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Managing Energy Transition Through Green Hydrogen Technology: A Techno-Economic and Operational Analysis from PT. XYZ

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Abstract

PT XYZ increases its contribution to reducing carbon dioxide (CO_2) emissions through the installation and operation of a Green Hydrogen Plant (GHP) supported by Solar Photovoltaic (PV) and Renewable Energy Certificates (REC). The primary focus of this study is on the integration of renewable technologies, economic impacts, and contributions to carbon emission reductions, all of which support the clean energy transition and the achievement of Net Zero Emission goals. The research methods include Levelized Cost of Energy (LCOE) and Levelized Cost of Hydrogen (LCOH) analysis, along with an evaluation of carbon emission reductions based on the GHG Protocol. The results show that the implementation of this strategy leads to a 1.53% improvement in internal energy consumption efficiency and a decrease in average internal energy consumption to 2.68% in 2024, compared to the baseline of 3.5%. From an environmental perspective, carbon emission reductions reach 2,282.28 tons CO_2e per year. Economically, the LCOE and LCOH analyses demonstrate the cost feasibility and operational efficiency of integrating this green technology. The conclusion of this study confirms that the integration of renewable energy through Solar PV and REC with Green Hydrogen Plant (GHP) has a positive impact on energy efficiency, carbon emission reduction, and the transition towards the company's Net Zero Emission target by 2030.

Keywords: Green Hydrogen Plant, Net Zero Emission, Renewable Energy Certificate, Solar Photovoltaic, Techno-Economics.

INTRODUCTION

The transformation of the global energy system is becoming increasingly urgent due to the serious challenges caused by climate change triggered by increasing greenhouse gas (GHG) emissions, especially carbon dioxide (CO_2) (Yoro & Daramola, 2020). The energy sector, as the main contributor to GHG emissions, is the main focus in efforts to mitigate global warming. The increasing concentration of GHG has triggered various significant environmental, social, and economic impacts, so that an energy transition strategy is needed towards a cleaner and more sustainable system (Jaiswal et al., 2022).

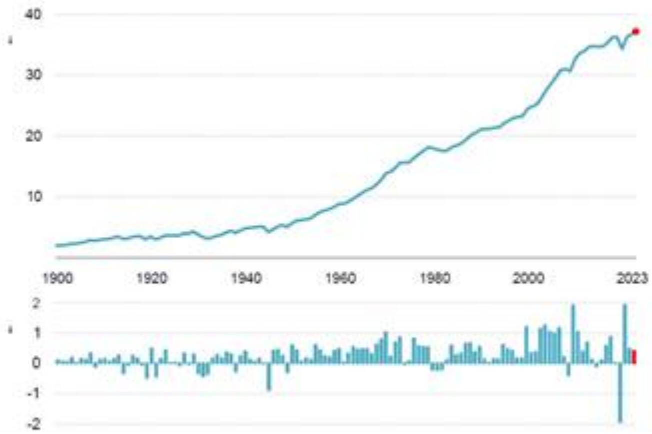

Figure 1. Graph of global energy-related CO2 emissions (1900-2023)
Source: International Energy Agency Publications, 2024

According to data from the International Energy Agency (IEA), carbon dioxide emissions from the energy sector peaked at 37.4 gigatons in 2023, underscoring the urgency to reduce dependence on fossil fuels and accelerate the adoption of renewable energy technologies. One promising solution is Green Hydrogen, which is produced using renewable energy sources like Solar Photovoltaic (PV) and supported by Renewable Energy Certificates (RECs). This technology offers substantial potential for reducing carbon emissions while increasing energy efficiency, thus becoming a pivotal component of the transition to a sustainable energy system. Research by Ostadi et al. (2020) reveals that the integration of renewable energy in the electrolysis process significantly reduces carbon emissions, making it a primary solution in climate change mitigation efforts. Furthermore, Huang et al. (2023) emphasize that combining green hydrogen technology with renewable energy sources can enhance overall energy efficiency, contributing to a reduction in both energy consumption and the carbon emissions associated with the energy system.

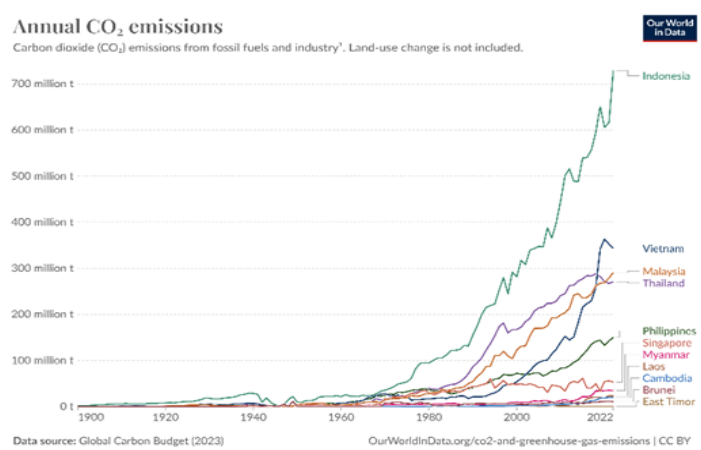

Figure 2. Graph of carbon dioxide (CO2) emissions in Southeast Asia 1900 – 2022
Source: Global Carbon Budget, 2023

In Southeast Asia, countries such as Indonesia face high emissions due to their reliance on fossil fuels, a situation further exacerbated by rapid industrialization and urbanization (Kurniawan & Managi, 2018). Within this context, PT. XYZ, a major energy provider in Indonesia, has committed to integrating renewable energy into its operations through the implementation of a Green Hydrogen Plant (GHP), supported by Solar PV and REC. This initiative aligns with global efforts to achieve Net Zero Emission targets and represents a critical step toward promoting energy sustainability in the region.

The novelty of this research lies in its focus on the integration of Solar PV and REC technologies with Green Hydrogen Plant (GHP), particularly within the Southeast Asian energy landscape (Njoh, 2021). By evaluating the technical, economic, and environmental impacts of this integration, the study aims to address a critical gap in the literature regarding the feasibility of green hydrogen in the region. The research emphasizes a comprehensive techno-economic analysis through Levelized Cost of Energy (LCOE), Levelized Cost of Hydrogen (LCOH), and potential emission reductions, providing a unique contribution to understanding how these technologies can be operationalized in the context of energy transition goals.

The primary purpose of this study is to assess the integration of Solar PV and REC technologies with GHP to evaluate its technical feasibility and operational efficiency (Martinez et al., 2021). This research aims to provide valuable insights into the economic and environmental impacts of implementing green hydrogen technology, focusing on how it can contribute to the reduction of carbon emissions and enhance energy efficiency. The study offers practical recommendations for implementing green hydrogen-based technologies within the energy industry, especially in Southeast Asia, supporting the transition to a more sustainable energy system and aiding in the achievement of Net Zero Emission targets.

RESEARCH METHODS

This study uses a case study approach to evaluate the implementation of Green Hydrogen Plant (GHP) supported by Solar Photovoltaic (PV) and Renewable Energy Certificates (REC) at PT. XYZ. This study focuses on the analysis of techno-economic aspects, environmental impacts, and technology integration to support energy efficiency and carbon emission reduction (Al Lagtah et al., 2019). PT. XYZ was chosen as the object of research because of its role as one of the leading energy providers in Indonesia that is committed to the transition towards a sustainable energy system. This study utilizes primary and secondary data to support the analysis. The types of data used include:

1) Energy Consumption Data: Average internal energy consumption of PT. XYZ from 2023 to 2024, with an efficiency baseline of 3.5%.

Table 1. Internal Electrical Energy Consumption (2014–2024)

Tahun	Total Electr. Energy Production	Internal Electr. Energy Consumption	
	MWh	MWh	%
2014	8,050,753.98	307,249.26	3.82
2015	8,236,484.86	273,692.90	3.32
2016	7,504,750.95	288,705.64	3.85
2017	7,034,449.89	254,859.33	3.62
2018	7,606,257.09	267,469.26	3.52
2019	7,583,407.11	271,406.38	3.58
2020	5,550,218.94	189,999.44	3.42
2021	7,454,621.86	194,996.69	2.62
2022	6,956,433.93	141,815.28	2.04
2023	7,286,999.22	209,635.14	2.88
2024	-	-	-

Source: (Internal PT.XYZ, 2024)

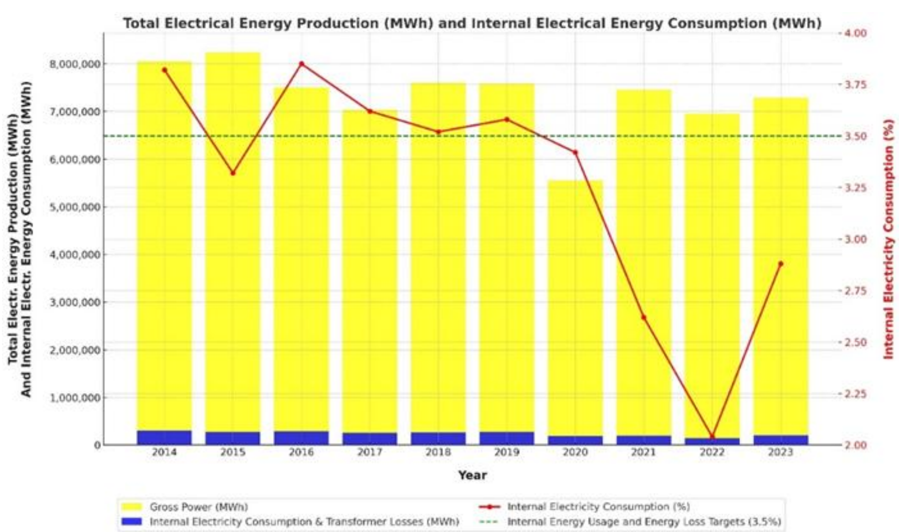

Figure 3. Graph of Internal Electrical Energy Consumption (2014–2024)

Source: (Internal PT.XYZ, 2024)

2) Carbon Emission Data: Annual carbon emission reduction data based on GHP and Solar PV utilization, measured before and after GHP implementation in tonsCO_2e..
3) Techno-Economic Data
   LCOE and LCOH analysis to assess cost feasibility.
   a) Levelized Cost of Energy (LCOE): Measures the average cost of energy production from Solar PV.
   b) Levelized Cost of Hydrogen (LCOH): Calculates the cost of green hydrogen production from GHP.

4) Renewable Energy Source Data: Technical specifications of Solar PV and RECs that support GHP operations.

This study also considers the validity and reliability of the data by comparing the results of the analysis with previous literature and using a standard calculation approach in assessing LCOE and LCOH (Khouya, 2020). The main limitation of this study is that it relies on internal data from PT. XYZ, so its application may differ outside the context of this company. However, this study provides a framework that can be replicated by other energy companies or organizations with specific adjustments.

Evaluation Method

Energy Efficiency Evaluation of Technology Integration

The percentage of internal electricity consumption to total gross production is calculated using the formula:

$$\text{Internal Consumption Percentage}(\%) = \left(\frac{\text{Internal Consumption (MWh)}}{\text{Gross Power (MWh)}}\right) \times 100$$

Then, the amount of GHP contribution is calculated based on the portion of electrical energy used by GHP against the total internal electrical energy usage of the company. The formula used is:

$$\text{GHP Contribution}(\%) = \left(\frac{\text{Energy Used by GHP}}{\text{Total Internal Energy Consumption}}\right) \times 100$$

Economic Impact Analysis

This study employs Levelized Cost of Energy (LCOE) and Levelized Cost of Hydrogen (LCOH) to assess the cost efficiency of the integration of renewable energy technologies in the Green Hydrogen Plant (GHP) (Choe et al., 2024).

a) LCOE Evaluation

These metrics are widely recognized in evaluating the costs of energy production from renewable sources. According to Sinaga et al. (2019), LCOE is a critical metric for determining the average cost of producing electricity over the lifetime of a project. In this study, LCOE is used to evaluate the total cost of energy production from Solar Photovoltaic (PV) and Renewable Energy Certificates (REC) during the project period. This cost is calculated using the following formula:

LCOE of Solar PV

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \text{Discounted Annual Costs}}{\sum_{t=1}^{n} \text{Discounted Annual Energy}}$$

LCOE of Renewable Energy Certificate (REC)

$$\text{LCOE (USD/MWh)} = \frac{\text{Total Electricity Consumption Costs (USD)}}{\text{Total Annual Energy (MWh)}}$$

b) LCOH Evaluation

Similar to LCOE, LCOH is used to assess the cost efficiency of producing green hydrogen from renewable energy sources. According to Yang et al. (2018), LCOH is a key metric to determine the average cost of producing hydrogen over the lifetime of the production system. In this study, LCOH is calculated by considering the capital expenditure (CAPEX), operational expenditure (OPEX), and the energy consumption for hydrogen production from Solar PV and REC. This calculation helps determine the economic viability of using green hydrogen in large-scale energy production while considering factors such as energy consumption, investment, and maintenance costs (María Villarreal Vives et al., 2023). The formula for LCOH is as follows: LCOH calculation uses the formula used in the following calculations:

$$\mathrm{LCOH} = \frac{\mathrm{CAPEX} - \frac{V_R}{(1+r)^T} + \sum_{n=1}^{T} \frac{A_n+E_n+C_R}{(1+r)^n}}{\sum_{n=1}^{T} \frac{Y_n}{(1+r)^n}}$$

where :

a. CAPEX is the initial investment,
b. VR is the residual value of fixed assets,
c. An is the operating costs in year n,
d. En is the energy consumption costs in year n,
e. CR is the electrolyzer replacement cost,
f. Yn is the hydrogen production volume in year n,
g. T is the project life cycle,
h. r is the discount rate, generally used as the reference rate of return.

Environmental Impact Analysis

To assess the environmental impact of integrating renewable energy into the Green Hydrogen Plant (GHP), this study uses the Greenhouse Gas (GHG) Protocol, specifically Scope 2 emissions, to measure carbon emission reductions. The GHG Protocol Scope 2 Guidance, developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), provides a framework for measuring emissions from electricity consumption. This helps evaluate the role of renewable energy in reducing carbon emissions and combating climate change.

The environmental impact is calculated by measuring the reduction in carbon dioxide (CO_2) emissions due to the shift from fossil fuels to renewable energy sources (Razmjoo et al., 2021). This is key to understanding the GHP's contribution to mitigating climate change and moving towards a sustainable energy system. The carbon reduction is based on the energy used by the GHP and the proportion of renewable energy it consumes.

Emissions from Electrical Energy Consumption (Scope 2 Emissions)

To quantify the carbon emissions reduction from electricity consumption, the following formula can be applied:

$$\mathbf{E_{S2} = C \times EF}$$

where :

a. ES2 is Scope 2 emissions (tons CO2e).
b. C is the electricity consumption replaced by Solar PV (MWh).
c. EF is the electricity grid emission factor (CO2e per MWh).

Emissions from Use of Renewable Energy Certificates (RECs)

Additionally, for market-based emissions using Renewable Energy Certificates (RECs), the following formula is used to calculate market-based Scope 2 emissions:

$$E_{MB,S2} = C_{MBI} \times (EF_{MBI} - EF_{res})$$

where:

a. EMB,S2 is the market-based Scope 2 emissions.
b. CMBI is the energy consumption supplied by energy with market-based instruments (e.g. RECs).
c. EFMBI is the emission factor of energy with market-based instruments (usually zero for RECs).
d. EFres is the residual grid emission factor (without energy claimed by RECs).

Emission Factors

The following table presents the emission factors used in this study for calculating the carbon emissions reductions associated with the integration of renewable energy technologies into the Green Hydrogen Plant (GHP) (Kwon & Koo, 2024). These emission factors are based on the regulations and guidelines provided by the Indonesian Ministry of Energy and Mineral Resources (ESDM) and the Directorate General of Electricity (Dirjen Ketenagalistrikan), which outline the official emission factors for various energy sources used in the electricity system.

Table 2. Emission Factors of the Electricity System in 2019

(Grid Name) Province	Total Power Plants	OM	BM	Emission Factor (ton CO_2/MWh)			
				CM Ex-Post		CM Ex-Ante	
		ton CO_2/MWh		OM=0.5 BM=0.5	OM=075 BM=0.25	OM=0.5 BM=0.5	OM=075 BM=0.25
(Jamali) Banten, DKI Jakarta, West Java, Central Java, Yogyakarta, East Java	302	0.80	0.94	0.87	0.84	0.87	0.83

Source: https://gatrik.esdm.go.id

Notes:

a. Column 3 is OM, which is the Operating Margin.
b. Column 4 is BM, which is the Build Margin.
c. Columns 5 and 7 are Emission Factor values for mitigating greenhouse gas emissions (GHG) for all activities, excluding wind and solar power plants (PLTB and PLTS).
d. Columns 6 and 8 are Emission Factor values for mitigating GHG emissions specifically for wind and solar power plant activities (PLTB and PLTS).

These emission factors are critical for determining the environmental impact of the Green Hydrogen Plant (GHP) in terms of carbon dioxide (CO_2) emissions. The factors reflect the energy mix of the grid, where fossil fuel-based sources like coal and natural gas have higher emission factors compared to renewable sources such as solar and wind, which are virtually emissions-free. In this study, the following emission factors are used to calculate the reduction in Scope 2 emissions from the consumption of renewable energy:

1) Grid Emission Factor (EF): This represents the emission factor of the grid electricity that is replaced by renewable energy sources such as Solar PV. The EF for the grid is typically provided by national or regional authorities based on the energy mix used for electricity generation in a specific area.
2) Renewable Energy Certificates (REC) Emission Factor (EFMBI): The emission factor for electricity supplied through market-based instruments such as RECs is typically zero since renewable energy sources do not produce direct emissions. The value of this factor is set to zero for clean energy supplied through RECs, which is a key advantage in using such mechanisms to reduce carbon footprints.
3) Residual Grid Emission Factor (EFres): This is the emission factor for electricity that remains in the grid after subtracting the amount of electricity generated from renewable sources. It accounts for the emissions associated with fossil fuel-based energy that is still being consumed in the grid. The EFres is used in the market-based emissions calculation when RECs are used.

The use of these emission factors allows for the accurate calculation of Scope 2 emissions reductions when renewable energy sources replace conventional grid electricity. By utilizing renewable energy through technologies like Solar PV and RECs, significant reductions in carbon emissions can be achieved, contributing to sustainability goals and climate change mitigation.

RESULT AND DISCUSSION

Energy Efficiency Evaluation of Technology Integration

As outlined in the Research Method section, this study evaluates the efficiency of integrating Green Hydrogen Plant (GHP) with Solar Photovoltaic (PV) and Renewable Energy Certificates (REC) (Magni et al., 2024). The primary focus of this evaluation is to assess the contribution of GHP to improving internal energy consumption efficiency at PT. XYZ by replacing some of the energy traditionally supplied from the grid with renewable energy sources.

Table 3. Total production with internal energy consumption

Month	Year 2023			Year 2024		
	Gross Power (MWh)	Internal Consumption		*Gross Power* (MWh)	Internal Consumption	
		MWh	%		MWh	%
Januari	584,394.00	17,740.00	3.04	668,168.00	20,381.00	3.05
Februari	484,977.00	16,097.00	3.32	446,465.86	12,465.74	2.79

Month	**Year 2023**			**Year 2024**		
	***Gross Power* (MWh)**	**Internal Consumption**		***Gross Power* (MWh)**	**Internal Consumption**	
		MWh	**%**		**MWh**	**%**
Maret	602,261.00	11,461.00	1.90	698,825.00	15,588.00	2.23
April	493,482.00	16,253.00	3.29	579,865.00	14,860.00	2.56
Mei	609,825.00	16,875.00	2.77	500,000.00	10,000.00	2.00
Juni	624,058.00	19,000.00	3.04	567,600.00	17,873.00	3.15
Juli	613,316.00	21,474.00	3.50	704,792.00	18,053.00	2.56
Agustus	277,428.00	6,674.00	2.41	713,487.00	18,849.00	2.64
September	663,365.00	17,825.00	2.69	738,440.00	18,244.00	2.47
Oktober	686,648.00	19,848.00	2.89	771,682.00	22,447.00	2.91
November	635,146.00	17,957.00	2.83	648,505.00	19,663.00	3.03
Desember	606,447.00	17,625.00	2.91	666,666.00	-	-
Total	**6,881,347.00**	**198,829.00**	**2.89**	**7,037,829.86**	**188,423.74**	**2.68**

Source: (Researcher Processed Results, 2024)

The data presented in Table 2 shows the comparison between the gross power production and internal energy consumption for the years 2023 and 2024. The results highlight a reduction in internal energy consumption from 2.89% in 2023 to 2.68% in 2024, indicating an improvement in energy efficiency following the integration of renewable energy sources through GHP.
Next, Based on the data above:

a. Energy used by GHP = 2,880 MWh
b. Total Internal Energy Consumption in 2024 = 188,423.74 MWh

$$\text{GHP Contribution}(\%) = \left(\frac{2,880}{188,423.74}\right) \times 100\% = 1.53\%$$

Table 4. Results of internal energy efficiency calculations

Evaluation Parameter	**Evaluation Result**
Internal Energy Consumption	2.89% (2023) decreased to 2.68% (2024)
Solar PV & REC Contribution	1.53% towards internal energy efficiency
Company Baseline	3.5% (2024)

Source: (Researcher Processed Results, 2024)

As shown in Table 3, GHP's contribution to internal energy efficiency is quantified as 1.53%, which represents the share of energy supplied by Solar PV and REC compared to the total internal energy consumption. This highlights that renewable energy has successfully replaced a portion of the electricity previously drawn from the grid.

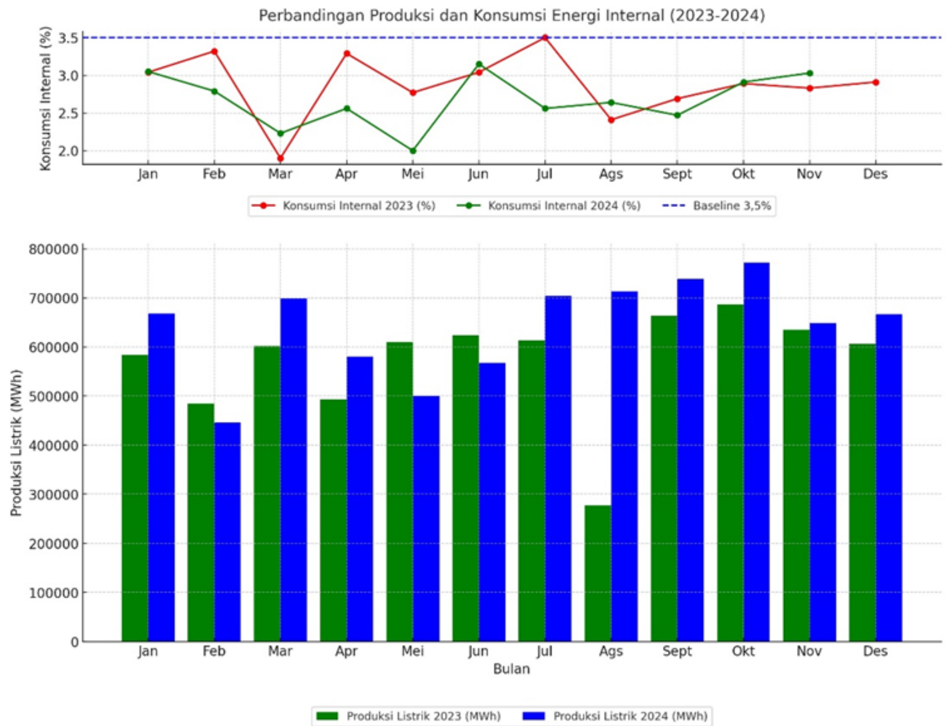

Figure 4. Graph of Energy Efficiency Evaluation from Technology Integration (2023-2024)
Source: (Researcher Processed Results, 2024)

These findings demonstrate that GHP, supported by Solar PV and REC, has contributed to a reduction in energy consumption from conventional sources, improving the company's energy efficiency and supporting its transition toward more sustainable energy practices.

Economic Impact Analysis

As outlined in the Research Method section, Levelized Cost of Energy (LCOE) and Levelized Cost of Hydrogen (LCOH) are used to evaluate the cost efficiency of integrating Solar Photovoltaic (PV) and Renewable Energy Certificates (REC) into the Green Hydrogen Plant (GHP). LCOE measures the average cost of energy production from renewable sources, while LCOH calculates the cost of green hydrogen production, factoring in investment, operational, and energy consumption costs (Al-Mahmodi et al., 2025). These metrics are crucial for assessing the economic viability of the GHP and comparing it to traditional fossil-based energy production.

The results of the evaluation are presented in the following tables, which provide detailed information on energy production, internal energy consumption, and the contributions of renewable energy sources (Solar PV and REC) to the overall energy efficiency.

LCOE Evaluation

Table 5. Solar PV Investment Costs

Component	Value	Description
Initial Investment (CAPEX)	390.276 USD	Total cost of the Solar PV project, including EPC
Operational & Maintenance Costs (OPEX)	1.951,38 USD/year	Annual budget for operational and maintenance costs
Annual Energy Production (E)	640 MWh	Total energy produced by the PV system each year
Discount Rate (r)	5% per year	Discount rate for calculating the present value of costs and energy
Project Lifetime (n)	25 years	The project lifetime reflecting the economic life of the Solar PV system

Source: (Researcher Processed Results, 2024)

Table 6. Results of Solar PV LCOE Calculation

Total Solar PV Cost (USD)	Total Energy (MWh)	LCOE *Solar PV*		
		USD/MWh	USD/kWh	IDR/kWh
390.276	**640**	**44,26**	**0,0443**	**686**

Source: (Researcher Processed Results, 2024)

Table 7. REC Purchase Costs

Component	Value	Description
REC Cost	Rp. 35.000 / MWh	Price before tax
Total Annual Energy	2.077 MWh	Total renewable energy delivered annually
REC Price	Rp. 80.701.450	Price after tax
Electricity Price	Rp. 2.880	Price of electricity per MWh
Total Electricity Energy Price	Rp.5.981.760	Annual Energy x Price
Total REC Price	**86.683.210**	in IDR
	5.592,44	in USD (1 USD = 15.500 IDR)

Source: (Researcher Processed Results, 2024)

Table 8. REC Investment Costs

Total REC Cost (USD)	Total Energy (MWh)	*LCOE REC*		
		USD/MWh	USD/kWh	IDR/kWh
5.592,44	**2.077**	**2,69**	**0,00269**	**41,695**

Source: (Researcher Processed Results, 2024)

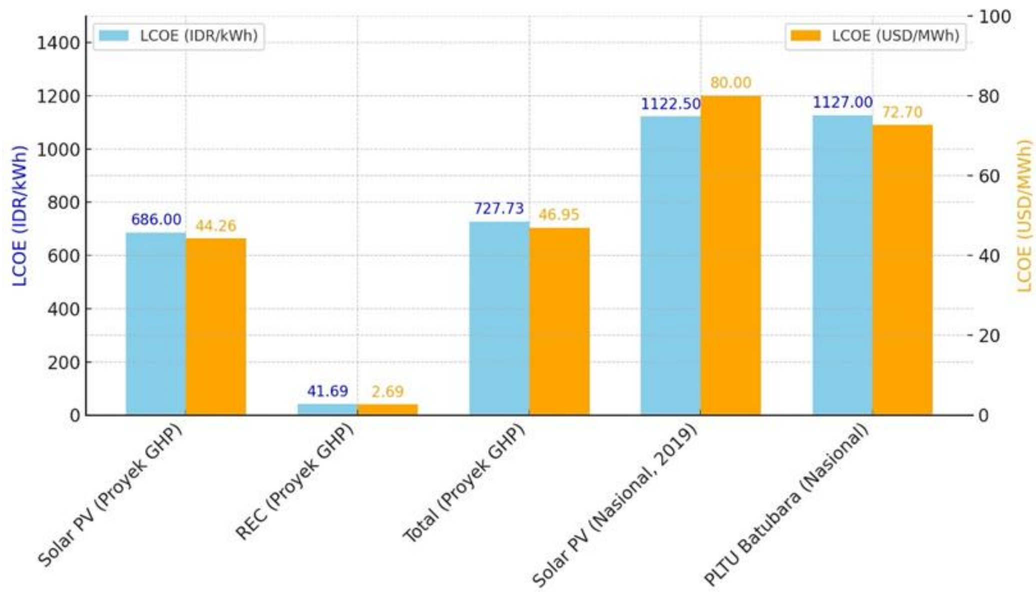

Figure 5. Comparison of Levelized Cost of Energy (LCOE) for PT. XYZ Green Hydrogen Plant with national benchmarks

Source: (Researcher Processed Results, 2024)

Based on the evaluation above, the Total LCOE of the GHP project is 46.95 USD/MWh (727.73 IDR/kWh). This figure is lower than the average cost of fossil-based electricity generation in Indonesia, which is between 905-1349 IDR/kWh (58.4-87 USD/MWh). The following table provides a comparison of the LCOE costs between this project and national and global standards:

Table 9. Results of Total LCOE Evaluation of PT.XYZ GHP Project

Category	*LCOE* (IDR/kWh)	*LCOE* (USD/MWh)
Solar PV	686	44,26
REC	41,69	2,69
Total (REC Project)	**727,73**	**46,95**
Solar PV (National, 2019)	845-1400	60-100

Category	***LCOE* (IDR/kWh)**	***LCOE* (USD/MWh)**
Coal Power Plant (National)	905-1349	58,4-87

Source: (Researcher Processed Results, 2024)

From the calculation results, the Total LCOE shows the average cost required to produce 1 unit of energy (kWh or MWh) by combining the cost of energy production by Solar PV and procurement of Renewable Energy Certificates (REC). The Total LCOE is 46.95 USD/MWh (or 727.73 IDR/kWh) this represents the overall cost that includes elements of sustainability and compliance with renewable energy standards.

LCOH Evaluation

Table 10. Main Data of Green Hydrogen Plant Project

Component	**Value**	**Discription**
Investment Cost or Asset Value (CAPEX)	2.012.085,79 USD	Total investment cost or asset value, minus depreciation
Operational & Maintenance Costs (OPEX)	17.388,805 USD	Total operational and maintenance costs for the year
LCOE Cost/MWh	46,95 USD/MWh	Price of renewable electricity energy per 1 MWh
Total Annual Energy Consumption	2.803 MWh/year	Total renewable electricity energy consumption required for GHP
Annual Hydrogen Production (H)	51 Tons/year	Total hydrogen gas production per year

Source: (Researcher Processed Results, 2024)

With additional assumptions used in the calculation:

a. Discount Rate (r) = 5% per year
b. Project Life (n) = 25 years

Table 11. Comparison of LCOH GHP PT.XYZ

Category	***LCOH* (USD/kg H2)**	**Description**
GHP Project PT.XYZ	5,72	Latest LCOH evaluation result, based on Solar PV and REC.
Indonesia (2020)	6,0–10,0 (average: 8,00)	Hydrogen production cost based on Solar PV in Indonesia
ASEAN Projection (2030)	4,0–6,2 (average: 5,10)	Projected green hydrogen cost in the ASEAN region

Global Target (2050)	2,0–3,4 (average: 2,70)	Global hydrogen cost efficiency target

Source: (Researcher Processed Results, 2024)

Figure 6. Comparison of Levelized Cost of Hydrogen (LCOH) for PT. XYZ Green Hydrogen Plant with national and global benchmarks

Source: (Researcher Processed Results, 2024)

These results show that the average cost to produce one kilogram of hydrogen in the Green Hydrogen Plant is 5.72 USD/Kg or 88,669.92 IDR/Kg. This LCOH value provides an overview of the cost efficiency in hydrogen production using renewable energy sources from Solar PV and REC and is competitive when compared to fossil fuel-based hydrogen technology.

Environmental Impact

The environmental impact analysis focuses on the carbon dioxide (CO_2) emission reductions resulting from the integration of renewable energy sources, such as Solar Photovoltaic (PV) and Renewable Energy Certificates (REC), into the Green Hydrogen Plant (GHP). The tables below present the results of the evaluation.

Table 12 Green Hydrogen Plant Evaluation Results

Evaluation Aspect	Unit	Data/Information
Energy from Solar PV	MWh/year	640
Energy from REC	MWh/year	2.077
Total Renewable Energy Usage	**MWh/year**	**2.717**
Emission Reduction from Solar PV	ton CO_2e	537,6
Emission Reduction from Solar REC	ton CO_2e	1.744,68

Total Emission Reduction	**ton CO_2e/year**	**2.282,28**

Source: (Researcher Processed Results, 2024)

Table 12 shows the total renewable energy usage and the associated emission reductions. The GHP utilizes 2,717 MWh of renewable energy annually, with 537.6 tons CO_2e reduced from Solar PV and 1,744.68 tons CO_2e reduced from REC, resulting in a total reduction of 2,282.28 tons CO_2e per year.

Table 13. Results of Emission Reduction Calculations

Emission Source	Energy Consumption (MWh)	Emission Factor (ton CO_2e per MWh)	Baseline Emissions (ton CO_2e)	Actual Emissions (ton CO_2e)	Emission Reduction (ton CO_2e)
Solar PV	640	0.84	537,6	0	537,6
REC	2077	0.84	1.744,68	0	1.744,68
Total	**2717**	**-**	**2.282,28**	**0**	**2.282,28**

Source: (Researcher Processed Results, 2024)

Table 13 provides further details on the emission reduction calculations, showing that both Solar PV and REC have zero actual carbon emissions. The energy consumption from these sources has led to significant reductions in baseline CO_2 emissions, as outlined in the table.

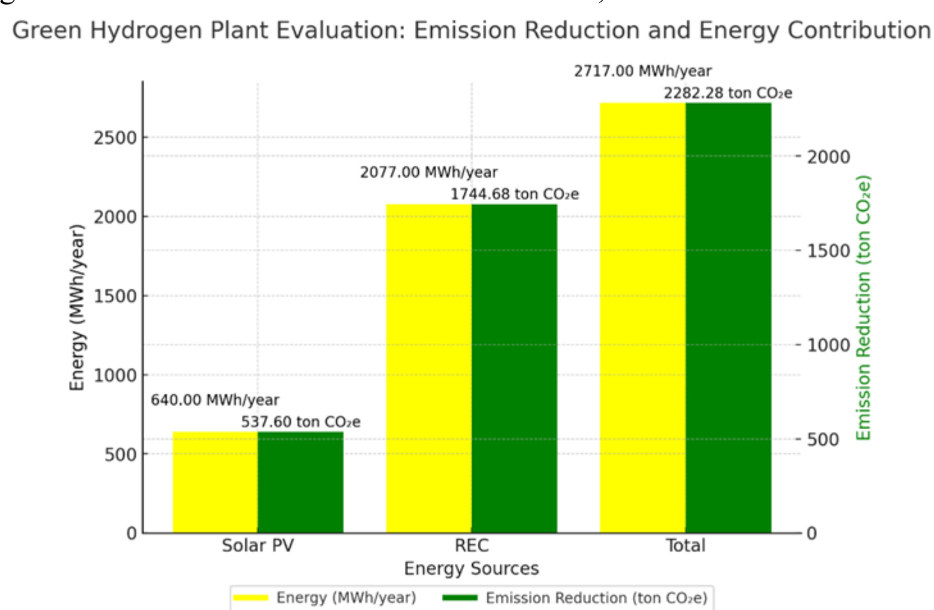

Figure 7. Graph of Carbon Emission Reductions from Solar PV and REC Integration in GHP

Source: (Researcher Processed Results, 2024)

From the evaluation results presented, it can be seen that all energy consumption from Solar PV and Renewable Energy Certificates (REC) produces zero actual carbon emissions. Solar PV contributes to a reduction in emissions of 537.6 tonsCO_2e, while REC contributes more, namely 1744.68 tonsCO_2e. Overall, the total emission reduction achieved reached 2282.28 tonsCO_2e.

Comparison with Previous Research:

The results of this study align with those of Huang et al. (2023), who highlighted that the integration of renewable energy technologies with hydrogen production can significantly improve energy efficiency by approximately 2-3%. Our findings support this assertion, showing a measurable increase in energy efficiency as a result of integrating Solar Photovoltaic (PV) and Renewable Energy Certificates (REC) into the Green Hydrogen Plant (GHP) system. Additionally, this study corroborates the findings of Urs et al. (2023), who emphasized the substantial potential of green hydrogen in reducing carbon emissions, particularly in the industrial sector. By incorporating these renewable energy sources into hydrogen production, the present study similarly demonstrates significant carbon emission reductions, further supporting the role of green hydrogen as a key technology in climate change mitigation.

CONCLUSION

This study evaluates the techno-economic and operational aspects of the integration of green technologies, namely Solar Photovoltaic (PV), Renewable Energy Certificates (REC), and Green Hydrogen Plant (GHP) at PT. XYZ. The results of the study indicate that the integration of Solar PV and REC has successfully increased the efficiency of internal energy consumption by 1.53%, with a decrease in energy consumption from 2.89% in 2023 to 2.68% in 2024, compared to the baseline of 3.5%. In terms of economy, the Levelized Cost of Energy (LCOE) generated from Solar PV and REC is recorded at 46.95 USD/MWh (727.73 IDR/kWh), while the Levelized Cost of Hydrogen (LCOH) for green hydrogen production at GHP is 5.72 USD/Kg (88,669.92 IDR/Kg), which shows better cost efficiency compared to fossil fuel-based technologies. On the environmental side, the implementation of this technology has succeeded in reducing carbon emissions by 2,282.28 tons of CO_2e per year, supporting the achievement of the Net Zero Emission target in 2030 while contributing to global climate change mitigation.

This study recommends the use of Solar PV and REC technology as renewable energy that is feasible to be applied to replace fossil fuels, not only in GHP equipment but also in other equipment that requires large amounts of energy in the industrial sector. This step can accelerate the transition to more environmentally friendly energy without sacrificing operational reliability. In addition, further research is needed to improve the efficiency of electrolysis technology in the production of green hydrogen, as well as to study the potential application of green hydrogen in other sectors such as transportation, manufacturing, and petrochemicals to support a clean and sustainable energy transition globally.

BIBLIOGRAPHY

Al Lagtah, N. M. A., Onaizi, S. A., Albadarin, A. B., Ghaith, F. A., & Nour, M. I. (2019). Techno-economic analysis of the effects of heat integration and different carbon capture technologies on the performance of coal-based IGCC power plants. *Journal of Environmental Chemical Engineering*, *7*(6), 103471. https://doi.org/10.1016/j.jece.2019.103471

Al-Mahmodi, M., Ayadi, O., Wang, Y., & Al-Halhouli, A. (2025). Sensitivity-based techno-economic assessment approach for electrolyzer integration with hybrid photovoltaic-wind plants for green hydrogen production. *International Journal of Hydrogen Energy*, *97*, 904–919. https://doi.org/10.1016/j.ijhydene.2024.12.002

Choe, C., Gu, J., Haider, J., Qyyum, M. A., Al-Muhtaseb, A. H., Abri, R. Al, & Lim, H. (2024). A feasibility study of green hydrogen liquefaction for hydrogen refueling station: Multi-criteria based integrative assessment. *Journal of Cleaner Production*, *449*, 141699. https://doi.org/10.1016/j.jclepro.2024.141699

Huang, X., Qu, Y., Zhu, Z., & Wu, Q. (2023). Techno-Economic Analysis of Photovoltaic Hydrogen Production Considering Technological Progress Uncertainty. *Sustainability*, *15*(4), 3580. https://doi.org/10.3390/su15043580

Jaiswal, K. K., Chowdhury, C. R., Yadav, D., Verma, R., Dutta, S., Jaiswal, K. S., SangmeshB, & Karuppasamy, K. S. K. (2022). Renewable and sustainable clean energy development and impact on social, economic, and environmental health. *Energy Nexus*, *7*, 100118. https://doi.org/10.1016/j.nexus.2022.100118

Khouya, A. (2020). Levelized costs of energy and hydrogen of wind farms and concentrated photovoltaic thermal systems. A case study in Morocco. *International Journal of Hydrogen Energy*, *45*(56), 31632–31650. https://doi.org/10.1016/j.ijhydene.2020.08.240

Kurniawan, R., & Managi, S. (2018). Coal consumption, urbanization, and trade openness linkage in Indonesia. *Energy Policy*, *121*, 576–583. https://doi.org/10.1016/j.enpol.2018.07.023

Kwon, H., & Koo, B. (2024). Integrated hydrogen production strategy based on multi-objective optimization considering carbon dioxide emission reduction goals. *Applied Thermal Engineering*, *236*, 121717. https://doi.org/10.1016/j.applthermaleng.2023.121717

Magni, G. U., Battistelli, F., Trovalusci, F., Groppi, D., & Astiaso Garcia, D. (2024). How national policies influence energy community development across Europe? A review on societal, technical, and economical factors. *Energy Conversion and Management: X*, *23*, 100624. https://doi.org/10.1016/j.ecmx.2024.100624

María Villarreal Vives, A., Wang, R., Roy, S., & Smallbone, A. (2023). Techno-economic analysis of large-scale green hydrogen production and storage. *Applied Energy*, *346*, 121333. https://doi.org/10.1016/j.apenergy.2023.121333

Martinez, S., Michaux, G., Bouvier, J.-L., & Salagnac, P. (2021). Numerical investigation of the energy performance of a solar micro-CHP unit. *Energy Conversion and Management*, *243*, 114425. https://doi.org/10.1016/j.enconman.2021.114425

Njoh, A. J. (2021). A systematic review of environmental determinants of renewable energy performance in Ethiopia: A PESTECH analysis. *Renewable and Sustainable Energy Reviews*, *147*, 111243. https://doi.org/10.1016/j.rser.2021.111243

Ostadi, M., Paso, K. G., Rodriguez-Fabia, S., Øi, L. E., Manenti, F., & Hillestad, M. (2020). Process Integration of Green Hydrogen: Decarbonization of Chemical Industries. *Energies*, *13*(18), 4859. https://doi.org/10.3390/en13184859

Razmjoo, A., Gakenia Kaigutha, L., Vaziri Rad, M. A., Marzband, M., Davarpanah, A., & Denai, M. (2021). A Technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce <math altimg="si1.svg"> <mrow> <msub> <mtext>CO</mtext> <mn>2</mn> </msub> </mrow> </math> emissions in a high potential area. *Renewable Energy*, *164*, 46–57. https://doi.org/10.1016/j.renene.2020.09.042

Sinaga, R., Tuati, N. F., Beily, M. D. E., & Sampeallo, A. S. (2019). Modeling and analysis of the solar photovoltaic levelized cost of electricity (LCoE) - case study in Kupang. *Journal of Physics: Conference Series*, *1364*(1), 012066. https://doi.org/10.1088/1742-6596/1364/1/012066

Urs, R. R., Sadiq, M., Mayyas, A., & Al Sumaiti, A. (2023). Technoeconomic Assessment of Various Configurations Photovoltaic Systems for Energy and Hydrogen Production. *International Journal of Energy Research*, *2023*, 1–13. https://doi.org/10.1155/2023/1612600

Yang, M., Wang, S. S., Li, D. Y., Su, X., Sun, Y., & Jia, Y. P. (2018). Cost-benefit analysis of centralized photovoltaic power generation considering environmental benefit under the life cycle. *Journal of Northeast Electric Power University*, *38*(6), 21–28.

Yoro, K. O., & Daramola, M. O. (2020). CO2 emission sources, greenhouse gases, and the global warming effect. In *Advances in Carbon Capture* (pp. 3–28). Elsevier. https://doi.org/10.1016/B978-0-12-819657-1.00001-3