

The Role of Financing in Green Hydrogen Projects: The German, Australian and Brazilian Cases

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ABSTRACT

The main challenge of hydrogen electrolysis is the high costs of the hydrogen production. For a decarbonized energy sector, new investments are needed to drive the shift of CO₂ from intensive technologies to sustainable technologies. However, it is not easy for investors to choose these options. Currently green hydrogen project accounts for more than 500 undergoing initiatives around the world and should grow quickly in the coming years. From several feasibility studies, green hydrogen originating from renewable power is technically viable today and is quickly approaching economic competitiveness. The focus is on deployment and learning-by-doing to reduce electrolyzers' costs and supply chain logistics. This will require an appropriate funding schemes, mostly led by public sector and in some cases private sector as well. The analysis of the financing structure in Germany, Australia and Brazil shows that the role of the government in this nascent industry is fundamental for its viability. The results of our model ratifies this perception, where the governmental arm acts in an indispensable route for the feasibility of green hydrogen and consequently reduction of the carbon footprint so as to meet the Paris Agreement and the transition to a neutral economy.

INTRODUCTION

Energy transition is one of the main mechanisms for limiting global warming to 1.5°C by 2050. A mindset transformation will be necessary in all processes that emit greenhouse gases (GHG), such as energy transformation, consumption of goods and services, among others. Thus, the energy sector plays a central role as renewable energy (RES) and newer efficient and sustainable technologies gain technological maturity and reduce their costs, becoming essential for the climate goal to be met. According to IRENA (2021), in the decarbonization process foreseen until 2050, more than 90% of the technological solutions involve the insertion of RES, electrification, energy efficiency, bioenergy with carbon capture and storage (CCS) and green hydrogen (H₂V). The latter, according to the IRENA, will account for 12% of final energy consumption, 66% of which will come from RES.

Hydrogen Council (2021) considers a more optimistic scenario involving a more effective participation of hydrogen in the final energy consumption in 2050, equivalent to 22%, with the participation of H₂V possibly reaching 80% of this composition. According to the 2050 demand scenarios, developing new uses for H₂V will be a great challenge, since its destination will initially replace gray hydrogen (H₂C) in pilot projects through Research, Development and Innovation (RD&I) proposals (IEA, 2021a).

Considering that the hydrogen industry is a nascent sector, the structuring of its production chain, on a global level, needs to break technological and regulatory barriers, as well as promote cost reduction to make its scalability feasible (Kovac *et al.*, 2021). In other words, countries that seek intense decarbonization and energy security but with low RES production capacity tend to position themselves as importers. Those with high renewable energy production capacity and competitive cost price emerge as possible exporters (BMW, 2020).

That being said, the number of proposed hydrogen projects is steadily increasing. According to the Hydrogen Council (2021), there are 522 projects with a capacity of more than 1 MW planned for implementation, of which 70% are expected to be operational by 2030. These are mostly located in Europe (50%), followed by Asia (23%) and North America (13%). It is worth noting that among the proposed H₂V projects, more than 50% are classified as "announced", i.e., projects with declared intentions or in the initial study phase. The smallest portion, called "mature", presents advanced feasibility studies, and is in the final investment phase (operational or also under construction). Regarding the scale of the projects, most are in the MW scale, with only 8% being in the GW scale.

If these projects are carried out, it is estimated an investment around US\$ 160 billion by 2030, with H₂V production accounting for 60%, end-use feasibility for 28%, and storage, transport and distribution infrastructure for the remaining 12%. Given this positive outlook, the volume of resources needed to these projects' implementation will undoubtedly stemming from the public and private sectors, in the various possibilities of financial structuring, regardless being in initial or operational phase.

It should be emphasized that Germany is the flagship of this change in terms of structuring the hydrogen economy. The German national strategy aims at consolidating its industry and society based on the development of this sector. However, given its inability to be self-sufficient, the country focus on international cooperation, since most of the estimated demand for hydrogen would come from imports (BMWi, 2020). This factor presents a new frontier for the expansion of installed capacity of the electrolyzers and, consequently, of the RES in countries like Australia and Brazil, with the role as potential exporters.

In 2019, Australia declared in its national strategy the goal of being a major player in hydrogen exports by 2050. Notably, the country is promoting initiatives ranging from funding and pilot projects across the value chain, to develop regulatory and certification aspects (COAG, 2019).

In terms of H2V, Brazil is still in the initial stages of infrastructure and has only presented the guidelines for the National Hydrogen Program so far (MME, 2021). Nevertheless, the high production potential of RES, the availability of greenfield and the interconnected system of energy transmission and ports place the country as one of the potential exporters in the electrolytic route of hydrogen (McKinsey & Company, 2021).

In light of the abovementioned context, this paper has the scope of analyzing H2V projects in Australia, Brazil and Germany, for which the financing structure, scalability, end use and competitiveness in the consumer market are compared. The main contribution is to point out which variables are indispensable for the success of a H2V plant project and its spillover effects. Thus, the paper is organized as follows: section 2 presents a current overview of H2V financing, section 3 presents the methodology, section 4 discusses the results, and section 5 presents main conclusions and recommendations for future studies.

HYDROGEN PROJECT FINANCING OUTLOOK

According to Jolink (2017), with the conclusion that the energy transition will not happen on its own and considering the forthcoming urgency, the governments have accepted the role of market maker and are creating structures that provide long-term guarantees for private companies to innovate and develop renewable energy production. At the same time, the governments have realized that the risks and costs of renewable energy surpass by far those of the other technologies. For most private investors, the combination of high risk and low return is an area of low interest. The framework developed by Polzin *et al.* (2020) provides some direction, from both corporate and technology perspectives, by relating the R&D life cycle to a required funding mix. In this case, it is assumed that public investments occur via grants, subsidies and incentives, since such modalities tend to lead to a positive cash flow for the companies. Pilot demonstration, pre-commercial and niche phases are the most challenging, as cash flows usually become negative. Only when the companies reach positive flows, usually in the commercial phase, they are expected to be profitable and thus bankable. In this way, Figure 1 shows different sources of financing in the phases of project life cycle, considering they have different risk and return profiles and need to match the expectations from entrepreneurs.

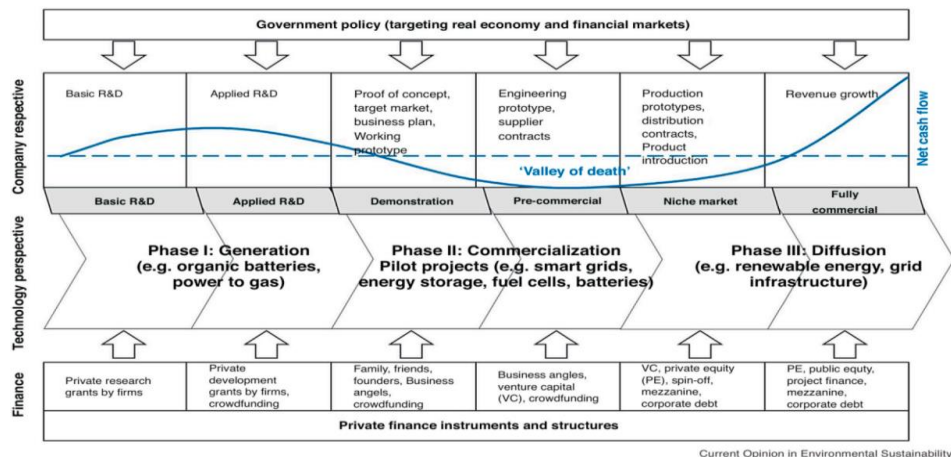


Figure 1 - Financing energy technology innovation and entrepreneurship.

Source: Polzin and Sanders (2020).

One feature of the innovation process is the potential gap in the resources that can arise between the decreasing government aid and the increasing investment needs, which is referred in the literature as the "valley of death". According to Mazuzucato (2017), government agencies are involved in about 50% of the R&D spending in the renewable energy sector. In the market creation and deployment phase, another variety of public sector players come into the picture, i.e., from government agencies and state public banks to private equity (PE) and venture capital (VC) investment funds. However, it is debatable whether the degree of government support and protection should only be in the regulatory sphere or also in the financial. In this way, Europe has recently announced € 70 billion of public funding pledged by different governments in order to support the hydrogen industry, with half of it coming from the European

Union. The scope of this financial support is to help reduce the cost of H2V production, aiming at greater competitiveness, encourage the spread of end uses in the industrial and transportation sectors, and improve equipment performance, particularly for the electrolytic process, promoting a cost-competitive hydrogen route (Natixis, 2020).

Sander *et al.* (2021) argue that debt-financed hydrogen project is still insipient, which is challenging given that no financial agent has enough resources on its own to develop a scalable market in a renewable energy technology. Therefore, financial solutions such as Project Finance (PF) are more feasible for larger scale projects with commercialization potential. However, obtaining PF depends on the project's ability to demonstrate sufficient future cash flow generation to cover both operating expenditures and costs. Leveraging a project with third parties financing can increase the return on equity, reduce the sponsor's initial commitment, provide an attractive allocation of risk, and attract tax benefits through interest rate deduction. The abovementioned authors further conclude that the entrepreneur needs to liaise credible technology with an established customer base or long-term contracts with power producers and off takers, securing prices and mitigating uncertainties.

According to WEF (2021), most companies have identified difficulties in securing affordable financing to implement innovative technological advances in H2V. The main factors that still hamper financing are: (a) the returns are not proportional to the levels of risk allocated, (b) high technological risk, (c) volatility in the price of production factors, and (d) only few results in pilot projects. This study also mentions that there is a mismatch in short-term financing, between 5 to 7 years, incompatible with the maturity of the investment, which is long-term (roughly 20 years). In addition, the liquidity is also limited in decarbonization infrastructure as well as in validation projects. The amortization needs of these projects range from 10 to 20 years, creating a mismatch between them and the investment propensity of the infrastructure investors.

Despite those funding hurdles, countries such as Germany, Australia, and even Brazil have initiated small-scale projects, which are being supported by public resources and private capital. Germany has presented the largest initiatives in H2V development, through pilot and operational projects, as well as through greater availability of financial resources. According to IEA (2021), by 2030, € 9 billion of public investments have been committed to it. Of these, it should be highlighted the financing of € 8 billion via the program called Important Projects of Common European Interest (IPCEI), for 62 projects throughout the H2V value chain. Furthermore, due to its position as a hydrogen importer, the country created the program H2 Global, whose objective is to promote the production, use, and development of transporters at the national and international levels, through an auction-based mechanism that will establish long-term purchase contracts on the supply side and short-term sales contracts on the demand side. It should be noted that an amount of € 900 million is planned to support this stage (H2 GLOBAL, 2021).

Australia, according to CSIRO (2022), has more than 80 projects announced throughout the value chain, with emphasis on export development. In terms of financial commitment, an investment of US\$ 900 million is expected by 2030.

Finally, Brazil is one of the most promising countries for the development of the hydrogen economy in terms of H2V production capacity and exportation. However, since Brazil has not launched its national strategy yet, the funding mechanisms to be adopted in this seed stage are unclear. Nevertheless, it should be pointed out that the R&D incentives related to the program of the National Electric Energy Agency (ANEEL) have already attracted investments in hydrogen and these tend to grow, especially in the northeastern states of the country. The National Bank for Economic and Social Development (BNDES) may also release a funding mechanism for hydrogen and has already been studying the potential of this nascent industry, seeking alignment with its traditional RES loan lines that could be adjusted for H2V.

METHODOLOGY

In this work, we will perform principal component analysis (PCA), which is a technique to reduce the size of a data matrix in order to represent it in a low dimension, since not all random variables are significant. It is possible to aggregate both continuous and categorical variables. The dimensions formed by PCA is a linear combination of the continuous variables used, and the outcome is a higher order covariance sequence (decreasing in its overall contribution). If they have positive (negative) covariance, they tend to show similar (opposite) behavior. Considering a situation where there are 'k' characteristics of 'n' individuals in a population, the matrix will be of the following form:

$$X_{n \times k} = \begin{bmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{1n} & \cdots & x_{nk} \end{bmatrix} \quad (\text{Eq. 1})$$

The interdependence structure among the variables in the data matrix is represented by the covariance matrix 'S'. Since this structure can be complicated, the PCA analysis transforms the structure represented above (Eq. 1) into another matrix Y, whose variables are uncorrelated (orthogonal to each other) and have ordered variances. From the above matrix X, it is possible to estimate the population variance-covariance matrix, represented by S. The matrix S is symmetric and also of order 'k x k', such that:

$$S_{k \times k} = \begin{bmatrix} \text{Var}(x_1) & \text{Cov}(x_1, x_2) & \text{Cov}(x_1, x_3) & \cdots & \text{Cov}(x_1, x_k) \\ \text{Cov}(x_2, x_1) & \text{Var}(x_2) & \text{Cov}(x_2, x_3) & \cdots & \text{Cov}(x_2, x_k) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \text{Cov}(x_k, x_1) & \text{Cov}(x_k, x_2) & \text{Cov}(x_k, x_3) & \cdots & \text{Var}(x_k) \end{bmatrix} \quad (\text{Eq. 2})$$

Since the characteristics are usually expressed in units that differ from one another, it is convenient to standardize them in order to there is a single basis for comparison, with an average of 0 and variance equals to 1. To determine the principal components, it is necessary to solve the characteristic equation of the matrix S:

$$\det [S - \lambda I] = 0 \quad (\text{Eq. 3})$$

Assuming that the roots of the characteristic equation are given by $\lambda_1, \dots, \lambda_k$, then for each eigenvalue (or "score") k , there is a normalized eigenvector a_k (or "loadings"), where:

$$a_k = \begin{bmatrix} a_{k1} \\ \vdots \\ a_{kk} \end{bmatrix} \quad (\text{Eq. 4})$$

Therefore, the k -th principal component is established by:

$$Y_k = a_{k1}X_1 + a_{k2}X_2 + a_{kk}X_k \quad (\text{Eq. 5})$$

There are four properties of the principal components, namely: (i) the variance of the principal component Y_i is equal to the value of eigenvalue; (ii) the first component has the largest variance, following in descending order; (iii) the total variance of the original variables is equal to the sum of the eigenvalues, which is equivalent to the total variance of the principal components; (iv) the principal components are not correlated with each other. Taking these properties in consideration, the importance of a principal component is given by the proportion of the total variance explained by the component. To determine the number of components used, it is usually considered the amount of components that accumulates 70% or more proportion of the total variance. To evaluate the degree of influence of each variable X_i on component Y_j , it should be calculated the correlation between them. If the objective is to compare the influence of each X_i on Y_j , the weight of each variable on the component must be calculated.

For the present work, the IEA (2021b) database of hydrogen projects was used. In this database, where hydrogen projects announced in the world are described, the main information and technical characteristics of the projects are presented, such as based country, development status, production technology, production capacity, dedicated (or not) energy source and intended end uses. Given these characteristics and proposed objective of this work, four selection criteria were defined. The first criterion was the definition of the countries to be evaluated (Germany, Australia and Brazil), while the second was the selection of the production technology (PEM electrolyzers, alkaline and other types of electrolysis). The third criterion was related to the origin of the electricity entering the grid (surplus of renewable electricity and renewable energy plants). Finally, the fourth criterion was related to the product of the project (green hydrogen). With those criteria applied, 35 projects were identified.

As expected, projects with financial economic feasibility studies and under development are the most prevalent, with 31.4% and 25.7%, respectively. When it is broken down by electrolyzer technology, other types (CCS, etc.) correspond to 48.6%, while PEM comprises 37.1%. These technologies are the most used among of the three countries analyzed, given the necessity for hydrogen grid injection in gas and the lower acquisition cost. The renewable energy used is mainly solar/photovoltaic (23.3%) and onshore wind farms (20.0%). In terms of electrolyzer capacity, almost half (45.7%) is small scale (< 10 MW) and 20% are medium scale (between 10 MW and 100 MW). Finally, in order to evaluate the economic and financial aspects, we added to the original database the following variables: (i) CAPEX; (ii) OPEX; (iii) LCOE; (iv) LCOH; (v) WACC; (vi) Equity; (vii) Debt; (viii) Grant; and (ix) End Use, based on deepening dive on the projects' prospects.

RESULTS AND DISCUSSIONS

Based on the methodology presented in the previous section, PCA was applied with the following assumptions: (a) in cases of values not defined or unavailable in the project, the data from the national hydrogen strategies within the three countries was assumed; (b) End Use was established as dichotomous explanatory variables; (c) the variables Country, Status, Electrolyzer Technology, Production, and Electricity Type were categorized.

It can be seen that one principal component already explains more than 90% of the outcome of the H2V projects and the subsequent components have incremental effects. When checking the linear combination of variables vis-à-vis the projects, two projects appear as outliers, one Australian (Project NEO) and the other German (Wilhelmshaven LNG terminal). This is explained by the fact that they are the only two large-scale projects, i.e., 1 GW and 410 MW, among the 35 projects evaluated, which may indicate an additional caution in our analysis (see Figure 1 above). Regarding the influence of each variable, it can be said that CAPEX and Electrolyzer installed capacity form two major contributors in

both components, followed by financing (Equity, Grant and in smaller contribution Debt), OPEX and WACC. The levelized costs of electricity (LCOE) and hydrogen (LCOH) have marginal effects, because they only help in the importance of component 2.

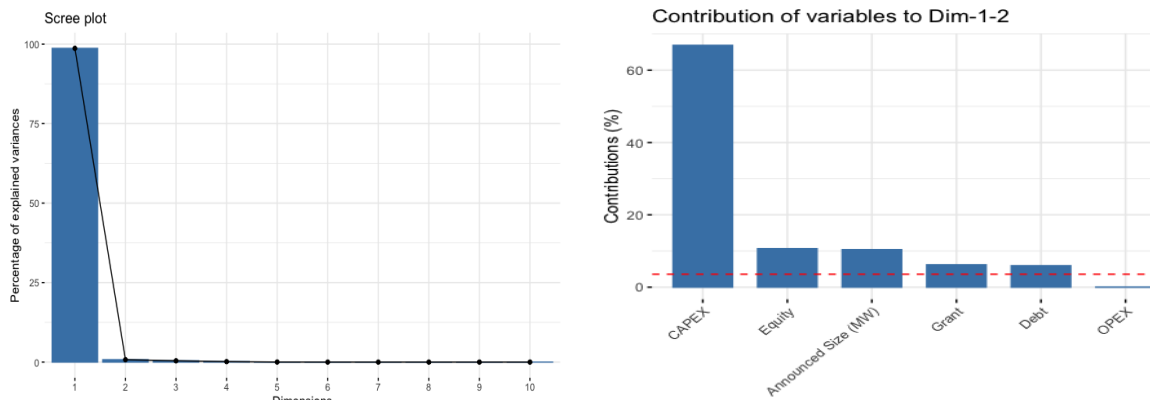


Figure 2 - Principal components explained by variable contributions.
Source: Made by the Authors

This result is fully in line with Jolink (2017), as there is a perception that the energy transition will not happen by itself and the governments must absorb the role of market maker by creating structures that provide funding guarantees for private companies to invest in H2V and in other types of renewable energy. In addition, the governments are realizing that the risk-cost ratio of renewable energy surpasses by far those of the other technologies and therefore, for most investors, the combination of high risk and low return is a no-go economic area, leaving renewable energy projects with a low priority in terms of investment. In the specific case of hydrogen, which is a nascent industry, it is noted the importance of CAPEX and its respective financing as fundamental to the success of these projects. In this sense, Equity (15%) and Grants (8%) are essential for the model output.

Another important point is the scale of these projects, considering that it is able to influence both components. It should be emphasized that the main projects are still in the pilot phase or in study phase of the economic and financial feasibility (finished or under development), as demonstrated in Figure 3. In addition, the predominance of solar/photovoltaic and wind energy as sources for the catalytic process must be noted. This fact converges with Jolink (2017), according to which, in the period 2012 and 2017, one third of all private equity investments was focused on the renewable energy industry, with venture capital funds targeting solar projects.

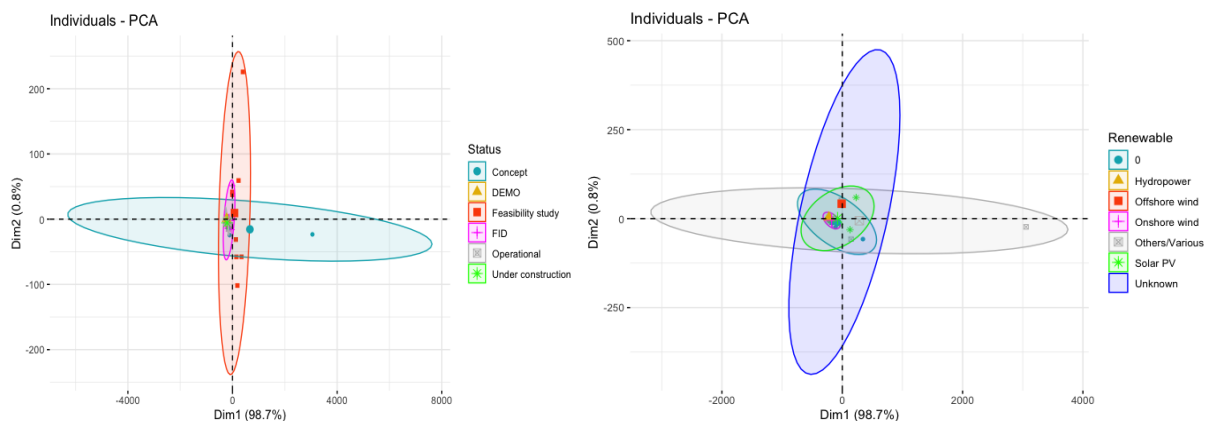


Figure 3 - Principal components by project types and electricity type in the electrolytic route.
Legend: (left) DEMO = Demonstration; FID = Feasibility Study in Development
(right) 0 and Unknown = Data unavailable in IEA (2021a)
Source: Made by the Authors

Disregarding the outlier projects from Germany and Australia as mentioned above, the following results are rendered by the model (see Figure 4): (i) there are four principal components, of which the first is the most relevant with almost 80% explanation; and (ii) it can be stated that CAPEX and Grant are the two major contributors to the first two components, followed by Equity and electrolyzer production capacity.

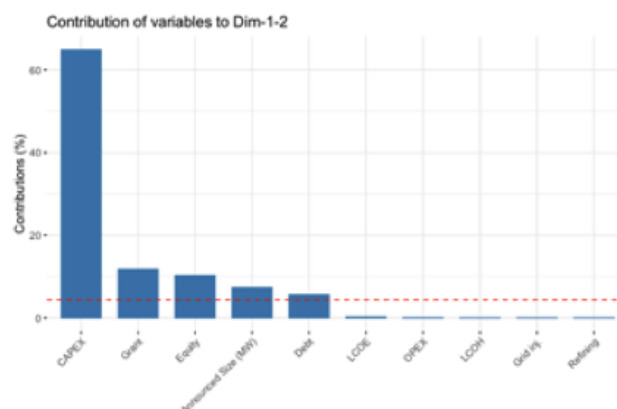


Figure 4 - Principal components by variable importance (except outliers).
Source: Made by the Authors

In fact, given the nascent context of the H2V industry, as most of the projects are of medium and small scale, a large part of the financing of their respective CAPEX stems mainly from agencies and governmental bodies (BMW, BMV, ARENA, ANEEL), development banks (KfW, CEFC, BNDES, etc.) or directly from Federal or State Governments.

CONCLUSIONS AND FURTHER RESEARCH

Private financing has increasingly retreated from financing risky productive activities. One of the reasons is that the private sector has been disinvesting in the “R-side” of the R&D projects given its increasing short-termism, caused by the corporate governance structures that prioritize quarterly returns, the macroeconomic conditions and the shareholders claim for maximizing return. On the other hand, shareholders have focused on the problems associated with short-term financing in science-based industries, which are better served by long-term financing, especially in the case of a new sector as the green hydrogen industry. Thus, when H2V projects receive long-term government funding, they can learn more and dare to invest in areas that will require a lot of trial and error. For all these reasons, the type of funding that innovators receive is not neutral and can affect both the rate and the direction of the innovation. Therefore, the results of this study ratify such perception, according to which the governmental arm has an indispensable route for the feasibility of H2V industry and the consequent reduction of the carbon footprint to meet the Paris Agreement and the transition to a neutral economy. In short, it is necessary a propulsive engine for develop this industry, through funding structured by public-private partnerships, with the public sector having the main role to mitigate its risks, particularly in the early stages of R&D until the pre-commercial phase.

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