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Feasibility Assessment of Wind Energy in Poto Tano, West Sumbawa: An Integrated Economic, Environmental, and Financial Approach

Muhammad Abiyyu Farras[1], Muhammad Inditiya Gegar Laras[2]
Vistula University, Poland
Email: mfarras1@stu.vistula.edu.pl[1], minditi1@stu.vistula.edu.pl[2]

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Wind Energy, Feasibility Research, RETScreen, Renewable Energy, Financial Analysis, Environmental Impact

ABSTRACT

Indonesia's commitment to energy transition and climate change mitigation has intensified focus on renewable energy development, particularly wind energy as a viable alternative to fossil fuels. This research assesses the feasibility of wind energy development in Poto Tano, West Sumbawa, West Nusa Tenggara, Indonesia, through an integrated analysis of energy production, environmental benefits, and financial viability. As part of Indonesia's commitment to diversify its energy mix and reduce greenhouse gas emissions, wind energy offers a clean, renewable alternative to fossil fuels. The research examines the potential of wind energy by utilizing RETScreen Expert software to simulate energy production based on local wind data, estimate project costs, and evaluate financial performance using metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR). The environmental assessment focuses on emission reductions achieved through the displacement of fossil fuel-based electricity generation. A comprehensive cost analysis, including capital expenditure (CapEx), operational expenditure (OpEx), and maintenance costs, is presented alongside a sensitivity analysis to explore the impact of key variables on project outcomes. The research further investigates financial risks using scenario-based simulations. Results show that the region possesses consistent and strong wind resources, especially during the dry season, supporting the viability of wind power generation. The findings demonstrate that the project can contribute to Indonesia's renewable energy targets, offer socio-economic benefits to the local community, and align with national energy and environmental policy goals. This research provides a holistic reference for future wind energy initiatives in similar geographical contexts.

INTRODUCTION

Feasibility Assessment of Wind Energy in Poto Tano, West Sumbawa: The global energy sector is undergoing a significant transition, driven by the urgent need to mitigate climate change, enhance energy security, and reduce reliance on finite fossil fuel resources (Argentiero & Falcone, 2020). Renewable energy, particularly wind energy, has emerged as a central pillar of this transition, reflecting broader trends in global energy policy, technological advancements, and economic considerations (Kern & Rogge, 2016). In recent decades, increasing awareness of the environmental consequences of fossil fuel consumption has been a major driver of renewable energy adoption. Fossil fuels—including coal, oil, and natural gas—have been the dominant sources of energy for over a century; however, their use has led to severe environmental degradation, including air pollution, acid rain, and, most notably, the accumulation of greenhouse gases (GHGs) in the atmosphere, which contributes to global warming (Yang, 2023). The Paris Agreement, adopted in 2015, marked a watershed moment in international climate policy, setting the goal of limiting global temperature rise to well below 2°C above pre-industrial levels (Azhgaliyeva & Mishra, 2021). This agreement has spurred nations to increase their investment in renewable energy as a means to achieve their climate targets (Shen et al., 2023). Citations should be written using a bodynote format such as (Uwuigbe & Ajibolade, 2013), (Wang, 2016), (Muttakin et al., 2015) and relevant to the bibliography/bibliography (recommended using the Mendeley Application).

Among the various forms of renewable energy, wind energy has gained prominence due to its scalability, cost-effectiveness, and technological maturity. The rapid development of wind turbine technology has significantly improved the efficiency and reliability of wind energy systems (Aziz et al., 2023). Modern wind turbines are capable of converting wind into electricity more efficiently, and their increased size and capacity have driven down the cost of wind energy (Meckling, 2018). According to the International Renewable Energy Agency (IRENA), the levelized cost of electricity (LCOE) from onshore wind has decreased by over 60% since 2010, making it one of the most competitive sources of new power generation in many regions (Hanh Phan, 2022). Government policies have also played a critical role in the global expansion of wind energy (Bebi et al., 2022). Many countries have implemented supportive policies, such as feed-in tariffs (FITs), tax incentives, and renewable portfolio standards, which have created favorable market conditions for wind energy projects. These policies, coupled with global efforts to phase out fossil fuel subsidies, have further accelerated the adoption of wind energy (DeLong et al., 2010).

Despite this rapid growth, challenges such as the intermittency of wind power, grid integration issues, and the need for substantial upfront investment remain significant barriers. Ongoing advancements in energy storage technologies, grid management systems, and international cooperation are expected to address these challenges, paving the way for continued growth in the renewable energy sector (Chang & Phoumin, 2021). In this context, Indonesia, as the largest archipelagic country in the world with vast renewable energy potential, stands at a critical juncture in shaping its future energy strategy (Dwi Tjahjana, 2023).

Indonesia’s energy sector is currently dominated by fossil fuels, particularly coal and oil, which account for a large share of electricity production. However, this dependency has raised environmental concerns and exposed the country to volatility in global energy markets. The government of Indonesia has set ambitious targets for renewable energy development through its National Energy Policy (KEN) and the General Plan for National Energy (RUEN), aiming to achieve a 23% share of renewables in the energy mix by 2025. Among the various renewable energy sources, wind energy is gaining attention due to its potential in several regions, especially in eastern Indonesia.

Poto Tano, located in West Sumbawa, West Nusa Tenggara, is one such region identified as having considerable potential for wind energy development. The geographic location of Poto Tano plays a significant role in its suitability for wind energy generation. Situated between the islands of Sumbawa and Lombok, it benefits from natural wind corridors and experiences consistent and strong winds, particularly during the dry season (Fajry et al., 2023). The wind patterns are influenced by the monsoonal climate, with the southeast trade winds providing a reliable and steady wind resource for much of the year (Berawi et al., 2016). The area's low population density and available land further enhance its suitability, minimizing land use conflicts and allowing for the development of large-scale wind farms with minimal disruption to communities (Niesten et al., 2018).

In line with these favorable conditions, this research aims to evaluate the feasibility of a wind energy project in Poto Tano through a comprehensive assessment that integrates technical, financial, and environmental dimensions (Halimatussadiah et al., 2024). The research employs RETScreen Expert, a software developed by Natural Resources Canada, which is widely used for evaluating the viability of renewable energy projects. The software provides a platform to simulate energy production based on wind data, perform cost analysis, assess environmental impact through greenhouse gas emissions reductions, and evaluate financial metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR) (Kassem, Gökçekuş, et al., 2023; Daskalaki et al., 2021).

This research further includes a sensitivity and risk analysis to understand the financial robustness of the project under varying assumptions (Ismail et al., 2020). The purpose is not only to validate the technical and economic feasibility of developing wind energy in this region but also to provide a replicable model for similar initiatives in other underutilized areas across Indonesia (Hardianto et al., 2017). The project aligns with national development priorities and supports the United Nations' Sustainable Development Goals (SDGs), particularly Goal 7, which emphasizes access to affordable, reliable, sustainable, and modern energy for all (Ntanos, 2023).

By highlighting the potential of wind energy in Poto Tano, this research contributes to the broader discourse on sustainable energy development in Indonesia. The findings are expected to serve as a reference for policymakers, investors, and researchers interested in advancing the renewable energy agenda, reducing reliance on fossil fuels, and promoting environmental sustainability through localized energy solutions. Ultimately, this research aims to demonstrate how regional wind energy projects can contribute meaningfully to national energy resilience and climate objectives while fostering inclusive socio-economic development in rural areas.

METHOD

This research focuses on Poto Tano, located in West Sumbawa, West Nusa Tenggara, Indonesia. The site was selected due to its consistent wind patterns and favorable topography, which have been recognized by national energy authorities as suitable for wind energy development. Positioned between Sumbawa and Lombok islands, Poto Tano benefits from natural wind corridors that enable stable and strong airflow throughout most of the year, especially during the dry season.

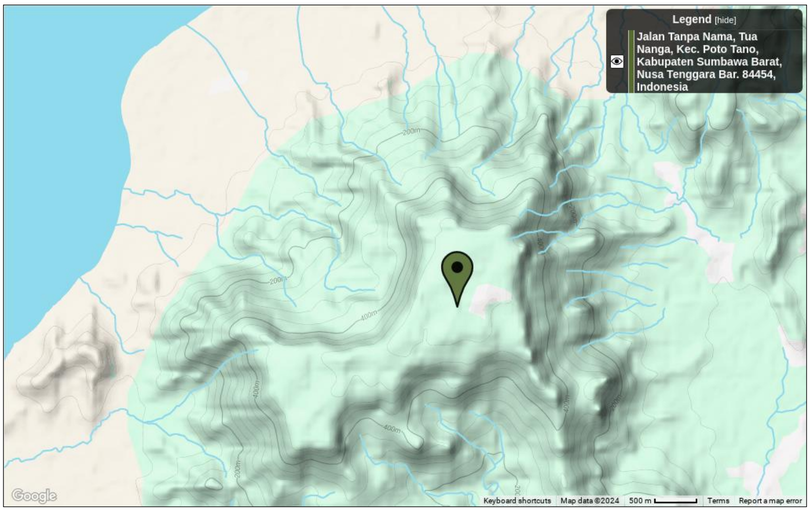


Figure 1. Research Location

Figure 1. highlights the geographical context of Poto Tano. The region's coastal characteristics, low population density, and availability of open land make it ideal for wind energy infrastructure. Additionally, the area's limited grid congestion and minimal land-use conflict further support its selection as the case research site.

This research utilized secondary data obtained from trusted institutional sources. Meteorological and climate data were collected from national databases, including wind speed, temperature, and elevation records. These data were used to simulate energy production, estimate greenhouse gas reductions, and conduct financial viability assessments.

The technical inputs included site-specific wind speed at hub height, turbine specifications, and location elevation. Financial inputs included capital costs, operational and maintenance expenses, and local electricity price assumptions. Environmental inputs accounted for avoided emissions by comparing wind energy output with fossil-fuel-based baselines.

Key performance indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), and annual energy yield were calculated. Sensitivity analysis was conducted to test how fluctuations in energy production, investment costs, and electricity prices would affect the project's overall feasibility. This approach helped to identify which variables posed the greatest risks and which scenarios offered the most stable returns.

The methodology followed a structured and sequential workflow to ensure consistency and analytical depth. The research began with identifying the problem and defining the objectives based on national renewable energy goals. A literature review was then conducted to assess previous studies and establish a foundation for analysis.

Following that, site selection and data collection were carried out. Wind speed and supporting data were obtained and validated before being used in the simulation model. The simulation phase evaluated energy output, costs, financial viability, and environmental impact. A sensitivity analysis followed to test the resilience of financial outcomes under different assumptions.

The process begins with defining the research scope, then moves through data acquisition, model setup, simulation, analysis, and finally interpretation of results. Each step builds on the previous one, ensuring that the findings are grounded in empirical evidence and logical progression. By following this systematic methodology, the research ensures reliable, replicable, and policy-relevant results that can inform future wind energy development in Indonesia.

RESULTS AND DISCUSSION

Energy Production Analysis

The data presented in this research were collected from January to December 2023, offering a comprehensive profile of wind conditions in Poto Tano, West Nusa Tenggara, Indonesia. Sourced through a combination of ground sensors, satellite data, and meteorological records from BMKG, the dataset ensures high accuracy (Kassem et al., 2023). Throughout the year, the average wind speed was 2.6 m/s, with monthly fluctuations between 1.9 m/s and 3.0 m/s. While these wind speeds are moderate, the consistency observed across months indicates a stable and reliable source of wind energy. The region's average wind power density of 277 W/m² further supports the site's technical viability.

Table 1 Site Reference Conditions

Month	Temperature (°C)	Humidity (%)	Air Pressure (kPa)	Wind Speed (m/s)	Wind Power Density (W/m^2)
Jan	26,7	83,4	99,4	2,9	275

Feb	26,5	85,0	99,4	3,0	271
Mar	26,8	82,6	99,4	2,3	278
Apr	27,1	80,3	99,5	2,2	281
May	26,8	78,6	99,5	2,6	283
Jun	26,1	77,3	99,6	2,9	279
Jul	25,6	75,2	99,6	3,0	277
Aug	25,9	72,6	99,7	2,9	280
Sep	26,9	71,1	99,6	2,6	278
Oct	27,9	70,6	99,5	2,3	273
Nov	28,0	74,3	99,4	1,9	272
Des	27,2	80,1	99,4	2,3	277
Annual	**26,8**	**77,6**	**99,5**	**2,6**	**277**

Environmental conditions recorded in 2023 also affirm the feasibility of deploying wind energy infrastructure. With an average air pressure of 99.5 kPa, temperature of 26.8°C, and relative humidity around 77.6%, the climate remains stable and favorable for turbine operation. Wind speeds were consistently above 2.0 m/s year-round, with peaks reaching 3.5 m/s in February and July. These conditions allow for steady electricity generation, especially using modern turbine technologies that function efficiently even at low wind speeds (Langer et al., 2022).

Moderate humidity levels between 70% and 85% help minimize corrosion risks and maintenance issues, thus extending equipment lifespan. The combined presence of stable wind flow and manageable environmental stressors makes Poto Tano an ideal candidate for wind energy investment aligned with national sustainability goals (Moya et al., 2018).

Table 2. Proposed Wind Energy Power Plant

Power Capacity (MW)	25
Manufacturer	Gamesa
Model	G114-2.5MW – 125m
Number of Turbines	10
Capacity Factor (%)	40
Initial Costs ($/kW)	2.500
Initial Costs ($)	62.500.000
O&M Costs ($/kWh)	75
O&M Costs ($)	1.875.000
Electricity Rate (monthly) ($/kWh)	0,11
Electricity Exported to Grid (kWh)	87.600.000
Electricity Export Revenue ($)	9.636.000

Table 2 outlines the technical and financial specifications of the proposed wind power plant. The selected turbine model, Gamesa G114-2.5MW with a 125m hub height, is based on prior successful deployments in Indonesia, such as the Sidrap wind farm. The project will install turbines to achieve a total power capacity of 25 MW, with an initial investment of $2,500 per kW and a total project cost of $62.5 million. These parameters follow standard values set by PLN, including a fixed operation and maintenance (O&M) cost of $0.075 per kWh and an electricity selling price of $0.11 per kWh.

Cost Analysis

The table presented outlines both the initial capital expenditures and the annual Operations and Maintenance (O&M) costs associated with the proposed wind energy project in Poto Tano, West

Nusa Tenggara. These values are standardized by PLN, Indonesia's state-owned electricity company, and reflect data from previous national wind energy developments.

Table 3 Cost Analysis

Initial Costs	**Costs ($)**
Feasibility Research	3.125.000
Development	12.500.000
Engineering	15.625.000
Power System	25.000.000
Contingencies	6.250.000
	62.500.000

O&M Costs	**Costs ($)**
Insurances	468.750
Parts & Labour	750.000
GHG Monitoring & Verification	187.500
Community Benefits	281.250
Contingencies	187.500
	1.875.000

The initial cost of the project is divided into five major categories. The Feasibility Study, allocated at $3,125,000, covers essential activities such as technical and environmental assessments, site surveys, and wind resource monitoring. The Development cost, totaling $12,500,000, includes land acquisition, legal and administrative procedures, and obtaining permits from relevant authorities. The Engineering component is estimated at $15,625,000, encompassing the design, layout, and technical planning of the wind farm and associated grid connection infrastructure. The most substantial portion, Power System, amounts to $25,000,000, and includes the purchase and installation of turbines, electrical equipment, access roads, and substation development. Contingencies of $6,250,000 are allocated to mitigate financial risks arising from unforeseen challenges during construction and commissioning.

Emission Analysis

Table 4 Base Case Electricity System

Fuel Type	**Fuel Mix (%)**	**Emission (kg/GJ)**			**Generation Efficiency (%)**	**T&D Losses (%)**	**Emission Factor (tCO_2/MWh)**
		CO_2	**CH_4**	**N_2O**			
Coal	60	92,7	0,0145	0,0029	33,8	9,0	1,097
Gas	21	49,6	0,0010	0,0009	40,8	9,0	0,483
Oil	6	74,1	0,0029	0,0019	28,6	9,0	1,034
Hydro	7	0	0,0000	0,0000	100,0	9,0	0,000
Geothermal	5	0	0,0000	0,0000	30,0	9,0	0,000
Biomass	0,5	0	0,0299	0,0037	23,3	9,0	0,031
Solar	0,3	0	0,0000	0,0000	100,0	9,0	0,000
Wind	0,2	0	0,0000	0,0000	100,0	9,0	0,000
	100	225,7	0,0302	0,0067		**9,0**	**0,822**

The Base Case Electricity System table provides a detailed breakdown of the fuel mix, emissions, generation efficiency, and transmission and distribution (T&D) losses associated with different energy sources in the system. Coal, making up 60% of the energy mix, is the most significant contributor to emissions, with 92.7 kg of CO_2/GJ and an emission factor of 1.097 tCO_2/MWh. Wind energy accounts for only 0.2% of the total fuel mix, but it stands out for its zero emissions across all categories and its 100% generation efficiency.

Financial Analysis

Table 5. Financial Parameter

General Parameter		
Fuel Escalation Rate	%	0
Inflation Rate	%	3
Discount Rate	%	8
Reinvestment Rate	%	6
Project Life	Year	15
Finance Parameter		
Debt Ratio	%	70
Debt	$	43.750.000
Equity	$	18.750.000
Debt Interest Rate	%	7
Debt Term	year	10
Debt Payment	$/year	6.229.016

In Table 5 provide, The financial parameters for the Poto Tano wind energy project are grounded in Indonesia's key energy policies, including the Energy Law, National Energy Policy (KEN), and Regional Energy General Plan (RUED), ensuring alignment with national sustainability and emissions targets. Notably, the 0% Fuel Escalation Rate highlights wind energy's cost stability compared to fossil fuel-dependent power plants, shielding the project from market volatility. Other general parameters, such as the 3% Inflation Rate and 8% Discount Rate, account for macroeconomic trends and the time value of money, while the 6% Reinvestment Rate supports long-term project viability. The 15-year Project Life matches the operational lifespan of wind turbines and maximizes carbon credit benefits, reinforcing both financial and environmental returns.

Financially, the project adopts a 70% Debt Ratio, with $43.75 million in debt and $18.75 million in equity, a structure typical for capital-intensive renewable energy initiatives. The 7% Debt Interest Rate reflects Indonesia's lending conditions, while the 10-year loan term balances repayment feasibility with cost efficiency. Annual debt payments of $6.23 million underscore the need for steady revenue from electricity sales and carbon credits, ensuring cash flow stability. This carefully designed financial framework enhances the project's bankability, meeting lender requirements while delivering attractive returns to investors, ultimately supporting Indonesia's transition to sustainable energy.

The combination of regulatory-aligned general assumptions and market-reflective financial parameters ensures that the project is financially grounded, policy-compliant, and investment-ready.

The RETScreen model used in this analysis enables a holistic assessment of financial performance, integrating technical, economic, and environmental variables.

Table 6. Annual Revenue

Electricity Export Revenue		
Electricity Exported to Grid	MWh	87.600
Electricity Export Rate	$/kWh	0,11
Electricity Export Revenue	$	9.636.000
Electricity Export Escalation Rate	%	2
GHG Reduction Revenue		
Net GHG Reduction	tCO_2/yr	65.456
Net GHG Reduction – 15 year	tCO_2	981.835
GHG Reduction Credit Rate	$/ tCO_2	5
GHG Reduction Revenue	$	327.278
GHG Reduction Credit Duration	year	15
GHG Reduction Credit Escalation Rate	%	2

In Table 6, the Annual Revenue section presents the two primary income streams of the Poto Tano wind energy project generates annual revenue through two primary income streams: electricity exports and GHG reduction credits. Electricity export revenue, based on an annual generation of 87,600 MWh at $110/MWh, yields $9,636,000 per year, with a 2% annual escalation rate to account for tariff adjustments. GHG revenue comes from carbon savings of 65,456 tCO_2 annually, priced conservatively at $5/ton, contributing $327,278 per year, also with a 2% escalation rate to reflect potential market growth. Both revenue streams align with the project's 15-year operational lifespan, matching standard carbon credit certification periods. This dual-income structure ensures financial stability by diversifying revenue sources, reducing reliance on a single market, and mitigating risks from energy price volatility or policy changes.

Table 7. Costs, Savings, Revenue

Initial Cost ($)		
Feasibility Research	5%	3.125.000
Development	20%	12.500.000
Engineeering	25%	15.625.000
Power System	40%	25.000.000
Balance of system & miscellaneous	10%	6.250.000
Total Initial Cost	**100%**	**62.500.000**
Yearly Cash Flow – Year 1 ($)		
Annual Cost & Debt Payment	O&M	1.875.000
	Debt Payment – 10 years	6.229.016
	Total	8.104.016

Annual Savings & Revenue	Electricity Export Revenue	9.636.000
	GHG Reduction Revenue – 15 years	327.278
	Total	9.963.278
Net Yearly Cash Flow – Year 1		**1.859.263**

Table 7 details the initial capital expenditures and the expected Year 1 cash flow performance. The total capital cost is $62,500,000, allocated across major development stages.

The Feasibility Research accounts for 5% ($3,125,000), covering site identification, wind resource assessment, and preliminary financial modeling. The Development phase receives 20% ($12,500,000), reflecting the cost of permitting, legal processing, stakeholder consultations, and securing project financing. Engineering costs are budgeted at 25% ($15,625,000), including detailed design, procurement planning, and project management services. The Power System, the largest cost component at 40% ($25,000,000), includes turbine procurement, grid connection, and related electrical infrastructure. Finally, 10% ($6,250,000) is set aside for Balance of System and miscellaneous expenses, encompassing civil works, foundations, and contingency allowances.

Year 1 operating costs include $1,875,000 in Operations and Maintenance (O&M), covering routine servicing, parts replacement, insurance, and labor. The debt servicing cost of $6,229,016 represents the annual repayment obligation. This brings the total Year 1 outflow to $8,104,016.

Revenues for the same period include $9,636,000 from electricity sales and $327,278 from carbon credits, totaling $9,963,278. The resulting Net Yearly Cash Flow is $1,859,263, demonstrating the project's ability to generate surplus cash after meeting operational and financing costs. This positive cash flow confirms short-term financial viability and sets the foundation for long-term profitability.

Table 8. Financial Viability

Pre-tax IRR – Equity	%	16,7
Pre-tax MIRR – Equity	%	12
Pre-tax IRR – Assets	%	2,1
Pre-tax MIRR – Assets	%	3,4
Simple Payback	Year	7,7
Equity Payback	Year	7,5
Net Present Value (NPV)	**$**	**17.311.978**
Annual Life Cycle Savings	**$/year**	**2.022.551**
Benefit-Cost (B-C) Ratio		1,9
Debt Service Coverage		1,3

GHG Reduction Cost	**$\$/tCO_2$**	**-30,90**
Energy Production Cost	**$/kWh**	**0,107**

Financial performance metrics are provided in Table 8. The Pre-tax IRR on Equity is 16.7%, indicating strong profitability from an equity investor's perspective. The Pre-tax MIRR on Equity, a more conservative measure that assumes reinvestment at the reinvestment rate (6%), is 12%, still demonstrating healthy returns.

Asset-level metrics include a Pre-tax IRR on Assets of 2.1% and a MIRR of 3.4%. These lower returns are expected since they factor in the entire capital base, including debt. However, they remain positive and signify efficient use of capital.

The Simple Payback Period is 7.7 years, while the Equity Payback Period is 7.5 years, both suggesting timely recovery of the initial investment. The Net Present Value (NPV) of $17,311,978, using the 8% discount rate, affirms that the project generates returns beyond the initial outlay. The Benefit-Cost (B-C) Ratio of 1.9 indicates that for every dollar invested, $1.90 is returned in value, nearly doubling the capital outlay.

Debt Service Coverage Ratio (DSCR) stands at 1.3, meaning the project earns 30% more than required to meet its debt obligations. This is a key indicator of financial stability, showing the project's ability to meet liabilities even in adverse conditions.

The GHG Reduction Cost is negative (-$\$30.90/tCO_2$), meaning emissions are reduced while simultaneously generating financial benefits. The Energy Production Cost of $0.107 per kWh positions the wind farm competitively, particularly as fossil fuel prices fluctuate and environmental externalities are increasingly internalized.

Table 9. Yearly Cash Flow

Year	Pre-IRR ($)	Cumulative ($)
0	**-18750000**	-18750000
1	2002278,13	-16747721,87
2	2147591,5	-14600130,37
3	2295231,77	-12304898,59
4	2445228,09	-9859670,5
5	2597609,68	-7262060,82
6	2752405,8	-4509655,02
7	2909645,75	-1600009,27
8	3069358,85	**1469349,58**
9	3231574,4	4700923,98
10	3396321,7	8097245,68
11	9792645,77	17889891,45

12	9962544,3	27852435,74
13	10135062,16	37987497,91
14	10310228,4	48297726,31
15	10488071,91	58785798,22

Table 9 details the project's cash flow over its 15-year operational life. Year 0 records the initial equity investment of $18,750,000. Starting from Year 1, the project generates positive annual cash flows, beginning at $2,002,278 and growing annually due to escalation in electricity and carbon credit prices.

By Year 8, the project achieves a break-even point, with cumulative cash flow turning positive. Beyond this point, each year adds substantially to total returns, culminating in a cumulative cash flow of $58,785,798 by Year 15. These figures confirm long-term profitability, affirming the project’s bankability and alignment with investor expectations.

From the accompanying graphs, annual cash flow demonstrates consistent year-over-year growth, reflecting steady operational performance and favorable market assumptions. Cumulative cash flow shows a typical S-curve trajectory, with early investment recovery followed by accelerating returns, a hallmark of successful infrastructure projects.

Sensitivity Analysis

Sensitivity analysis in wind energy projects is crucial for assessing how changes in key variables impact the overall financial and operational performance. This analysis focuses on three primary financial metrics: Energy Production Cost (EPC), Equity Payback, and Net Present Value (NPV), with each evaluated against variations in Initial Costs, Operations and Maintenance (O&M) Costs, Electricity Export Rate, and Electricity Export Volume.

Energy Production Cost

The Energy Production Cost (EPC) captures the cost per unit of energy generated and is defined as:

$$Energy\ Production\ Cost = \frac{Total\ Lifetime\ Cost}{Total\ Lifetime\ Electricity\ Output}$$

Where CRF is the Capital Recovery Factor. This formula reflects how both capital and operational expenditures influence the cost-efficiency of electricity generation.

Variations in Initial Costs directly influence EPC. For instance, at the baseline, the EPC is $110.50/MWh. A 25% reduction in initial costs lowers the EPC to $80.22/MWh, whereas a 25% increase raises it to $120.60/MWh. Likewise, O&M costs significantly impact EPC. Reducing these costs by 25% brings the EPC down to $86.78/MWh, while a 25% increase pushes it to $120.60/MWh. These dynamics underscore that both CapEx and O&M expenses must be carefully managed to ensure competitive pricing.

Changes in Electricity Export Volume and Rate also shape EPC. While increasing the electricity export rate (e.g., by 25%) does not change EPC when the exported volume is fixed, altering the quantity of electricity exported profoundly affects it. Exporting 109,500 MWh instead of the baseline 87,600 MWh drops the EPC to $85.57/MWh, whereas a reduction to 65,700 MWh hikes the EPC to $142.62/MWh. This clearly shows that maximizing electricity export volumes is instrumental in maintaining low production costs.

Equity Payback

Equity Payback refers to the time required to recover the equity investment from project-generated net cash flows. It is calculated as:

$$\textit{Equity Payback} = \frac{\textit{Initial Equity Investment}}{\textit{Annual Net Cash Flow}}$$

This metric is sensitive to both Initial and O&M Costs. At baseline ($62,500,000 initial cost), the Equity Payback is 7.5 years. Reducing the initial cost by 25% shortens it to 3.5 years, while a 25% increase stretches it to 10.6 years. Similarly, a 25% decrease in O&M costs shortens the payback to 5.3 years, whereas a 25% rise extends it to 11.2 years.

The Electricity Export Rate and Volume also affect Equity Payback. Increasing the export rate to $137.50/MWh reduces the payback period to 5.7 years, while reducing it to $82.50/MWh elongates it. Similarly, exporting more electricity (109,500 MWh) cuts the payback period to 4.2 years, but if the volume drops to 65,700 MWh, it exceeds the project's expected lifespan, reflecting critical risk exposure. This underscores the project's reliance on maintaining both favorable electricity pricing and high generation output.

Net Present Value (NPV)

NPV represents the difference between the present value of cash inflows and outflows over the project's lifetime and is calculated using:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+r)^t} - C_0$$

At baseline ($62,500,000), the NPV is $17,311,978, indicating viability. A 25% reduction in initial cost increases NPV to $37,362,496, while a 25% increase flips it to -$4,632,035. This change reflects how front-loaded capital costs can make or break the investment's attractiveness.

Lower O&M costs (by 25%) increase NPV to $24,880,378, while higher costs (by 25%) reduce it to $7,215,177. Operational efficiency is thus essential to maintaining positive investment value.

A 25% increase in electricity export rate pushes NPV to $40,889,692, whereas a 25% decrease causes a substantial loss (-$23,949,021). This indicates the sensitivity of profitability to market price dynamics. Moreover, increasing the volume of exported electricity to 109,500 MWh raises NPV equivalently to $40,889,692, while reducing it to 65,700 MWh drives NPV to the same loss point, -$23,949,021. Hence, stable and high output not only secures revenue but also serves as a protective buffer against investment risk.

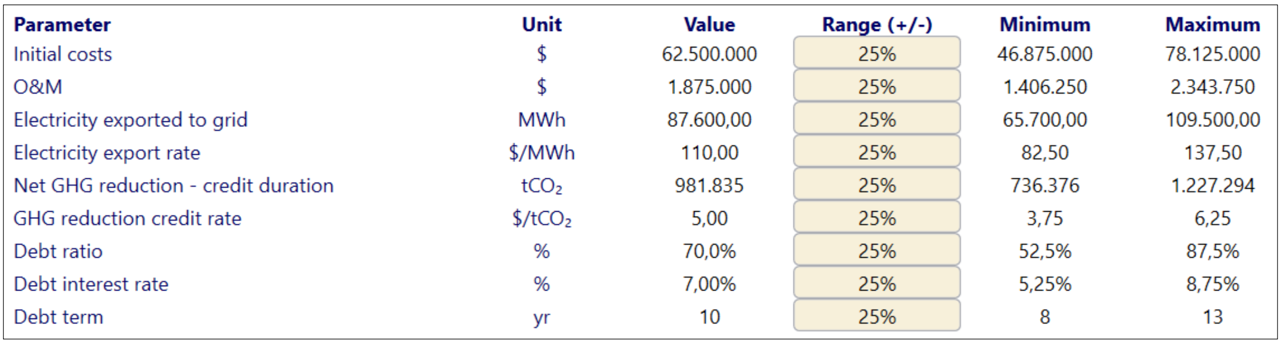
Taken together, these outcomes emphasize that a financially viable wind project hinges on four key levers: minimized capital and O&M expenditures, maximized electricity generation and export, and favorable, stable electricity export rates. In Poto Tano's context, these levers are particularly critical given the remote location and infrastructure dependencies, reinforcing the need for meticulous financial planning and operational efficiency to ensure long-term success.

Risk Analysis

Risk analysis is a vital component in evaluating the feasibility of renewable energy projects, particularly wind energy, where financial and operational variables can fluctuate significantly throughout the project's lifecycle. Table 13 outlines the key parameters used in the risk analysis: initial cost, O&M cost, electricity exported to the grid, electricity export rate, net GHG reduction, GHG reduction credit rate, debt ratio, debt interest rate, and debt term. Each of these variables was analyzed with a ±25% variation to account for uncertainties. Two major methodologies are used to assess the risk profile of the project: Impact Analysis and Monte Carlo-based Distribution Analysis.

Impact Analysis briefly assesses how the variation of each parameter individually influences the main financial indicators—Energy Production Cost, Equity Payback, and Net Present Value (NPV). The analysis, based on software output, provides a qualitative understanding of which inputs most strongly affect the outcomes, offering guidance for focusing risk mitigation strategies.

Table 10. Risk Analysis Parameter



Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	62.500.000	25%	46.875.000	78.125.000
O&M	$	1.875.000	25%	1.406.250	2.343.750
Electricity exported to grid	MWh	87.600,00	25%	65.700,00	109.500,00
Electricity export rate	$/MWh	110,00	25%	82,50	137,50
Net GHG reduction - credit duration	tCO_2	981.835	25%	736.376	1.227.294
GHG reduction credit rate	$\$/tCO_2$	5,00	25%	3,75	6,25
Debt ratio	%	70,0%	25%	52,5%	87,5%
Debt interest rate	%	7,00%	25%	5,25%	8,75%
Debt term	yr	10	25%	8	13

Energy Production Cost

The Monte Carlo simulation in Figure 5 presents the distribution of potential energy production costs. On the x-axis lies the energy cost per MWh (USD), while the y-axis shows the frequency or probability of each range. The simulations indicate a cost range from $91.37/MWh to $125.95/MWh, reflecting variability due to fluctuating inputs such as capital costs and energy generation levels.

The most probable value, indicated by the mode of the distribution, is $109.57/MWh. This figure appears with the highest frequency (~8%), suggesting that under most conditions, this value is the expected cost benchmark. Lower-end values like $91.37/MWh, though possible, are less frequent and likely result from optimal conditions (e.g., low CapEx or high generation). Conversely, the upper limit of $125.95/MWh appears in less favorable scenarios, including reduced electricity generation or increased operational costs. This spread underscores the importance of controlling key input parameters to manage energy cost variability.

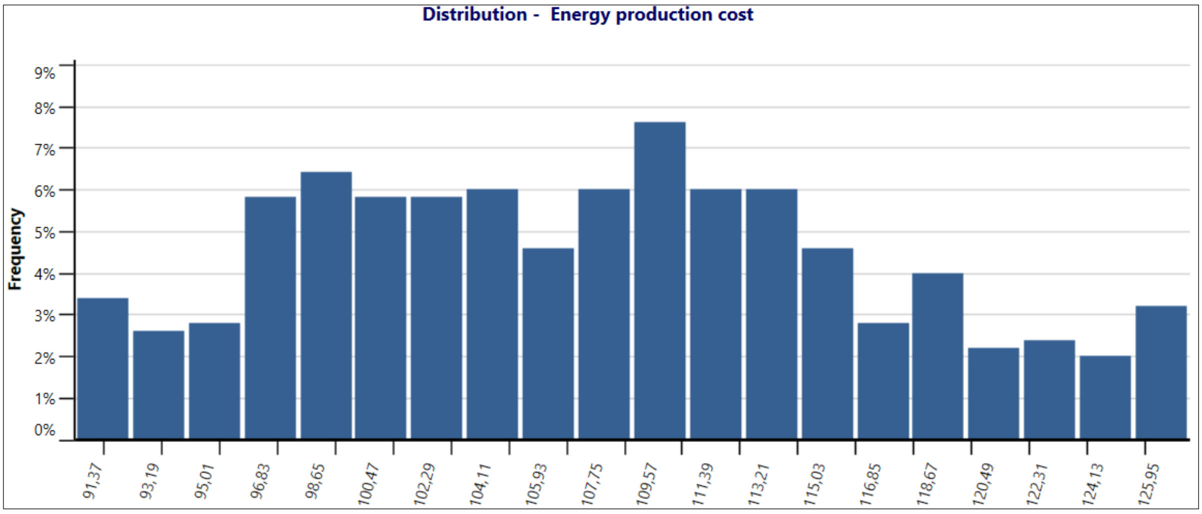


Figure 2. Distribution on Energy Production Cost

Equity Payback

Monte Carlo simulation results for equity payback, as shown in Figure 6, provide a probability distribution of how quickly the project's equity investment can be recovered. The x-axis represents the payback period in years, while the y-axis indicates frequency. The distribution ranges from a minimum of approximately 4.3 years to a maximum of 11.5 years, illustrating the uncertainty stemming from parameter fluctuations.

The most likely outcome is centered around 9.6 years, forming the peak of the distribution. A dense cluster is found between 8.1 and 10.7 years, reflecting the range where most simulation results fall. The left tail, where shorter payback periods (4.3 to 6.2 years) are found, suggests optimistic scenarios involving favorable electricity prices or minimized costs. On the other hand, the right tail (10.7 to 11.5 years) signals the risks of extended payback in the event of adverse financial or operational conditions. This distribution supports the need for strategic control over revenue streams and cost elements to ensure investment recovery within a reasonable timeframe.

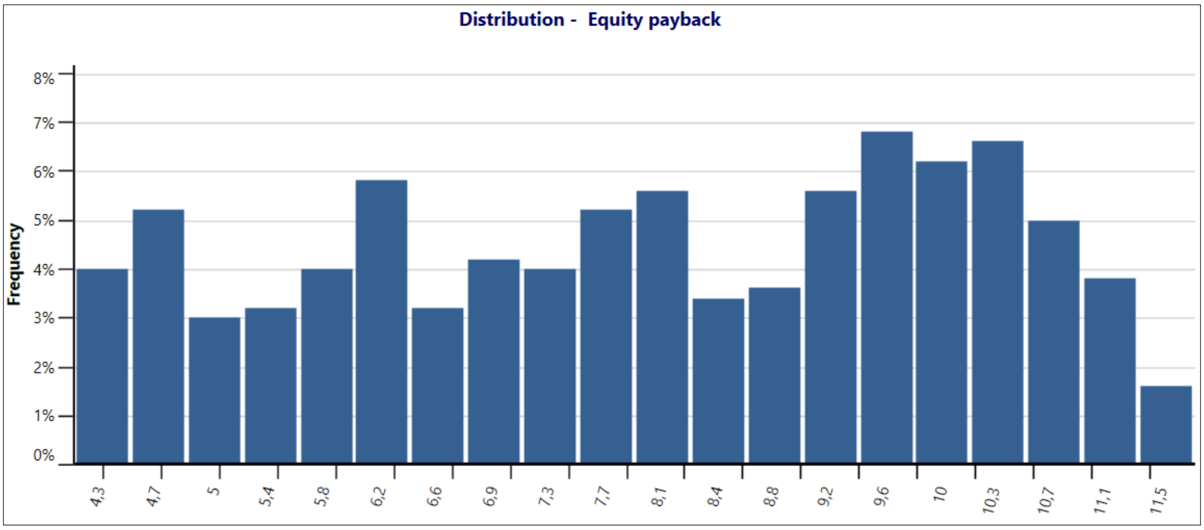


Figure 3. Distribution on Equity Payback

Net Present Value (NPV)

Figure 7 illustrates the Monte Carlo simulation output for Net Present Value. The x-axis displays the NPV outcomes in USD, and the y-axis shows the likelihood of each value (Suryani et al., 2024). The distribution is skewed and not perfectly symmetrical, signifying uneven risks and returns under different variable conditions (Pavel et al., 2017).

The most frequent NPV appears at the mode of the curve and reflects the most probable financial return from the project, assuming base-case conditions. The left tail of the distribution shows potential negative NPVs, occurring under scenarios such as low electricity export volumes or high capital and O&M costs. These outcomes serve as cautionary markers for the project's financial risk. In contrast, the right tail includes high NPV values, representing scenarios where the project performs better than expected—through increased electricity sales or lower costs (Reategui & Hendrickson, 2011).

The width of the distribution spread is a critical indicator of financial uncertainty. A wider spread implies a high level of sensitivity to input fluctuations, making it essential to reduce uncertainty in key inputs such as export prices, capital investment, and operating costs. Managing these risks effectively can help push the distribution toward higher NPVs and enhance project bankability (Silalahi et al., 2022).

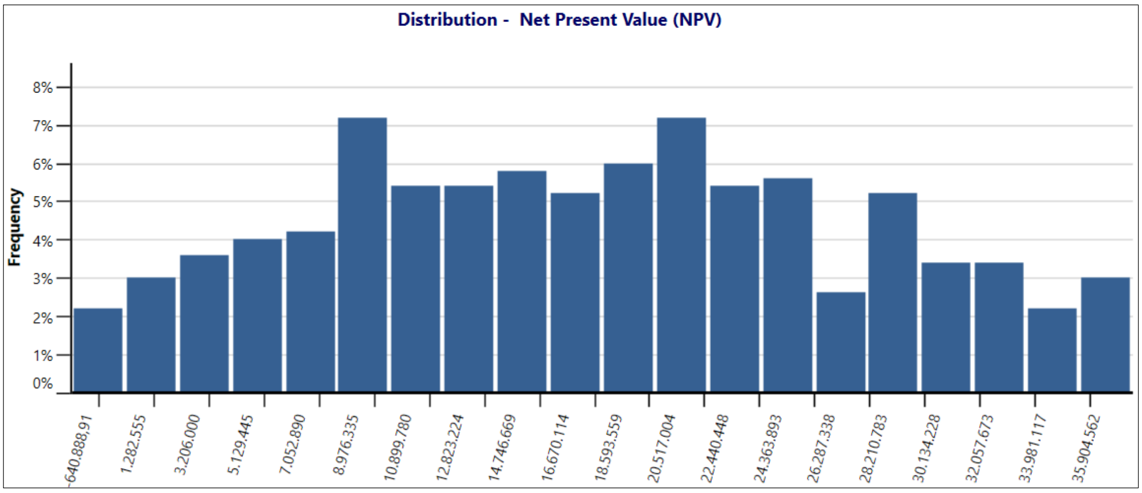


Figure 7 Distribution on Net Present Value (NPV)

Discussion

The comprehensive analysis of the Poto Tano wind energy project reveals its technical, environmental, and financial viability, offering a realistic pathway toward expanding Indonesia's renewable energy portfolio. This section integrates key findings to evaluate the site's potential, financial robustness, and the role of risk in long-term sustainability. From a technical standpoint, the energy production analysis affirms the feasibility of wind power development in Poto Tano. Although the wind speeds are moderate—averaging 2.6 m/s—the region benefits from consistent wind availability, enabling a high capacity factor of 40%. This figure surpasses comparable projects in Indonesia and suggests efficient and reliable energy generation. The project is expected to generate 87.6 million kWh annually, reinforcing the region's strategic importance in supporting national clean energy targets (Veers et al., 2020).

Financially, the project entails substantial commitments, with capital expenditures totaling $62.5 million and annual operational costs of $1.875 million. These figures reflect investments across feasibility studies, engineering, development, and infrastructure. The financial model, which includes a 70% debt ratio, requires a careful balancing act to manage debt payments of $6.229 million per year. The project's revenue stream is further strengthened by the sale of electricity to the grid and the generation of GHG Reduction Revenue of $327,278 annually through carbon credits. Environmental benefits are equally compelling. Emission reductions are projected at 6,480.1 tCO2 per year, positioning wind energy as a viable zero-emission alternative. This aligns with Indonesia's emission reduction commitments and creates additional value through carbon markets (Xiuqi et al., 2023; Zhang et al., 2023; Zhou et al., 2014).

The financial performance analysis yields encouraging metrics: a Net Present Value (NPV) of $17.3 million, a pre-tax Internal Rate of Return (IRR) of 16.7%, and a Benefit-Cost Ratio of 1.9. The equity payback period is estimated at 7.5 years. These indicators suggest that, under base case assumptions, the project is financially sound and attractive to investors. Impact analysis confirms that variables like electricity exported to the grid, export rate, and initial costs exert the greatest influence on cost and return outcomes. Although impact analysis offers a broad qualitative view, it is through the Monte Carlo simulations that a more granular understanding of risk is achieved.

The energy production cost simulations show a concentration around $109.57/MWh, while equity payback distributions cluster near 9.6 years. For NPV, most outcomes range around the $17 million mark, with wider spreads illustrating financial uncertainty. These simulations reinforce the importance of anticipating variability in key parameters. Altogether, these findings emphasize that while the project offers clear environmental and economic benefits, its success hinges on strategic planning, operational efficiency, and proactive risk mitigation.

CONCLUSION

The feasibility assessment of the wind energy project in Poto Tano, West Sumbawa, demonstrates strong potential in energy production, financial returns, and environmental impact. With stable wind speeds averaging 2.6 m/s and a capacity factor of 40%, the project is capable of generating 87.6 million kWh annually, significantly contributing to regional renewable energy supply. Financially, despite a substantial initial investment of $62.5 million and annual O&M costs of $1.875 million, the project shows sound viability with an NPV of $17.3 million, an IRR of 16.7%, and a payback period of 7.5 years. Environmentally, it offers notable benefits by reducing CO_2 emissions by roughly 6,480 tons per year, aligning with Indonesia's climate goals, and generating additional revenue through carbon trading. Sensitivity analysis highlights the need for careful financial planning and risk management due to vulnerabilities to key cost and price fluctuations. Future research should enhance wind resource assessment with advanced meteorological techniques, explore energy storage solutions to address intermittency, conduct thorough environmental and social impact evaluations, and promote collaborative partnerships among government, investors, and research institutions to support scaling and replication of wind energy projects across Indonesia.

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