Integration of Non-Conventional Renewable Energy Sources into an Off-Grid System for the Generation of Green Electricity and Hydrogen

Roberto Leiva-Illanes[1,2,*], German Amador[1,2] and Cynthia Herrera[1]

[1] Grupo de Investigación en Energía, Agua y Sostenibilidad / Universidad Técnica Federico Santa María, Viña del Mar (Chile)

[2] Grupo de Investigación en Movilidad y Combustibles Alternativos / Universidad Técnica Federico Santa María, Valparaíso (Chile)

*Correspondence: roberto.leiva@usm.cl

Abstract

The technical and economic feasibility of off-grid hybrid systems for green hydrogen production was evaluated, integrating photovoltaic (PV) and wind turbines (WT) with lithium-ion battery storage (BS) and proton exchange membrane electrolyzers (PEME) across three regions of Chile with distinct solar and wind resources. Hourly simulations assessed electricity generation, hydrogen production, and levelized costs of electricity (LCOE) and hydrogen (LCOH). Complementarity between solar and wind improves generation stability and electrolyzer operation. In Atacama, high solar irradiance and moderate wind allowed the PV+WT+BS system to achieve the lowest LCOE (108.8 USD/MWh) and LCOH (7.78 USD/kg H_2). In Magallanes, abundant wind favors WT+BS configurations. Systems relying solely on internal combustion engines (ICE) with natural gas exhibited higher costs (LCOE 218.6 USD/MWh, LCOH 12.7 USD/kg H_2) and CO_2 emissions. Battery storage mitigates renewable intermittency and optimizes electrolyzer utilization, while oversizing increases CAPEX without proportional benefits. Energy curtailment analysis highlighted hydrogen's role as a flexible storage vector. Hybrid renewable configurations offer technical viability and economic competitiveness for decentralized green hydrogen production, with resource availability critical for system design and cost-effectiveness. Strategic deployment in regions with high solar and wind potential maximizes efficiency and sustainability.

Keywords: PV, WT, Hydrogen, Electricity, Renewable Energy, Off-grid systems, Internal combustion engine.

1. Introduction

The global transition toward decarbonized energy systems has increased interest in green hydrogen as a clean energy carrier capable of storing and transporting renewable energy. Hydrogen production via water electrolysis powered by renewable sources offers the potential to reduce greenhouse gas emissions, enhance energy security, and provide a flexible vector for integrating variable energy sources (IEA, 2023). In regions with abundant solar and wind resources, decentralized hydrogen production can complement local electricity demand, support remote communities, and enable industrial applications with reduced reliance on fossil fuels (Ceylan and Devrim, 2023).

Off-grid hybrid systems combining photovoltaic (PV) and wind turbines (WT) with energy storage and electrolyzers have emerged as a promising solution to address the intermittency of renewable resources while providing continuous hydrogen production (Ceylan and Devrim, 2021, 2023; Come Zebra *et al.*, 2021). Lithium-ion battery systems (BS) allow short-term balancing of generation fluctuations, improving the operational efficiency of proton exchange membrane electrolyzers (PEME) and extending their lifetime by minimizing start-stop cycles. Such integrated systems can be designed to optimize the utilization of available renewable energy, reduce curtailment, and lower levelized costs of electricity (LCOE) and hydrogen (LCOH) (Al-Shetwi *et al.*, 2023; Sharma and Chinnappa Naidu, 2023; Grimaldi *et al.*, 2025).

Chile presents a unique opportunity for implementing renewable-based hydrogen systems due to its high solar irradiance in the north and strong, persistent winds in the south. Previous studies have highlighted the technical potential of PV and WT integration (Gallardo *et al.*, 2021; G and H, 2023; Hassan, Zuhair and Salman, 2023;

10.18086/swc.2025.07.06 Available at http://proceedings.ises.org

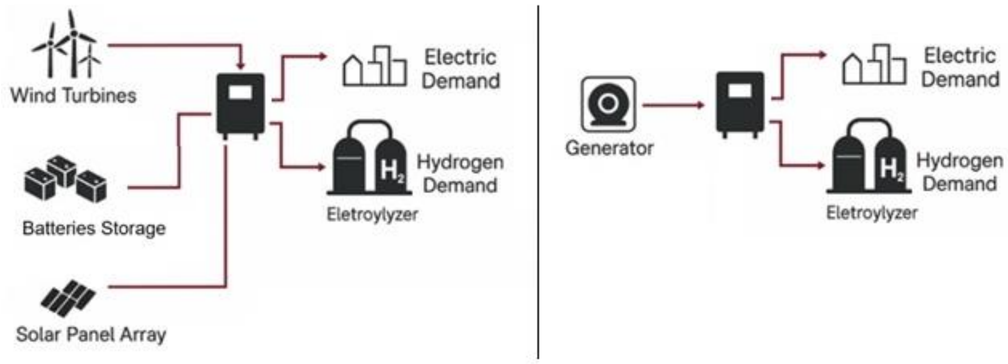
Leiva-Illanes *et al.*, 2025), but economic assessments considering hourly operation, energy storage, and electrolyzer performance remain limited. Understanding the interaction between local resource availability, system configuration, and storage capacity is essential for designing cost-effective and reliable green hydrogen production systems.

This work evaluates off-grid hybrid PV+WT+BS systems coupled with PEM electrolyzers in three Chilean regions with distinct resource profiles. The analysis compares electricity and hydrogen production, operational performance, and economic metrics, including LCOE and LCOH, with conventional hydrogen production using internal combustion engines (ICE) fueled by natural gas. The results provide insights into optimal system configurations, the role of storage, and the influence of resource variability on technical and economic feasibility, supporting strategic deployment of green hydrogen projects in Chile.

2. Methodology

Hourly modeling and simulation were conducted to evaluate the integration of wind turbines (WT) and photovoltaic (PV) power plants with lithium-ion battery storage (BS) and hydrogen production via proton exchange membrane electrolyzers (PEME) operating in an off-grid system, across three regions of Chile with different latitudes and distinct solar and wind resource profiles. The assessment compared the levelized cost of electricity (LCOE) and hydrogen (LCOH) and evaluated hydrogen production from renewable resources versus natural gas (a fossil fuel) using an internal combustion engine (ICE).

Figure 1 illustrates the schematic of the evaluated system, which consists of an off-grid configuration including a PV array, wind turbines (WT), a battery energy storage system (BS), and proton exchange membrane electrolyzers (PEME) for hydrogen production. The system is designed to operate independently from the on-grid electricity network, simultaneously meeting both electrical and green hydrogen demand. Generated electricity is managed through a central energy conversion and control unit, which distributes power to the electrical loads, the electrolyzers, and the battery bank. Surplus electricity is stored in the battery bank and can also be fed into the grid. The integrated renewable energy system (Figure 1a) is compared with a configuration coupled to a natural gas ICE generator (Figure 1b).



a) b)

Figure 1: System schematic. a) Integrated renewable energy system. b) System coupled to an ICE generator

The system was simulated on an hourly basis, and solar and wind resource data were obtained from the respective solar and wind explorers (Ministry of Energy of Chile, 2025a, 2025b) for each evaluated region (Table 1). The PV system was modeled using the SAM software (National Renewable Energy Laboratory (NREL), 2024), while the WT system was modeled using the Wind Explorer. Electrolyzers, batteries, ICE, and the integrated systems were modeled in MATLAB (MathWorks, 2025) and Excel.

Table 1: Evaluated locations

Location	Region	Latitude	Longitude	Altitude (m a.s.l)	Global radiation ($kWh/m^2/day$)	Wind speed (m/s)
L1	Atacama	-25.0961402	-69.5712401	2,775	7.12	9.2
L2	BiboBío	-37.5849	-72.5823	80	4.9	7.7
L3	Magallanes	-52.4489	-70.2547	256	3.1	11

The selected wind turbine has a nominal power of 100 kW_e, a rotor diameter of 21 m, a loss factor of 0.17, a hub height of 30 m, and corresponds to the Northern Power 100-21 model (Ministry of Energy of Chile, 2025b). The PV plant has a rated power output of 310.1 W, a module efficiency of 19.0%, and is coupled to an inverter with an efficiency of 98.6% (SunPower SPR-E19-310) (National Renewable Energy Laboratory (NREL), 2024). The PEM electrolyzer has a capacity of 100 kW_e, a specific electricity consumption (SEC) of 52 kWh/kg H_2, and a specific water consumption of 10 L/kg H_2 (Leiva-Illanes *et al.*, 2025). Finally, the installed capacity of the internal combustion engine (ICE) is 110 kW_e, with a heat rate of 10,778.4 kJ/kWh (electrical efficiency of 33.4%) (US Department of Energy, 2023), operating with natural gas.

Levelized costs of electricity (LCOE) and hydrogen (LCOH) were calculated following the methodology described in (Leiva-Illanes *et al.*, 2025).

The main economic parameters used are presented in Table 2.

Table 2. Main economic parameters (US Department of Energy, 2023; Grimaldi *et al.*, 2025; Leiva-Illanes *et al.*, 2025).

Parameters	Unit	WT	PV	PEME	BS	ICE
CAPEX	USD/kW	1200	741	1100	300	2354
O&M fixed costs	USD/kW/year	24	14.8	22	6	23.5
O&M variable costs (non-fuel)	USD/kWh	-	-	-	-	0.022

The water cost for the electrolyzer is 3 USD/m^3, and the natural gas price is 0.050 USD/kWh (GlobalPetrolPrices, 2025). A discount rate of 10% and a project lifetime of 20 years were considered.

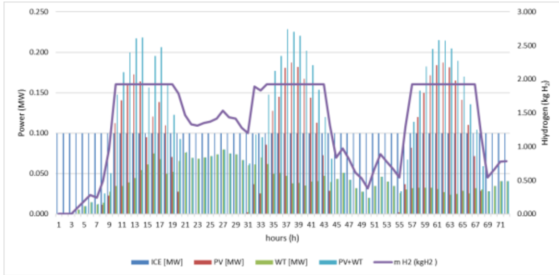
3. Result and discussion

Figure 2 shows the hourly variation of electricity generation and hydrogen production over three representative days of the summer period for the three analyzed locations. In general, a strong correlation is observed between solar radiation and PV generation, with peak outputs between 11:00 and 15:00 h, while the wind contribution exhibits greater temporal dispersion, complementing generation during periods of lower irradiance.

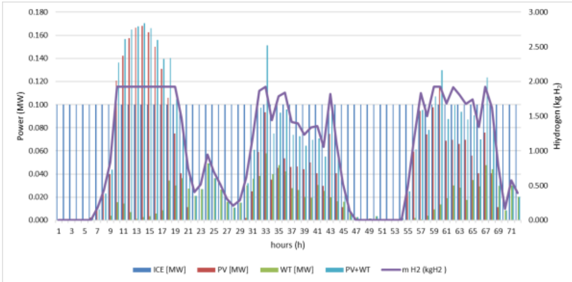
At location L1, characterized by high solar radiation and strong wind speeds, electricity generation is dominated by the PV system, enabling continuous operation of the electrolyzer during daylight hours. The battery primarily acts as a stabilizing element, storing excess energy and compensating for short-term power fluctuations. In L2, with lower solar irradiance but higher wind resources, electricity production is more stable throughout day and night. This supports a more uniform operation of the PEM electrolyzer, reducing downtime and improving its capacity factor, while also decreasing the battery discharge requirements.

Finally, in L3, the combined availability of wind and solar resources is lower than in the other two locations, resulting in reduced total hydrogen production. The battery plays a more active role in meeting the electrolyzer demand, although its capacity is limited by the intermittency of renewable sources. These results indicate that the complementarity between PV and WT enhances electricity generation stability and enables more continuous hydrogen production, particularly in locations where wind and solar profiles are temporally offset.

a)



b)



c)

Figure 2: Hourly electricity and hydrogen production during summer, a) L1, b) L2, c) L3

Table 3 summarizes the main annual results obtained for the three evaluated locations of the integrated PV+WT+BS system. In general, total electricity production (E) varies significantly between sites, reaching its maximum in L1 (705,253 kWh/year) due to high solar irradiance and the good performance of the PV field. In contrast, L2 exhibits the lowest total generation (467,846 kWh/year), resulting from the lower simultaneous availability of solar radiation and wind resources. The relative contribution of each source also differs across locations. In L1, the solar fraction (Epv) dominates total generation, whereas in L3, the wind contribution (Ewt) is predominant, indicating a better resource complementarity at this location. These results are reflected in the capacity factors (cf), with L1 achieving the highest value (26.8%), followed by L3 (20.2%) and L2 (17.8%).

Table 3: Main results of the integrated PV+WT+BS system

Parameter	Unit	L1	L2	L3
E	kWh/year	705,253	467,846	531,035
E_{pv}	kWh/year	431,273	290,853	189,265
E_{wt}	kWh/year	273,980	176,993	341,770
cf	%	26.8%	17.8%	20.2%
E_{H2}	kWh/year	520,267	374,950	462,365
cf_{H2}	%	59.4%	42.8%	52.8%
m_{H2}	kg/year	10,005	7,211	8,892
LCOE	USD/MWh	108.76	135.29	125.91
LCOH	USD/kg H_2	7.78	9.97	8.93

Regarding hydrogen production (E_{H2}), the behavior follows the trend of total available electricity. Location L1 records the highest annual generation (520,267 kWh/year), equivalent to 10,005 kg H_2/year, while L2 produces only 7,211 kg/year, reflecting the direct influence of energy availability on electrolyzer operation. The hydrogen system capacity factor (cf_{H2}) reaches 59.4% in L1, indicating efficient electrolyzer utilization under conditions of high irradiance and partial wind complementarity.

From an economic perspective, levelized costs of electricity (LCOE) and hydrogen (LCOH) show that L1 offers the best competitiveness, with values of 108.76 USD/MWh and 7.78 USD/kg H_2, respectively. In contrast, L2 exhibits the highest costs (135.29 USD/MWh and 9.97 USD/kg H_2), highlighting the dependence of economic performance on local renewable resources. These results demonstrate that the PV+WT+BS integration enables a more stable and competitive energy supply in sites with high irradiance and complementary wind resources, such as L1 and L3. Previous studies on off-grid systems have reported similar ranges for capacity factors and levelized costs of electricity and hydrogen (G and H, 2023; Leiva-Illanes *et al.*, 2024, 2025), confirming the consistency of the results obtained.

If the electrolyzer were coupled solely to a generator (ICE), the LCOE would increase to 218.55 USD/MWh, and the LCOH would reach 12.7 USD/kg H_2, significantly higher than those obtained with renewable-based hybrid configurations. This increase is mainly due to the high cost of fossil fuel and the lower overall system efficiency. Furthermore, the hydrogen produced in this case cannot be classified as green hydrogen, as the engine operates on natural gas, resulting in direct CO_2 emissions and a significantly higher carbon footprint.

In contrast, integrated PV+WT+BS plants exploit local renewable resources, solar radiation and wind, allowing emission-free electricity generation and lower levelized costs for both electricity and hydrogen. The temporal complementarity between solar and wind energy reduces supply intermittency and decreases the need for thermal backup. Additionally, incorporating a battery system (BS) helps smooth power fluctuations, optimizing electrolyzer operation and extending its lifetime by avoiding frequent start-stop cycles. However, hybrid renewable systems face technical and economic challenges associated with renewable resource variability, which can affect the continuity of the electrolysis process. This often requires partial oversizing of PV, WT, or storage subsystems, increasing initial investment (CAPEX). Maintenance costs and operational complexity are also typically higher than in conventional thermal systems, especially in remote areas or under extreme climatic conditions. On the other hand, an internal combustion engine (ICE) powered by natural gas (or another fossil fuel) provides continuous and controlled operation, with mature and widely available technology. Nevertheless, its reliance on fossil fuels entails variable costs subject to energy market fluctuations and greater exposure to decarbonization policies. In the case of a dedicated hydrogen ICE, investment costs increase significantly and fuel still represents a substantial fraction of total operational costs.

In summary, while the fossil-fuel-based generator offers greater operational stability and simplicity, the PV+WT+BS hybrid plant provides substantial advantages in terms of sustainability, energy independence, and long-term cost reduction. The results confirm that under favorable solar and wind resource conditions, hybrid configurations constitute a technically and economically viable option for decentralized green hydrogen production.

Figure 3 shows the results of the economic indicators, levelized cost of electricity (LCOE) and levelized cost of hydrogen (LCOH), for the three analyzed configurations: PV+BS, WT+BS, and the hybrid PV+WT+BS system, across the evaluated locations. The results demonstrate how the availability and complementarity of renewable resources directly influence the technical and economic performance of each configuration.

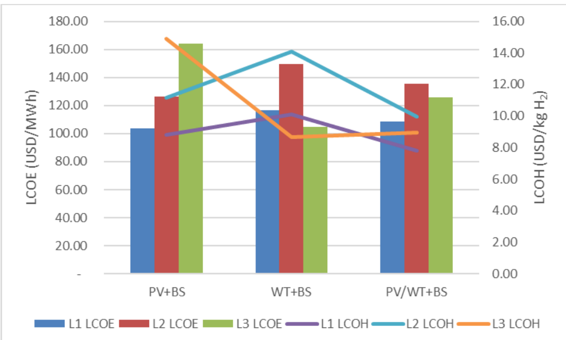


Figure 3: Results of LCOE and LCOH indicators for PV+BS, WT+BS, and PV+WT+BS configurations.

In the northern zone (L1, Atacama Region), the high solar irradiance and favorable wind resource allow the PV+WT+BS hybrid plant to achieve the lowest LCOE and LCOH values. The abundance of solar radiation generates high photovoltaic capacity factors, while wind complements production during non-solar hours, reducing intermittency and improving storage system utilization. In comparison, the PV+BS configuration exhibits slightly higher costs due to exclusive reliance on solar resources and the need for larger battery capacity to compensate for the lack of nighttime generation.

In the central-southern zone (L2, Biobío Region), the wind resource predominates, favoring the WT+BS configuration, which achieves competitive LCOE and LCOH values compared to the hybrid system. However, integrating the PV system improves supply stability and partially reduces battery usage, allowing more efficient operation of the electrolyzer. Although resource complementarity is lower than in the north, it still provides benefits for the overall system performance.

In the southern austral zone (L3, Magallanes Region), wind resources are excellent, with high and consistent wind speeds throughout the year, while solar radiation is limited. In this context, the WT+BS system shows the lowest production costs, confirming wind as the main suitable source for electricity generation and hydrogen production. Adding PV generation in this region contributes little to total performance, as its energy contribution is low and does not offset the increased investment associated with the solar field.

The results confirm that the PV+WT+BS hybrid integration improves economic performance in regions with high resource complementarity, such as northern Chile, where both solar and wind contributions are significant. In contrast, in regions dominated by a single renewable resource, such as Biobío and Magallanes, simpler configurations may be more cost-efficient. This highlights that the optimal selection of technological configuration must adapt to local resource conditions, balancing investment, operational stability, and hydrogen production costs.

Specifically, Magallanes stands out for its excellent wind potential, enabling continuous generation, high capacity factors, and low operational costs, positioning it as one of the most attractive regions in the country for green hydrogen development. Likewise, the northern zone benefits from extremely high solar irradiance, enabling exceptional photovoltaic yields and low production costs under hybrid schemes, consolidating it as another key region for large-scale green hydrogen projects.

Figure 4 shows the energy surpluses generated when curtailment is not utilized, that is, when excess energy is neither injected into the off-grid system nor stored in the batteries. These surpluses represent a significant potential loss of renewable resources, especially in systems with high solar or wind penetration. The magnitude of these surpluses directly depends on the variability of renewable sources and the installed storage capacity.

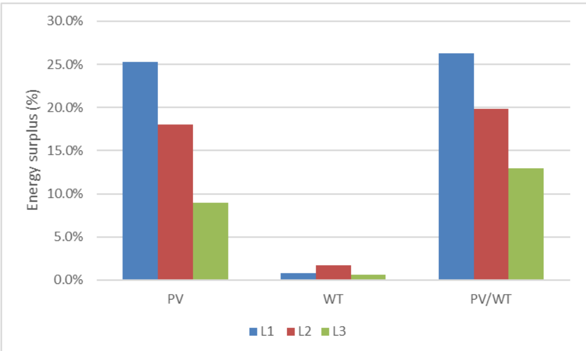


Figure 4: Electricity surpluses for photovoltaic, wind and photovoltaic/wind power configurations

Determining the optimal battery system size requires considering the energy dispatch strategy, battery investment and operating costs, hydrogen demand (if an electrolyzer is integrated), and hourly generation and consumption profiles. Oversizing the storage system can substantially increase the project CAPEX without a proportional improvement in energy utilization, while insufficient capacity leads to higher levels of curtailment. In this context, integrating an electrolyzer can help reduce surpluses by converting unused energy into hydrogen, increasing the overall system efficiency and enhancing profitability. Therefore, a combined analysis of dispatch strategy, technological costs, and final energy demand is essential to define the optimal balance between generation, storage, and utilization of available renewable resources.

Finally, the size of the storage system has a direct impact on the economic and operational indicators of the hybrid system. In general, as storage capacity increases, the levelized cost of hydrogen (LCOH) tends to decrease due to better utilization of energy surpluses and more stable operation of the electrolyzer, which increases its capacity factor. However, this benefit reaches a tipping point: oversizing the battery system significantly raises the total CAPEX without generating a proportional reduction in costs, due to the current high prices of electrochemical storage and the limited frequency of use during certain periods of the year.

4. Conclusions

The analysis assessed the technical and economic feasibility of off-grid hybrid systems for green hydrogen production, integrating photovoltaic (PV) and wind (WT) generation with lithium-ion battery storage (BS) and proton exchange membrane electrolyzers (PEME) across three representative regions in Chile with varying solar and wind resource profiles. The main conclusions are as follows:

The complementarity between solar and wind resources enhances the stability and continuity of electricity generation, reducing supply intermittency and optimizing electrolyzer operation. In particular, the PV+WT+BS combination exhibited synergistic performance in the northern region (L1, Atacama), where high solar irradiance is complemented by wind during non-solar hours, achieving the lowest levelized cost of electricity (LCOE = 108.8 USD/MWh) and hydrogen (LCOH = 7.78 USD/kg H_2).

Local renewable resource availability determines the technical and economic performance of the system. In regions with high irradiance (L1), PV generation dominates, while in areas with abundant and persistent wind (L3, Magallanes), wind power becomes the primary source. In contrast, the central-southern region (L2, Biobío), with intermediate resources, exhibits the lowest total production and highest costs (LCOH ≈ 9.97 USD/kg H_2), highlighting the strong dependence of profitability on local conditions.

Renewable-based hybrid systems outperform thermal systems with internal combustion engines (ICE) in terms of competitiveness and sustainability. When the electrolyzer is exclusively powered by a natural gas ICE generator, the LCOE and LCOH increase to 218.6 USD/MWh and 12.7 USD/kg H_2, respectively, while also generating direct CO_2 emissions. Therefore, PV+WT+BS systems are not only economically more attractive but also environmentally sustainable by producing emissions-free hydrogen.

Battery storage plays a key role in the operational stability of the electrolyzer, buffering generation fluctuations and preventing frequent start-stop cycles. However, its sizing must balance investment cost (CAPEX) with energy benefits: oversizing increases costs without proportional gains in utilization, whereas undersizing leads to energy curtailment losses.

The analysis of energy surpluses highlights the potential of hydrogen as a long-term storage vector. Electrolyzers enable the conversion of excess renewable energy into hydrogen, improving overall system efficiency and providing energy flexibility in off-grid scenarios.

From a geographic perspective, the Atacama and Magallanes regions emerge as the most competitive areas for green hydrogen projects in Chile. Atacama stands out for its very high irradiance and solar-wind complementarity, while Magallanes offers a continuous and stable wind resource throughout the year, with electrolyzer capacity factors exceeding 50%.

In summary, the results confirm that integrating hybrid PV+WT+BS technologies constitutes a technically and economically viable alternative for decentralized green hydrogen production in Chile. Optimal system configuration should consider local resource complementarity, available space, investment costs, and specific energy demand. Finally, the development of policies and incentives to reduce storage and electrolysis costs will be critical to establishing green hydrogen as a cornerstone of the national energy transition.

5. Acknowledgments

Thanks to the PILIA2504-UTFSM project and the GIEAS of the Universidad Técnica Federico Santa María (UTFSM)

6. References

Al-Shetwi, A.Q. *et al.* (2023) ‘Techno-economic assessment and optimal design of hybrid power generation-based renewable energy systems’, *Technology in Society*, 75(August), p. 102352. Available at: https://doi.org/10.1016/j.techsoc.2023.102352.

Ceylan, C. and Devrim, Y. (2021) ‘Design and simulation of the PV/PEM fuel cell based hybrid energy system using MATLAB/Simulink for greenhouse application’, *International Journal of Hydrogen Energy*, 46(42), pp. 22092–22106. Available at: https://doi.org/10.1016/j.ijhydene.2021.04.034.

Ceylan, C. and Devrim, Y. (2023) 'Green hydrogen based off-grid and on-grid hybrid energy systems', *International Journal of Hydrogen Energy*, 48(99), pp. 39084–39096. Available at: https://doi.org/10.1016/j.ijhydene.2023.02.031.

Come Zebra, E.I. *et al.* (2021) 'A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries', *Renewable and Sustainable Energy Reviews*, 144(July 2020). Available at: https://doi.org/10.1016/j.rser.2021.111036.

G, M.G. and H, S.O. (2023) 'Technical , economic , and CO 2 emissions assessment of green hydrogen production from solar / wind energy : The case of Chile', *Energy*, 278(PB), p. 127981. Available at: https://doi.org/10.1016/j.energy.2023.127981.

Gallardo, F.I. *et al.* (2021) 'A Techno-Economic Analysis of solar hydrogen production by electrolysis in the north of Chile and the case of exportation from Atacama Desert to Japan', *International Journal of Hydrogen Energy*, 46(26), pp. 13709–13728. Available at: https://doi.org/10.1016/j.ijhydene.2020.07.050.

GlobalPetrolPrices (2025) *Fuel Prices, Chile*. Available at: https://es.globalpetrolprices.com/Chile/natural_gas_prices/.

Grimaldi, A. *et al.* (2025) 'Techno-economic optimization of utility-scale battery storage integration with a wind farm for wholesale energy arbitrage considering wind curtailment and battery degradation', *Journal of Energy Storage*, 112(January), p. 115500. Available at: https://doi.org/10.1016/j.est.2025.115500.

Hassan, Q., Zuhair, A. and Salman, H.M. (2023) 'ScienceDirect Large-scale green hydrogen production via alkaline water electrolysis using solar and wind energy', *International Journal of Hydrogen Energy*, 48(88), pp. 34299–34315. Available at: https://doi.org/10.1016/j.ijhydene.2023.05.126.

IEA (2023) *Global Hydrogen Review 2023*, *Global Hydrogen Review 2023*. Available at: https://doi.org/10.1787/cb2635f6-en.

Leiva-Illanes, R. *et al.* (2024) 'Techno-economic evaluation for joint production of electricity and green hydrogen with hybrid concentrated solar power (CSP) and photovoltaic (PV) technologies coupled with PEM electrolyzers', in *Proceedings of EuroSun 2024*. Available at: https://proceedings.ises.org/?conference=eurosun2024&doi=10.18086/eurosun.2024.09.04&sort=title&mode=list.

Leiva-Illanes, R. *et al.* (2025) 'Generation of hydrogen and freshwater through a microgrid using internal combustion engines , micro gas turbines , and solar energy', in, pp. 1–9. Available at: https://doi.org/10.1088/1755-1315/1500/1/012087.

MathWorks (2025) 'MATLAB and Statistics Toolbox Release 2025a, The MathWorks, Inc., Natick, Massachusetts, United States.' Available at: www.mathworks.com.

Ministry of Energy of Chile (2025a) 'Solar Explorer'. Available at: http://solar.minenergia.cl/inicio.

Ministry of Energy of Chile (2025b) 'Wind Explorer'. Available at: https://eolico.minenergia.cl/inicio.

National Renewable Energy Laboratory (NREL) (2024) 'System Advisor Model (SAM)'. Available at: https://sam.nrel.gov/.

Sharma, P. and Chinnappa Naidu, R. (2023) 'Optimization techniques for grid-connected PV with retired EV batteries in centralized charging station with challenges and future possibilities: A review', *Ain Shams Engineering Journal*, 14(7), p. 101985. Available at: https://doi.org/10.1016/j.asej.2022.101985.

US Department of Energy (2023) *CHP Technologies: Reciprocating Engines - DOE/EE-2764*.