

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

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DECISION MAKING METHOD FOR SUSTAINABLE ENERGY PLANNING

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A thesis submitted in fulfilment of the
requirements for the award of the degree
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2018

To the Almighty Allah
To my beloved father and mother
To my loving family
Thank you

ACKNOWLEDGEMENT

First, I would like to thank Almighty God, the most gracious and the most merciful. Praise be to God who created us and gave us intelligence and guidance. Peace be upon our prophet, teacher of all mankind.

I would like to thank and convey my sincere appreciation to my supervisor, Ir. Dr. Md Pauzi bin Abdullah for his encouragement, guidance and support.

I would also like to thank the Universiti Teknologi Malaysia (UTM) for providing me with all the requirements and needs of a research student. I would particularly like to thank Ministry of Higher Education (MOHE) for funding my Ph.D. studies.

I would like to give special thanks and appreciation to my parents and siblings, who deserve my gratitude for their inseparable prayer, encouragement and endless patience. Words fail me in expressing my deepest appreciation to them, whose dedication, love and support gave me confidence. My thesis would not have been possible without their support and encouragement. Thank you.

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 mengendalikan 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 mengendalikan 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 kebolegunaan 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 i th criteria
a_i^-	-	Worst value of i th 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 i th alternative to the mission
C_{ik}^{A-G}	-	Relative contribution of the i th alternative to the k th goal
C_{kl}^{G-O}	-	Relative contribution of the k th goal to the L th objective
C_l^{O-M}	-	Relative contribution of the L th 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^*	-	j th criteria performance of the positive ideal solution
v_j'	-	j th criteria performance of the negative ideal solution
v_{ij}	-	Weighted normalized performance rating
w	-	Relative weight of matrix
w_j	-	Weight of j th 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 j th criteria
Γ_{0i}	-	Grey relational grade
Δ_{max}	-	Secondary biggest error
Δ_{min}	-	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.

REFERENCES

1. Lund, H. Renewable energy strategies for sustainable development. *Energy*. 2007. 32(6): 912-919.
2. Wang, J. J., Jing, Y. Y., Zhang, C. F., and Zhao, J. H. Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renew. Sustain. Energy Rev.* 2009. 13(9): 2263-2278.
3. Huang, J. P., Poh, K. L., and Ang, B. W. Decision analysis in energy and environmental modeling. *Energy*. 1995. 20(9): 843-855.
4. Cavallaro, F. Multi-criteria decision aid to assess concentrated solar thermal technologies. *Renew. Energy*. 2009. 34(7): 1678-1685.
5. Nijkamp, P., and Volwahren, A. New directions in integrated regional energy planning. *Energy Policy*. 1990. 18(8): 764-773.
6. Gagnon, L., Belanger, C., and Uchiyama, Y. Life-cycle assessment of electricity generation options: the status of research in year 2001. *Energy Policy*. 2002. 30(14): 1267-1278.
7. Hondo, H. Life cycle GHG emission analysis of power generation systems: Japanese case. *Energy*. 2005. 30(11): 2042-2056.
8. Jungbluth, N., Bauer, C., Dones, R., and Frischknecht, R. Life cycle assessment for emerging technologies: case studies for photovoltaic and wind power. *Int. J. Life Cycle Assess.* 2005. 10(1): 24-34.
9. Pehnt, M. Dynamic life cycle assessment (LCA) of renewable energy technologies. *Renew. Energy*. 2006. 31(1): 55-71.
10. Uchiyama, Y. Life cycle assessment of renewable energy generation technologies. *IEEJ Transac. Electr. Electron. Eng.* 2007. 2(1): 44-48.
11. Linares, P., and Romero, C. A multiple criteria decision making approach for electricity planning in Spain: economic versus environmental objectives. *J. Oper. Res. Soc.* 2000. 51(6): 736-743.

12. Jankowski, P. Integrating geographical information systems and multiple criteria decision-making methods. *Int. J. Geog. Inf. Syst.* 1995. 9(3): 251-273.
13. Greening, L. A., and Bernow, S. Design of coordinated energy and environmental policies: use of multi-criteria decision-making. *Energy Policy.* 2004. 32(6): 721-735.
14. Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., and Bansal, R. C. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renew. Sustain. Energy Rev.* 2017. 69: 596-609.
15. Gershon, M., and Duckstein, L. Multiobjective approaches to river basin planning. *J. Water Resour. Plann. Manag.* 1983. 109(1): 13-28.
16. Demirtas, O. Evaluating the best renewable energy technology for sustainable energy planning. *Int. J. Energy Econ. Policy.* 2013. 3: 23-33.
17. Delponte, I., Pittaluga, I., and Schenone, C. Monitoring and evaluation of Sustainable Energy Action Plan: Practice and perspective. *Energy Policy.* 2017. 100: 9-17.
18. Kerkvliet, H., and Polatidis, H. Offshore wind farms' decommissioning: a semi quantitative Multi-Criteria Decision Aid framework. *Sustain. Energy Technol. Assess.* 2016. 18: 69-79.
19. Burton, J., and Hubacek, K. Is small beautiful? A multicriteria assessment of small-scale energy technology applications in local governments. *Energy Policy.* 2007. 35(12): 6402-6412.
20. Ulutaş, B. H. Determination of the appropriate energy policy for Turkey. *Energy.* 2005. 30(7): 1146-1161.
21. Banos, R., Manzano-Agugliaro, F., Montoya, F. G., Gil, C., Alcayde, A., and Gómez, J. Optimization methods applied to renewable and sustainable energy: A review. *Renew. Sustain. Energy Rev.* 2011. 15(4): 1753-1766.
22. Zeng, Z., Nasri, E., Chini, A., Ries, R., and Xu, J. A multiple objective decision making model for energy generation portfolio under fuzzy uncertainty: Case study of large scale investor-owned utilities in Florida. *Renew. Energy.* 2015. 75: 224-242.
23. Alamdari, P., Nematollahi, O., and Alemrajabi, A. A. Solar energy potentials in Iran: A review. *Renew. Sustain. Energy Rev.* 2013. 21: 778-788.

24. Twidell, J., and Weir, T. *Renewable energy resources*. 2nd edition. London: Taylor and Francis. 2006
25. Suganthi, L., Iniyar, S., and Samuel, A. A. Applications of fuzzy logic in renewable energy systems—a review. *Renew. Sustain. Energy Rev.* 2015. 48: 585-607.
26. Chatterjee, N., and Bose, G. A COPRAS-F base multi-criteria group decision making approach for site selection of wind farm. *Decis. Sci. Lett.* 2013. 2(1): 1-10.
27. Mudakkar, S. R., Zaman, K., Khan, M. M., and Ahmad, M. Energy for economic growth, industrialization, environment and natural resources: living with just enough. *Renew. Sustain. Energy Rev.* 2013. 25: 580-595.
28. Bahadori, A., Nwaoha, C., and Clark, M. W. *Dictionary of Oil, Gas, and Petrochemical Processing*. London: Taylor and Francis. 2013
29. Da Silva, R. C., de Marchi Neto, I., and Seifert, S. S. Electricity supply security and the future role of renewable energy sources in Brazil. *Renew. Sustain. Energy Rev.* 2016. 59: 328-341.
30. Ferrey, S. *Environmental law: Examples and explanations*. 3rd edition. New York: Aspen Publishers. 2004
31. Schobert, H. H. *Energy and Society: An Introduction*. 2nd edition. Boca Raton: CRC Press. 2014
32. Fingas, M. *The Basics of Oil Spill Cleanup*. 3rd edition. Boca Raton: CRC Press. 2012
33. Lee, C. C. *Environmental Engineering Dictionary*. 4th edition. Maryland: Government Institutes. 2005
34. Kok, B., and Benli, H. Energy diversity and nuclear energy for sustainable development in Turkey. *Renew. Energy*. 2017. 111: 870-877.
35. Udum, S. Turkey's nuclear comeback. *Nonprolif. Rev.* 2010. 17(2): 365-377.
36. Levy, B. S., Wegman, D. H., Baron, S. L., and Sokas, R. K. *Occupational and Environmental Health: Recognizing and Preventing Disease and Injury*. 5th edition. Philadelphia: Lippincott Williams and Wilkins. 2006
37. Strantzali, E., and Aravossis, K. Decision making in renewable energy investments: a review. *Renew. Sustain. Energy Rev.* 2016. 55: 885-898.

38. Johnson, S. D., and Moyer, E. J. Feasibility of US renewable portfolio standards under cost caps and case study for Illinois. *Energy Policy*. 2012. 49: 499-514.
39. Kim, J., and Park, K. Financial development and deployment of renewable energy technologies. *Energy Econ*. 2016. 59: 238-250.
40. Eltawil, M. A., Zhengming, Z., and Yuan, L. A review of renewable energy technologies integrated with desalination systems. *Renew. Sustain. Energy Rev*. 2009. 13(9): 2245-2262.
41. Genoud, S., and Lesourd, J. B. Characterization of sustainable development indicators for various power generation technologies. *Int. J. Green Energy*. 2009. 6(3): 257-267.
42. Winebrake, J. J. *Alternate Energy: Assessment and Implementation Reference Book*. Lilburn: Fairmont Press. 2003
43. Bergmann, A., Colombo, S., and Hanley, N. Rural versus urban preferences for renewable energy developments. *Ecol. Econ*. 2008. 65(3): 616-625.
44. Li, J. Scaling up concentrating solar thermal technology in China. *Renew. Sustain. Energy Rev*. 2009. 13(8): 2051-2060.
45. Zhang, L., Zhou, P., Newton, S., Fang, J. X., Zhou, D. Q., and Zhang, L. P. Evaluating clean energy alternatives for Jiangsu, China: An improved multi-criteria decision making method. *Energy*. 2015. 90: 953-964.
46. Nigim, K., Munier, N., and Green, J. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources. *Renew. Energy*. 2004. 29(11): 1775-1791.
47. El Bassam, N., Maegaard, P., and Schlichting, M. L. *Distributed Renewable Energies for Off-Grid Communities: Strategies and Technologies Toward Achieving Sustainability in Energy Generation and Supply*. Amsterdam: Elsevier. 2013
48. Hussain, A., Arif, S. M., and Aslam, M. Emerging renewable and sustainable energy technologies: State of the art. *Renew. Sustain. Energy Rev*. 2017. 71: 12-28.
49. Glassley, W. E. *Geothermal Energy: Renewable Energy and the Environment*. Boca Raton: CRC Press. 2010
50. DiPippo, R. *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impacts*. 2nd edition. Amsterdam: Elsevier. 2008

51. Mason, I. G., Page, S. C., and Williamson, A. G. A 100% renewable electricity generation system for New Zealand utilising hydro, wind, geothermal and biomass resources. *Energy Policy*. 2010. 38(8): 3973-3984.
52. Li, K., Bian, H., Liu, C., Zhang, D., and Yang, Y. Comparison of geothermal with solar and wind power generation systems. *Renew. Sustain. Energy Rev.* 2015. 42: 1464-1474.
53. Abbasi, S. A., and Abbasi, N. The likely adverse environmental impacts of renewable energy sources. *Appl. Energy*. 2000. 65(1): 121-144.
54. Inhaber, H. Water use in renewable and conventional electricity production. *Energy Sources*. 2004. 26(3): 309-322.
55. Evans, A., Strezov, V., and Evans, T. J. Assessment of sustainability indicators for renewable energy technologies. *Renew. Sustain. Energy Rev.* 2009. 13(5): 1082-1088.
56. Dresselhaus, M. S., and Thomas, I. L. Alternative energy technologies. *Nature*. 2001. 414(6861): 332-337.
57. Evans, A., Strezov, V., and Evans, T. J. Sustainability considerations for electricity generation from biomass. *Renew. Sustain. Energy Rev.* 2010. 14(5): 1419-1427.
58. Bain, R. L., Overend, R. P., and Craig, K. R. Biomass-fired power generation. *Fuel Process. Technol.* 1998. 54: 1-16.
59. Gan, J., and Smith, C. T. A comparative analysis of woody biomass and coal for electricity generation under various CO₂ emission reductions and taxes. *Biomass Bioenergy*. 2006. 30(4): 296-303.
60. Gustavsson, L., and Madlener, R. CO₂ mitigation costs of large-scale bioenergy technologies in competitive electricity markets. *Energy*. 2003. 28(14): 1405-1425.
61. Styles, D., and Jones, M. B. Energy crops in Ireland: quantifying the potential life-cycle greenhouse gas reductions of energy-crop electricity. *Biomass Bioenergy*. 2007. 31: 759-772.
62. Hester, R. E., and Harrison, R. M. *Carbon Capture: Sequestration and Storage*. Cambridge: The Royal Society of Chemistry. 2010
63. Raison, R. J. Opportunities and impediments to the expansion of forest bioenergy in Australia. *Biomass Bioenergy*. 2006. 30(12): 1021-1024.

64. Bellarmine, G. T., and Urquhart, J. Wind energy for the 1990s and beyond. *Energy Convers. Manag.* 1996. 37(12): 1741-1752.
65. Jacobson, M. Z., and Delucchi, M. A. Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy.* 2011. 39(3): 1154-1169.
66. Papadopoulos, A., and Karagiannidis, A. Application of the multi-criteria analysis method Electre III for the optimisation of decentralised energy systems. *Omega.* 2008. 36(5): 766-776.
67. Anker, H. T., Olsen, B. E., and Rønne, A. *Legal Systems and Wind Energy: A Comparative Perspective.* Copenhagen: Kluwer Law International. 2008
68. Hasan, N. S., Hassan, M. Y., Majid, M. S., and Rahman, H. A. Review of storage schemes for wind energy systems. *Renew. Sustain. Energy Rev.* 2013. 21: 237-247.
69. Jäger, F. *Solar Energy Applications in Houses: Performance and Economic in Europe.* New York: Pergamon Press. 1984
70. Wengenmayr, R., and Bürke, T. *Renewable Energy: Sustainable Energy Concepts for the Future.* Weinheim: John Wiley and Sons. 2008
71. Fraas, L. M., and Partain, L. D. *Solar Cells and Their Applications.* Hoboken: John Wiley and Sons. 2010
72. Grágeda, M., Escudero, M., Alavia, W., Ushak, S., and Fthenakis, V. Review and multi-criteria assessment of solar energy projects in Chile. *Renew. Sustain. Energy Rev.* 2016. 59: 583-596.
73. Ellabban, O., Abu-Rub, H., and Blaabjerg, F. Renewable energy resources: Current status, future prospects and their enabling technology. *Renew. Sustain. Energy Rev.* 2014. 39: 748-764.
74. Cavallaro, F. A comparative assessment of thin-film photovoltaic production processes using the ELECTRE III method. *Energy Policy.* 2010. 38(1): 463-474.
75. Silveira, J. L., Tuna, C. E., and de Queiroz Lamas, W. The need of subsidy for the implementation of photovoltaic solar energy as supporting of decentralized electrical power generation in Brazil. *Renew. Sustain. Energy Rev.* 2013. 20: 133-141.

76. Panwar, N. L., Kaushik, S. C., and Kothari, S. Role of renewable energy sources in environmental protection: a review. *Renew. Sustain. Energy Rev.* 2011. 15(3): 1513-1524.
77. Sarkar, D., Datta, R., Mukherjee, A., and Hannigan, R. *An Integrated Approach to Environmental Management*. New Jersey: John Wiley and Sons. 2015
78. Khan, B. H. *Non-conventional Energy Resources*. 2nd edition. New Delhi: Tata McGraw Hill Education. 2009
79. Fulekar, M. H. *Environmental Biotechnology*. Enfield: CRC Press. 2010
80. Egré, D., and Milewski, J. C. The diversity of hydropower projects. *Energy Policy*. 2002. 30(14): 1225-1230.
81. Hobbs, B. F., and Meier, P. *Energy decisions and the environment: a guide to the use of multicriteria methods*. Boston: Kluwer Academic Publishers. 2000
82. Hiremath, R. B., Shikha, S., and Ravindranath, N. H. Decentralized energy planning; modeling and application—a review. *Renew. Sustain. Energy Rev.* 2007. 11(5): 729-752.
83. Othman, M. R., Repke, J. U., Wozny, G., and Huang, Y. A modular approach to sustainability assessment and decision support in chemical process design. *Ind. Eng. Chem. Res.* 2010. 49(17): 7870-7881.
84. Bhattacharyya, S. C. Energy access programmes and sustainable development: A critical review and analysis. *Energy Sustain. Dev.* 2012. 16(3): 260-271.
85. Østergaard, P. A. Reviewing optimisation criteria for energy systems analyses of renewable energy integration. *Energy*. 2009. 34(9): 1236-1245.
86. Cohce, M. K., Dincer, I., and Rosen, M. A. Energy and exergy analyses of a biomass-based hydrogen production system. *Bioresour. Technol.* 2011. 102(18): 8466-8474.
87. Honig, P., and Lalonde, R. The economics of drug development: a grim reality and a role for clinical pharmacology. *Clin. Pharmacol. Ther.* 2010. 87(3): 247-251.
88. Zahnd, A., and Kimber, H. M. Benefits from a renewable energy village electrification system. *Renew. Energy*. 2009. 34(2): 362-368.
89. Kiehl, J. T., and Trenberth, K. E. Earth's annual global mean energy budget. *Bull. Am. Meteorol. Soc.* 1997. 78(2): 197-208.
90. Zongxin, W., and Zhihong, W. Mitigation assessment results and priorities for China's energy sector. *Appl. Energy*. 1997. 56: 237-251.

91. Holleman, A. F., and Wiberg, E. *Inorganic Chemistry*. San Diego: Academic Press. 2001
92. Wierzbicka, A., Lillieblad, L., Pagels, J., Strand, M., Gudmundsson, A., Gharibi, A., Swietlicki, E., Sanati, M., and Bohgard, M. Particle emissions from district heating units operating on three commonly used biofuels. *Atmosph. Environ.* 2005. 39(1): 139-150.
93. Katal, F., and Fazelpour, F. Multi-criteria evaluation and priority analysis of different types of existing power plants in Iran: An optimized energy planning system. *Renew. Energy*. 2018. 120: 163-177.
94. Cinelli, M., Coles, S. R., and Kirwan, K. Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecol. Indic.* 2014. 46: 138-148.
95. Goumas, M., and Lygerou, V. An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects. *Eur. J. Oper. Res.* 2000. 123(3): 606-613.
96. Ghafghazi, S., Sowlati, T., Sokhansanj, S., and Melin, S. A multicriteria approach to evaluate district heating system options. *Appl. Energy*. 2010. 87(4): 1134-1140.
97. Georgopoulou, E., Lalas, D., and Papagiannakis, L. A multicriteria decision aid approach for energy planning problems: the case of renewable energy option. *Eur. J. Oper. Res.* 1997. 103(1): 38-54.
98. Sarabando, P., and Dias, L. C. Simple procedures of choice in multicriteria problems without precise information about the alternatives' values. *Comput. Oper. Res.* 2010. 37(12): 2239-2247.
99. Dey, B., Bairagi, B., Sarkar, B., and Sanyal, S. K. Group heterogeneity in multi member decision making model with an application to warehouse location selection in a supply chain. *Comput. Ind. Eng.* 2017. 105: 101-122.
100. Reichert, P., Borsuk, M., Hostmann, M., Schweizer, S., Spörri, C., Tockner, K., and Truffer, B. Concepts of decision support for river rehabilitation. *Environ. Model. Softw.* 2007. 22(2): 188-201.
101. Mateo, J. R. S. C. *Multi Criteria Analysis in the Renewable Energy Industry*. London: Springer. 2012

102. Ren, H., Gao, W., Zhou, W., and Nakagami, K. I. Multi-criteria evaluation for the optimal adoption of distributed residential energy systems in Japan. *Energy Policy*. 2009. 37(12): 5484-5493.
103. Yazdani, M., and Graeml, F. R. VIKOR and its applications: A state-of-the-art survey. *Int. J. Strateg. Decis. Sci.* 2014. 5(2): 56-83.
104. Marsh, K., IJzerman, M., Thokala, P., Baltussen, R., Boysen, M., Kaló, Z., Lönnngren, T., Mussen, F., Peacock, S., Watkins, J., and Devlin, N. Multiple criteria decision analysis for health care decision making—emerging good practices: report 2 of the ISPOR MCDA Emerging Good Practices Task Force. *Value Health*. 2016. 19(2): 125-137.
105. Kok, M. The interface with decision makers and some experimental results in interactive multiple objective programming methods. *Eur. J. Oper. Res.* 1986. 26(1): 96-107.
106. Mendoza, G. A., and Martins, H. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *For. Ecol. Manag.* 2006. 230(1): 1-22.
107. Kubler, S., Robert, J., Derigent, W., Voisin, A., and Le Traon, Y. A state-of-the-art survey & testbed of fuzzy AHP (FAHP) applications. *Expert Syst. Appl.* 2016. 65: 398-422.
108. Ekel, P., Kokshenev, I., Parreiras, R., Pedrycz, W., and Pereira Jr, J. Multiobjective and multiattribute decision making in a fuzzy environment and their power engineering applications. *Inf. Sci.* 2016. 361: 100-119.
109. Insua, D. R., and French, S. A framework for sensitivity analysis in discrete multi-objective decision-making. *Eur. J. Oper. Res.* 1991. 54(2): 176-190.
110. Marler, R. T., and Arora, J. S. Survey of multi-objective optimization methods for engineering. *Struct. Multidiscip. Optim.* 2004. 26(6): 369-395.
111. Xydis, G., and Koroneos, C. A linear programming approach for the optimal planning of a future energy system. Potential contribution of energy recovery from municipal solid wastes. *Renew. Sustain. Energy Rev.* 2012. 16(1): 369-378.
112. Ren, H., Zhou, W., Nakagami, K. I., and Gao, W. Integrated design and evaluation of biomass energy system taking into consideration demand side characteristics. *Energy*. 2010. 35(5): 2210-2222.

113. Liu, C. H., Lin, S. J., and Lewis, C. Evaluation of thermal power plant operational performance in Taiwan by data envelopment analysis. *Energy Policy*. 2010. 38(2): 1049-1058.
114. Sarica, K., and Or, I. Efficiency assessment of Turkish power plants using data envelopment analysis. *Energy*. 2007. 32(8): 1484-1499.
115. Romero, C. A general structure of achievement function for a goal programming model. *Eur. J. Oper. Res.* 2004. 153(3): 675-686.
116. Mezher, T., Chedid, R., and Zahabi, W. Energy resource allocation using multi-objective goal programming: the case of Lebanon. *Appl. Energy*. 1998. 61(4): 175-192.
117. Silva Herran, D., and Nakata, T. Renewable technologies for rural electrification in Colombia: a multiple objective approach. *Int. J. Energy Sector Manag.* 2008. 2(1): 139-154.
118. Jayaraman, R., Colapinto, C., La Torre, D., and Malik, T. Multi-criteria model for sustainable development using goal programming applied to the United Arab Emirates. *Energy Policy*. 2015. 87: 447-454.
119. Pohekar, S. D., and Ramachandran, M. Application of multi-criteria decision making to sustainable energy planning—a review. *Renew. Sustain. Energy Rev.* 2004. 8(4): 365-381.
120. Choudhary, D., and Shankar, R. An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India. *Energy*. 2012. 42(1): 510-521.
121. Cho, K. T. Multicriteria decision methods: an attempt to evaluate and unify. *Math. Comput. Model.* 2003. 37(9-10): 1099-1119.
122. Mardani, A., Jusoh, A., Zavadskas, E. K., Cavallaro, F., and Khalifah, Z. Sustainable and renewable energy: An overview of the application of multiple criteria decision making techniques and approaches. *Sustainability*. 2015. 7(10): 13947-13984.
123. Hajkowicz, S., and Higgins, A. A comparison of multiple criteria analysis techniques for water resource management. *Eur. J. Oper. Res.* 2008. 184(1): 255-265.
124. Zanakis, S. H., Solomon, A., Wishart, N., and Dubliss, S. Multi-attribute decision making: A simulation comparison of select methods. *Eur. J. Oper. Res.* 1998. 107(3): 507-529.

125. Ribeiro, R. A. Fuzzy multiple attribute decision making: a review and new preference elicitation techniques. *Fuzzy Sets Syst.* 1996. 78(2): 155-181.
126. Løken, E. Use of multicriteria decision analysis methods for energy planning problems. *Renew. Sustain. Energy Rev.* 2007. 11(7): 1584-1595.
127. Diaby, V., Campbell, K., and Goeree, R. Multi-criteria decision analysis (MCDA) in health care: a bibliometric analysis. *Oper. Res. Health Care.* 2013. 2(1): 20-24.
128. Wang, P., Zhu, Z., and Wang, Y. A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. *Inf. Sci.* 2016. 345: 27-45.
129. Zamani-Sabzi, H., King, J. P., Gard, C. C., and Abudu, S. Statistical and analytical comparison of multi-criteria decision-making techniques under fuzzy environment. *Oper. Res. Perspect.* 2016. 3: 92-117.
130. Chatterjee, P., and Chakraborty, S. Investigating the effect of normalization norms in flexible manufacturing system selection using multi-criteria decision-making methods. *J. Eng. Sci. Technol. Rev.* 2014. 7(3): 141-150.
131. Kabir, G., Sadiq, R., and Tesfamariam, S. A review of multi-criteria decision-making methods for infrastructure management. *Struct. Infrastruct. Eng.* 2014. 10(9): 1176-1210.
132. Zavadskas, E. K., and Turskis, Z. A new logarithmic normalization method in games theory. *Informatica.* 2008. 19(2): 303-314.
133. Milani, A. S., Shanian, A., Madoliat, R., and Nemes, J. A. The effect of normalization norms in multiple attribute decision making models: a case study in gear material selection. *Struct. Multidiscip. Optim.* 2005. 29(4): 312-318.
134. Wang, Y. M., and Luo, Y. Integration of correlations with standard deviations for determining attribute weights in multiple attribute decision making. *Math. Comput. Model.* 2010. 51(1): 1-12.
135. Shih, H. S., Shyur, H. J., and Lee, E. S. An extension of TOPSIS for group decision making. *Math. Comput. Model.* 2007. 45(7): 801-813.
136. Kurka, T., and Blackwood, D. Selection of MCA methods to support decision making for renewable energy developments. *Renew. Sustain. Energy Rev.* 2013. 27: 225-233.

137. Mardani, A., Jusoh, A., and Zavadskas, E. K. Fuzzy multiple criteria decision-making techniques and applications—Two decades review from 1994 to 2014. *Expert Syst. Appl.* 2015. 42(8): 4126-4148.
138. Salminen, P., Hokkanen, J., and Lahdelma, R. Comparing multicriteria methods in the context of environmental problems. *Eur. J. Oper. Res.* 1998. 104(3): 485-496.
139. Mahmoud, M. R., and Garcia, L. A. Comparison of different multicriteria evaluation methods for the Red Bluff diversion dam. *Environ. Model. Softw.* 2000. 15(5): 471-478.
140. Beynon, M., Rasmeyuan, S., and Russ, S. A new paradigm for computer-based decision support. *Decis. Support Syst.* 2002. 33(2): 127-142.
141. Dyer, J. S., Fishburn, P. C., Steuer, R. E., Wallenius, J., and Zionts, S. Multiple criteria decision making, multiattribute utility theory: the next ten years. *Manag. Sci.* 1992. 38(5): 645-654.
142. Kasanen, E., Wallenius, H., Wallenius, J., and Zionts, S. A study of high-level managerial decision processes, with implications for MCDM research. *Eur. J. Oper. Res.* 2000. 120(3): 496-510.
143. Janssen, R. On the use of multi-criteria analysis in environmental impact assessment in The Netherlands. *J. Multi-Crit. Decis. Anal.* 2001. 10(2): 101-109.
144. Troldborg, M., Heslop, S., and Hough, R. L. Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. *Renew. Sustain. Energy Rev.* 2014. 39: 1173-1184.
145. Sipahi, S., and Timor, M. The analytic hierarchy process and analytic network process: an overview of applications. *Manag. Decis.* 2010. 48(5): 775-808.
146. Dey, P. K. Integrated project evaluation and selection using multiple-attribute decision-making technique. *Int. J. Prod. Econ.* 2006. 103(1): 90-103.
147. Malkawi, S., and Azizi, D. A multi-criteria optimization analysis for Jordan's energy mix. *Energy.* 2017. 127: 680-696.
148. Stojcetovic, B., Nikolic, D., Velinov, V., and Bogdanovic, D. Application of integrated strengths, weaknesses, opportunities, and threats and analytic hierarchy process methodology to renewable energy project selection in Serbia. *J. Renew. Sustain. Energy.* 2016. 8(3): 1-16.

149. Haddad, B., Liazid, A., and Ferreira, P. A multi-criteria approach to rank renewables for the Algerian electricity system. *Renew. Energy*. 2017. 107: 462-472.
150. Al Garni, H., Kassem, A., Awasthi, A., Komljenovic, D., and Al-Haddad, K. A multicriteria decision making approach for evaluating renewable power generation sources in Saudi Arabia. *Sustain. Energy Technol. Assess.* 2016. 16: 137-150.
151. Ahmad, S., Nadeem, A., Akhanova, G., Houghton, T., and Muhammad-Sukki, F. Multi-criteria evaluation of renewable and nuclear resources for electricity generation in Kazakhstan. *Energy*. 2017. 141: 1880-1891.
152. Ebrahimi, M., Aramesh, M., and Khanjari, Y. Innovative ANP model to prioritization of PV/T systems based on cost and efficiency approaches: With a case study for Asia. *Renew. Energy*. 2018. 117: 434-446.
153. Kuleli Pak, B., Albayrak, Y. E., and Erensal, Y. C. Evaluation of sources for the sustainability of energy supply in Turkey. *Environ. Prog. Sustain. Energy*. 2017. 36(2): 627-637.
154. Köne, A. Ç., and Büke, T. An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey. *Energy Policy*. 2007. 35(10): 5220-5228.
155. Abotah, R., and Daim, T. U. Towards building a multi perspective policy development framework for transition into renewable energy. *Sustain. Energy Technol. Assess.* 2017. 21: 67-88.
156. Wang, B., Kocaoglu, D. F., Daim, T. U., and Yang, J. A decision model for energy resource selection in China. *Energy Policy*. 2010. 38(11): 7130-7141.
157. Dhouib, D. An extension of MACBETH method for a fuzzy environment to analyze alternatives in reverse logistics for automobile tire wastes. *Omega*. 2014. 42(1): 25-32.
158. Ertay, T., Kahraman, C., and Kaya, I. Evaluation of renewable energy alternatives using MACBETH and fuzzy AHP multicriteria methods: the case of Turkey. *Technol. Econ. Dev. Econ.* 2013. 19(1): 38-62.
159. Strantzali, E., Aravossis, K., and Livanos, G. A. Evaluation of future sustainable electricity generation alternatives: The case of a Greek island. *Renew. Sustain. Energy Rev.* 2017. 76: 775-787.

160. Özkale, C., Celik, C., Turkmen, A. C., and Cakmaz, E. S. Decision analysis application intended for selection of a power plant running on renewable energy sources. *Renew. Sustain. Energy Rev.* 2017. 70: 1011-1021.
161. Topcu, Y. I., and Ulengin, F. Energy for the future: An integrated decision aid for the case of Turkey. *Energy.* 2004. 29(1): 137-154.
162. Zhang, W., Wang, C., Zhang, L., Xu, Y., Cui, Y., Lu, Z., and Streets, D. G. Evaluation of the performance of distributed and centralized biomass technologies in rural China. *Renew. Energy.* 2018. 125: 445-455.
163. Govindan, K., and Jepsen, M. B. ELECTRE: A comprehensive literature review on methodologies and applications. *Eur. J. Oper. Res.* 2016. 250(1): 1-29.
164. Beccali, M., Cellura, M., and Mistretta, M. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. *Renew. Energy.* 2003. 28(13): 2063-2087.
165. Cavallaro, F., and Ciraolo, L. A multicriteria approach to evaluate wind energy plants on an Italian island. *Energy Policy.* 2005. 33(2): 235-244.
166. Browne, D., O'Regan, B., and Moles, R. Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. *Energy.* 2010. 35(2): 518-528.
167. Dinca, C., Badea, A., Rousseaux, P., and Apostol, T. A multi-criteria approach to evaluate the natural gas energy systems. *Energy Policy.* 2007. 35(11): 5754-5765.
168. Mourmouris, J. C., and Potolias, C. A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. *Energy Policy.* 2013. 52: 522-530.
169. Gomes, C. F. S., Costa, H. G., and de Barros, A. P. Sensibility analysis of MCDA using prospective in Brazilian energy sector. *J. Model. Manag.* 2017. 12(3): 475-497.
170. Lai, Y. J., Liu, T. Y., and Hwang, C. L. TOPSIS for MODM. *Eur. J. Oper. Res.* 1994. 76(3): 486-500.
171. Behzadian, M., Otaghsara, S. K., Yazdani, M., and Ignatius, J. A state-of-the-art survey of TOPSIS applications. *Expert Syst. Appl.* 2012. 39(17): 13051-13069.

172. Boran, F. E., Etöz, M., and Dizdar, E. Is Nuclear Power an Optimal Option for Electricity Generation in Turkey?. *Energy Sources Part B: Econ. Plann. Policy*. 2013. 8(4): 382-390.
173. Kuleli Pak, B., Albayrak, Y. E., and Erensal, Y. C. Renewable energy perspective for Turkey using sustainability indicators. *Int. J. Comput. Intell. Syst.* 2015. 8(1): 187-197.
174. Brand, B., and Missaoui, R. Multi-criteria analysis of electricity generation mix scenarios in Tunisia. *Renew. Sustain. Energy Rev.* 2014. 39: 251-261.
175. Garg, R. K., Agrawal, V. P., and Gupta, V. K. Coding, evaluation and selection of thermal power plants—A MADM approach. *Int. J. Electr. Power Energy Syst.* 2007. 29(9): 657-668.
176. Vučijak, B., Kupusović, T., Midžić-Kurtagić, S., and Čerić, A. Applicability of multicriteria decision aid to sustainable hydropower. *Appl. Energy*. 2013. 101: 261-267.
177. Rojas-Zerpa, J. C., and Yusta, J. M. Application of multicriteria decision methods for electric supply planning in rural and remote areas. *Renew. Sustain. Energy Rev.* 2015. 52: 557-571.
178. Quijano H, R., Botero B, S., and Domínguez B, J. MODERGIS application: Integrated simulation platform to promote and develop renewable sustainable energy plans, Colombian case study. *Renew. Sustain. Energy Rev.* 2012. 16(7): 5176-5187.
179. Morán, J., Granada, E., Míguez, J. L., and Porteiro, J. Use of grey relational analysis to assess and optimize small biomass boilers. *Fuel Process. Technol.* 2006. 87(2): 123-127.
180. Sarucan, A., Baysal, M. E., Kahraman, C., and Engin, O. A hierarchy grey relational analysis for selecting the renewable electricity generation technologies. *Proceedings of the 2011 World Congress on Engineering*, July 6-8. London, UK: WCE. 2011. 1149-1154.
181. Liu, G., Baniyounes, A. M., Rasul, M. G., Amanullah, M. T. O., and Khan, M. M. K. General sustainability indicator of renewable energy system based on grey relational analysis. *Int. J. Energy Res.* 2013. 37(14): 1928-1936.
182. Xu, G., Yang, Y. P., Lu, S. Y., Li, L., and Song, X. Comprehensive evaluation of coal-fired power plants based on grey relational analysis and analytic hierarchy process. *Energy Policy*. 2011. 39(5): 2343-2351.

183. Akay, D., Boran, F. E., Yilmaz, M., and Atak, M. The evaluation of power plants investment alternatives with grey relational analysis approach for Turkey. *Energy Sources Part B: Econ. Plann. Policy*. 2013. 8(1): 35-43.
184. Šliogerienė, J., Turskis, Z., and Streimikiene, D. Analysis and choice of energy generation technologies: The multiple criteria assessment on the case study of Lithuania. *Energy Procedia*. 2013. 32: 11-20.
185. Štreimikienė, D., Šliogerienė, J., and Turskis, Z. Multi-criteria analysis of electricity generation technologies in Lithuania. *Renew. Energy*. 2016. 85: 148-156.
186. Baležentis, T., and Streimikiene, D. Multi-criteria ranking of energy generation scenarios with Monte Carlo simulation. *Appl. Energy*. 2017. 185: 862-871.
187. Bellman, R. E., and Zadeh, L. A. Decision-making in a fuzzy environment. *Manag. Sci.* 1970. 17(4): 141-164.
188. Zadeh, L. A. Fuzzy sets. *Inf. Control*. 1965. 8(3): 338-353.
189. Kabak, Ö., and Ervural, B. Multiple attribute group decision making: A generic conceptual framework and a classification scheme. *Knowl. -Based Syst.* 2017. 123: 13-30.
190. Luthra, S., Mangla, S. K., and Kharb, R. K. Sustainable assessment in energy planning and management in Indian perspective. *Renew. Sustain. Energy Rev.* 2015. 47: 58-73.
191. Soni, V., Singh, S. P., and Banwet, D. K. Precise decisions in Indian energy sector by imprecise evaluation. *Int. J. Energy Sect. Manag.* 2016. 10(1): 118-142.
192. Şengül, Ü., Eren, M., Shiraz, S. E., Gezder, V., and Şengül, A. B. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renew. Energy*. 2015. 75: 617-625.
193. Boran, F. E., Boran, K., and Menlik, T. The Evaluation of Renewable Energy Technologies for Electricity Generation in Turkey Using Intuitionistic Fuzzy TOPSIS. *Energy Sources Part B: Econ. Plann. Policy*. 2012. 7(1): 81-90.
194. Boran, F. E. A new approach for evaluation of renewable energy resources: A case of Turkey. *Energy Sources Part B: Econ. Plann. Policy*. 2018. 13(3): 196-204.

195. Abdullah, L., and Najib, L. Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: choosing energy technology in Malaysia. *Int. J. Sustain. Energy*. 2016. 35(4): 360-377.
196. Çolak, M., and Kaya, İ. Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey. *Renew. Sustain. Energy Rev*. 2017. 80: 840-853.
197. Khishtandar, S., Zandieh, M., and Dorri, B. A multi criteria decision making framework for sustainability assessment of bioenergy production technologies with hesitant fuzzy linguistic term sets: The case of Iran. *Renew. Sustain. Energy Rev*. 2017. 77: 1130-1145.
198. Erdogan, M and Kaya, I. An integrated multi-criteria decision-making methodology based on type-2 fuzzy sets for selection among energy alternatives in Turkey. *Iran. J. Fuzzy Syst*. 2015. 12(1): 1-25.
199. Balin, A., and Baraçlı, H. A fuzzy multi-criteria decision making methodology based upon the interval Type-2 fuzzy sets for evaluating renewable energy alternatives in Turkey. *Technol. Econ. Dev. Econ*. 2017. 23(5): 742-763.
200. Gershon, M. The role of weights and scales in the application of multiobjective decision making. *Eur. J. Oper. Res*. 1984. 15(2): 244-250.
201. Büyüközkan, G., and Karabulut, Y. Energy project performance evaluation with sustainability perspective. *Energy*. 2017. 119: 549-560.
202. Streimikiene, D., Balezentis, T., Krisciukaitienė, I., and Balezentis, A. Prioritizing sustainable electricity production technologies: MCDM approach. *Renew. Sustain. Energy Rev*. 2012. 16(5): 3302-3311.
203. Yazdani, M., Chatterjee, P., Zavadskas, E. K., and Streimikiene, D. A novel integrated decision-making approach for the evaluation and selection of renewable energy technologies. *Clean Technol. Environ. Policy*. 2018. 20(2): 403-420.
204. Shafiee, M. A fuzzy analytic network process model to mitigate the risks associated with offshore wind farms. *Expert Syst. Appl*. 2015. 42(4): 2143-2152.
205. Li, N., and Zhao, H. Performance evaluation of eco-industrial thermal power plants by using fuzzy GRA-VIKOR and combination weighting techniques. *J. Clean. Prod*. 2016. 135: 169-183.

206. Kahraman, C., Kaya, İ., and Cebi, S. A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process. *Energy*. 2009. 34(10): 1603-1616.
207. Goumas, M. G., Lygerou, V. A., and Papayannakis, L. E. Computational methods for planning and evaluating geothermal energy projects. *Energy Policy*. 1999. 27(3): 147-154.
208. Haralambopoulos, D. A., and Polatidis, H. Renewable energy projects: structuring a multi-criteria group decision-making framework. *Renew. Energy*. 2003. 28(6): 961-973.
209. Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., and Kiosses, I. Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy*. 2009. 37(5): 1587-1600.
210. Goletsis, Y., Psarras, J., and Samouilidis, J. E. Project ranking in the Armenian energy sector using a multicriteria method for groups. *Ann. Oper. Res.* 2003. 120(1): 135-157.
211. Yurdakul, M., and Ic, Y. T. Application of correlation test to criteria selection for multi criteria decision making (MCDM) models. *Int. J. Adv. Manuf. Technol.* 2009. 40(3-4): 403-412.
212. Grandhi, S., and Wibowo, S. The selection of renewable energy alternative using the fuzzy multiattribute decision making method. *12th International Conference on Fuzzy Systems and Knowledge Discovery*, August 15-17. Zhangjiajie, China: IEEE. 2015. 195-200.
213. Yazdani-Chamzini, A., Fouladgar, M. M., Zavadskas, E. K., and Moini, S. H. H. Selecting the optimal renewable energy using multi criteria decision making. *J. Bus. Econ. Manag.* 2013. 14(5): 957-978.
214. Georgiou, D., Mohammed, E. S., and Rozakis, S. Multi-criteria decision making on the energy supply configuration of autonomous desalination units. *Renew. Energy*. 2015. 75: 459-467.
215. Kaya, T., and Kahraman, C. Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Syst. Appl.* 2011. 38(6): 6577-6585.
216. Kaya, T., and Kahraman, C. Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. *Energy*. 2010. 35(6): 2517-2527.

217. Saeedpoor, M., and Vafadarnikjoo, A. Corrigendum to “Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul”[Energy 35 (6)(2010) 2517–2527]. *Energy*. 2015. 79: 536-537.
218. Sharma, D., Vaish, R., and Azad, S. Selection of India’s energy resources: A fuzzy decision making approach. *Energy Syst.* 2015. 6(3): 439-453.
219. Chang, C. W., Wu, C. R., Lin, C. T., and Lin, H. L. Evaluating digital video recorder systems using analytic hierarchy and analytic network processes. *Inf. Sci.* 2007. 177(16): 3383-3396.
220. Kain, J. H., and Söderberg, H. Management of complex knowledge in planning for sustainable development: the use of multi-criteria decision aids. *Environ. Impact Assess. Rev.* 2008. 28(1): 7-21.
221. Zavadskas, E. K., Turskis, Z., and Vilutiene, T. Multiple criteria analysis of foundation instalment alternatives by applying Additive Ratio Assessment (ARAS) method. *Arch. Civ. Mech. Eng.* 2010. 10(3): 123-141.