22nd International Conference on Renewable Energies and Power Quality (ICREPQ'24)
Bilbao (Spain), 26th to 28th June 2024
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.22, September 2024

Green Hydrogen from Hydroelectric Energy: Assessing the Potential at the Abanico Power Plant in Morona Santiago Province

A. Barragán-Escandón[1], S. Arostegui Gutiérrez[1], E. Zalamea-Leon[2], X. Serrano-Guerrero[1]

[1] Energy Transition Research Group,
Universidad Politécnica Salesiana Calle Vieja y Elia Liut – Cuenca, 010103, Azuay (Ecuador)
Phone:+593 7 4135250

[2] Facultad de Arquitectura y Urbanismo, Universidad de Cuenca
Av 12 de abril y Agustín Cueva – Cuenca, 0101168 Azuay (Ecuador) Phone/
Fax number: (+593)4051000

Abstract. A key strategy for optimizing the utilization of clean energy sources involves integrating energy vectors to effectively manage surplus power generated from renewable sources. This study specifically delves into the assessment of a hydrogen (H_2) generation project utilizing energy generated by the Hidroabanico power plant. Over a span of 13 years, the average monthly energy production was meticulously scrutinized, with a determination that 20% of this energy would be allocated for H_2 production. The operational framework of the prototype plant, which relies on Proton Exchange Membrane (PEM) electrolyser technology, is comprehensively elucidated. This system boasts an annual energy capacity capable of reaching 62,439 MWh (20% of total production), culminating in the production of 1,123 Tn of H_2. However, it is noteworthy that this quantity remains relatively limited compared to analyses conducted utilizing alternative technologies.

Key words. Hydrogen fuel, electrolizer, PEM.

1. Introduction

The rapid growth in the global economy has made different energy sectors more resource-intensive. This has led to serious consequences that have negatively influenced environmental and social aspects [1][2]. The current global energy demand is primarily met by fossil fuels, accounting for a total of 80%, not only causing pollution but also being limited in quantity. It is anticipated that by 2050, these resources will be depleted or become costly to obtain. Therefore, there is a search for new, unlimited, and clean energy sources.

One of the main drivers of industrial development is access to energy based on non-renewable sources such as oil or coal for electricity production. Their intensive use has caused local and global environmental deterioration in addition to external dependency in many places. Reducing their usage is imperative to mitigate the impacts of climate change. These systems use non-renewable resources for power generation [3], and produce greenhouse gas emissions hurting the air in cities [4][5]. This underscores why numerous countries have set their sights on minimizing carbon emissions in their energy production mandates. [6].

The 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 28), held at the end of 2023, proposed accelerating zero and low- emission technologies, including the production of low- carbon hydrogen. Hydrogen can serve as a means to store clean energy, provided that the associated source for its production is renewable, such as biomass, waste, geothermal, solar, hydraulic, or wind. While it can also be obtained from non-renewable sources, the environmental benefits are questioned precisely due to the pollution caused during the extraction, transportation, and utilization of such raw materials.

The exploration of alternatives to replace the current energy matrix reliant on fossil fuels is highly diverse. Analyzing the optimal options for each specific context becomes essential. Consequently, there has been a notable shift towards the development and integration of clean intermittent technologies like wind, solar, and hydroelectric power. Despite their potential, these technologies currently face challenges related to their fluctuating nature, making them insufficient to meet demands without effective power exceeding management. As a solution, efforts are being directed towards energy storage alternatives, with hydrogen (H_2) emerging as a promising choice on a global scale. Various instances showcasing its adoption and applications in different contexts underscore the versatility and potential of hydrogen as an alternative energy source.

Given this scenario, obtaining energy from renewable sources has become an essential ally in the face of global warming [7]. Currently, alternatives for energy storage are being considered with the aim of storing it during hours of high demand [8]. Therefore, the use of H_2 as an energy vector is being considered with increasing intensity, since it provides an ideal alternative to complement the production of renewable hydroelectric energy, as it is versatile and non-polluting.

As is the case in Turkey, which uses 1.6% of installed energy in the form of H_2, this gas is mainly used for ammonia production. The H_2 plant established in the city of Haliç produces up to 65 kg per day with an electrolyzer powered by renewable energy and can store up to 100 kg per day [9]. On the other hand, a study conducted in Niger analyzed 3 options for H_2 production. The option with the best results was the one with a generation potential of 1,959 TWh. With PEM technology, a production of 35.58 million tons of H_2 was projected. Having a water demand of 641.87 million m³ [10]. In the Russian Federation, a H_2 production plan for the iron and steel industry is envisaged. The capacity of the PEM electrolyzer is 500 kW with an approximate production of 16,200 kg/year [11].

2. Methodology

A. Project information

The production capabilty of electrolytic H_2 from the generation of the Abanico hydroelectric power plant is analyzed. This plant is located in southeastern Ecuador, in the province of Morona Santiago at a distance of approximately 15 kilometres from the city of Macas. Hidroabanico has five turbines providing a total power of 37.50 MW of hydropower [12].

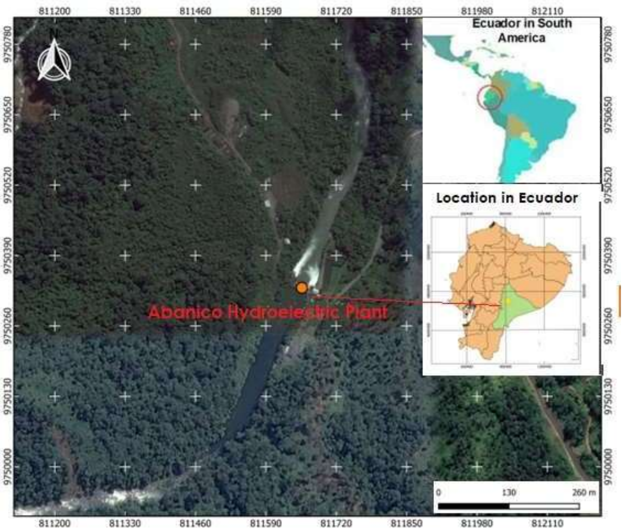

Fig. 1 Project location map

The purpose of this analysis is to propose a scenario in which a portion of the energy generated is directed to the production of H_2. The company Hidroabanico has requested that 20% of the hydraulic energy entering the plant be used for this purpose. The energy will be stored in a storage system to take advantage of the hydroelectric project's generation production.

B. Data acquisition

The study's data was provided by Hidroabanico. The information was collected using PowerLogic ION8600 billing metering units as the primary meter and the ION8650 backup meter. These meters are utilized in power generation plants due to their high accuracy for measuring energy bidirectionally in various usage modes. Monthly production values were analyzed from 2008 to 2021. On the other hand, in the 2011 period, no data was provided and thus this stage was not taken into account. The average energy consumption for each month was calculated, and subsequently, it was determined that 20% of this energy could be converted into H2. Using this calculation, an estimate of the available power was generated.

C. H_2 production through PEM electrolyzer

H_2 is obtained through the splitting of atoms in molecules, using a variety of technologies such as electrolysis and thermochemical processes. It can be produced from hydrogenated substances like water, methane, and hydrocarbons, as well as through the reforming of fossil fuels.

The energy uses of hydrogen production are categorized by colors, which indicate the cleanliness of its generation. Among the most common types are blue hydrogen, extracted from natural gas deposits, and green hydrogen, obtained from renewable energy sources, with solar and wind energy being the cleanest options. Others, such as black or brown hydrogen, result from coal gasification, while grey hydrogen is produced through the reforming of methane from natural gas. From an environmental standpoint, the type of hydrogen depends on the source facilitating its production. Hence, the preferable choice is to produce hydrogen through renewable energies, aiming for a highly sustainable opportunity in sectors known for causing pollution [13].

The properties of H_2 have positioned it as a crucial element in the energy transition, serving as a vital intermediary. Through the process of re-electrification, this gas is utilized to provide electricity to the system. Various technologies, including electrolysis, fuel cells, and H_2 storage, play pivotal roles in advancing this energy industry [14]. In this study, parameters from a PEM electrolyzer were employed due to the significant advantages offered by this technology. These systems are modular in nature, facilitating their transportation and installation, as their components are contained within inner containers, enabling placement virtually anywhere [10]. Furthermore, this technology can operate at high current densities and voltages, producing H_2 of exceptionally high purity, reaching levels of up to approximately 99% [15].

Figure 2 describes the operating system of a H_2 generation plant. A PEM electrolyzer is fed by hydroelectric power. This energy enters a rectifier for AC to DC transformation. After the rectification of the current, it enters the electrolyser. Inside this device the molecular splitting of H2O takes place. The water enters the anode where electrolysis takes place releasing H+ ions, which pass through the membrane forming molecular H_2. After this, the gas is accumulated at the cathode to be stored [16]. Finally, the gas is ready to be distributed.

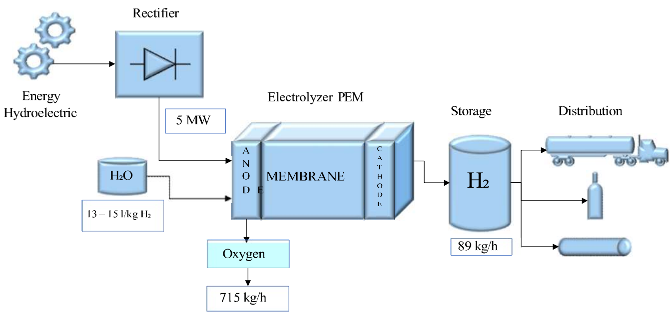

Fig. 2 Schematic diagram for green H_2 production

For the corresponding calculations, the parameters of a 5 MW pilot power plant of the ANDRITZ brand were used. This company offers this prototype plant with the aforementioned characteristics for purchase and installation. This infrastructure can produce 89 kg/h with a pressure of 30 bar. The system requires 13 to 15 litres of water for its operation. The water used in this process must be free of impurities since the purity of the H2 generated will depend on this [17]. And the quantity of hydrogen is calculated from (1).

$$H_2 = \frac{E * n}{E_2}$$

E: electrical energy consumed MWh
n: is the rectifier efficiency (90 %)
Ee: The efficiency of the process converting energy into hydrogen (0.05 MWh/kg of H_2)

A rectifier efficiency of 90% was used since it was considered a common value within these devices.

3. Result

D. H_2 production

The planning and implementation of sustainable energy projects have become a vitally important objective today. In this context, the efficient use of renewable sources has generated a marked interest in the scientific community and the industrial sector. The present research focuses on evaluating the feasibility of a project involving the production of H_2 from the energy generated by the Hidroabanico hydroelectric power plant.

Through the analysis of energy production over an extensive period of 13 years. This period has been the database to calculate the monthly average of electric power generation. This information is essential to develop the necessary calculations and, consequently, to obtain the average electricity production corresponding to each of the 12 months of the year.

This methodology allowed for precise and consistent determination of H_2 production within the scope of the project. The results have important implications for the efficiency and sustainability of energy production from renewable sources. This paper presents a detailed account of the methodological approach, calculations, and results of the innovative project.

Figure 3 shows the energy generation averages for the 12 months with an average annual production of 312,195 MWh. In the third column, the calculation of 20% of the average energy of the corresponding months is carried out. Thus, the total energy aggregate for H_2 production is 62,439MWh. As a consequence of the latitude, the power production is quite similar every month since the location is close to the equator in a rainy region.

Figure 4 details the calculation of H_2 production over a year, presenting the corresponding monthly values. Within the framework of this research, it was possible to determine a total amount of hydrogen production of 1123 Tn, which highlights the feasibility and potential of this generation proposal. The months of slightly higher production (January, July and December) are also highlighted.

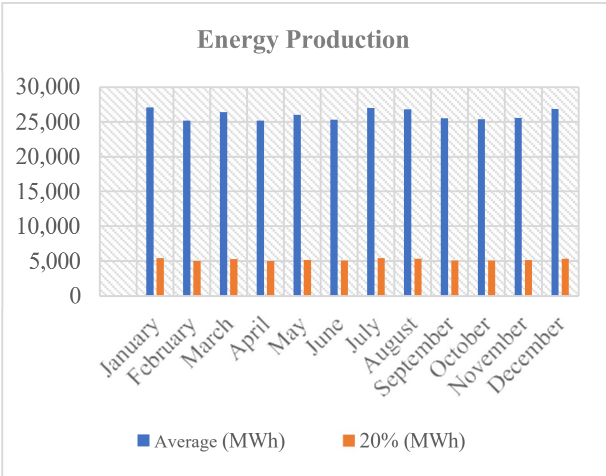

Fig. 3 Energy production

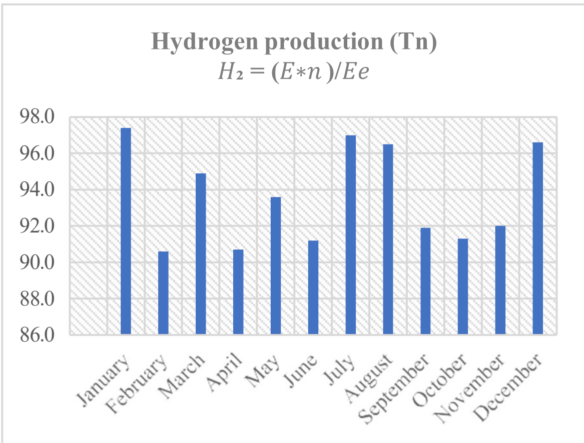

Fig. 4 Green H_2 production

However, this quantity of hydrogen is 2.80 times smaller than what could be obtained by utilizing photovoltaic panels in urban areas, as indicated in [18]. This suggests that while hydroelectric energy may indeed represent an optimal renewable resource for hydrogen production, it may not always be the superior choice compared to other technologies.

E. Possible hydrogen uses

H_2 serves two main purposes: as a raw material and as an energy carrier. In the chemical industry, it is a crucial component in synthesizing various products, including fertilizers like ammonia, hydrochloric acid, and H_2 peroxide [19]. H_2 is emerging as an alternative to natural gas, taking advantage of the local pre-existing infrastructure for this fuel with minor adjustments. Additionally, its versatility extends to the possibility of using it in combination with natural gas, a strategy that seeks to significantly reduce carbon emissions [20].

However, one of the most promising and significant advances in the quest for a cleaner, more sustainable future lies in the development of H_2 fuel cell-powered vehicles. This technology has gone beyond mere conceptualization and has found application in road vehicles that demonstrate impressive potential to revolutionize mobility. It provides a viable, environmentally friendly alternative [21].

If a bus covers an average of 68,652.85 km per year, and considering the typical efficiency associated with current hydrogen-powered buses at 0.1 kg of H_2 per kilometer, the hydrogen produced from this research could potentially supply a maximum 163 buses covering this distance [18].

F. Cost analysis

With the specialized literature, reports, technical data sheets and information from the network, an assessment of the electrolytic hydrogen generation rates was made. It is also important to clarify that the prices analysed correspond to other countries since this technology is not yet commercial in Ecuador.

Through an analysis carried out by [22], where the production costs of green hydrogen in different parts of the world are analysed. The values obtained were compared, having a variation of 6.7 - 11.4 euros per kg of H_2 generated, transforming dollars (reference value €1 is $1.10) these values would be 7.39 - 12.57 dollars. For the Andes region, a price of $6.39 - 8.60 was calculated, having one of the lowest production values in this study.

Geographical location plays a fundamental role when analysing the production cost of these technologies since their operation is closely linked to the climatic conditions that influence energy generation. In this context, the southern region of the American continent is characterized by favourable water conditions, which directly affects the costs associated with energy generation [23].

On the other hand, a study conducted in Chile where the costs of green H_2 production by electrolysis is analyzed has an approximate range of $2 - 6 per kilogram of H_2. In this study some costs (storage and transportation) were not taking in account, also 4 locations with high energy production were studied. Therefore, the best option for the production of this energy sector was selected [24].

To conduct a cost analysis, it is important to consider the price of electricity produced by Hidroabanico, which is fixed at 4.70 cents per kWh. This value is regulated by the state agency responsible for overseeing production, distribution, and transmission costs. It is worth noting that this is the rate at which the state purchases each kWh produced by the project [25].

Comparison of electrolyzer capital costs between systems is difficult because information on important parameters is often missing. However, when adjusted for inflation, cost reductions in alkaline methods have been moderate in recent years. While PEM systems price reductions have been significant, making costs more competitive with alkaline technology. These cost reductions have been achieved primarily through research and development, in the absence of significant market intervention [26]. It is because of this and the technological advantages that PEM systems are considered within this research.

Regardless of the characteristics of each type of electrolyzer, the average costs for the implementation of a 1MW power unit vary significantly from $450/kW for alkaline technologies to $870/kW for PEMs. It is important to note that these values may vary according to several factors, such as scale of installation, geographical location, resource availability and technological advances [27]. There are no H_2 plants in the region or in Ecuador. A real price for this technology cannot be estimated. Therefore, only the different prices and production cost projections can be analyzed.

G. Discussion

The production of green H_2 from renewable sources is a promising alternative for sustainable energy supply. This research evaluates the results of producing green H_2 through an electrochemical process powered by hydro power clean energy, in the context of reducing emissions and transitioning to cleaner energy matrices.

The production cost in Ecuador of H_2 is 1.77 $/kg [28], considering the average cost of electricity, water, supplies, electrifier, annual investment, and operation and maintenance. This would be around 2 million dollars for the analyzed project.

There are studies that analyze the production of hydrogen under different conditions, specifically at rates of 50, 100, and 200 kilograms per day [30]. While the investigations share similarities in technology and process, a significant difference arises in the evaluated power [29]. This study found lower power compared to the reference case studies. The discrepancy can be attributed to several variables, including system configuration, operating conditions, and design parameters.

4. Conclusion

The evaluation of green hydrogen generation from the Hidroabanico hydroelectric power plant presents encouraging results. Through the analysis of energy production over 13 years, a monthly average of electricity generation was obtained, this being the basis for calculating the 20% of energy destined for hydrogen production. This approach ensures sustainable and consistent production.

The selection of a PEM electrolyzer was driven by its modularity, ease of transport and installation, high efficiency, and capacity for high-purity hydrogen production. The calculation of hydrogen production over the course of one year resulted in a total of 1,123 Tn, showcasing the viability of the project and its potential to bolster the sustainable energy landscape. However, it's important to note that the applications for the energy allocated for hydrogen production are somewhat restricted, particularly in transportation. When compared with other technologies, hydrogen production from hydroelectric energy may not always be the optimal choice.

In 2022, the nominal power in Ecuador was 8,864.37 MW, of which 5,425.72 MW (58.56%) correspond to power plants with renewable energy sources and 3,483.65 MW (38.79%) to power plants with non-renewable energy sources.

Among the total installed capacity, hydroelectric power plants predominate among renewable sources, with 5,191.30 MW (95.68%). In 2022, the total gross energy production in the country reached 33,008.30 GWh. Ecuador still has significant untapped hydroelectric potential, which could also translate into a capacity as a hydrogen (H_2) producer. Therefore, it is necessary to analyze this energy vector as part of the national energy transition.

References

[1] S. Wang, L. Xing, and H. Chen, " Impact of marine industrial structure on environmental efficiency," *Management of Environmental Quality*, vol. 31, no. 1, pp. 111-129, 2019.

[2] Q. Zhu, X. Li, F. Li, and D. Zhou, " The potential for energy saving and carbon emission reduction in China's regional industrial sectors," *Science of the Total Environment,* vol. 716, p. 135009, 2020.

[3] M. Liu *et al.*, " Issues and opportunities facing hydrolytic hydrogen production materials," *Chemical Engineering Journal*, vol. 461, p. 141918, 2023.

[4] M. Khzouz, E. Gkanas, S. Du, and J. Wood, " Catalytic performance of Ni-Cu/Al2O3 for effective syngas production by methanol steam reforming," *Fuel*, vol. 232, pp. 672-683, 2018.

[5] Z. Yao *et al.*, " Achieving excellent cycle stability in Zr-Nb-Co-Ni based hydrogen isotope storage alloys by controllable phase transformation reaction," *Renewable Energy*, pp. 500-587, 2022.

[6] H. Kim, A. Kim, M. Byun, and H. Lim, " Comparative feasibility studies of H2 supply scenarios for methanol as a carbon- neutral H2 carrier at various scales and distances," *Renewable Energy*, vol. 180, pp. 552-559, 2021.

[7] B. D. Catumba *et al.*, " Sustainability and challenges in hydrogen production: An advanced bibliometric analysis," *International Journal of Hydrogen Energy*, vol. 48, no. 22, pp. 7975-7992, 2023.

[8] J. Morante, *El almacenamiento de la electricidad.* Barcelona, Spain: Fundación Gas Natural Fenosa, 2014.

[9] C. Amil and M. Zeki, " The importance of hydrogen for energy diversity of Turkey's energy production: 2030 projection," *International Journal of Hydrogen Energy*, vol. 47, no. 45, pp. 19935-19946, 2022.

[10] R. Bhandari, " Green hydrogen production potential in West Africa – Case of Niger," *Renewable Energy*, vol. 196, pp. 800-811, 2022.

[11] E. Galitskaya and O. Zhdaneev, " Development of electrolysis technologies for hydrogen production: A case study of green steel manufacturing in the Russian Federation," *Environmental Technology & Innovation*, vol. 27, p. 10257, 2022.

[12] Hidroabanico, " Hidroabanico–Estamos comprometidos con el crecimiento del Ecuador," hidroabanico. com.ec. https://hidroabanico.com.ec/proyecto/ (accessed Aug. 14, 2024).

[13] B. Basak, B. Jeon, T. Kim, J. Lee, P. Chatterjee, and H. Lim, " Dark fermentative hydrogen production from pretreated lignocellulosic biomass: Effects of inhibitory byproducts and recent trends in mitigation strategies, *Renewable and Sustainable Energy Reviews*, vol. 133, p.110338, 2020.

[14] M. Yue, H. Lambert, E. Pahon, R. Roche, S. Jemei, and D. Hissel, " Hydrogen energy systems: A critical review of technologies, applications, trends and challenges," *Renewable and Sustainable Energy Reviews*, vol. 146, p. 111180, 2021.

[15] ANDRITZ, " Proton Exchange Membrane (PEM)," andritz.com. https://www.andritz.com/products-en/metals/green-hydrogen/pem (accessed Aug. 14, 2024).

[16] C. Hitam and A. Jalil, " A review on biohydrogen production through photo-fermentation of lignocellulosic biomass," *Biomass Conversion and Biorefinery*, vol. 13, no. 10, pp. 8465-8483, 2023.

[17] L. F. Valdivieso, " Evaluacion del potencial del proyecto eolico minas de Huascachaca para la produccion de hidrogeno verde," B.A. thesis, Universidad Politecnica Salesiana, Cuenca, Spain, 2023.

[18] A. Cevallos-Escandón, E. A. Barragan-Escandón, E. Zalamea-León, X. Serrano-Guerrero, and J. Terrados-Cepeda, " Assessing the feasibility of hydrogen and electric buses for urban public transportation using rooftop integrated photovoltaic energy in Cuenca ecuador," *Energies*, vol. 16, no. 14, p. 5569, 2023.

[19] M. Rasul, M. Hazrat, M. Sattar, M. Jahirul, and M. Shearer, " The future of hydrogen: Challenges on production, storage and applications," *Energy Conversion and Management*, vol. 272, p. 116326, 2022.

[20] K. Patil, P. Khanwalkar, S. Thipse, K. Kavathekar, and S. Rairkar, " Development of HCNG blended fuel engine with control of NOx emissions," in *2009 Second International Conference on Emerging Trends in Engineering & Technology*, Dec. 2009, pp. 1068-1074.

[21] D . Cullen *et al.*, " New roads and challenges for fuel cells in heavy-duty transportation," *Nature Energy*, vol. 6, no.5, pp. 462-474, 2021.

[22] J. Collis and R. Schomäcker, " Determining the production and transport cost for H2 on a global scale," *Front.*

Energy Res., vol.10, p. 909298, 2022.

[23] J. Scafidi, M. Wilkinson, S. Gilfillan, N. Heinemann, and R. Haszeldine, " A quantitative assessment of the hydrogen storage capacity of the UK continental shelf," *International Journal of Hydrogen Energy*, vol. 46, no. 12, pp. 8629-8639, 2021.

[24] M. Garcia and S. Oliva, " Technical, economic, and CO2 emissions assessment of green hydrogen production from solar/wind energy: The case of Chile," *Energy*, 2023, doi: 10. 1016/j.energy.2023.127981.

[25] ARCRNNR, *Actualización del análisis y determinación del costo del servicio público de energía eléctrica.* Quito, Ecuador: ARCRNNR, 2020.

[26] IEA. (09 de 2022). " Electrolysers – Analysis - IEA. " iea.org. https://www.iea.org/reports/electrolysers (accessed Aug. 14, 2024).

[27] A. Patonia and R. Poudineh, *Cost-competitive Green Hydrogen: How to Lower the Cost of Electrolysers?.* Oxford, UK: The Oxford Institute for Energy Studies, 2022.

[28] F. Posso, J. L. Espinoza, J. Sánchez, and J. Zalamea, " Hydrogen from hydropower in Ecuador: Use and impacts in the transport sector," *Int. J. Hydrogen Energy*, vol. 40, pp. 15432–15447, 2015.

[29] R. El-Emam and H. Özcan, " Comprehensive review on the techno-economics of sustainable large-scale clean hydrogen production," *Journal of Cleaner Production*, vol. 220, pp. 593-609, 2019.

[30] I. Moradpoor, S. Syri, and A. Santasalo-Aarnio, " Green hydrogen production for oil refining – Finnish case," *Renewable and Sustainable Energy Reviews*, vol. 175, p. 113159, 2023.