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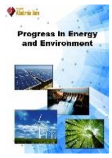

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Original Article

Multi-criteria decision analysis for evaluation of potential renewable energy resources in Malaysia

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Abstract

Switching to renewable energy resources as an alternative is critical for developing countries in order to ensure energy security and diversify their energy supply. Malaysia is endowed with biomass, solar, waste-to-energy, wind, and hydro energy potentials, although these have not been fully explored. This is because the country continues to rely extensively on conventional fossil-fuel energy sources such as coal and petroleum to generate power and consume energy. On the other hand, demand for energy is increasing as a result of population growth and a booming economy. Thus, this study intends to identify suitable potential renewable energy resources that can benefit Malaysia by analysing the outcomes of Focus Group Discussions (FGD) using the Analytic Hierarchy Process (AHP) as an analytical technique. Five renewable energy resources were evaluated: biomass, solar, waste to energy, wind, and hydro energy while five criteria were identified: carbon production, operational costs, location characteristics, energy, and availability of renewable energy resources. The outcome suggested a strategic focus on solar energy for Malaysia due to consideration in carbon production. This information will assist decision-makers in strategizing the most suitable renewable energy resources for Malaysia.

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1 Introduction

Recently, energy security and climate change are two major issues being discussed around the world. It is related to the consumption of non-renewable fossil-fuel energy that plays a vital role in economic growth. Alternatively, renewable energy emerged as a crucial resource that is ideal for a sustainable environment [1]. By definition, energy is the ability to do work and in life, energy is very essential for running daily activities and it is required in transportation, industrial activities, agriculture as well as telecommunication. But there will be severe impacts to the environment if the energy resources are not well-managed. Therefore, many governments of the world especially the developed nations invested in biomass, hydropower, wind or solar energy as a source of renewable energy in order to reduce reliance on the non-renewable fossil-fuel energy [2].

Malaysia has a diverse energy mix, including oil, fossil fuels, coal, and renewable energy sources such as solar, biomass, and hydro. With a total area of 329,845 km^2, Malaysia's geographic position offers numerous benefits for broad usage of most renewable energy sources [3]. Malaysia is also blessed with a tropical climate with an average year-round temperature of 20–35 °C and relative humidity of 80–90% [4]. Tropical climate in Malaysia causes unpredictable sun radiation such as shadow and other negative effects [5]. Despite its abundant

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resources, the country's industrial and transportation sectors rely on fossil fuels [6]. In 2009, the industrial sector in Malaysia utilised 43% of total energy which the main energy used was electricity and gas, exceeding the transportation sector, which consumed 36% [6]. Moreover, in the same year, non-renewable fossil-fuel energy resources such as coal, natural gas, and oil were used to generate about 94.5% of all power while the remaining was generated from hydroelectricity.

During the 8th Malaysian Plan for 2001 to 2005, the Fifth Fuel Policy was introduced. By 2005, the Fifth Fuel Policy sought to produce 5% of the country's energy from renewable sources. However, it achieved the target only 0.3% and the development use of renewable energy was stepped up even further during the 9th Malaysian Plan (2006 to 2010). After that, the Malaysian government continues to prioritise the development of renewable energy sources. Research by Kardooni R. et al. [4] showed that the government sought to attain a renewable energy target of 985 MW by 2015, or 5.5% of Malaysia's overall power generating mix, under the 10th Malaysian Plan (2011–2015). In addition, in 2010, the National Renewable Energy Policy was established, with the goal of renewable energy sources providing 11% of total energy by 2020.

In this study, Analytical Hierarchy Process (AHP) is used as an analytical tool to assess the potential renewable energy resources for Malaysia, based on the results obtained from Focus Group Discussion (FGD). The methodology also integrates experts' input and data analytics and helps decision-makers model long-term strategies for renewable energy development.

2 Methodology

Analytical Hierarchy Process (AHP) is a technique to organize and analyse complex decisions and it is used in this study. AHP has three parts which are goal, criteria and the alternatives [7]. By quantifying the criteria and alternative choices, AHP provides a rational framework for making a decision and relates all the elements to gain a goal. In this study, the goal is to suggest the most potential renewable energy resources in Malaysia. The criteria are determined to be carbon production, operational cost, location features, energy and availability of renewable energy resources. On the other hand, five types of renewable energy resources being considered as the alternatives to this research are biomass, solar, hydro, municipal solid waste and wind energy. During the hierarchy design stage, the selection of these criteria and alternatives was assisted by literature review and focus group discussion (FGD). FGD has been conducted among nine experts from three different local universities in Malaysia, who are experts in renewable energy research field. All the nine members are deemed qualified as experts based on their affiliation, contributed authoritative works in renewable energy field (minimum of 20 international publications) and identified as authority in their field (more than 10 years research experience). The moderator and the members in the FGD utilized The Malaysia Renewable Energy Roadmap (MyRER) published in 2021 [6] as a referred document for the discussion. The FGD is crucial to ensure the non-biasness in choosing criterion and relatively based on a knowledge-based consensus. Details on calculation and stepwise procedures for the AHP analysis can be viewed in previous publication [7].

2.1 Selection of renewable energy resources

Based on FGD, five types of renewable energy resources are chosen as the alternatives to this research. Biomass, solar, hydro, municipal solid waste and wind were chosen for this study and evaluated for their suitability to be the most potential renewable energy resources in Malaysia.

2.2 Biomass energy

Biomass and solar energy, according to Malaysia's Ministry of Energy, Green Technology, and Water, have enormous potential as renewable energy sources. Palm oil leftovers, wood residues, and rice husks are examples of biomass resources that may be utilised to generate heat and power [6]. Bioenergy is one of the most flexible low-carbon and renewable energy sources since it can be used to generate energy and reduce long-term emissions throughout the energy spectrum of electricity, heat, and transportation. On the other hand, waste, heat, and liquid transportation fuels are among the low-risk energy deployment paths for bioenergy [5]. Bioenergy is the term for electricity and gas produced from organic materials, often known as biomass. Malaysia is able to generate energy from biomass because of the availability of palm oil biomass resources, which account for 80–90% of the country's total biomass [5].

2.3 Solar energy

In the case of solar energy, Malaysia's climatic circumstances are ideal for the development of solar energy owing to plentiful sunlight, with an average daily solar insolation of 5.5 kWm^2, or 15 MJ/m^2 [8]. Malaysia's monthly sun irradiation is predicted to be 400–600 MJ/m^2 [8] and solar power generation has a potential of up to 6500 MW [9]. After that, solar energy is the best backup energy source since it offers several advantages over other options. Solar energy is a readily available and environmentally friendly energy source obtained from the sun that may be used to create power directly [10]. According to Wan Abdullah et al. [9], rooftop solar installation can possibly lower monthly bills by subscribing to a single set tariff given by solar leasing companies [9].

2.4 Hydro energy

Malaysia has a lot of hydro potential, with year-round high temperatures and humidity, as well as a lot of rain. As a result of these characteristics, Malaysia becomes one of the world's greatest hydropower potential regions with 189 rivers totaling roughly 57,300 kilometres [9]. Micro hydro has a potential to produce a small scale of electricity from 5 kW to 500 kW and is possible to adopt in Malaysia. Furthermore, small hydro is also regarded as the cleanest energy source, as it emits considerably fewer greenhouse gases than large-scale hydro [11].

2.5 Waste to energy

Malaysia collected around 49,670 t/day of municipal solid waste [12]. In Malaysia, landfill is the preferred method of solid waste management, with 85% of materials being disposed of in landfills; this high proportion is due to the low budget of this method of solid waste management [13]. The municipal solid waste that is disposed of in the landfills is mostly not undergoing gas recovery and municipal solid waste is recycled at a rate of 5.5% and composted at a rate of 1.0% [14]. Waste-to-energy facilities pollute the air less than coal-fired power plants, but comparable with the natural gas-fired power plants.

2.6 Wind energy

In comparison to other countries such as China, the United Kingdom (UK) or Germany, Malaysia has a low wind speed zone [15]. China has the largest wind power capacity built, which is 114,609 MW, while the United Kingdom and Germany, 12,440 MW and 39,165 MW respectively [15]. The monthly mean wind speed ranges from 1.5 to 4.5 m/s [16]. Not all places in Malaysia have the same forces of wind because Mersing, Johor, and Kuala Terengganu have been recognised as high wind locations in Peninsular Malaysia, whereas Kudat and Sabah in East Malaysia have the highest wind potential [17]. According to International Renewable Energy Agency (IRENA), current worldwide wind energy generation is at 622,704 MW and Malaysia has the ability to generate between 500 and 2000 MW of power from wind energy [15]. Because wind energy is a sustainable source of energy, it has a minimal carbon footprint [18]. However, onshore and offshore wind plants have distinct carbon footprints; onshore producing 4.64 gCO2eq/kWh and offshore producing 5.25 gCO2eq/kWH h because for construction, offshore wind turbines require much more steel and cement than their onshore counterparts [19]. In addition, no offshore wind farm projects have yet been constructed on the water's surface in Malaysia [17].

2.7 Selection of criteria influencing the renewable energy resources priority

Five criteria are chosen for this research via FGD. Carbon production, operational cost, location features, energy and availability of renewable energy resources were chosen for this study to evaluate the influence of criteria in choosing the most potential renewable energy resources in Malaysia.

2.8 Carbon production

Carbon production such as carbon dioxide (CO_2) emissions is important to be reduced and controlled. It is because CO_2 emissions from the burning of fossil fuel can cause global warming, climate change and depletion of the ozone layer [20]. Hence, by using renewable energy, it can mitigate the environmental impacts of fossil fuel.

2.9 Location Features

Location for implementing renewable energy is being focused in this study because it can affect the effectiveness of the renewable energy project. Location of the sources and the location to run a project or build suitable infrastructure are being emphasized for efficiency [21].

2.10 Operational Cost

Every project to implement renewable energy needs a proper cost projection in order for the stakeholders to determine the strategy to reach the goals and objectives [22]. It is a significant point because cost management on a project aid in the establishment of a project's cost baseline. Therefore, better planning could be conducted. Moreover, when fossil fuel costs rise, a greater dependence on renewable energy can help safeguard consumers.

2.11 Energy capacity

When a generator is working at maximum power, its energy capacity is the quantity of electricity it can generate. This maximum amount of power, which is usually defined in megawatts (MW) or kilowatts, is used by utilities to estimate how much electricity a generator can handle. Impacts of this energy connection capacity is important to design a system that integrates renewable energy into the existing electricity grids [23].

2.12 Availability of renewable energy resources

Availability of renewable energy resources can be tracked by determining its production over the year, month and daily. The design of future renewable energy systems required reliable supply of various renewable energy resources [24]. Different renewable energy resources have a different level of production based on Malaysia's characteristics and where it comes from [9]. For example, solar and wind are coming naturally to the earth while municipal solid waste is coming from activities at homes, businesses, and hospitals.

2.13 Analytical Hierarchy Process (AHP)

2.13.1 Developing a model

The AHP analysis started with the creation of a decision hierarchy, also known as decision modelling [7]. AHP begins by breaking down the complicated Multi Criteria Decision Making (MCDM) problem into a hierarchy of interconnected decision factors, such as goals, criteria, and alternatives, which are organised in a hierarchical framework as illustrated in Fig. 1.

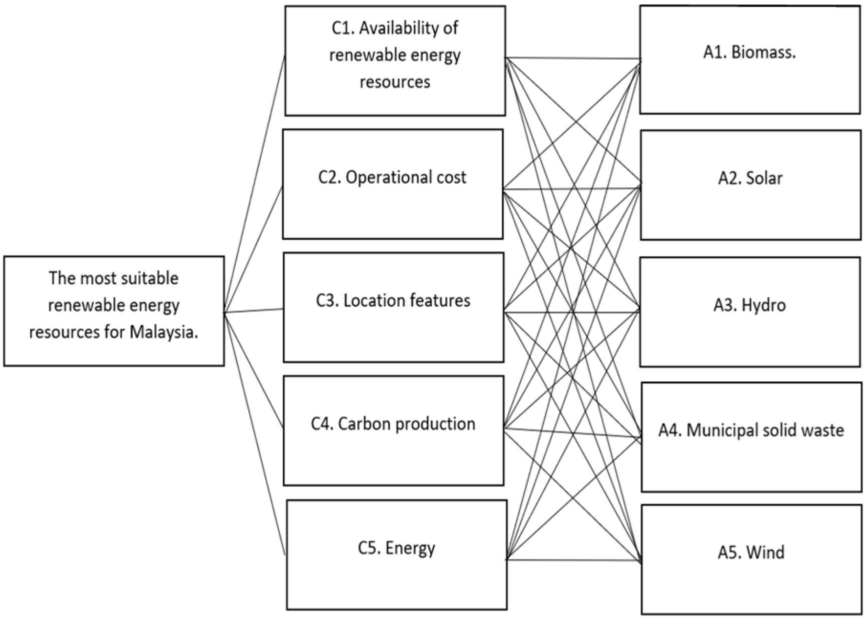

Fig. 1 AHP hierarchy.

2.13.2 Deriving priorities for selected criteria

After constructing the AHP hierarchy, the priorities for the chosen criteria were set up through pairwise comparison according to the results of FGD. In most cases, the decisions made in determining priority from FGD were subjective. The main reason of variable weightage as output from the FGD is that the members of FGD need to agree or disagree with each other. This shows how a group thinks about an issue, the range of opinions and ideas, and the differences, based on their years of experiences and practises. As a result, consistency analysis is required to decrease the model's biasness. It is critical to check if the original preference ratings are accurate. Eq. (1) and (2) shown in Table 1 are used to determine the consistency indices, while Table 2 depicted the random consistency index. In addition, the standard pairwise comparison scale (Table 3) used in this study has nine levels that are applied in AHP multiple pairwise comparisons. It is used to describe the degree to which one element is preferred over another [7]. Table 4 shows the pairwise matrix comparison of the criteria, depicting the values determined from FGD.

Table 1 Consistency indices parameters.

Parameter	Formula
Consistency Index, CI*	λ max - n / n-1 (**Eq. 1**)
Consistency Ratio (CR)	Constant Index/ Random Index (CI/RI) (**Eq. 2**)

**In complete consistency, the matrix A hold the rank 1 and maximum eigenvalue; λ max = n*

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Table 2 Random consistency index.

n	3	4	5	6	7
Random Index	0.58	0.90	1.12	1.24	1.32

Table 3 Pairwise comparison scale.

Importance Intensity	Definition	Explanation
1	Importance is equal	Two actions that contribute equally to the goal
3	Moderate importance	One activity has a modest advantage over another based on the experience and judgement
5	Strong importance	One activity is greatly favoured over another by experience and judgement
7	Demonstrated importance	An activity is significantly favoured over another, as seen by its dominance in practise
9	Very great importance	The proof that one activity is preferable to another is of the greatest level of confirmation
2, 4, 6, 8	In between values	When compromise is needed between two adjacent judgements

Table 4 Pairwise comparison matrix of criteria.

Research Criteria	Carbon production	Location features	Operational cost	Energy	Availability of renewable energy resources
Criteria Weightage	0.5026	0.2602	0.1343	0.0678	0.0348
Carbon production	1	3	5	7	9
Location features	1/3	1	3	5	7
Operational cost	1/5	1/3	1	3	5
Energy	1/7	1/5	1/3	1	3
Availability of renewable energy resources	1/9	1/7	1/5	1/3	1

The AHP analysis can only be continued if the computed consistency ratio (CR) is less than or equal to 0.10 [7]. Any greater number at any level suggests that the decisions should be reconsidered. In this study, as shown in Table 5, the consistency ratio (CR) calculated is 0.05327 which is less than 0.10. Thus, the decision-making by using AHP is continued because the judgement matrix is consistent and deemed significant.

Table 5 Results of AHP calculations for criteria.

<table>
<tr><th>Criteria</th><th>Criteria Weightage</th><th>ƛ max, CI and RI</th><th>Consistency Ratio (CR)</th></tr>
<tr><td>Carbon production</td><td>0.5026</td><td rowspan="5">ƛ max = Total all ratio of weightage sum value and criteria weights ÷ 5
(Answer: 5.2346)
CI = ƛ max - n/n-1
= (5.2346 - 5)/5-1
= 0.05865
RI = 1.12 (n=5)</td><td rowspan="5">CR = CI/RI

= 0.05865/1.12
= 0.05237

0.05237 is less than 0.10</td></tr>
<tr><td>Location features</td><td>0.2602</td></tr>
<tr><td>Operational cost</td><td>0.1343</td></tr>
<tr><td>Energy</td><td>0.0678</td></tr>
<tr><td>Availability of renewable energy resources</td><td>0.0348</td></tr>
</table>

2.13.3 Developing local priorities for the selected alternatives

Table 6 shows the criteria for evaluating the selected alternatives. The third step of AHP is to compare the alternatives using the specified criteria, then determine their relative priority depending on each criterion;

Availability of renewable energy resources (Table 7), operational cost (Table 8), location features (Table 9), carbon production (Table 10) and energy (Table 11), displaying the local priorities for the selected alternatives.

Table 6 Evaluation of the alternatives based on a set of criteria.

Criteria/ Alternatives	Biomass [6,7,20,24]	Solar [8,19]	Hydro [9,11]	Municipal solid waste (MSW) [12-14]	Wind [15-19]
Availability of renewable energy resources	Abundance About 80 to 90% total country biomass	Abundant amount of solar radiation Monthly solar irradiation is 400 to 600 MJ/m2	-Electricity production from hydro is 18,166 GWh by year 2030	85% of MSW are ending up at landfills 0.5 kg to 0.8 kg per person per day of waste can be generated	Monthly mean wind speed is between 1.5 and 4.5 m/s
Operational cost	Increase capacity of biomass = increase investment costs	-Higher cost - But will decrease the monthly bill through Feed-in Tariff (FiT)	-RM 3.5 million for mini hydro (net present value)	Cost more than RM100 for 1 tonne of MSW on operational cost of waste-to-energy plant	Capital-intensive investment Need suitable technology for low wind
Location features	-Not far from biomass resources; transportation cost	-Malaysia is situated at the equatorial region - has lowland areas and hot climate	-Generous rainfall all year round -Has enough water capacity for targeted energy generation -Good sedimentation	-Landfills; has leachate collection system and wide areas	-Wind energy potential is depending on the location -Malaysia is situated in a low wind speed
Carbon production	Most versatile forms of low carbon and renewable energy	Solar panel manufacturing; 50 gram of CO2 per kWh, 20 times less than carbon output of coal-powered electricity sources	Can reduce fossil fuels carbon emission	Burning MSW for waste-to-energy could result air pollution but less than coal plants	Can reduce carbon emissions
Energy power	Has a potential to generate 2400 MW from biomass	6500 MW potential of solar radiation	Mini hydro could generate 5kW to 500kW of energy	550 kWh of energy per ton of waste	500 to 2,000 MW of electricity could be generated

Table 7 Pairwise comparison matrix of alternatives for availability of renewable energy resources.

C1: Availability of renewable energy resources	Biomass	Solar	Hydro	Municipal solid waste	Wind	Priority vector
Biomass	1	9	5	7	1/6	0.352316337
Solar	1/9	1	7	4	9	0.278101296
Hydro	1/5	1/7	1	4	1/2	0.076966778
Municipal solid waste	1/7	1/4	1/4	1	5	0.08804731
Wind	6	1/9	2	1/5	1	0.204568279

Table 8 Pairwise comparison matrix of alternatives for operational cost.

C2: Operation cost	Biomass	Solar	Hydro	Municipal solid waste	Wind	Priority vector
Biomass	1	3	4	1/3	5	0.253840013
Solar	1/3	1	1/4	5	7	0.210772341
Hydro	1/4	4	1	1/5	4	0.175370828
Municipal solid waste	3	1/5	5	1	1/5	0.245134778
Wind	1/5	1/7	1/4	5	1	0.114882041

Table 9 Pairwise comparison matrix of alternatives for location features.

C3: Location feature	Biomass	Solar	Hydro	Municipal solid waste	Wind	Priority vector
Biomass	1	1/7	5	1/3	7	0.155707291
Solar	7	1	7	5	7	0.528382367
Hydro	1/5	1/7	1	1/5	3	0.06197084
Municipal solid waste	3	1/5	5	1	7	0.217960787
Wind	1/7	1/7	1/3	1/7	1	0.035978716

Table 10 Pairwise comparison matrix of alternatives for carbon production.

C4: Carbon production	Biomass	Solar	Hydro	Municipal solid waste	Wind	Priority vector
Biomass	1	1/5	1/5	4	5	0.168241903
Solar	5	1	3	5	5	0.390179806
Hydro	5	1/3	1	6	1/5	0.203822945
Municipal solid waste	1/4	1/5	1/6	1	1/5	0.041647768
Wind	1/5	1/5	5	5	1	0.196107578

Table 11 Pairwise comparison matrix of alternatives for energy.

C5: Energy	Biomass	Solar	Hydro	Municipal solid waste	Wind	Priority vector
Biomass	1	7	5	4	7	0.476526652
Solar	1/7	1	9	7	5	0.277055289
Hydro	1/5	1/9	1	1/3	1/4	0.042328417
Municipal solid waste	1/4	1/7	3	1	1/5	0.073971398
Wind	1/7	1/5	4	5	1	0.130118244

2.13.4 Identifying overall priorities

The overall priority for each alternative is computed after collecting the local priorities, which reflect the preferable choice with regards to each criterion. Overall priority matrix obtained from this process is shown in Table 12.

The most viable alternative with regards to the chosen criteria was calculated in this study using the Overall Priority Vector (OPV). The renewable energy resource with the greatest OPV is the most likely to be selected as a good fit for Malaysia as the most suitable renewable energy resources for a sustainable environment.

Table 12 Overall priority matrix.

	Carbon production	Location features	Operational cost	Energy	Availability of renewable energy resources	Overall priority
Criteria weights	0.5026	0.2602	0.1343	0.0678	0.0348	
Biomass	0.1682	0.1557	0.2538	0.4765	0.3523	0.2813
Solar	0.3901	0.5283	0.2107	0.2770	0.2781	0.3368
Hydro	0.2038	0.0619	0.1753	0.0423	0.0769	0.1120
Municipal solid waste	0.0416	0.2179	0.2451	0.0173	0.0880	0.1333
Wind	0.1961	0.0359	0.1148	0.100118244	0.2045	0.1363

3 Results and discussion

According to the results of the AHP computation on the relevance of criteria weightage presented beforehand, carbon production was the criterion with the greatest effect in selecting the appropriate renewable energy resource priority (Table 4). The results obtained as criteria weightage is shown below in Fig. 2**,** listed from the lowest to the highest; availability of renewable energy resources (0.0348), energy (0.0678), operational cost (0.1343), location features (0.2602) and carbon production (0.5026). On the other hand, Fig. 3 depicted the priorities weightage of renewable energy resources according to each selected criterion.

It should be noted that the overall priority vector (OPV) of each alternative indicates how important it is to be chosen as a suitable renewable energy resource. From the results shown in Fig. 4, the highest OPV is solar (0.3369), followed by biomass (0.2813), wind (0.1363), municipal solid waste (0.1334) and least preferably is hydro (0.1121). In conclusion, based on AHP, solar energy is the most suitable choice for a renewable energy resource for Malaysia.

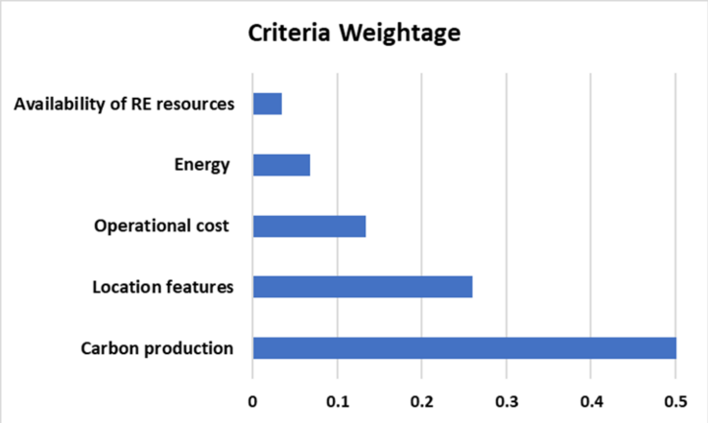

Fig. 2 Criteria weightage of selected criteria.

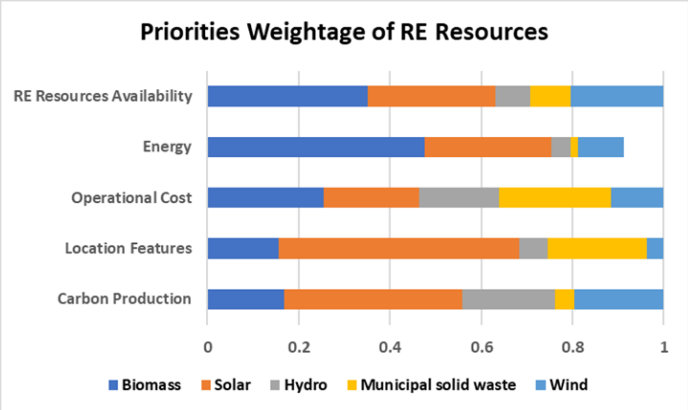

Fig. 3 Priorities weightage of renewable energy resources according to the selected criteria.

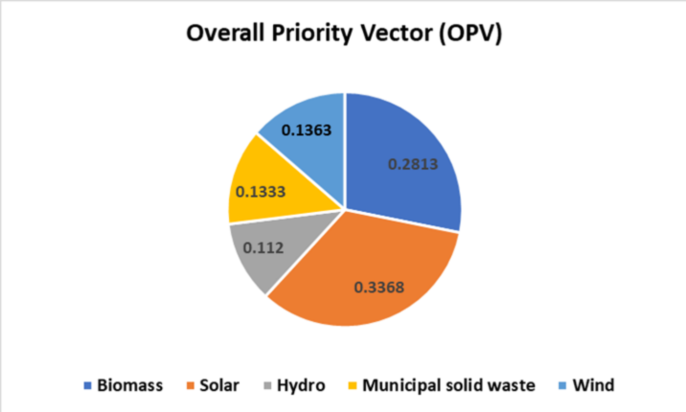

Fig. 4 Overall Priority Vector (OPV).

The Association of South-East Asia Nations (ASEAN), as the regional-cooperation organization which Malaysia is a member state, have a common collective target to increase the component of renewable energy in their primary energy supply to 23 % by 2025 [25]. However, this neutral alliance of countries could not intervene in each other's national renewable energy policy due to the neutrality principle but could always share inputs and technology to develop renewable energy resources. Table 13 summarizes the type of renewable energy in focus by Southeast Asian countries, its energy policy instruments and access of its population to electricity [26-28].

Table 13 Summary of renewable energy status in Southeast Asian countries.

Countries	Renewable energy resources in focus	Energy policy instruments	Population access to electricity
Malaysia	Solar, Biomass	Capital subsidies, Feed-in-tariff, Nett energy metering	Very high
Indonesia	Solar, Wind	Feed-in-tariff	Intermediate
Brunei	Solar, Waste to energy	Currently developing	Very high
Singapore	Solar, Waste to energy	Tax incentives, Feed-in-tariff, Permits	Very high
Myanmar	Hydro	Need to be formulated	Intermediate
Thailand	Biomass, Hydro	Tax incentives, Feed-in-tariff, Permits	High
Philippines	Hydro, Biomass, Wind, Geothermal, Tidal	Renewable portfolio standard, Capital subsidies, tax incentives, feed-in-tariff	High
Cambodia	Hydro	Tax incentives, Permits	Low
Vietnam	Hydro	Tax incentives, Feed-in-tariff, Permits	Intermediate
Laos	Hydro, Biomass	Tax incentives, Permits	Low

4 Concluding remarks

This study uses a priority estimation technique called Analytic Hierarchy Process (AHP) to evaluate the potential renewable energy production through a quantitative examination of diverse renewable energy resources. This methodology aids in making a clear decision based on a thorough evaluation of important criteria. Initially through the FGD, important criteria for evaluation are determined, which are the carbon production, operational cost, location features, energy and availability of renewable energy resources.

Based on the analysis, solar energy with 33.69% of overall priority vector is deemed the highest potential renewable energy resource to be used in Malaysia. However, Malaysia, similar with the other Southeast Asian countries, are still highly dependent on non-renewable fossil-fuel energy, especially in the total primary supply. To achieve the desired component of renewable energy in the primary energy supply to 23 % by 2025, Malaysia must work quickly to reduce its reliance on non-renewable energy sources and begin to invest and develop electricity generation capacity using renewable energy resources with the focus on solar, followed by biomass, wind, municipal solid waste and hydro energy.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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