Net Present Value (NPV) Analysis of Solar Microgrids for Off-Grid Rural Schools in the Philippines, integrating Carbon Credit Valuation and Sensitivity Analysis

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Abstract. This research investigates the economic feasibility of solar microgrid deployment in five remote off-grid educational facilities across the Philippines—spanning Regions XII, IVB, X, IX, and BARMM—utilizing a multi-criteria financial framework involving Net Present Value (NPV), carbon credit valuation, and sensitivity analysis. The study addresses the critical research gap in transitioning from diesel-dependent paradigms to decentralized renewable energy by quantifying the fiscal barriers to rural electrification. Baseline NPV results across all five sites yielded consistently negative values, confirming that under current market conditions and without external subsidies, standalone solar microgrids remain economically prohibitive for off-grid schools. While carbon credit integration offers a mechanism for quantifying environmental externalities, the current market valuation of ₱500/ton (approx. USD 8.50/ton) CO_2 provides an annual revenue of only ₱704.31 to ₱1,408.61, which is an insufficient fiscal offset to achieve break-even points. Stochastic sensitivity analysis identifies the discount rate (8%–14%) and Capital Expenditure (CAPEX)as the most critical determinants of project viability. The findings underscore a systemic "viability gap" that necessitates strategic policy interventions, including grant-based funding, low-interest green financing, and community-led ownership models to bridge the divide between environmental necessity and financial sustainability in developing island nations.

1 Introduction

1.1 Background of the study

The global imperative for sustainable energy has intensified as developing nations seek to bridge energy access gaps while meeting climate commitments [1]. In the Philippines, an archipelagic nation with complex geographical barriers, off-grid rural communities—particularly educational facilities—suffer from persistent energy deficits that hinder

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socio-economic development [2]. Historically, these remote areas have relied on localized diesel generators; however, these systems are increasingly untenable due to volatile fuel prices, high maintenance costs, and significant environmental degradation [3].

Solar photovoltaic (PV) microgrids have emerged as a decentralized and resilient alternative, leveraging the region's abundant solar irradiance to provide clean, reliable power [4]. For rural schools, the electrification provided by these systems is a critical catalyst for digital literacy and improved learning outcomes [5]. Despite the clear social and environmental advantages, the deployment of solar microgrids in the Philippines faces significant financial hurdles, requiring robust economic appraisal to justify public expenditure and attract private investment [6].

1.2 Statement of the Problem

While the technical viability of solar microgrids is well-established, their economic feasibility in the specific context of Philippine rural schools remains precarious [7]. Traditional financial assessments, such as standard Net Present Value (NPV) calculations, often yield negative results because they fail to account for the "green" value of the project, such as avoided carbon emissions [8]. Furthermore, renewable energy investments are highly sensitive to fluctuating market conditions—including discount rates and capital expenditures (CAPEX)—which can drastically alter project outcomes [9]. There is a critical research gap in applying a multidimensional economic model that integrates Carbon Credit Valuation and Sensitivity Analysis to determine if these environmental "hidden values" can flip the financial narrative for off-grid educational electrification [10].

1.3 Research Objectives

To evaluate the economic feasibility of implementing solar microgrids for off-grid rural schools in the Philippines through a Net Present Value (NPV) analysis that incorporates carbon credit valuation and sensitivity analysis. Specifically,

1.3.1. To construct a comprehensive Net Present Value (NPV) model that evaluates the financial viability of solar microgrids for off-grid rural schools in the Philippines, incorporating key financial parameters such as capital expenditures (CAPEX), operational expenditures (OPEX), energy production, and discount rates.

1.3.2. To integrate the economic value of carbon emissions avoided through carbon credit valuation into the NPV model using relevant market prices and emission factors to assess the environmental benefits of solar microgrids.

1.3.3. To perform a sensitivity analysis by varying key input parameters such as discount rates, solar irradiation, and energy prices to determine the impact on the NPV and evaluate the robustness of the financial projections.

1.4 Scope and Limitation

The scope of this research is specifically focused on the economic feasibility of solar microgrids in five selected off-grid rural schools across different regions of the Philippines. The analysis is primarily centered on Net Present Value (NPV) modeling, incorporating carbon credit valuation and sensitivity analysis based on 2023–2024 market conditions. Technical evaluations are limited to solar photovoltaic (PV) system efficiency and estimated energy production derived from localized irradiation data.

However, the study is subject to several limitations, including the reliance on purposive sampling which may not represent the diverse energy needs of all 47,000+ Philippine public schools. The financial projections are also constrained by the volatility of international carbon market prices and the accuracy of local diesel cost data. Additionally, the study does not account for the long-term social impact or the psychological benefits of electrification on student performance, focusing strictly on quantitative economic metrics.

1.5 Significance of the Study

This study provides a critical economic framework for stakeholders aiming to bridge the energy access gap in the Philippines [1]. For policymakers, the research offers empirical data on how carbon credit valuation can be leveraged to offset the high capital costs of rural electrification [8, 11]. Educational institutions benefit from a clearer understanding of how reliable energy directly supports digital literacy and long-term learning outcomes [4, 5]. Furthermore, this research contributes to the global discourse on "energy democracy" by demonstrating how decentralized microgrids can empower marginalized communities [12]. Finally, for private investors, the sensitivity analysis identifies the specific financial thresholds required to make off-grid solar projects a viable alternative to traditional fossil fuel-based systems [9, 13]

1.6 Conceptual Framework

The conceptual framework of this study is structured using an Input-Process-Output (IPO) model to systematically evaluate the economic feasibility of solar microgrids, as shown in figure 1.

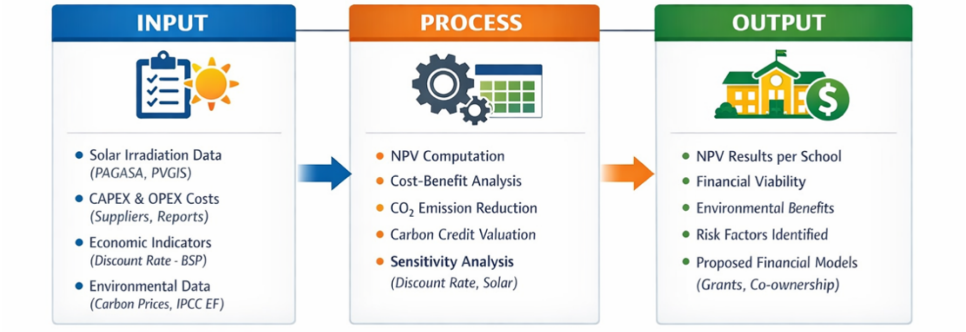

Fig. 1. IPO Model

The Input stage involves the collection of foundational technical, financial, and environmental data required for the analysis. This includes solar irradiation values derived from PAGASA and online databases like PVGIS, as well as capital expenditures (CAPEX) and operational expenditures (OPEX) sourced from local supplier quotations and industry reports. Furthermore, the model incorporates economic indicators such as discount rates from the Bangko Sentral ng Pilipinas and environmental parameters including carbon credit market prices and IPCC emission factors for diesel generators.

The Process stage entails the quantitative modeling and analysis of the collected data through a spreadsheet-based system. At this phase, the Net Present Value (NPV) is calculated using the standard formula, factoring in the time value of money and battery replacement costs. The process also integrates environmental valuation by quantifying avoided CO_2 emissions and converting them into annual carbon credit revenue streams. Finally, a Sensitivity Analysis is performed by varying key parameters—such as discount rates and solar irradiation—to evaluate the robustness of the financial projections across different scenarios.

The Output stage represents the empirical findings and strategic conclusions derived from the analysis. The primary results include the determined NPV for each of the five selected rural schools, highlighting their financial viability or lack thereof under current market assumptions. Additionally, the output provides a monetary valuation of the environmental benefits and identifies critical risk factors through sensitivity results. Ultimately, these findings culminate in proposed alternative financial models, such as grant funding and community co-ownership, to support the sustainable adoption of solar microgrids in remote educational settings.

1.7 Theoretical Framework

The study is grounded in the integration of classical financial investment theories, environmental economics, and risk management principles to address the unique challenges of rural electrification. At the core of the framework is the Net Present Value (NPV) Theory, a fundamental principle of corporate finance which asserts that the value of an investment is the sum of its discounted future cash flows minus initial costs [6]. This theory provides the primary mathematical lens for evaluating the long-term economic viability of solar microgrids by accounting for the time value of money.

However, because traditional NPV often overlooks non-market benefits, this study incorporates Environmental Externality Theory, which argues that the "hidden" environmental costs or benefits of a project—such as avoided CO2emissions—should be internalized into the financial model [7, 8]. This is operationalized through Carbon Credit Valuation, assigning a tangible monetary value to the environmental displaced costs of diesel generation.

Furthermore, the framework utilizes Sensitivity and Risk Theory to account for the inherent uncertainties of renewable energy investments [9, 10]. Since factors such as solar irradiance, capital expenditures (CAPEX), and discount rates are subject to market and climatic fluctuations, sensitivity analysis allows for the examination of how variations in these input parameters impact the robustness of the project's profitability. By combining these theories with principles of Reliability Engineering and global investment standards, the framework shifts the appraisal from a narrow commercial focus to a comprehensive perspective that evaluates the project’s financial and environmental sustainability in developing nations [14, 15].

2 Review of Related Literature

The appraisal of renewable energy projects in the modern era necessitates a move beyond simple cost-benefit analysis [1]. R. Brealey et al. emphasize that Net Present Value (NPV) remains the primary metric for assessing long-term investment viability, as it accurately accounts for the time value of money [6]. However, in the specific context of environmental economics, R. Perman et al. and C. Hepburn argue that traditional NPV models often overlook critical environmental externalities [7, 8]. By quantifying avoided CO2 emissions through formal carbon credit valuation, researchers can more accurately reflect the total social and environmental return on investment [2, 8].

In Southeast Asia, the Asian Development Bank has highlighted that high upfront capital costs remain the primary barrier to widespread microgrid adoption [11]. This financial barrier is compounded by technical and market uncertainties; J. Mun and S. Awerbuch suggest that sensitivity analysis and risk modeling are essential to address the inherent variability in solar irradiance and fuel price fluctuations [9, 10]. Recent studies by B.K. Sovacool et al. further suggest that community-based financial models and policy advocacy are necessary when purely commercial metrics fall short of project goals [13].

Furthermore, the integration of reliability engineering can optimize the long-term operational sustainability of these installations to protect against technical failure [14]. Global energy investment trends reported by the International Energy Agency support the transition toward decentralized grids to ensure a just and resilient energy transition [15]. Finally, regional economic updates emphasize that off-grid solar solutions are increasingly recognized as the most cost-effective path for rural electrification in developing island nations where centralized infrastructure is physically and financially prohibitive [11, 12]

3 Methodology

3.1 Research Design

This study employs a quantitative economic modeling approach to evaluate the feasibility of solar microgrids in five off-grid rural Philippine schools. The research design integrates Net Present Value (NPV) analysis with environmental externalities and sensitivity testing to address the financial complexities of renewable energy in remote settings.

3.2 Sampling Site and Selection

A purposive sampling method was utilized to select five remote elementary schools from Region IV-B, Region IX, Region X, Region XII, and BARMM. These sites were chosen based on their status as "far-off" schools identified by the National Electrification Administration (NEA) and Department of Education (DepEd) as lacking reliable electricity access. This selection ensures geographical diversity across the Philippines and represents varying solar irradiation zones and student populations.

3.3 Data Acquisition and Parameters

Technical and financial data were synthesized from multiple legitimate sources to ensure model accuracy.

- **Technical Input:** Solar irradiation data ($kWh/m^2/day$) were retrieved from PAGASA and verified via Global Solar Atlas and PVGIS.

- **Cost Parameters:** Capital Expenditures (CAPEX) were derived from 2023-2024 market supplier quotations, while Operational Expenditures (OPEX) were estimated based on industry standards for maintenance and battery replacement cycles.

- **Financial Rates:** Discount rates were set between 8% and 14%, reflecting potential fluctuations in project risk and local financing costs based on Bangko Sentral ng Pilipinas and World Bank standards.

3.4 Mathematical Modelling

The economic viability was determined through a spreadsheet-based NPV model using the following governing equation:

$$NPV = -CAPEX + \sum_{t=1}^{n} \frac{CF_t + CR_t}{(1+r)^t} - PV_{battery} \quad (1)$$

Where:
- CF_t represents the annual avoided diesel fuel costs.
- CR_t is the Carbon Credit Revenue, calculated by multiplying the avoided emissions (2.68 kg CO_2/kWh) by a conservative market price of P0.50/kg.
- r is the discount rate.
- $PV_{battery}$ is the present value of scheduled battery replacements.

3.5 Sensitivity Analysis

To assess the robustness of the financial projections, a sensitivity analysis was conducted by varying four primary variables by ±10%: CAPEX, discount rate, solar irradiation, and energy prices. This allows for the identification of which parameters most significantly influence the project's economic "break-even" point in the Philippine context.

4 Results and Discussion

4.1 Net Present Value (NPV) per School

The financial appraisal of solar microgrids for the five selected sites—Region XII, Region IVB, Region X, Region IX, and BARMM—yielded consistently negative Net Present Value (NPV) results [7, 8]. Based on 2023–2024 market conditions, the NPV ranged from -₱274,452.99 to -₱477,842.01, as shown in Table 1, confirming that under current standalone commercial assumptions, these projects are not financially viable [6, 9].

This economic deficit is primarily attributed to the high Capital Expenditure (CAPEX) required for off-grid battery-integrated systems, which ranges from ₱324,600 to ₱840,000 per site [1, 6]. Furthermore, the periodic cost of battery replacements acts as a significant "silent" financial burden that traditional renewable energy models often underestimate [14]. These findings align with reports from the Asian Development Bank, which identify high upfront costs as the leading barrier to microgrid adoption in the Philippines [11].

Table 1. Calculated Net Present Value (NPV) for each school

Rural Schools	NPV,Php
Elementary School in Region XII	-274,452.99
Elementary School in Region IV-B	-477,842.01
Elementary School in Region X	-321,085.86
Elementary School in Region IX	-425,673.38
Elementary School in BARMM	-277,963.77

4.2 Impact of Carbon Credit Valuation

To quantify the environmental benefits, the study integrated carbon credit revenue based on an emission factor of 2.68 kg CO2/kWh [2, 7]. While the solar microgrids successfully displaced diesel-based emissions, the resulting annual revenue was modest, ranging from ₱704.31 to ₱1,408.61 per school, as shown in Table 2.

Albeit this revenue stream provides a consistent economic benefit and enhances the project's "green" profile, it is currently insufficient to flip the negative NPV into positive territory at a carbon price of ₱500 per ton (approx. USD 8.50). This highlights a critical policy gap: for carbon credits to meaningfully drive rural electrification, higher market valuations or secondary environmental subsidies are required [8, 12].

Table 2. Calculated Annual Carbon Credit Revenue for each school

Rural Schools	Energy per year, kWh	Estimated Avoided Emission, kg CO_2	Annual Carbon Credit Revenue, Php
Elementary School in Region XII	525.60	1408.61	704.31
Elementary School in Region IV-B	1051.20	2817.22	1408.61

Elementary School in Region X	657.00	1759.76	879.88
Elementary School in Region IX	919.80	2465.08	1232.53
Elementary School in BARMM	788.40	2112.91	1056.46

4.3 Robustness through Sensitivity Analysis

The sensitivity analysis revealed that the projects are most volatile concerning Discount Rates and CAPEX [9, 10]. A ±10% variation in these parameters resulted in NPV fluctuations of over ₱100,000 in some scenarios, particularly for the Elementary School in Region IVB, as illustrated in Table 3.

Table 3. Calculated New NPV for each school

Rural Schools	NPV,Php	New NPV,Php
Elementary School in Region XII	-274,452.99	-227,882.35 to -358,817.30
Elementary School in Region IV-B	-477,842.01	-394,402.32 to -628,485.42
Elementary School in Region X	-321,085.86	-266,419.53 to -419,373.57
Elementary School in Region IX	-425,673.38	-350,474.06 to -561,999.03
Elementary School in BARMM	-277,963.77	-230,488.19 to -361,865.78

Variations in solar irradiation and energy prices had a measurable but less drastic impact on the overall financial outcome [1, 14]. The fact that NPV remained negative across all tested variations underscores that the problem is structural rather than transactional [15]. Consequently, moving toward a "gold standard" implementation requires shifting from purely commercial financing to blended models involving grant funding, low-interest "green" loans, and community co-ownership [4, 5].

5 Conclusion

This study concludes that standalone solar microgrids for off-grid rural schools in the Philippines—specifically in Regions XII, IVB, X, IX, and BARMM—are currently not economically viable under conventional private-sector investment models. The Net Present Value (NPV) consistently yielded negative results, driven by high capital expenditures (CAPEX) and the recurrent financial burden of battery replacements. While the integration of Carbon Credit Valuation provides a measurable environmental benefit by quantifying avoided CO2 emissions, the current market valuation of ₱500 per ton (approx USD 8.50) is insufficient to offset the substantial upfront costs and operational deficits.

Furthermore, the sensitivity analysis highlights that project viability is most critically threatened by high discount rates and initial procurement costs, underscoring that the financial gap is structural rather than site-specific. Ultimately, while these projects offer profound social and educational value, they cannot be realized through market mechanisms alone; they require a paradigm shift in how "green" energy is financed for the public good.

6 Recommendation

To bridge the gap between technical feasibility and economic viability, several strategic interventions are recommended to support the sustainable adoption of solar microgrids in remote educational settings. First, the Philippine government, through the National Electrification Administration (NEA) and the Department of Education (DepEd), should aggressively pursue grant funding and subsidies to drastically reduce initial capital expenditures (CAPEX), effectively shifting financial risk away from end users in these vulnerable regions. In addition, multi-lateral agencies and financial institutions should provide low-interest "green" loans to mitigate the high sensitivity to discount rates identified in this study, which currently acts as a primary barrier to project profitability.

Moreover, there is a critical need for policy advocacy to establish higher carbon credit floor prices or secondary environmental subsidies, ensuring that the monetary value of avoided CO2 emissions becomes a significant and reliable revenue stream. Furthermore, implementing community participation and co-ownership models can enhance operational sustainability and reduce long-term maintenance overheads by fostering local stewardship of the energy infrastructure. Finally, future implementations should integrate advanced reliability engineering and predictive maintenance systems to extend the life cycles of critical components, such as batteries, thereby reducing the "silent" recurring costs that currently undermine the net present value of off-grid solar initiatives.

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