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Article

A multi-criteria decision analysis to rank energy alternative options using analytic hierarchy process with a sustainable criteria: A case study of Mae Sariang, Mae Hon Song Province, Thailand

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Abstract: Providing and using energy efficiently is hampered by concerns about the environment and the unpredictability of fossil fuel prices and quantities. To address these issues, energy planning is a crucial tool. The aim of the study was to prioritize renewable energy options for use in Mae Sariang's microgrid using an analytical hierarchy process (AHP) to produce electricity. A prioritization exercise involved the use of questionnaire surveys to involve five expert groups with varying backgrounds in Thailand's renewable energy sector. We looked at five primary criteria. The following four combinations were suggested: (1) Grid + Battery Energy Storage System (BESS); (2) Grid + BESS + Solar Photovoltaic (PV); (3) Grid + Diesel Generator (DG) + PV; and (4) Grid + DG + Hydro + PV. To meet demand for electricity, each option has the capacity to produce at least 6 MW of power. The findings indicated that production (24.7%) is the most significant criterion, closely followed by economics (24.2%), technology (18.5%), social and environmental (18.1%), and structure (14.5%). Option II is strongly advised in terms of economic and structural criteria, while option I has a considerable advantage in terms of production criteria and the impact on society and the environment. The preferences of options I, IV, and III were ranked, with option II being the most preferred choice out of the four.

Keywords: microgrid; renewable energy; analytic hierarchy process

1. Introduction

The United Nations (UN) established the Sustainable Development Goals (SDGs), a collection of 17 objectives that provide a shared framework for world peace and prosperity both now and in the future. It has been acknowledged that one of the most important and relevant energy goals is Goal 7. To guarantee that everyone has access to modern, sustainable, and reasonably priced energy, its three primary components—improving energy efficiency, expanding the percentage of renewable energy, and guaranteeing that everyone has access to energy—are designed to be implemented (United Nations, 2024).

Among various solutions to encourage SDG7, microgrid is dominated due to it can provide in both off-grid and on-grid for electricity management. In addition, there are many advantages for microgrid such as: improving electric reliability; enhancing resilience and recovery; lower energy costs for consumers and businesses; improving environment and promoting clean energy; enhancing strengthens the central grid; bolsters cybersecurity; brings economic value to society; and improving community well-being (Wood, 2024). A microgrid is a small-scale, low-voltage power system that combines energy storage, automated control systems, power generation, information and communication technologies, and electricity consumption into one cohesive unit (Meenual and Usapein, 2021c). It is a collection of distributed energy resources (DER) and linked loads that operates within well-defined electrical boundaries and as a single, controllable unit in connection to the grid (Kaewvata et al., 2021). The system is considered a solution for the effective management of renewable energy generation and can reduce costs and pollution when used in conjunction with energy storage and proper management. Typically, 20%–25% of a microgrid's capacity comes from renewable sources; however, if a suitable renewable energy source is available, that percentage could go up. Microgrids have been adopted by numerous Asian nations to improve the availability of electricity in remote and island regions (Meenual and Usapein, 2021a, 2021b).

Based on the various sources of energy for microgrid management, it is the rising of questions that how to choose the best option for producing electricity from microgrid system. Additionally, in order to develop guidelines for efficient microgrid management, it is necessary to investigate how priorities should be set and what criteria should be taken into account. One helpful tool for addressing the quantitative and intangible criteria that can complicate an assessment is the analytical hierarchy process (AHP). It deconstructs a complex decision into clear objectives, alternatives, and criteria. It then ranks the criteria and assesses the alternatives according to the criteria that are most understandable to the general public. Furthermore, AHP can detect data inconsistencies and assist researchers in resolving necessary issues. AHP has been used in numerous studies in the energy industry (Ahmad and Tahar, 2014; Alanazi et al., 2023; Wang et al., 2021).

A prior study selected the optimal option according to each techno-economic criterion using AHP. AHP was employed to support decision-making in the process of energy planning with renewable energies for rural areas. Specifically, it was used to prioritize a set of criteria, subcriteria, and alternatives (Algarín et al., 2017; Kulkarni et al., 2017). In Myanmar, Numata et al. (2020) used AHP to identify the challenges associated with mini-grid deployment and to propose multifaceted strategies that go beyond economic considerations. To assess the optimal choice for choosing renewable sources in microgrids, three dimensions—economic, environmental, and technological—were identified. When compared to alternatives with multiple renewable sources, the results showed that a microgrid with just one source performs the worst (Zhang et al., 2021). In addition, the production and structure criteria were determined for AHP when decision making related to renewable power plant (Chanchawee and Usapein, 2018). However, the result of the AHP analysis for selecting renewable sources depends on the context of each location and the criteria specification for each project. Political and regulatory issues were found to have the biggest impact when AHP was used in India to evaluate the factors preventing the growth of solar energy (Ahmad and Tahar, 2014).

Although there have been many studies on AHP in microgrid systems, Thailand's use of renewable energy in microgrid planning for electricity production is a unique situation (Chaichan et al., 2022). In actuality, neither concurrent technical nor environmental nor social nor economic criteria have been established, nor have systematic decision-making methods been considered in the planning of the microgrid's renewable energy supply. Thus, the purpose of this study was to investigate, while taking into consideration its limitations and gaps, the application of Analytic Hierarchy Process (AHP) in decision-making regarding the renewable source of microgrid's electricity plan.

This study is organized into six main sections: (1) an overview of Mae Sariang's microgrid and alternative renewable energy sources; (2) the development of a questionnaire; (3) the target group; (4) the implementation of the survey; (5) the data analysis by AHP; and (6) the final ranking of renewable source options to produce electricity for Mae Sariang's microgrid. The sections that follow provide an explanation of each step's specifics. Business Performance Management Singapore (BPMSG) processed the AHP analysis to determine the priorities for a set of criteria using pairwise comparisons (Goepel, 2018).

2. Theory

A subfield of operational research called Multi Criteria Decision Making (MCDM) employs analytical techniques to help decision-makers. It aids in solving complicated issues involving erratic goals, diverse data, conflicting interests, and uncertainty. As shown in **Figure 1**, The goal of multiattribute decision-making (MADM) is to separate out unique options from a group of options. On the other hand, decision problems involving multiple objectives and alternatives are more likely to be addressed by multiobjective decision-making, or MODM.

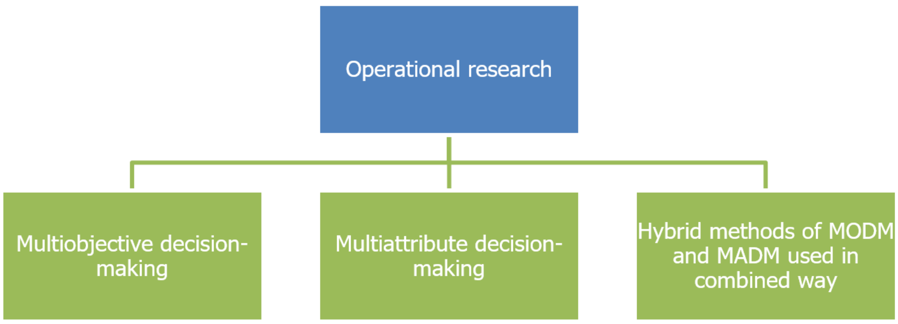

Figure 1. A broad categorization of operational research (Adapted from Kumar et al. (2020)).

The hybrid draws the conclusions that a decision maker needs by combining the best features of the two approaches. The methods used in MCDM enable us to take into account all the shades and concerns that the decision makers need to address. There are many types of MCDM applied for energy planning such as weighted sum method (WSM), weighted product method (WPM), analytical hierarchy process (AHP), TOPSIS, ELECTRE, and preference ranking organization method for enrichment evaluation (PROMETHE). The Analytical Hierarchy Process (AHP) is a widely used Multi-Criteria Decision Making (MCDM) method, and it has several strong points that make it particularly effective:

1) Structured Framework: AHP provides a systematic and structured framework for decision-making by breaking down complex decisions into a hierarchy of sub-problems, which can be more easily comprehended and analyzed.

2) Pairwise Comparisons: AHP allows for pairwise comparisons of criteria and alternatives, making it easier for decision-makers to express their preferences on a relative scale. This helps in capturing both qualitative and quantitative aspects of a decision problem.
3) Consistency Check: AHP includes a consistency ratio to check the consistency of the judgments made during pairwise comparisons. This helps ensure that the judgments are reliable and logically sound.
4) Quantitative and Qualitative Integration: AHP effectively combines both quantitative data and qualitative assessments, allowing decision-makers to incorporate a wide range of information and perspectives into their analysis.
5) Intuitive and User-Friendly: The method is intuitive and user-friendly, making it accessible to decision-makers without requiring an extensive mathematical background. This ease of use facilitates participation and consensus-building among stakeholders.
6) Flexibility and Adaptability: AHP is flexible and can be adapted to a wide variety of decision-making contexts and problem types. It can handle both simple and complex decision problems, and it is applicable across diverse fields such as business, engineering, healthcare, and public policy.
7) Sensitivity Analysis: AHP allows for sensitivity analysis, which enables decision-makers to understand how changes in the input data or criteria weights affect the final decision. This helps in assessing the robustness of the decision and in identifying critical factors.
8) Hierarchical Representation: The hierarchical structure of AHP helps in organizing and visualizing the decision problem, making it easier to identify the relationships between the overall goal, criteria, sub-criteria, and alternatives.

Overall, the strong point of AHP lies in its ability to simplify complex decision-making processes, ensure consistency in judgments, and incorporate a wide range of information, making it a versatile and reliable tool for multi-criteria decision-making.

To apply AHP, the first step was to set the goal; the next was to select an alternative. The alternative selection assessment was based on the primary criteria. A pairwise comparison was required in order to compare criteria and alternatives. To compare quantitative values, the criteria weights for the decision option performance scores were determined. On a nine-point rating system, the stakeholders were asked to indicate which criterion or alternative they preferred over the other in each pair. **Table 1** shows the scale of pairwise comparisons.

Table 1. Description of scale for pairwise comparisons.

Level of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favor one activity over another.
5	Strong more importance	Experience and judgement strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another; and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.

The next step, which is exclusive to the AHP, is to transfer the weights to a matrix after obtaining the pairwise comparison result (Saaty, 1980). Equation (1) serves as an example of how the square matrix of pairwise comparisons $A = [aij]$ will be filled in. The i rows are horizontal, and the j columns are vertical. Each element of a matrix is often denoted by a variable with two subscripts.

$$Aw = \begin{bmatrix} 1 & p & q \\ 1/p & 1 & r \\ 1/q & 1/r & 1 \end{bmatrix} \quad (1)$$

When making pairwise comparisons between criteria or alternatives, it is important that the judgments are consistent to ensure the reliability of the decision-making process. The consistency index (CI) helps quantify the degree of consistency in the judgments. CI can be calculated by Equation (2),

$$\mathrm{CI} = \frac{\lambda \max - n}{n - 1} \quad (2)$$

where λmax is the maximum eigen value of A, and n is the size of the matrix ($n \times n$).

To interpret the CI, it is often compared to the Random Consistency Index (RI), which is derived from a large sample of randomly generated matrices of the same order. The consistency ratio (CR) can be calculated by Equation (3),

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (3)$$

where RI, as indicated in **Table 2**, is the random consistency of matrix A, which can be calculated using a standard table suggested by Sindhu et al. (2016). A CR of 0.1 (10%) or less is generally considered acceptable. If the CR exceeds this threshold, it suggests that the pairwise comparisons may be inconsistent, and the decision-makers should review and revise their judgments to improve consistency.

Table 2. Random consistency.

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Sindhu et al. (2016).

3. Case study

One of the districts in Thailand with the highest frequency of power outages is Mae Sariang District, Mae Hong Son Province. Mae Sariang District receives its energy supply from the Hod substation, which is situated about 110 kilometers away. Furthermore, several kinds of small power sources, including solar, micro-hydro, and diesel power plants, can generate electricity. The Provincial Electricity Authority of Thailand (PEA) owns and operates this 22 kV distribution system, which is also referred to as the Mae Sariang microgrid system. Nevertheless, it is not enough to meet the demand for local load and has a low probability of producing electricity (Tephiruk et al., 2018).

Mae Hong Son Province, Thailand, is divided into seven districts, one of which is Mae Sariang District, as shown in **Figure 2**. The provincial court, district prison, provincial treasury, provincial land, and other government offices are situated there, along with other government buildings, in the southern part of Mae Hong Son Province. Complex mountains and thick forests make up about 90% of the region. The entire area, 2497.2 square kilometers, makes up 18.9 percent of the province of Mae Hong Son. Mae Hong Son Province's most populated district, Mae Sariang District, is home to 54,529 people (Thidarat, 2020).

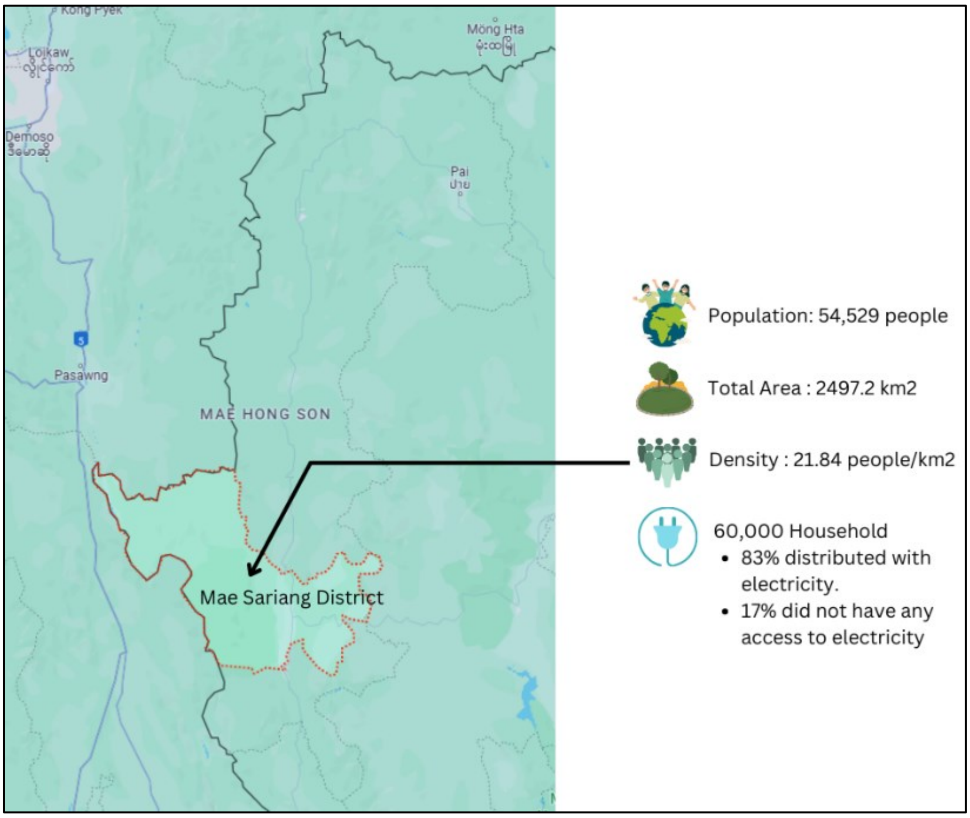

Figure 2. Location of Mae Sariang District in Mae Hong Son province.

The Mae Sarang microgrid was powered by five primary sources: 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.

4. Methodology

4.1. Background information

Knowledge about Mae Sariang's microgrid was acquired through expert consultations, stakeholders, and literature reviews. The government publications, books, websites, and scholarly journals that were previously mentioned in the Introduction section were used to review the documents pertaining to the Multi Criteria Decision Making (MCDM), AHP, Thai electricity production, and energy policy in Thailand.

4.2. Questionnaire and survey

The questionnaire for this study was broken down into five main sections: (1) respondent information; (2) main criteria comparisons made in pairs; (3) sub-criteria comparisons made in pairs; (4) pairwise comparisons of renewable energy options in Thailand; and (5) an open-ended section for respondents' unstructured comments. Pairwise comparisons were conducted using the structured form, which was connected to five primary criteria. The primary criteria and supporting criteria were developed during a focus group meeting with 37 participants from various stakeholders, including policy makers, the Ministry of Industry, the Electricity Generating Authority of Thailand (EGAT), university lecturers, energy specialists, and partners in the private sector for the production of electricity. **Figure 2** shows the steps of applying the analytical hierarchy process in the study.

Possible alternative energy sources in the Mae Sariang microgrid system (under the assumption that it must be able to produce at least 6 MW of electricity to respond to electricity loads) consist of four alternative choices: (1) Grid + Battery Energy Storage System (BESS); (2) Grid + BESS + Solar Photovoltaic (PV); (3) Grid + Diesel Generator (DG) + PV; and (4) Grid + DG + Hydro + PV. The details of the main criteria and sub-criteria can be explained as follows:

- Economic Criteria

The economic aspect was related to the electricity production cost and the operation and maintenance (O&M) costs. The electricity production cost refers to the cost of producing electricity with various types of energy sources in the microgrid system. O&M cost refers to the cost of maintaining the electricity production system from various types of renewable energy and maintenance in case of breakdown or damage. Both costs were determined in the economic aspect.

- Structure Criteria

This criterion refers to the lifetime of the renewable energy production system and the decline in performance each year. Because each renewable energy technology has a different lifespan, this criterion is intended to determine the number of years it will continue to operate satisfactorily without unexpected major shutdowns and the ability to expand in the future with existing or enhanced technology.

- Technology Criteria

Technology that can lead to technology transfer, job creation, and investing in accessory equipment within the country. In addition, this criterion considers the ability to operate the electricity production even in the absence of the main grid.

- Production Criteria

Electricity production concerns the issue of electrical efficiency. This efficiency is the ration of energy produced to energy input. Another issue is the power plant utilization rate which means the ratio of energy actually produced to full production capacity in one year.

- Social and Environmental impacts

This criterion determines whether the pollution emissions are within the standard level or are so low that the standard does not affect people’s health and living things. This included the greenhouse gas emissions both directly and indirectly emitted from technology.

4.3. Focus group

Since the research topic is highly specific and pertains to a group of experts, the respondents in this study were specifically defined. As a result, **Table 3** illustrates the division of the respondents into five groups.

Table 3. Information about the respondents who answer the questionnaire.

Number of groups	Stakeholders	Respondents
Group I	Organization in charge of developing plans and policies for renewable energy	• Energy Policy and Planning Office, Ministry of Energy • Department of Alternative Energy Development and Efficiency, Ministry of Energy
Group II	Thai government-owned company that generates and distributes power	• Electricity Generating Authority of Thailand (EGAT) • Provincial Electricity Authority (PEA)
Group III	Energy specialists with over ten years of experience conducting energy research	• Researchers and lecturers from universities
Group IV	People in the private sector who operate in the renewable energy industry	• The Federation of Thai Industries
Group V	Public sector individuals who have knowledge of energy and renewable energy in Thailand	

4.4. AHP application to rank renewable energy sources for Mae Sariang's microgrid

As seen in **Figure 3**, there were multiple steps involved in applying AHP. Setting the goal was the first step, which was then followed by choosing an alternative. The primary criteria served as the foundation for the alternative selection assessment. The goal of the AHP diagram is to illustrate the hierarchical relationship between the target, criteria, and alternatives. Comparing alternatives and criteria necessitated a pairwise comparison. The decision option performance scores' criteria weights were obtained in order to compare quantitative values. The stakeholders were asked to rank their preferences for one criterion or alternative over another in each pair on a nine-point scale, as shown in **Table 1**.

After obtaining the pairwise comparison result, the next step is to transfer the weights to a matrix, which is a method unique to the AHP (Saaty, 1980). The square matrix of pairwise comparisons $A = [aij]$ will be filled in as shown in the example of Equation (1). The CI and CR were calculated and checked in according to Equations (2) and (3). Using pairwise comparisons, Business Performance Management Singapore (BPMSG) processed the AHP analysis to determine the priorities for a set of criteria.

When receiving the results, rank the alternatives from highest to lowest based on the overall scores. Then, the alternative with the highest score is usually chosen as the best option. By following these steps, AHP helps decision-makers systematically and logically evaluate complex decisions, ensuring consistency and thorough consideration of all relevant factors.

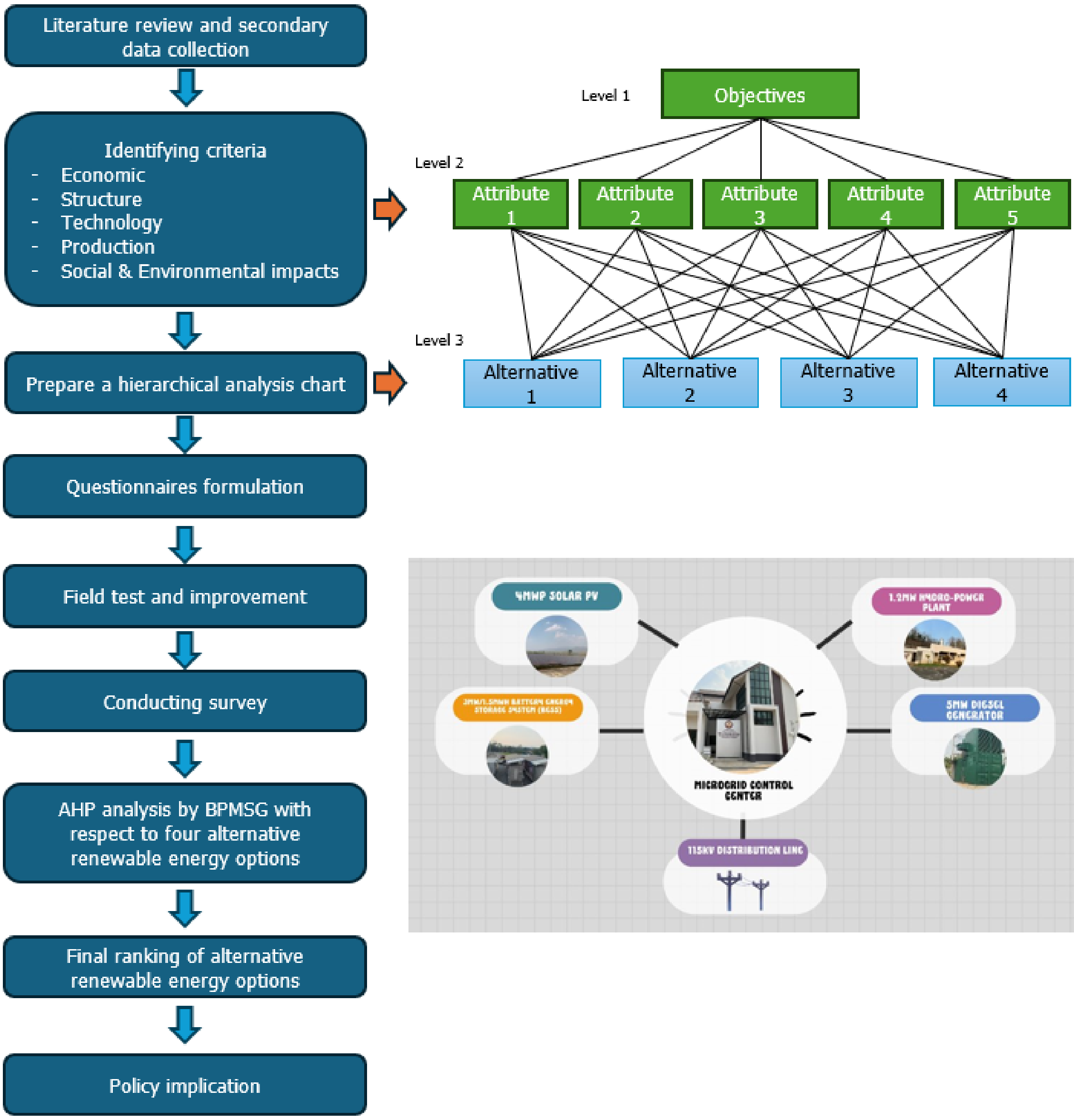

Figure 3. Steps of applying the analytical hierarchy process in the study.

5. Results and discussion

Results of weighting criteria

In order to generate electricity for Mae Sarang's microgrid, the study presented here assessed and ranked four alternative renewable energy options based on five primary criteria that were important to stakeholders.

The production criterion was found to be the most favored, while structure was found to be the least, according to the criteria-wise preference analysis. Technology, as well as the effects on society and the environment, are ranked lower than the economic criteria. The production criterion was assigned the highest percentage of weight (24.7%), followed by economics (24.2%), technology (18.5%), social and environmental (18.1%), and structure (14.5%), according to the questionnaire survey responses, as shown in **Figure 4**.

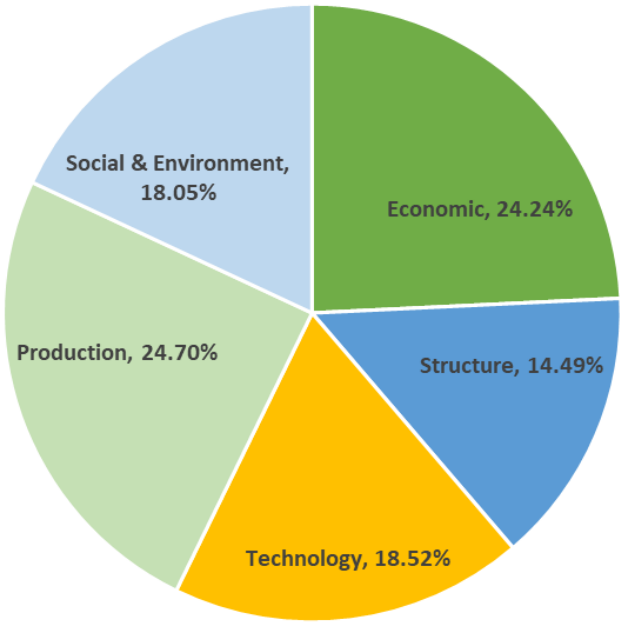

Figure 4. Weights of the five criteria for determining the renewable energy options.

The prioritization results are shown in **Figure 5**. In the case of economics (**Figure 5a**), it can be seen that the option II (Grid + BESS + PV) was very much preferred and closely followed by option IV (Grid + DG + PV + Hydro), and option III (Grid + DG + PV), while option I (Grid + BESS) was less valued for this criterion. This result means that respondents were of the opinion that solar energy plus battery storage are well-equipped in terms of cost and ability to make a better signal for the investment than other options. In terms of structure criteria (**Figure 5b**), option II was still the most preferred; on the other hand, option III was ranked the lowest. The trend of ranking was the same as economics and technology criteria (**Figure 5c**). Although the costs associated with purchasing solar and battery systems are very high, respondents remain confident that it will be the technology of the future to meet the low cost and long-term stability of renewable power generation.

In terms of production, the result was different (**Figure 5d**). Option I had the highest priority score, but this score was close to that for option II. The lowest priority score was given to option III, followed by option IV, respectively. While option I was ranked top priority in terms of social and environmental criterion, option III was ranked the lowest, as shown in **Figure 5e**. This result can be implied that option I can give the confidence in the aspect of power system reliability. Due to the experience of power outages, which can cause economic damage and human living to the community, option I was chosen as the highest priority even though there is no benefit in terms of environmental impact.

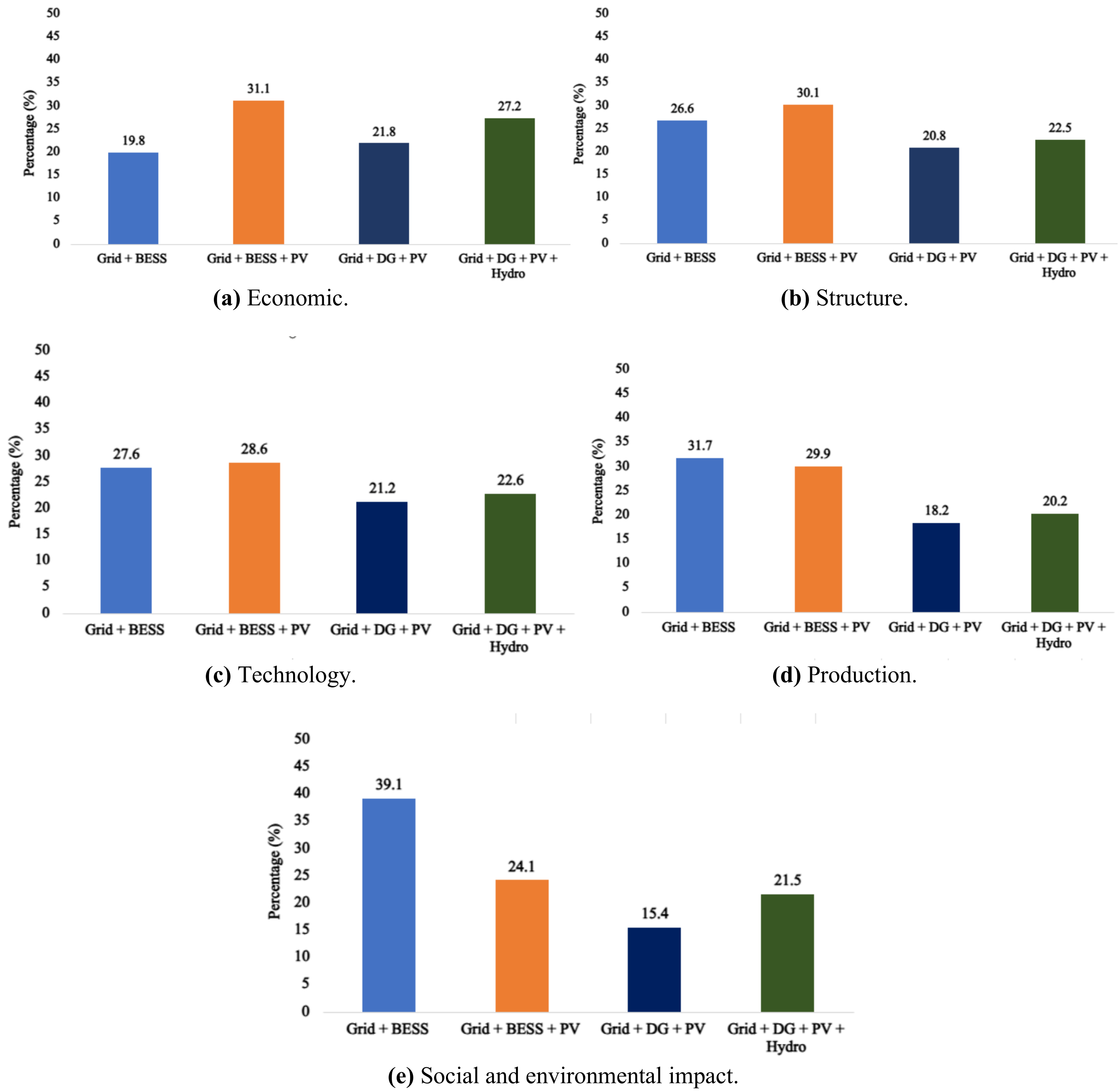

Figure 5. Priority of alternative renewable energy options based on five main criteria: **(a)** economic; **(b)** structure; **(c)** technology; **(d)** production; and **(e)** social and environmental impact.

Figure 6 shows the overall findings for Mae Sarang's microgrid's renewable energy options ranking. The study's findings showed that each option is significant and fiercely rivals the others. It is still necessary to choose the best course of action for the microgrid system's benefit. Option II was the most highly ranked option, with options I, IV, and III following in order. With the advancements in solar power generation technology today, this option is top-rated as it produces electricity at a low cost and is worth the investment. According to the International Renewable Energy Agency (IRENA), the cost of solar PV has fallen dramatically over the past decade, making it one of the most cost-effective sources of electricity generation (IRENA, 2020). Moreover, solar power systems have a significantly lower environmental impact compared to conventional energy sources, particularly in terms of greenhouse gas emissions (Fthenakis and Kim, 2011). However, the only disadvantage of this system is the production cost of batteries, which, despite rapid cost reductions, remains relatively high, posing a challenge for large-scale storage solutions (Nykvist and Nilsson, 2015). In the future, if such costs can be reduced, the system is expected to be an efficient technology using 100% renewable energy, which will not only be used in large industries but also in homes.

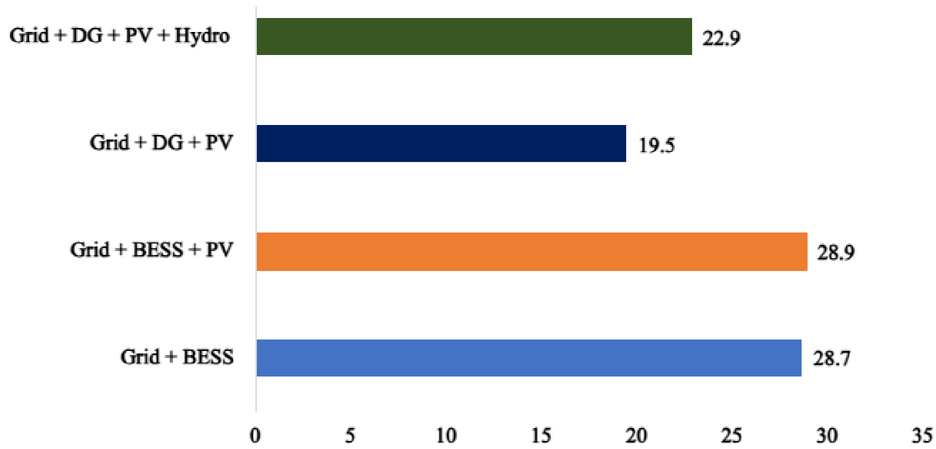

Figure 6. Overall priority of alternatives renewable energy options corresponding to all criteria.

The worst option is clearly option III due to concerns about climate change. Large sources of greenhouse gas emissions can be generated from diesel generators. The range of carbon intensity for each technology can be shown in **Table 4**. While the project aims to produce electricity without using fossil fuels, this backup plan is still in place in case of emergency. However, the fossil fuel option will be gradually eliminated from the system once the microgrid system is stable and reliable.

Table 4. Carbon intensity of electricity production for each technology.

Technology	Carbon Intensity (g CO2e/kWh)	References
Solar PV	20–60	IPCC (2014), Fthenakis et al. (2008)
Wind	10–20	IPCC (2014), NREL (2013)
Hydropower	1–30	IPCC (2014), Hertwich (2013)
Geothermal	10–40	IPCC (2014), Frick et al. (2010)
Coal	820–1050	IPCC (2014), IEA (2017)
Natural Gas	450–550	IPCC (2014), IEA (2017)
Oil	650–900	IPCC (2014), IEA (2017)
Nuclear	5–15	IPCC (2014), Warner and Heath (2012)
Biomass	20–200	IPCC (2014), Cherubini et al. (2009)

6. Conclusions

This study represents the first attempt to rank the renewable energy options available in Mae Sarang’s microgrid in Thailand using the AHP methodology. The primary criteria used to assess each renewable resource option made up the framework of the AHP model. Economic, structural, production, technological, social, and environmental impact criteria were determined for this study. The model results show that the most important criterion is production (24.7%), with economics (24.2%), technology (18.5%), social and environmental (18.1%), and structure (14.5%) following closely behind. Option I has a significant advantage in terms of production criteria and the impact on society and the environment, whereas option II is highly recommended in terms of economic and structural criteria. The results showed that option II is the most favored choice out of the four, with options I, IV, and III coming in order of preference.

The study on prioritizing renewable energy options for Mae Sariang's microgrid using the Analytical Hierarchy Process (AHP) offers valuable insights, effectively leveraging AHP's structured decision-making framework. The involvement of expert groups ensures informed prioritization based on five primary criteria, highlighting production, economics, technology, social and environmental impact, and structure. However, the study faces several limitations. Involving only five expert groups may result in a narrow perspective, lacking comprehensive stakeholder representation. Subjective criteria weighing in AHP can introduce bias, and its static nature does not account for dynamic changes in the renewable energy sector. Practical implementation challenges, such as integrating multiple energy sources, are not fully addressed. Continuous evaluation and broader stakeholder engagement are essential to address these challenges for robust energy planning.

Author contributions: Conceptualization, BY and PU; methodology, BY and PU; validation, PU; formal analysis, BY; investigation, BY and PU; resources, PU and CM; data collection, BY; writing—original draft preparation, BY and PU; writing—review and editing, PU, SJ and CM; visualization, PU; supervision, SJ. All authors have read and agreed to the published version of the manuscript.

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