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Article

A Multicriteria Decision-Making Model for the Selection of Suitable Renewable Energy Sources

Chia-Nan Wang [1], Jui-Chung Kao [2,*], Yen-Hui Wang [3,*], Van Thanh Nguyen [4,*], Viet Tinh Nguyen [4] and Syed Tam Husain [4]

[1] Department of Industrial Engineering and Management, National Kaohsiung University of Science and Technology, Kaohsiung 80778, Taiwan; cn.wang@nkust.edu.tw
[2] Institute of Marine Affairs and Business Management, National Kaohsiung University of Science and Technology, Kaohsiung 80778, Taiwan
[3] Department of Information Management, Chihlee University of Technology, New Taipei City 220305, Taiwan
[4] Faculty of Commerce, Van Lang University, Ho Chi Minh City 70000, Vietnam; tinh.nv@vlu.edu.vn (V.T.N.); tam.husain@vlu.edu.vn (S.T.H.)
* Correspondence: jckao@webmail.nkmu.edu.tw (J.-C.K.); ttxyhw@mail.chihlee.edu.tw (Y.-H.W.); thanh.nguyenvan@vlu.edu.vn (V.T.N.)

Abstract: With the expansion of its industrial and manufacturing sectors, with the goal of positioning Vietnam as the world's new production hub, Vietnam is forecast to face a surge in energy demand. Today, the main source of energy of Vietnam is fossil fuels, which are not environmentally friendly and are rapidly depleting. The speed of extraction and consumption of fossil fuels is too fast, causing them to become increasingly scarce and gradually depleted. Renewable energy options, such as solar, wind, hydro electrical, and biomass, can be considered as sustainable alternatives to fossil fuels. However, to ensure the effectiveness of renewable energy development initiatives, technological, economic, and environmental must be taken in consideration when choosing a suitable renewable energy resource. In this research, the authors present a multi-criteria decision-making model (MCDM) implementing the grey analytic hierarchy process (G-AHP) method and the weighted aggregates sum product assessment (WASPAS) method for the selection of optimal renewable energy sources for the energy sector of Vietnam. The results of the proposed model have determined that solar energy is the optimal source of renewable energy with a performance score of 0.8822, followed by wind (0.8766), biomass (0.8488), and solid waste energy (0.8135) based on the calculations of the aforementioned methods.

Keywords: renewable energy; wind energy; solid waste energy; solar energy; biomass energy; MCDM; G-AHP; WASPAS

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1. Introduction

Climate change and environmental pollution are increasing in Vietnam. Renewable energy projects are planned to rapidly replace fossil fuels. However, due to limitations in power transmission, some renewable energy projects are unable to develop, which leads to the increasing requirement of importing electricity, and existing thermal power plants continue to emit pollutants. This is the problem posed by the government in finding an effective solution to develop renewable energy sources in Vietnam.

An overview of alternatives energy sources in Vietnam—including wind, solar, solid waste, and biomass—is presented. These sources of renewable energies have mature production technologies. The government of Vietnam has introduced some pilot renewable energy initiatives which have shown promising results. However, renewable energy still only contributes a small part of the country's total energy production and only a handful of large-scale projects have been developed.

1.1. Solar Energy

Solar power in Vietnam is an emerging industry group, along with the development of renewable energy sources around the world. The desire is to replace the exploitation of fossil fuel energy sources such as coal and gas in the hope of limiting the harm to the environment and save investment costs. By taking advantage of Vietnam's geographic location near the equator, and with high hours of sunlight relative to the common baseline, solar energy is a high potential renewable energy that Vietnam can develop. Therefore, Decision 2068/QD-TTg dated to 25 November 2015 of TTCP approved a strategy for developing renewable energy of Vietnam to 2030 with a vision to 2050 [1].

Solar power is a source of electricity converted from the Sun's irradiation through solar panels based on the photoelectric effect of the semiconductors inside the solar panel. To exploit solar energy, we connect many devices to form a solar power system, converting from there the solar energy into an electricity supply for human activities and production [2].

Solar PV cells have the advantages of being environmentally friendly, and flexible in the design of energy collection zones and power capacity. As a model displayed in Figure 1, solar panels can be installed on roofs, farms or on water, which makes this type of renewable energy not require a solid foundation, be easy to maintain, and any failures can easily be detected and repaired [1].

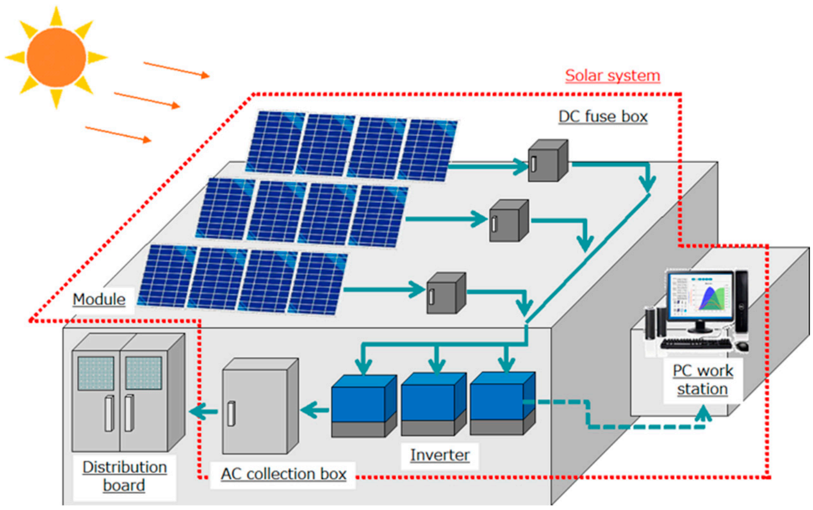

Figure 1. Solar power system [3].

Solar energy has great potential in Vietnam, especially in the southern part of the country. The annual number of sunny hours in the northwest region is about 1897–2102 h. The central regions enjoy 1400 to 1700 sunny hours per year, and the southern provinces receive 1900 to 2700 sunny hours a year [4]. According to the assessment, areas with a number of sunny hours of 1800 h/year or more can be considered for solar energy project development. As the data shows, most regions of Vietnam meet this requirement, especially the southern region of the country.

1.2. Wind Energy

Vietnam also has considerable potential for wind energy development, due to the country's tropical climate and long coastline. Vietnam has the highest potential for wind energy amongst all the countries of the Indochina Peninsula with 39% of the country's territory having high wind speed (higher than 6 m/s) and around 8% having high wind energy potential. It is estimated that Vietnam has an annual potential wind energy of 30 GW of onshore wind energy and another 100 GW of offshore wind energy.

1.3. Biomass Energy

Vietnam is also considered to have good potential to develop biomass energy, due to the country's high agricultural production. The country's potential biomass resources from agricultural, livestock and organic wastes can produce around 400 MW of energy annually [4]. Some types of biomass that can be immediately and technically converted to electricity production or applying energy cogeneration technology are rice husks, byproducts of sugar production process, domestic waste in big cities, livestock wastes, and other organic wastes and byproducts from the production of agricultural–forestry-fishery products.

1.4. Solid Waste Energy

Vietnam averages 35,000 tons of urban domestic waste and 34,000 tons of rural domestic waste a day. The amount of garbage in Hanoi capital and Ho Chi Minh City is 7000–8000 tons of waste per day [5]. Currently, over 70% of waste in Vietnam is being handled mainly by landfill technology, of which 80% are unhygienic landfills, harmful to the environment. Only 13% of the waste is burned for energy [5].

Landfilling is an outdated technology that consumes land and causes many environmental harms, creating a fire risk, groundwater pollution, gas emissions, causing diseases to workers and people living around them, attracts animals (dogs, birds, rodents, insects, . . .) [5]. The landfill, in addition to the negative impact on the environment, also faces opposition from people near the garbage disposal area, increasing costs for collection and transportation while waste resources are being wasted [5].

According to experts in the environment and electricity industries, respectively, waste incineration technology to generate electricity is increasingly and widely applied due to several noticeable advantages compared to other technologies, such as 90–95% reduction volume and volume of waste; can make use of heat; reduction of greenhouse gas emissions compared to landfilling; minimizing water pollution, bad smell... [5]

In this research the author proposed a multicriteria decision making model (MCDM) for ranking four potential renewable energies resources. Grey-AHP combines the classic analytic hierarchy process (AHP) and grey clustering is applied for determining the weight of all criteria. The weighted aggregates sum product assessment (WASPAS) method is then used for ranking all potential type of renewable energies. The study has proposed a useful and implementable model to support decision-making in renewable energy construction investment projects, the results and developed model of this study can be consulted reference for decision-making in other territories or countries.

2. Literature Review

Choosing an optimal renewable energy source is a multi-criteria decision-making problem where the decision makers must consider not only quantitative but also qualitative criteria. Therefore, a dedicated MCDM model can be developed to assist the decision makers to make the optimal choice.

In the past decades, multiple MCDM models have been developed to support different decision-making processes in various industry sectors [6–10]. These models vary from each other by using unique sets of criteria or different MCDM techniques. Popular decision-making problems that MCDM models are developed for include supplier selection problems [11,12], facility location selection problems [13,14], sustainable supply chain design problems [15,16], etc.

In the renewable energy sector, MCDM models are also frequently applied to solve multi-criteria decision-making problems [17–22]. Chien et al. [23] introduced a fuzzy MCDM model to evaluate and select an optimal hydroelectric plant location. The proposed model employed a fuzzy analytical network Process (FANP) model to calculate the weights of relevant criteria, then the technique for order of preference by similarity to ideal solution (TOPSIS) method is applied to calculate the performance score of the potential locations. The model was applied to a case study in Vietnam and the result showed that the optimal location for a hydroelectric plant is Nghe An Province. Trojanowska and Nęcka [24] performed a comparative research of four different MCDM methods—simple additive weighting (SAW), synthetic measure of development (SMD), weighted aggregated sum product assessment (WASPAS), and TOPSIS—in solving the sustainable energy development evaluation problem. As a result, the SMD method was the preferred method for the problem. The selected SMD method was then applied to analyze the sustainable energy development of different regions of Poland. The result showed that the northern region of Poland is the most developed in term of energy sustainability.

Ali and Jang [25] developed a MCDM-based geographic information system (GIS) model to evaluate potential wind farm sites in South Korea, considering technical and economic criteria. Furtado and Sola [26] introduced a fuzzy complex proportional assessment (COPRAS-F)-based GIS model to support the location selection problem of photovoltaic plants. The proposed model considered business sustainability criteria including economic, technical, environmental, and social criteria. Mostafaeipour et al. [27] developed an MCDM-based GIS model to evaluate potential geo-thermal project locations in Afghanistan. The proposed model is based on the stepwise weight assessment ratio analysis (SWARA) method and the additive ratio assessment (ARAS) method. The model result suggests that the optimal location for a geo-thermal project in Afghanistan is Ghazni province.

In the past few years, there have been some MCDM models developed to support decision makers with the renewable energy source selection. Butkiene et al. [28] performed a comprehensive analysis of MCDM methods developed to evaluate renewable energy sources for the household sector. Popular methods include TOPSIS, WASPAS, and PROMETHEE. Chamzini et al. [29] introduced a COP-RAS-AHP methodology to evaluate potential sources of renewable energy based on economic and technical criteria. Büyüközkan et al. [30] evaluated renewable energy alternatives using a novel fuzzy MCDM model based on the hesitant fuzzy linguistic AHP and COPRAS techniques. The model considered the United Nations' Sustainable Development Goals with economic, sociopolitical, technical, and environmental criteria. The result of the proposed model suggests that hydro power is the most suitable source of renewable energy.

While there have been MCDM models developed to support decision makers with the renewable energy source selection, few of them look at the problem under fuzzy decision-making environment and in developing countries. In this research, a dedicated MCDM model based on Grey AHP and WASPAS techniques is developed to support the renewable energy selection making process in developing country. Grey AHP is chosen to calculate the weighting of the criteria as it provides better accuracy in the estimation of the weighting values than the classic AHP model. WASPAS is utilized to calculate the ranking of the alternatives as due to its simplicity in calculation while providing reliable results, which helps improve the applicability of the proposed model. The two methodologies are also widely available in various decision-making software, which allows the proposed model to be easily applied into real-world problems. The proposed model is then applied into a case study of renewable energy selection problem of Vietnam.

3. Methodology

3.1. Research Methodology

The research uses the following methodology in order to verify the multicriteria decision model used to determine the most suitable location to setup a renewable energy power plant as shown in Figure 2.

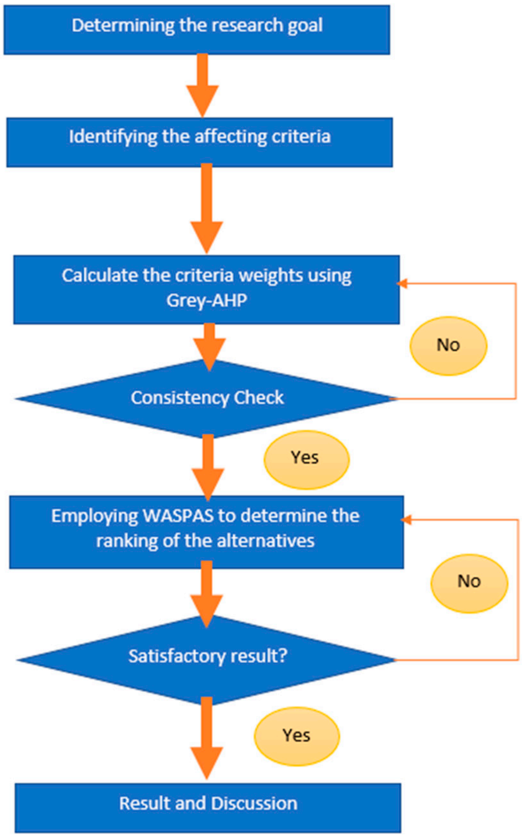

Figure 2. Research Process.

3.2. Grey Systems Theory

Grey theory was first introduced by Deng back in 1982 to handle problems with conditions that were uncertain and used discrete data and incomplete information [31]. Grey systems were utilized to handle unknown data within the data set should any information were missing. Not all experts hold strong opinions and expertise well in their field so their opinions can differ in strength at times. This leads to varying options which results in data inconsistency or make it impossible to determine the membership function. For such cases, the grey systems theory is used along with fuzzy mathematics in order to comprehend experts' opinion on the subject matter. Since grey system theory is able to utilize fuzzy mathematics in its system, it is advantageous compared to other methodologies that analyzes missing data and information. The theory uses a totally different system of analysis with a different set of numbers called grey numbers. From grey numbers, other mathematical forms can be used such as grey relations, and grey matrices. A set of numbers that are unknown exactly is known as an interval of grey numbers. If P is a reference set then Y grey sets of P reference sets with two $M_y(Z)$ symbols as upper and lower limits of a grey set, are defined by Equation (1):

$$\begin{cases} \underline{M_y}(P) : P \to [0,1] \\ \underline{M_y}(P) : P \to [0,1] \end{cases} \quad \overline{M_y}(P) \geq \underline{M_y}(P) \tag{1}$$

where y grey set is a fuzzy set that includes GST over fuzzy and its flexibility of dealing fuzzy issues if $\overline{M_y}(P) = \underline{M_y}(P)$.

3.2.1. Grey Assessment and Ranking

The following steps are used to determine the ranking in a grey environment with q independent alternative and r criteria [32–34]:

Step 1: Preference of alternative i over the criterion j through Equation (2).

$$\otimes x_{ij} = \frac{1}{k}\left[\otimes x_{ij} + \otimes x_{ij}^2 + \ldots + \otimes x_{ij}^k\right],\ i = 1,2,\ldots.q;\ j = 1,2,\ldots r \tag{2}$$

where $\otimes x_{ij}^k$ is the assessment data given by the kth expert for the ith alternative in terms of the jth criterion shown by $\otimes x_{ij} = [\underline{x_{ij}^k}, \overline{x}_{ij}^{-k}]$ as a grey number.

Step 2: A grey decision matrix is created, where $\otimes x_{ij}$ being linguistic variables, which are grey numbers:

$$D = \begin{bmatrix} \otimes x_{11} & \otimes x_{12} & \ldots & \otimes x_{1r} \\ \otimes x_{21} & \otimes x_{22} & \ldots & \otimes x_{r} \\ \vdots & \vdots & & \\ \otimes x_{q1} & \otimes x_{q2} & \ldots & \otimes x_{qr} \end{bmatrix} \tag{3}$$

Step 3: The decision matrix is then normalized.

$$D = \begin{bmatrix} \otimes x_{11}^* & \otimes x_{12}^* & \ldots & \otimes x_{1r}^* \\ \otimes x_{21}^* & \otimes x_{22}^* & \ldots & \otimes x_{2r}^* \\ \vdots & \vdots & & \\ \otimes x_{q1}^* & \otimes x_{q2}^* & \ldots & \otimes x_{qr}^* \end{bmatrix} \tag{4}$$

1-Is the criterion is beneficial

$$\otimes x_{ij}^* = \left[\frac{\underline{x}_{ij}}{x_j^{max}}, \frac{\overline{x}_{ij}}{x_{ij}^{max}}\right] \tag{5}$$

2-When the criterion is a cost

$$\otimes x_{ij}^* = \left[\frac{-\overline{x}_{ij}}{x_{ij}^{min}} + 2, \frac{-\underline{x}_{ij}}{x_{ij}^{min}} + 2\right] \tag{6}$$

Step 4: The ideal positive alternative or the relatively optimal solution is determined. Assume that there are j alternatives defined as u = $\{\otimes u_1, \otimes u_2, \ \ldots,\ \otimes u_r\}$. Then the best alternative would be u^{max} = $\left\{\otimes u_1^{max}, \otimes u_2^{max},\ \ldots,\ \otimes u_r^{max}\right\}$ that can be calculated using the following equation:

$$u^{max} = \left\{\left[max\, xi\_{}_{1\le i\le q}^{*}1, maxxi_{1\le i\le q}^{*}1\right],\ \left[max\, xi\_{}_{1\le i\le q}^{*}2, maxxi_{1\le i\le q}^{*}2\right], \ldots, \left[max\, xi\_{}_{1\le i\le q}^{*}r, maxxi_{1\le i\le q}^{*}r\right]\right. \tag{7}$$

Step 5: The following two equations are used to compare each alternative with u^{max} by using the grey possibility degree:

$$P\{\otimes x \le \otimes y\} = \frac{\max(0,1^*) - \max\left(0, \overline{x} - \underline{y}\right)}{L^*}$$
$$L^* = L(\otimes x) + L(\otimes y) \tag{8}$$

Considering the relationship of $\otimes x$ alternative, and $\otimes y$ alternative, a total of four possibilities can be derived:

(1) If $\overline{x} = \overline{y}$, $\underline{x} - \underline{y}$ then $\otimes x = \otimes y$. This leads to: P$\{\otimes x \le \otimes y\}$ = 0.5
(2) If $\underline{y} > \overline{x}$ then $\otimes x < \otimes y$. This leads to: P$\{\otimes x \le \otimes y\}$ = 1
(3) If $\overline{y} < \underline{x}$ then $\otimes x > \otimes y$. This leads to: P$\{\otimes x \le \otimes y\}$ = 1

Should there be interference and P$\{\otimes x \le \otimes y\}$ > 0.5 then $\otimes x < \otimes y$.
Should there be interference and P$\{\otimes x \le \otimes y\}$ < 0.5 then $\otimes x > \otimes y$.

Therefore it is possible to make the following comparison between the available options u = {u1, u2, . . . , um} and the ideal positive option u^{max}:

$$P\{ui \leq u^{max}\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\otimes x_{ij}^{*} \leq u_{j}^{max}\right\} \tag{9}$$

Step 6: Ranking of Alternatives. Should the value of $p(u_i)$ is less than $p(u^{max})$, the ranking of alternative i is favoured. Conversely, the closer $p(u_i)$ is to 1, the lesser the significance of the alternative is.

3.2.2. Calculation of the Relative Grey Score

In order to calculate the relative grey score for options in this study, grey numbers were used on a scale of 10 according to the following Table 1:

Table 1. Equivalent Grey Numbers.

Equivalent Grey Numbers	Abbreviation Symbol	Linguistic Variables	Level of Importance
[8, 10]	EMI	Extreme Importance	9
[6, 8]	VSI	Very Strong Importance	7
[4, 6]	SI	Strong Importance	5
[2, 4]	MI	Medium Importance	3
[1, 2]	EI	Equivalent Importance	1

Step 1: Each grey score can be calculated for alternative i and criterion j using the following equation:

$$\otimes G_{ij} = \frac{1}{k}[\otimes G_{ij}^{1} + \otimes G_{ij}^{2} + \ldots + \otimes G_{ij}^{k} \tag{10}$$

where $\otimes G_{ij}^{k}$ is the assessment value given by the kth decision-maker for the ith alternative in terms of jth criterion that could be shown by $\otimes G_{ij}^{k} = \left[\underline{G}_{ij}^{k}, \overline{G}_{ij}^{k}\right]$ as a grey number.

Step 2: A grey decision matrix is then created, where $\otimes G_{ij}^{k}$ are linguistic variables.

Step 3: The decision matrix is then normalized to be calculated based on the criteria assessed:

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} \ldots\ldots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} \ldots\ldots & \otimes G_{2n} \\ \vdots & \vdots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} \ldots\ldots & \otimes G_{mn} \end{bmatrix} \tag{11}$$

(A) Should the variables be positive (the more the better):

$$\otimes G_{ij}^{*} = \left[\frac{\underline{G}_{ij}}{G_{j}^{max}}, \frac{\overline{G}_{ij}}{G_{j}^{max}}\right];\ G_{j}^{max} = max_{1\leq i\leq m}\{\overline{G}_{ij}\} \tag{12}$$

(B) Should the variables be negative (the less the better):

$$\otimes G_{ij}^{*} = \left[\frac{G_{j}^{min}}{\underline{G}_{ij}}, \frac{G_{j}^{min}}{\overline{G}_{ij}}\right];\ G_{j}^{min} = min_{1\leq i\leq m}\left\{\underline{G}_{ij}\right\} \tag{13}$$

Step 4: The ideal alternative is then determined based on the type of problem required to be solved.

Step 5: The relative grey coefficient is then derived. Using the following equation, the relative grey coefficient between $£_{Oi(j)}$ and reference options considering the *i*th alternative, which is shown with $£_{Oi(j)}$, is calculated:

$$£_{Oi(j)} = \frac{min_i\left\{D_{Oi(j)}\right\} + pmax_i max_j\left\{D_{Oi(j)}\right\}}{D_{Oi(j)} + pmax_i max_j\left\{D_{Oi(j)}\right\}}; 1 \le i \le m, 1 \le j \le n \tag{14}$$

where $D_{Oi(j)}$ is the Minkowski distance between the reference alternative considering the *j*th criterion. The coefficient of the reference alternative is assessed with p in the equation is equal to 0.5.

Step 6: Calculation of the relative grey score. Using the following equation, the relative grey score between $£_{Oi(j)}$ and the reference alternative is determined:

$$\Upsilon_{Oi(j)} = \sum_{j=1}^{n} \frac{1}{n} £_{Oi(j)} \tag{15}$$

3.3. Grey-AHP

A G-AHP model is recommended that combined the ideas of grey system theory (GST) and analytical hierarchy process (AHP) together. The steps of utilizing G-AHP are as follows:

(1) Goal setting: The best type of energy resource is set as the primary goal.
(2) The assessment criteria are developed–the main and sub-criteria are selected based on a literature review and experts' opinion on the subject matter.
(3) Introducing alternatives: There are four type of renewable energy that are considered as alternatives.
(4) A decision hierarchy is constructed: After selecting the criteria and alternatives, a hierarchy is built with the objective placed on the top, the criteria on the second level and the alternatives on the third level. This is an overall framework no matter each problem as described in Figure 3.
(5) Paired comparison matrix is then created: A paired comparison matrix of each row in the hierarchy is then created with each element in the matrix being a grey number.

$$D = \begin{bmatrix} \otimes X_{11} & \cdots & \otimes X_{1n} \\ \vdots & & \vdots \\ \otimes X_{m1} & \cdots & \otimes X_{mn} \end{bmatrix} = \begin{bmatrix} \left[\underline{X_{11}}, \overline{X_{11}}\right] & \cdots & \left[\underline{X_{1n}}, \overline{X_{1n}}\right] \\ \vdots & & \vdots \\ \left[\underline{X_{m1}}, \overline{X_{m1}}\right] & \cdots & \left[\underline{X_{mn}}, \overline{X_{mn}}\right] \end{bmatrix} \tag{16}$$

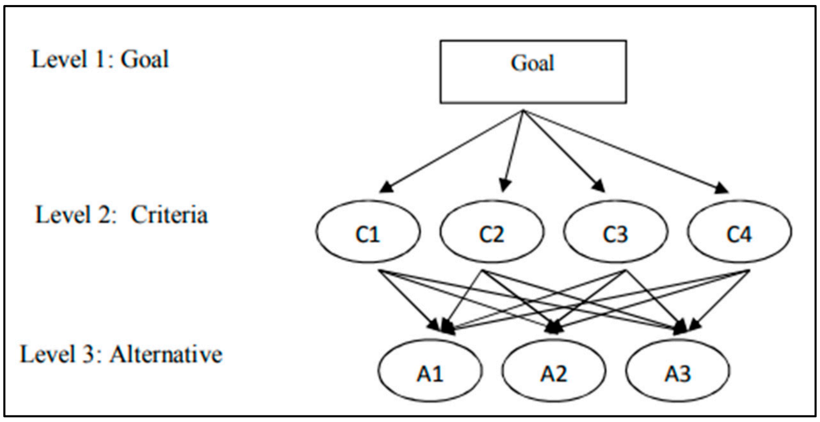

Figure 3. Hierarchy of decisions.

(1) The paired comparisons matrix is then normalized:

$$D = \begin{bmatrix} \otimes X_{11}^* & \cdots & \otimes X_{1n}^* \\ \vdots & & \vdots \\ \otimes X_{m1}^* & \cdots & \otimes X_{mn}^* \end{bmatrix} = \begin{bmatrix} \left[\underline{X_{11}^*}, \overline{X_{11}^*}\right] & \cdots & \left[\underline{X_{1n}^*}, \overline{X_{1n}^*}\right] \\ \vdots & & \vdots \\ \left[\underline{X_{m1}^*}, \overline{X_{m1}^*}\right] & \cdots & \left[\underline{X_{mn}^*}, \overline{X_{mn}^*}\right] \end{bmatrix} \tag{17}$$

$$\underline{X_{ij}^*} = \left[\frac{2\underline{X_{ij}}}{\sum_{i=1}^m \underline{X_{ij}} + \sum_{i=1}^m \overline{X_{ij}}}\right] \tag{18}$$

$$\overline{X_{ij}^*} = \left[\frac{2\overline{X_{ij}}}{\sum_{i=1}^m \underline{X_{ij}} + \sum_{i=1}^m \overline{X_{ij}}}\right] \tag{19}$$

(2) The relative weighting of each criterion and alternative is then determined. The relative weighting of factors in each level of the hierarchy are determined by using paired comparisons matrix that is normalized as a grey number.

$$w_i = \frac{1}{n}\sum_{i=1}^{m}[\underline{X_{ij}^*}, \overline{X_{ij}^*}] \tag{20}$$

(3) Calculating the Consistency Rate (CR):

The consistency ratio of the paired comparisons matrix is then evaluated. If the consistency rate is lower than 0.1, then matrix D (decision-maker judgment about the preference of factors under comparison) is accepted, otherwise the contents of matrix D are considered reliable for providing suitable results. The equations below are used to determine the CR:

$$\begin{array}{c} WSV = D \times W_i cv = \frac{WSV}{W_i} \\ \lambda_{max} = \frac{cv}{n} \\ CI = \frac{\lambda_{max} - n}{n} \\ CR = \frac{CI}{RI} \end{array} \tag{21}$$

RI is the mean consistency rate for the random variable. For each random variable, there is a mean consistency *RI* which is shown in Table 2.

Table 2. *RI* for each value of n criteria.

Scale	Very High	High	Moderately High	Average	Moderately Poor	Poor	Very Poor
Grey Number $\otimes G$	[0.9,1]	[0.7,0.9]	[0.6,0.7]	[0.4,0.6]	[0.3,0.4]	[0.1,0.3]	[0,0.1]

(4) The weights of each alternative are then determined. The vector of the weights for each alternative are multiplied correspondingly with the vector of weights for the criteria which are in the form of grey numbers.

(5) The alternative ranking: In order to rank each alternative, the final weight is used. The following equation determines the final ranking of each alternative based on the vector of positive ideal weight:

$$S^{max} = \left[\underline{w_{si}^{max}}, \overline{w_{si}^{max}}\right]$$

We then use the grey possibility degree. If the grey weight of the ith option is $\left[\underline{w_i}, \overline{w_i}\right]$ and $s_i = \left[\underline{w_{si}^{max}}, \overline{w_{si}^{max}}\right]$ is the positive ideal option, the grey possibility degree p($S^{max} < s_i$) for each option is calculated and the option having the lowest calculated value, will be selected as the best option.

The grey possibility degree is now ultilized. For each grey weight, $\left[\underline{w_i}, \overline{w_i}\right]$, for ith alternative and the positive ideal alternative being $s_i = \left[\underline{w_{si}^{max}}, \overline{w_{si}^{max}}\right]$, the degree $\mathrm{p}(S^{max} < s_i)$ of each alternative is determined. The alternative with the lowest degree is chosen as the best alternative.

3.4. The Weighted Aggregates Sum Product Assessment (WASPAS)

MCDM techniques like the weighted product model (WPM) and weighted sum model (WSM), are popular in deciding the best alternative when encountering a decision-making problem. The combination of the aforementioned methods, WASPAS, is amongst the newest techniques that can increase the accuracy in selecting the best alternative [35]. The WASPAS method is also proven from the study to have better accuracy than the WPM and WSM method.

The WASPAS method has been applied in multiple applications in recent years. Regarding energy alternative fields, Bagocius et al. [36] discussed the WASPAS method combined with entropy methods in order to determine an optimal location of a deep-water port as a requirement for Europe. A study regarding selecting a location for a shopping center location using a combined method of Fuzzy WASPAS and Fuzzy AHP was utilized due to the complexity of the problem by Turkis et al. [37]. Therefore, based on aforementioned studies, the WASPAS method and its accuracy is used for this study of risk qualitative analysis (RQA) which is explained as follows [35]:

(1) A decision matrix is constructed $X = \left[x_{ij}\right]_{q\times r}$, where where x_{ij} is the performance of the ith alternative with respect to the jth criterion, q is the number of alternatives and r is the number of criterion.

(2) The two equations below are used to normalize the decision matrix:

For maximizing criteria:

$$\overline{\mathrm{X}}_{ij} = \frac{x_{ij}}{max_i x_{ij}} \tag{22}$$

For minimizing criteria:

$$\overline{\mathrm{X}}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \tag{23}$$

(3) The following equation is used to calculate the importance of the ith alternative:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{\mathrm{X}}_{ij} W_j, \tag{24}$$

where is W_j weight (relative importance) of the jth criterion.

(4) The total importance of ith alternative is then calculated using the following equation:

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{\mathrm{X}}_{ij}\right)^{w_j}, \tag{25}$$

(5) The two methods of WSM and WPM are then combined together using joint additive based on the following equation:

$$Q_i = 0.5 Q_i^{(1)} + 0.5 Q_i^{(2)}. \tag{26}$$

(6) A more generalized equation of the WASPAS method in calculating the importance is defined by the equation below:

$$Q_i = \lambda \sum_{j=1}^{n} \overline{\mathrm{X}}_{ij} W_j + (1-\lambda) \prod_{j=1}^{n} \left(\overline{\mathrm{X}}_{ij}\right)^{w_j}, \ \lambda = 0, \ldots, 1 \tag{27}$$

4. Case Study

In order to promote the existing advantages of a coastal province, which is sunny, windy and strong in agriculture to diversify energy supplies, and develop renewable energy sources, are prioritized by Vietnam in considering sustainable development solutions.

Based on the overview provided of each type of energy in the Introduction, Vietnam's current energy situation requires the government to focus on a particular renewable energy type which is the target of this research with the proposed methodology. Due to the uncertainty nature of each renewable energy and no relationship of how energy is obtained from each source of renewable energy, the criteria is best sorted using the G-AHP method. The WASPAS method then is used to continue applying the results of the G-AHP method for the criteria and implement with the alternatives to determine the optimal alternative based on the weighted criteria calculated.

In this research, the authors applied MCDM model for ranking potential renewable energy resources of Vietnam. The criteria are chosen based on related literatures and expert reviews and opinions and are shown in Table 3.

Table 3. All criteria affecting to make decision process.

No	Criteria	Symbol	Beneficial/Cost
1	Capital Cost	CO	Cost
2	Operation and management Cost	OM	Cost
3	Electricity	EC	Cost
4	Technical Maturity	TM	Benefit
5	Efficiency	EF	Benefit
6	Reliability	RE	Benefit
7	Grid availability	GA	Benefit
8	Land Requirement	LR	Cost
9	Emission	EM	Cost
10	Stress on eco-system	SS	Cost
11	Social Benefits	SB	Benefit
12	Job creation	JC	Benefit
13	Social Acceptance	SA	Benefit
14	National Energy Security	NS	Benefit
15	Economic Benefits	NE	Benefit

The hierarchical structure creation of Grey-AHP for the decision problem is shown in Figure 4. In the first stage, grey AHP is applied for determining the weight of fifteen criteria base on the opinion of 10 experts including policy makers and project managers. The results of G-AHP are shown in Table 4 using the calculations of Equations (17)–(20) in the Methodology section. The methodology of G-AHP have been carefully calculated based on the nature of each criteria whether it is a beneficial criterion or a cost criterion.

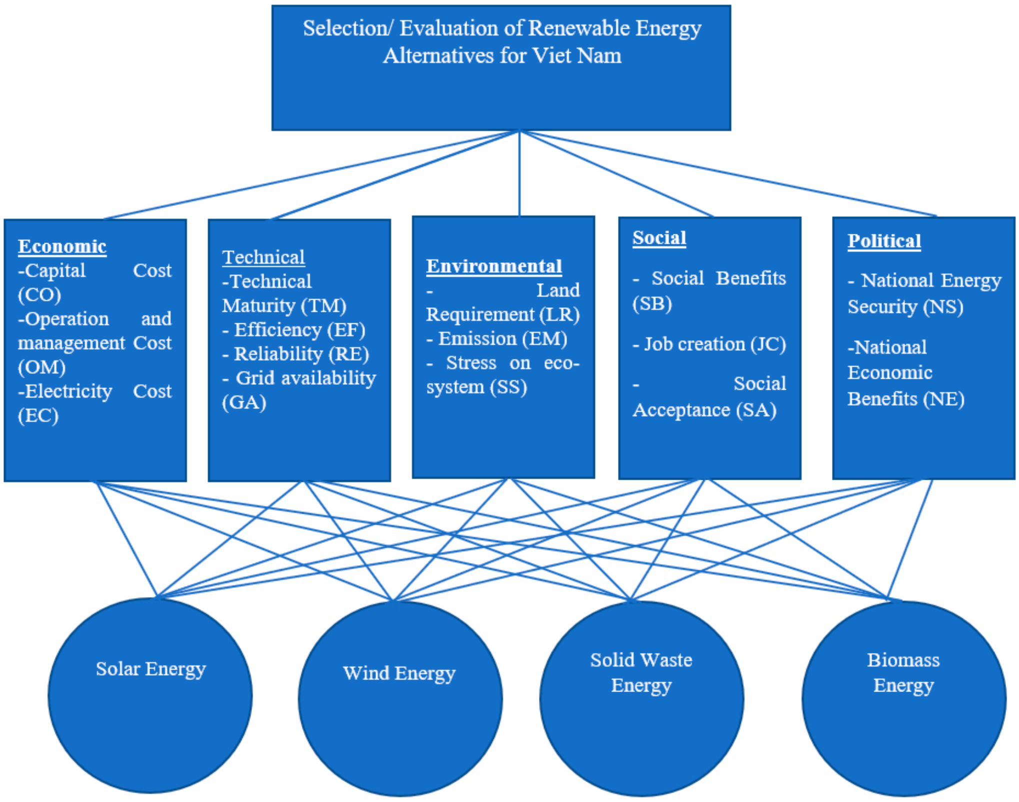

Figure 4. The hierarchical structure creation for the decision problem.

Table 4. Crisp weight from Grey-AHP.

No	Criteria	SUM		Grey Weights		Crisp Weights
1	Capital Cost	0.7536	1.4283	0.0502	0.0952	0.0727
2	Operation and management Cost	0.6241	1.1546	0.0416	0.0770	0.0593
3	Electricity	0.5115	0.9155	0.0341	0.0610	0.0476
4	Technical Maturity	0.6102	1.0642	0.0407	0.0709	0.0558
5	Efficiency	0.6110	1.1207	0.0407	0.0747	0.0577
6	Reliability	0.4094	0.7453	0.0273	0.0497	0.0385
7	Grid availability	0.5387	0.9849	0.0359	0.0657	0.0508
8	Land Requirement	0.6097	1.1347	0.0406	0.0756	0.0581
9	Emission	0.7121	1.3320	0.0475	0.0888	0.0681
10	Stress on eco-system	0.6855	1.2796	0.0457	0.0853	0.0655
11	Social Benefits	0.7904	1.4486	0.0527	0.0966	0.0746
12	Job creation	0.9264	1.6871	0.0618	0.1125	0.0871
13	Social Acceptance	1.1746	1.9860	0.0783	0.1324	0.1054
14	National Energy Security	0.8778	1.5470	0.0585	0.1031	0.0808
15	Economic Benefits	0.8205	1.5158	0.0547	0.1011	0.0779

For ranking four potential renewable energy: solar energy (A1), wind energy (A2), solid waste energy (A3) and biomass energy (A4), the authors applied the WASPAS model in the final stage using Equations (22)–(27) with the results found in Table 5.

Table 5. Normalized Matrix.

	A1	A2	A3	A4
CO	0.8889	1.0000	0.8889	0.7778
OM	0.7778	1.0000	0.8889	0.8889
EC	0.8889	0.7778	1.0000	0.8889
TM	0.7778	1.0000	1.0000	0.8889
EF	1.0000	0.7778	0.6667	1.0000
RE	1.0000	0.8750	0.8750	1.0000
GA	1.0000	0.6667	0.7778	0.7778
LR	0.7778	0.8889	0.8889	1.0000
EM	1.0000	0.7778	0.6667	0.8889
SS	1.0000	0.7500	0.8750	1.0000
SB	1.0000	0.6667	0.7778	0.6667
JC	0.6667	0.7778	0.8889	1.0000
SA	0.8889	0.7778	0.8889	1.0000
NS	0.8889	0.6667	1.0000	0.6667
NE	0.8750	1.0000	0.7500	0.8750

Based on the normalized matrix that has been converted from the WASPAS method, the matrix is then multiplied with the weight of each criteria determined in Table 4. The results are then shown in Table 6 showing the comparison of each criterion to the according alternative and the ranking score calculated.

Table 6. Weighted Normalized Matrix.

	A1	A2	A3	A4
CO	0.0646	0.0727	0.0646	0.0566
OM	0.0461	0.0593	0.0527	0.0527
EC	0.0423	0.0370	0.0476	0.0423
TM	0.0434	0.0558	0.0558	0.0496
EF	0.0577	0.0449	0.0385	0.0577
RE	0.0385	0.0337	0.0337	0.0385
GA	0.0508	0.0339	0.0395	0.0395
LR	0.0452	0.0517	0.0517	0.0581
EM	0.0681	0.0530	0.0454	0.0606
SS	0.0655	0.0491	0.0573	0.0655
SB	0.0746	0.0498	0.0580	0.0498
JC	0.0581	0.0678	0.0774	0.0871
SA	0.0936	0.0819	0.0936	0.1054
NS	0.0718	0.0539	0.0808	0.0539
NE	0.0681	0.0779	0.0584	0.0681

The matrix is then exponentially multiplied to normalize back to values of closest to 1 based on the results of Table 6. Table 7 displays the obtained results after exponential normalization.

The weights of the criteria are then used to run the WASPAS model. Q_{i1} and Q_{i2} are the performance scores of each alternative calculated using the weighted sum model and weighted product model, respectively. The final performance score of each alternative (Q_i) is then calculate from Q_{i1} and Q_{i2}. The results of the WASPAS model are shown in Table 8 and Figure 5 below:

Table 7. Exponentially weighted Matrix.

	A1	A2	A3	A4
CO	0.9915	1.0000	0.9915	0.9819
OM	0.9852	1.0000	0.9930	0.9930
EC	0.9944	0.9881	1.0000	0.9944
TM	0.9861	1.0000	1.0000	0.9934
EF	1.0000	0.9856	0.9769	1.0000
RE	1.0000	0.9949	0.9949	1.0000
GA	1.0000	0.9796	0.9873	0.9873
LR	0.9855	0.9932	0.9932	1.0000
EM	1.0000	0.9830	0.9728	0.9920
SS	1.0000	0.9813	0.9913	1.0000
SB	1.0000	0.9702	0.9814	0.9702
JC	0.9653	0.9783	0.9898	1.0000
SA	0.9877	0.9739	0.9877	1.0000
NS	0.9905	0.9678	1.0000	0.9678
NE	0.9897	1.0000	0.9778	0.9897

Table 8. Rank results of four potential renewable energy resource.

Alternatives	Q_{i1}	Q_{i2}	Q_i
A1	0.8887	0.8822	0.8854
A2	0.8223	0.8135	0.8179
A3	0.8552	0.8488	0.8520
A4	0.8854	0.8766	0.8810

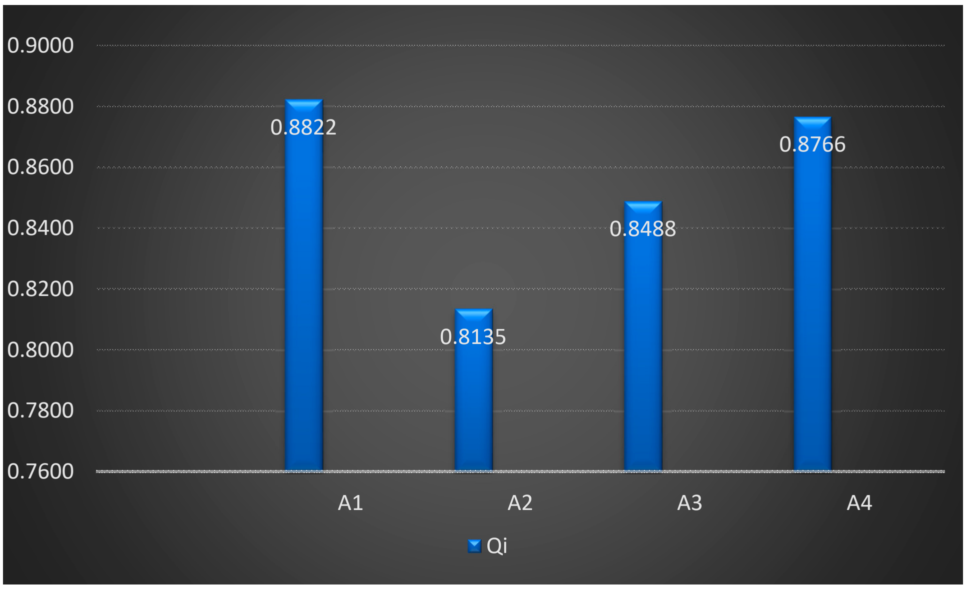

Figure 5. Final ranking.

From Table 8 and Figure 5, the results indicate that solar power generation is the optimum source for meeting the energy requirements followed by biomass, solid waste, and wind energy generating plants based accordingly on each beneficial and cost criterion.

5. Sensitivity Analysis and Discussion

5.1. Sensitivity Analysis

The stability and robustness of the proposed model is tested using the concept of sensitivity analysis. In this research, the removal of the political criterion, which includes national energy security and national economic benefits sub-criteria, is used to perform the sensitivity analysis. The result is shown in Figure 6 below:

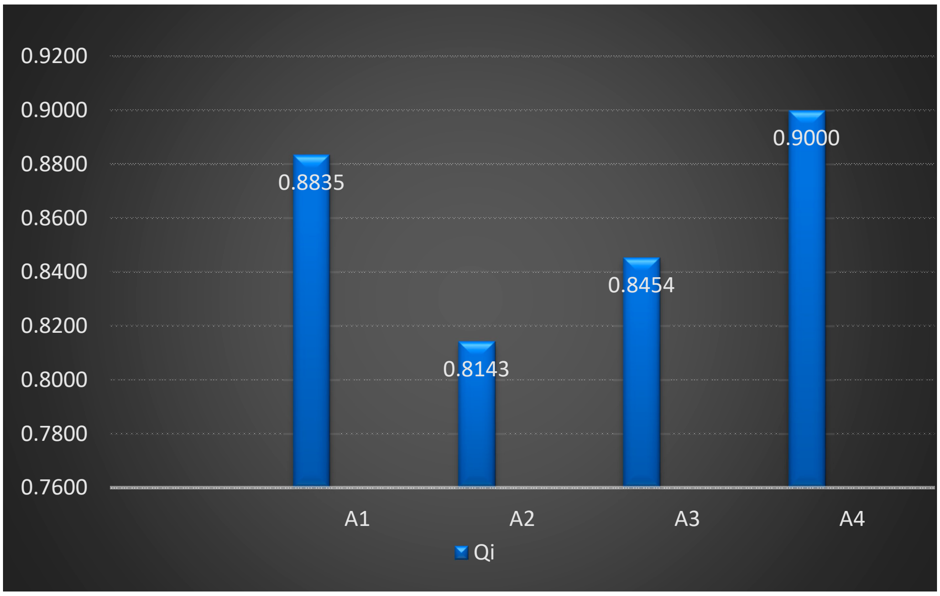

Figure 6. Final ranking without the political criterion.

From Figure 6, it can be seen that the ranking results stay unchanged with the removal of the political criterion. this suggests that the result of the model is robust, even if the political criterion and its sub-criteria are not considered.

5.2. Discussion

One of the solutions for sustainable energy development in Vietnam in the future is to step by step diversify energy supply, open up power sources based on renewable energy sources for which Vietnam has potential, especially wind, solar energy, biomass energy and solid waste energy. The paper focuses on presenting the potential of renewable energies, the evaluation criteria to choose the most suitable renewable energy through a multi-criteria decision-making model, from which to perform effective decision making in renewable energy development projects, helping develop renewable energy effectively. While there have been MCDM models developed to support decision makers in renewable energy source selection, few of them look at the problem in a fuzzy decision-making environment and in developing countries.

The proposed method utilized grey AHP and WASPAS as these techniques are easy to understand and widely available in different decision making support software packages which allows decision makers to better utilize the model. In the case study, the model suggested that solar power is the optimal source of renewable energy in the case of Vietnam, closely followed by biomass energy. A sensitivity test utilizing the removal of the political criterion is performed to test the reliability of the result. Figure 6 shows that the ranking of the alternatives was unchanged, thus confirming that the result of the proposed model is reliable, even if the political criterion is removed.

6. Conclusions

Over the past two years, Vietnam has made strong strides in renewable energy development. Vietnam has become one of the most vibrant and attractive renewable energy markets in Southeast Asia. However, this rapid development is also posing new challenges in the comprehensive development of the grid system, land use, electricity price, human resources/employment and other resources. Thus, in order to develop renewable energy sources towards sustainable development, the government needs to determine the appropriate type of renewable energy to be exploited in each specific period.

In this research the author proposed a multicriteria decision making model (MCDM) for ranking four potential renewable energies resources. Grey-AHP combines the classical analytic hierarchy process (AHP) and grey clustering is applied for determining the weight of all criteria, and the weighted aggregates sum product assessment (WASPAS) method is used for ranking all potential type of renewable energies. The study has proposed a useful and easy-to-implement model to support decision-making in renewable energy construction investment projects, the results and developed model of this study can be consulted reference for decision-making in other territories or countries.

This research can be beneficial to decision makers, researchers, and organizations to understand project-based evaluation to design and plan better sustainable energy projects. However, the proposed approach still has limitations which further studies can look into such as the need to perform comparative studies with different approaches to the problem or to expand the proposed methodology in order to be applied it to solving decision-making problems of specific renewable energy projects.

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