

Techno-Economic Analysis of Hydrogen Production at the Songawayaua Geothermal Power Plant

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Abstract. This study evaluates the techno-economic feasibility of integrating green hydrogen production with geothermal energy at the Songawayaua Geothermal Power Plant (GPP) in North Maluku, Indonesia. Although Indonesia holds a geothermal potential of 23.9 GW, utilization remains limited—especially in remote, low-demand regions—leaving substantial untapped resources. This research proposes a 30 MW geothermal development scenario, allocating 10 MW for grid electricity and 20 MW for hydrogen production using Proton Exchange Membrane (PEM) electrolysis, representing a novel configuration in the national context.

The techno-economic analysis reveals that electricity sales alone result in a negative Net Present Value (NPV) of USD –110 million under current tariff regulations. Conversely, hydrogen production achieves an output of 2,800 tons/year with a Levelized Cost of Hydrogen (LCOH) of USD 1.47/kg. The integrated system becomes economically feasible at a hydrogen selling price of USD 8.53/kg (NPV = 0) and commercially viable at USD 13/kg (IRR = 12%).

This study contributes new insights by quantifying critical economic thresholds and price sensitivities in geothermal-hydrogen integration. Unlike previous studies that examine each system separately, this work presents an integrated pathway that enhances renewable energy utilization and supports Indonesia's Net Zero Emissions (NZE) 2060 target.

Keywords: *Hydrogen, Electrolysis, Techno-economic, Songawayaua, Geothermal*

1 Introduction

Global climate change, driven by greenhouse gas emissions from the energy, industrial, and transportation sectors, has become one of the most pressing challenges facing the world today. In Indonesia, the transportation sector alone contributed approximately 161.6 million tons of CO₂ in 2022 [12], making it one of the largest sources of emissions. To achieve the country's Net Zero Emissions (NZE) target by 2060, a transition to clean and sustainable energy sources is

essential—one of which is the utilization of green hydrogen as both an energy carrier and a long-term energy storage solution [6].

Green hydrogen, produced through water electrolysis using renewable energy, has become a central component of global energy strategies. In the Indonesian context, harnessing the country's geothermal energy potential to support hydrogen production offers a strategic pathway. Indonesia possesses approximately ± 23.9 GW of geothermal potential, yet only around 10% has been developed [7]. In particular, Eastern Indonesia—regions such as Maluku and Papua—holds abundant geothermal resources, but suffers from low local electricity demand. Under these circumstances, converting geothermal energy into hydrogen presents an optimal solution for enhancing resource utilization [18].

Integrating hydrogen production with geothermal power plant (GPP) offers both technical and environmental advantages. Unlike intermittent sources such as solar and wind, GPP provide a stable baseload power supply, making them well-suited for continuous operation of electrolyzer systems, especially Proton Exchange Membrane (PEM) types [10]. This integration can result in more cost-competitive hydrogen production with a significantly lower carbon footprint.

Globally, similar projects have been implemented, such as the Hellisheidi GPP in Iceland, which diverts part of its geothermal output for hydrogen production [4]. Other initiatives in countries like Japan and New Zealand have explored hybrid geothermal–hydrogen systems [2]. In Indonesia, preliminary studies by Ricardo et al. (2022) have identified the potential for such integration on Pantar Island; However, to date, there have been few concrete studies evaluating the technical and economic feasibility of such implementation, particularly in remote island regions.

The Songawayaua GPP, located on Bacan Island, North Maluku, is planned for 2x5 MW electricity system development under the (Electricity Supply Business Plan (RUPTL) 2021–2030 by PT PLN (Persero) [15]. However, according to Monte Carlo Simulation [16], the estimated reserve capacity reaches 30 MW, allowing an excess of 20 MW to be allocated for hydrogen production.

The study is expected to contribute meaningfully to Indonesia's green energy development strategy while enriching global literature on renewable energy–hydrogen integration.

2 Methodology

2.1 Research Design

This study is a quantitative analysis combining technical and economic assessments through a feasibility study simulation of a Green Hydrogen Plant (GHP) using PEM electrolysis integrated with a Single Flash Condensing Turbine Geothermal Power Plant (GPP). A Monte Carlo simulation was applied to estimate reservoir capacity at the Songawayaua site, incorporating geological and thermal variability. Using 1,000 iterations and normal distribution assumptions, the simulation produced a probabilistic capacity estimate that supports the proposed 30 MW development scenario.

2.2 Data and Data Sources

The data used in this study are secondary data, including:

- Technical data of the Songawayaua Geothermal Power Plant based on the Pre-Feasibility Study report by PT NewQuest Geotechnology (2020) and related research studies.
- Technical specifications of the electrolyzer based on the ITM Power Neptune V product.
- Comparative data from reports published by IEA (2021), IRENA (2019), the Ministry of Energy and Mineral Resources (MEMR) of Indonesia, among others.
- Assumptions regarding energy prices, investment costs, O&M costs, and hydrogen selling prices obtained from official literature sources.

2.3 Technical Parameter Data

a. Songawayaua Geothermal Working Area

Table 2.1 Profile of Songawayaua Geothermal Working Area [16]

Category	Information
Upflow Zone	Located beneath Mount Lansa, with fluid flow directed northward towards the Pele-Pele surface manifestations.
GWA Area Size	Approximately ±42,540 hectares.
Reservoir Temperature	Estimated between 220–240°C (based on mixing models and 3D MT resistivity inversion).
Surface Manifestations	Identified at 29 locations, consisting of: <ul style="list-style-type: none"> – Steam vents – Hot springs

Category	Information
	<ul style="list-style-type: none"> – Cold springs – Seawater intrusions
Types of Geoscientific Surveys	<ul style="list-style-type: none"> – Geology: rock mapping, structural geology, hydrothermal alteration mapping. – Geochemistry: analysis of hot water, gases (CO₂, H₂S, CH₄), isotopes (δ¹⁸O, δD); dominant Na-Cl type. – Geophysics: Gravity, Magnetotellurics (MT), Transient Electromagnetic (TDEM), Microearthquake (MEQ), LIDAR surveys.
Conceptual Model	Upflow system originating from Mount Lansa towards Pele-Pele, indicating a narrow and elongated reservoir zone.
Exploration Well Plan	<ul style="list-style-type: none"> – SW-A1: targeting the Mt. Pele prospect area. – SW-B1: targeting the Mt. Lansa prospect area.
Well Design	Standard hole type design.
Power Plant Design	Single Flash Condensing Turbine technology.
Potential Capacity	Up to 30 MW, with estimated output per well 5.4 MW

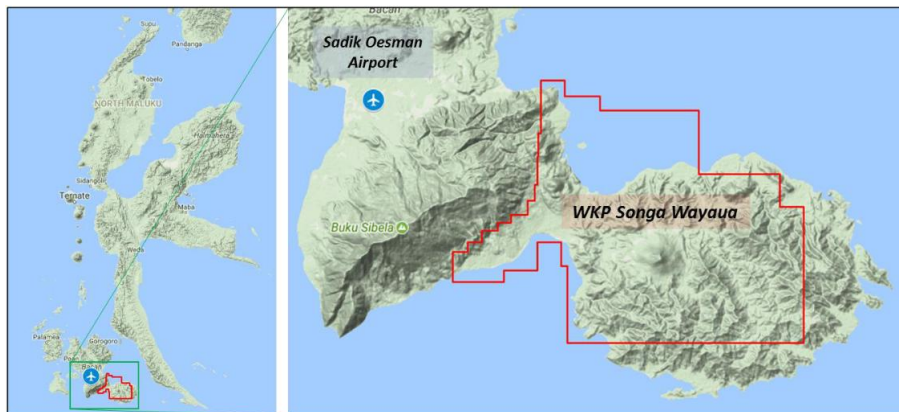


Figure 2.1 The Songawayaua Geothermal Working Area is located on Bacan Island, South Halmahera scale 1:315.000

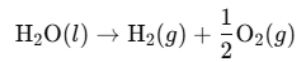
b. Proton Exchange Membrane (PEM) Electrolysis

This process involves the splitting of water into hydrogen and oxygen using an electrical energy source derived from new and renewable energy (NRE) technologies. Common electrolysis technologies include alkaline water electrolysis, Proton Exchange Membrane (PEM) electrolysis, and solid oxide electrolysis.

In this study, hydrogen production is carried out using PEM-based water electrolysis. The PEM technology utilizes a polymer membrane that allows only

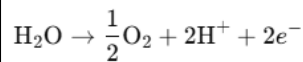
proton ions (H^+) to pass through, while effectively separating the produced hydrogen and oxygen gases.

The overall water electrolysis reaction can be represented as follows:

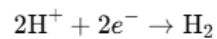


This process occurs through two electrochemical reactions at the electrodes:

- Anode (water oxidation):



- Cathode (proton reduction):



From a thermodynamic perspective, the minimum energy required to produce 1 kg of hydrogen corresponds to its Lower Heating Value (LHV) of 33.3 kWh/kg or its Higher Heating Value (HHV) of 39.4 kWh/kg [6]. The efficiency of an electrolyzer is defined as the ratio between the energy stored in the produced hydrogen and the electrical energy consumed, and is generally expressed by the following formula [5]:

$$\eta = \frac{LHV_{H_2}}{E_{input}} \quad (1)$$

Meanwhile, the hydrogen production rate from the electrolyzer can be calculated using the following relationship [5]:

$$\dot{m}_{H_2} = \frac{\eta \cdot P_{el}}{LHV_{H_2}} \quad (2)$$

where \dot{m}_{H_2} is the hydrogen production rate (kg/hour), η is the system efficiency, P_{el} is the electrical input power (MW), and LHV_{H_2} is the lower heating value of hydrogen expressed in MWh/kg.

In addition, water consumption is a critical parameter in electrolyzer systems, where approximately 9 liters of demineralized water are required to produce 1 kg of hydrogen [8].

c. Proton Exchange Membrane (PEM) Electrolyzer

Table 2.2 Technical Parameter of Electrolyzer

No	Item	Value	Source
1	Total Capacity	20 MW	
2	Capacity Factor	90%	
3	Type of Electrolyzer	<i>Proton Exchange Membrane (PEM)</i>	
4	Product	ITM Power, Neptune V	https://itm-power.com/products/neptune-5
5	Unit Capacity	5 MW	https://itm-power.com/products/neptune-5
6	Total Units Required	4 Units	
7	Specific Energy Consumption	55.9 kWh/kg H ₂	https://itm-power.com/products/neptune-5
8	Higher Heating Value (HHV) H ₂	39.4 kWh/kg H ₂	<i>US Department of Energy (DOE)</i> , Hydrogen and Fuel Cell Technologies Office, "Hydrogen Properties," 2020.
9	Lower Heating Value (LHV) H ₂	33.3 kWh/kg H ₂	<i>Hydrogen Energy Center</i> , "Hydrogen Energy Basics," 2021.
10	Efficiency	59-70%	https://itm-power.com/products/neptune-5
11	COD Year	2030	
12	Lifetime	25 year	
13	Operating Range	12.5-100%	https://itm-power.com/products/neptune-5
14	Output Pressure	30 bar(g)	https://itm-power.com/products/neptune-5

Table 2.2 presents the technical parameters of a 20 MW Green Hydrogen Plant (GHP) using Proton Exchange Membrane (PEM) electrolyzers, based on ITM Power Neptune V specifications. The system operates with 4 units of 5 MW each, a 90% capacity factor, and a 25-year lifetime. It consumes 55.9 kWh/kg H₂, with efficiency ranging from 59–70% [9]. The Lower Heating Value (LHV) of 33.3 kWh/kg is used to calculate energy conversion efficiency, which is critical for determining the Levelized Cost of Hydrogen (LCOH) in the economic analysis.

d. Schematic Diagram of Electrolysis Process

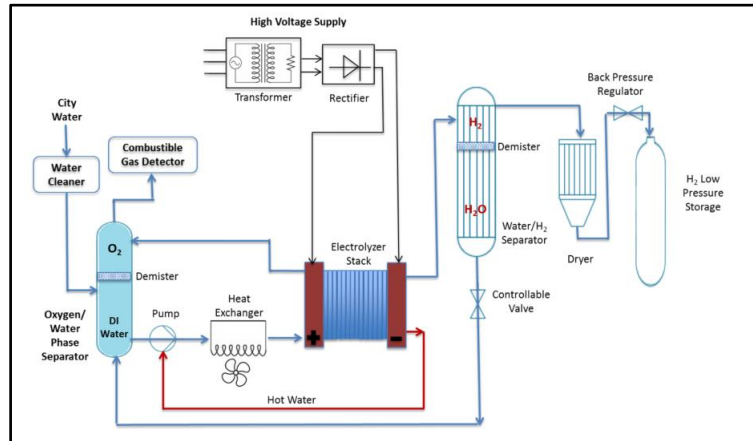


Figure 2.2 Schematic Diagram of Electrolysis Process [11]

Figure 2.2 illustrates the working principle of a Proton Exchange Membrane (PEM) electrolyzer system for hydrogen production.

City water is first purified through a water cleaner and then deionized (DI). The DI water is pumped through a heat exchanger and directed to the electrolyzer stack, where high voltage supplied via a transformer and rectifier splits the water into hydrogen and oxygen.

Oxygen is separated and vented, while hydrogen passes through a series of demisters and a water/hydrogen separator to remove moisture. The dry hydrogen then flows through a controllable valve, a dryer unit, and a back pressure regulator before being stored in a low-pressure hydrogen storage tank. Safety components like a combustible gas detector ensure safe operation.

2.4 Economic Parameter Data

a. Net Present Value (NPV)

Net Present Value (NPV) is a metric that calculates the present value of cash flows generated by a project, subtracted by the initial investment cost. NPV is used to determine whether an investment is profitable. The equation is expressed as follows [19]:

$$\text{NPV} = \sum_{t=1}^n \frac{CF_t}{(1+r)^t} - C_0 \quad (3)$$

Description:

CF_t : Cash flow at period t

r : Discount rate

C_0 : Initial investment

n : Time period

Interpretation:

A positive NPV indicates financial viability, as it reflects a net gain over the investment period.

b. Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the annual rate of return generated by an investment. IRR is the discount rate at which the Net Present Value (NPV) equals zero. The equation is expressed as follows [1]:

$$0 = \sum_{t=1}^n \frac{CF_t}{(1 + IRR)^t} - C_0 \tag{4}$$

Interpretation:

If the $IRR >$ the required discount rate, the project is considered feasible.

If the $IRR <$ the discount rate, the project is considered not feasible.

c. Payback Period

The Payback Period (PP) is the amount of time required to recover the initial investment from the cash flows generated by the project. The equation is expressed as follows [14]:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual Cash Flow}} \tag{5}$$

Interpretation:

A shorter payback period indicates a more rapid recovery of the initial investment, which is generally preferred as it reduces exposure to long-term financial risk.

d. Levelized Cost of Hydrogen (LCOH)

The Levelized Cost of Hydrogen (LCOH) is used to calculate the average production cost of hydrogen per kilogram over the lifetime of the project. It serves as an important metric for determining the economic efficiency of a hydrogen project :

$$\text{LCOH} = \frac{\sum(\text{Annual Costs})}{\text{Annual Hydrogen Production}} \tag{6}$$

Interpretation:

A lower LCOH indicates higher economic competitiveness of hydrogen relative to alternative fuels.

e. **Electricity Selling Price Based on Perpres No.112/2022**

Table 2.3 Electricity Selling Price Perpres No.112/2022 [3]

No	Capacity	Maximum Benchmark Price (cent USD/kWh)	
		Year 1 to 10	Year 11 to 30
1	Up to 10 MW	$(9.76 \times F)^*$	8.30
2	>10 MW to ≤ 50 MW	$(9.41 \times F)^*$	8.00
3	>50 MW to ≤ 100 MW	$(8.64 \times F)^*$	7.35
4	>100 MW	$(7.65 \times F)^*$	6.50

**The maximum benchmark price is the result after multiplying the base value by factor F.*

No	Region	All Capacities (factor F)
1	Java, Madura, Bali	1.00
	- Small Islands	1.10
2	Sumatra	1.10
	- Riau Archipelago	1.20
	- Mentawai	1.20
	- Bangka Belitung	1.10
	- Small Islands	1.15
3	Kalimantan	1.10
	- Small Islands	1.15
4	Sulawesi	1.10
	- Small Islands	1.15
5	Nusa Tenggara	1.20
	- Small Islands	1.25
6	North Maluku	1.25
	- Small Islands	1.3
7	Maluku	1.25
8	West Papua	1.50
9	Papua	1.50

2.5 Assumptions and Limitations of the Study

This study is subject to the following assumptions and limitations:

- The Commercial Operation Date (COD) of the GPP and GHP projects is projected for the year 2030.

- It is assumed that a sufficient supply of pure water is available to meet the requirements of the electrolysis process.
- The electricity selling price follows the regulations stipulated in Perpres No. 112/2022.
- The data used are based on the Pre-Feasibility Study report of the Songawayaua GPP and related research studies, as well as the technical specifications of the ITM Power Neptune V electrolyzer.
- The results of this study are specific to the case analyzed and may not be generalized to other projects.

3 Results

3.1 Technical Analysis of the 1×30 MW Geothermal Power Plant (Scheme: 10 MW for Grid Electricity)

The following outlines the key technical parameters used to generate 10 MW of electrical power, which will be supplied from the total installed capacity of 30 MW:

Table 3.1 Technical Analysis Data for the 1×30 MW GPP Scenario (10 MW Grid Scheme)

No	Item	Value
1	Capacity	30 MW
2	Type of Power Plant	Single Flash Condensing Turbine
3	Estimated COD Year	2030
4	Lifetime	30 year
5	Capacity Factor	90%
6	Well Drilling	
	-Exploration	2 wells
	-Production	7 wells
	-Injection	1 wells
7	Steam Consumption/MW	7.6 ton/year
8	Dryness	26%
9	Total energy production: 30 MW	236,520 MW/year
10	Energy delivered to the grid: 10 MW	78,840 MW/year

Table 3.1 shows the result of a 30 MW geothermal power plant using a Single Flash Condensing Turbine. The plant is expected to begin operation in 2030, with a lifetime of 30 years and a capacity factor of 90%. Drilling includes 2 exploration wells, 7 production wells, and 1 injection well. Steam consumption is 7.6 tons/hour per MW, and the steam dryness is 26%. The total annual energy production is 236,520 MWh, with 78,840 MWh delivered to the grid from a 10 MW allocation.

3.2 Economic Analysis of the 1×30 MW Geothermal Power Plant (Scheme: 10 MW for Grid Electricity)

Table 3.2 Capital Expenditure (CAPEX) Scenario for 1x30 MW GPP

DESCRIPTION	UNIT	Price	Total	TOTAL CAPEX
Exploration Cost				
Biaya Studi Geologi dan Geophysics	1	1.000.000	1.000.000	1.000.000
Biaya Konstruksi (jalan, well pad) pengadaan tanah dan perijinan	1	6.766.029	6.766.029	6.766.029
Biaya Drilling Sumur Eksplorasi	2	6.500.000	13.000.000	13.000.000
Pengujian Sumur	2	300.000,00	600.000	600.000
Total Exploration Cost				21.366.029
Development				
Biaya Studi Kelayakan dan studi G&G	1	2.000.000	2.000.000	2.000.000
Biaya Konstruksi (jalan, well pad), pengadaan lahan dan perijinan	1	7.713.770	3.856.885	3.856.885
Biaya Drilling Sumur Development	7	6.500.000	45.500.000	45.500.000
Biaya Drilling Sumur Injeksi	1	6.500.000	6.500.000	6.500.000
Biaya Manajemen Proyek	5%	63.900.000	3.195.000	3.195.000
Gathering & Separation System	30	380.000	11.400.000	11.400.000
EPC Power Plant (MW)	30	1.750.000	52.500.000	52.500.000
Biaya Overhead Pengembang	1	3.300.000	1.650.000	1.650.000
Pengujian Sumur	8	300.000,00	2.400.000	2.400.000
Total Development Cost				129.001.885
TOTAL COST				150.367.914
TOTAL COST PER MW				5.012.264

Table 3.2 shows that the total project cost amounts to USD 150.3 million, with a unit cost of **USD 5 million per MW**. The largest cost components are EPC of the power plant and well drilling. Drilling costs refer to the 2023 KESDM [13]drilling efficiency guideline, estimated at USD 3,250 per meter.

According to *Cost of Production from Geothermal Power Projects in Indonesia* by Jim Randle (2019) [17], O&M costs for geothermal plants are 1.875 USD cents/kWh, adjusted annually for inflation (2.22% based on US PPI, 2016–2025). With a 30 MW capacity and a 90% capacity factor, annual energy production is estimated at 236,520,000 kWh, resulting in total annual O&M costs of approximately **USD 4.43 million**.

Table 3.3 Economic Indicators of the 1x30 MW GPP Scenario (10 MW Scheme for Grid Sales)

No	Item	Value
1	WACC	7.48%
2	Perpres No.112/2022 Price	122.33 USD/MWh
3	Financial Price	
	-NPV=0	317.35 USD/MWh
	-IRR=12%	419.42 USD/MWh
4	Payback Period	
	-PP (NPV=0)	19.25 year
	-PP (IRR=12%)	10.72 year

Table 3.3 presents the electricity selling price set by Perpres No. 112/2022 is **USD 122.33/MWh**, while the break-even price to achieve **NPV = 0** is **USD 317.35/MWh**. To reach an **IRR of 12%**, a price of **USD 419.42/MWh** is required. This indicates that the financial price far exceeds the regulated price, making the project financially unfeasible under current policy.

If electricity is sold at or below **USD 122.33/MWh** (Perpres 112/2022 price), the project yields an NPV of **-110 million USD**, confirming its economic unviability. This outcome stems from the fact that total investment covers the full 30 MW development, while revenues are based on only 10 MW allocated to the grid. The remaining 20 MW is designated for hydrogen production, making the overall feasibility highly dependent on the hydrogen selling price in the next analysis.

3.3 Technical Analysis of the 20 MW Green Hydrogen Plant

Table 3.4 Technical Analysis Data for the 20 MW GHP

No	Item	Value	Source
1	Total Capacity	20 MW	
2	Capacity Factor	90%	
3	Demineralized Water Req.	9 L/kg H ₂	IRENA. 2020
4	Electricity Consumption	157,680 MW/year	Calculated
5	H ₂ Production	2,820,751 kg/year H ₂	Calculated

Table 3.4 presents the GHP operating parameters, including capacity factor, efficiency, and specific power consumption. These parameters form the basis for calculating hydrogen output and determining overall energy efficiency of the system.

3.4 Economic Analysis of the 20 MW Green Hydrogen Plant

Table 3.5 Capital Expenditure (CAPEX) Scenario for 20 MW GHP

No	Item	Value	Source
1	Total Capacity	20 MW	
2	Capacity Factor (CF)	90%	
3	Operating Duration	7884 hours/year	
4	PEM electrolyzer (inc BoP & EPC)	1,100,000 /MW	IRENA (2020)
5	Compressor	42,450 /MW	UK Mentari-Ricardo (2023)
Total CAPEX		\$ 22,849,000.00 /20 MW	

Table 3.5 presents that a 20 MW GHP project using a PEM electrolyzer has a total CAPEX of **USD 22.85 million**. According to IEA (2022), annual O&M costs for electrolyzer systems are 5% of CAPEX, amounting to **USD 1.14 million per year**. The resulting Levelized Cost of Hydrogen (LCOH) is **USD 1.47 per kg of H₂**.

3.5 Integrated Economic Analysis: 1x30 MW Geothermal Power Plant and 20 MW Green Hydrogen Plant

Table 3.6 Economic Indicators of the Integrated 1x30 MW GPP and 20 MW GHP

No	Item	GPP 30 MW (Scheme: 10 MW to Grid)		H ₂ Plant 20 MW	Unit
		Value			
1	Total Investment	173,216,914			USD
	-GPP (30 MW)	150,367,914			USD
	-H ₂ Plant (20 MW)			22,849,000	USD
2	Electricity Selling Price Perpres 2022	122.33			USD/MWh
3	Hydrogen Selling Price			8.53	USD/kg H ₂
4	NPV	-110,339,861		110,339,862	USD
	Total NPV	1			USD
5	IRR	7.48%			
6	Payback Period	9.89			Year

Table 3.6 presents the total investment for the integrated 30 MW GPP and 20 MW GHP is **USD 173.2 million**. With only 10 MW of electricity sold to the grid, the geothermal project alone yields an NPV of **-USD 110 million**, indicating it is not financially viable on its own. To ensure overall project feasibility, hydrogen must be sold at a minimum of **USD 8.53/kg**, generating an NPV of **+USD 110 million**. This balances the total NPV to positive, making the integrated project financially viable.

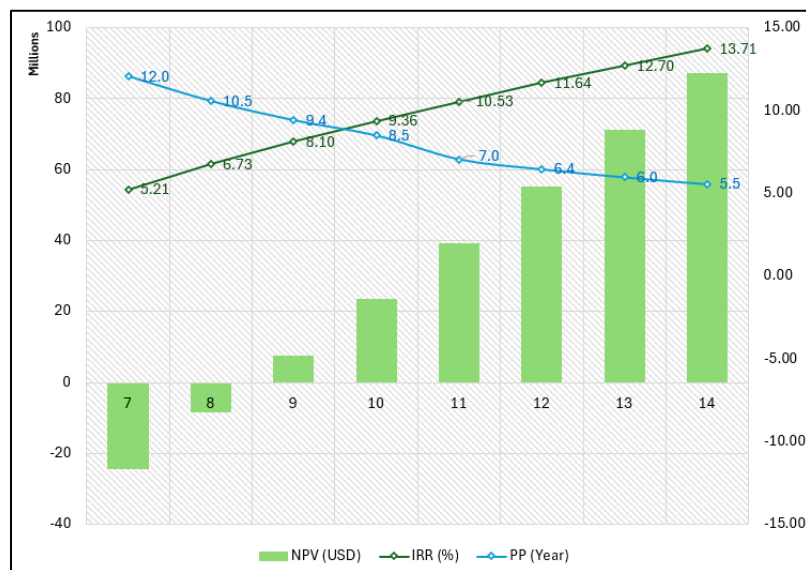


Figure 3.1 The Impact of Hydrogen Selling Price (USD/kg) on the NPV, IRR, and Payback Period of the Integrated GPP & GHP Project

Figure 3.1 illustrates how variations in hydrogen selling price affect NPV, IRR, and payback period. The results show that a selling price of **USD 8.53/kg H₂** is required to achieve an NPV of **positive**, with an **IRR of 7.48%** and a **9.89-year payback period**—which corresponds to the project's Weighted Average Cost of Capital (WACC). To reach a more attractive **NPV of USD 71.2 million**, **IRR of 12%** with an **6-year payback period**, the hydrogen price must increase to **USD 13.00/kg**. These findings demonstrate that hydrogen pricing significantly influences project viability.

4 Conclusion and Recommendation

This study confirms the technical and economic feasibility of integrating green hydrogen production—via Proton Exchange Membrane (PEM) electrolysis—with the Songawayaua geothermal power plant. Electricity sales from the 10 MW allocation are financially unviable under current tariffs (NPV = –USD 110 million). However, with an additional 20 MW for hydrogen production, the project becomes viable at a hydrogen price of USD 8.53/kg (payback period: 9.89 years), and commercially attractive at USD 13/kg (IRR = 12%, payback: 6 years). These findings highlight the potential of geothermal-hydrogen integration as a strategic solution for remote, low-demand regions, aligning with Indonesia's Net Zero Emissions (NZE) 2060 target.

Further research is recommended to assess the techno-economic aspects of hydrogen storage, transport, and distribution infrastructure, as well as the development of domestic and export market mechanisms. Additionally, scenario-based analyses involving future policy incentives and hydrogen pricing models would provide deeper insight into implementation feasibility under real-world conditions. Further research on hydrogen logistics and market development is essential to enhance implementation prospects.

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