RANKING AND AGGREGATION-BASED MULTIPLE ATTRIBUTES DECISION MAKING METHOD FOR SUSTAINABLE ENERGY PLANNING

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To the Almighty Allah

To my beloved father and mother

To my loving family

Thank you

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ABSTRACT

In sustainable energy planning, the selection of a suitable Renewable Energy Sources (RES) for energy supply and evaluation of different RES technologies is a complex decision-making process. This is because there are many conflicting criteria that need to be considered. It becomes more complicated when qualitative data is involved in addition to quantitative data. Previous studies use Multiple Attribute Decision Making (MADM) methods for decision making, which work well with quantitative data but not with qualitative data. There are some MADM methods that can handle with both qualitative and quantitative data but suffer from complex computation burden. It becomes more difficult when more than one MADM method or more than one Decision Maker (DM) need to be considered. Different results will be obtained since different MADM methods or different DMs provide different results. This thesis proposes a new MADM method to overcome the limitations of previous methods. It consists of two parts which are ranking and aggregation techniques. The proposed ranking technique able to deal with quantitative and qualitative data through sorting process according to beneficial and non-beneficial criteria without normalizing the data. Then the proposed aggregation technique able to overcome the problem of different rankings due to different MADM methods or different DMs. The idea is to modify the preference ranking organization method for enrichment evaluations, where a preference index is assigned when comparing two alternatives at one time with respect to their ranking position instead of the criteria. Four case studies are examined to illustrate the effectiveness of the proposed ranking method while three case studies are evaluated to demonstrate the applications of the proposed aggregation method. For verification, Spearman's rank correlation coefficient is utilized to determine an agreement of the proposed method with the existing MADM methods. The results show the strength of the proposed method as it yields a correlation coefficient of more than 0.87 in all case studies. The results show an excellent correlation with those obtained by past researchers, which specifically prove the applicability of the proposed method for solving sustainable energy planning decision problem.

ABSTRAK

Dalam perancangan tenaga lestari, pemilihan sumber tenaga boleh diperbaharui (RES) yang sesuai untuk bekalan tenaga dan penilaian teknologi RES yang berbeza adalah proses penghasilan keputusan yang kompleks. Ini kerana terdapat banyak kriteria bercanggah yang perlu diambil kira. Ia menjadi lebih kompleks apabila data kualitatif terlibat sebagai tambahan kepada data kuantitatif. Kajian terdahulu menggunakan kaedah penghasilan keputusan pelbagai atribut (MADM) untuk penghasilan keputusan, di mana ia berfungsi dengan baik dengan data kuantitatif tetapi tidak dengan data kualitatif. Terdapat beberapa kaedah MADM yang boleh mengendali data kualitatif dan kuantitatif tetapi mengalami prosedur pengiraan yang kompleks. Ia menjadi lebih sukar apabila lebih daripada satu kaedah MADM atau lebih daripada satu pembuat keputusan (DM) yang perlu diambil kira. Keputusan yang berbeza akan diperoleh kerana kaedah MADM yang berlainan atau DM yang berbeza akan menghasilkan keputusan yang berbeza. Tesis ini mencadangkan kaedah MADM yang baharu untuk mengatasi pembatasan kaedah terdahulu. Ia terdiri daripada dua bahagian iaitu teknik pemeringkatan dan pengagregatan. Teknik pemeringkatan yang dicadangkan dapat mengendali data kuantitatif dan kualitatif melalui proses pengisihan menurut kriteria berfaedah dan tidak berfaedah tanpa menormalkan data. Kemudian teknik pengagregatan yang dicadangkan dapat mengatasi masalah pemeringkatan yang berbeza disebabkan oleh kaedah MADM yang berlainan atau DM yang berbeza. Ideanya adalah dengan mengubah kaedah pemeringkatan keutamaan organisasi untuk penilaian pengayaan, di mana indeks keutamaan diberikan apabila membandingkan dua alternatif pada satu masa mengikut kedudukan pemeringkatannya dan bukannya kriteria. Empat kajian kes diperiksa untuk menggambarkan keberkesanan kaedah pemeringkatan cadangan manakala tiga kajian kes dinilai untuk menunjukkan penggunaan kaedah pengagregatan cadangan. Untuk pengesahan, pekali korelasi kedudukan Spearman digunakan untuk menentukan keserasian kaedah cadangan dengan kaedah-kaedah MADM yang sedia ada. Keputusan menunjukkan kekuatan kaedah yang dicadangkan telah menghasilkan pekali korelasi lebih daripada 0.87 dalam semua kajian kes. Keputusan menunjukkan korelasi yang cemerlang dengan keputusan yang diperoleh oleh penyelidik-penyelidik terdahulu, di mana secara khususnya membuktikan kebolehgunaan kaedah yang dicadangkan untuk menyelesaikan masalah keputusan perancangan tenaga lestari.

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LIST OF ABBREVIATIONS

AHP	-	Analytic Hierarchy Process
ANP	-	Analytic Network Process
ARAS	-	Additive Ratio Assessment
BWM	-	Best Worst Method
CBA	-	Cost Benefit Analysis
CO_2	-	Carbon Dioxide
CI	-	Consistency Index
COPRAS	-	Complex Proportional Assessment
CR	-	Consistency Ratio
CSP	-	Concentrated Solar Power
DA	-	Decision Analyst
DEA	-	Data Envelopment Analysis
DM	-	Decision Maker
ELECTRE	-	Elimination and Choice Expressing Reality
FMADM	-	Fuzzy Multiple Attribute Decision Making
GP	-	Goal Programming
GRA	-	Grey Relational Analysis
GRC	-	Grey Relational Coefficient
GRG	-	Grey Relational Grade
HDM	-	Hierarchical Decision Model
LCCA	-	Life Cycle Cost Analysis

LP	-	Linear Programming
MACBETH	-	Measure Attractiveness by a Categorical Based Evaluation Technique
MADM	-	Multiple Attribute Decision Making
MATLAB	-	Matrix Laboratory
MCDM	-	Multiple Criteria Decision Making
MODM	-	Multiple Objective Decision Making
MOORA	-	Multi-Objective Optimization by Ratio Analysis
MW	-	Megawatts
NAIADE	-	Novel Assessment to Imprecise Assessment and Decision Environments
NGO	-	Non-Governmental Organizations
NIS	-	Negative Ideal Solution
NO_x	-	Nitrogen Oxide
PIS	-	Positive Ideal Solution
PROMETHEE	-	Preference Ranking Organization Method for Enrichment Evaluation
PV	-	Photovoltaic
RES	-	Renewable Energy Sources
RI	-	Random Index
RPI	-	Rank Performance Index
SAW	-	Simple Additive Weighting
SO_2	-	Sulphur Dioxide
SWRO	-	Sea Water Reverse Osmosis
VIKOR	-	VIseKriterijumska Optimizacija I Kompromisno Resenje
WASPAS	-	Weighted Aggregated Sum Product Assessment

LIST OF SYMBOLS

α	-	Coefficient necessary
a^*	-	Ideal solution
a'	-	Anti-ideal solution
a_i^*	-	Best value of ith criteria
a_i^-	-	Worst value of ith criteria
A	-	Matrix of pairwise comparison
$A1$	-	Alternative with first position in the ranking list
$A2$	-	Alternative with second position in the ranking list
C	-	Concordance index
C_i^{A-M}	-	Overall contribution of the ith alternative to the mission
C_{ik}^{A-G}	-	Relative contribution of the ith alternative to the kth goal
C_{kl}^{G-O}	-	Relative contribution of the kth goal to the Lth objective
C_l^{O-M}	-	Relative contribution of the Lth objective to the mission
D	-	Discordance index
h	-	Strength
I	-	Number of chosen alternative
m	-	Matrix size
n	-	Number of criteria
p_i	-	Aggregate probability index
p_{ij}	-	Performance indicator
p_j	-	Preference functions

Q - Set of criteria for which one alternative is good than other alternative

Q' - Set of criteria for which one alternative is good than other alternative

Q_i - Degree of utility

Q_j - Aggregating index

r_i - Relative closeness degree

R^* - Minimum individual regret

R_j - Individual regret

s_j^* - Positive distance between alternative and the ideal solution

s_j' - Negative distance between alternative and the anti-ideal solution

S^* - Maximum group utility

S_i - Overall performance rating

S_j - Group utility

S_o - Overall performance index of optimal alternative

v - Weight for the strategy of maximum group utility

v_j^* - jth criteria performance of the positive ideal solution

v_j' - jth criteria performance of the negative ideal solution

v_{ij} - Weighted normalized performance rating

w - Relative weight of matrix

w_j - Weight of jth criteria

W - Eigenvector

x_{aj} - Performance of alternative a in terms of criteria j

x_{bj} - Performance of alternative b in terms of criteria j

$\gamma_{0i}(j)$ - Grey relational coefficient of jth criteria

Γ_{0i} - Grey relational grade

Δmax - Secondary biggest error

Δmin - Secondary smallest error

ζ	-	Distinguished coefficient
$\emptyset$	-	Net flow
$\emptyset^{+}$	-	Positive flow
$\emptyset^{-}$	-	Negative flow
λ_{gb}	-	Solution appurtenance to the bad class
λ_{gg}	-	Solution appurtenance to the good class
λ_{max}	-	Maximum eigenvalue
λ_{t}	-	Total appurtenance of each alternative
Π	-	Preference index

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Rapid advancement in technology and economic development are linked closely to high energy consumption to create a better life environment. However, the energy consumed is being supplied by non-renewable energy resources such as coal and oil, which with time passing by, these resources are depleting fast. Furthermore, the production of electricity from these resources has been causing severe environmental problems such as climate change and global warming, which greatly jeopardize the environment.

In view of these problems, many related organizations have encouraged intensive research in Renewable Energy Sources (RES). RES are derived from natural sources such as geothermal, biomass, wind, solar and hydro. Compared to non-renewable energy sources, RES have the following major advantages: (1) they are continually replenished by nature and; (2) they provide energy with little environmental impact and negligible emissions. Therefore, RES appear to be the ideal and effective energy sources for the future global energy portfolio.

Promoting the deployment of RES is one of the sustainable energy development strategies [1]. Sustainable development is related to organizing principle for satisfying human needs to employ its social and economic activities without undermining the integrity and stability of the natural sources [2]. Hence, the concept of sustainable energy planning is the ability for the energy supply to satisfy the energy requirement without causing damage to the environment, while ensuring that energy demand is met in a sustainable manner. The challenging issue in energy planning is to make the best decision in choosing the suitable energy source among various energy alternatives and evaluating different RES technologies.

During the 1970s, decision making in energy planning was directed primarily towards using energy models to understand the energy-economy relationships established in the energy sector [3]. However, the traditional approach, in this case, Cost Benefit Analysis (CBA) is inadequate to deal with energy planning problem since CBA is only based on economic impacts [4]. This analysis would be very limiting because it would only give information based on the cost and would not include other valuable information. As environmental challenges become increasingly important, decision making in energy planning was restructured by considering environmental awareness in the 1980s [5]. Life Cycle Cost Analysis (LCCA) attempts to assess environmental impact by investigating and comparing the full environmental footprint which is the amount of harmful gases emitted by different energy sources, including RES [6-10]. However, LCCA typically only considers known and quantifiable environmental impacts while social impacts generally are not considered.

Owing to the fact that many criteria need to be considered to characterize and quantify energy alternatives, it is obvious that sustainability assessment of energy planning is a complex decision-making process [11]. The presence of numerous criteria such as technical, economic, environmental and social criteria adds to the difficulties in solving this problem. It needs to be recognized that energy alternatives can be superior from one to another in terms of certain aspects but weaker in terms of the other aspects; as each energy source differs economically, technologically, environmentally simultaneously, and in terms of social acceptance. For example, wind turbine may be highly efficient but it is very expensive to set up, while nuclear reactor may have a low operational cost but also have potentially high security and safety risks. It becomes more difficult to identify the energy source that excels in all criteria [4]. The need to incorporate multiple criteria requires a valuable approach to reduce the complexity of sustainable energy planning.

Over the years, Multiple Criteria Decision Making (MCDM) method has emerged as a formal methodology that can provide valuable assistance in formulating acceptable solutions in the process of decision making. MCDM has desirable feature to evaluate the alternatives from the best to the worst under multiple and conflicting criteria by taking into account the Decision Maker (DM) preferences [12]. Specifically, MCDM can be classified as Multiple Objective Decision Making (MODM) method and Multiple Attribute Decision Making (MADM) method [13]. MODM underperforms MADM which MODM method is applicable only for cases where exact or quantitative data is available. For that reason, MADM method is well suited to deal with the sustainable energy planning that usually involves quantitative and qualitative data.

At the present time, there are different MADM methods that have been applied by researchers to tackle sustainable energy planning [14]. Each method has its own specific mathematical formulation in analysing and solving the problem. The approaches to this method can be categorized into several categories, from simple approaches such as distance-based technique that require very little information to sophisticated approaches that require extensive information such as pairwise comparison, outranking and fuzzy techniques. Accordingly, there is one major issue regarding the utilization of existing MADM methods. It is well identified that the simple approaches efficiently work with only quantitative data. Whereas, the sophisticated approaches outperform the simple approaches since they can deal very well with both quantitative and qualitative data. Despite its potential, the sophisticated approaches have one major disadvantage that relates to high computational efforts due to there are numerous steps required to deal with qualitative data [13].

Furthermore, the utilization of more than one MADM method or consideration of more than one DM in sustainable energy planning may be viewed as a challenging issue. It is known when the problem considers only a single MADM method or a single DM, the decision-making process becomes straightforward. Meanwhile, the need to incorporate multiple MADM methods and multiple DMs are subjected to inconsistencies. This is because different MADM methods provide different solutions [15]. For the case of multiple DMs, different outcomes will be obtained since the preferred assessments by different DM may vary substantially while evaluating decision information. The question arises on how to determine a single final solution when seeking a mutual concession. The solution for this question is not easy since some conflicting issues or factors need to be compromised and this would be crucial in the decision making.

This thesis proposes a new MADM method based on ranking approach to overcome the limitation of existing MADM methods in dealing with qualitative data. The proposed ranking method offers several advantages:

i. Effectively deal with qualitative and quantitative data without the need to normalize or scale the data.
ii. Very straightforward to implement thus less time-consuming.
iii. Does not require pairwise comparison process as this process contributes to lengthy procedure especially when involving a large number of alternatives and criteria.
iv. Does not require any parameter or threshold to be set up since determining the appropriate parameters is quite problematic where different DMs may provide different values.

This thesis also proposes a new MADM method based on aggregation approach to produce a consensus solution from multiple DMs and multiple MADM methods. The proposed aggregation method has several advantages:

i. It solves the inconsistency among several decision outcomes.
ii. It reduces the conflict in deciding the optimum results.
iii. It guarantees the efficient implementation of the solutions selected.

1.2 Problem Statements

This research is staged based on three main issues. The first issue is the problem of the existing MADM methods, which are unable to solve sustainable energy planning in the presence of qualitative data. Therefore, such methods may be unsuitable for the type of decision problem involving qualitative data. Even though there are few MADM methods that can capture this issue, some methods have complex computational procedures which is time-consuming. Meanwhile, some methods require additional parameters to set up before utilizing it. Example of these methods are Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) and Elimination and Choice Expressing Reality (ELECTRE). For that reason, it is difficult to determine appropriate value of the parameter, thus becoming impractical.

The second issue is the lack of a consensus solution from the multiple DMs or multiple MADM methods under consideration in sustainable energy planning. The involvement of multiple DMs such as experts who have the relevant knowledge and experience in energy planning field is essential when the data for evaluation process may not be easily obtainable. Also, the utilization of multiple MADM methods in solving this planning is required as to produce a more trustworthy decision. However, involvement of multiple DMs contributes towards inconsistent outcomes. It can be explained when each DM have their own opinion when assessing their preferences. Besides, different MADM methods can yield different results due to the different mathematical formulation. The question is, how can a consensus outcome be found regarding collective solutions resulting from multiple DMs involvement or MADM methods?

The third issue is the problem of measuring the agreements of MADM methods in order to determine the similarity between two sets of rankings or two variables. Previously, there are two types of correlation coefficient which are commonly used for this purpose. The first is Pearson’s product moment correlation coefficient, which measures the strength of the relationship between two variables that are quantitative in nature. However, this correlation coefficient is not suitable for qualitative data, especially rank data. The second is the Spearman’s rank correlation coefficient, which measures the association between two variables that are qualitative in nature. If it is to be applied in quantitative data, the variables must first be ranked and the correlation coefficient is then calculated based on these rankings.

1.3 Research Objectives

Based on the described problem statements, the research objectives are as follows:

i. To develop a new MADM method based on ranking approach for solving sustainable energy planning that involves quantitative and qualitative data.
ii. To propose a new MADM method based on aggregation approach for solving sustainable energy planning to provide a consensus solution.
iii. To evaluate the effectiveness of the new ranking and aggregation approach by comparing it with other well-known MADM methods using Spearman's rank correlation coefficient.

1.4 Research Scopes

This research is based on a sustainable energy planning decision problem. Even though this problem may include the application of site selection to implant an energy generation, this thesis only focuses on selecting the best energy source or renewable energy technology for a given application. Regarding the selection process, there are many decision making methods applied in this problem such as CBA, LCCA and MODM method but this thesis only focuses on development of a new MADM method based on ranking and aggregation approach. When proposing the new MADM method, the following assumptions and limitations must be considered:

1. This thesis does not provide the weighting methodology for decision-making process. It is assumed that all criteria have been assigned reasonable weights before applying the proposed MADM method.
2. Even though the proposed ranking method can effectively handle qualitative data, there is a limitation in this method where it cannot deal with missing and interval data.
3. When applying the proposed aggregation method, there is a limitation of this method where tied rankings may occur due to the same net flows, even

though the performances of all alternatives with respect to each criterion are different.

4. Even though there is another technique to validate the effectiveness of the proposed method such as Pearson’s product moment correlation coefficient, only Spearman’s rank correlation coefficient is applied in this thesis.

1.5 Significance of Study

With the cost of fossil fuels rising every year, every country must reconsider the selection of energy sources. The main question is which energy sources each country should invest in for gaining the best utility? To answer this question, many researchers initiate works to introduce sustainable energy planning, which in return, benefit the electric utilities and society. Hence, electric utilities are urged to seek and identify a set of energy sources to meet the energy requirements or demands in an optimal manner for the benefit of people.

Sustainable energy planning can sometimes be a challenging task involving trade-offs among various energy sources, a range of indicators and preferences of the DM or stakeholders that need to be considered for this planning [16]. It is for this reason that MADM methods have been employed in different approaches to make assessment of the efficacy of each single action, the ranking of the options to maximize their impact and the decision concerning further steps to be promoted to strengthen the sustainable energy planning.

MADM method assists policymakers to guide discussions and decision making. Also, it can be used by various stakeholders, including energy regulator; central government; Non-Governmental Organizations (NGO); potential investor; environmental group; and the others; to help identify more sustainable energy sources. A large number of stakeholders with different views and preferences make the application of MADM method particularly suitable [17].

When using MADM method, all indicators are weighted according to the preferences to indicate its relative importance, thus the most suitable energy source is selected after reaching a consensus among all stakeholders [18]. Therefore, the best energy source can benefit all stakeholders. For example, potential investor may earn an economic advantage such as financial benefits while energy regulator may get an advantage from environmental aspects such as carbon emissions reduction. Also, the nation or the country able to enjoy the benefit of cheap sustainable energy in the long run.

To sum up, MADM method emerged as a formal methodology to face available technical information and enable stakeholder values to be especially valuable in sustainable energy planning. This method can also act to improve the accountability and transparency of the decisions reached as well as making the decision process fair and legitimises the results of decision [19]. In a way, properly designed decision making framework should not require a complicated computation procedure, which can be easily understood by policy makers and various stakeholders.

1.6 Thesis Organization

This thesis is divided into seven chapters.

In the following chapter, Chapter 2 presents the description of non-renewable energy sources and RES as well as evaluation criteria, structure of data and involvement of DM in sustainable energy planning.

Chapter 3 provides an extensive review regarding MADM method in sustainable energy planning.

Chapter 4 details out the research methodology for the proposed MADM method, which is ranking and aggregation to solve sustainable energy planning problem.

In Chapter 5, four case studies related to sustainable energy planning are presented for illustrating the applicability of proposed ranking method.

Three case studies related to sustainable energy planning are presented for testing the usefulness of proposed aggregation method in Chapter 6.

Chapter 7 presents the conclusion of this research and several recommendations are given for possible directions of future work.

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