated renewable energy facility for hydrogen production may provide some insights into the status quo. As such, Figure 4 shows that onshore wind leads the way with 22 operational hydrogen facilities using this renewable energy source around the globe today, followed by solar photovoltaic (PV) power plants with 20 dedicated plants. Further, there are 7 hydrogen projects fuelled by dedicated hydropower projects around the globe with 4 having unknown energy sources, while the remaining 13 projects are labeled as having „other" or „various" energy sources.

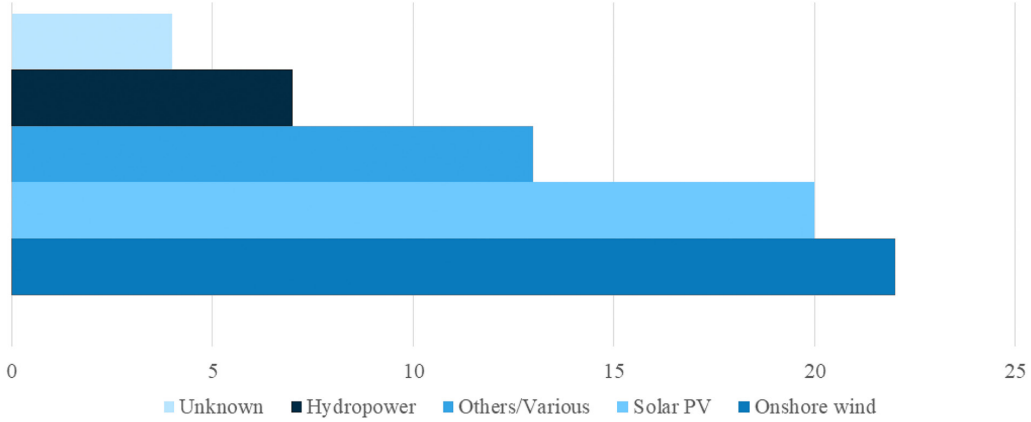

Figure 4. Dedicated renewable energy sources for operational hydrogen projects (number of projects)

Source: Own calculations based on IEA, 2022

5. FUTURE RESEARCH DIRECTIONS

One of the future research directions refers to the size of the hydrogen projects, both operational and planned, expressed in megawatt hours, to understand whether the leading countries in terms of number of projects are also the ones with the most ambition in terms of industrial development of the hydrogen production technologies.

Another direction would be to look into the differences in the hydrogen technologies themselves. For example, it would be insightful to understand whether there is any technological shift between the currently operational hydrogen facilities and the planned facilities: are there newer, more efficient technologies being pursued, and do all countries follow the same technological path?

6. CONCLUSION

In conclusion, the findings presented in this paper highlight that hydrogen production has a global character, with a far-reaching and widespread geographical distribution especially when it comes to the planned projects. The data presented emphasizes the significance of renewable electricity as an energy source for hydrogen production facilities in the future, but there are some leading countries today that set themselves apart, among which Germany is noteworthy regardless of the indicator assessed (planned/operational projects, with/without dedicated renewable electricity).

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