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PRODUCTION MANAGEMENT AND MARKETING

THE ASSESSMENT OF RENEWABLE ENERGY SOURCES WITH FUZZY MCDM: THE CASE OF BARMM REGION, PHILIPPINES

MASTERS THESIS

Prepared by

Art Marvin Magsanay ARAÑAS

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DECLARATION

I hereby certify that my Master's Thesis, entitled "The Assessment of Renewable Energy Sources with Fuzzy MCDM: The Case of the BARMM Region, Philippines," is the result of my original and independent work, conducted in full compliance with scientific and academic standards. All sources and materials utilized have been duly acknowledged, cited, and referenced in accordance with academic regulations. I have thoroughly reviewed and understood the plagiarism policies and procedures of Niğde Ömer Halisdemir University.

15/07/2024

Art Marvin Magsanay ARAÑAS

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ABSTRACT
MASTER THESIS

THE ASSESSMENT OF RENEWABLE ENERGY SOURCES WITH FUZZY MCDM: THE CASE OF BARMM REGION, PHILIPPINES

ARAÑAS, Art Marvin Magsanay
Department of Business Administration
Production Management and Marketing
Supervisor: Dr. Ayse TOPAL
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Energy and a reliable access to it plays a very crucial role in our lives for it affects almost every aspect of it. It is essential for business, industries and services, as well as education, healthcare, communication. Lack of access to reliable energy hinders economic growth, as studies have shown how energy poverty and overall poverty are correlated.

The Bangsamoro Autonomous Region in Muslim Mindanao (BARMM) has been experiencing an energy crisis for a long time, with government electrification data showing that 58.26% of its households have no access to electricity. Because of this, the members of the parliament have urged through a resolution the Ministry of Environment, Natural Resources and Energy to craft a comprehensive power development plan to explore the available renewable energy options in the region, namely geothermal, hydropower, biomass, solar and ocean energy. The creation of such plan aims to promote renewable energy and improve efficient use of energy, and consequently support livelihood programs for the population living in off-grid and un-electrified areas.

Through a literature review, this study has identified several Multi Criteria Decision Making (MCDM) methods to contribute towards the government's initiative. Six experts were identified and tasked to do criteria weight evaluation through pairwise comparison which was then treated with Fuzzy AHP. Their evaluation showed that economic criteria is the most important criteria to consider in selecting renewable energy options in the region.

Furthermore, the experts were tasked to rate the performance of each alternative against each criterion, and Fuzzy TOPSIS, Fuzzy WASPAS and Fuzzy MOORA were used to process their responses. The results were consistent in showing that solar energy is the best alternative. Investing in solar energy doesn’t only provide a solution to the region’s perennial problem but could also contribute to the county’s goal of reducing reliance to fossil fuels and increasing the share of renewable energy to the power mix.

Keywords: Fuzzy MCDM, Philippines, Renewable Energy.

ÖZET
YÜKSEK LİSANS TEZİ

YENİLENEBİLİR ENERJİ KAYNAKLARININ MCDM İLE DEĞERLENDİRİLMESİ: FİLİPİNLER BARMM BÖLGESİ ÖRNEĞİ

ARAÑAS, Art Marvin Magsanay
İşletme Anabilim Dali
Üretim Yönetimi Ve Pazarlama Bilim Dali
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Enerji ve enerjiye güvenilir erişim hayatımızın neredeyse her yönünü etkilediği için çok önemli bir rol oynamaktadır. İş dünyası, endüstriler ve hizmetlerin yanı sıra eğitim, sağlık ve iletişim için de gereklidir. Güvenilir enerjiye erişim eksikliği, ekonomik büyümeyi engellemektedir; çünkü araştırmalar, enerji yoksulluğu ile genel yoksulluğun nasıl ilişkili olduğunu göstermiştir.

Müslüman Mindanao'daki Bangsamoro Özerk Bölgesi (BARMM) uzun süredir bir enerji krizi yaşamaktadır; hükümetin elektrifikasyon verileri, hanelerin %58,26'sının elektriğe erişiminin olmadığını göstermektedir. Bu nedenle parlamento üyeleri, Çevre, Doğal Kaynaklar ve Enerji Bakanlığı'na, bölgedeki mevcut yenilenebilir enerji seçeneklerini (jeotermal, hidroelektrik, biyokütle, güneş ve okyanus enerjisi) araştırmak için kapsamlı bir enerji geliştirme planı hazırlaması yönünde bir kararla çağrıda bulunmuştur. Böyle bir planın oluşturulması, yenilenebilir enerjiyi teşvik etmeyi, enerjinin verimli kullanımını geliştirmeyi ve sonuç olarak şebekeden bağımsız ve elektriksiz alanlarda yaşayan nüfus için geçim programlarını desteklemeyi amaçlamaktadır.

Literatür taraması yoluyla bu çalışma, hükümetin inisiyatifine katkıda bulunacak çeşitli Çok Kriterli Karar Verme yöntemlerini belirlemiştir. Altı uzman belirlenerek ikili

karşılaştırmalar yoluyla kriter ağırlık Bulanık AHP ile elde edilmiştir. Belirlenen kriter ağırlıkları, bölgede yenilenebilir enerji seçeneklerinin seçiminde ekonomik kriterlerin dikkate alınması gereken en önemli kriter olduğunu göstermiştir.

Alternatiflerin sıralaması için Bulanık TOPSIS, Bulanık WASPAS ve Bulanık MOORA kullanılmıştır. Sonuçlar, güneş enerjisinin en iyi alternatif olduğunu gösterme konusunda tutarlı bulunmuştur. Güneş enerjisine yatırım yapmak yalnızca bölgenin daimi sorununa bir çözüm sağlamakla kalmayacak, aynı zamanda ülkenin fosil yakıtlara olan bağımlılığı azaltma ve enerji karışımında yenilenebilir enerjinin payını artırma hedefine de katkıda bulunabilecektir.

Anahtar Kelimeler: Bulanık MCDM, Filipinler, Yenilenebilir Enerji.

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ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BARMM	Bangsamoro Autonomous Region in Muslim Mindanao
BOCR	Benefits, Opportunities, Costs and Risks
CEM	Clean Energy Ministerial
DOE	Department of Energy
EDAS	Evaluation based on Distance from Average Solution
FMEA	Failure Mode and Effect Analysis
EPIMB	Electric Power Industry Management Bureau
EPIRA	Electric Power Industry Reform Act
GEAP	Green Energy Auction Program
IEA	International Energy Agency
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
LASURECO	Lanao del Sur Electric Cooperative, Inc
LGU	Local Government Unit
MAFAR	Ministry of Agriculture, Fisheries and Agrarian Reform
MAGELCO	Maguindanao Electric Cooperative, Inc.
MCDM	Multi-Criteria Decision Making
MENRE	Ministry of Environment, Natural Resources and Energy
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
NEDA	National Economic Development Authority
PCECP	Philippine Conventional Energy Contracting Program
PDP	Philippine Development Plan
Php	Philippine Peso
PREMS	Philippine Renewable Energy Market System
PSALM	Power Sector Assets and Liabilities Management Corporation

PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RCOA	Retail Competition and Open Access
REAMD	Rural Electrification Administration and Management Division
REC	Renewable Energy Certificates
RPS	Renewable Portfolio Standard
TOPSIS	Technique For Order Of Preference By Similarity To Ideal Solution
WASPAS	Weighted Aggregated Sum Product Assessment
WSM	Weighted Sum Method
WPM	Weighted Product Method
VIKOR	Vlekriterjumsko Kompromisno Rangiranje

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1. INTRODUCTION

The Philippines, a country located in Southeast Asia, is made up of more than seven thousand islands and home to 119 million Filipinos. The country is an archipelago divided into three large island groups, namely, Luzon, Visayas, and Mindanao, and strategically divided to 17 distinct regions. The country's capital city is Manila situated in the National Capital Region (NCR) in the island group of Luzon.

According to the World Economic Outlook published by the International Monetary Fund (IMF) published in 2022, in view of the world's largest economy, the Philippines ranks the 40th and 17th in Asia (IMF, 2022). Agriculture is the major economic player among various sectors encompassing 23% of the country's total employment (World Bank, 2018). This is in harmony with the country's landscape of vast stretches of agricultural lands especially in the less urbanized and rural areas. Just like some countries, the difference between the state of living in the urban and rural areas are highly noticeable, that's why more than half of the population resides in the island of Luzon which houses most urbanized cities and the Philippines' central administrative region and capital.

This disparity is not only shown in the economic indicators such as poverty incidence of provinces in the said regions but as well as the provinces access to power for production and consumption. Problems on access to power may impose various problems not only on economic performance but also to the state of living of the community in the said provinces. As a country, the Philippines face the following electric insecurity problems: growing electric demand, scarcity of supply in relation to the demand, and the discrepancy in the rural and urban areas' electrification rates (Taniguchi, 2019). Since signing the Paris Climate Agreement in 2016, the Philippines has demonstrated a resolute dedication to collaborating with other nations in the fight against climate change. Regardless of financial challenges, the country has also made a commitment to promoting renewable energy as a means of addressing these concerns.

Data presented in Table 1.1 shows the electrification levels of countries belonging to the Southeast Asian region. The data reveals that in 2021, the Philippines is ranked 9th out of 11 Southeast Asian nations in terms of electricity level throughout the country's population. Meanwhile, neighboring countries such as Brunei, Lao PDR, Malaysia, Singapore, Thailand, Timor Leste, and Vietnam have achieved 100% electrification, falling from being 7th place in 2020.

Table 1.1 The availability of electricity in Southeast Asian Countries

Countries	2019	2020	2021
Brunei Darussalam	100.0	100.0	100
Cambodia	84.00	86.40	82.50
Indonesia	98.85	96.95	99.21
Lao PDR	98.39	99.31	100
Malaysia	100.0	100.0	100
Myanmar	68.31	70.41	72.47
Philippines	95.29	96.39	97.49
Singapore	100.0	100.0	100
Thailand	99.90	100.0	100
Timor-Leste	90.63	96.00	100
Vietnam	99.40	100.0	100

Source: World Bank (2021).

It was reported in a January 2021 Philippine Daily Inquirer article written by Domingo 2021, that 93% of the Filipino households have sufficient electricity access. Moreover, the 38th Status Report on the Implementation of the Electric Power Industry Reform Act (EPIRA) published by the Department of Energy (DOE) in 2021 indicates that there are 1.62 million homes in the Philippines without electricity. This represents approximately 7% of the overall population, according to data collected till October 2020. (Domingo, 2021).

From the same report, the DOE have revealed that at the end of December 2020, the rate of home electrification in the nation has reached 94.5%. This means that out of a total of 22,984,971 prospective homes, 1,263,495 homes still do not have access to electricity.

However, an updated data coming from the department would show that as of 2021, electrification level among households have reached 95.41 percent, a 0.9 percent increase. Table 1.2 shows the electrification level of households by region as of 2021.

Table 1.2 Philippine Households Regional Electricity Availability*

Region	Potential HH**	Served HH	Unserved HH	Electrification Level (%)
CAR	395,881	416,019	16,729	95.8
I	1,151,629	1302,954	10,781	99.1
II	804,380	912,519	2,761	99.7
III	2,566,558	3156,553	5,218	99.8
IV-A	3,404,598	4215,220	21,330	99.4
IV-B	682,668	716,775	52,792	92.3
V	1,216,421	1211,604	66,868	94.5
NCR	3,095,766	3597,953	0	100
Luzon	13,318,261	15,529,597	176,479	98.7
VI	1,716,637	1,785,205	90,603	94.7
VII	1,699,148	1,848,931	34,649	98
VIII	985,913	1,059,718	16,386	98.3
Visayas	4,401,968	4,693,854	141,638	96.8
IX	799,219	666,247	132,990	83.4
X	1,049,929	109,0696	22,049	97.9
XI	1,177,461	1,076,762	119,038	89.9
XII	1,050,680	953,151	102,119	90.3
CARAGA	574,338	745,775	0	100
BARMM	620,385	260,759	361,409	41.74
Mindanao	5,265,012	4,793,390	737,605	85.99
Philippines	22,984,971	25,016,841	1,055,722	95.41

* Electrification Level by December 2021 as reported June 2022
**Based on the 2015 Census of Population by PSA
Source: DOE (2021a).

It must be noted that Table 1.2 shows that the actual households exceed the potential household. The lack of a more recent census as a point of reference is the reason why the figures for prospective homes are based on the 2015 census of population. As a result, the distribution companies are currently serving a larger number of homes compared to 2015.

Moreover, Table 1.2 shows that in 2021, CARAGA and the National Capital Region (NCR) regions reached complete electricity supply in 2021. Conversely, the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM) had the lowest level of electricity, with just 41.74% of its homes having access to electricity, indicating that less than half of its houses are connected to the power grid.

Formerly simply called as the Autonomous Region in Muslim Mindanao (ARMM) until 2019, the region is comprised of provinces of which majority of the population are of Muslim faith. Not only that this region possesses the lowest electrification rate among the rest of country, but the provinces belonging the region are consistently among the provinces with the highest poverty incidence throughout the years.

This is concerning because studies have shown that a reliable electricity access is crucial in reducing poverty levels and the development of economic progress in emerging nations (Fujii et al., 2018). Access to power is also crucial for generating prosperity, according to Kaya and Kahraman (2010). (Kaya & Kahraman, 2010).

This is parallel to the findings of the research conducted by Mendoza et al. (2019) indicating that the BARMM region in the Philippines faces the highest level of energy poverty, and that at the same time, regions with a significant prevalence of energy poverty are also characterized by high levels of income poverty. Data shows that BARMM has the greatest level of poverty in the Philippines in 2021. Approximately 39.4% of homes in BARMM survive beneath the poverty threshold, reported by the Bangsamoro Information Office (2021).

The study of Mendoza et al. (2019) employed a specialized Multidimensional Energy Poverty Index designed for the Philippines, which assesses various aspects of energy poverty in five dimensions encompassing seven indicators, reflecting fundamental energy services that may impact individuals or households.

Additionally, their study noted that energy poverty has adverse effects on measures of quality of life, well-being, health, life expectancy, and literacy rates. A separate research investigation carried out in Indonesia by Ikhsan and Amri (2022) revealed a one-way causality between electricity access and the reduction of poverty in rural areas and non-food expenditures within households.

Hence, solving the problem on electrification in the region may much as well bring ease to the economic hardship in the area throughout the years. One plausible method that is forwarded by the Ministry of Environment, Natural Resources and Energy (MENRE) is the investigation of the presence of renewable energy alternatives in the region and pushing forward towards its utilization. Available renewable energy alternatives found in the Philippines include geothermal, wind, solar, hydropower, and biomass sources.

Since then, the members of the parliament have identified the following renewable energy options available for utilization as per Parliament Resolution No. 598 series of 2021 as proposed by the Bangsamoro Parliament (2021):

a. As of 2013, there is an estimated to be 290 megawatts geothermal energy potential in Mindanao,
b. In terms of hydropower, there are 17 potential sites in worth of access within BARMM region with a capacity of 27.15 megawatts,
c. The location has a strong potential for solar power production, since it has an average output of 5 to 5.5 kilowatt per meter squared per day,
d. The region has five recognized locations with potential for tidal and ocean energy, with a projected total output of 8 MW,
e. Rice basse potential resources, accounting for biomass energy potential, are projected at 4.47MW, while coconut is at 84.87MW.

On May 26, 2022, the Philippine Department of Finance issued directives to the Power Sector Assets and Liabilities Management Corporation (PSALM) to limit the supply of electricity to Maguindanao Electric Cooperative, Inc. (MAGELCO) and disconnect Lanao del Sur Electric Cooperative, Inc. (LASURECO) from the grid. These actions were taken in response to the failure of both cooperatives to settle long-standing outstanding debts amassed over the years.

In a news article published in the Philippine Star written by Yang (2022), it was revealed that as of April 2022 MAGELCO has an outstanding payable of Php 3.8 Billion (≈ 66.9 Million USD), while LASURECO's unpaid electricity bills to the government reached a sum of Php 12.9 Billion (≈ 226.9 Million USD). These two electric cooperatives serve both Maguindanao (del Norte and del Sur) and Lanao del Sur provinces, respectively, which comprises the mainland BARMM.

However, the government's decision to curtail and disconnect these electric cooperatives were appealed by Chief Minister Ahod "Al Haj Murad" Ebrahim in a letter to the Energy Secretary, the Finance Secretary and PSALM's president and CEO. It was reported by Fernandez on the Inquirer news portal that the regional government is looking into the creation of an entity that will manage these cash-strapped distribution utilities in Lanao del Sur and Maguindanao province (Fernandez, 2022).

1.1 Research Gap

Though providing solution to this pressing electric crisis is seen to have relevant effects, no significant research was published and available in aiding the government to identify which of these renewable energy sources available are most suitable and appropriate in relation to various factors.

Researchers from countries who were faced with similar dilemma have employed Multi Criteria Decision Making (MCDM) in policy-making such as identifying which factors should be given more and less attention and narrowing down which energy options are most suitable from their respective situations.

As a matter of fact, there is no literature available showing the use of MCDM being applied in the field of energy planning and management not only in the region but in the Philippines as a whole.

This is the research gap that the researchers would try to exploit and, in the process, develop a ranking of renewable energy alternatives that may aid the government and its officials implement data-driven solutions to alleviate the current situation of the region.

The study will also enhance what is presently known and practiced by conducting a study of this nature for the first time in the Philippines and by using a mix of methods that were not commonly used in the field of energy planning.

1.2 Objectives

The conduct of the study aims to identify which among the available renewable energy options is/are the most viable and appropriate to be utilized in the region. To achieve this, the study specifically aims the following:

a. Determine the available renewable energy options in the region,
b. Identify which MCDM tool/s should be employed in the study,
c. Prepare and verify a list criteria and corresponding sub-criteria of factors relevant in the decision making through a literature review,
d. Evaluate which factors do experts and stakeholders identify as the most and least important in relation to the short-listed criteria and their corresponding sub-criteria, and
e. Determine the suitability of these renewable energy options based on the data gathered.

1.3 Methodology

In understanding that there are multiple factors to be considered and that these factors vary in importance according to the experts, the use of MCDM is appropriate and important in choosing the best renewable energy alternative. The use of this tool for energy planning and management among research that are conducted have been published worldwide. The methods of ranking renewable energy alternatives will be reviewed in-depth in the literature with MCDM.

A two-part survey questionnaire will be distributed to experts to satisfy the objectives set by this study. A set of criteria with their corresponding sub-criteria will be short-listed and verified through a review of related studies. This obtained set of criteria will then be sent to the experts for them to evaluate the weight of these criteria and their respective sub-criteria, with respect to the selection and investment of a renewable energy source in BARMM. The criteria data will be analyzed using fuzzy AHP and criteria weight will be determined. Then, the experts will be asked to rate the renewable energy options in relation to the identified criteria and sub-criteria. The data collected for alternative rating will be analyzed with fuzzy TOPSIS, fuzzy WASPAS, and fuzzy MOORA. Finally, sensitivity analysis will be conducted.

1.4 Limitations

The study is limited to BARMM and the energy crisis that the region is facing. Respondents of this study are identified as experts and decision makers that are connected to energy planning, management and policy making.

Though a popular energy source in some parts of the Philippines, wind energy wasn’t cited as an available option for utilization in the region. Hence, this study will only focus on the enumerated energy sources and how they rank against various evaluation methods.

2. ASSESSMENT OF ENERGY POLICIES IN THE PHILIPPINES

As a country, the Philippines faces the following electric insecurity problems: growing electric demand, scarcity of supply in relation to the demand, and the discrepancy in the electrification rates in the rural and urban areas (Taniguchi, 2019). Table 2.1 shows the total energy mix in the Philippines and the self-sufficiency level in 2021.

Table 2.1 Total Energy and Self-Sufficiency Level

	2020	2021	Growth
Indigenous Energy	29676	30301	2.1%
Oil	456	392	-14.2%
Natural Gas	3288	2820	-14.2%
Coal	6836	7414	8.5%
Hydro	1790	2287	27.7%
Geothermal	9249	9184	-0.7%
Biomass	7563	7611	0.6%
Wind	88	109	23.7%
Solar	118	126	7.1%
Biodiesel	131	157	19.2%
Bioethanol	155	200	29.3%
Imported Energy	26902	28943	7.6%
Oil	15997	17261	7.9%
Coal	10710	11499	7.4%
Bioethanol	194	183	-6.2%
Total Energy	**56577**	**59243**	**4.7%**
Renewable Energy (RE)	19290	19857	2.9%
Clean Energy (RE + Natural Gas)	22578	22677	0.4%
Self Sufficiency (%)	**52.5**	**51.1**	

Note: Values except growth rate are in kTOE (kiloton of oil equivalent)
Source: DOE (2021a).

Based on the data, it can be observed that the self-sufficiency showed a slight decrease in 2021, however it still shows that over half of the mix was sourced from indigenous energy sources. In terms of electrification, data from World Bank ranks the Philippines 8th among the 11 ASEAN countries (World Bank, 2021).

Electrification among the households across the 17 regions of the archipelago reached 95.41 percent in 2021 in comparison to 94.5 percent in 2020 (DOE, 2021a; DOE, 2022b), with 2 of its regions reaching total electrification level. However, more than half of households in BARMM don't have access to electricity, as the region shows a lowly 41.74 percent of electrification while majority of the other regions are closer to reaching total electrification.

To govern and manage activities relative to energy exploration is one of the Department of Energy's mandates upon its creation through Republic Act 7638. Since then, various laws have been approved expressing policies of the Philippines with regards to the country's energy.

2.1 The Electric Power Industry Reform Act

Republic Act 9136 commonly known by the people as the Electric Power Industry Act (EPIRA) of 2001 provides the system to restructure the industry and related sectors engaged in providing electric power in the Philippines. According to the policy brief of the Senate Economic Planning Office, the purpose of passing EPIRA into law is to ensure to the power consumers in the country an affordable and reliable access to electricity. This act implemented reforms on the country's power industry prior to 2001, one of these reforms was to restructure the industry into four distinct sectors and functions: generating, transmitting, distributing, and supplying power.

According to the Republic Act 9136, with the passage EPIRA, the following are adopted as the policies of the State:

(a) Secure and expedite the country's nationwide electrification,

(b) Make sure quality, reliable, secure and affordable electric power is available,

(c) Make certain honest and rational electricity rates within a framework of open and equitable competitive environment, promoting responsibility to the public to enhance operational efficiency and the global competitiveness of Philippine products,

(d) Attract private investment and broaden ownership across the sectors tasked with generating, transmitting, and distributing power,

(e) Guarantee impartial and equal management of both public and private parties during the restructuring of the power industry,

(f) Safeguard the welfare of the public as it is influenced by the costs and services of power utilities and other distributors,

(g) Promote energy sources and infrastructure that are socially and environmentally compatible,

(h) Foster the use of new, local renewable energy alternatives in generating power and reduce reliance on foreign energy,

(i) Establish an systematic and clear privatization of the of the National Power Corporation (NPC)'s assets and liabilities,

(j) Create an independent reliable regulatory board and system to safeguard public welfare and increase the competitiveness of the market, and

(k) Encourage energy efficiency and other demand side management approaches.

Generally, EPIRA was enacted to achieve a competitively priced and reliable energy access to the power consumers in the country by restructuring the industry and adopting the ideal architecture of competitive markets, according to Brucal and Ancheta (2018), citing Joskow (2005).

Under EPIRA, the generation sector was made open and more competitive. The National Transmission Commission (Transco) was established to take over power transmission which was previously done by the National Power Commission (NPC), including the commission's power and obligation for preparation, development, central operation and high voltage transmission facilities maintenance, as well as managing grid interconnectedness and supplementary services.

The distribution sector was opened but remained regulated. On the other hand, suppliers to the contestable market in the supply sector weren't required national franchise to operate. However, price rates in both the distribution and supply sectors were made subject to the Energy Regulatory Commission (ERC). ERC is another autonomous agency created pursuant to Section 38 of EPIRA to regulate and oversee its implementation.

Together with the EPIRA's unbundling of the industry into four different sector comes the unbundling of electricity rates which is expected to lower the price which consumers pay based on their consumption. According to Section 36 of the Republic Act, transmission and generation rates must be individually itemized, detailing the individual costs of each service in compliance with ERC regulations.

To accurately reflect service delivery costs, inter-grid subsidies between Luzon and Visayas, intra-grid subsidies within Luzon, and interclass subsidies between residential and industrial consumers were abolished in 2005. To assist low-income consumers, the government introduced the lifeline rate and the Universal Charge for Missionary Electrification (UCME). Although these measures offer financial relief to underprivileged households, they are viewed as distortionary due to their impact on the pricing structure.

Based on section 73 of EPIRA, lifeline rate is a social pricing strategy wherein a subsidized rate will be given to low-income consumers who doesn't have the means to pay the full cost of electricity. According to Brucal and Ancheta (2018), subsidy for lifeline rate will be charged to consumers in the higher consumption bracket. Upon implementation of EPIRA in 2001, the lifeline rate mechanism was supposed to last for 10 years, however in 2011, RA 10150 was passed to extend the effectivity of the lifeline rate for another decade and was extended to another 30 years through RA 11552 which was signed on 2021 to ease the burden of increasing electricity rates to consumers in the marginalized sectors.

As stipulated in Section 34 of EPIRA, Energy Regulatory Commission (ERC) is tasked with determining, setting, and approving a universal electricity charge. This charge is levied on all electricity users and serves various purposes, including funding missionary electrification initiatives. These initiatives aim to provide electricity to remote and underserved areas, ensuring broader access to electrical services across the country. This is to provide electrification to areas which aren't serviced yet by power transmission systems.

2.2 The Wholesale Electricity Spot Market and Retail Competition and Open Access

Wholesale Electricity Sport Market (WESM) was created through Section 30 of EPIRA for energy trading. The total execution of the Retail Competition and Open Access (RCOA) is the goal of EPIRA. As sectors were opened and the industry gradually becoming more competitive, consumers will have the freedom of choosing their own supplier of electricity. The recognition of these consumers as part of the contestable market will be done based on their consumption, gradually lowering the requirement throughout the implementation until the inclusion of households.

Based on Section 31, RCOA was supposed to commence not later than three years after implementation of the republic act with the compliance of the following considerations: (a) founding of the WESM; (b) separation of the transmission and distribution charges; (c) initial removal of the cross-subsidies; and (d) achieving at least 70% privatization of NPC's generating assets and full privatization of the Luzon and Visayas NPC power plants. However, RCOA was declared to commence in December of 2012 and commercially implemented in June of 2013, way behind the expected roll-out. In the initial implementation, consumers with 1 MW and above consumption, are recognized as contestable consumers, that is after ERC regulations, and these contestable consumers now have several options for their power supplier. However, by the end of 2021, only consumers with an average 500 kw per month consumption were included (Ravago, 2023).

In the 40th Status Report of the EPIRA implementation published by the Department of Energy for the period covering until April 2022, the department cites the following highlights:

(a) Power sector liabilities were reduced,

(b) RA 11552 was passed for the extended implementation of lifeline rates to the marginalized community for an additional 30 years,

(c) Supply and demand remained manageable in the year 2021,

(d) The Wholesale Electricity Spot Market has transitioned into the 5-minute energy market,

(e) A circular promulgating the provision requiring the system operator to select providers of ancillary services through a competitive process.

(f) No power-generating utility has exceeded both the maximum allowed market share and total power generation capacity.

(g) There has been a recorded eight percent increase in relation to the preceding year in the total registered contestable customers with regards to RCOA,

(h) Household electrification level rose to 95.41% as of December 2021, and

(i) The DOE has promulgated 9 department circulars to ensure development and enhancement of the WESM.

Brucal and Ancheta (2018) revisited the achievements of implementing EPIRA as well as the lessons and challenges since its implementation. Their study cited that according to DOE (2017), the electricity supply has been enough to supply consumer's access. The proportion of power outages in households have also dropped significantly (National Statistics Office 1995,2004). Electrical prices, as reported by Meralco (2015), have declined since the implementation, citing an 8.38 percent drop in 2015 relative to the rate paid by consumers in 2000 (Brucal & Ancheta, 2018). However, power rates post-implementation is still relatively higher to the rates prior to the implementation of the act (Ravago et al., 2018). In contrary, electricity prices have increased more slowly in the post-EPIRA period (Ravago, 2023). Table 2.2 shows the average electricity among the island groups in the Philippines, which still shows an increase from September 2021 to December 2021.

Table 2.2 Average Electricity Prices in the Philippines

	September 2021	December 2021
Luzon	8.63	9.25
Visayas	8.44	8.78
Mindanao	9.37	10.28
Philippines	**8.73**	**9.42**

Source: DOE (2021b).

Brucal and Ancheta (2018) further finds that efficiency have improved both in the generation and transmission sector. Furthermore, there has been a significant reduction in electricity lost during transmission and distribution since 2005. Specifically, losses dropped from 17% in 1995 to 9% in 2014 (World Bank, 2018). However, even with this decline, the country still appears above some countries in Asia with high distribution and transmission losses, which adds burden to the consumer's monthly bill. This prompts for investment in these sectors. During EPIRA, the government have been receiving more income in form of taxes paid prior to the reform (Asian Development Bank, 2016).

Notwithstanding the achievements brought about the implementation of the act, Ravago (2023) and Brucal and Ancheta (2018) state that EPIRA missed some of its major targets and reforms are needed to be done, while NEDA believes that completing the reforms stated in the act will lead to cost reduction and make the energy mix more cost competitive.

2.3 The Microgrid Systems Act

Following provisions outline in Section 2 of EPIRA which mandates the total electrification of the country, "An Act Promoting the Use of Microgrid Systems to Accelerate the Total Electrification of Unserved and Underserved Areas Nationwide", shortly known as Republic Act 11646 or the Microgrid Systems Act was officially approved into law in January 2022. RA 11646 promulgates that it is the state's policy to:

(a) Promote enduring community development and poverty alleviation initiatives as a means toward national development through widened access to energy.

(b) Expedite provision of renewable energy access to all users in the Philippines, particularly focusing on areas currently without access to electric power.

(c) Promote private sector participation in these areas,

(d) Ensure a competitive and equitable environment for various energy sources, prioritizing affordable, local, renewable, and eco-friendly energy options, and

(e) Establish a flexible regulatory framework that encourages innovation and benefits consumers in the electric power sector.

RA 11646 defines microgrid systems as a self-contained power system that can operate independently or connected to the main grid, consisting of various power sources, such as generators, and connected devices, all within a specific area. This act promotes the use of microgrid system providers (MGSPs) to provide access to electricity to areas declared by DOE as unserved or underserved by the distribution utilities. Unserved areas refer to areas with no access to the grid, distribution and other systems, while underserved areas would refer to areas which has electricity access less than 24 hours daily.

Altomonte and Guinto (2022) acknowledges the viability of using microgrid systems to increase energy security in the Philippines and recommends that the development of microgrid systems be included in the country's energy plan. In their study, they cite that the development of microgrid systems is reliable as it encourages the increase of usage of greener energy alternatives and a more secure energy access by decentralization and its implementation could harmonize and clarify functions and limitations of government agencies tasked for energy policies.

It can be observed in Table 2.3 that the huge share in the power generation in both 2020 and 2021 can be accounted to the renewable energy sector. Moreover, a 10 percent growth have been observed in that sector, which shows that there is a positive development towards the country's long-time aim of an increased percentage of use of green alternative energy usage in the power mix to 35% by 2030.

Table 2.3 Power Generation, by Source and Grid

	2020 (GWh)	2021	Growth (%)
Coal	58,176	62,052	7
Oil	2,474	1,616	-35
Natural Gas	19,497	18,675	-4
Renewable Energy	21,609	23,771	10
Geothermal	10,757	10,681	-1
Hydro	7,192	9,185	28
Biomass	1,261	1,165	-8
Solar	1,373	1,470	7
Wind	1,026	1,270	24
Total	101,756	106,115	4

Source: DOE (2021a).

2.4 Biofuels Act of 2006 and Renewable Energy Act of 2008

In recognition on the price fluctuations on imported fuels and the impact of a country's reliance on it, together with the impact it brings to the economy and the environment, Biofuels Act of 2006 also known as RA 9367 was passed into law in 2007. The act explicitly declared that it is the state's policy to reduce dependence on foreign fuels, develop energy from indigenous and clean sources to reduce toxic releases and ensure the development of alternative energy source, without causing harm to public health, the ecosystem, and the environment, and increase rural employment and income consistent with the country's aim towards economic growth.

Within 6 months of the passage of the Biofuels Act, the DOE is tasked to gradually reduce reliance and usage of harmful gasoline additives in the fuel, and it is tasked that all liquid fuels sold in the country for motors and engines shall make use of local biofuels. An incentives plan was put into place to attract investors, such as exemptions in taxes, incentives and financial assistance.

Bioethanol and biodiesel are what the government refers to as biofuel. Biofuel is produced from various crops such as cassava, sugar cane and sweet potato blended with gasoline. Biodiesel, on the other hand, is derived from a blend of coconut oil and petrodiesel.

Table 2.4 Greenhouse Gases Emission by Sector and Activity

Sector and Activity	2020	2021	GR
Industry	11.32	12.5	10.4%
Transport	28.16	31.54	12.0%
Others [(2)]	11.35	12.13	6.8%
Electricity Generation	70.95	73.88	4.1%
Energy [(3)]	0.79	0.4	-49.2%
Total	122.6	130.4	6.4%

Notes: (1) Million tons of CO2 Equivalent (MTCO2e)
(2) includes Households, Services and Agriculture Sectors
(3) includes Oil refining, Electricity and other Energy sector own use and losses
Source: DOE (2021a).

Table 2.4 shows that 15 years after the passing of the Biofuels Act of 2006, electricity generation still is the biggest greenhouse gases contributing sector and activity in the Philippines, showing a growth from 70.95 MtCO2e in 2020 to 73.88 MtCO2e in 2021. The Philippines' transition to cleaner and low-carbon energy alternatives would be beneficial in terms of cost and reduction of ambient air pollution especially in the urban communities (World Bank, 2023).

To further ease the country's reliance on depleting resources and lower the electricity rates by finding cheaper solutions, RA 9513 or the Renewable Energy Act of 2008 was approved in December of 2008. The act is defined as an act aiming to encourage the development, use, and sale of renewable energy resources and for other purposes. This act explicitly declares that it is the policy of the state to:

(a) Expedite discovery and advancement of renewable energy alternatives to achieve self-sufficiency in the energy sector,

(b) Widen the usage of renewable energy,

(c) Promote the advancement and usage of green energy alternatives as means to efficiently cut or decrease toxic emissions, and

(d) Build the necessary systems and infrastructures to implement the stipulations expressed in this law and other laws.

The act offers incentives to the renewable energy industry in three ways: (1) a seven-year income tax holiday and tax exemptions; (2) a corporate income tax of 10% instead of the usual 30% after the income tax holiday ends; and (3) a real estate tax cap of 1.5% on the initial requirement of building facilities and equipment needed to generate energy. Promoting the purchase, grid connection, and distribution of electricity produced by businesses using renewable energy sources is emphasized by the law. Furthermore, value-added tax will not apply to electricity produced from renewable sources (IEA, 2017).

The renewable energy sources which were utilized to generate power in the sector are hydropower, biomass, solar, geothermal and wind energy sources. Shown in table 2.5 are the installed and dependable generating capacity of the various renewable energy sources from 2018 to 2021.

Table 2.5 Generating Capacity of Renewable Energy Sources

	2018	2019	2020	2021
Geothermal				
Installed Generating Capacity (MW)	1944	1928	1928	1928
Dependable Generating Capacity (MW)	1770	1792	1753	1753
Electricity Generation (GWh)	10435	10691	10757	10681
Hydropower				
Installed Generating Capacity (MW)	3701	3760	3779	3752
Dependable Generating Capacity (MW)	3473	3508	3527	3500
Electricity Generation (GWh)	9384	8025	7192	9293
Wind				
Installed Generating Capacity (MW)	427	427	443	427
Dependable Generating Capacity (MW)	427	427	443	427
Electricity Generation (GWh)	1153	1042	1026	1279
Solar				
Installed Generating Capacity (MW)	896	921	1019	1317
Dependable Generating Capacity (MW)	740	737	817	1034
Electricity Generation (GWh)	1249	1246	1373	1470
Biomass				
Installed Generating Capacity (MW)	258	363	483	489
Dependable Generating Capacity (MW)	182	227	285	291
Electricity Generation (GWh)	1105	1040	1261	1165

Source: DOE (2021a).

The International Renewable Energy Agency (IRENA) adopts a framework that outlines the large-scale renewable energy's socio-economic effects, and classifies them as macroeconomic, distributional, energy system-related and other cross-sectoral effects (IRENA, 2014).

2.5 Philippine Energy Plan 2020-2040

Despite recent challenges faced in the pandemic, the DOE continues its initiatives to pursue renewable alternatives and increase their shares in application. The Philippine Energy Plan talks about policies in place with regards to the discovery and utilization of the country’s renewable energy alternatives, emphasizing development towards a clean and sustainable energy future (DOE, 2023a).

Renewable Energy Market (REMs) rules create a market for trading Renewable Energy Certificates (RECs) among participants and establish procedures for implementing the Renewable Portfolio Standard (RPS) in areas with and without access to the power grid. The Philippine Renewable Energy Market System (PREMS) was launched to manage REC accounts online effectively.

On July 14, 2020, the Green Energy Auction Program Guidelines (GEAP) were introduced to offer more options in the market. This involved auctioning 2,000 MW of renewable energy capacity from eligible suppliers, fostering competitiveness in the renewable energy sector. This initiative helps renewable energy producers secure Power Supply Agreements and sell their energy at a fair base price.

To ensure safety and security measures, DOE crafted the Renewable Energy Safety, Health and Environment Rules and Regulations (RESHERR) Code of Practice, setting safety protocols covering all facilities engaged in renewable energy generation. The code also contains provisions protecting the environment from pollution and other environmental concerns which may result from renewable generation.

2.6 Philippine Development Plan 2023-2028

The Philippine Development Plan (PDP) covering years 2023 to 2028 which was released by the National Economic Development Authority (NEDA) outlines a clear assessment of the energy situation in the Philippines, the challenges, and the strategy framework and policies to move forward.

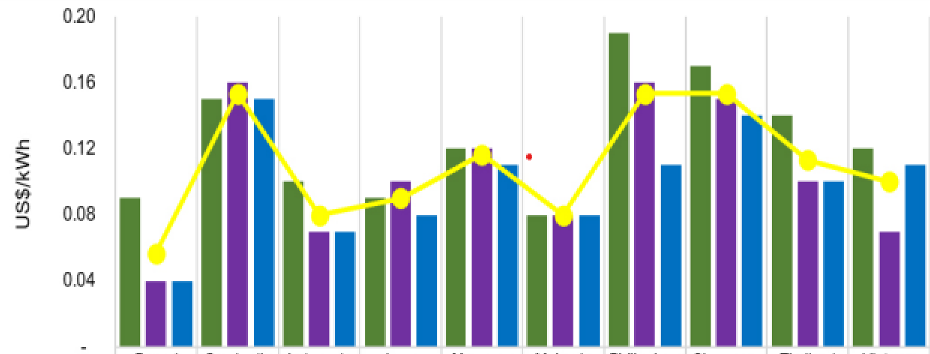
Based on history, the country have one of the most expensive power prices in the Asian region. Table 2.6, as adapted from the PDP, shows the residential electricity prices in the Philippines in comparison to select countries as well as other economic and energy indicators. Data shows that though the Philippines has the lowest GDP per capita among the selection, its residential electricity prices is higher than countries with relatively higher GDP per capita.

Table 2.6 Key Economic and Energy Indicators in Select Countries

	Per capita electricity generation	Per capita electricity consumption	Net installed electricity capacity	Share of renewables in electricity production	Population	Per capita GDP	Electricity transmission and distribution losses	Residential Electricity Prices
Philippines	0.88	0.9	26.2	23.5	111	3412.6	9.4	16.3
Indonesia	1	1	66.8	13.2	276.4	3855.8	9.4	9.6
Thailand	2.53	2.9	45.3	14.8	70	6270.4	6.1	10.4
Malaysia	4.69	5.1	34.2	12.2	32.8	10827.3	5.8	5
Singapore	8.6	9.5	12.6	2	5.5	66176.4	2	18.3
China	5.37	5.1	2064.7	28.3	1412.4	11188.3	5.5	8.1
Japan	7.44	7.9	346.5	24.6	125.7	35278.4	4.3	32.6
S. Korea	10.75	10.9	132.1	8.9	51.7	32644.7	3.3	10
New Zealand	9.28	8.4	9.4	78.8	5.1	40779	6.5	18.6

Source: National Economic Development Authority (2023).

Because of this relatively higher power prices, the country is less attractive to Foreign Direct Investments (FDIs), especially the energy-demanding investments. Figure 2.1 highlights the difference of average electric rates among the countries in the ASEAN region in USD/kWh.



	Brunei	Cambodia	Indonesia	Laos	Myanmar	Malaysia	Philippines	Singapore	Thailand	Vietnam
Residential	0.09	0.15	0.10	0.09	0.12	0.08	0.19	0.17	0.14	0.12
Commercial	0.04	0.16	0.07	0.10	0.12	0.08	0.16	0.15	0.10	0.07
Industrial	0.04	0.15	0.07	0.08	0.11	0.08	0.11	0.14	0.10	0.11
Average	0.06	0.15	0.08	0.09	0.12	0.08	0.15	0.15	0.11	0.10

Figure 2.1 Comparative Electricity Rates in the ASEAN Region (as of June 2021)
Source: DOE (2022).

Figure 2.1 illustrates that as of June 2021, the Philippines have the most expensive electricity rate in ASEAN together with Cambodia and Singapore. Philippines also have the most expensive rate among residential consumers in the region, and the highest among commercial users together with Cambodia. A study conducted by Ravago et al. (2019) reveals that higher electricity costs were found to contribute deindustrialization, leading to a decline in industry share and in the average income per person that is more rapid than it would otherwise be.

In other words, among other possible factors, higher power prices lead to decline in industrial jobs. The same study made a direct comparison between Philippines and Indonesia and the results have shown that in Indonesia, where electric prices are substantially cheaper, power-demanding manufacturing industries have grown more, while in contrast in the Philippines, where the prices are higher, less power-demanding and more labor-focused industries have shown growth.

The Philippines is particularly vulnerable to fluctuations in global fuel prices due to its status as a country that primarily relies on energy imports. Disturbances in the fuel supply chain like the attacks on Saudi Aramco oil facilities, the global oil price hike, as well as the on-going war between Russia and Ukraine have caused instability in local fuel prices. The continuous rise in the prices of fossil fuel during 2021 and 2022 increases the risk of the power plants losing economic value (NEDA, 2023).

NEDA reveals that the Philippines have the lowest energy usage per person in the ASEAN region. This is said to be partly caused by lower electrification rates and higher prices of electricity in the country. Even with this limited generation and consumption, the table highlights that the Philippines have the highest transmission and distribution loss among the selected countries, suggesting inefficient grid and distribution systems. Moreover, a comparative note by Ravago (2023) made between the Philippines and other Asian countries found that consumers are also charged for system failures and aids, further bringing the prices of electricity higher.

Table 2.7 Electricity Consumption by Sector

Sector	2020	2021	Growth
Households	34,292	34,981	2%
Services	20,727	21,119	2%
Industrial	25,566	27,623	8%
Others	2,658	4,903	84%
Utilities Own Use	8,771	7,521	-14%
Power Losses	9,742	9,968	2%
Total	101,756	106,115	4%

Source: DOE (2021a).

In the data shown in Table 2.7, it can be examined that power losses accounts to almost a third of the power consumption of households and half of the services sector. Moreover, a slight 2 percent growth is also shown from 2020 to 2021, which shows that the problem has not been fixed at that period, further increasing the burden to the consumers.

The Philippines having one of the longest and strictest movement control and lockdown during the COVID-19 pandemic significantly lowered the utilization of energy, and in turn the generation. NEDA reports that during that period, power generation from coal have dropped. While power that is sourced from natural gas plants have also dropped, at the same time it has increased its total share to power generation. Other sources remained stable while there’s a slight increase in solar and biomass generation.

The aforementioned decrease of the Malampaya gas and the absence of indigenous gas alternative caused the government to push the development of the liquified natural gas (LNG) industry. Two projects that were granted by the DOE are anticipated to serve markets once served by Malampaya (Ravago & Roumasset, 2021). On top of these, the deliberate and unforeseen outrages to power facilities led to a shortage of supplies, in turn caused disruptions to commercial activities.

Restriction on ownership of renewable power projects of non-Filipino citizens has been eased. This movement, in consonance with the pronouncement made by the DOE, aims to help the government reach its goal of expanding renewable energy’s total share in the county’s total power generation mix up to 35 percent by 2030 and half of the mix by 2040. The provisions of the Philippine Constitution and policies set by the Renewable Energy Act of 2008 only allows up to 40 percent of foreign ownership for companies involved in exploring, developing and using alternative and sustainable energy resources in the country, and 60 percent to be owned by Filipino nationals. However, the Department of Justice has passed a legal opinion to exempt these companies and allow 100 percent foreign ownership.

Problems on grid congestion, total electrification and the ailing of electric cooperatives still persists. Grid modernization which could enable the addition of more renewable energy sources in the power mix is moving at a slow pace. Natural and man-made disasters also threaten the resiliency of the grid. This causes problems in the supply’s security and dependability as the grid remains scattered together with the late implementation of the Visayas-Mindanao interconnection, two of the three major island groups of the country. This imposes a major barrier to reaching the 5 percent of the population which is still living without electricity.

Electric cooperatives across the country are ailing financially, due to various reasons. In 2022, the Philippine government through the Department of Finance has ordered the PSALM to curtail MAGELCO's supply and disconnect LASURECO from the grid due to their failure of paying outstanding debts amassed over the years. These two electric cooperatives provide power to Lanao del Sur and Maguindanao provincesof the BARMM region. According to the Department of Energy Key Statistics of 2021, only less than 50 percent of the region have access to electricity.

Energy projects' processing and approval increased the cost of doing business. According to NEDA, energy projects processing and approval on average takes 1876 calendar days and requires 359 signatories from 74 agencies.

Based on this assessment, NEDA cites that the power sector is filled with the challenges of improving energy security and cost-competitiveness, establishing an optimal energy mix, adequate supply and efficiency in usage and delivery of energy. Moreover, protecting low-income households from increasing energy prices and ensuring resiliency against climate-related disasters that may cause power disruption are challenges that the government aims to tackle in the PDP.

Moving forward, the desired outcome of the PDP regarding the energy sector is to provide affordable, accessible, reliable, and clean energy. NEDA outlines the following strategy framework to move towards this goal (NEDA, 2023):

A. Lowering the cost of electricity by implementing game-changing reforms. To make energy more affordable and cost-competitive, the primary strategy is to ensure that the reforms which are included in the EPIRA will be fully implemented and accelerate the execution of the RCOA. Relaxing the requirements and enabling the participation of end-users in RCOA sets up a competitive retail sector. The Green Energy Option Program's implementation would enable consumers with a 100-kilowatt consumption to have the option of choosing renewable energy as their preferred energy supply.

Ravago (2023) observed that in comparison to other countries, Filipino consumers are still taxed for power losses as well as power subsidies. The government aims to rationalize the tax collection system so that customers will not be charged for the power that they did not use.

New windows of competition will be opened and set-up by the government in phases to proactively adjust and allow greater participation among the sectors as challenges arise.

The relaxation on the ownership restriction of renewable energy generation plants is seen to increase generation capacity and in turn reduce cost. Moreover, there is an emphasis on strict compliance to the Grid Operation and Maintenance Program to develop a timetable of scheduled outages. Performance assessment and audit will be conducted to these facilities to identify issues and implement measures necessary to improve operations.

B. Coordinating investments in generation, transmission, and distribution to enhance delivery of energy. A plan designed to a coordination of key industry players, accounting present issues, and providing beneficial arrangements will bring investors to the country in the future. This plan will also entail rationalizing bureaucratic processes as well as the enactment of the Ease of doing Business (Republic Act 11032) together with the Energy Virtual One-stop Shop (Republic Act 11234) and the directives to the Local Government Unit (LGU) to facilitate putting up energy projects.

Transmission lines will be upgraded and modernized to support the transition to cleaner energy. Congested transmission lines will be resolved either by putting up additional lines or reducing subsidies which may cause excessive power generation. Potentially, this will result to energy efficiency by reduced cost, improved reliability, plus counter-balanced market power.

Energy delivered to communities unreached by the grid will be reduced gradually these areas will be connected to the main grid progressively or as off-grid power generation will be enhanced and developed.

The government will also pursue the shift from conventional fuel vehicles to e-vehicles. The government is set to execute the Comprehensive Roadmap for Electric Vehicle Industry, following the Electric Vehicle Industry Development Act (Republic Act 11697). This is expected to increase demand in electricity, as well as the investments in the electric vehicles market.

C. Creating the conditions necessary for the market to supply the ideal fuel mix. The government must provide incentives for suitably clean and dependable power to the market in addition to allowing the market to provide an ideal fuel mix. According to NEDA, the ideal mix of energy sources should be a combination of those which are affordable, sufficient to meet a country's needs based on its development level, and facilitate a smooth shift to cleaner energy options. This environment must enable efficient energy transition. Investments must go to generation which will use the most cost-efficient fuel sources. Regulations will be streamlined, and pollution tax will be imposed.

With the decrease of the Malampaya natural gas supply, NEDA plans to hasten the development of the natural gas industry. The creation of a regulatory framework will be prioritized, and investments will be promoted and guided. New oil and gas fields will be probed, and while the industry develops, demand and usage outside electricity generation will be explored.

Not only will the liberalization of the restrictions on the ownership of power projects be seen to reduce cost, but it will also stimulate investments toward efficient energy transition. The participation of foreign entities into the renewable energy industry would enable the clean energy alternatives more available to the public, making it easier for the government to achieve its target.

The government will address the intermittency problems of the renewables to facilitate their entry into the power mix. Capacity markets will cover flexible generation plants which can adjust generated output to fill in the intermittent supply of renewable energy. The gas industry development will bring investments to gas-fueled generation plants with rapid starting and turning-off capabilities to compensate the fluctuating supply. Innovation in the delivery, including energy storage systems and a digitalized energy system as well as diversification of the wind-solar portfolio will be done to address problems on intermittency of renewable energy generation.

Not only will renewable energy be pushed in the power mix, but the government will also investigate adding nuclear energy into it as well. The Philippines has the first nuclear power plant in Southeast Asia, located in Bataan and completed in 1986. The passage of Executive Order no. 64 directs the government and its agencies to reevaluate the inclusion of nuclear energy into the power mix.

The Philippines will continue implementing the Philippine Conventional Energy Contracting Program (PCECP) to maximize the utilization of the country's existing indigenous energy sources, as well as to amplify the awarding of Petroleum Services Contracts (PSCs). Challenges regarding exploration activities in the West Philippine Sea will also be addressed by the government moving forward.

D. The government will enhance demand side management systems. The government will lead by example in making efficient consumption of energy and conservation be observed by the consumers. The Government Energy Management Program, which is tasked to promote reduction of power consumption by 10 percent, will be implemented, while the Energy Efficiency Act Roadmap together with the National Energy Efficiency and Conservation Plan will be improved. Demand Side Management circular will be issued to encourage optimal use of energy by the consumers, as well as encouraging participation in the Net-Metering Program and Interruptible Load Program. Moreover, more products will be put into the jurisdiction of the Philippine Energy Labeling Program.

E. To meet rising demand and take advantage of the growing clean technology market, investments in energy innovation will be made. These innovations will focus on improving energy supply through thermal storage, digital grid management, and energy storage systems. On the consumer end, smart meters and energy-efficient appliances will be introduced to optimize energy consumption. The government will provide an environment encouraging investments in innovations, facilitating cleaner energy's entry to the market and answer increasing demand.

2.7 A Year into the Marcos Administration

In the first year of President Ferdinand R. Marcos, Jr after being elected to office in June 2022, the government has cited the following with regards to the energy situation in the country (DOE, 2023b):

- The administration faced challenges in ensuring energy supply, particularly due to external factors like the war in Ukraine and the situation of the prices in the imported coal and fuel market. This is in addition to the shortfall of 1200MW because of the end of the Malampaya Gas Agreement together with the lack of other natural gas supply which could have had a substantial impact in the Luzon grid. However, these challenges were addressed through immediate and short-term procedures and the power generators' strict compliance with their maintenance schedule.

- Moving forward, generation facilities became operational in the said time period and has continued in advancing the country's very own natural gas supply. The country is also gearing forward towards greater use of renewable energy. An Energy Virtual One-Stop (EVOSS) System platform is also established to streamline the processes involved as well as integrating key and additional agencies needed.
- The government has made a significant reform by allowing full 100 percent foreign ownership in the renewable energy sector. Through this, foreign companies can now invest in and own projects involving renewable energy supply in the country

- The timely completion of the grid connections and the highways needed for electricity has also been emphasized by the government such that additional generation capacity will ultimately be accessed in the household level through the distribution centers.

- The Philippine government revisited its standing programs and policies regarding the electric power industry because of the fact that the country have one of the highest electricity costs in ASEAN while lagging behind electrification.

- With its goal of total electrification by 2030 and gradually reduce costs of electricity, the Philippines must ensure the total implementation of EPIRA, which has been enacted in place for more than 20 years now, while at the same time review its implementation and evaluate where reforms must be made. Studies have shown that the act's implementation of subsidies and taxing power losses towards the consumers may have imposed further burden on the consumers financially, thus investments and reforms are suggested on these sectors.

Another thing that the government has been looking into is the transition of the country towards cleaner energy. The government has set its goal on having renewable energy provide half the country's total power share by 2040. As this is seen to be more cost efficient in the long run, green renewable energy is seen to also solve the problems in electrification in missionary areas given the facilities and utilities to bring power to underserved and unserved areas.

3. A REVIEW OF MULTI-CRITERIA DECISION MAKING IN RENEWABLE ENERGY

3.1 Multi-Criteria Decision Making (MCDM)

The use of MCDM methods in problems relating to energy have been very popular among literatures and studies. Specifically, the applications of these methods were seen in solving several energy problems such as management, planning, selection, distribution of resources, policies and policymaking, and management of creating energy.

Wang et al. (2009), defined MCDM, which is sometimes denoted as Multi-Criteria Decision Analysis (MCDA), as a systematic approach for making complicated decisions for problems with high levels of uncertainty, competing goals, diverse data and information sources, various goals and standpoints, and taking into consideration the highly complex and changing biophysical and socioeconomic structures. This level of complexity is evident in Figure 1 as to how renewable energy sources can be integrated into an areas energy supply system.

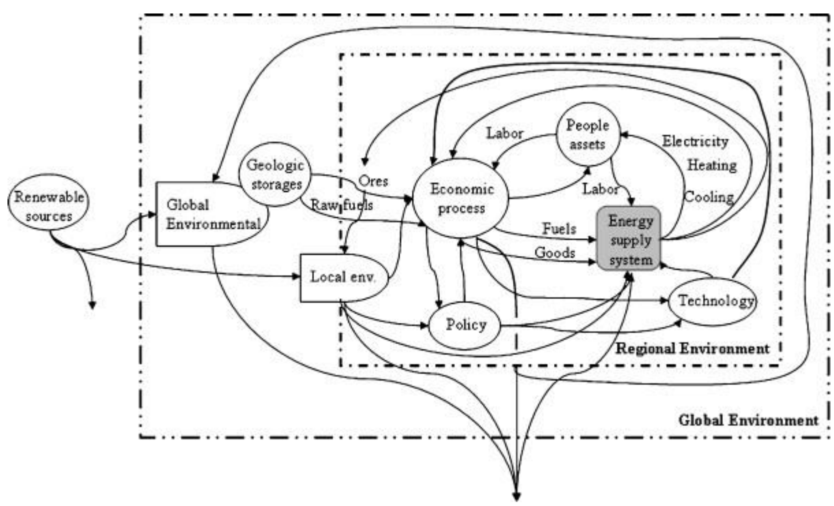


Figure 3.1 A Complex Energy System
Source: Wang et al. (2009).

This paper will explore how MCDM have been used in solving various energy problems and which method have been used or methods have been used together to reach desired conclusion. Along the process, different criteria with their corresponding sub-criteria that were given emphasis while energy alternatives were ranked will also be examined.

Methods that are popularly utilized among literatures include AHP (analytic hierarchy process), Fuzzy AHP, TOPSIS (technique for order of preference by similarity to ideal solution), Fuzzy TOPSIS, WPM (weighted product method), WSM (weighted sum method), PROMETHEE (preference ranking organization method for enrichment evaluation), VIKOR (Vlekriterjumsko Kompromisno Rangiranje, which means multi-criteria optimization and compromise solution in Serbian), ANP (analytic network process) among others. Table 3.1 presents various MCDM methods used in ranking renewable energy sources among various literature.

Table 3.1 MCDM Methods Used and Their Results

Author/s	Year	Country	Method	Results
Amer & Daim	2011	Pakistan	AHP	Biomass > Wind > Solar Thermal > Solar Photovoltaic
Shen et al.	2011	Taiwan	AHP	Hydro > Solar > Wind > Geothermal > Ocean > Biomass
Kaya & Kahraman	2011	Turkey	Fuzzy AHP, Fuzzy TOPSIS	Wind > Biomass > Solar > CHP > Hydra > Nuclear > Conventional
Sadeghi et al.	2012	Iran	Fuzzy AHP, Fuzzy TOPSIS	Solar > Wind > Hydropower > Geothermal
Stein	2013	USA	AHP	Wind > Solar PV > Hydro > Geothermal
Yazdani-Chamzini et al.	2013	Spain	AHP, COPRAS	Biomass(co-combustion in conventional central) > Wind($10 \leq P \leq 50$ MW) > Solar Thermo > Hydro ($25 \leq P \leq 50$ MW) > Biofuels ($P\leq 2$MW) Wind ($5 \leq P \leq 10$ MW) > Hydro($10 \leq P \leq 25$ MW) > Biomass(forest industrial wastes) > Biomass (farming industrial wastes)=Biomass (forest and agricultural wastes) > Biomass (energetic cultivations) > Wind power($P \leq 5$ MW) > Hydro($P \leq 10$ MW)
Ahmad & Tahar	2014	Malaysia	AHP	Solar >Biomass > Hydropower > Wind
Kabak & Dağdeviren	2014	Turkey	ANP, BOCR	Hydro > Solar > Wind > Geothermal > Biomass

Author/s	Year	Country	Method	Results
Troldborg et al.	2015	Scotland	PROMETHEE	PV > Wind offshore > Solar thermal > Hydro > Wind onshore > Tidal > Wave > Geothermal > Biomass
Şengül et al.	2015	Turkey	Fuzzy TOPSIS	Hydro > Geothermal > Regulator > Wind
Štreimikienė et al.	2016	Lithuania	ARAS, AHP	Nuclear > Biomass > Hydropower >Gas Combined Heat and Power > Wind > Geothermal
Ahmad et al.	2017	Kazakhstan	AHP	Hydro > Solar > Wind > Nuclear > Biomass
Haddad et al.	2017	Algeria	AHP	Solar > Wind > Biomass > Geothermal > Hydropower
Colak & Kaya	2017	Turkey	Fuzzy AHP, Fuzzy TOPSIS	Wind > Solar > Hydraulic > Biomass > Geothermal > Wave > Hydrogen
Toklu & Taskin	2018	Turkey	Fuzzy AHP, Fuzzy TOPSIS	Wind > Solar > Hydropower > Nuclear > Geothermal > Biomass
Wu et al.	2018	China	Fuzzy AHP, CPT	PV > Hydropower> Solar Thermal > Wind > Biomass
Lee & Chang	2018	Taiwan	WSM, VIKOR, TOPSIS, ELECTRE	Hydro > Solar PV > Wind > Biomass > Geothermal (WSM) Hydro > Solar PV > Wind > Geothermal > Biomass (TOPSIS) Hydro >> Wind >Solar PV > Biomass > Geothermal (VIKOR) Hydro > Solar PV > Wind > Biomass > Geothermal (ELECTRE)
Karatop et al.	2020	Turkey	Fuzzy AHP, EDAS, Fuzzy FMEA	Hydropower > Solar > Wind > Biomass > Geothermal (Fuzzy AHP) Wind > Hydropower > Solar > Biomass > Geothermal (FMEA)
Alizadeh et al.	2020	Iran	ANP, BOCR	Solar > Wind > Biomass > Nuclear> Hydro > Geothermal
Wang et al.	2019	Pakistan	Fuzzy AHP	Wind > Solar > Biomass

Introduced in the 1970s by Thomas Saaty, AHP enables executives to understand a complicated scenario by analyzing it into an order structure of criteria, further down to respective sub-criteria, and alternatives that are available. Decision makers can then identify the available alternatives' compatibility with regards to the evaluation criteria by evaluating them at their respective levels through a pair-wise comparisons (Ahmad & Tahar, 2014). The use of AHP has been widespread among literature concerning renewable energy problems.

AHP was used in Pakistan in a study conducted by Amer & Daim (2011) focusing on selection of renewable energy sources. This was the first time that AHP was used in Pakistan. A survey instrument was given to experts coming from universities and the industry, asking them to quantify their judgements and preferences with regards to the alternatives and their relative evaluation against criteria and sub-criteria. The economic dimension was found to be the most critical criterion to be considered among economic, social, environmental, and political dimensions, with emphasis on economic cost as the most important sub-criterion. The study found out that upon consideration of the various criteria, Biomass energy, followed by wind energy, were found to be the most suitable renewable energy alternative.

Instead of selecting which single renewable energy alternative is most appropriate for Taiwan in a number of criteria, Shen et al. (2011) employed AHP to identify which source goes well with Taiwan's 3E (economic, energy and environment) goals. In their study, alternatives were evaluated in four different scenarios, namely the status quo, the economic scenario, the energy scenario and the environment scenario, with more weight given to the dominant policy goal on each scenario. Their results have shown that non-pumped storage hydropower performs the best among four scenarios.

Stein (2013) made use of real data gathered from government and academic sources instead of expert opinions in ranking energy generated from renewable and non-renewable energy sources in USA. The study results have shown that energy generated from renewable sources, particularly in the following order: Wind, Solar PV, Hydro, Geothermal; ranks above non-renewable energy sources and provide more overall benefits. The same results still show despite adjusting criteria weights after conducting sensitivity analysis.

Ahmad & Tahar's (2014) study was the first attempt in determining the suitability of the available green energy alternatives in Malaysia in hopes of boosting the share of renewables in their national energy mix by developing a sustainable electricity generation system. Economic criteria was determined to be the most crucial criteria and resource potential being the most crucial sub-criteria. Moreover, the results of the study have shown that solar is the best alternative for Malaysia.

Troldborg et al. (2014) made use of PROMETHEE in assessing sustainability of eleven green energy alternatives in Scotland. Nine evaluation criteria for sustainability were identified through literature review and were given equal weights. Their results have shown that photovoltaic source is ranked first, then heat pumps and offshore wind sources when all criteria were given equal importance. However, their study acknowledges the uncertainty of using generic values determined from a national scale and infers that uncertainty will be lessened for cite-specific energy projects.

AHP was also used to determine alternative energy resources for electricity generation for the first time in Kazakhstan in a study conducted by Ahmad et al. (2017) where they have identified the most essential criteria to be economic criteria while the most essential sub-criteria is capital cost. They have further concluded that based on the expert group's opinion that socio-economic considerations are more crucial as opposed to concerns relating to technology and the environment. Ultimately their study has shown that hydropower energy should be the alternative to be developed.

In view towards the goal of energy gathered from renewable sources reach 40% share of the power generation mix in Algeria, Haddad et al. (2017) used AHP to rank the available energy alternatives. Their results identified solar energy and wind energy as the well-suited alternate sources and that concerns pertaining to social and environmental criteria must be given utmost consideration, while the most crucial sub-criterion is the energy's impact to the ecosystem.

Karatas et al. (2018) made use of a hybrid approach consisting of TOPSIS, AHP and VIKOR to assess the performance of energy management in Turkey in comparison to other selected countries from 2001 to 2016. In their approach, they used AHP to calculate for the weights of importance of the various criteria and use these weights with VIKOR and TOPSIS to rank the alternatives.

As introduced by Yoon and Hwang (1995) TOPSIS determines the best alternative among available others by establishing a negative and positive point, and evaluate the alternatives with respect to their distance from these points, the farthest from the negative while at the same time being the nearest to the positive point being the best one. On the other hand, VIKOR as introduced by Opricovic (1998) functions similarly with TOPSIS but gives emphasis on the importance of the distance between these points and alternatives.

Instead of identifying suitable renewable energy alternatives, the study of Sahabmanesh & Saboohi (2017) employed AHP in developing a Sustainable Energy System Model (SESM) among 29 identified indicators for Hamedan province in Iran.

To identify and assess key factors for sustainable energy planning in India, Luthra et al. (2015) employed a fuzzy AHP analysis. Their findings revealed that the most important key factor for assessment is the environmental factor.

The use of AHP in various literatures was seen to be popular as researchers have used this technique, an iteration of it known as Fuzzy AHP, or in a hybrid manner with other MCDM techniques as well. In doing Fuzzy AHP and fuzzy iterations of other MCDM techniques, fuzzy numbers are used instead of crisp numbers in the calculation. Doing the technique in the fuzzy system environment reduces the possibility of parameter unit errors in data collection and conversion, thereby reducing errors in mathematical calculation (Kore et al., 2017).

The study of Kaya and Kahraman (2011) made use of Fuzzy AHP and modified Fuzzy TOPSIS in to identify and rank renewable energy sources in Turkey. Their study concluded that energy coming from wind sources was the best among six alternatives and the conventional method and have identified that environmental criteria was the most essential criteria to be considered, as well as CO_2 emissions as the most essential sub-criteria. However, on their sensitivity analysis where sub-criteria weights were adjusted, biomass appeared to be the first alternative three times among four cases of adjustment.

Similarly, Sadeghi et al. (2012) utilized a combination of Fuzzy AHP and Fuzzy TOPSIS to evaluate energy alternatives in the Yazd province in Iran. Their study found out that solar energy best renewable energy alternative for the province, which was found to be consistent with results of other studies they cited. Economic criteria was identified as the most vital criteria and technical feasibility was the most vital sub-criteria.

The same hybrid approach utilizing both Fuzzy AHP and Fuzzy TOPSIS were used by Çolak & Kaya (2017) and Toklu & Taşkın (2018) in ranking and selecting renewable energy alternatives in Turkey, which was previously cited as done by Kaya & Kahraman (2011). The results of the two studies, though conducted at different periods (2017 & 2018) still showed consistent result from 2011 that for Turkey, energy coming from wind sources is the best. However, Çolak & Kaya's (2017) results have shown that economic criterion should be given more consideration among six other criteria and the availability of funds as the sub-criteria to be considered at that time among 29 sub-criteria evaluated. On the other hand, the study of Toklu & Taşkın (2018) have revealed that the technical criteria and efficiency sub-criteria were given more importance at the time of the conduct of their study.

Another hybrid approach was used by Karatop et al. (2021) when the fuzzy version of AHP was used in combination with EDAS (evaluation based on distance from average solution) and comparing the results of the evaluation with Fuzzy FMEA (failure mode and effect analysis) for the assessment process regarding alternative energy investments in Turkey. The authors claim that the that the usage of EDAS in combination with Fuzzy AHP is because the method was seen to be effective in the presence of comparative criteria, and the calculation of distance from ideal and rare solutions were seen as advantageous in comparison to other MCDM methods which were compromise-based; and it is simpler and has a lower computational approach, citing studies conducted by Özbek and Engür (2018), and Ecer (2018). The ranking results of Fuzzy AHP and EDAS will then be compared with the risk analysis results done with Fuzzy FMEA. Their findings have revealed that the country must invest towards hydropower energy according to the Fuzzy AHP and EDAS combination, while the Fuzzy FMEA evaluation showed preference towards wind energy.

Wu et al. (2018) used Cumulative Prospect Theory in combination with Fuzzy AHP to evaluate the available energy alternatives for China's sustainable energy planning. The authors argued that one flaw of classic MCDM is the assumption that the experts and decision makers are rational thinkers, hence employing CPT which stemmed from the Prospect Theory introduced by Kahneman and Tversky (1979). This theory factors in risk on an individual's decision making. In Wu et al. (2018), criteria and sub-criteria were shortlisted after the conduct of a literature review and then evaluated using Fuzzy AHP and the weight given by the experts and determine the performance of these alternatives while taking into consideration the risk preferences. Their findings have shown that Solar PV is the most suitable alternative for China, while economy and land requirement as the most important criterion and the most important sub-criterion, respectively.

Kabak & Dağdeviren (2014) employed a mixed model of BOCR (benefits, opportunities, costs and risks) and ANP in ranking and selecting renewable alternatives in Turkey. Citing the study of Liang and Li (2007), the researchers argue that ANP's ability to account for the complex relationships and interdependencies between different evaluation criteria is what makes it different from AHP. One disadvantage of using ANP is the difficulty in establishing evaluation criteria in fields where it wasn't applied much. Hence, the authors used BOCR and evaluate the alternatives against its benefits, opportunities, cost, and risk. However, the team of experts have decided that BOCR are not at equal, and in return have added five more strategic factors to evaluate from literature, namely technology, economy, global effects, security, and human well-being. Their results have shown that economy is the most important criterion, benefits being the most important BOCR factor and hydropower energy as Turkey's most suitable renewable energy option.

Alizadeh et al. (2020) employed the same hybrid approach in advancing renewable energy planning and management, and decision-making methods by using Iran as a case to analyze. The criteria that were identified and used were technology, economy, global effects, security, human well-being, and the environment, appearing at L1. BOCR and BOCR network which contains the sub-criteria evaluated follow at L2 and L3 respectively and the alternatives to be evaluated appear at L4. The study's findings indicate that the experts considered the benefits coming from the renewable energy should be given utmost importance, while technology and job creation were found to be the most crucial criterion sub-criterion respectively. Furthermore, experts' evaluation has shown that the most preferred renewable energy alternative for Iran is solar energy.

Lee & Chang (2018) have employed and compared four MCDM methods, namely WSM, VIKOR, TOPSIS, and ELECTRE, for ranking available energy alternatives in Taiwan. Ten criteria were identified from literature review and were weighted according to available data by utilizing the Shannon Entropy Method. Technology was found as the most significant criteria, while efficiency was identified as the most significant sub-criteria. Five available alternatives were then assessed based on their performance against the four MCDM methods, and hydropower was ranked first among all of them.

MCDM methods have also been popular among studies outside energy planning and renewable energy selection. Fuzzy WASPAS (Weighted Aggregated Sum Product Assessment), a combination of WSM and WPM have also been used in studies involved in identifying crucial information infrastructures (Turskis et al., 2019), selection of improvement projects (Rudnik et al., 2021), construction site selection (Turskis et al., 2015). Fuzzy MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) was also used in selecting best hotels (Gürbüz & Erdinç, 2018), selecting the best industrial engineering sector (Akkaya et al. 2015).

3.2 Evaluation Criteria

Based on the various literatures reviewed, solving energy problems by selecting renewable energy options are commonly done by evaluating them against four main evaluation criteria, namely economic, technological, environmental, and social aspects, as well as various sub-criteria which some of these studies have shared in common as shown in Table 3.2. Similarly, this study will make use of the four primary evaluation criteria and ten sub-criteria. Table 3.3 shows a summary of these sub-criteria, a brief description and studies which have also used these sub-criteria in the past.

Table 3.2 MCDM Methods and Various Evaluation Criteria

Author	Method/s	Economic Criteria	Technological Criteria	Environmental Criteria	Social Criteria
Ahmad & Tahar (2014)	AHP	Technology Cost Operational Life Resource Potential Feed-in Tariff rate	Maturity Efficiency Lead Time	Land requirement CO2 Emission Environmental Impact	Social Acceptance Job Creation
Ahmad et al. (2017)	AHP	Capital Cost Operational Cost Financial Support	Maturity Efficiency Lead Time Resource availability Grid Connectivity	Emissions Environmental Impact Land Requirement	Public Acceptance Job Creation
Amer & Daim (2011)	AHP	R&D Cost Capital Cost O & M cost Electricity cost Economic Value/Viability	Maturity Efficiency Reliability Deployment Time Expert Human Resource Distribution Grid Availability Resource availability	Land requirement CO2 Emission Stress on Eco-system	Social benefits Job creation Social acceptance
Colak & Kaya (2017)	Fuzzy AHP, Fuzzy TOPSIS	Levelized Energy Cost Service Period Availability of Funds Affordability Payback Period Contribution to Economy	Energy Production Capacity Maturity Efficiency Reliability Installed Capacity Feasibility Risk Duration of Preparation and Implementation Phase	Greenhouse Gas Emission Land Requirement Waste Disposal Needs Environmental Damage Other Environmental Effects	Compatibility with National Energy Policy Labor Impact Political Acceptance Social Acceptance

Author	Method/s	Economic Criteria	Technological Criteria	Environmental Criteria	Social Criteria
			Continuity and Predictability of Performance Local Technical Knowhow		
Haddad et al. (2017)	AHP	Investment Cost O & M cost Life Service Payback Period	Maturity Energy Systems Safety Reliability Energy Production Capacity	Impact on Eco-system Potential for Reduction of Greenhouse Gases	Social benefits Social acceptance Political Acceptance
Kaya & Kahraman (2011)	Fuzzy AHP, Fuzzy TOPSIS	Investment Cost O & M cost	Efficiency Exergy Efficiency	NOx Emission CO2 Emission Land Use	Social Acceptance Job Creation
Lee & Chang (2018)	WSM, VIKOR, TOPSIS, ELECTRE	Investment Cost O & M cost Electricity Cost	Efficiency Capacity Factor Technical Maturity	Greenhouse Gas Emission Land Use	Job Creation Social Acceptance
Sadeghi et al. (2012)	Fuzzy AHP, Fuzzy TOPSIS	Job Creation Investment Cost O & M cost	Duration of Preparation and Implementation Phase Continuity and Predictability of Performance Technical Feasibility	Pollutant Emission Land Requirement Impact on Eco-system	Compatibility with National Energy Policy Objectives Political Acceptance Social Acceptance
Şengül et al. (2015)	Fuzzy TOPSIS	Investment Cost O&M Cost Payback Period	Efficiency Installed Capacity Amount of Energy Produced	Land Use Value of CO2 Emission	Job Creation
Shen et al. (2011)	AHP	Local Economic Development Increasing Employment Technical Maturity		SOx and NOx Emissions Reduction Carbon Emissions Reduction	

Author	Method/s	Economic Criteria	Technological Criteria	Environmental Criteria	Social Criteria
		Potential for Commercialization Market Size Reasonableness for Investment Cost		Environmental Sustainability Low Land Requirement	
Stein (2013)	AHP	Total Overnight Cost Variable O&M Fixed O&M Fuel Costs	Production Efficiency Capacity Factor	External Costs Loss of Life Expectancy	Fuel Reserve Years Job Creation Net Import as % of consumption
Štreimikienė et al. (2015)	ARAS, AHP	Economic Efficiency Technology's Competitiveness Production Cost Value of the Technological Complex	Technology's Rated Capacity Reliability Innovativeness Durability	Contribution to the total energy balance Effects on Climate Change and Pollution Cuts Treatment of Waste Compliance with Local Natural Conditions	Influence on Social Welfare Influence on Sustainable Development Public Acceptance
Toklu & Taskin (2018)	Fuzzy AHP, Fuzzy TOPSIS	Investment Cost O & M cost R&D Cost Service Life Payback Period Source Potential Return on Investment	Energy Production Capacity Technological Maturity Reliability Safety Efficiency Exergy Efficiency Accident Risks & Effects Availability of Sources	NOx Emission CO2 Emission Greenhouse Gas Emission Land Requirement Impact on Eco-System	Social Benefits Social Acceptability Job Creation
Troldborg et al. (2014)	PROMETHEE	Levelized Energy Cost Contribution to Economy	Potential Total Power Generation Technology Maturity Reliability	Greenhouse Gas Emission Impact on Amenity Area Requirements	Social Acceptability
Wang et al. (2019)	Fuzzy AHP	Capital Cost	Maturity	Land Requirements	Job Creation

Author	Method/s	Economic Criteria	Technological Criteria	Environmental Criteria	Social Criteria
Wu et al. (2018)	Fuzzy AHP, CPT	R&D Cost O & M Cost Resource Potential Generation Cost Capital Cost O & M cost Electricity Cost Payback Period	HR Experts Efficiency On-Grid Access Lead Time Maturity Efficiency Reliability Availability	Emissions Impact on the Environment Land Requirement Impact on Eco-system	Public Acceptance Government Policies National Energy Security Employment Creation Social Acceptance Social Benefits
Yazdani-Chamzini et al. (2013)	AHP, COPRAS	Potential Market Power Investment Ratio Implementation period O&M Costs	Resource reserves Operating Hours Useful Life	CO2 Emission Reduction	

Table 3.3 Sub-Criteria Description and Related Literature

Criteria	Type	Description	Related Literature
Economic			
Investment Cost	Cost	Expenses incurred in setting up and starting the plant.	Ahmad et al. (2017) Amer & Daim (2011) Haddad et al. (2017) Kaya & Kahraman (2011) Lee & Chang (2018) Sadeghi et al. (2012) Şengül et al. (2015) Shen et al. (2011) Stein (2013) Toklu & Taskin (2018) Wang et al. (2019) Wu et al. (2018)
O & M Cost	Cost	Expenses incurred in keeping the plant operational, including scheduled maintenance.	Amer & Daim (2011) Haddad et al. (2017) Kaya & Kahraman (2011) Lee & Chang (2018) Sadeghi et al. (2012) Şengül et al. (2015) Stein (2013) Toklu & Taskin (2018) Wang et al. (2019) Wu et al. (2018) Yazdani-Chamzini et al. (2013)
Technological			
Efficiency	Benefit	The ratio of output energy to input energy.	Ahmad & Tahar (2014), Ahmad et al. (2017) Amer & Daim (2011) Colak & Kaya (2017) Kaya & Kahraman (2011) Lee & Chang (2018)

Criteria	Type	Description	Related Literature
			Şengül et al. (2015) Stein (2013) Toklu & Taskin (2018) Wang et al. (2019) Wu et al. (2018)
Capacity Factor	Benefit	Percentage of the total electrical energy generated and the installed capacity	Colak & Kaya (2017) Haddad et al. (2017) Lee & Chang (2018) Şengül et al (2015) Stein (2013) Štreimikienė et al. Toklu & Taskin (2018) Troldborg et al. (2014)
Maturity	Benefit	The prevalence of the technology and whether it had reached theoretical efficiency to function.	Ahmad & Tahar (2014), Ahmad et al. (2017) Amer & Daim (2011) Colak & Kaya (2017) Haddad et al. (2017) Lee & Chang (2018) Shen et al. (2011) Toklu & Taskin (2018) Troldborg et al. (2014) Wang et al. (2019) Wu et al. (2018)
Reliability	Benefit	The ability of the plant to function as it was intended.	Amer & Daim (2011) Colak & Kaya (2017) Haddad et al. (2017) Štreimikienė et al. (2015) Toklu & Taskin (2018) Troldborg et al. (2014) Wu et al. (2018)
Environmental			

Criteria	Type	Description	Related Literature
Greenhouse Gas Emissions	Cost	The amount of GHG emitted due to the plant's operation.	Ahmad & Tahar (2014), Ahmad et al. (2017) Amer & Daim (2011) Colak & Kaya (2017) Kaya & Kahraman (2011) Lee & Chang (2018) Sadeghi et al. (2012) Şengül et al. (2015) Shen et al. (2011) Štreimikienė et al. (2015) Toklu & Taskin (2018) Troldborg et al. (2014) Wang et al. (2019) Yazdani-Chamzini et al.
Land Use	Cost	The land area required by the system to operate.	Ahmad & Tahar (2014), Ahmad et al. (2017) Amer & Daim (2011) Colak & Kaya (2017) Kaya & Kahraman (2011) Lee & Chang (2018) Sadeghi et al. (2012) Şengül et al. (2015) Shen et al. (2011) Toklu & Taskin (2018) Troldborg et al. (2014) Wang et al. (2019) Wu et al. (2018)
Social			
Social Acceptance	Benefit	The public's opinion and its extent on the implementation of the power plant.	Ahmad & Tahar (2014), Ahmad et al. (2017) Amer & Daim (2011) Colak & Kaya (2017) Haddad et al. (2017)

Criteria	Type	Description	Related Literature
			Kaya & Kahraman (2011) Lee & Chang (2018) Sadeghi et al. (2012) Štreimikienė et al. (2015) Toklu & Taskin (2018) Troldborg et al. (2014) Wang et al. (2019) Wu et al. (2018)
Job Creation	Benefit	The potential employment opportunities for the locals due to the development of the RE system.	Ahmad & Tahar (2014), Ahmad et al (2017) Amer & Daim (2011) Kaya & Kahraman (2011) Colak & Kaya (2017) Lee & Chang (2018) Sadeghi et al. (2012) Şengül et al. (2015) Stein (2013) Toklu & Taskin (2018) Wang et al. (2019) Wu et al. (2018)

3.2.1 Economic Criteria

- Investment Cost - includes expenses associated with drilling, engineering services, building roads and establishing connection to the national grid, purchasing mechanical equipment, technology installations, and other related construction activities. Investment cost is the perhaps the most cited sub-criteria in the economic criteria among studies involving renewable energy selection (Wang et al., 2009).

- O&M Cost – covers both the operation and powerplant maintenance of the renewable energy system. This cost encompasses the expenses associated with keeping the plant functional, such as employee salaries and the cost of parts and spares necessary for scheduled maintenance activities (Amer & Daim, 2011).

3.2.2 Technical Criteria

- Efficiency – denoted as to the volume of usable energy that may be produced from the renewable energy source in relation to the input. As a frequently utilized metric for efficiency assessment, the efficiency coefficient is expressed as the proportion of output to input (Lee & Chang, 2018).

- Maturity – The maturity level of technology is determined by how widespread it is from local to global scales. This criterion reflects whether the renewable energy alternative has attained its potential or if it could still show improvement and developments. (Amer & Daim, 2011).

- Capacity Factor – This refers to the percentage representing the l energy generated during a specific timeframe compared to the energy that would have been generated if the unit had operated continuously at full power throughout the same period (Stein, 2013).

- Reliability - described as the capability of a device or system to operate accordingly to its intended design, its ability to be failproof, its capacity to fulfill a specified task in defined circumstances over a time period, and its proficiency in "failing well" without causing catastrophic consequences (Wang et al., 2009).

3.2.3 Environmental Criteria

- Greenhouse Gas Emissions – one of the popular criteria used in assessing the security and dependability of renewable energy, this pertains to the measure of greenhouse gas (GHG) emissions resulting from the operation of a specific renewable energy system (Lee & Chang, 2018).

- Land Use - Since the RE system has a direct effect on the environment and landscape, the evaluation process must be significantly concerned with the amount of land each plant requires, as various energy systems may require varying land areas even if they all produce the same products (Lee & Chang, 2018).

3.2.4 Social Criteria

- Social Acceptance - a significant measure which reflects the collective sentiment of the community and stakeholders towards the implementation of energy systems from a user's perspective, as the viewpoints of the general population and the user base, together with the interest groups can significantly affect the duration and completion of an RE systems. Social acceptance is identified as a qualitative criterion rather than a measurable and quantifiable criterion (Wang et al., 2009).

- Job Creation – The development to the operation of renewable energy systems may require huge manpower, the well-being of local residents by evaluating enhancements in quality of life and the generation of employment opportunities must be considered (Lee & Chang,2018).

4. METHODOLOGY

After identifying the evaluation criteria and their respective sub-criteria as well as the alternatives to be evaluated, this study will make use of the MCDM methods reviewed in the previous chapter to determine which alternative is best for renewable energy development in BARMM. Fuzzy AHP will be used to calculate the criteria weights from the expert evaluation. Moreover, Fuzzy TOPSIS, Fuzzy WASPAS and Fuzzy MOORA will be employed to rank these alternatives. Fuzzy TOPSIS is selected as one of the evaluation methods because of its popularity as shown in similar studies, while Fuzzy WASPAS and Fuzzy MOORA were selected because of their novelty in relation to the subject at hand. Figure 4.1 shows the hierarchical structure from which this study will be conducted.

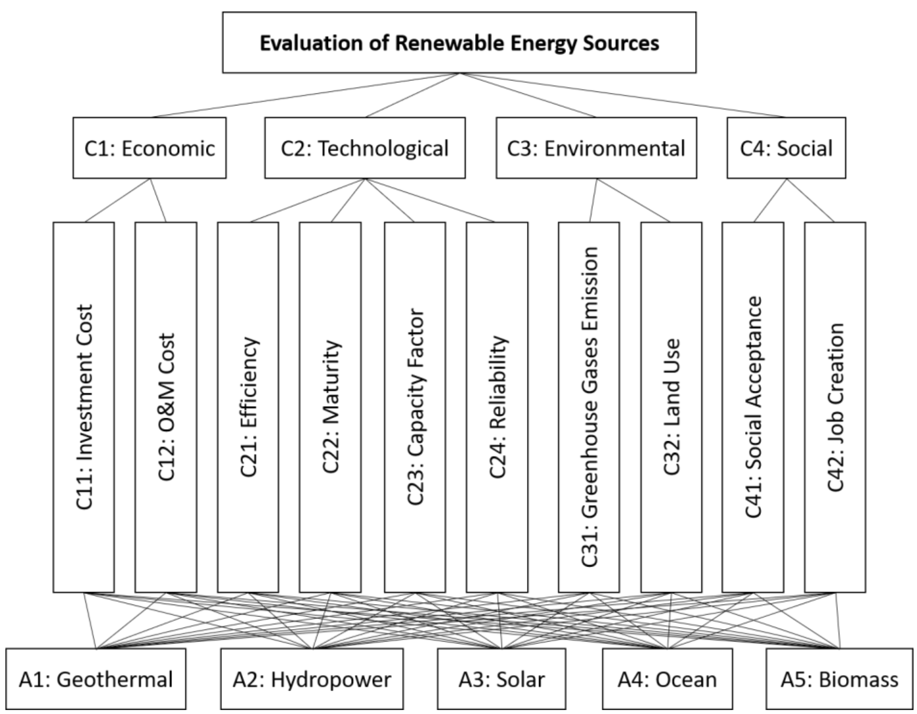


Figure 4.1 Renewable Energy Sources Evaluation Hierarchy

4.1 Criteria Weight Calculation using Fuzzy AHP

Since it is not possible to do mathematical calculations with linguistic evaluation, this study adopted a 9-point scale used in a study done by Kaya & Kahraman (2011) which used Fuzzy AHP to assess the importance of each evaluation criteria and sub-criteria. In this way, each evaluation term in the scale were given equivalent triangular fuzzy numbers as shown in Table 4.1.

Table 4.1 Fuzzy Evaluation Equivalent for Pairwise Comparison

Linguistic Terms	Fuzzy Score
Absolutely Strong (AS)	(2, 5/2, 3)
Very Strong (VS)	(3/2, 2, 5/2)
Fairly Strong (FS)	(1, 3/2, 2)
Slightly Strong (SS)	(1, 1, 3/2)
Equal (E)	(1, 1, 1)
Slightly Weak (SW)	(2/3, 1,1)
Fairly Weak (FW)	(1/2, 2/3, 1)
Very Weak (VW)	(2/5, 1/2, 2/3)
Absolutely Weak (AW)	(1/3, 2/5, 1/2)

Source: Kaya & Kahraman (2011).

Experts from industries related to renewable energy were determined and were sent questionnaires to do pairwise evaluation among criteria, sub-criteria and alternatives. To calculate the weight of the criteria, the geometric mean derived from the experts' evaluation will be used. Ayhan (2013) have cited and used a method introduced by Buckley (1985) in calculating for the importance of criteria and alternatives by using Fuzzy AHP and geometric mean, which will also be used in this research to quantify the relative criteria importance as shown in the steps:

Step 1. Experts will make a pairwise assessment of the energy options according to a linguistic scale as shown in Table 4.1. An evaluation matrix shown in Eq. 4.1 $\tilde{d}_{ij}^{k}$ where indicates the kth decision makers' evaluation of ith criterion versus jth criterion in the linguistic evaluation's assigned triangular fuzzy number equivalent.

$$\widetilde{D}^k = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{12}^k & \cdots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \tilde{d}_{22}^k & \cdots & \tilde{d}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{d}_{m1}^k & \tilde{d}_{m2}^k & \cdots & \tilde{d}_{mn}^k \end{bmatrix} \tag{4.1}$$

Step 2. In the case that there are multiple experts who will evaluate the criteria, each of their response $\tilde{d}_{ij}^k$ will be averaged through $\tilde{d}_{ij}$and is calculated in Eq. 4.2:

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{K} \tilde{d}_{ij}^k}{k} \tag{4.2}$$

Step 3. Following the averaged evaluations, the pairwise evaluation matrix is also changed by using Eq. 4.3 below:

$$\widetilde{D} = \begin{matrix} \tilde{d}_{11} & \dots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \dots & \tilde{d}_{nn} \end{matrix} \tag{4.3}$$

Step 4. The study of Buckley (1985) shows the geometric mean of fuzzy numbers of each criterion below in Eq. 4.4. At this point $\widetilde{r_i}$ still represents triangular fuzzy numbers.

$$\widetilde{r_i} = \left(\prod_{j=1}^{n} \tilde{d}_{ij} \right)^{\frac{1}{n}} \quad i = 1,2 \ldots n \tag{4.4}$$

Step 5. To calculate the fuzzy weight of each criterion through Eq. 4.5, Ayhan (2013) discussed the next step in 3 sub steps:

Step 5a. Solve for the vector summation of $\widetilde{r_i}$.

Step 5b. Solve for the reciprocal value of the summation vector by raising it to the (-1) power. Transform it to ascending order by replacing the fuzzy triangular number.

Step 5c. Solve for the weight of criterion i $\widetilde{w_i}$ by multiplying each $\widetilde{r_i}$ with the reverse vector as shown in Eq. 4.5.

$$\widetilde{w_i} = \tilde{r}_i x (\tilde{r}_1 + \tilde{r}_2 \ldots + \tilde{r}_n)^{-1} \tag{4.5}$$

$$= (lw_i, mw_i, uw_i)$$

Step 6: To defuzzify $\widetilde{w}_i$, the Centre of Area method which was proposed by Chou and Chang (2008) will be used, shown in Eq. 6 below:

$$M_i = \frac{(lw_i + mw_i + uw_i)}{3} \quad \textbf{(4.6)}$$

Step 7. The defuzzified weight of criterion i, denoted as M_i is a non-fuzzy number. However the summation of these weights must be equal to 1, hence they will be normalized through Eq. 7:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad \textbf{(4.7)}$$

Performing these steps would give the relative weight of each criteria, which will then be used to evaluate the alternatives through Fuzzy TOPSIS, Fuzzy WASPAS, and Fuzzy MOORA.

The decision makers were also tasked to evaluate the renewable energy alternatives against the 10 sub-criteria with the scale shown in Table 4.2. The linguistic scale and their fuzzy number equivalent were also adopted and modified from the study of Kaya & Kahraman (2011).

Table 4.2 Fuzzy Evaluation Scores for Alternatives

Linguistic Terms	Fuzzy Score
Very Good (VG)	(7,8,9)
Good (G)	(6,7,8)
Medium Good (MG)	(5,6,7)
Fair (F)	(4,5,6)
Medium Poor (MP)	(3,4,5)
Poor (P)	(2,3,4)
Very Poor (VP)	(1,2,3)

4.2 Fuzzy TOPSIS

Nădăban et al. (2016) summarizes the Fuzzy TOPSIS method as follows:

Step 1. Assigning rating to the criteria and to the alternatives. Fuzzy AHP was used in determining criteria weights for this study. Assuming a decision group has K members, the fuzzy rating of the k^{th} member about renewable energy alternative A_i with respect to criterion C_j is denoted $\tilde{x}_{ij}^{k} = a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k}$ and the weight of criterion C_j is denoted by $\widetilde{w}_{ij}^{k} = w_{j1}^{k}, w_{j2}^{k}, w_{j3}^{k}$.

Step 2. Calculating the aggregated fuzzy ratings for renewable energy options. The accumulated fuzzy rating denoted by $\tilde{x}_{ij}^{k} = \left(a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k}\right)$ of i^{th}alternative in relation to the jth criterion can be obtained as shown below:

$$a_{ij} = \min_{k} a_{ij}^{k}, \;\; b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^{k}, c_{ij} = \max_{k}\{c_{ij}^{k}\} \qquad \textbf{(4.8)}$$

Step 3. Compute the normalized fuzzy decision matrix $\tilde{R} = [\tilde{r}_{ij}]$, where

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c*_j}, \frac{b_{ij}}{c*_j}, \frac{c_{ij}}{c*_j}\right) \; and \; c*_j = \max_{i}\{c_{ij}\} \text{ (benefit criteria)} \qquad \textbf{(4.9)}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^{-}}{c_{ij}}, \frac{a_j^{-}}{b_{ij}}, \frac{a_j^{-}}{a_{ij}}\right) \; and \; a_j^{-} = \min_{i}\{a_{ij}\} \text{(cost criteria)} \qquad \textbf{(4.10)}$$

Step 4. Solve for the weighted normalized fuzzy decision matrix, with Eq. 4.11 and 4.12.

$$\tilde{V} = (\tilde{v}_{ij}) \qquad \textbf{(4.11)}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \qquad \textbf{(4.12)}$$

Step 5. Find the FPIS (Fuzzy Positive Ideal Solution) and the FNIS (Fuzzy Negative Ideal Solution) as shown in Eq. 4.13 and 4.14 respectively:

$$A^{*} = (\widetilde{v*}_1, \widetilde{v*}_2, \ldots \widetilde{v*}_n) \; where \; \widetilde{v*}_j = \max_{i} \tilde{v}_{ij3} \qquad \textbf{(4.13)}$$

$$A^{-} = (\tilde{v}_1^{-}, \tilde{v}_2^{-}, \ldots \tilde{v}_n^{-}) \; where \; \tilde{v}_j^{-} = \min_{i} \tilde{v}_{ij1} \qquad \textbf{(4.14)}$$

Step 6. Assign d_i^* and d_i^- as the distance of alternative A_i from FPIS and FNIS respectively, as shown in Eq. 4.15 and 4.16 below. This pertains to the alternative's distance from the positive and negative ideal solutions.

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right) \tag{4.15}$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) \tag{4.16}$$

Step 7. Compute the coefficient of closeness of each alternative as shown in Eq. 4.17:

$$CC_i = \left(\frac{d_i^-}{d_i^- + d_i^*}\right) \tag{4.17}$$

Step 8. Lastly, determine the order of the renewable energy options according to the closeness coefficient, the alternative having the highest CC_i being the best.

4.3 Fuzzy WASPAS

Another method to be used in identifying the most suitable renewable energy option for BARMM will be Fuzzy WASPAS which makes use of a combination of WSM and WPM.

Given that there is an aggregated decision matrix available, we can proceed with the next steps of the Fuzzy WASPAS method, enumerated by Turksis et al. (2019) as follows:

Step 1. Normalize the preliminary values of all the attributes $\tilde{x}_{ij}$ and create normalized decision matrix through Eq. 4.18.

$$\tilde{\bar{X}}_{ij} = \begin{cases} \dfrac{\tilde{x}_{ij}}{\max\limits_i \tilde{x}_{ij}} \; if \; \max\limits_i \tilde{x}_{ij} \; is \; preferrable, \\ \dfrac{\min\limits_i \tilde{x}_{ij}}{\tilde{x}_{ij}} \; if \; \min\limits_i \tilde{x}_{ij} \; is \; preferable; \end{cases} \quad i = \overline{1,m}, j = \overline{1,n} \tag{4.18}$$

Step 2. Using Eq. 4.19, solve for the normalized weighted fuzzy decision matrix $\tilde{X}_q$ for the WSM:

$$\tilde{\tilde{X}}_q = \begin{bmatrix} \tilde{\tilde{x}}_{11} & \dots & \tilde{\tilde{x}}_{1j} & \dots & \tilde{\tilde{x}}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{i1} & \dots & \tilde{\tilde{x}}_{ij} & \dots & \tilde{\tilde{x}}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\tilde{x}}_{m1} & \dots & \tilde{\tilde{x}}_{mj} & \dots & \tilde{\tilde{x}}_{mn} \end{bmatrix};\ \tilde{\tilde{x}}_{ij} = \tilde{\bar{x}}_{ij}\tilde{w}_j, i = \overline{1,m}, j = \overline{1,n} \qquad \textbf{(4.19)}$$

Step 3. Using Eq. 4.20, construct the normalized weighted fuzzy decision matrix $\tilde{X}_p$ for WPM:

$$\tilde{\tilde{X}}_p = \begin{bmatrix} \tilde{\bar{\bar{x}}}_{11} & \dots & \tilde{\bar{\bar{x}}}_{1j} & \dots & \tilde{\bar{\bar{x}}}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\bar{\bar{x}}}_{i1} & \dots & \tilde{\bar{\bar{x}}}_{ij} & \dots & \tilde{\bar{\bar{x}}}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\bar{\bar{x}}}_{m1} & \dots & \tilde{\bar{\bar{x}}}_{mj} & \dots & \tilde{\bar{\bar{x}}}_{mn} \end{bmatrix};\ \tilde{\bar{\bar{x}}}_{ij} = \tilde{\bar{x}}_{ij}^{\tilde{w}_j}, i = \overline{1,m}, j = \overline{1,n} \qquad \textbf{(4.20)}$$

Step 4. Solve for the respective values of optimality function for WSM and WPM for each alternative using Eqs. 4.21 and 4.22 respectively:

$$\tilde{Q}_i = \sum_{j=1}^{n} \tilde{\tilde{x}}_{ij}, i = \overline{1,m} \qquad \textbf{(4.21)}$$

$$\tilde{P}_i = \prod_{j=1}^{n} \tilde{\tilde{x}}_{ij}, i = \overline{1,m} \qquad \textbf{(4.22)}$$

To defuzzify $\tilde{Q}_i$ and $\tilde{P}_i$, the center-of-area will be used as shown in Eq. 4.23 and 4.24.

$$Q_i = \frac{(Q_{ia} + Q_{ib} + Q_{ic})}{3} \qquad \textbf{(4.23)}$$

$$P_i = \frac{(P_{ia} + P_{ib} + P_{ic})}{3} \qquad \textbf{(4.24)}$$

Step 5. To determine the integrated utility function for a renewable energy option, Eq. 4.25 will be used as shown below:

$$K_i = \lambda \sum_{j=1}^{m} Q_i + (1-\lambda) \sum_{j=1}^{m} P_i,\ \lambda = 0, \dots 1{,}0 \leq K_i \leq 1 \quad \textbf{(4.25)}$$

λ in Eq. 4.26 is calculated on the premise that sum of WSM scores must be also equivalent to the sum of WPM scores, and if λ = 0, WASPAS turns into WPM and if λ = 1, WASPAS turns into WSM (Zavadskas et al., 2012).

$$\lambda = \frac{\sum_{i=1}^{m} P_i}{\sum_{i=1}^{m} Q_i + \sum_{i=1}^{m} P_i} \quad \textbf{(4.26)}$$

Step 6. Rank the performance of each alternative based on the results of Eq. 4.25. The energy source with the largest K_i value is determined to be the best.

4.4 Fuzzy MOORA

Another MCDM method that will be employed in looking for the best green energy option for BARMM will be Fuzzy MOORA. Still utilizing the aggregated decision matrix using Eq. 4.8, we proceed with the steps of the Fuzzy MOORA method as enumerated by Akkaya et al. (2015):

Step 1. Normalize the decision matrix as $\tilde{X}_{ij}^{*} = \left(x_{ij}^{l*}, x_{ij}^{m*}, x_{ij}^{u*}\right)$.

$$x_{ij}^{l*} = x_{ij}^{l} \Big/ \sqrt{\sum_{i=1}^{m} \left[(x_{ij}^{l})^2 + (x_{ij}^{m})^2 + (x_{ij}^{u})^2\right]} \quad \textbf{(4.27)}$$

$$x_{ij}^{m*} = x_{ij}^{m} \Big/ \sqrt{\sum_{i=1}^{m} \left[(x_{ij}^{l})^2 + (x_{ij}^{m})^2 + (x_{ij}^{u})^2\right]} \quad \textbf{(4.28)}$$

$$x_{ij}^{u*} = x_{ij}^{u} \Big/ \sqrt{\sum_{i=1}^{m} \left[(x_{ij}^{l})^2 + (x_{ij}^{m})^2 + (x_{ij}^{u})^2\right]} \quad \textbf{(4.29)}$$

Step 2. Calculate the weighted normalized decision matrix using the weights obtained through Fuzzy AHP as: $\tilde{v}_{ij} = ({v_{ij}}^l, {v_{ij}}^m, {v_{ij}}^u)$

$$ {v_{ij}}^l = w_j {x_{ij}}^{l*} \quad \textbf{(4.30)} $$

$$ {v_{ij}}^m = w_j {x_{ij}}^{m*} \quad \textbf{(4.31)} $$

$$ {v_{ij}}^u = w_j {x_{ij}}^{u*} \quad \textbf{(4.32)} $$

Step 3. Solve for the normalized performance value by subtracting the summation of the cost criteria from the summation of the benefit criteria, as illustrated in Eq. 4.33 below:

$$ \tilde{y}_i = \sum_{j=1}^{g} \tilde{v}_{ij} - \sum_{j=g+1}^{n} \tilde{v}_{ij} \quad \textbf{(4.33)} $$

Where $\sum_{j=1}^{g} \tilde{v}_{ij}, j = 1 \ldots g$, for benefit criteria and $\sum_{j=g+1}^{n} \tilde{v}_{ij}, j = g + 1 \ldots n$, for cost criteria, and g = maximum and (n-g) being the maximum and minimum number of criteria to be evaluated, respectively.

Step 4. To defuzzify the normalized performance values, BNP (Best Non-Fuzzy Performance) will be solved as illustrated in Eq. 4.34 as: $\tilde{y}_i = {y_i}^l, {y_i}^m, {y_i}^u$

$$ BNP_i\,(y_i) = \frac{({y_i}^u - {y_i}^l) + ({y_i}^m - {y_i}^l)}{3} + {y_i}^l \quad \textbf{(4.34)} $$

The calculated values $BNP_i\ (y_i)$ will be ranked from the highest to smallest, the energy option bearing the highest value being the best energy option.

5. APPLICATION AND RESULTS

5.1 Application

By performing the methods enumerated on the previous section, the following shows the data which were gathered and analyzed for this study and the results of the respective calculations. Survey questionnaires were distributed to six experts from the government, industry and the academic field, all related to decision making regarding renewable energy. The profile and affiliation of the respondents are shown in the Table 5.1 below.

Table 5.1 Profile of Experts

Experts	Profile/Affiliation
Expert 1	Executive Director of Institute and Professor
Expert 2	Electronic Company Area Manager
Expert 3	Minister
Expert 4	Chief Energy Regulations Officer
Expert 5	Minister
Expert 6	Director, Environmental Management Services

This two-part survey questionnaire asks the experts to evaluate the how important each criteria and sub-criteria is with respect to each other, as well as rating the performance of five renewable energy options that were declared as available and resolved as to be explored in BARMM. Table 5.2 below shows the collected expevaluations of the experts with regards to the pairwise comparison done between the main criteria, namely Economic (C1), Technical (C2), Environmental (C3) and Social (C4).

Table 5.2 Experts Main Criteria Evaluation

Criteria		C1	C2	C3	C4
C1	E1	E	VS	SS	E
	E2	E	SS	E	SW

Criteria		C1	C2	C3	C4
	E3	E	FS	SS	SS
	E4	E	SS	E	FS
	E5	E	FS	FS	FS
	E6	E	E	E	SW
C2	E1	VW	E	SS	FW
	E2	SW	E	E	FS
	E3	FW	E	FS	SS
	E4	E	E	SS	SW
	E5	FW	E	FS	FS
	E6	E	E	SW	SW
C3	E1	SW	SW	E	VW
	E2	E	E	E	VS
	E3	SW	FW	E	FS
	E4	E	SW	E	SW
	E5	FW	FW	E	VS
	E6	E	SS	E	SW
C4	E1	E	FS	VS	E
	E2	SS	FW	VW	E
	E3	SW	SW	FW	E
	E4	FW	SS	SS	E
	E5	FW	FW	VW	E
	E6	SS	SS	SS	E

By applying Fuzzy AHP, the decision matrix in Table 5.2 is then transformed to their fuzzy equivalent by using Eq. 4.3 as shown in aggregated decision matrix in Table 5.3:

Table 5.3 Fuzzy Decision Matrix for Main Criteria Evaluation

	C1			C2			C3			C4		
C1	1.00	1.00	1.00	1.08	1.33	1.75	1.00	1.08	1.33	0.89	1.17	1.42
C2	0.68	0.81	0.94	1.00	1.00	1.00	0.94	1.17	1.50	0.81	1.11	1.42
C3	0.81	0.94	1.00	0.72	0.89	1.08	1.00	1.00	1.00	0.96	1.33	1.61
C4	0.78	0.89	1.17	0.78	0.97	1.33	0.80	0.94	1.31	1.00	1.00	1.00

By using Eq. 4.4, we get the fuzzy geometric mean of each criterion denoted by $\widetilde{r_i}$ and their fuzzy weights $\widetilde{w_i}$ using Eq. 4.5. By Using the Center of Area Method, the respective fuzzy weights are then defuzzified to M_i to evaluate their importance and normalized to N_i using Eq. 4.7. The evaluation criteria are then ranked according to their weights. These are all shown in Table 5.4.

Table 5.4 Normalized Weight and Ranking of Main Evaluation Criteria

	$\widetilde{r_i}$			$\widetilde{w_i}$			M_i	N_i	Rank
C1	0.991	1.139	1.348	0.203	0.276	0.381	0.287	0.277	1
C2	0.847	1.011	1.190	0.174	0.245	0.337	0.252	0.243	2
C3	0.863	1.029	1.149	0.177	0.249	0.325	0.250	0.242	3
C4	0.834	0.950	1.194	0.171	0.230	0.338	0.246	0.238	4

As shown, the experts have evaluated that Economic (C1) is the most important evaluation criterion, then followed by Technical (C2), Environmental (C3) and Social (C4). Following this, the experts performed pairwise comparison to each criterion's sub-criteria. In the same way their responses were converted to their fuzzy equivalents and aggregated, and Fuzzy AHP was used to evaluate the responses. Their global weight and rank are shown in Table 5.5.

Table 5.5 Global Weight and Ranking of Sub-Criteria

Criteria	Global Weight	Rank
Investment Cost (C11)	0.159	1
O&M Cost (C12)	0.118	5
Efficiency (C21)	0.075	7
Maturity (C22)	0.062	8
Capacity Factor (C23)	0.056	9
Reliability (C24)	0.050	10
GHG Emissions (C31)	0.118	4
Land Use (C32)	0.123	3
Social Acceptance (C41)	0.140	2
Job Creation (C42)	0.098	6

Investment Cost (C11) is identified as the most important sub-criterion among ten (10) sub-criteria which is then followed by Social Acceptance (C41).

The experts were tasked to evaluate the performance of the renewable energy alternatives with respect to the sub-criterion in the latter part of the questionnaire. Table 5.6 shows the collected responses of the experts for this part.

Table 5.6 Evaluation of Renewable Energy Alternatives

Alternative		C11	C12	C21	C22	C23	C24	C31	C32	C41	C42
	E1	MP	F	F	F	MP	MP	VP	G	G	P

Alternative		C11	C12	C21	C22	C23	C24	C31	C32	C41	C42
Geothermal (A1)	E2	P	F	G	G	F	G	F	P	F	G
	E3	F	F	MG	MG	MG	MG	MP	MP	MG	F
	E4	P	F	F	VG	F	G	F	P	G	F
	E5	MP	MP	MG	MG	MG	MG	MP	MP	MG	MG
	E6	G	G	MP	P	P	MP	MG	MG	MP	MP
Hydropower (A2)	E1	VP	F	VG	VG	VG	VG	VP	G	P	G
	E2	P	G	G	MG	MG	G	P	P	G	G
	E3	VP	VP	VG	VG	VG	VG	VP	VP	VG	VG
	E4	VP	F	VG	VG	F	G	VP	F	VG	G
	E5	VP	VP	VG	VG	VG	VG	VP	VP	VG	VG
	E6	MG	MG	MP	MP	MP	F	F	MG	MP	MP
Solar (A3)	E1	VP	VP	MG	G	VG	G	VP	F	VG	F
	E2	VP	P	VG	G	G	VG	VP	VP	VG	VG
	E3	P	MP	G	VG	G	G	VP	VP	VG	MG
	E4	VP	MP	VG	G	F	G	VP	P	VG	G
	E5	VP	VP	VG	VG	VG	VG	VP	VP	VG	VG
	E6	MG	MG	MP	MP	MP	P	F	F	MP	MP
Ocean (A4)	E1	F	MG	MP	P	P	VP	VP	VP	P	MP
	E2	VP	P	G	G	G	G	VP	P	VG	VG
	E3	F	F	F	F	F	F	F	F	F	F
	E4	F	MG	G	MP	F	MP	VP	MG	G	F
	E5	MG	MG	MP	MP	MP	MP	MG	MG	MP	MP
	E6	G	G	P	P	P	MP	MG	MG	MP	MP
Biomass (A5)	E1	P	VP	MG	VG	F	VG	G	VP	VG	VG
	E2	P	F	G	F	MP	F	F	P	F	G
	E3	MP	MP	G	MG	G	MG	P	P	MG	MG
	E4	VP	F	VG	F	F	G	MG	F	VG	G
	E5	MP	MP	MG	MG	MG	MG	MP	MP	MG	MG
	E6	G	G	P	P	P	MP	MG	MG	MP	MP

The first MCDM method used is Fuzzy TOPSIS. A fuzzy equivalent decision matrix is then formed to aggregate the responses of the six experts using Eq. 4.8. The normalized fuzzy decision matrix $\tilde{R}$ is then formed by identifiying cost and benefit criteria and normalizing them using Eqs. 4.9 and 4.10 as shown in Table 5.7. Economic (C1) and Environemnt (C3) criteria are then identified as cost criteria, consequently making their respective sub-criteria as cost sub-criteria as well.

Table 5.7 Normalized Fuzzy Decision Matrix

Sub- Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
C11	0.125	0.143	0.143	0.125	0.125
	0.231	0.353	0.353	0.200	0.261
	0.500	1.000	1.000	1.000	1.000
C12	0.125	0.125	0.143	0.125	0.125
	0.194	0.222	0.286	0.182	0.222
	0.333	1.000	1.000	0.500	1.000
C21	0.333	0.333	0.333	0.222	0.222
	0.611	0.796	0.759	0.556	0.685
	0.889	1.000	1.000	0.889	1.000
C22	0.222	0.333	0.333	0.222	0.222
	0.648	0.778	0.759	0.481	0.611
	1.000	1.000	1.000	0.889	1.000
C23	0.222	0.333	0.333	0.222	0.222
	0.537	0.722	0.722	0.500	0.556
	0.778	1.000	1.000	0.889	0.889
C24	0.333	0.444	0.222	0.111	0.333
	0.630	0.796	0.741	0.481	0.667
	0.889	1.000	1.000	0.889	1.000
C31	0.143	0.167	0.167	0.143	0.125
	0.231	0.375	0.400	0.261	0.194
	1.000	1.000	1.000	1.000	0.500
C32	0.125	0.125	0.167	0.143	0.143
	0.222	0.240	0.316	0.214	0.261
	0.500	1.000	1.000	1.000	1.000
C41	0.333	0.222	0.333	0.222	0.333
	0.648	0.704	0.815	0.574	0.685
	0.889	1.000	1.000	1.000	1.000
C42	0.222	0.333	0.333	0.333	0.333
	0.556	0.759	0.704	0.556	0.704
	0.889	1.000	1.000	1.000	1.000

The respective criteria weights as shown in Table 5.5 are then applied to the normalized decision matrix, which is shown in Table 5.8.

Table 5.8 Weighted Normalized Fuzzy Decision Matrix for Fuzzy TOPSIS

Sub- Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
C11	0.020	0.023	0.023	0.020	0.020
	0.037	0.056	0.056	0.032	0.042
	0.080	0.159	0.159	0.159	0.159

Sub- Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
C12	0.015	0.015	0.017	0.015	0.015
	0.023	0.026	0.034	0.021	0.026
	0.039	0.118	0.118	0.059	0.118
C21	0.025	0.025	0.025	0.017	0.017
	0.046	0.059	0.057	0.042	0.051
	0.066	0.075	0.075	0.066	0.075
C22	0.014	0.021	0.021	0.014	0.014
	0.040	0.048	0.047	0.030	0.038
	0.062	0.062	0.062	0.055	0.062
C23	0.012	0.019	0.019	0.012	0.012
	0.030	0.041	0.041	0.028	0.031
	0.044	0.056	0.056	0.050	0.050
C24	0.017	0.022	0.011	0.006	0.017
	0.032	0.040	0.037	0.024	0.034
	0.045	0.050	0.050	0.045	0.050
C31	0.017	0.020	0.020	0.017	0.015
	0.027	0.044	0.047	0.031	0.023
	0.118	0.118	0.118	0.118	0.059
C32	0.015	0.015	0.021	0.018	0.018
	0.027	0.030	0.039	0.026	0.032
	0.062	0.123	0.123	0.123	0.123
C41	0.047	0.031	0.047	0.031	0.047
	0.090	0.098	0.114	0.080	0.096
	0.124	0.140	0.140	0.140	0.140
C42	0.022	0.033	0.033	0.033	0.033
	0.055	0.075	0.069	0.055	0.069
	0.087	0.098	0.098	0.098	0.098

The main characteristic of Fuzzy TOPSIS is to identify which option has the least distance from the most ideal solution and farthest from the least ideal solution. The FPIS and FNIS are then computed by using Eqs. 4.13 and 4.14 respectively. Each alternative's distance to the positive ideal solution, denoted by d*, and to the negative ideal solution, denoted by d^{-}, are determined and the coefficient of closeness (CC) is solved using Eq. 4.17. Ideally, the best alternative should be the nearest from the positive ideal solution and the farthest from the negative ideal solution. This is reconciled by identifying the alternative with the highest coefficient of closeness.

Table 5.9 Alternative's Coefficient of Closeness and Rank

Alternative	d+	d-	CC	Rank
Geothermal	0.204	0.071	0.257	5
Hydropower	0.025	0.243	0.907	2
Solar	0.012	0.245	0.953	1
Ocean	0.146	0.149	0.505	4
Biomass	0.094	0.182	0.658	3

The alternative with the highest CC is then determined to be the most ideal alternative, at this case Solar Energy (A3) as shown in Table 5.9. This is closely followed by Hydropower, Biomass, Ocean and lastly Geothermal Energy.

To evaluate the renewable energy options using the Fuzzy WASPAS method, Eq. 4.19 was used to build the fuzzy decision matrix for WSM as shown in Table 5.10.

Table 5.10 Weighted Normalized Fuzzy Decision Matrix for WSM

Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
C11	0.054	0.062	0.062	0.054	0.054
	0.136	0.208	0.208	0.118	0.154
	0.371	0.743	0.743	0.743	0.743
C12	0.042	0.042	0.048	0.042	0.042
	0.079	0.091	0.117	0.074	0.091
	0.188	0.564	0.564	0.282	0.564
C21	0.071	0.071	0.071	0.047	0.047
	0.189	0.246	0.234	0.172	0.212
	0.392	0.440	0.440	0.392	0.440
C22	0.040	0.060	0.060	0.040	0.040
	0.163	0.195	0.190	0.121	0.153
	0.367	0.367	0.367	0.326	0.367
C23	0.035	0.053	0.053	0.035	0.035
	0.125	0.169	0.169	0.117	0.130
	0.257	0.331	0.331	0.294	0.294
C24	0.050	0.066	0.033	0.017	0.050
	0.130	0.165	0.153	0.100	0.138
	0.258	0.290	0.290	0.258	0.290
C31	0.059	0.069	0.069	0.059	0.052
	0.115	0.188	0.200	0.130	0.097
	0.568	0.568	0.568	0.568	0.284
C32	0.055	0.055	0.073	0.063	0.063
	0.111	0.120	0.158	0.107	0.130

Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
	0.303	0.606	0.606	0.606	0.606
C41	0.163	0.109	0.163	0.109	0.163
	0.379	0.411	0.476	0.335	0.400
	0.625	0.704	0.704	0.704	0.704
C42	0.079	0.118	0.118	0.118	0.118
	0.231	0.316	0.293	0.231	0.293
	0.429	0.482	0.482	0.482	0.482

Eq. 4.20 was then used to build the fuzzy decision matrix for WPM as shown in Table 5.11.

Table 5.11 Weighted Normalized Fuzzy Decision Matrix for WPM

Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
C11	0.213	0.236	0.236	0.213	0.213
	0.421	0.541	0.541	0.387	0.452
	0.742	1.000	1.000	1.000	1.000
C12	0.310	0.310	0.334	0.310	0.310
	0.510	0.540	0.599	0.497	0.540
	0.693	1.000	1.000	0.793	1.000
C21	0.616	0.616	0.616	0.516	0.516
	0.859	0.932	0.918	0.834	0.890
	0.975	1.000	1.000	0.975	1.000
C22	0.576	0.668	0.668	0.576	0.576
	0.897	0.939	0.933	0.833	0.884
	1.000	1.000	1.000	0.979	1.000
C23	0.608	0.695	0.695	0.608	0.608
	0.865	0.927	0.927	0.851	0.872
	0.961	1.000	1.000	0.981	0.981
C24	0.727	0.790	0.646	0.528	0.727
	0.909	0.954	0.940	0.860	0.919
	0.983	1.000	1.000	0.983	1.000
C31	0.331	0.362	0.362	0.331	0.307
	0.480	0.612	0.632	0.511	0.440
	1.000	1.000	1.000	1.000	0.751
C32	0.284	0.284	0.338	0.308	0.308
	0.471	0.490	0.562	0.463	0.511
	0.738	1.000	1.000	1.000	1.000
C41	0.462	0.347	0.462	0.347	0.462
	0.776	0.814	0.887	0.723	0.802
	0.944	1.000	1.000	1.000	1.000

Criteria	Alternative				
	Geothermal	Hydropower	Solar	Ocean	Biomass
C42	0.484	0.589	0.589	0.589	0.589
	0.783	0.892	0.864	0.783	0.864
	0.959	1.000	1.000	1.000	1.000

With these values, the optimality function for Fuzzy WSM and Fuzzy WPM method can be computed by using Eqs. 4.21 and 4.22 denoted by $\tilde{Q}_i$ and $\tilde{P}_i$, respectively. This is to be defuzzified using the center of area technique as shown in Eqs. 4.23 and 4.24 for each method respectively. Following WSM, the alternative with the higher Q_i in is the most appropriate option, while the option with the highest P_i will be considered the best option following the WPM method. To reconcile these two methods under Fuzzy WASPAS, the lambda value denoted by λ was solved using Eq. 4.26 to determine the alternative with the highest utility function K_i shown in Eq. 4.25. Table 5.12 below shows the integrated utility function values of the alternatives using the Fuzzy WASPAS method.

Table 5.12 Integrated Utility Function for Fuzzy WASPAS

Alternative	Qi	Pi	Ki	FWSM Rank	FWPM Rank	FWASPAS Rank
Geothermal	0.202	0.111	0.159	5	5	5
Hydropower	0.264	0.350	0.305	2	2	2
Solar	0.268	0.355	0.310	1	1	1
Ocean	0.225	0.248	0.236	4	4	4
Biomass	0.241	0.254	0.247	3	3	3

The table reveals that Solar energy is the best energy option selected by the experts based on their evaluation. This is closely followed by Hydropower energy. It must also be noted that the rank of the alternatives is consistent within the Fuzzy WASPAS, Fuzzy WSM, and Fuzzy WPM.

The third MCDM method used to determine which renewable energy option is the most suitable for BARMM is Fuzzy MOORA. The main characteristic of MOORA is using ratio analysis while making use of the cost and benefit criteria. After forming an aggregated decision matrix out of the experts' responses, it is normalized using Eqs. 4.27 – 4.29. These normalized values are shown in Table 5.13.

Table 5.13 Normalized Fuzzy Decision Matrix for Fuzzy MOORA

Alternative	Geothermal	Hydropower	Solar	Ocean	Biomass
C11	0.103622	0.051811	0.051811	0.051811	0.051811
	0.224514	0.146797	0.146797	0.259054	0.198608
	0.414487	0.362676	0.362676	0.414487	0.414487
C12	0.144556	0.048185	0.048185	0.096371	0.048185
	0.248958	0.216834	0.168649	0.26502	0.216834
	0.385483	0.385483	0.337298	0.385483	0.385483
C21	0.122748	0.122748	0.122748	0.081832	0.081832
	0.225037	0.29323	0.279592	0.204579	0.252314
	0.327327	0.368243	0.368243	0.327327	0.368243
C22	0.081872	0.122808	0.122808	0.081872	0.081872
	0.238792	0.286551	0.279728	0.177389	0.225147
	0.368423	0.368423	0.368423	0.327487	0.368423
C23	0.087528	0.131292	0.131292	0.087528	0.087528
	0.211527	0.284467	0.284467	0.196939	0.218821
	0.306349	0.393877	0.393877	0.350113	0.350113
C24	0.123227	0.164303	0.082151	0.041076	0.123227
	0.232762	0.294376	0.273838	0.177995	0.246454
	0.328605	0.369681	0.369681	0.328605	0.369681
C31	0.056296	0.056296	0.056296	0.056296	0.112593
	0.243951	0.150124	0.140741	0.215803	0.290865
	0.394075	0.337779	0.337779	0.394075	0.450372
C32	0.106282	0.053141	0.053141	0.053141	0.053141
	0.239135	0.221421	0.16828	0.247992	0.203707
	0.425128	0.425128	0.318846	0.371987	0.371987
C41	0.120909	0.080606	0.120909	0.080606	0.120909
	0.235101	0.255252	0.295555	0.208232	0.248535
	0.322424	0.362727	0.362727	0.362727	0.362727
C42	0.081317	0.121976	0.121976	0.121976	0.121976
	0.203293	0.277834	0.257504	0.203293	0.257504
	0.325269	0.365927	0.365927	0.365927	0.365927

Using Eqs. 4.30 – 4.32, the respective criteria weights are then applied to the decision matrix, shown in Table 5.14.

Table 5.14 Weighted Normalized Fuzzy Decision Matrix for Fuzzy MOORA

Alternative	Geothermal	Hydropower	Solar	Ocean	Biomass
C11	0.016	0.008	0.008	0.008	0.008
	0.036	0.023	0.023	0.041	0.032
	0.066	0.058	0.058	0.066	0.066
C12	0.017	0.006	0.006	0.011	0.006
	0.029	0.026	0.020	0.031	0.026
	0.045	0.045	0.040	0.045	0.045
C21	0.009	0.009	0.009	0.006	0.006
	0.017	0.022	0.021	0.015	0.019
	0.024	0.028	0.028	0.024	0.028
C22	0.005	0.008	0.008	0.005	0.005
	0.015	0.018	0.017	0.011	0.014
	0.023	0.023	0.023	0.020	0.023
C23	0.005	0.007	0.007	0.005	0.005
	0.012	0.016	0.016	0.011	0.012
	0.017	0.022	0.022	0.020	0.020
C24	0.006	0.008	0.004	0.002	0.006
	0.012	0.015	0.014	0.009	0.012
	0.017	0.019	0.019	0.017	0.019
C31	0.007	0.007	0.007	0.007	0.013
	0.029	0.018	0.017	0.026	0.034
	0.047	0.040	0.040	0.047	0.053
C32	0.013	0.007	0.007	0.007	0.007
	0.030	0.027	0.021	0.031	0.025
	0.053	0.053	0.039	0.046	0.046
C41	0.017	0.011	0.017	0.011	0.017
	0.033	0.036	0.041	0.029	0.035
	0.045	0.051	0.051	0.051	0.051
C42	0.008	0.012	0.012	0.012	0.012
	0.020	0.027	0.025	0.020	0.025
	0.032	0.036	0.036	0.036	0.036

Performance values are then calculated using Eq. 4.33, and defuzzified using Eq. 4.34, denoted as the Best Non-Fuzzy Performance, shown in table Table 5.15.

Table 5.15 Fuzzy MOORA Performance Values

Alternative	${y_i}^l$	${y_i}^m$	${y_i}^u$	y_i	Rank
Geothermal	-0.00309	-0.01549	-0.05256	-0.02371	5
Hydropower	0.02851	0.039354	-0.01798	0.016627	2
Solar	0.030005	0.053863	0.000825	0.028231	1
Ocean	0.008579	-0.0333	-0.03645	-0.02039	4

Biomass	0.017353	0.000737	-0.03545	-0.00579	3

Based on this, Solar energy is the best alternative for BARMM as it has the highest BNP, followed by Hydropower, Biomass, Ocean and Geothermal energy. Table 5.16 shows the result of the three MCDM methods used in the study.

Table 5.16 Results of the Various MCDM Methods

Alternative	FTOPSIS	FWASPAS	FMOORA	Rank
Geothermal	5	5	5	5
Hydropower	2	2	2	2
Solar	1	1	1	1
Ocean	4	4	4	4
Biomass	3	3	3	3

5.2 Sensitivity Analysis

In performing the various MCDM methods, it is shown that the evaluation weights greatly affect the order of the renewable energy options. In this paper, a sensitivity analysis was performed to preview how the results would change if weights were adjusted. A scenario where all sub-criterion weights are equal at 0.1 each was used, and the results are shown in Table 5.17.

Table 5.17. Sensitivity Analysis

Alternative	FTOPSIS	FWASPAS	FMOORA	Rank
Geothermal	5	5	4	5
Hydropower	1	2	2	2
Solar	2	1	1	1
Ocean	4	4	5	4
Biomass	3	3	3	3

When sub-criteria weights are set at the same value out of 100 percent, the order of the alternatives change in Fuzzy TOPSIS and Fuzzy MOORA however remains unchanged in the Fuzzy WASPAS.

5.3 Results

Through extensive literature review, the study has identified four major evaluation criteria, namely economic, technical, environmental and social. Furthermore, ten (10) sub-criteria were also identified in connection to the four main evaluation criteria. These are investment cost, O&M cost, efficiency, maturity, capacity factor, reliability, GHG emission, land use, social acceptance and job creation.

These criteria and sub-criteria were popularly used in studies relating to energy planning and selection of renewable energy. investment cost and O&M cost were selected for the economic criteria as they were seen to be critical in selecting renewable energy options especially in areas such as the region which is struggling with poverty. Under technical criteria, technical reliability, efficiency, maturity and capacity factor were considered because it is crucial if the present state of the renewable energy options available is mature enough, as well as the technical capacity to operate them are in a level that they can be operated efficiently, on top of the cost that they will incur. GHG emissions as well as land use were considered under environmental criteria, because as the Philippines is moving towards cleaner and greener energy by 2030, government programs must also be aligned with the goal of lessening reliance towards fossil fuel. And lastly, social acceptance and job creation were determined under the social criteria to consider how the public would feel about this program as well as the employment opportunities that it will bring.

The literature review also helped identify Fuzzy AHP as the method to determine importance of evaluation criteria and sub-criteria, and three MCDM methods to evaluate the performance of the renewable energy options against the various criteria and sub-criteria, namely Fuzzy TOPSIS, Fuzzy WASPAS and Fuzzy MOORA. Multiple MCDM methods were used to evaluate and ensure consistency of the results.

Six experts and decision makers were identified and tasked to answer a two-part survey questionnaire. The first part of the questionnaire required the experts to perform a pairwise comparison of the evaluation criteria and sub-criteria, using a scale provided. Their responses were then transformed into triangular fuzzy numbers. Using triangular fuzzy numbers were seen to be more effective in quantifying uncertain and qualitative data.

Using Fuzzy AHP, the experts' responses were aggregated to measure the importance of criteria and sub-criteria with respect to each other, as well as how do they weigh in relation to ranking alternatives. Experts' evaluations showed that Economic criterion is the most important criterion to be considered in selecting renewable energy options for the region. As some areas of the region live below the poverty threshold, consideration for the costs to be incurred are given since there are priority programs in place for poverty alleviation, and investing for renewable energy options may in a way affect them. Investment Cost on the other hand was identified as the most critical sub-criterion in evaluating renewable energy options, closely followed by Social Acceptance.

In evaluating the performance of the renewable energy options, Fuzzy TOPSIS was used. Alternatives were evaluated by their distance towards a positive ideal solution and away from a negative ideal solution by finding their coefficient of closeness. Solar energy was seen to be the alternative with the highest coefficient of closeness, hence the best alternative. This is followed by hydropower energy, biomass, ocean and then geothermal energy.

Fuzzy WASPAS was also used to determine the order of the renewable energy options with respect to the various criteria. This method is a hybrid of the weighted sum method and weighted product method and leverages the strength of both methods to improve decision accuracy. Results have shown that solar energy is the best alternative, followed by hydropower energy. Moreover, the results of Fuzzy WSM and Fuzzy WPM is consistent with the Fuzzy WASPAS results, showing the same order of alternatives.

Lastly, Fuzzy MOORA was used to rank the renewable energy options. This method gives emphasis on ratio analysis and the type of criteria whether they are cost or benefit. The method showed that solar energy is the best alternative, All three MCDM methods yielded consistent results, showing solar as the best renewable energy alternative and that the government should focus on that.

Sensitivity analysis was also implemented to determine how the order of the alternatives would change should some factors be changed. At this case, the renewable energy alternatives were evaluated with equal sub-criteria weights.

The analysis showed that when evaluation sub-criteria were given equal importance, hydropower would rank first over solar energy as the best alternative when evaluated using Fuzzy TOPSIS. Results remained the same for Fuzzy WASPAS. Geothermal energy ranked higher than ocean energy, which ranked last, when using Fuzzy MOORA, while the three highest ranking alternatives remained the same.

6. DISCUSSION AND CONCLUSION

To address the perennial energy crisis in BARMM, the members of the parliament have submitted a resolution urging the Ministry of Environment, Natural Resources and Energy (MENRE) to formulate a power development plan and explore renewable energy options to improve the quality of life of its constituents and lessen GHG emissions. Five renewable energy options were identified in the resolution, namely: geothermal, hydropower, biomass, solar and ocean energy.

The resolution strongly suggests that the development of a comprehensive power development plan shall promote efficient use of energy, development of a renewable energy program and innovation, consequently supporting livelihood programs for off-grid and un-electrified communities, which accounts to 58.26% of the region's population. A study conducted by Mendoza et al. (2019) shows that the region has the highest energy poverty rate in the country, with a further implication that places with high energy poverty rate also has higher poverty rates. This is parallel to the government's data that the provinces within the region also live below the poverty threshold.

To supplement the effort, this study reviewed literature pertaining to renewable energy selection, energy planning, policy making and decision making to determine which among the identified renewable energy options probable for exploration is the best energy option the government should focus on and implement, and how do the other renewable options rank as they were evaluated. It must be noted that there are no similar nor related studies published which focused on this problem in the region though studies have shown how this problem have appeared to affect other aspects of the lives of constituents.

Through the literature review, MCDM methods namely Fuzzy AHP, Fuzzy TOPSIS, Fuzzy WASPAS and Fuzzy MOORA were identified as the methods to be used in evaluating criteria and evaluating the renewable energy alternatives against these criteria and their respective sub-criteria.

Six experts and decision makers affiliated with energy planning and policy making were given questionnaires to do the evaluation, and results have showed that the most important criteria to consider is the economic criteria, while the most important sub-criteria to consider is investment cost. The MCDM methods and the sensitivity analysis showed consistent results that solar energy is the best alternative for the region.

With these findings, it is recommended that the region should invest in developing the solar energy to solve the energy problems in the region. By investing in solar energy, the regional government can create a more efficient energy infrastructure and contribute to reduction of GHG emissions and reliance on fossil fuels, ultimately leading to the country’s goal of increasing the share of renewable energy in the energy mix to 35% by 2030 and contributing to long-term economic and environmental benefits. As energy poverty is also connected with economic poverty, investing in a solution could create multiple benefits to the region’s constituents. Hydropower energy, which is already a promising renewable energy resource used in the neighboring region, must also be considered as another renewable energy alternative to invest in.

Further studies are also recommended in which other MCDM methods will be used to evaluate the alternatives against various criteria. Future researchers must also consider increasing the number of criteria and using more scenarios in the sensitivity analysis.

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