COMMENTARY

Balancing hope and hype on hydrogen's role in the Philippine energy transition

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ABSTRACT

Hydrogen (H_2) presents a unique opportunity for the Philippines' energy landscape. Using hydrogen as an 'energy vector' for industrial, power, and transportation applications represents a promising and sustainable solution in its ongoing efforts to address climate change and transition towards a cleaner energy future. However, unlocking this potential requires first addressing regulatory and policy gaps. This challenge has many different facets, such as the need for regulations to support the hydrogen infrastructure development, the establishment of clear standards for safe hydrogen production, storage and handling, streamlining of permit and license applications, monitoring of solar or wind power plants coupled with electrolysis process, provision of more substantial support for research and innovation, and promotion of hydrogen-based products.

This policy brief describes the current landscape and identifies the regulatory and policy gaps that policymakers must fill while highlighting the Philippines' potential for hydrogen energy and energy storage in the short and long run. It is crucial to have a complete policy framework that addresses regulatory clarity, financial incentives for infrastructure development, technical capacity, support for R&D, and strategic export planning. The Philippines can utilize its renewable resources, improve energy security, and cut emissions by filling these gaps.

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1. Potential of hydrogen as an 'energy vector'

H_2 energy storage emerges as a frontrunner in storing renewable energy due to its ability to effectively manage energy supply fluctuations and predict when to supply in the power grid. The main advantages of H_2 are:

1. It is cleaner than fossil fuels.
2. No harmful emissions.
3. Developers can repurpose current gas infrastructures for H_2 use.
4. It has a higher density than other electrochemical energy storage.

Additionally, compared to other various energy storage technologies such as pumped hydropower, flywheels, thermal storage, and supercapacitors, hydrogen production can cover large-scale operations, could respond and discharge in a dynamic range, and can be stored in long durations without degrading its purity and quality (Körner, 2015). This quality of H_2, in turn, guarantees a reliable, uninterrupted power supply for communities reliant on microgrid systems.

KEYWORDS

green hydrogen, policy recommendations, energy vector, energy transition, renewable energy

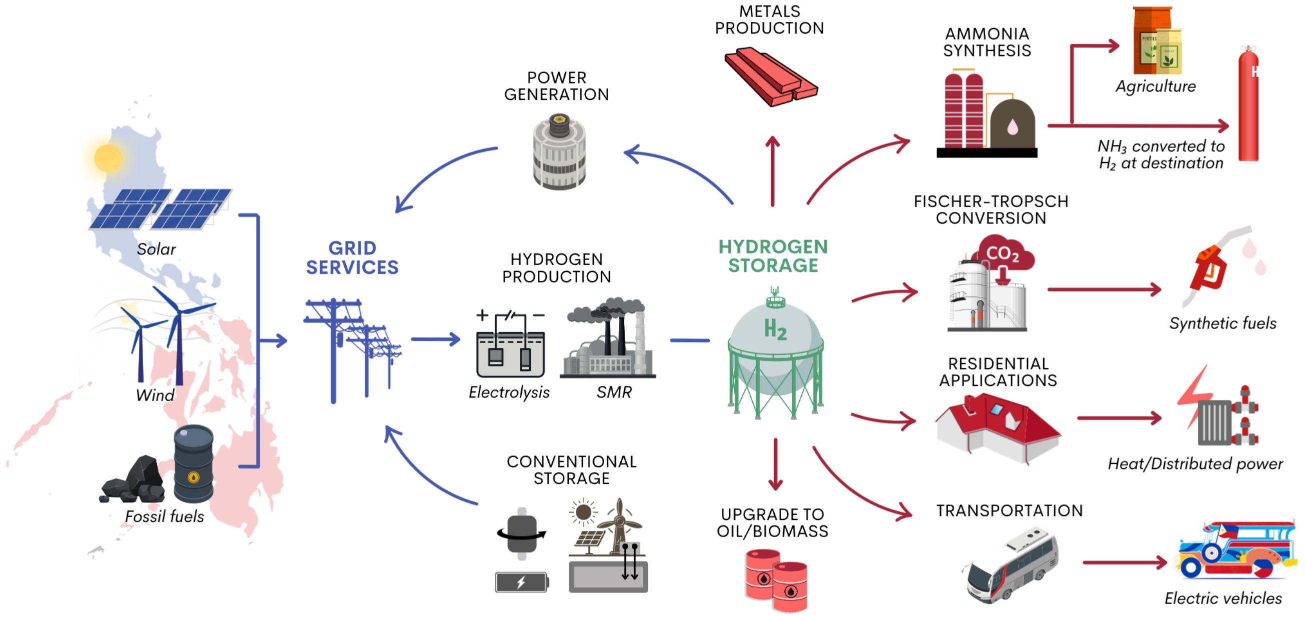

Figure 1: The use cases and applicability of hydrogen in various sectors.

Figure 1 shows the use cases of H_2 and its applicability in various sectors and some organizations that could benefit from its use. This paper provides a detailed discussion of its application in the Philippine setting in Section 2. As can be seen in the diagram, renewable energy projects (from solar and wind) could convert electricity to H_2 via electrolysis. Project proponents can use stored compressed H_2 to generate electricity, provide heat, power vehicles, and serve as a feedstock for industrial processes. This utilization makes H_2 an 'energy vector,' the energy available for use from the source at a distance of time and space (Krajačić et al., 2008). However, implementing H_2 technologies has technical challenges, such as efficient electrolysis, hydrogen storage, and infrastructure development. This set of challenges necessitates research, development, and investment to realize the full potential of using hydrogen energy.

Depending on how projects produce H_2 and how the process affects the environment, H_2 takes on several "colors" among the many colors; readers can see the most common ones in Figure 2. 'Green hydrogen' is a prime example of sustainable production because projects produce H_2 using renewable energy, and it is entirely independent of the use of fossil fuels. While 'blue hydrogen' is still produced from natural gas (i.e., methane) and coal but uses carbon capture technologies. Lastly, 'gray hydrogen' is produced also from natural gas (i.e., methane) and coal but without CO_2 emission control technologies (as compared to blue hydrogen).

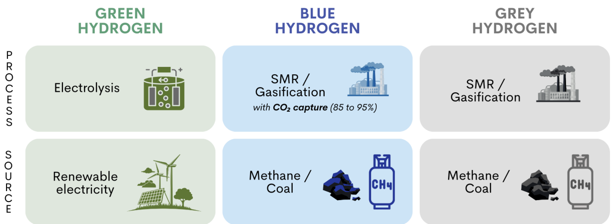

Figure 2: The main colors of hydrogen based on production methods and sources.

Green hydrogen, an emerging carbon-neutral alternative, is a promising solution to transition to cleaner energy sources. Beyond its environmental friendliness, hydrogen energy has a variety of advantages. One notable benefit is its long-term storage capability, making it an ideal solution for storing excess energy generated from intermittent renewable sources, such as solar and wind, for use during periods of high demand or when renewable generation is low. Also, hydrogen is a viable alternative to diesel backup power, providing a cleaner and more sustainable option for reliable energy supply, especially in off-grid applications. Its independence from fluctuating fuel prices offers economic stability and resilience. Furthermore, hydrogen-based systems operate silently and produce no noxious odors, enhancing their appeal for urban and residential use (Le et al., 2023).

It could be seen that hydrogen presents a unique opportunity for the Philippines' energy landscape. This policy brief describes the current situation and future outlook of hydrogen use in the Philippines. Additionally, this paper reports the results of the techno-economic analysis performed and reports the calculated levelized cost of green hydrogen in the Philippines. At the end of the paper, the regulatory and policy gaps that policymakers must fill were highlighted.

2. Current situation and future outlook of hydrogen use in the Philippines

The Philippines still relies heavily on fossil fuels to meet its increasing energy demands. *Figure 3* shows data from the Philippine Department of Energy (DOE) reflecting fossil fuels such as coal, oil, and natural gas accounted for about 77% of the power generation mix. In contrast, renewables contributed around 22% in 2021 (Department of Energy, 2021b). It could be noted that there is a disparity between the installed generating capacity *(Figure 3a)* and power generation of coal *(Figure 3b)*. It is related to the underutilization of oil in terms of power generation. Coal is generally cheaper and more cost-effective as a fuel source compared to oil, especially when considering the volatility of oil prices in the global market. The Philippines has invested in coal-fired power plant infrastructure and technology over the years. As a result, the country has a significant installed capacity for coal-fired power generation, which allows it to generate a large portion of its electricity from coal.

To mitigate climate change's devastating and costly effects, the government commits to a projected reduction of greenhouse gas (GHG) emissions and avoidance of GHG by 75% by 2030 while expanding renewable energy sources to 35%.

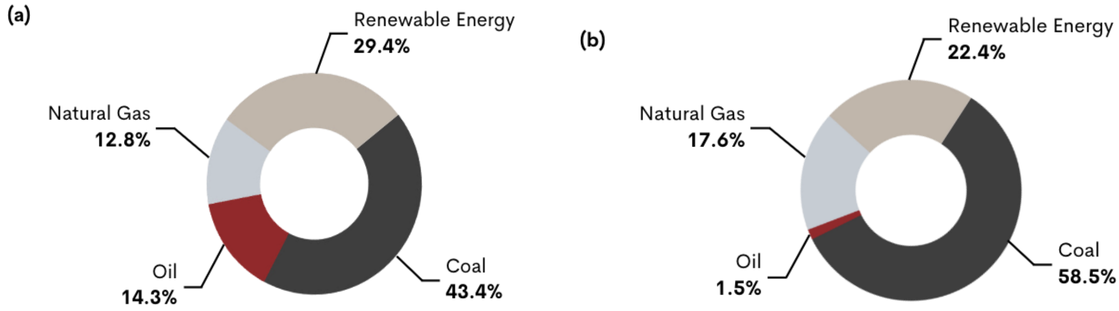

Figure 3: The Philippine energy mix: (a) Installed generating capacity and (b) power generation by source (DOE, 2021).

The Philippines' use of hydrogen technologies (i.e., electrolyzers and fuel cells) is still in its early stages as there are limited deployed units in specific fields such as telecommunications and the chemical industry. Proponents and observers should focus on developing a solid knowledge base through research, teaching, training, and specialized hydrogen technologies component production. The government should strongly consider strengthening industry-academia relationships to encourage market-driven research and early implementation of the technologies, as is done in developed nations (Abeleda & Espiritu, 2022). The Philippine Energy Research and Policy Institute (PERPI) has been signed into law (RA 11572) on 30 July 2021 and serves as a tool for decision-makers to enhance energy research and policy development. However, as of writing, the PERPI has yet to be operationalized by the University of the Philippines System despite appointing new members of its Board and its Executive Director. No laws and only a single circular -with a prospective one on the way- are specific to hydrogen and fuel cells in the Philippines. It's important to note that in the context of the Philippine Energy Plan 2020-2040 published in 2021 (Department of Energy, 2021a), which outlines strategies to achieve energy security, affordability, and sustainability, there is a lack of details in the discussion on how to use hydrogen as an energy vector. This set of details could range from small-scale power supply in off-grid modes to large-scale chemical energy exports.

Hydrogen has a critical role in ammonia synthesis. The Philippines' reliance on agriculture makes ammonia production an essential industry. The Philippine Phosphate Fertilizer Corporation (Philphos) and Atlas Fertilizer Corporation are currently the largest local fertilizer producers. Smaller amounts of fertilizer are also produced by small to medium-sized producers. Hydrogen is a primary feedstock through the Haber-Bosch process as it combines with nitrogen to form ammonia. Alternatively, green hydrogen in ammonia production results in 'green ammonia' without contributing to the emission of greenhouse gases in the agricultural sector. However, as seen in *Table 1*, the commercial readiness index of green ammonia in the Philippine context is still low and will only be applicable in the long run (more than five years from now). There is currently limited industrial use of green hydrogen in the country. Oil refineries (e.g., Petron) and petrochemical companies produce hydrogen to support their operations processes, such as hydrotreating. Additionally, the use of hydrogen in the steel industry has a low demand primarily due to the lack of steel manufacturing facilities in the Philippines. Furthermore, hydrogen for transportation and mobility applications is still far from commercial readiness in the country. Even though its technological readiness level and applicability to trucks and heavy equipment vehicles is higher than battery-powered electric vehicles, the lack of hydrogen refueling stations makes it challenging to deploy these fuel cell-powered cars. Necessary infrastructures and the regulations and policies that come with them should be established first in the country. Lastly, as of 2022 (World Bank, 2023), 2.9 million Filipinos still live without electricity, mainly due to the country's archipelagic geography. Most people or communities without electricity live on remote islands not connected to the main grid due to the high connectivity costs (Ocon et al., 2023). These remote or micro-grid islands are inherently characterized by their reliance on fluctuating or intermittent renewable energy sources. Proponents can use hydrogen technologies to provide the electricity needs of these communities; however, these would include high initial costs, challenges in hydrogen transportation and storage, lack of local expertise, and limited energy demand.

Table 1: The technological readiness and commercial competitiveness of different use cases of hydrogen in the Philippine context.

Hydrogen Application	Technological Readiness Level (TRL)[1]	Commercial Readiness Index (CRI)[2]	Reference
Fuel for transportation (e.g., fuel cell vehicles)	4	1	Andres (2004), Agaton et al. (2022)
Aviation sector (e.g., hydrogen-powered aircrafts)	1	N/A	Rappler (2021), Keating (2021)
Power generation (e.g., backup power from Smart fuel cell systems)	9	3	Abeleda & Espiritu (2022)
Heat for industry (e.g., steel, paper, cement, food, glass, etc.)	2	1	Agaton et al. (2022)
Chemicals (e.g., fertilizers, fuel refining, etc.)	7	1	Collera & Agaton (2021)

[1] *TRL levels: 1-Research idea; 2-Applied research idea; 3-Project plan; 4-Development; 5-Standardization; 6-Preclinical evaluation; 7-Technology transfer; 8-Clinical evaluation; 9-Commercialization (Raffaini & Manfredi, 2022)*

[2] *CRI levels: 1-Hypothetical commercial proposition; 2-Commercial trial, small scale; 3-Commercial scale up; 4-Multiple commercial applications; 5-Market competition driving widespread development; 6-Bankable asset class (ARENA, 2014)*

Despite the abovementioned challenges, Japan and South Korea seek to acquire hydrogen to help with their decarbonization efforts (Lauerman, 2021). Due to its potential for renewable energy, the Philippines' advantageous geographic location can make it a significant provider of green hydrogen. This export possibility boosts regional cooperation in the pursuit of sustainable energy goals in addition to providing economic benefits. Moreover, as part of its transition to sustainable solutions, Smart Communications, Inc. (Smart), the wireless division of PLDT Inc. of the Philippines, started to deploy fuel cell sites in off-grid areas in the second quarter of 2021. Hydrogen for backup power in telecommunication base stations is the most applicable in the Philippines. The company plans to establish around 90 green cell sites in collaboration with SerEnergy of Denmark, using fuel cells to produce sustainable energy through electrochemical processes. This program emphasizes Smart's dedication to environmental responsibility and technological innovation and aligns with government policies against new coal power facilities (Smart Public Affairs, 2021). After this announcement, however, it is difficult to find additional information on how many actual fuel cell systems-based backup power deployments were made by the proponents.

3. Levelized cost of green hydrogen in the Philippines

Prior work investigated the renewable energy potential of the Philippines; Ocon et al. (2021) proposed a pathway in which total dependence on renewable energy across the power, transportation, heat, and desalination sectors. Observers expect the role of hydrogen to focus on the transport sector as an alternative fuel or a precursor to other synthetic fuels.

To date, grey hydrogen is the most prevalent kind of hydrogen in the market due to its cheap cost of around 2 USD/kg (IEA, 2022). The goal of cleaner hydrogen technologies is to produce hydrogen that is competitive with grey hydrogen. The solar and wind potential of the Philippines is abundant enough for green hydrogen production. Storing intermittent solar and wind power for future use in the form of hydrogen gas via the electrolysis process is the usual path for green hydrogen production (Jang et al., 2021).

The high renewable energy potential of the Philippines is widely explored (Ocon et al., 2021; Castro et al., 2022). However, the potential for green hydrogen production from solar- and wind-powered electrolysis is unknown. The viability and competitiveness of green hydrogen production in the Philippines can be investigated by performing techno-economic analysis of RE-electrolysis systems to determine the costs associated with developing such plants; and accounting for the predicted production rate of hydrogen, the cost per kilogram of hydrogen (LCOH) can be determined.

The high renewable energy potential of the Philippines is widely explored (Ocon et al., 2021; Castro et al., 2022). However, there is room to discover the potential for green hydrogen production from solar- and wind-powered electrolysis in the Philippines. Research can investigate the viability and competitiveness of green hydrogen production in the Philippines by performing a techno-economic analysis of RE-electrolysis systems to determine the costs associated with developing such plants and accounting for the predicted production rate of hydrogen; such work can determine the cost per kilogram of hydrogen (LCOH).

3.1. Techno-economic analysis

The solar photovoltaics (solar PVs) were modeled after the commercial brand Trina Solar TSM-PC 14 (Trina Solar, 2015) and the wind turbine power curve was modeled after Vestas V129-3.0 (Wind-turbine-models, 2015).
This analysis models the solar photovoltaics (solar PVs) after the commercial brand Trina Solar TSM-PC 14 (Trina Solar, 2015) and the wind turbine power curve after Vestas V129-3.0 (Wind-turbine-models, 2015).

Table 2: Techno-economic assumptions used in this study.

Component	Techno-economic assumptions							
	CapEx ($/kW)	OpEx ($/kW-y)	Lifetime (y)	2030 CapEx ($/kW)	2030 OpEx ($/kW-y)	2030 Lifetime (y)	Remarks	Ref.
Solar PV: Trina Solar TSM-PC14	1 818.83	18.19	20	1 329.29	13.29	20	Derating factor: 80% Temp coeff. of P: -0.41%/C°	Trina Solar (2015), IRENA (2019a)
Wind turbine: Vestas V126-3.0	983.99	24.60	20	715.01	17.88	20	Hub height: 119 m Power curve taken into account.	Wind-turbine-models (2015), IRENA (2019b)
Alkaline water electrolyzer (AWE)	1 450.72	72.54	8	*base:* 1 143.52 *2x:* 838.98 *10x:* 773.73	*base:* 70.67 *2x:* 41.95 *10x:* 38.69	8	4.5 kWh/cu. m H_2 (4.2 in 2030)	Schmidt et al. (2017)
Proton exchange membrane electrolyzer (PEMEC)	1 626.94	81.35	6	*base:* 1 353.65 *2x:* 1 121.75 *10x:* 943.08	*base:* 67.68 *2x:* 56.09 *10x:* 47.15	8	4.2 kWh/cu. m H_2 (4.1 in 2030)	Schmidt et al. (2017)
Solid oxide electrolyzer (SOEC)	3 562.24	178.11	5	*base:* 2 647.02 *2x:* 2 060.16 *10x:* 1 747.88	*base:* 132.35 *2x:* 103.01 *10x:* 87.39	10	3.7 kWh/cu. m H_2 (3.7 in 2030)	Schmidt et al. (2017)

Table 2 summarizes the techno-economic assumptions used in this study. This study takes the projections of the parameters for 2030 from Schmidt et al. (2017) to provide predictions for the LCOH in 2030. This study also adapts the three funding scenarios for the 2030 projections. Also, this study considers three electrolyzer types, namely alkaline water electrolyzer (AWE), proton exchange membrane electrolyzer (PEMEC), and solid oxide electrolyzer (SOEC).
This study determines CapEx and OpEx for 2030 by using the method described by Sens et al. (2021), utilizing cumulative installed capacity and price history to predict values in the future.

This study takes the historical CapEx data for solar PVs and wind turbines from Feldmann et al. (2022) and US DOE (2022) and for installed capacities from IRENA (2019a) and IRENA (2019b).

Resource data such as solar global horizontal irradiance (solar GHI) and wind speed are essential to calculate the amount of energy that solar PV and wind turbine plants can harness. This study takes from satellite data published by Blanco et al. (2015). Additionally, a discount rate, the rate of return to determine present cash flow from future cash flows of 8% and a feedstock deionized water price of 0.01 USD/kg was assumed in the evaluation of the LCOH. The defined parameters were processed through Island Systems $LCOE_{min}$ Algorithm (ISLA), an in-house Python-based microgrid systems modeling software, to calculate the net present cost (NPC) and the annual energy production of the plant. Resource availability dictates the energy production, which, in turn, scales with the hydrogen production governed by a fixed ratio of energy-to-hydrogen conversion different for every electrolyzer type. This study uses NPC, the cost of deionized water, and the hydrogen production rate to calculate the LCOH by adding the NPC and water cost and dividing by the amount of hydrogen produced.

In the operation of the electrolyzers, this study assumes that the electrolyzers would only be operational when the power input was at least 10% of the total capacity of the electrolyzer which is a safety protocol to limit the hydrogen-oxygen ratio to non-explosive levels (de Groot et al., 2022). With this assumption, this study adjusts the lifetimes of the electrolyzers based on the expected fraction of time that the system is operational. This study expects to have different values based on renewable resource availability. This variability yields different electrolyzer lifetimes for different provinces. For systems where the electrolyzer lifetime is less than the wind turbine or solar PV lifetime, this study accounts for the salvage value using NPC calculation. The capacity of the electrolyzer matches the capacity of the power source. Due to the size of the individual units, wind turbine systems are at a capacity of 6 MW, while solar PV systems are at 5 MW. For the projections, both solar- and wind-powered systems have a capacity of 30 MW.

This study performs this method for all electrolyzer types, solar and wind, and provinces. This study takes the locations in each province that provide the highest solar GHI and wind speed as representative locations for each province. This study generates a heat map by calculating the LCOH for each province. It will show locations where green hydrogen production is cheap for all solar and wind electrolyzer types and for all provinces.

3.2. LCOH Heatmap

Figures 4a and *4b* show the LCOH heatmaps for solar and wind, respectively. For solar-powered electrolysis, the lowest LCOH calculated was in Pangasinan, with 5.95 USD/kg, 6.48 USD/kg, and 10.01 USD/kg for AWE, PEMEC, and SOEC, respectively.

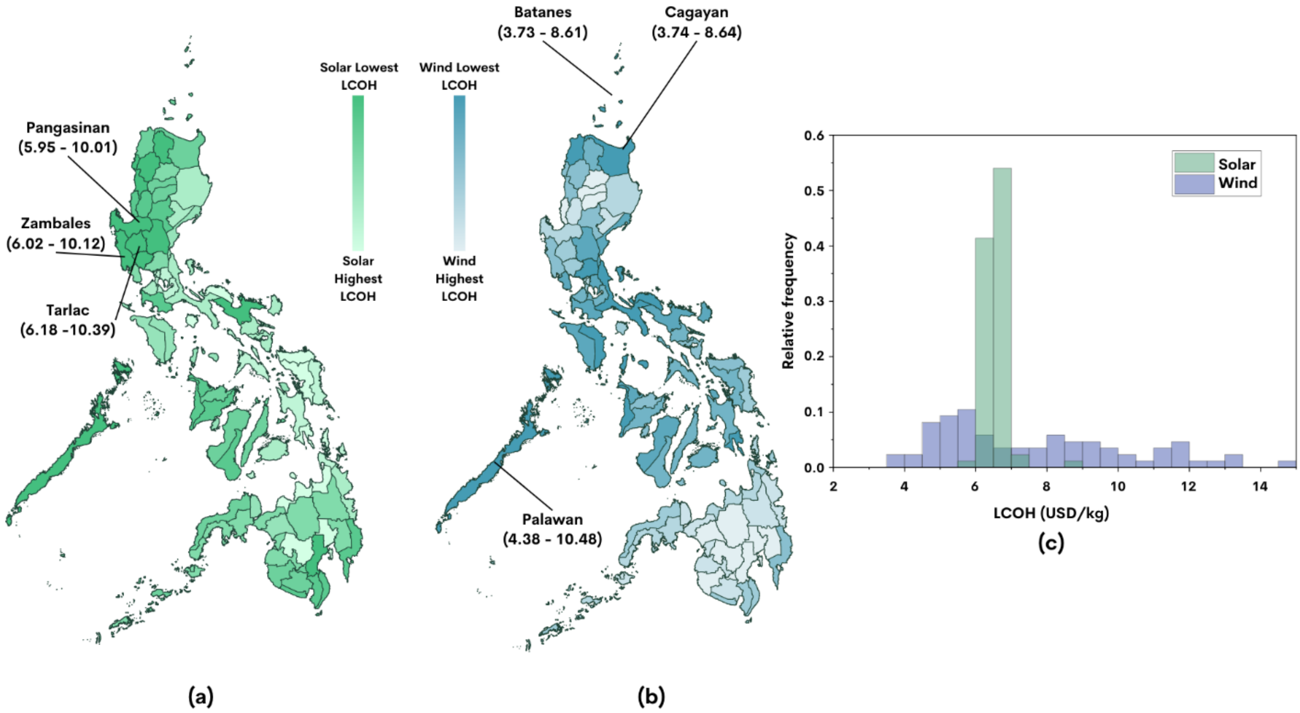

Figure 4: Levelized cost of hydrogen (LCOH) heatmaps for (a) solar- and (b) wind-powered electrolysis plants. The three provinces with the lowest LCOH in 2022 for each power source are indicated in each map. Values are in USD/kg. (c) Histogram of LCOH for wind- (blue) and solar-powered (green) AWE systems.

The location with the lowest LCOH value for wind is Batanes, with 3.73 USD/kg, 4.69 USD/kg, and 8.61 USD/kg for AWE, PEMEC, and SOEC, respectively. In the present scenario, no value of LCOH has breached the value of 2 USD/kg, which is considered the price of hydrogen to be competitive with grey hydrogen (IEA, 2022). In addition, this study characterizes the solar LCOH by a narrower range of values compared to wind, as shown in the histogram (*Figure 4c*), which implies the general availability of sunlight compared to wind with usable speeds. Wind-powered electrolysis systems have more favorable LCOH in provinces along the coasts and islands.

This study ascertains the absence of favorable wind speeds in some provinces, such as Ifugao and Bukidnon, from the discrepancy between operational time and capacity factor. In these provinces, the system runs 50 to 60% of the time but only has a 5-10% capacity factor. This feature implies that while the wind turbine can achieve more than 10% of electrolyzer capacity, the power generated stays at a lower value. Operations in these provinces are then less efficient due to the surrounding topography. Both Ifugao and Bukidnon are enclosed by mountain ranges which inhibit the prevalence of favorable wind speeds, hence the power produced stays at a low value for most of the time that the system is operational. The discrepancy between the capacity factor and operational time calculated in this study for solar PV systems is usually less than 5%. The general availability of usable sunlight is evident in the trends observed for solar PV systems. Cloud cover – highly dependent on climate type – is the limiting factor for these systems.

The operational time dictates the true lifetime of the electrolyzer. This study expects the electrolyzer to have a lower lifetime in provinces where the system runs for a more significant fraction of time. For this methodology, the electrolyzer lifetime also serves as the project lifetime, so a high fraction of operational time will also result in higher salvage values for the other components, such as solar PV and wind turbine, and consequently NPC. On the other hand, a system with a low operational time will yield higher project lifetimes limited to a maximum of 20 years which is the lifetime for solar PV and wind turbines as it would be impractical to replace these with new ones for the remaining lifetime of the electrolyzer which is expected to be short. For this methodology, reaching a high lifetime denotes poor resource availability, and investing new equipment in an underperforming system is inappropriate.

3.3. 2030 Projections

The LCOH for the year 2030 was also projected using historical data for capital expenses and cumulative installed capacity for solar PV and wind (see *Table 2*). This study takes the electrolyzer costs and lifetime from Schmidt et al. (2017), depending on the research and development funding scenario. This study updates energy-to-hydrogen conversion efficiency to account for technological development.

The base scenario, or business-as-usual case, described by Schmidt et al. (2017) failed to yield an LCOH lower than the 2030 target of 1 USD/kg. However, the deviation from the target LCOH (2 USD/kg in 2022 and 1 USD/kg in 2030) for the lowest values is generally decreasing except for the worst case for SOEC-wind turbine system with the highest LCOH value and the best and median cases for AWE-wind turbine system, both in the 2030 base scenario. The trends on which provinces have favorable LCOH values and the discrepancy between operating time and capacity factor are similar to those of 2022.

For the other funding scenarios, the LCOH values calculated are lower than the base scenario but still greater than 1 USD/kg. The lowest LCOH value for the 2× funding scenario is only 1.43 USD/kg away from the target while the gap is 1.31 USD/kg for the 10× funding scenario. More funding for the research and development of electrolyzer technologies assisted in closing the gap to grey hydrogen in terms of economic competitiveness in the near future.

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3.4. Fuel cell-electrolyzer energy storage system

This paper explores the off-grid application of hydrogen in another study by comparing hydrogen energy storage (electrolyzer, fuel cell, and H_2) to Li-ion storage combined with solar PV as a retrofit to existing diesel power plants of three different scales.

In the present costs and efficiencies, adding a fuel cell-electrolyzer component, a hydrogen storage tank, and a solar PV to an existing diesel system will only result in a higher levelized cost of electricity (LCOE). The introduction of a Li-ion battery lowers the LCOE instead. This trend implies that hydrogen technologies still need to be commercially mature to be a feasible alternative for battery storage.

In the calculations conducted on this work, there are three different scales - modeling the configurations after Balongbong HEPP, Catanduanes (large scale: 35 MW diesel plant); Ticao DPP, Masbate (medium scale: 3.5 MW diesel plant); and Cabungaan DPP, Western Samar (small scale: 47 kW diesel plant).

Table 3 indicates that adding hydrogen conversion technologies is not advantageous. In scenarios where this paper uses hydrogen technologies, the LCOE is significantly higher than systems with Li-ion storage, solar PV + diesel, and diesel only.

Additionally, this study calculates LCOH for each province for solar- and wind-powered systems and all electrolyzer types (AWE, PEMEC, and SOEC). This paper utilizes spatial data for solar GHI and wind speed to pinpoint reference locations for each province for techno-economic simulations. This paper predicts that Pangasinan will have the lowest LCOH value for solar PV systems, followed by Zambales and Tarlac. Batanes, Cagayan, and Palawan yielded the lowest LCOH values for wind turbine systems.

While these calculations have predicted promising potential for wind-powered electrolysis plants in Batanes and Cagayan, more focused studies are needed to more accurately compute LCOH by narrowing down the locations, considering a more complex configuration closer to an actual green hydrogen plant, and performing optimization of plant configuration.

Table 3: Summary of the results of LCOH calculations for 2022 and projected 2030 LCOH values for different funding scenarios for electrolyzer development described by Schmidt et al. (2017). LCOH values are reported in USD/kg.

Case	Levelized Cost of Hydrogen (USD/kg)											
	2022			2030: Base scenario			2030: 2× funding			2030: 10× funding		
	AWE	PEMEC	SOEC	AWE	PEMEC	SOEC	AWE	PEMEC	SOEC	AWE	PEMEC	SOEC
Solar best	5.95	6.48	10.01	4.76	4.54	6.20	3.66	4.05	5.23	3.53	3.72	4.71
Solar median	6.57	7.15	11.04	5.18	4.94	6.84	3.99	4.47	5.77	3.85	4.11	5.19
Solar worst	8.63	9.40	14.53	5.71	5.45	7.55	4.39	4.92	6.36	4.24	4.52	5.72
Wind best	3.73	4.69	8.61	3.46	3.27	4.53	2.43	2.74	3.56	2.31	2.44	3.15
Wind median	8.20	10.23	18.30	7.59	7.18	9.74	5.32	6.04	3.85	5.06	5.38	6.82
Wind worst	41.48	48.61	41.72	36.47	34.53	49.00	25.88	29.73	38.89	24.68	26.6	34.32

Table 4: Summary of the results of the evaluation of hydrogen technologies as an alternative energy storage system in the addition of solar PV to existing diesel power plants.

Configuration	Solar PV (kW)	Li-ion (kWh)	Fuel cell (kW)	Electrolyzer (kW)	H_2 storage (kg)	Diesel (kW)	Initial CapEx (M USD)	LCOE (USD/kWh)
BALONGBONG HEPP, Catanduanes								
Diesel						35 000	17.5	0.498
Solar PV + Diesel	83 739					35 000	89.3	0.402
Solar PV + Li-ion + Diesel	73 272	13 084				35 000	89.5	0.365
Solar PV + Hydrogen + Diesel	83 739		0	0	0	35 000	89.3	0.402
Solar PV + Hydrogen + Diesel (forced)	83 739		10 000	10 000	20	35 000	139	0.442
TICAO DPP, Masbate								
Diesel						3 500	1.75	0.475
Solar PV + Diesel	9 036					3 500	9.49	0.386
Solar PV + Li-ion + Diesel	7 295	1 431				3 500	8.94	0.359
Solar PV + Hydrogen + Diesel	9 036		0	0	0	3 500	9.49	0.386
Solar PV + Hydrogen + Diesel (forced)	9 036		1 000	1 000	2	3 500	14..5	0.423
CABUNGAAN DPP, Western Samar								
Diesel						47	0.024	0.555
Solar PV + Diesel	128					47	0.133	0.446
Solar PV + Li-ion + Diesel	119	44				47	0.156	0.406
Solar PV + Hydrogen + Diesel	128		0	0	0	47	0.133	0.446
Solar PV + Hydrogen + Diesel (forced)	128		100	100	0.2	47	0.633	0.687

These results also imply that aside from technological advancement, abundant funding is necessary to help green hydrogen compete with grey hydrogen in the near future, and even more aggressive investment is needed to force the present competitiveness of green hydrogen in the Philippines. Economic policies are also an effective instrument to break the barriers to green hydrogen production. Incentives such as subsidies and tax exemptions for renewable energy and hydrogen technologies can reduce the corresponding costs, thus lowering LCOH. Penalties for carbon emissions and fossil fuels will have the same effect on the competitiveness of hydrogen but by making fossil fuels more expensive. Such economic policies are vital to the transition towards a cleaner energy system.

4. Hydrogen energy plans of HDF Energy in the Philippines

This section will examine the hydrogen energy infrastructure plans of Hydrogène de France (HDF) Energy in the Philippines. HDF Energy specializes in hydrogen-based energy solutions and garners international attention for its innovative approach to decarbonizing various industries. They design and operate high-capacity, large-scale hydrogen-to-power systems that generate power from renewable energy sources, complemented by power multi-megawatt fuel cells (HDF Energy, n.d.).

Leveraging its expertise, HDF Energy has proposed to introduce hydrogen as a potent energy source in the Philippines by developing a hydrogen power plant in Mindanao through the HDF RenewStable® Energy project in partnership with the Mindanao Development Authority (MinDa) (Peñalosa, 2023). In addition to the ample renewable energy sources available in the region, the potential to address energy security challenges (e.g., costly, unreliable, and unsustainable electricity supply) in remote areas caused by the difficulty of transporting diesel fuel to the islands drives the prioritization of hydrogen energy projects in Mindanao. Subsequent sections will highlight the potential benefits, challenges, and policy considerations associated with implementing hydrogen power plant projects in the country.

4.1. Proposed infrastructures

HDF Energy's hydrogen energy plans in the Philippines are currently in the development stage, and observers see progress with the recent signing of two Memoranda of Understanding (MoUs) during the 10th Philippines–France Joint Economic Committee meeting held at the French Ministry of Foreign Affairs. The first MoU was signed with DOE and MinDa to encourage and facilitate investments in hydrogen projects within the Mindanao region. The second MoU was signed with the National Power Corporation (NPC) to promote collaborative studies, research and development, information exchange, and technical assistance to facilitate the deployment of Renewstable® projects (see *Figure 5*) in remote areas.

HDF Energy will establish large-scale hydrogen production facilities that utilize wind or solar energy and water to generate electricity, providing continuous power to off-grid areas. More specifically, the developers of the Olutanga Hydrogen Renewable Power Plant Project will build the project on a 50-hectare property in Talusan, Olutanga Island. The plant may generate an initial 10 MW hydrogen fuel cells, potentially expanding its capacity to 50 MW and complementing battery energy storage facilities (Chandak, 2023). There are reports on the planned implementation of similar RenewStable® energy projects in ten more sites in Mindanao, including Zamboanga del Norte, and in the islands of Tawi-Tawi, Sulu, and Basilan (Palicte, 2023).

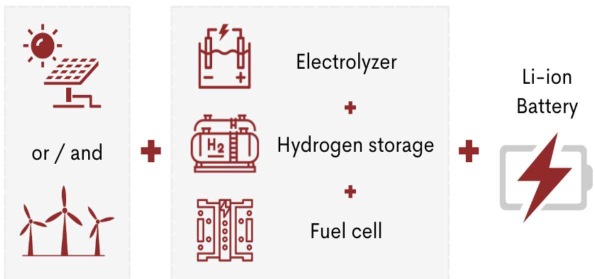

Figure 5: Schematic of the key components/facilities in a RenewStable® power plant. These energy projects harness wind or solar energy to generate electricity, accompanied by battery energy storage facilities (HDF Energy, n.d.).

According to the local officials of the island, some of their municipalities need to catch up in terms of development due to a shortage of vital infrastructure and a reliable power source (Manaytay, 2022). Diesel power generates electricity through its power supply agreements with Zamboanga del Sur Rural Electric Cooperative II (ZAMSURECO II). With the introduction of these renewable energy projects in the region, officials said that their residents can have a sufficient supply of reliable electricity. However, considering the economic feasibility of hydrogen production in the country, investments in such energy projects may not be financially sustainable compared to alternative hybrid power systems despite the relative cost decrease. Still, initiatives from interested companies are worth pursuing, especially for energy projects that are profitable in the long term, allowing them to recover their capital investment within a reasonable timeframe (Castro et al., 2022).

4.2. Changing Policy Landscape

Philippine Hydrogen policies are presently promulgated by the DOE. The Philippine Congress has not yet enacted a statutory framework for hydrogen research and development. The Philippine Senate considered Bills on Hydrogen Research, Promotion, and Development during the Fifteenth Congress (July 2010 to 2013) and Sixteenth Congress (July 2013 to 2016) (Senate, 2010 and 2013). However, there were no counterpart bills in the House of Representatives during the same Congressional periods. Similarly, subsequent Congressional cycles – including the present Nineteenth Congress (July 2022 to 2025) - have not seen any bill filings by members of either chambers concerning Hydrogen development as of December 2023.

On 25 November 2020, the DOE issued Special Order No. SO2020-11-0041 creating the Hydrogen and Fusion Energy Committee (HFEC). Through the Special Order, the DOE tasks the HFEC with the duty to conduct a study on the effect of hydrogen on the country's energy mix and the possibility of hydrogen as an option for power and transport fuel supply (DOE, 2020). However, three years after its inception, the DOE has yet to publicly release the HFEC study results, although the Philippine Energy Plan reports the broad strokes of the HFEC study's recommendations as of February 2021. Strangely, the HFEC includes studies on nuclear or atomic energy prospects – concepts arguably very different from H_2 development (DOE, 2021a).

Although Republic Act No (RA) 11697 or the "Electric Vehicle Industry Development Act" (EVIDA) does not explicitly mention H_2, the statute provides broad coverage for "electric vehicles" (EVs) such that its definition includes hybrid EVs. This statutory construction gives ample interpretative space for including hybrid H_2 EVs within the statute's scope. Similarly, the policy declarations of the law emphasize the promotion and innovation support in alternative energy technologies, further strengthening interpretations of H_2's role in the EV industry.

The DOE has recently paid attention to H_2 production and development prospects in the Philippines. On 20 November 2023, the DOE issued Department Circular (DC) No. 2023-11-0031, or the Guidelines on the Awarding of Service Contracts for the Exploration, Development, and Production of Native Hydrogen, which provides that Presidential Decree No. (PD) 87, or the Oil Exploration and Development Act of 1972, governs the exploration, development, and production of naturally occurring native H_2 (DOE, 2023a).

During the last quarter of 2023, the DOE also conducted public consultations on a Circular Providing a National Policy and General Framework, Roadmap, and Guidelines for Hydrogen in the Energy Sector. This paper's authors had the privilege and opportunity to meaningfully interact in refining the said DOE Circular. For example, this paper's authors recommended clauses to cover the decommissioning of H_2 projects to cover the project's life cycle. The DOE Department Circular (DC) DC2024-01-0001 was then published on 29 January 2024. While the DOE Circular makes bold strides in providing a national framework for DOE's regulatory role in H_2 development, crafting the specific industry codes and standards will still be work products of subsequent technical working groups that the DOE may form. Most importantly, the DC does not squarely address how H_2 can compete despite the high price point of the present LCOH values. While the DOE Circular directs readers' attention to possible incentives for H_2 development, it remains silent on more proactive regulatory steps such as, for example, separate auctions or competitive selection processes for H_2 in the electric power industry (DOE, 2023b).

4.3. Summary

Rural off-grid island communities often lack access to electricity; even when they do, the availability and quality are subpar. Olutanga Island is among the remote islands in the Philippines that are confronting challenges in securing stable electricity. Yet, previous studies have demonstrated that hybrid power systems (i.e., combining renewable energy and diesel generators) are seen to be the most viable solution for the electrification of rural communities (Lozano et al., 2019; Rehman et al., 2016). Such systems allow end-users to address seasonal energy source fluctuations while protecting them from unpredictable fuel supply and prices.

Diesel generators are the island's main power supply, but they are becoming less sustainable due to their costly maintenance and environmental drawbacks. A recent feasibility study by the German-Philippine Chamber of Commerce and Industry (GPCCI) showed that implementing green hydrogen and fuel cell technology could be a more advantageous approach for rural electrification through distributed power generation using renewable energy sources (NOW GmbH, 2021).

Moreover, the assessment of the current status and prospective developments of the Philippine Fuel Cell Research and Development (R&D) also highlighted the potential benefits of exploring both hydrogen energy infrastructure and existing geothermal power plants, given the country's status as the world's second-largest producer of geothermal energy (Abeleda & Espiritu, 2022).

However, these hybrid power systems will likely ~~to~~ entail higher investment costs than pure diesel generators. Nevertheless, conducting techno-economic studies in the region could help optimize these systems or provide insights into whether adopting hybrid power represents the most economical solution for rural electrification, particularly concerning long-term economic implications and carbon footprint reduction compared to diesel power plants (Lozano et al., 2019).

5. Challenges and policy considerations

Aside from the presented H_2 hard infrastructure plans, soft infrastructures such as policy, regulatory measures, and safety aspects associated with the introduction of hydrogen power must also be implemented to ensure their successful deployment and sustainable operation in the country. A clear regulatory framework in the Philippines is necessary for potential investors to commit to hydrogen-related initiatives. Some of the challenges and policy considerations associated with the implementation of hydrogen and electrochemical storage devices are listed below:

a) Policy and funding: The high upfront costs for the infrastructure and equipment installation may be a significant barrier, so government authorities must develop policies that incentivize the adoption of hydrogen-based energy solutions. Moreover, the government and relevant stakeholders must explore financial mechanisms (e.g., incentives, multilateral financing, grants from domestic and international donors, including through the CSR frameworks of firms, low-interest loans from development, etc.) and public-private partnerships to support these kinds of energy initiatives. Similarly, the government may consider strategically carving a space for H_2 auctions or competitive selection processes to address the wide gap in LCOH compared to conventional battery storage systems.

b) Regulatory framework: The government also needs to develop a comprehensive regulatory framework to encourage private sector involvement, ensure safety standards, and facilitate the integration of hydrogen technologies into existing energy systems. Regulations should cover safety standards for infrastructure and equipment, emission standards, and grid integration guidelines. In a recent advisory, the DOE released a Department Circular that aims to establish a national policy along with a comprehensive framework, roadmap, and guidelines for the effective utilization of hydrogen in the energy sector. This outlines the government's commitment to ensuring a continuous, adequate, and economic supply of energy through the exploration, production, management, and development of the country's indigenous energy sources.

c) Safety protocols: Hydrogen is highly flammable and requires stringent safety protocols throughout production, transportation, storage, and usage. Hydrogen energy power plants must adhere to international safety standards and implement measures to prevent accidents, leaks, and other potential hazards.

d) Public awareness and engagement: A crucial aspect of implementing hydrogen energy power plants is generating public awareness and acceptance regarding the benefits and safety of hydrogen-based technologies. Public outreach campaigns and education programs are vital to address misconceptions and build trust.

e) Research and development: In collaboration with research institutions and universities, continuous research and development efforts can contribute to refining safety protocols and addressing any emerging challenges. Moreover, the challenge in harnessing hydrogen energy lies in insufficient technical human resources and a limited source of green jobs, hindering the development of necessary expertise. The need for qualified personnel or skilled professionals to ensure the effective implementation of hydrogen energy initiatives limits the country's progress in this crucial sector. This includes conducting techno-economic studies aimed at optimizing energy systems and assessing the cost-effectiveness of hybrid power for rural electrification.

Nonetheless, the Philippine government is still dedicated to achieving energy self-sufficiency in response to the escalating energy needs. The DOE is actively advancing the adoption of renewable energy sources and modernizing the primary power grids. They established the HFEC to extensively study how hydrogen energy fits into the energy mix and what applications might be appropriate for the country. Strangely, however, the two energy forms the committee will handle, hydrogen and nuclear, are very much unrelated regarding processes and technologies.

The mentioned characteristics of hydrogen and the promising trajectory of decreasing prices make hydrogen energy solutions a potential for the Philippines to transition towards a sustainable and low-carbon economy. This initiative aligns with the Philippines' energy goals by leveraging renewable resources, creating job opportunities, and reducing greenhouse gas emissions. However, addressing financial, regulatory, and social challenges is also essential to realize the full potential of hydrogen energy and ensure its successful integration into the national energy system. The combined soft and hard infrastructure implementation would ensure the country's secure, efficient, and sustainable integration of hydrogen-based energy solutions.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

CONTRIBUTION OF INDIVIDUAL AUTHORS

D.M. writing - draft preparation and organization of text, review and editing, Philippine context inclusion; H.T. LCOH text, calculations of LCOH, tables and figures; J.B. case studies, tables and figures; M.C. calculations of LCOH, tables and figures; P.B. policy context, writing policy recommendations; J.P. review and editing; J.O. project administration and implementation, conceptualization, supervision, review and editing, funding acquisition.

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DEFINITION OF TERMS

Alkaline water electrolyzer (AWE)	An electrolyzer technology that consists of an anode and cathode immersed in an alkaline solution, separated by a diaphragm. It operates at lower temperatures, and typically uses precious metal catalysts, making it suitable for large-scale hydrogen production.
Blue hydrogen	A type of hydrogen produced from natural gas through steam methane reforming (SMR) but captures the carbon dioxide emissions before they are released into the atmosphere.
Carbon capture technologies	Systems attached to carbon-producing technologies to reduce carbon emissions by converting gaseous carbon products to less dispersive, hence less harmful to the environment, states.
Dynamic range	Used in this context to describe a process that can be controlled at a wide range of operating conditions.
Electrolysis	A process by which an electric current is passed through a substance to drive a non-spontaneous chemical reaction.
Energy vectors	Any substances, methods or systems capable of storing energy which can be later converted into other forms for utilization or transportation from one place to another.
Fuel cells	Electrochemical devices that directly transform the chemical energy of a fuel (often hydrogen) into electrical energy by the reverse process to that of electrolysis: hydrogen reacts with oxygen to produce water and electrical current.
Gasification (Coal)	The process of producing hydrogen from coal with the alternate reactions with air and steam to produce heat and to produce hydrogen using heat, respectively. Carbon emissions come in the form of carbon dioxide and carbon monoxide.
Global Horizontal Irradiance (GHI)	A measure of the total solar radiation received on a horizontal surface at a specific location.
Green ammonia	An eco-friendly ammonia that has been produced using sustainable methods that minimize carbon dioxide emissions and environmental impact, often using green hydrogen from renewable sources.
Green hydrogen	A type of hydrogen produced by splitting water (i.e., electrolysis) and the energy used to power electrolysis comes from renewable sources such as solar, wind, etc.
Grey hydrogen	A type of hydrogen produced by steam reforming fossil fuels such as coal or natural gas, and the waste carbon dioxide is emitted directly into the atmosphere.
Hydrogen economy	A concept where hydrogen serves as the primary commercial fuel to provide a significant portion of a nation’s energy and services.
Island Systems $LCOE_{min}$ Algorithm (ISLA)	An in-house (of University of the Philippines Diliman - Laboratory of Electrochemical Engineering) energy systems modeling tool used to optimize the hybrid system configuration and calculate the levelized cost of electricity (LCOE) and the system reliability.
Levelized cost of electricity	A techno-economic parameter used to represent the average net present cost per

(LCOE)	unit of energy output from a power plant over its entire lifetime.
Levelized cost of hydrogen (LCOH)	A metric that quantifies the cost to produce one kilogram of green hydrogen, while considering the estimated investment and the operational costs involved in its production.
Net present cost	A financial tool to evaluate the overall cost and financial performance of a project or investment, regardless of the type of energy product involved, over its entire lifetime, while taking into account the time value of money.
Polymer electrolyte membrane electrolyzer (PEMEC)	Similar to AWE, but uses a solid polymer electrolyte membrane with an acidic nature instead of an alkaline aqueous electrolyte. It operates at moderate temperatures with high efficiency, making it suitable for portable and distributed hydrogen production applications such as fuel cell vehicles.
Power-to-gas (P2G)	Involves the conversion of electrical power into gaseous energy carriers such as methane or hydrogen via methanation or water electrolysis.
Solid oxide electrolyzer (SOEC)	Another type of electrolyzer technology that uses a solid ceramic material as the electrolyte which facilitates the selective transfer of negatively charged oxygen ions to the anode. It operates at high temperatures and is highly efficient, making them ideal for applications with high-temperature heat sources and industrial processes demanding efficient hydrogen production.
Steam Methane Reforming (SMR)	The process of producing hydrogen from natural gas (mainly methane) by contact with steam with the help of metal-based catalysts. The byproducts are carbon dioxide and carbon monoxide.
Techno-economic analysis	A method of assessing the economic benefits and risks of an industrial process or product. Values set for the costs, efficiencies, and tax rates are referred to as ‘techno-economic assumptions.’
Water electrolyzers	Technologies that use electricity to split water molecules into oxygen and hydrogen.