Feasibility Analysis of Hybrid Energy Systems for Remote Community Electrification: A Comparative Study in Ban Pha Dan, Lamphun, Thailand

Benjamarporn Thepwinyakit[1] Narakorn Songkittirote[1] Nuttiya Tantranont[2] Surachai Narrat Jansri[1] Worajit Setthapun[1] Suchat Srikaew[3] and Hathaithip Sintuya[1*]

[1] Asian Development College for Community Economy and Technology (adiCET),
[2] Chiang Mai Rajabhat University, 180 Moo 7 Chotana Rd., Khilek, Mae Rim, Chiang Mai 50180, Thailand
[3] Renewable Energy for Sustainable Association, Nong Han, San Sai, Chiang Mai 50290, Thailand

[1]Corresponding author: E-mail address: hathaithip_nin@cmru.ac.th, Tel. +66931872968

Received: 3 May 2023, Revised: 17 May 2023, Accepted: 20 May 2023, Published online: 30 April 2024

Abstract

Microgrid is a promising technology that can be applied to create reliable electricity in remote community. This research examined optimal hybrid electricity generation strategies for remote community microgrid using Ban Pha Dan Community in Lamphun, Thailand as a case study. Three distinct energy configurations were analyzed: a Solar Energy and Battery Supply system; a Solar Energy, Battery, and Diesel Generator system; and a Solar Energy, Battery, and Biogas Power Generation system. The investigation reveals that the Solar Energy, Battery, and Diesel Generator configuration yields the most cost-effective and reliable system, with a Levelized Cost of Energy (LCOE) of 7.85 baht and a Net Present Cost (NPC) of 7.15M. Despite the environmental benefits of the Biogas system, the higher capital expenditure makes it less favorable. This study provides a systematic framework for the deployment of community microgrids and accentuates the potential of mixed renewable and conventional energy systems in remote communities.

Keywords: Renewable energy, Sustainability, Energy independence, Microgrid, Solar power

INTRODUCTION

Reliable access to electricity is vital for societal development and enhancing the quality of life, particularly in remote communities such as Ban Pha Dan, located in Lamphun, Thailand. The geographical challenges and isolation make extending traditional power transmission lines impractical, necessitating the exploration of alternative, locally feasible electricity generation methods [1,2]. Community microgrids, harnessing power from locally available renewable resources, have emerged as a promising solution. The Ban Pha Dan community serves as a prime example of this model, having transitioned from a village without electricity to a community powered by a microgrid that generates 102 kWh from photovoltaic (PV) sources and is supplemented by 307.2 kWh of battery storage [3,4].

The objective of the current research is to evaluate the potential for implementing the Ban Pha Dan model in other remote communities, focusing on identifying the most efficient, stable, and cost-effective methods of electricity generation. The methodology involves a detailed analysis of the electricity usage behavior of the Ban Pha Dan community, serving as a representative model to understand electricity consumption patterns in remote communities [5]. In light of previous studies such as Wasantha and Abeydeera's exploration of PV-biogas hybrid power systems [4], and Kabir, Kumar, and Kumar's examination of a similar hybrid system in the context of rural India [6], this research further contributes to the body of knowledge by exploring the feasibility of these models in the unique context of Ban Pha Dan. The study leverages the Homer Pro simulation program to analyze the efficiency, stability, and cost-effectiveness of each alternative energy configuration, thereby providing empirical insights that could guide future energy planning in similar remote communities.

This paper presents three case studies, each exploring a different combination of alternative energy sources: solar energy, battery supply, diesel generator, and biogas power generation [6,7,8]. The case studies were created based on the actual economic data and pricing information for power generation systems and installations in Thailand. The Homer Pro software was employed to analyze the efficiency, stability, and cost-effectiveness of each energy source in these cases, building upon previous research on remote community electrification. The research underscores the potential of biogas power generation as a feasible energy source that can significantly reduce investment costs, promote sustainability, and foster community development. In doing so, it contributes to the broader discourse on developing sustainable and affordable electricity solutions for remote communities and offers valuable insights into the potential of renewable energy sources for remote community electrification.

RESEARCH METHODS

This research conducts a comprehensive investigation of electricity generation methodologies for remote communities, using the Pha Dan Community in Lamphun, Thailand, as a model. The study encompasses three distinct case studies:

(1) Solar Energy and Battery Supply

(2) Solar Energy, Battery, and Diesel Generator

(3) Solar Energy, Battery, and Biogas Power Generation.

Each case is devised to explore a unique renewable energy system configuration, offering a comparative analysis on their performance, cost-effectiveness, and feasibility. The methodology starts by defining the scope of each case study. This involves determining the specific elements of the renewable energy system to be investigated, including solar panels, batteries, diesel generators, and biogas generators. The next step involves the meticulous definition of key data parameters essential for the Homer Pro simulation. These parameters fall into four main categories: Community Load, Cost of Component, System Constraints, and Economic Data. The values for these parameters are derived from reliable sources. For instance, the inflation rate is obtained from the Bank of Thailand, while equipment costs are gathered from quotes from private companies. Table 1 presents these key data parameters, which serve as the input data for the Homer Pro simulation.

Table 1: Key Parameters for Homer Pro Simulation

Parameter Category	Component	Description	Reference
Load Demand	-	Peak load: 170 kW	Community load assessment
Component Costs	Photovoltaic System	Initial installation (including Balance of System): 18,000 baht/kW, Replacement cost: 12,000 baht, Operation & Maintenance (O&M): 3 baht/year	Quotations from private companies
Component Costs	Battery	Initial installation (including Balance of System): 10,000 baht/kWh, Replacement cost: 8,000 baht, Nominal throughput: 90 kWh per string	Quotations from private companies
Component Costs	Biogas System	Initial installation (including fermentation tank and wastewater treatment pond): 6,200,000 baht, Replacement cost: 16,000 baht, O&M: 1.5 baht/op. hour, Fuel Price per cubic meter: 9 baht	Quotations from private companies
Component Costs	Diesel Generator	Initial installation: 500,000 baht, O&M: 3 baht/op. hour, Wages for maintenance workers per year: 127,750 baht	Quotations from private companies
System Constraints	Battery	Designed lifetime: 5 years, Nominal throughput: 500,000 kWh	Manufacturer specifications
System Constraints	Photovoltaic System	Designed lifetime: 25 years	Manufacturer specifications

Parameter Category	Component	Description	Reference
System Constraints	Inverter	Designed lifetime: 15 years, System efficiency: 95%	Manufacturer specifications
Economic Factors	-	Discount rate: 6.650, Inflation rate: 2.67	Discount rate derived from the minimum loan interest rate (MLR), Inflation rate from the Bank of Thailand

Once the data parameters are defined, they are input into the Homer Pro simulation software. Homer Pro uses powerful optimization algorithms to calculate the most cost-effective configuration of the components of the renewable energy system for each case study. The software provides optimal feasible solutions that detail system sizing and configuration. Following the Homer Pro simulation, an in-depth analysis and comparison of the results are conducted. This analysis scrutinizes various factors, including the system's efficiency, its cost-effectiveness, and its capacity to meet the community's electricity demand reliably. Figure 1 illustrates the schematic representation of the research methodology, from defining the case studies to conducting the Homer Pro simulation and data analysis.

The final step of the methodology involves summarizing the findings and framing recommendations for the future implementation of community microgrids in remote areas. The research aims to provide a comprehensive and practical framework that remote communities can refer to when considering the implementation of a community microgrid. This research ultimately seeks to contribute valuable insights to the discourse on renewable energy solutions for remote communities, and to inspire further studies and policy discussions in this area.

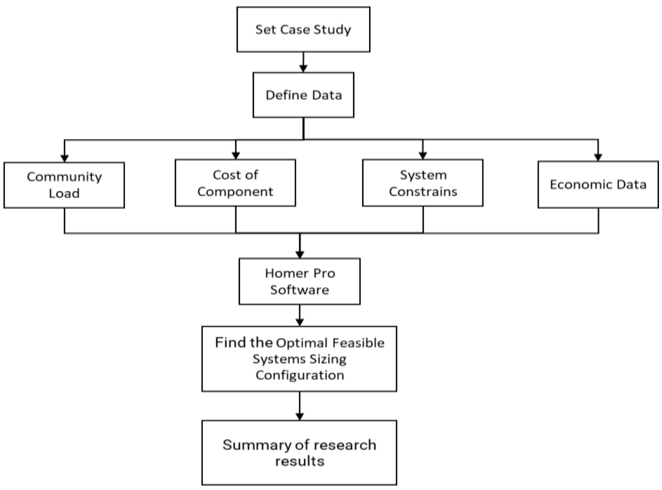

Figure 1. Schematic Representation of the Research Methodology

RESULTS AND DISCUSSION

1. Study the electricity usage of the model community

Based on the information provided, Ban Pha Dan is a remote community located in GPS position 18.365182579993913, 99.03796031194881. The community is situated in a national forest reserve area and therefore, by law, cannot have buildings built in the area. However, the villagers have lived there since their ancestors and as electricity is a necessary aspect of life, the villagers funded and received 102 kWp solar panels and 307.2 kWh batteries, along with the construction of electricity distribution poles throughout the village. From Figure. 2, the data on Ban Pha Dan's electricity usage shows an average daily consumption of 55.6 kW, with a total electricity consumption ranging from 340.70 kWh to 2,618.60 kWh over the course of 18 months. From data analysis of the electricity usage data reveals that there are fluctuations in electricity consumption throughout the year. The highest consumption was recorded in the months of May and June, with a total of 2,618.60 kWh and 2,293.00 kWh respectively. On the other hand, the lowest consumption was observed in the months of October and November, with 340.70 kWh and 566.40 kWh respectively.

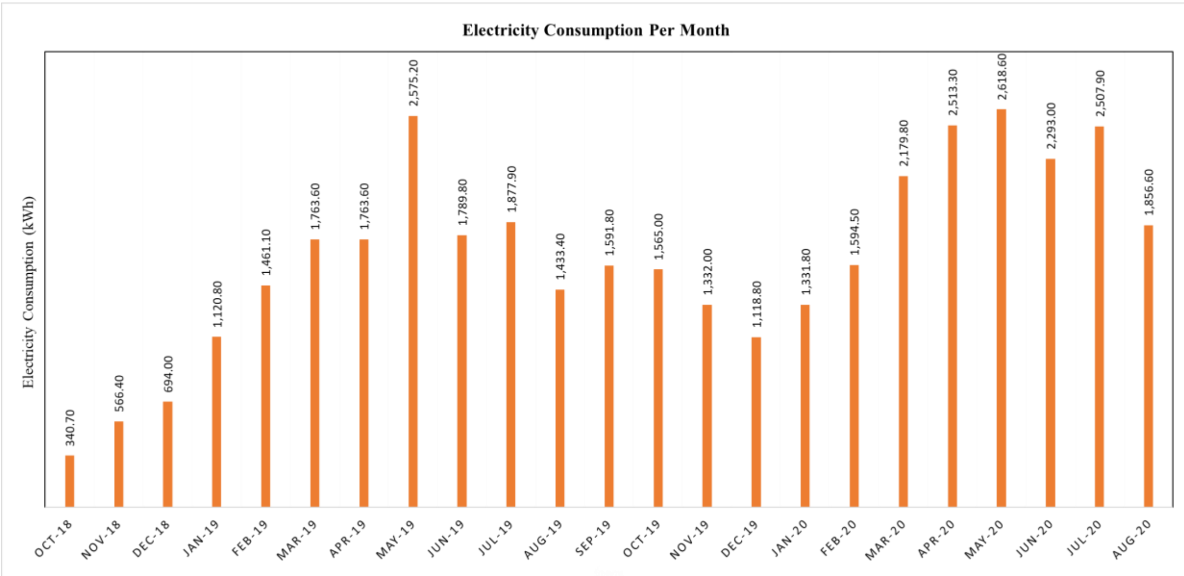

Figure 2. Electricity Consumption of Ban Pha Dan

2. Analysis of case studies using Homer program

This section will present the results of the case studies by applying the data of electricity consumption in Ban Pha Dan Community to the Homer program. The case studies are as follows:

2.1 Study of Power Generation from Solar Energy and Battery Supply: Case Study 1

In this case study, the focus is on studying power generation from solar energy and battery supply in a remote community located in Pha Dan village. The objective of this study is to analyze the energy usage behavior of the community and extract knowledge that can be applied to other remote areas.

The Homer Pro simulation outputs for the Solar Energy and Battery Supply case recommend an optimal configuration involving a 100 kW solar photovoltaic (PV) system and a 200 kWh battery storage system. This arrangement was determined capable of satisfying the electricity demand of the community. The simulation also provided key financial metrics, offering an in-depth understanding of the economic feasibility of the Solar Energy and Battery Supply system. A summary of these metrics is provided in Table 2. The renewable fraction (Ren Frac), representing the percentage of the total electricity generated by renewable sources, was calculated as 100%. This result indicates that the entire electricity demand of the community can be met using renewable energy, rendering this system fully sustainable. From an economic perspective, the Net Present Cost (NPC) of 14.7 million baht and Levelized Cost of Electricity (LCOE) of 10.65 baht/kWh indicate the relative affordability of the system. The annual operating cost is expected to be around 384,929 baht, with an overall present worth of 2,267,067 baht. Moreover, the system exhibits a promising financial return with a return on investment of 15.5% and an internal rate of return of 21%. The system pays for itself in approximately 3.68 years, as indicated by the simple payback period, while the discounted payback period stands at 4.09 years, considering the time value of money. In conclusion, the Solar Energy and Battery Supply configuration emerges as a viable, efficient, and cost-effective solution for electricity generation in remote communities. It attains a 100% renewable fraction and exhibits favorable economic performance indicators, underscoring its potential as a sustainable model for remote community electrification.

2.2 Study of Electricity Production from Solar Energy, Battery, and Diesel Power Generation: Case Study 2

This case study aims to determine the most suitable power generation system for a remote community in Thailand, using a hybrid renewable energy system with a Diesel generator. The system consists of photovoltaic (PV) modules, a converter, a battery bank, and a biogas generator. The Solar Energy, Battery, and Diesel Generator case, as modeled by the Homer Pro simulation software, presents another effective configuration for electricity generation in remote communities. This arrangement involves a 100 kW solar PV system, a 100 kWh battery storage system, and a 50 kW biodiesel generator, all of which together are capable of meeting the electricity demand of the community. The key financial metrics that emerged from this case are summarized in Table 2. The renewable fraction in this case was determined to be 84.4%, suggesting that a majority of the electricity generated comes from renewable sources, while the rest is supplemented by the diesel generator. A notable aspect of this case is its economic feasibility. The Net Present Cost (NPC) stands at 7.15 million baht, with a Levelized Cost of Electricity (LCOE) of 7.85 baht/kWh. The annual operating cost is relatively low at 294,366 baht, contributing to a present worth of 1,872,521 baht. The system's financial return is robust, with a return on investment of 15.5% and an internal rate of return of 21.9%. The system's payback periods are also relatively short, with a simple payback period of 3.11 years and a discounted payback period of 3.44 years. In summary, the Solar Energy, Battery, and Diesel Generator configuration proves to be a reliable and economical solution for electrifying remote communities. Although its renewable fraction is lower compared to the Solar Energy and Battery Supply case, it remains an effective model, considering its lower NPC, favorable return on investment, and shorter payback periods.

2.3 Study of Electricity Production from Solar Energy, Battery, and Biogas Generation: Case Study 3

The third case study modeled by Homer Pro simulation software involves a configuration of a 100 kW solar PV system, a 100 kWh battery storage system, and a 50 kW biogas generator. This configuration is capable of meeting the electricity demand of the community. The financial metrics derived from this case are detailed in Table 2. Similar to the previous case, the renewable fraction for this configuration is 84.4%, implying that the majority of the electricity generated comes from renewable sources, supplemented by the biogas generator. The economic feasibility of this case is characterized by a Net Present Cost (NPC) of 7.25 million baht and a Levelized Cost of Electricity (LCOE) of 7.95 baht/kWh. The annual operating cost is slightly lower than the previous case at 293,207 baht, leading to a present worth of 1,774,529 baht. The return on investment for this case is 13.6%, and the internal rate of return is 19.2%. The system presents a simple payback period of 3.45 years and a discounted payback period of 3.85 years. In summary, the Solar Energy, Battery, and Biogas Generator configuration offers a sustainable and economically viable solution for remote communities. Although it has a slightly higher NPC and LCOE compared to the Solar Energy, Battery, and Diesel Generator case, it still holds potential due to its renewable fraction and economic returns. The final decision between these cases would involve a further evaluation of local context, such as resource availability and environmental considerations.

Table 2. Financial Analysis of studies Case

Financial Metrics	Case 1	Case 2	Case 3
Net Present Cost (NPC)	9.47 million baht	7.15 million baht	7.25 million baht
Levelized Cost of Electricity (LCOE)	10.65 baht/kWh	7.85 baht/kWh	7.95 baht/kWh
Annual Operating Cost	384,929 baht	294,366 baht	293,207 baht
Capital Expenditure (CAPEX)	3.81 million baht	2.83 million baht	2.94 million baht
Present Worth	2,267,067 baht	1,872,521 baht	1,774,529 baht
Annual Worth	170,329 baht/year	127,510 baht/year	120,837 baht/year
Return on Investment	16.4%	15.5%	13.6%
Internal Rate of Return	22.3%	21.9%	19.2%

Financial Metrics	Case 1	Case 2	Case 3
Simple Payback Period	3.68 years	3.11 years	3.45 years
Discounted Payback Period	4.09 years	3.44 years	3.85 years

CONCLUSION

This research aimed to identify the most efficient, stable, and cost-effective solution for electricity generation in remote communities. To achieve this, three distinct scenarios were examined: Solar Energy and Battery Supply, Solar Energy, Battery, and Diesel Generator, and Solar Energy, Battery, and Biogas Power Generation. The first scenario, Solar Energy and Battery Supply, as highlighted in a study by Prasad and Saini (2021), recommended a configuration of a 100kW solar cell and a 200kWh battery [9]. This fully renewable energy system demonstrated a renewable fraction of 100%, with a Net Present Cost (NPC) of 14.7 million baht and Levelized Cost of Electricity (LCOE) of 10.65 baht. The second case, Solar Energy, Battery, and Diesel Generator, integrated an additional diesel generator into the system, aligning with the findings of Kaygusuz (2020) on the potential of such hybrid systems [10]. This scenario saw a decrease in NPC to 7.15 million baht and LCOE to 7.85 baht, with a renewable fraction of 84.4%. The final case study, Solar Energy, Battery, and Biogas Power Generation, included a biogas generator in the system, as advocated by Chong, Nielsen, and Low (2022) for achieving sustainable remote community electrification [11]. The NPC rose slightly to 7.25 million baht, and the LCOE marginally increased to 7.95 baht, maintaining a renewable fraction of 84.4%.

While the biogas model has numerous advantages, such as lower energy costs and the ability to convert community waste into energy, the research findings indicate that the Solar Energy, Battery, and Diesel Generator model offers the most balanced solution. This echoes the findings of Barua, Islam, and Ahmed (2018) on the potential of hybrid solar-diesel-battery systems for off-grid remote community electrification [12]. Despite a slightly higher NPC and LCOE than the biogas model, it maintains a considerable renewable fraction and has a lower initial investment cost. This model's various advantages, such as its cost-effectiveness, reliability, and the incorporation of renewable energy sources, make it a viable and sustainable solution for remote communities like Pha Dan Community in Lamphun, Thailand. Future research could aim to enhance the efficiency and cost-effectiveness of this model, making it even more appealing to similar communities worldwide. That said, it's important to consider the unique benefits of the Solar Energy, Battery, and Biogas Power Generation model, such as waste management and compost production, aligning with Bensah and Brew-Hammond's (2020) findings on the potential benefits of biogas technology [13]. In conclusion, while each scenario presents its unique set of advantages, this research supports the idea that the Solar Energy, Battery, and Diesel Generator model offers the most advantages and potential applications for remote communities.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Renewable Energy for Sustainable Association (RESA), Takadnua Subdistrict Municipality, Ban Pha Dan Community, Chiang Mai Rajabhat University (CMRU) and Asian Development College for Community Economy and Technology (adiCET) for their support and assistance in conducting this research. Their invaluable contributions to this project have been greatly appreciated and have greatly enhanced the outcome of this study. The authors would like to thank CMRU and adiCET for providing a supportive research environment, enabling the team to successfully complete this work.

REFERENCES

[1] Schmid, J., El-Hag, M., & Hammad, A. (2018). Off-grid hybrid renewable power systems for rural electrification in developing countries: A review. **Renewable and Sustainable Energy Reviews**, 82, 3999-4010.

[2] Ahmed, T. K., & Islam, A. M. K. (2019). Feasibility study of a hybrid solar-biogas-battery power system for rural electrification in Bangladesh. **Sustainable Energy Technologies and Assessments**, 36, 41-50.

[3] Benouz, S., Mellit, A., & Kalogirou, S. A. (2011). Feasibility study of hybrid photovoltaic/wind power systems for rural electrification in Algeria. **Energy Policy**, 39(5), 2778-2788.

[4] Wasantha, P. L. P., & Abeydeera, K. W. R. (2009). A feasibility study on a PV-biogas hybrid power system for rural electrification. Renewable Energy, 34(2), 320-326.

[5] Barua, G., Islam, M., & Ahmed, A. (2018). Modeling and simulation of a solar-biogas hybrid power system for off-grid rural electrification in Bangladesh. **Journal of Renewable Energy**, 2018, Article ID 3854293, 15 pages.

[6] Kabir, A. S., Kumar, S., & Kumar, S. (2019). Solar PV-biogas-battery hybrid system for off-grid power generation in rural areas of India: A techno-economic analysis. **Renewable Energy**, 139, 862-874.

[7] Al-Jaberi, A., & Borresen, J. O. (2019). Renewable energy hybrid power system for off-grid applications in Oman: A case study. **Energy Reports**, 5, 252-259.

[8] Haque, S. B., Khan, M. F., Imtiaz, S. H., & Hasan, M. Z. (2016). Design and analysis of a photovoltaic-wind-battery hybrid power system for remote areas in Bangladesh. **Journal of Renewable Energy**, 2016, Article ID 7062878, 10 pages.

[9] Prasad, R., & Saini, R. P. (2021). Techno-economic analysis of off-grid PV/battery energy systems for remote rural areas of developing countries. **Solar Energy**, 221, 166-181.

[10] Kaygusuz, K. (2020). Hybrid renewable energy systems for remote rural areas in developing countries. **Journal of Cleaner Production**, 269, 122251.

[11] Chong, W. T., Nielsen, P. N., & Low, S. T. (2022). A technical review on biogas generation from biowaste for off-grid electricity supply. **Renewable and Sustainable Energy Reviews**, 152, 111508.

[12] Barua, G., Islam, M., & Ahmed, A. (2018). Modeling and simulation of a solar-biogas hybrid power system for off-grid rural electrification in Bangladesh. **Journal of Renewable Energy**, 2018, Article ID 3854293, 15 pages.

[13] Bensah, E. C., & Brew-Hammond, A. (2020). Biogas technology dissemination in Ghana: history, current status, future prospects, and policy significance. **International Journal of Energy and Environmental Engineering**, 3(2), 91-109.