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A Comparative Analysis of Life Cycle Costs and Emissions in Mae Sariang's Microgrid Energy Scenarios

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ABSTRACT

This study evaluates the life cycle costs, net present value (NPV), and greenhouse gas (GHG) emissions of three energy scenarios for the Mae Sariang microgrid system to assess the economic and environmental impacts of different energy sources. The reliance on renewable energy has become increasingly vital in addressing energy sustainability and reducing carbon footprints. The analysis reveals that Scenario I, primarily utilizing solar energy, achieved the lowest life cycle cost per kilowatt-hour (kWh) at 6.18 and the highest NPV of 226,583,036 baht, while also producing the fewest GHG emissions at 21,239 $kgCO_2e$/year. In contrast, Scenario II, dependent on grid electricity, incurred the highest costs and emissions at 25,180 $kgCO_2e$/year, reflecting its reliance on higher-carbon sources. Scenario III, which incorporates diesel generation, demonstrated moderate emissions at 22,240 $kgCO_2e$/year but resulted in a negative NPV of -2,690,330 baht due to high fuel expenses. The findings highlight that prioritizing renewable energy sources not only enhances financial viability but also minimizes environmental impact. Therefore, the study concludes that adopting a renewable-focused approach in microgrid systems offers substantial economic and ecological benefits. Policy recommendations include incentivizing renewable energy integration, promoting energy efficiency measures, and developing supportive frameworks to reduce reliance on high-carbon electricity, ultimately enhancing the feasibility and sustainability of energy systems.

Keywords: Life Cycle Cost, Microgrid, Renewable Energy, Net Present Value, Greenhouse Gas
JEL Classifications: K2, L5, P5

1. INTRODUCTION

Thailand, a country with a rapidly growing economy and increasing energy demands, faces unique challenges in ensuring reliable, sustainable, and cost-effective energy access, particularly in its remote and rural areas (ERIA, 2021). The traditional centralized power generation and distribution systems, while effective in urban centers, often struggle to provide consistent energy to isolated communities. In this context, microgrids have emerged as a promising solution to address these challenges by offering localized power generation, which can be tailored to the specific needs of different regions (Meenual and Usapein, 2021).

Microgrids, which integrate renewable energy sources such as solar and wind with energy storage systems, provide an opportunity to reduce dependence on fossil fuels, enhance energy security, and mitigate environmental impacts (Colson and Nehrir, 2009; Lasseter and Paigi, 2004; Mahmoud et al., 2017). However, the adoption of microgrids in Thailand hinges not only on their technical feasibility but also on a thorough understanding of their life cycle costs (LCC). This encompasses the total costs associated with the development, operation, maintenance, and eventual decommissioning of microgrids over their lifespan.

To compare the life cycle cost (LCC) of microgrids, one must consider all of the expenses incurred during the microgrid's lifetime, including fuel, decommissioning, operation and maintenance (OandM), and initial capital costs. Understanding the long-term financial feasibility of microgrids in relation to conventional centralized power systems or alternative energy sources is made easier by this analysis. The comparison of life cycle cost can be shown in Table 1.

In Thailand, where government policies increasingly support renewable energy and decentralized power systems, understanding the life cycle costs of microgrids is essential for stakeholders, including policymakers, energy providers, and community leaders. This article aims to analyze the life cycle costs of microgrids in the Thai context, comparing them with traditional power systems and evaluating their economic viability in the long term. Through this analysis, we seek to provide insights into the potential of microgrids to contribute to Thailand's sustainable energy future.

2. METHODOLOGY

2.1. Life Cycle Cost Assessment

Life cycle cost assessment is a powerful tool in analyzing the economic sustainability of energy systems. The tool considers economic performance throughout the entire life cycle, covering investment, operations, maintenance and disposal. Effective life cycle cost assessments will require gathering enough data and, in some cases, making the assumptions necessary for the analysis. Life cycle cost analysis can be calculated according to equation 1.

Life cycle cost = Capital costs + Lifetime operating costs (1)

In cases where operating cost data cannot be collected, an estimation method based on a percentage of the investment budget will be used. Microgrid project operating costs are as low as 1% of the investment budget (Jacob et al., 2018) and do not exceed 5–13% of the investment budget (Arriaga et al., 2016; Horhoianu and Eremia, 2017).

2.2. Net Present Value (NPV)

The worthiness of investing in a microgrid project can be calculated from the Net Present Value (NPV). This indicator represents the calculation of cash flows by adjusting the value of cash flows occurring in each period to the same point, namely at the present. The calculation is shown as Equation 3.3.

$$NPV = \sum_{t=0}^{n} \frac{\text{Net cash flow}}{(1+i)^{t}} \quad (2)$$

Where, n refers to age of the system, t refers to year of operation, and i refers to interest rate. If the calculated NPV value is positive, it indicates that the project is profitable and worth for the investment. On the other hand, if the NPV is negative, the project is loss-making.

2.3. Greenhouse Gas Emission

To calculate greenhouse gas emission from each option of producing electricity from microgrid, the quantity of electricity from each source was used to mutiply with carbon intensity as shown in equation (3).

$$kWh_i \times CI_i = \text{GHG emissions} \quad (3)$$

Where, kWh_i refers to the electricity production of source i, and CI_i refers to carbon intensity of source i. Table 2 shows the carbon intensity of producing electricity in each source.

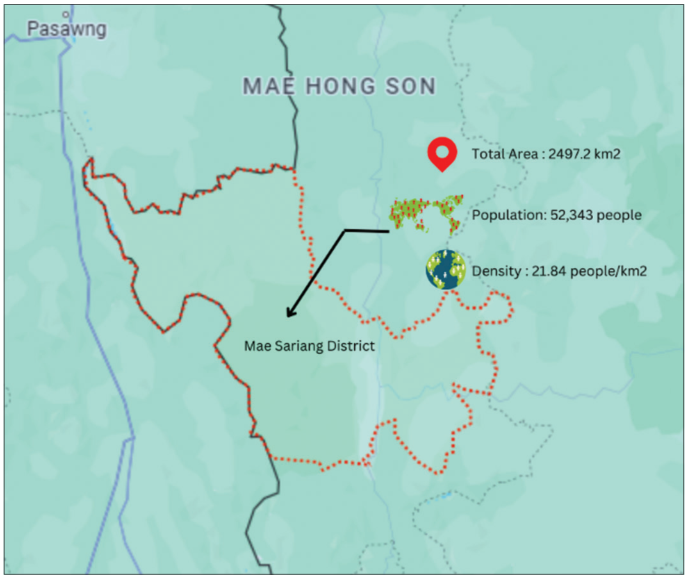
2.4. Case Study

Mae Sariang District, Mae Hong Son Province, is one of the districts in Thailand that experiences power outages most frequently (Figure 1). About 110 km away, at the Hod substation, is where Mae Sariang District gets its electricity. Additionally, a variety of small power sources, such as diesel power plants, micro hydropower, and solar power, are capable of producing electricity. Also known as the Mae Sariang microgrid system, this 22 kV distribution system is owned and run by the Provincial Electricity Authority of Thailand (PEA). However, it is insufficient to fulfill the demand for local load and has little chance of generating electricity (Tephiruk et al, 2018). A 1.2 MW hydroelectric plant, a 5 MW diesel generator, a 3 MW/1.5 MWh battery energy storage system (BESS), a 115 kV distribution line, and a 4 MWp solar PV system were the five main power sources for the Mae Sarang microgrid.

Table 1: The comparison of life cycle cost of microgrids versus traditional power systems

Cost component	Microgrids	Traditional power systems	References
Initial capital costs	• Higher due to on-site generation, storage, and infrastructure.	• Typically lower, as costs are spread over large infrastructure.	IRENA, 2020; NREL, 2022
Operation and maintenance	• Variable: Lower in remote areas; potentially higher due to multiple generation sources.	• Generally higher due to extensive infrastructure and centralized generation maintenance.	Homer, 2015; Wiser et al., 2017
Fuel costs	• Lower for renewable-based microgrids; higher for diesel or natural gas-based microgrids.	• High for fossil fuel-based systems; lower for centralized renewables (e.g., hydro, nuclear).	IRENA, 2020; NREL, 2022
Decommissioning costs	• Generally lower, especially for renewable energy systems.	• It can be significant, particularly for nuclear and fossil fuel plants.	Wiser et al., 2017
Resilience and reliability	• Higher resilience, especially in remote or disaster-prone areas.	• Lower resilience; more susceptible to widespread outages.	Homer, 2015; NREL, 2022
Environmental impact	• Lower, especially for renewable-based microgrids.	• Higher, particularly for fossil fuel-based systems.	IRENA, 2020; NREL, 2022

Figure 1: Location of Mae Sariang district in Mae Hong Son province



2.5. Scenarios

List of construction costs for the Mae Sariang microgrid was shown in Table 3 and the cost of electricity production from each source was shown in Table 4. In this assessment of the life cycle costs for the Mae Sariang microgrid system, operational costs were found to be 2% of the system's construction costs, while replacement costs were 1.5% of the construction costs.

This percentages estimate accounts for routine replacements and upgrades of parts, like inverters, batteries, and other high-wear components, over time to maintain optimal performance. However, certain technologies and advanced components might lower or raise this estimate based on their durability and maintenance needs.

Life cycle cost assessment is divided into 3 scenarios: (1) Grid + PV + BESS (2) Grid + BESS and (3) Grid + DG + PV + Hydro with the assumptions for each option as follows.

(1) Grid + PV + BESS (Scenario I)

In this scenario, it is considered that solar energy can be operated 4 h/day, 365 days/year, with a production capacity of 4 MW. Battery energy storage systems can be used for 2 h/day, 365 days/year, with a production capacity of 3 MW. The additional electricity demand will be used from the transmission line. Details of electricity production from each source can be shown in Table 5.

(2) Grid + BESS (Scenario II)

In this scenario, the entire electrical system is assumed to rely entirely on electricity from the transmission line and to store electricity in batteries. Details of electricity units from each source are shown in Table 5.

(3) Grid + DG + PV + Hydro (Scenario II)

In this scenario, the solar power system can operate for 4 h/day, 365 days/year, with a production capacity of 4 MW, while the battery can operate for 2 h/day, 365 days/year, with a production capacity of 3 MW, hydropower can operate for 24 h/day, 60 days/year, with a production capacity of 1.2 MW, and diesel generators can operate for 3 h/day, 120 days, with a production capacity of 5 MW, with the diesel price set at 30 baht per liter. The remaining electricity units will be used from the power transmission line. Details of electricity units from each source are shown in Table 5.

Table 2: Carbon intensity of producing electricity in each source

Technology	Carbon Intensity ($g\ CO_2e/kWh$)	References
Solar PV	20–60	Fthenakis et al., 2008; IPCC, 2014
Wind	10–20	IPCC, 2014; NREL, 2013
Hydropower	1–30	Hertwich, 2013; IPCC, 2014
Geothermal	10–40	Frick et al., 2010; IPCC, 2014
Coal	820–1050	IEA, 2017; IPCC, 2014
Natural Gas	450–550	IEA, 2017; IPCC, 2014
Oil	650–900	IEA, 2017; IPCC, 2014
Nuclear	5–15	IPCC, 2014; Warner and Heath, 2012
Biomass	20–200	Cherubini et al., 2009; IPCC, 2014

Table 3: List of construction costs for the Mae Sariang microgrid system

Items	Cost	Unit
1. Microgrid System and Controller, Microgrid EMS, Microgrid Controller	31,500,000	Baht
2. BESS, Battery Energy storage System, including Power Conversion system, Charger, 3 MW/1.5 MWh		
3. Fiber optic communication system	5,000,000	Baht
4. Transformer (4MW)	3,000,000	Baht
5. Cutting switch for feeder remote terminal unit	5,000,000	Baht
6. Microgrid building	25,000,000	Baht
7. Overhead fee	20,000,000	Baht
Total	89,500,000	Baht

Table 4: Electricity production cost from each source

Energy sources	Cost range (USD/kWh)	Source
Diesel	\$0.20 – \$0.50	IRENA, 2020; NREL, 2022
Solar	\$0.03 – \$0.10	IRENA, 2021
Hydro	\$0.03 – \$0.15	Worldbank, 2024
Battery Storage	\$0.10 – \$0.30 (for storage only)	Lazard, 2021
Grid	\$0.10 to \$0.13 USD per kWh	EGAT, 2024

Table 5: Electricity production from each scenario

Electricity sources	Estimated electricity production (MWh/year)		
	Scenario I	Scenario II	Scenario III
PV	8760	-	8760
BESS	2190	2190	2190
Grid	41610	50370	38082
Hydro	-	-	1728
Diesel	-	-	1800

3. RESULTS AND DISCUSSION

3.1. Life Cycle Cost per kWh

The life cycle cost analysis includes items listed in Table 3, excluding the construction costs of hydro power plants, solar farms, and diesel generators, as these systems are already established. Figure 2 presents the results of LCC per kWh.

As shown in Figure 2, Scenario II incurs the highest cost per kWh due to its reliance on electricity from the transmission line. Scenario III also incurs high electricity production costs due to the substantial operating expenses of diesel generation. In contrast, Scenario I achieved the lowest production cost, as it primarily relies on solar power, which has the lowest operational costs among renewable energy sources.

3.2. Net Present Value Results

The Net Present Value (NPV) results are presented in Table 6. The purchase price of electricity from various renewable energy sources was referenced from the National Energy Policy Committee Meeting Resolution No. 3/2022 (No. 158), as detailed in Table 7.

As shown in Table 6, Scenario I yielded the highest NPV due to revenue from selling electricity generated from renewable sources. As for scenario III, the NPV was equal to −2,690,330 baht. Although it had income from selling electricity from renewable energy, it operated electricity generation from diesel, which has the cost of this type of fuel, causing the NPV of the project to be negative.

In conclusion, Scenario I not only shows the highest NPV but also demonstrates the financial benefits of prioritizing renewable energy sources in the microgrid system. Scenarios II and III would require cost or revenue adjustments to become viable options.

3.3. Greenhouse Gas Emissions Assessment

In this section, we have assessed greenhouse gas emissions from each electricity generation scenario using the emission intensity of greenhouse gas emission values as shown in Table 2.

The greenhouse gas emission results of each scenario are shown in Figure 3. It was found that scenario I had the lowest greenhouse gas emission at 21,239 $kgCO_2e$/year, followed by scenario III (22,240 $kgCO_2e$/year) and scenario II (25,180 $kgCO_2e$/year), respectively.

The greenhouse gas emission results highlight clear differences among the three scenarios, reflecting the relative carbon intensities of each approach. Scenario I, which produced the lowest emissions at 21,239 $kgCO_2e$/year, likely benefits from a more efficient mix of low-carbon or renewable energy sources, or it may feature advanced efficiency measures. This lower emission intensity could make it a favorable option in terms of environmental impact.

Scenario III, with emissions of 22,240 $kgCO_2e$/year, shows a moderate increase relative to Scenario I. This could imply a different combination of energy sources or a marginally less efficient process. Nonetheless, its proximity to Scenario I suggests that it might be a viable alternative, particularly if other factors such as cost, availability, or operational flexibility are considered.

Figure 2: LCC per kWh in this study

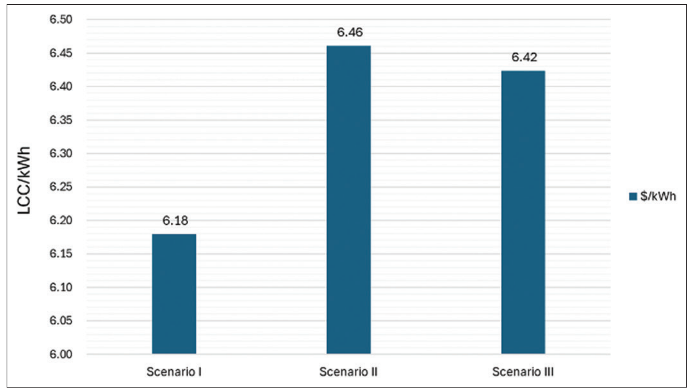


Figure 3: The result of greenhouse gas emissions in each scenario

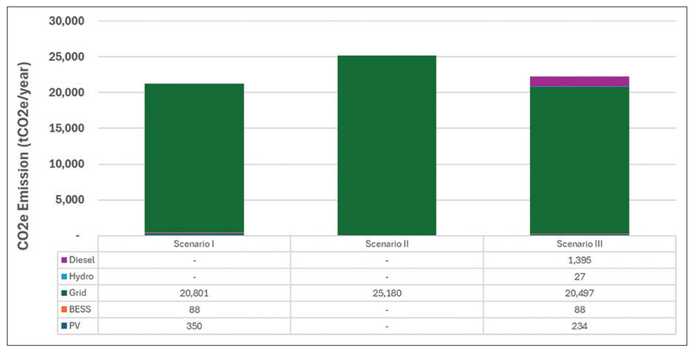


Table 6: Net present value (NPV) results in each scenario

Scenario	NPV	Unit
I	226,583,036	Baht
II	−58,076,964	Baht
III	−2,690,330	Baht

Table 7: The purchase price of electricity from renewable energy (ERC, 2022)

Renewable fuel	Price (baht/kWh)
Biogas	2.0724
Wind	3.1014
Solar	2.1679
Solar+BESS	2.8331

Finally, Scenario II exhibits the highest emissions at 25,180 $kgCO_2e$/year, indicating that it likely incorporates energy sources or technologies with a higher carbon intensity or less efficiency. This makes it the least favorable from a greenhouse gas emission perspective, and it may be beneficial to investigate possibilities for emissions reduction within this scenario.

4. CONCLUSION

This study evaluated three energy scenarios for the Mae Sariang microgrid system, focusing on life cycle cost (LCC) per kilowatt-hour (kWh), net present value (NPV), and greenhouse gas (GHG) emissions. The LCC analysis revealed that Scenario I, which primarily relies on solar power, had the lowest cost per kWh due to the low operational costs associated with solar energy. Scenario II, heavily dependent on electricity from the transmission line, had the highest cost per kWh due to expensive grid electricity. Scenario III also exhibited high costs, driven by the significant expenses associated with diesel generation. The NPV assessment demonstrated that Scenario I was the most financially viable, achieving the highest NPV due to income generated from selling renewable energy. Scenario II, relying solely on grid electricity, lacked this revenue stream and showed lower financial returns. Scenario III's reliance on diesel generation led to a negative NPV of -2,690,330 baht, with high fuel costs outweighing revenue from renewable sources. In terms of GHG emissions, Scenario I was the most environmentally favorable, producing the lowest emissions at 21,239 $kgCO_2e$/year thanks to its renewable focus. Scenario III followed with slightly higher emissions (22,240 $kgCO_2e$/year), likely due to a partial reliance on diesel. Scenario II exhibited the highest emissions (25,180 $kgCO_2e$/year), reflecting its dependence on high-carbon grid electricity.

In summary, Scenario I stands out as the optimal choice, achieving the lowest costs, highest NPV, and minimal emissions, showcasing the economic and environmental benefits of a renewable-focused microgrid system. Scenario III, while less cost-effective, remains a feasible alternative, whereas Scenario II would require significant adjustments to become a viable option.

The limitation of this study those should be concerned with (1) the study relies on assumed or historical cost data, which may not fully reflect future market fluctuations in energy prices, technology costs, and policy incentives; (2) variability in solar radiation and diesel fuel prices could impact the accuracy of financial projections. To address the limitation related to assumptions in cost and energy data, future research can incorporate the following strategies: (a) Implement a small-scale pilot project to collect actual cost and energy performance data over time; and (b) monitor operational and maintenance costs to refine life cycle cost (LCC) assumptions.

The result of this study can be beneficial to energy and sustainability researchers, policymakers, and government agencies involved in rural electrification and energy planning. It is also relevant to renewable energy developers, engineers, and financial analysts assessing the feasibility of microgrid projects. Additionally, environmental consultants and NGOs focused on carbon reduction strategies may find the study valuable for promoting sustainable energy solutions.

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