LEVERAGING POST-MINING ASSETS FOR RENEWABLE ENERGY: A RETSCREEN TECHNO-ECONOMIC AND CARBON CREDIT ANALYSIS OF PT BUKIT ASAM'S SOLAR PV PROJECT

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Abstract

The increasing global demand for clean energy and decarbonization is driving coal-dependent companies to transform their business strategies. PT Bukit Asam Tbk (PTBA), a major coal-mining enterprise in Indonesia, is pursuing renewable energy projects that support the country's energy transition agenda. This research examines the economic feasibility of establishing a large-scale photovoltaic (PV) power plant on PTBA's reclaimed mining land in Muara Enim, South Sumatra. Using a quantitative approach, the study applies RETScreen Expert to model technical performance, assess financial outcomes, and estimate reductions in greenhouse gas (GHG) emissions. Project feasibility is measured through Net Present Value (NPV), Internal Rate of Return (IRR), Levelized Cost of Electricity (LCOE), Payback Period (PBP), cost–benefit analysis, and potential carbon credits from GHG mitigation. Data on climate conditions, financial parameters, and technical inputs were collected from literature, secondary datasets, and regulatory sources. Results show that the project is financially sound across different scenarios: in the baseline case, it achieves an NPV of USD 604,946, a pre-tax equity IRR of 14%, a payback period of 8.1 years, and a Benefit–Cost Ratio (BCR) of 1.3; in the optimal case, with carbon credits included, the project reaches an NPV of USD 6,104,817, a pre-tax equity IRR of 43%, a 5-year payback, and a BCR of 3.5. RETScreen demonstrates strong capability in scenario modeling, identifying critical design factors, and assessing project suitability for implementation.

Keywords: Decarbonization, Renewable Energy, Energy Transition, Photovoltaic Power Plant, Financial Feasibility, RETScreen

INTRODUCTION

Indonesia's coal sector has a long historical trajectory, beginning in the colonial period and continuing through independence to the present, with many companies eventually going public. For decades, major coal producers have been the backbone of national electricity supply, but they are now increasingly challenged by zero-emission policies. Global momentum for clean energy, stricter environmental regulations, volatile coal prices, and weakening demand have all disrupted the stability of their business models. Many firms still rely heavily on a single line of business, making diversification an urgent strategic necessity. This study aims to: (i) evaluate the financial feasibility of developing a utility-scale solar PV project on PTBA's post-mining land; (ii) estimate potential revenues from greenhouse-gas (GHG) mitigation through carbon credits; and (iii) assess whether such a project aligns with PTBA's sustainability strategy from an independent analytical perspective. To achieve this, RETScreen is applied as an integrated tool for importing meteorological datasets (e.g., NASA/SSE), simulating PV system performance, calculating LCOE, NPV, IRR, and payback periods, as well as estimating GHG reductions for project appraisal (Akpahou et al., 2023; Baccay Sy et al., 2020; EL-Shimy, 2009; Singh et al., 2022; Sreenath et al., 2021). RETScreen's scenario-analysis function is also used to assess policy and financial drivers such as carbon-credit revenues, tariff frameworks, and financing costs, with precedents including the Cirata floating PV project in Indonesia, the de-dieselization program in Nias Island, and a 20 MW solar plant in Hami, (Chen et al., 2014; Paradongan et al., 2024; Rifansyah & Hakam, 2024). Existing literature highlights RETScreen's strength as a comprehensive platform for techno-economic-environmental evaluation, combining embedded climate and PV databases with supplementary modeling or measured data when higher resolution is required.

The originality of this study lies in addressing gaps in previous work by proposing the utilization of post-mining land, which reduces upfront investment costs for utility-scale PV development and improves financial indicators such as NPV. In addition, the research positions the project as part of PTBA's commitment to green energy and long-term sustainability. Finally, the study incorporates avoided carbon tax and potential carbon-credit revenue into project cash flow modeling, tested under varying tariff, pricing, and financing scenarios, with sensitivity and Monte Carlo risk analyses applied to capture uncertainties.

REVIEW OF LITERATURE

Recent research highlights the growing feasibility of solar photovoltaic (PV) projects across different regions worldwide, particularly when supported by favorable policies and incentive mechanisms. Among the key determinants, electricity tariffs consistently emerge as the most influential factor for PV project viability. (Paradongan et al., 2024) For example, in Nias, Indonesia, the tariff ranges from USD 0.0799–0.1319/kWh in years 1–10 and USD 0.0417–0.0688/kWh in years 11–30. While the cost of diesel generation (~USD 0.396/kWh) makes solar attractive for PLN due to cost savings, tariff-only schemes remain unappealing for Independent Power Producers (IPPs). In the Cirata project, setting the tariff at ~USD 0.0695/kWh, combined with higher GHG credit values, substantially improves NPV and IRR, with the project's LCOE reported at ~USD 0.0699/kWh (Rifansyah & Hakam, 2024).

Overall, existing literature underscores that electricity-rate assumptions are the most sensitive variables in RETScreen analysis, as adjustments in tariff inputs significantly shift NPV and IRR outcomes, even with unchanged GHG reductions.

Technical precision and simulation models also play a central role in these assessments. (Bentouba et al., 2021) compared RETScreen and HOMER Pro in Algeria, finding HOMER Pro more accurate in replicating real plant performance, particularly in hot climates where polycrystalline modules underperform. Similarly, (Khan et al., 2023) compared SAM and RETScreen for a 600-kW PV project in Saudi Arabia, confirming both models as reliable, with minimal deviation. HOMER was also applied in (Aziz et al., 2020) to analyze Baghdad's household microgrid, identifying a hybrid system as the most economical. In Ghana, (Agyekum & Nutakor, 2020) assessed a PV-Wind-Diesel-Battery hybrid, which proved feasible but remained heavily diesel-dependent, though higher solar shares and falling costs could improve its competitiveness.

Installed capacities in the reviewed studies vary widely. Small-scale systems range from ~1–5 kW in Iran, ~5.8–13.9 kW in Baghdad's microgrids, a 4.2 kW rooftop with dual-axis tracking in Mediterranean cities, and ~15.5–53.6 kW rooftop systems for SMEs in Pakistan, demonstrating how project sizing is tailored to load profiles and site constraints (Ahmad et al., 2022; Aziz et al., 2020; Kassem et al., 2021; Zandi et al., 2017). At medium scale, examples include a 600-kW commercial grid-tied system in Riyadh, a 5 MW land-based PV plant in Malaysia, and a proposed 50 MW project at UENR Nsoatre, Ghana, reflecting a transition from building-scale to estate or campus-level (Khan et al., 2023; Obeng et al., 2020; Sreenath et al., 2021). At the utility scale, studies often focus on standardized 10–26–100 MW blocks for site assessments, such as 10 MW projects across 29 Egyptian locations, 23 Kenyan sites, and seven cities in Uttar Pradesh, India, alongside cases of 26 MW in Nias and 100 MW in Bati, Ethiopia (Baccay Sy et al., 2020; EL-Shimy, 2009; Paradongan et al., 2024; Samu et al., 2019; Singh et al., 2022).

Regional conditions such as resource potential, climate, grid infrastructure, and policy design play a decisive role in shaping project feasibility. For instance, in Egypt, multi-site screening identifies several highly profitable locations like Wahat Kharga due to strong solar resources and supportive policy frameworks. In contrast, Kenya's 23-site evaluation shows only 13 financially viable projects under current tariffs and costs (EL-Shimy, 2009; Samu et al., 2019). Markets with lower tariffs or insufficient incentives, however, require explicit policy support. For instance, Iran's household PV segment is only attractive under subsidy scenarios, while Benin's 10 MW project becomes feasible only with feed-in tariffs of ~USD 0.10/kWh or higher (Akpahou et al., 2023; Zandi et al., 2017).

Drawing from earlier studies on renewable energy as an alternative approach to electricity generation, this research marks an important step for an Indonesian coal-based energy company in shifting its operations toward green energy. The photovoltaic (PV) system is initially intended to supply the company's internal demands, such as mining operations and office facilities, while in the longer term, it has the potential to deliver broader benefits to surrounding communities as part of the company's sustainability initiatives. A summary of the literature review derived from the referenced studies is presented in Table 1.

Author & Year	Electricity Rates (USD)	Region	Capacity	Initial Cost (USD)	O&M Cost (USD/annual)	Analytical Tool Used	Result of Profitability
(Rifansyah & Hakam, 2024)	0.0581 & 0.0695 USD/kWh	Cirata,Indonesia	145 MW	129,000,000	Not specified	RETScreen	Profit. NPV 86.5M; IRR 32.5% ;PP 6.3 yrs
(Baccay Sy et al., 2020)	0.057 (1.6 ETB/kWh)	Bati, Ethiopia	100 MW	Not Stated	Not Stated	RETScreen	Profit. NPV: Positive, IRR: Not stated, PP: Not stated
(Alhassan et al., 2023)	0.10/kWh	Akosombo, Ghana	420 MWp	567,030,000	504000	RETScreen	Profit. NPV: USD 32.66 million, IRR: not stated, PP: 12 yrs
(Ahmad et al., 2022)	0.085–0.105	Punjab, PK	15.5–53.6 kW	15,500–53,630	155–536	RETScreen	Profit. NPV: up to 14,947 USD, IRR: up to 14.9%, PP: 7.7–9.7 yr
(Paradongan et al., 2024)	0.0595/kWh	Nias, Indonesia	26 MW	25,975,000	338,000	RETScreen	Profit. NPV: 33 million USD, IRR: 41.8%, PP: 4.8 yrs
(Bentouba et al., 2021)	N/A	Algeria	20 MW	N/A	N/A	HOMER & RETScreen	Profit. HOMER: NPV ↑ (5% less than real), t=3.75. RETScreen: NPV ↑↑ (14% higher), t=6.12.
(Aziz et al., 2020)	0.0084–0.0672 (buy); 0.0042–0.0336 (sell)	Baghdad, Iraq	5.8 kW PV + 16 batt	$12,940 (capital); NPC: $29,713	~$10/kW/year (PV); $8/year/batt	HOMER	Profit. NPC: $29,713. COE: $0.165. IRR: Not stated. RF: 28.7%.
(Agyekum & Nutakor, 2020)	0.382 / kWh	Southern Ghana	~25 MW hybrid	$880,103	$1,456,296.72	HOMER	Profit. NPV: $666,513, IRR: 8.9%, Payback: 9.53 years
(Sukmawan et al., 2021)	Not stated	Cirata, Indonesia	145 MWac	Not stated	Not stated	Meteonorm 7	Profit. CF: 16.68%, PR: 88%, Energy: 254 GWh/year
(Khan et al., 2023)	0.0528 (real LCOE)	Riyadh, KSA	600 kW	USD 270,000	Not specified	SAM, RETScreen	Profit. NPV > 0; IRR not stated; PP: ~6.5 years; LCOE: 0.0528 USD/kWh
(Akpahou et al., 2023)	0.110 – 0.128 /kWh	Benin (7 cities)	10 MW	$18,500,000	$130,000 (13 USD/kW/yr)	RETScreen	Not Profit. NPV: -21.86 million USD. IRR not stated. Becomes profitable at FiT ≥ 0.15 USD/kWh.
(Obeng et al., 2020)	0.109–0.124 / kWh	Ghana	50 MW	$65.5M–$69.5M	Based on IRENA data	PVsyst, RETScreen	Profit. NPV: $6.55M–$13.24M; IRR: 3.8%–5.2%; PBP: 6.4–7.2 yrs; Cost-Benefit Ratio: >1
(EL-Shimy, 2009)	0.42/kWh	Egypt	10 MW	103,740,822	334,500.00	RETScreen	Profit. NPV: $144.3M (Wahat Kharga), IRR Equity: 24.9%, IRR Asset: 9.3%, Payback: 4.9 yrs
(Sreenath et al., 2021)	0.102 – 0.122 (LCOE)	Malaysia	5 MW	1.36 million USD/MW	13 USD/kW/year	RETScreen	Profit (Site 2). NPV: 1.24 million USD, IRR: 17.10%, PP: 7.9 yrs
(Singh et al., 2022)	-	Allahabad, UP	10 MWp	-	-	RETScreen	Profit. NPV: $27,394.59, IRR: 16.5%, MIRR: 12.3%, PP: 9.4 yrs
(Kassem et al., 2021)	0.0255–0.17 (varies by area)	Coastal Mediterranean	4.2 kW	5,000	Not stated	RETScreen	Profit. NPV: $27,477 (Alexandria), IRR not stated, Payback: 2.8–6.6 years, LCOE: 0.0334–0.0475 USD/kWh
(Samu et al., 2019)	0.12/kWh (FiT)	Kenya	10 MW	18,050,000	330750	RETScreen	Profit. NPV: $3.44M, IRR: 25.4%, PP: 7.3 yrs (best at Nakuru)
(Zandi et al., 2017)	0.012–0.089 (residential)	Iran	1–5 kW	~$3000/kW (max)	Not specified	RETScreen	Profit (Fourth Scenario, 5 kW): IRR 33.3%, Simple Payback 5.8 yrs, Equity Payback 4.1 yrs

(Goswami et al., 2019)	0.026/kWh	India	10 MW	10,470,309	1,105,376.87 (5 yrs)	PVSyst	Profit. NPV: Not stated, IRR: Not stated, Levelized Tariff: 0.026/kWh (<0.042/kWh ground)
(Chen et al., 2014)	-	Hami, China	20 MWp	~USD 36.5 million*	~USD 23.4 million*	RETScreen	Profit. NPV: ¥152–163 million; IRR: 24.6–26.1%; Payback: 8.0–8.2 yrs; PI: 4.37–4.60.

RESEARCH METHOD

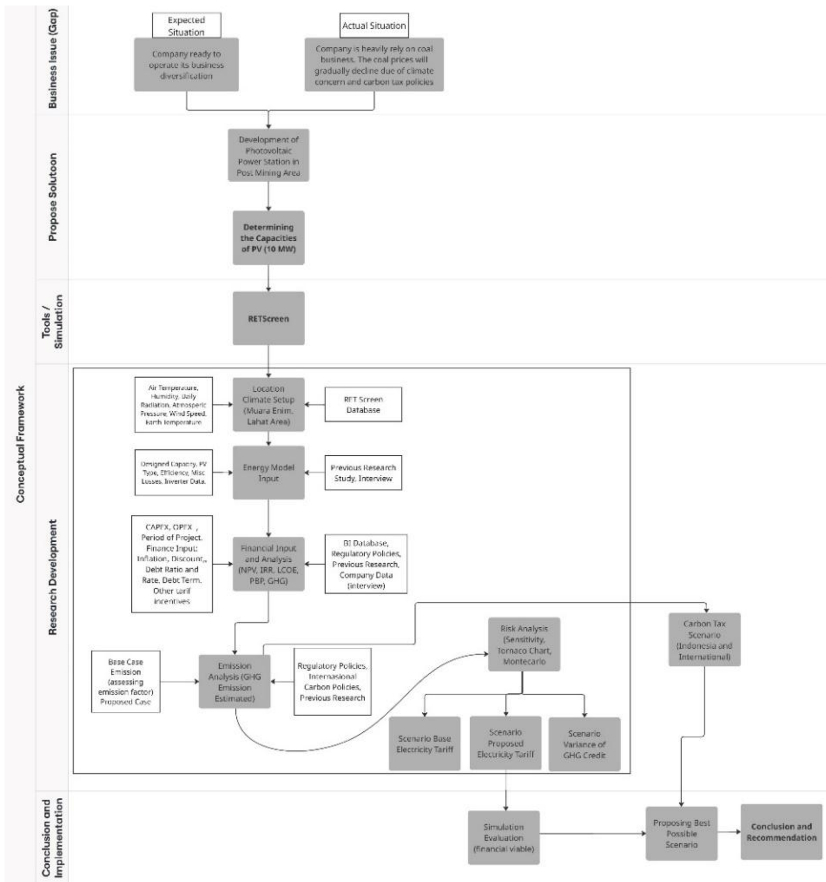


Figure 1. Research Framework

Figure 1 illustrates the conceptual framework underpinning this study. The framework outlines the rationale for conducting the research, followed by the proposed solution approach. It also specifies the analytical tools to be employed and presents the sequential steps of the analysis during the development phase, culminating in the overall conclusions. The framework is aligned with the company's strategic direction to diversify beyond coal in response to the global energy transition. The study begins with identifying the central business challenge, followed by defining the research questions and objectives, which emphasize financial feasibility and potential revenues from carbon credits. Insights from prior studies demonstrate that RETScreen has been widely adopted for evaluating both utility-scale and distributed solar PV systems. RETScreen is particularly valuable for its capacity to incorporate site-specific solar irradiance data and assess critical performance indicators such as energy production, greenhouse gas (GHG) reductions, Net Present Value

(NPV), and Internal Rate of Return (IRR). As the initial step of the analysis, Table 2 presents a climate assessment for the project site, generated by RETScreen using NASA datasets. The reference location for this climate data is Lahat Regency, which borders Muara Enim and remains part of PTBA's mining concession area. To further illustrate the proximity between Lahat and Muara Enim, Figure 2 provides a regional map of both regencies.

Table 2. Climate Data

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	23,4	83,4%	4,39	96,3	2,9	24,2	0	417
February	23,8	81,6%	4,90	96,3	2,4	24,8	0	386
March	24,1	82,0%	4,98	96,2	2,1	25,3	0	438
April	24,5	82,6%	4,88	96,1	1,6	25,6	0	435
May	24,8	79,0%	4,75	96,1	1,9	25,8	0	460
June	25,2	73,1%	4,73	96,1	2,4	26,3	0	455
July	25,1	71,2%	4,57	96,1	2,4	26,3	0	467
August	25,3	70,0%	4,49	96,2	2,7	26,7	0	475
September	24,7	75,8%	4,32	96,2	2,3	26,1	0	442
October	24,3	79,7%	4,18	96,2	2,1	25,7	0	444
November	23,8	83,8%	4,03	96,2	2,3	25,0	0	415
December	23,5	84,2%	3,98	96,3	3,0	24,3	0	418
Annual	**24,4**	**78,8%**	**4,51**	**96,2**	**2,3**	**25,5**	**0**	**5.252**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA

Figure 2. Location of Lahat and Muara Enim Regency

3.2 Techno-Economic Analysis

Assessing the techno-economic feasibility of renewable energy projects is a vital stage in project appraisal. This evaluation includes examining key financial metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Period (DPBP), Levelized Cost of Electricity (LCOE), and Payback Period. In addition, the cost of emissions is determined through the Greenhouse Gas (GHG) Emission Reduction Cost. Together, these indicators offer critical insights into the project's profitability, investment risks, and overall cost-effectiveness.

The Internal Rate of Return (IRR)

$$IRR = \sum (Cn / (1 + IRR)^n) \text{ from } n = 0 \text{ to } N \quad (1)$$

where:

- C_n= Net cash flow in year *n*
- IRR = Internal Rate of Return
- *n* = Year or period in which the cash flow occurs

Payback Period (PBP)

$PBP = (C - IG) / [(Cener + Capa + CRE + CGHG) - (CO\&M + Cfuel)]$	(2)

C = The total annual revenue generated by the project
IG = The Initial Investment cost of the project
Cener = The annual revenue generated from the sale of clean energy produced by the project
Capa = The annual revenue generated from carbon credits or other programs that reward GHG emission reduction
CRE = Represents any additional revenue streams associated with the project that are related to emission reduction efforts
CGHG = Represents any direct financial benefits associated with reducing greenhouse gas emissions
CO&M = The annual Cost of Operation and Maintenance for the project
Cfuel = The annual Cost of Fuel for the project.

Net Present Value (NPV)

$NPV = \sum (Cn / (1 + r)^\wedge n)\ from\ n = 0\ to\ N$	(3)

Cn = The net cash flow in year n
r = The discount rate used to present value the future cash flows
n = The year or period for each cash flow

GHG Emission Reduction Cost (GRC)

$GRC = NPV/\Delta GHG$	(4)

NPV = The Net Present Value of the project
ΔGHG = The change in Greenhouse Gas Emissions achieved by the project

Levelized Cost of Electricity (LCOE)

$LCOE = \frac{Sum\ of\ cost\ over\ lifetime}{Sum\ of\ electricity\ generated\ over\ lifetime}$	(5)

Benefit-Cost Ratio (B-C):

$$\textbf{B- C} = \frac{\sum_{n=1}^{N}\frac{Benefit}{(1+r)^n}+\frac{Salvage}{(1+r)^N}}{CAPEX+\sum_{n=1}^{N}\frac{Cost}{(1+r)^n}} \quad (6)$$

NPV = The Net Present Value of the project
N = Total Project Duration
n = Years n of the project
r = Discount rate

The data inputs used in the RETScreen simulation are presented in Tables 3 and 4, detailing the specific parameters for the Energy Model and Financial Analysis:

Table 3 Energy Model

Parameters	Value (units)	References
Resource Assessment Capacity	10 MW	(Background: as option to support the current 3x10 MW in transition phase usage of CFPP for electricity input for TE facility) (PTBA:2025)
Area Availability	200 Hectare	(Internal Report) (PTBA:2025)
Inverter Efficiency	95%	RETScreen
Inverter Capacity	9 MW	RETScreen
Inverter Miscellaneous losses	1%	RETScreen
MAIN COST		
Initial Investment	800 USD / kW	Internal Data and (IESR, 2023) with consideration of utilization of Post Mining Assets
OPEX	14.40 USD/kWYear	(IESR, 2023)

Table 4. Financial Model Input

Finance Parameter	Value (units)	Reference
Inflation rate	2.37	(Trading Economics July, 2025)
Discount rate	10%	IESR 2024 (Fearnehough et al., 2024)
Project life	25 Year	(Company Guidance)
Debt Interest rate	5.25%	(Trading Economics July, 2025)
Debt Ratio	70%	(Company Guidance)
Debt Term	15 Year	(Rifansyah & Hakam, 2024)
Electricity tariffs as Base Scenario	0.086 USD/kWh (first 10 year) and 0.047 after 10 Year	Perpres 112/2022 (Republik Indonesia, 2022)

In this study, several scenarios were developed to determine the most appropriate option for implementation. The scenarios include:

a. Tariff Adjustment Scenario.

The first scenario applies the base electricity export tariff to assess the project's financial viability under existing regulations, specifically Annex 1, Point 7 of Presidential Regulation No. 112 of 2022 (Republik Indonesia, 2022). For tariff adjustments, the same regulation is used but with reference to Annex 1, Point 5. The distinction lies in the regulatory context: Point 7 involves government participation, particularly in land utilization, whereas Point 5 treats the project as a company-led initiative without government involvement.

b. GHG Emission Reduction Price Scenario.

Following the tariff scenario, this case incorporates GHG emission reduction pricing into RETScreen. The first step uses Indonesia's current GHG credit price as listed on IDX Carbon 2025 (Lundgreen, 2025). The analysis then extends to the Voluntary Carbon Market (VCM), adopting the price levels referenced by (Senken, 2023). Finally, the scenario considers the IMF's proposed benchmark, which represents the highest GHG credit value among the available options (IMF, 2022).

c. Carbon Tax Benefit Scenario.

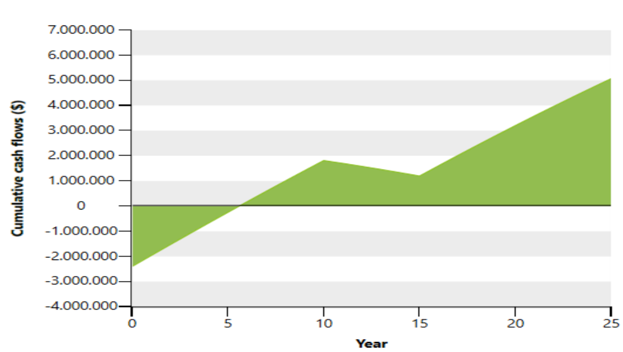
Once RETScreen confirms the project's financial feasibility, the potential savings from avoided carbon tax are estimated. Domestically, this refers to Indonesia's carbon tax framework under Law No. 7 of 2021 on the Harmonisation of Tax Regulations (UU No. 7 Tahun 2021, 2021). For international benchmarking, the study refers to the IMF's 2022 policy recommendations (IMF, 2022).

RESULTS AND DISCUSSION

Result Analysis

This section presents the RETScreen simulation results for a 10 MW PV project located on PTBA's post-mining site and discusses them in relation to the research objectives. The analysis covers three cases: the base regulated tariff model, a corporate self-initiated tariff scheme, and scenarios incorporating GHG credit pricing, each further examined through sensitivity testing and Monte Carlo simulations.

A. Electricity Tariff: Base and Adjusted Scenarios



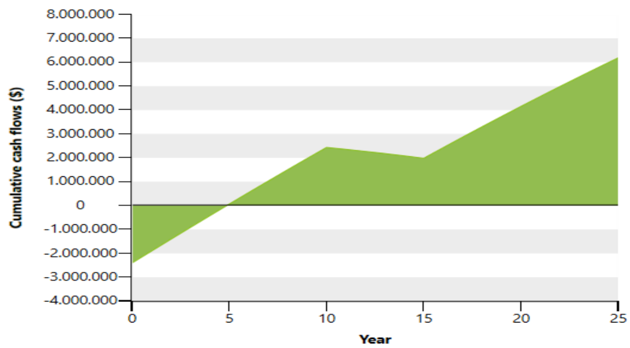
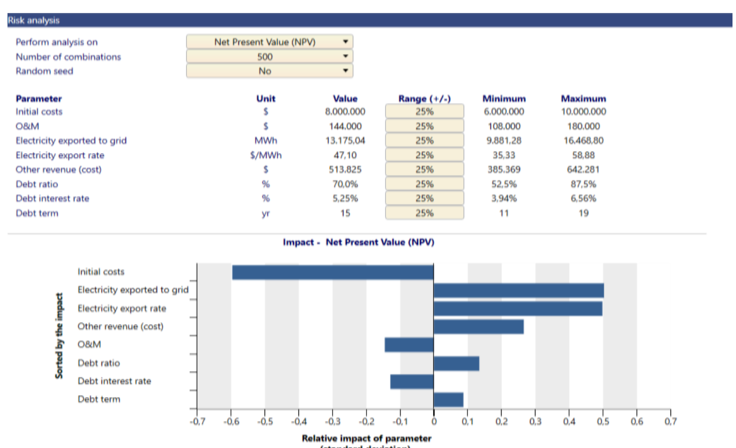


Figure 3. Cash Flow: Base Electricity Tariff Scenario vs. Adjusted Electricity Tariff Scenario

Figure 3 illustrates a comparison of project cash flows under two tariff schemes outlined in Presidential Regulation No. 112/2022 (Republik Indonesia, 2022). In the base scenario (Annex 1, Point 7), the tariff is set at USD 0.086/kWh for the first 10 years and USD 0.047/kWh thereafter. With constant technical assumptions, this results in an LCOE of USD 0.068/kWh, an NPV of USD 604,946, a pre-tax equity IRR of 14%, a pre-tax asset IRR of −0.54%, a payback period of 8.1 years, and a BCR of 1.3. The slightly negative asset IRR could be mitigated by applying a uniform tariff across the 25-year project span. In the adjusted scenario (Annex 1, Point 5), tariffs of USD 0.090/kWh (years 1–10) and USD 0.0496/kWh (years 11–25) improve project performance, producing an NPV of USD 1,082,022, a pre-tax equity IRR of 17%, a pre-tax asset IRR of 0.58%, a payback period of 7.6 years, and a BCR of 1.5. Compared with the base case, this adjustment yields an NPV increase of approximately USD 477,076.


Risk analysis

Perform analysis on	Net Present Value (NPV)
Number of combinations	500
Random seed	No

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	8.000.000	25%	6.000.000	10.000.000
O&M	$	144.000	25%	108.000	180.000
Electricity exported to grid	MWh	13.175,04	25%	9.881,28	16.468,80
Electricity export rate	$/MWh	47,10	25%	35,33	58,88
Other revenue (cost)	$	513.825	25%	385.369	642.281
Debt ratio	%	70,0%	25%	52,5%	87,5%
Debt interest rate	%	5,25%	25%	3,94%	6,56%
Debt term	yr	15	25%	11	19

Figure 4. Tornado Chart: Base Electricity Tariff Scenario

The tornado chart in Figure 4 presents the sensitivity analysis results, illustrating how various model parameters influence NPV. Among the tested variables, capital expenditure (CAPEX) shows the most significant negative impact, indicating that higher upfront investment costs substantially reduce NPV. The next key factor is the volume of electricity exported to the grid, which is closely tied to technical parameters such as the capacity factor.

The third and fourth most influential variables are tariff-related: (3) the electricity tariff itself and (4) supplementary tariff elements beyond the base tariff (e.g., multi-step carbon pricing, grant allocations, or similar mechanisms). These findings suggest that lowering CAPEX, enhancing capacity factors, and introducing tariff improvements could meaningfully strengthen project NPV.

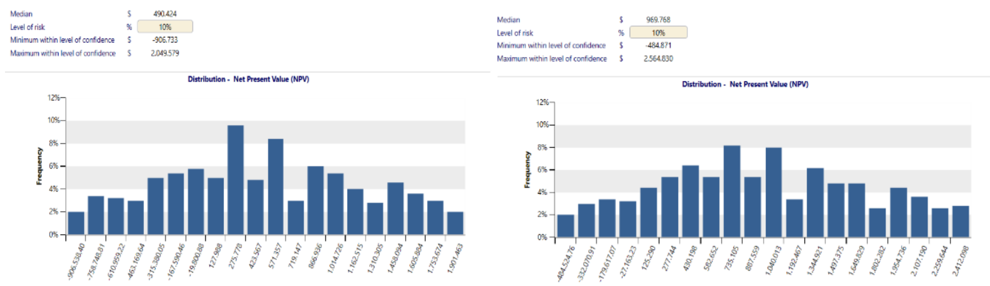


Figure 5. Monte Carlo Simulation: Base and Adjusted Electricity Tariff Scenarios

Figure 5 illustrates the results of a 500-run Monte Carlo analysis of NPVs for both the base and adjusted tariff cases. In the base scenario, outcomes are largely positive, with a median NPV of USD 490,424, though the range spans from –USD 906,733 to +USD 2,049,579, reflecting sensitivity to CAPEX and tariff fluctuations. The adjusted tariff scenario shifts the distribution to the right and reduces downside risk, yielding a higher median NPV of USD 969,768, only four negative outcomes, and a 10% risk interval of about –USD 484,871 to +USD 2,564,830. Given its stronger risk profile, the adjusted tariff is proposed as the reference basis for the subsequent GHG-credit scenario.

B. GHG Credit Rate Scenario

With the adjusted electricity tariff (Annex 1, Point 5 of Presidential Regulation No. 112/2022) as the pricing reference (Republik Indonesia, 2022)., three levels of GHG-credit rates were assessed (see Figure 6). At USD 1.98/tCO_2 (Lundgreen, 2025), the project achieves an NPV of USD 1,280,925, pre tax equity IRR of 18.2%, pre-tax asset IRR of 1.1%, a simple payback of 7.4 years, BCR of 1.5, and cumulative cash flow of USD 6,731,518. Increasing the credit to USD 6.97/tCO_2 (Senken, 2023) boosts NPV to USD 1,782,200, raises the equity/asset IRRs to 21.1% and 2.4%, reduces payback to 7.1 years, increases BCR to 1.7, and yields cumulative cash flow of USD 8,112,131 an NPV gain of USD 501,275 compared to the USD 1.98/tCO_2 case. At USD 50/tCO_2 (IMF, 2022) , NPV surges to USD 6,104,817, equity/asset IRRs rise sharply to 43.0% and 10.9%, payback shortens to 5.0 years, BCR reaches 3.5, and cumulative cash flow grows to USD 20,017,492. This highest GHG-credit case delivers an NPV improvement of approximately USD 4,823,892 relative to the USD 1.98/tCO_2 scenario. The corresponding cash flow patterns are shown in Figure 6.

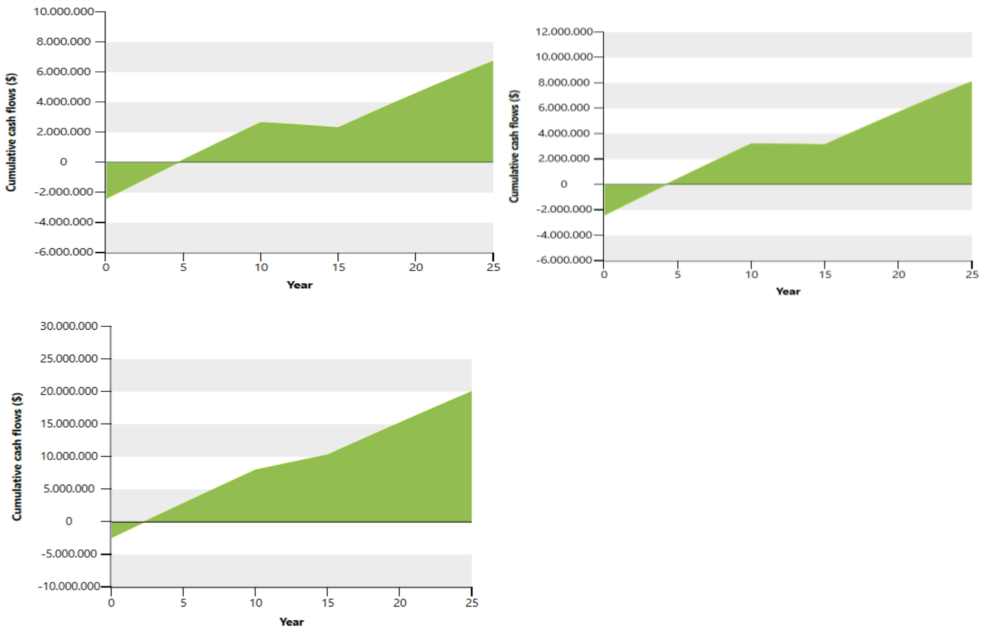


Figure 6 Cashflow for GHG 1.98, 6.97, and 50

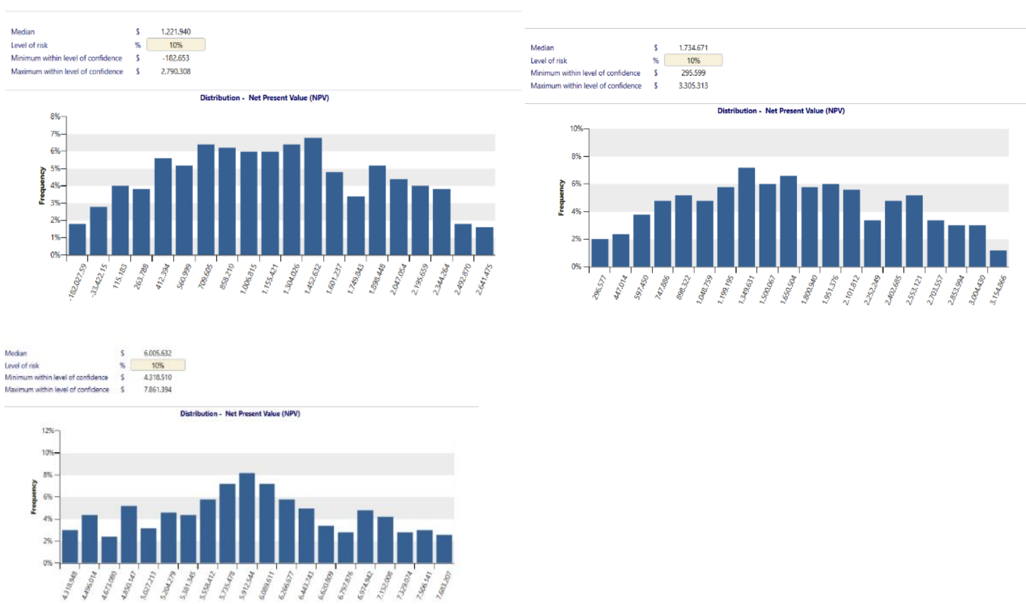


Figure 7. Monte Carlo Results for GHG Credits at 1.98, 6.97, and 50 USD/tCO_2

Figure 7 presents the outcomes of 500 Monte Carlo simulations for the three GHG credit scenarios. At the current IDX price of USD 1.98/tCO_2e, the project shows a median NPV of approximately USD 1.22 million, with a 90% confidence interval ranging from USD 0.18 million to +USD 2.79 million. While results are generally favorable, they remain highly sensitive to CAPEX, capacity factor, and tariff assumptions. Increasing the credit rate to USD 6.97/tCO_2 raises the median NPV to about USD 1.735 million (90% CI: USD 0.30–3.31 million), significantly reducing the probability of negative outcomes. At USD 50/tCO_2, under the independent tariff framework, the median NPV climbs substantially to USD 6.089 million, with a narrower 90% confidence interval of USD 4.3 7.8 million, marking it as the most favorable scenario compared to the others.

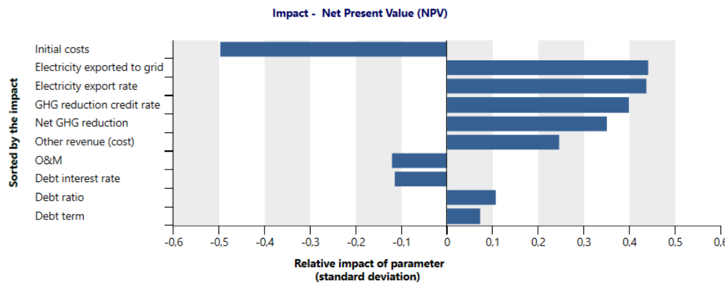


Figure 8. Tornado Chart under a High GHG Reduction Rate

From a risk assessment perspective, Figure 8 highlights a shift in parameter importance: the GHG credit rate emerges as the fourth-most influential factor, demonstrating that higher carbon credit values can directly enhance NPV. The combination of the independent-tariff scheme and a GHG credit price of USD 50/tCO_2 significantly boosts project feasibility while limiting downside risks. Based on all the tested scenarios, the most favorable configuration is the combination of an adjusted electricity tariff in accordance with Annex 1, Point 5 of Presidential Regulation No. 112/2022 (Republik Indonesia, 2022). and the GHG credit price aligned with IMF's guidance. This scenario can be considered the optimal pathway for the project.

C. Project Benefits to the Company: Emission Reduction and Carbon Tax

Between 2022 and 2024, PTBA's Sustainability Report (PTBA, 2024), recorded a steady rise in electricity-related carbon emissions in its South Sumatra operations, as summarized in Table 5.

Table 5. Details of Emissions Produced by the Company

Year	CO_2 Emissions (tCO_2e)
2022	92,486
2023	95,664
2024	101,924

CO_2 emissions are projected to keep increasing in line with higher electricity demand and the wider adoption of electric-powered mining equipment. The proposed 10-MW PV project is anticipated to generate around 13,175 MWh of electricity annually. Based on the 2019 grid emission factors published by the Directorate General of Electricity, Ministry of Energy and Mineral Resources (Ditjen Ketenagalistrikan ESDM Indonesia, 2019), the Sumatra region has an emission factor ranging from 0.84 to 0.93 tCO_2/MWh. As shown in Figure 9, this study applies a factor of 0.903 tCO_2/MWh, resulting in an estimated annual GHG reduction of about 11,067 tCO_2.

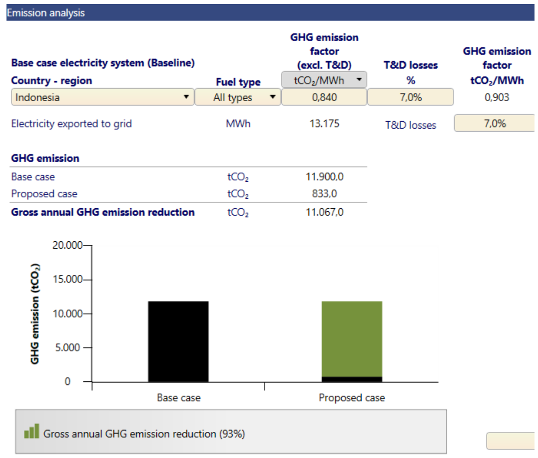


Figure 9. GHG Emission Reduction Data by RETScreen

With the company's three-year average electricity-related emissions recorded at 96,691.33 tCO_2, the proposed solar PV (PLTS) project is projected to cut emissions by roughly 11,067 tCO_2 annually. This reduction corresponds to around 11.45% of the company's average electricity-based emissions. Based on this verified annual reduction figure, the potential avoided cash outflow or its equivalent credit value was calculated and is presented in Table 6, applying a 10% discount rate across the operational lifespan of the PLTS project.

Table 6. Estimated Avoided Carbon Tax Costs

Carbon Tax Reference	Price / tCO_2e	Annual (USD)	PV 25 yrs @10% (USD)
UU HPP (National Floor) (UU No. 7 Tahun 2021, 2021)	Rp 30.00	20,610	187,080
IMF ICPF (Middle-Income) (IMF, 2022)	USD 50	553,350	5,022,780

Discussion

Table 7 Comparison Study From Photovoltaic Study

Author	Scenario	Country	PV Capacity (MW)	Type of solar PV	Debt Interest Rate (%)	Electricity Tariffs (USD/kWh)	Initial Costs (USD/kW)	NPV (USD)	Simple Payback Period (Year)	LCOE (USD/kWh)
This Research	Base Case	**Indonesia**	**10**	**Ground Mounted (Uses Post Mining Asset)**	**5.25**	0.086 (first 10 year) + 0.047 (after 10 year)	**800**	$ 604,946.00	8.1	**0.068**
	Electricity Upgrade					0.090 (first 10 year) + 0.049 (after 10 year)		$ 1,082,022.00	7.6	
	Applying International Market GHG Credit Rate					0.090 (first 10 year) + 0.049 (after 10 year)		$ 1,782,200.00	7.1	

	Recommended Scenario (best tariff and best GHG reduction price)					0.090 (first 10 year) + 0.049 (after 10 year)		$ 6,104,817.00	5	
(Rifansyah & Hakam, 2024)	Base Case	**Indonesia**	**145**	**Floating**	**7**	0.0581	890	$ 1,089,695.54	12.11	**0.07**
	Carbon Emission					0.0581		$ 58,229,809.92	7.1	
	Electricity Tariff Adjustment					0.0695		$ 26,140,729.92	9.95	
	Recommended Scenario					0.0695		$ 87,827,979.31	6.3	
(EL-Shimy, 2009)	Recommended site (Wahat Kharga)	**Egypt**	**10**	Ground-mounted, **two-axis tracker** (mono-Si HIT)	7	**0.42**	**10,374**	$ 144,300,000.00	**4.9**	**0.199**
	Least-favourable site (Safaga)					0.42		$ 95,100,000.00	7.1	0.242
	Average across 29 sites					0.42		$ 115,100,000.00	6.1	0.223

Table 7 provides a comparative analysis of this PLTS feasibility study with: (i) Indonesian PV projects of varying installed capacities reported by (Rifansyah & Hakam, 2024), and (ii) a project of similar scale in Egypt by (EL-Shimy, 2009).. Since the Egyptian study predates the sharp global decline in solar costs after 2011, its initial CAPEX and resulting LCOE are significantly higher. This finding is consistent with (IRENA, 2024), which documents notably elevated PV LCOE levels before 2011. The cross-case comparison seeks to identify the main factors that influence project bankability and feasibility outcomes. This study demonstrates that utilizing post-mining land for a 10 MW solar PV project at PT Bukit Asam offers both economic and environmental benefits. The RETScreen analysis confirms financial feasibility under adjusted tariff and carbon credit scenarios, while also showing significant GHG emission reductions that support the company's sustainability strategy. These findings highlight the potential of post-mining assets to accelerate Indonesia's energy transition and strengthen corporate contributions to green energy development.

CONCLUSION

Under the base tariff scenario, following Annex 1 of Presidential Regulation No. 112/2022, Point 7, the PV project shows moderate feasibility with projected results: NPV USD 604,946; pre-tax equity/asset IRR of 14%/−0.54%; payback period of 8.1 years; and BCR of 1.3. Nevertheless, risks remain if parameters shift such as tariff reductions, CAPEX escalation, or lower technical performance as highlighted in the tornado and Monte Carlo analyses. A stronger option is the adjusted tariff under Annex 1, Point 5, which improves outcomes to an NPV of USD 1,082,022, equity/asset IRR of 17%/0.58%, payback of 7.6

years, and BCR of 1.5, while keeping LCOE constant at USD 0.068/kWh. Incorporating GHG credits further enhances project viability under the Annex 1, Point 5 tariff scheme. At USD 1.98/tCO_2, the project records NPV USD 1,280,925, equity/asset IRR of 18.2%/1.1%, payback of 7.4 years, and BCR of 1.5. At USD 6.97/tCO_2, results strengthen to NPV USD 1,782,200, IRR 21.1%/2.4%, payback of 7.1 years, and BCR of 1.7. At USD 50/tCO_2, the project achieves substantial gains: NPV USD 6,104,817, equity/asset IRR 43.0%/10.9%, payback 5.0 years, and BCR 3.5. Although the lower credit rates show limited impact in the tornado analysis, the Monte Carlo outputs at USD 50/tCO_2 demonstrate a significant rightward shift, confirming the GHG credit rate as a decisive driver of feasibility.

From the emissions perspective, the PV system offsets approximately 11,067 tCO_2 annually, equivalent to 11.45% of the company's average electricity-related emissions between 2022–2024, thereby mitigating potential carbon-tax exposure. Based on Indonesia's HPP Law reference price, lifetime savings are estimated at USD 187,080, while at USD 50/tCO_2 the value rises to about USD 5,022,780. In terms of recommendations, several external factors critically influence feasibility. For carbon policies, Indonesia could strengthen alignment with advanced-economy standards and guidance from international clean-energy bodies, while also accelerating carbon-market development, since current domestic credit prices remain low. At the same time, IRENA's 2024 data highlights ongoing declines in PV LCOE, reflecting continuous innovation and efficiency improvements that further support project competitiveness.

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