Economic, Environmental, Social and Technical Assessment of Energy Production Methods in the Philippines Using Analytical Hierarchy Process Approach

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Abstract. The Philippines depends on imported fuels for its energy needs, driving the development of energy production methods and affecting sustainable growth. Considering the economic, environmental, social, and technical factors, this study assessed conventional and renewable energy production methods (EPMs) using the Analytical Hierarchy Process (AHP) approach. Thirty experts from energy companies, academia, and regulatory bodies were consulted for this study. The methodology involved a literature review and SpiceLogic AHP software analysis. In the Business-as-Usual (BAU) scenario, the economic criterion (0.450) was prioritized, with coal (0.554) being the top source owing to its cost-effectiveness. The emission scenario prioritized environmental criteria (0.394), favoring natural gas (0.466) for lower-emission values. The Kea scenario emphasized environmental criteria (0.338), with wind energy (0.412) preferred for minimal environmental impact. The Tui scenario showed a preference for solar energy (0.375), emphasizing economic criteria (0.401). The policy implications include prioritizing natural gas infrastructure, phasing out coal, enhancing oil production standards, increasing renewable energy investment, promoting financial incentives, improving resource management, and strengthening regulations for a sustainable energy mix. Future research should examine more energy sources, scenarios, and stakeholder engagement to evaluate the long-term sustainability.

1 Introduction

The Philippines, an archipelagic nation, relies heavily on imported fuel to satisfy its energy requirements. The increasing energy demand has prompted the exploration of various energy production methods that impact sustainable development. The energy mix comprises fossil fuels (coal, oil, and natural gas) and renewable sources (hydro, solar, wind, and biomass) [1].

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Import dependence affects energy security and price stability, and the energy sector contributes significantly to carbon emissions [2]. Globally, the scarcity of safe, low-carbon energy alternatives to fossil fuels presents a major challenge, leading to ongoing issues with energy access and emission. In the Philippines, despite improved electricity access, challenges persist, including growing demand, supply scarcity, and rural-urban electrification disparities [3].

The research gap lies in the lack of a comprehensive sustainability assessment of energy production methods using multi-criteria decision-making that considers economic, environmental, technical, and social (ETS) factors. This study addresses this gap through an Analytical Hierarchy Process (AHP) analysis of energy production methods in the Philippines. It examined different ways to produce energy in the Philippines, both traditional and renewable, using the AHP. The goals were to identify environmental, social, technical, and economic factors through expert surveys; create a framework for AHP analysis; use the SpiceLogic AHP software to rank these factors and energy methods; and suggest policies based on the AHP analysis results.

This study provides insights into the sustainability of energy production in the Philippines, thereby supporting the transition to sustainable energy systems. The results will benefit policymakers, energy planners, investors and researchers. This study employed a systematic literature review and quantitative descriptive-comparative research to develop sustainability indices and compare the energy production methods.

2 Methods

A quantitative descriptive-comparative research design was employed, which involved collecting and analyzing numerical data to develop a sustainability index and compare the performance of different energy production methods in the Philippines. Purposive sampling was used to select experts for this study, deliberately choosing participants who were the most representative of the study's objectives. Thirty experts (10 each from regulators, academia, and Energy Companies) were consulted. A series of collection stages were employed, such as the pre-collection, collection proper, and post-collection stages

Frequency analysis identified the most prevalent subcriteria preferred by experts. An AHP tool was used to analyze the experts' input. This tool solves complex problems with multiple criteria using a hierarchical approach. The SpiceLogic AHP software was mainly used to facilitate the analysis of expert inputs and judgements. First, a hierarchical structure for comparing the energy production methods was developed, as shown in Figures 1 and 2.

Subsequently, priorities must be established. In pairwise comparisons, numerical values are allocated to criteria based on expert preferences. The Saaty scale requires experts to conduct pairwise comparisons to establish the priorities and weights. The next step verified the judgment consistency using the consistency index (CI). To validate the CI value, it should be compared with the random consistency index (RI). This parameter represents the average consistency index of the matrices with random inputs. The results were consistent when $CR \leq 0.1$. If $RC > 0.1$, it indicates inconsistency, requiring a judgment review. For problems with subcriteria, the previous step must be repeated through pairwise comparisons to determine the subcriteria importance relative to higher levels. Next, the priorities for alternatives must be defined by comparing alternatives according to the criteria and sub-criteria. Finally, the global weights are determined by multiplying the local weights by the global weights of the criterion with the next higher priority. The sum of the overall weights of the alternatives for each criterion serves as a mechanism for obtaining scores for all the possible alternatives [4].

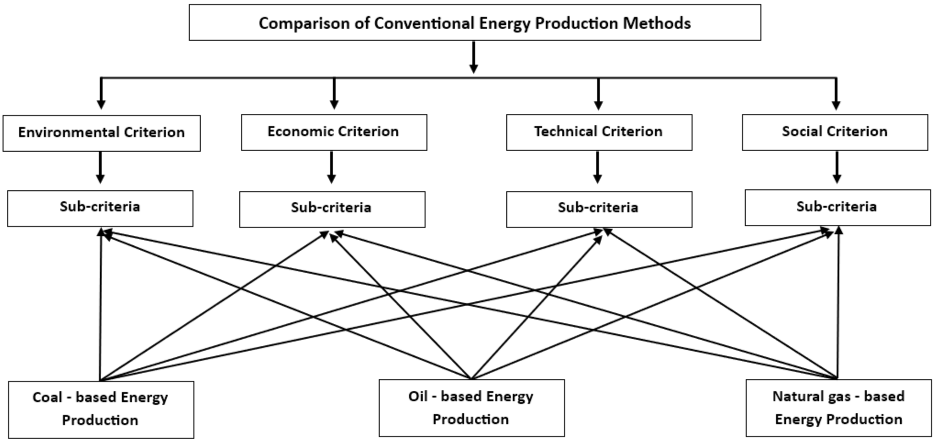

Fig. 1. Hierarchy Framework for Conventional EPMs

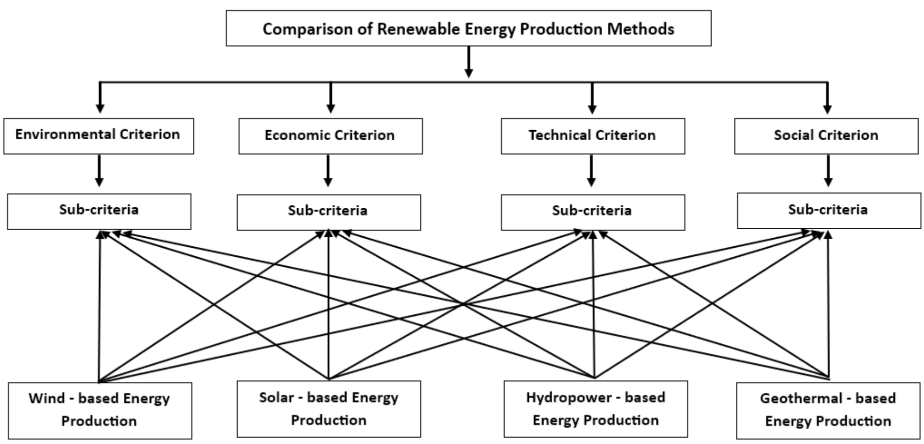

Fig. 2. Hierarchy Framework for Renewable EPMs

2.1 Future Scenario Building of the Philippine Energy Sector

The AHP method used weightings based on future scenarios in the energy sector in the Philippines. These scenarios help determine which energy options are best for a country. Four future scenarios were created to determine the suitable energy production methods (EPMs). There are two types of scenarios: (1) those using fossil fuels and (2) those using renewable energy sources. Each type has scenarios that require scientific evaluation.

2.1.1 Conventional Fossil Fuel-Based Method (e.g., coal, oil, gas)

- Business-as-Usual (BAU) Scenario. Assumes that current trends will continue without any significant changes, which is a plausible assumption for short- to medium-term forecasting [5].

- Emission Scenario. A scenario for estimating future levels of greenhouse gas emissions from conventional energy production methods and comparing them with the current levels [6].

2.1.2 Renewable Energy-Based Method (e.g., wind, solar, hydro, geo)

- Kea Scenario. A scenario that envisions a future in which climate change is viewed as the most significant concern facing society .
- Tui Scenario. A scenario that views climate change as only one of several competing challenges. In this scenario, the economy and welfare of the people remain priorities for the government and society [7].

A systematic review of related studies was performed to establish the study criteria. The following main criteria were established: environmental, economic, technical, and social criteria. The sub-criteria of the study were established following consultation with the identified experts.

3 Results and Discussion

3.1 Expert's Preferences for Sub-Criteria

Based on experts' responses, the preferred sub-criteria of the experts in each of the criteria (e.g. economic, environmental, social, technical) are summarized in the succeeding tables below.

Table 1. Sub-Criteria Order of Preference

Rank	Economic	Environmental	Social	Technical
1	Economic Effectiveness	Water & Land Resources Impact	Health Impacts	Energy Efficiency
2	Operation and Maintenance Cost	Hazardous Waste Management	Safety Impacts	Technology Availability
3	Investment Opportunities	Gas Emission	Social Acceptability	Resource Availability
4	Service Life	Life-Cycle Emission	Social Benefits	Reliability

Table 1 shows that within the economic subcriteria, experts prioritized initiatives that provided optimal financial returns, minimized operational costs, and maximized investment potential. Regarding the environmental subcriteria, the experts underscored the importance of resource conservation while expressing concerns about pollution and waste. In the social subcriteria, experts prioritized health considerations and the immediate benefits to individual and community well-being, emphasizing the necessity of community support and approval for any initiative. Concerning the technical subcriteria, the experts highlighted the importance of efficiency in assessments. Their focus on technology and resource availability underscores concerns about feasibility, practicality, and the capacity to sustain operations and achieve project objectives.

3.2 Conventional Sources: Prioritization of Criteria, Sub-Criteria and EPMs

3.2.1 Business-as-Usual Scenario Basis

Table 2. Prioritization Matrix of Main Criteria for BAU Scenario

Variables	Environmental	Economic	Technical	Social	Weightings
Environmental	2	0.33	0.5	0.5	0.120
Economic	3	1	2	3	0.450
Technical	2	0.5	1	2	0.260
Social	2	0.33	0.5	1	0.171
Consistency Ratio					0.027

The prioritization matrix for the business-as-usual scenario shows a strong emphasis on economic factors, with a priority weighting of 0.450 as shown in Table 2. This indicates that economic considerations are crucial in decision-making for conventional energy production, aligning with existing studies that highlight the dominance of economic factors in energy policy decisions.

Table 3. Prioritization Rankings and Weightings of EPMs for BAU Scenario

Rank	Energy Production Methods	Weightings
1	Coal	0.544
2	Oil	0.316
3	Natural Gas	0.140

In the BAU scenario, coal is the top choice for energy production. It has a score of 0.544 because it is inexpensive and easily obtainable as shown in Table 3. However, these have negative effects on the environment and society. Oil was the second choice, with a score of 0.316. It is valued for its economic benefits and technical ease, but it also harms the environment and health of workers. Natural gas was third with a score of 0.140. Although it is cleaner than coal and oil, its benefits are not sufficient to beat the top two [8]. This ranking shows a reliance on traditional, cost-effective energy sources and highlights the need to address their environmental and health impacts in the future.

3.2.2 Emission Scenario Basis

Table 4. Prioritization Matrix of Main Criteria for Emission Scenario

Variables	Environmental	Economic	Technical	Social	Weightings
Environmental	1	2	2	2	0.394
Economic	0.5	1	1	0.5	0.169
Technical	0.5	1	1	1	0.197
Social	0.5	2	1	1	0.239
Consistency Ratio					0.023

In the emission scenario analysis, prioritization revealed a significant shift towards environmental considerations, with a priority weighting of 0.394 as shown in Table 4. This indicates a strong emphasis on mitigating the environmental impacts of conventional energy production methods, reflecting growing concerns about climate change and sustainability.

Table 5. Prioritization Rankings and Weightings of EPMs for Emission Scenario

Rank	Energy Production Methods	Weightings

1	Natural Gas	0.466
2	Oil	0.313
3	Coal	0.221

The energy production methods were ranked, showing a preference for natural gas, with a score of 0.466 as shown in Table 5. This indicates that natural gas is the best option because it is less harmful to the environment than coal and oils. Oil was ranked second with a score of 0.313. It is economically and technically feasible but has significant environmental and health impacts. Coal was ranked third, with a score of 0.221. Although it is cheap, it has high environmental and social impacts, making it less favorable. Choosing natural gas over coal and oil shows a move towards cleaner energy, which helps reduce greenhouse gas emissions and combats climate change.

3.3 Renewable Sources: Prioritization of Criteria, Sub-Criteria and EPMs

3.3.1 Kea Scenario Basis

Table 6. Prioritization Matrix of Main Criteria for Kea Scenario

Variables	Environmental	Economic	Technical	Social	Weightings
Environmental	1	5	1	1	0.338
Economic	0.2	1	0.5	0.33	0.099
Technical	1	2	1	1	0.270
Social	1	3	1	1	0.293
Consistency Ratio					0.030

Table 6 shows that in the KEA scenario, which envisions climate change as the most significant concern, the prioritization data reflected a strong emphasis on environmental and social criteria, with priority weightings of 0.338 and 0.293, respectively. This indicates a heightened focus on sustainability and societal impacts in the decision-making process for renewable energy production, which aligns with contemporary climate-focused strategies.

Table 7. Prioritization Rankings and Weightings of EPMs for Kea Scenario

Rank	Energy Production Methods	Weightings
1	Wind	0.412
2	Solar	0.247
3	Hydropower	0.186
4	Geothermal	0.154

The renewable energy methods were ranked, and wind energy ranked first with a score of 0.412 as shown in Table 7. This indicates that wind energy is considered the best choice because it is better for the environment and health than other renewable sources of energy. Solar energy was ranked second with a score of 0.247. It is economically and technically feasible, but has environmental and social impacts. Hydropower and geothermal energy scored 0.186 and 0.154, respectively. These are good options but do not meet the environmental and social standards of wind energy and solar energy. The preference for wind energy indicates a move towards energy that benefits the environment and health, supporting global efforts to fight climate change and promote sustainable development. This suggests that while economic and technical factors are important, there is a stronger focus on energy solutions that provide environmental and social benefits..

3.3.2 Tui Scenario Basis

Table 8. Prioritization Matrix of Main Criteria for Tui Scenario

Variables	Environmental	Economic	Technical	Social	Weightings
Environmental	1	0.33	0.5	0.2	0.095
Economic	3	1	2	2	0.401
Technical	2	0.5	1	0.5	0.178
Social	5	0.5	2	1	0.326
Consistency Ratio					0.049

Table 8 shows that in the Tui scenario, which views climate change as one of several competing challenges, prioritization shows a strong emphasis on economic and social criteria, with priority weightings of 0.401 and 0.326, respectively. This indicates a focus on economic viability and societal welfare, reflecting the priorities of a government and society that balance multiple challenges, including economic stability and public welfare.

Table 9. Prioritization Rankings and Weightings of EPMs for Tui Scenario

Rank	Energy Production Methods	Weightings
1	Solar	0.375
2	Wind	0.279
3	Hydropower	0.215
4	Geothermal	0.131

In the rankings for renewable energy methods, solar energy was the top choice, with a score of 0.375 as shown in Table 9. This means that in the Tui scenario, solar energy is seen as the best option because it is good for the economy and society and has a moderate environmental impact [9]. Wind energy was second with a score of 0.279, indicating that it is technically possible and accepted by people. Hydropower (0.215) and geothermal energy (0.131) followed. Although these are good options, they do not currently meet the economic and social standards of solar and wind energy. The preference for solar energy indicates a move towards energy solutions that offer significant economic and social benefits. This suggests that while environmental and technical factors are important, there is a stronger focus on energy solutions that provide broad economic and social advantages than on environmental factors.

3.4 Policy Recommendations for Philippine Energy Policy and Planning

3.4.1 Conventional Sources

Prioritizing infrastructure development is essential for shifting to natural gas energy production. With the highest weighting (0.466) under the emission scenario, natural gas was favored because of its minimal environmental impact. It strikes a balance among environmental, social, and economic criteria, making it a viable transitional energy source for low carbon systems [10]. The Philippines should focus on investing in gas infrastructure, such as pipelines and liquefied natural gas (LNG) terminals, with support from the Asian Development Bank to diversify its energy supply mix.

Gradual phase-out regulations should be implemented to minimize coal usage. Despite its economic benefits, coal ranked lowest (0.221) because of its environmental and health impacts. Policies should aim to reduce coal consumption and invest in cleaner alternatives [11]. The Philippines should develop transition plans to replace coal-fired plants with natural gas and renewables, aligning with the International Renewable Energy Agency's (IRENA) recommendations for environmental and health benefits.

Oil production practices need to be improved through enhanced safety and environmental standards. Although oil ranked second (0.313), stricter regulations are necessary to mitigate its environmental and health impacts[12]. Implementing stringent environmental regulations is crucial, focusing on reducing emissions, preventing spills, and protecting ecosystems in line with the Occupational Safety and Health Administration (OSHA) guidelines for worker and community protection.

3.4.2 Renewable Sources

Prioritizing wind energy infrastructure development is essential. The findings indicate that wind energy is highly ranked because of its minimal environmental impact and associated health benefits, with a weighting of 0.412, highlighting its potential as a primary renewable energy source. Investment should be directed towards infrastructure and policy support to optimize the adoption of these technologies. Wind energy plays a crucial role in reducing greenhouse gas emissions and improving air quality. The Philippines should prioritize wind projects in regions with high potential, such as Ilocos Norte, in alignment with its high priority in both scenarios [13].

The expansion of solar energy requires financial incentives to encourage installation. Solar energy ranked second in the Kea scenario (0.247) and first in the Tui scenario (0.375), indicating its economic feasibility and high social acceptance. Tax breaks, grants, and loans can stimulate the development of residential and commercial projects. The Solar Energy Industries Association (SEIA) notes significant increases in installations where incentives are present. In the Philippines, solar energy should be promoted through government incentives and public–private partnerships (PPP), given its high TUI scenario ranking and potential benefits [14]. Enhancing resource management should be the focus of future studies. Policies should address the impact of renewable energy on natural resources and the environment.

The environmental criterion prioritizes the impact on water and land resources (0.387 weighting). Effective management ensures sustainable development and minimizes environmental degradation. The National Renewable Energy Laboratory (NREL) emphasizes integrated resource management to prevent these negative impacts [15]. Philippine regulations should address the environmental effects of renewable energy initiatives, particularly focusing on water and land resources.

4 Conclusions and Recommendations

This study assessed energy production sustainability in the Philippines using AHP and evaluated sources based on environmental, economic, technical, and social criteria. The AHP-driven software provides a comprehensive analysis of priorities and trade-offs in energy policy decision-making. The results highlight the need for a balanced approach to energy planning that considers multiple factors, emphasizing the Philippines' need to transition toward a mix of conventional and renewable energy sources. For conventional energy, the priorities include natural gas adoption, coal phase-out, and enhanced oil production safety. Expanding wind and solar projects while ensuring effective resource management is crucial for the development of renewable energy. These policy recommendations can help the Philippines achieve a sustainable energy future. The authors recommend that future studies incorporate broader stakeholder involvement, conduct longitudinal analyses of sustainability impacts, and develop scenarios that account for technological, policy and market changes.

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