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Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan

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ABSTRACT

Multi-criteria decision making (MCDM) methods are becoming increasingly popular in solving energy selection problems because these problems involve multiple and often conflicting criteria. This paper presents comparative analysis of ranking renewable energy sources (RES) for electricity generation in Taiwan using four MCDM methods - WSM, VIKOR, TOPSIS, and ELECTRE. The Shannon entropy weight method is used to assess the importance of each criterion for the ranking of RES. After that, four MCDM methods are utilized for quantitative evaluation to rank all available RE alternatives. From the weights estimation results, efficiency is the first priority in all evaluation criteria, followed by job creation, operation, and maintenance cost. The purpose of this study is to rank the priorities of various RES and propose recommendations for Taiwan's RE development. The ranking results show that hydro is the best alternative in Taiwan, followed by solar, wind, biomass and geothermal. Furthermore, sensitivity analysis of the weights was conducted considering the ranking results heavily depend on the criteria weight. The results of sensitivity analysis indicated that when financial or technical aspects are focused upon, hydropower is the best RES because its technology is the most mature and the cost is the lowest in Taiwan. In addition, from an environmental perspective, wind energy is the best choice, and from the social perspective, solar PV is the best choice. The findings of this study can provide useful information to energy decision makers and serve as a reference for Taiwan's energy policy.

1. Introduction

Energy plays an important role in a country's economic development and it is a crucial factor in human life [1]. However, high consumption of fossil fuels leads to serious environmental problems, such as increasing greenhouse gas (GHG) emissions, which has led to global warming and climate change [2]. Most countries are actively developing renewable energy (RE) or sustainable energy to cope with environment crises [3–6]. From the negotiation of the Kyoto Protocol in 1997 to the Paris Climate Change Conference in the end of 2015, many countries are strongly aware of the enormous threat of climate change and are devoted to carbon reduction and green economy development. Therefore, the transition from fossil sources to clean energy is an important issue for many countries. Taiwan has almost no energy sources of its own, with nearly 98% of its energy consumption depending on imports, and almost all fossil fuels coming from turbulent areas such as the Middle East [7]. In order to overcome the challenges of energy security and reduction of GHG emissions, expanding the supply and utilization of RE and accelerating the development of the RE industry have become important energy policies for Taiwan [8]. Taiwan government has clearly defined RE development goals and promoted various regulations, incentives, and technology R&D to improve the development of RE.

According to the statistical report from REN21 (Renewable Energy Policy Network for the 21st Century) in 2015, the installed capacity of RE is 1849 GW and the total investment is nearly 300 billion US dollar globally. The proportion of RE supply has reached 23.7% [9] and the average annual growth rate is 5.9%. In addition, International Renewable Energy Agency (IRENA) estimated that global RE employment increased by 5% and reached 8.1 million in 2015 [10]. IRENA also forecasts that RE will account for almost 40% of global energy by 2030 due to reduction in technical costs.

RE is clean and inexhaustible energy that offers many benefits such as being free and plentiful compared to conventional fossil fuel energy. However, RE suffers from production and capacity limitations due to the variability of solar sunshine and wind power. In particular, the

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electric cost of RE is higher than that of fossil fuels today. Moreover, infrastructure management (IM) is an important issue of the RE development. In many cases, IM decisions involve uncertainty, multiple and conflicting criteria. This can make it more difficult to solve. Therefore, this paper builds an MCDM model to rank RES for Taiwan's RE development, by simultaneously taking into account the economic, technical, environmental, and social aspects. In addition, it can help decision maker to identify IM problems in Taiwan. In the recently published "2017 Taiwan white paper" [11], the government actively encourages more international companies to participate in some projects for helping Taiwan develop world-class infrastructure. Based on the above aspects, this study proposes some questions as below:

- Which criteria should be used to evaluate RES in Taiwan?
- Which RE should be prioritized in Taiwan according to appropriate selected criteria?
- How do ranking results change due to variations of criteria weight?

The purpose of this study is to answer these questions so as to help Taiwan's government come up appropriate solutions for developing RE.

In this study, five types of RE including wind, solar photovoltaic (PV), hydro, biomass, and geothermal energy in Taiwan are addressed as follows. The total installed capacity of RE has reached 4319 MW, consisting of 2089 MW (48%) for hydro, 842 MW (20%) for solar PV, 741 MW (17%) for biomass, and 647 MW (15%) for wind power [12]. The total power generation of RE was 10,471 GWh with 4470 GWh produced by hydro, accounting for 43% of total power generation, followed by biomass (34%), wind (15%), and solar PV (8%).

The statuses of these RES in Taiwan are described as follows.

1.1. Hydro

Hydro power is the largest single renewable electricity source, providing 16% of world electricity [10]. Approximately 28 GW of new hydro capacity were installed in 2015, increasing total global capacity to about 1064 GW [9]. Hydro power has been developed more than a century, and related technology and experience has become quite mature. It also represents the first development and utilization of RE in Taiwan. Electricity is generated by the flow of water without any fuel and no emissions, and the cost of the electricity produced is very competitive. The average annual rainfall of Taiwan is about 800 million tons with hydropower potential of about 25,700 MW. The theoretical hydro power mainly originates from 76 rivers [13]. Compared to the existing total installed capacity of 2089 MW and the power generation about 4470 GWh (excluding the pumped storage hydropower), the developed proportion of hydro power in Taiwan is still very low. Since the development of large hydropower stations is fully saturated, the future development of hydroelectric power will focus on small or medium size reservoirs.

1.2. Wind power

Wind power is the conversion of wind into a useful form of energy. Wind power, as an alternative to fossil fuels, is one of the cleanest sources of energy. Large-scale commercialization of global wind power technology has been realized for more than 20 years. Production technology is quite mature, and in recent years the market has shown stable growth. It is estimated that the installed capacity will reach 535 GW by 2018, and account for 5.2% of the global power supply.

Taiwan is located in the northeastern monsoon prevailing region; and the western part of the island has an abundant wind potential. Since the launch of the first commercial large-scale wind farm in 1989 until the end of 2016, 30 wind farms and 341 turbines were installed. The total installed capacity is about 677 MW, compared with the 2008 "Renewable Energy Development Ordinance" growth of 81% [14]. Due to the lower electric cost, wind power generation is considered to be the energy with a higher capacity for development. However, due to limited land area, the future should develop offshore wind farm to increase the amount of wind power generation. There are about 450 onshore and 800 offshore wind turbines projected to be installed by 2030, with the installed capacity of 1200 MW and 4000 MW, respectively.

1.3. Solar energy

Solar energy obtained from the sun's radiation is converted into other forms of energy, usually heat or electricity. This is the most abundant source of energy available for humans. Most of this energy resource comes directly or indirectly from the sun. For electricity generation from solar energy, solar PV, and solar thermal conversion processes are commonly used. In this paper, only solar PV is considered as a RES. Solar power is a clean and renewable energy source, it is abundant and environmentally friendly. In recent years, the global capacity of solar PV has grown dramatically. According to the estimation of International Energy Agency (IEA), it will account for 11% of the global electricity supply [15]. Nearly 50 GW of new solar PV power capacity were installed around the world in 2015 [9].

The cumulative installed capacity of Taiwan's solar PV was 668 MW in 2015, generating 810 GWh. Solar PV is a variable RE; its power generation cost is high and it has the limitations of power supply uncertainty and variability. However, it has advantages such as safety, sustainability, energy saving, and carbon reduction. There are two favorable conditions for developing solar PV in Taiwan. First, there is sunny weather in southern Taiwan, with more than two-third of its area having over 145 W/m2 of sunshine, especially in Tainan and Kaohsiung [7]. Second, Taiwan is the world's second largest solar PV producer, with a capacity for developing solar PV. In addition, Taiwan's government promoted the project "Million Rooftop PVs Program" and provided financial incentives to encourage the development of solar PV [16]. Therefore, there is great potential for the production of solar PV in Taiwan.

1.4. Biomass

Biomass energy is derived from any organic material, including biomass generation (bagasse, black liquor, and biogas) and waste to generation (municipal solid waste). It has the same inexhaustible characteristic as wind and solar energy, and because of the use of waste materials, both waste recycling and energy production can be achieved simultaneously. According to IEA statistics, biomass is the most widely used RE, and the world's fourth largest energy source after coal, petroleum, and natural gas [13]. It can supply about 10% of the world's primary energy demand, accounting for about 76% of all RE use in the world [10]. In the end of 2015, the installed capacity of biomass was 740 MW, including 629 MW of waste. At present, the main source of biomass power generation are 24 waste incineration plants all over Taiwan. The power generation is 3600 GWh, supplying 890,000 households a year. The future goal is to increase the installed capacity to 950 MW in 2030 [17].

1.5. Geothermal

Geothermal energy is the natural heat extracted from the earth's crust, which comes from the lava inside the earth in the form of heat. Geothermal is a special power generation resource compared to other RE technologies. The advantage is that it can be tapped 24 h a day without interruption. Unlike wind or solar energy, which are affected by the weather, it can be used as the base load of electricity. Therefore, it has attracted worldwide attention. 27 countries in the world have geothermal power plants with a total installed capacity of 12.64 GW in 2015 [17]. In addition, geothermal power plants require less space than other RE power plants. This is relatively suitable for Taiwan. Taiwan is located at the boundary between the Philippines plate and the Eurasian plate, with abundant geothermal reserves. It is estimated that the total potential area of the deep geothermal system of the island is about 4532 km^2 and the total storage potential is about 31.8 GW [17]. However, the actual development capacity can be limited due to the technical maturity and landscape. The installed capacity target is to reach 100 MW by 2020 and 150 MW by 2025.

2. Literature review

Multi-criteria decision making (MCDM) methods have been applied to several types of energy problems, including energy planning and selection, energy resource allocation, energy policy, and management of building energy [18]. These issues have been discussed from a single criterion decision problem, such as maximizing profit or minimizing cost, to complex multi-criteria decision problems [19]. According to Wang et al. [18], the most frequently used criteria are investment cost, CO_2 emissions, efficiency, operation and maintenance cost, land use, fuel cost, and job creation.

MCDM methods include WSM (weighted sum method), WPM (weighted product method), AHP (analytic hierarchy process), fuzzy AHP, TOPSIS (technique for order of preference by similarity to ideal solution), fuzzy TOPSIS, PROMETHEE (preference ranking organization method for enrichment evaluation), ELECTRE (elimination et choice translating reality), VIKOR (visekriterijumsko kompromisno rangiranje) and multi-objective programming. Each method has its advantages and disadvantages as well as application fields; none of the methods dominate the other methods. More than one method can be used to solve the same multi-criteria decision problem and provide more robust decision information [20].

AHP has been widely used to evaluate power plants and rank priority of development. For instance, Chatzimouratidis and Pilavachi [21] implemented AHP for the analysis of power plants' impact on the living standard, considering a number of criteria such as CO_2, land required, job creation, and social acceptance. Their results show that solar PV, oil, coal, hydro, and wind plants are the most stable under different criteria weights. Amer and Daim [22] applied AHP to evaluate four types of RE technology options. The criteria included technical, economic, social, environmental, and political aspects of a total of 20 criteria, of which the investment cost is the most important, followed by electric cost. The results indicate that biomass energy and wind energy emerge as the preferred alternatives. Ahmad and Tahar [23] utilized AHP for the selection of RES in Malaysia. Their study took technical, economic, social, and environmental aspects, with twelve sub-criteria (e.g., maturity, efficiency, public acceptance, job creation, CO_2 emission, land requirement) into consideration. Their results show that efficiency and CO_2 rank as the 2nd and 4th most important criteria, respectively. They suggested that solar PV is the best RES for Malaysia, followed by biomass, hydropower, and wind. Stein [19] established a comprehensive multi-criteria model based on real data to compare the ranking of various renewable and non-renewable electric energy production technologies according to 11 key criteria. Their study concluded that solar, wind, hydropower, and geothermal offer the most overall benefits.

Furthermore, other methods such as VIKOR, TOPSIS, ELECTRE, PROMETHEE and integrated methods are usually used to solve multi-objective RE problems. For instance, Sengül et al. [24] utilized the fuzzy TOPSIS method with a numerical example under a fuzzy environment, considering nine criteria (e.g. land use, operation and maintenance cost, installed capacity, efficiency, investment cost, job creation, and CO_2 emission) to rank RE supply systems in Turkey. Their analysis showed that hydro is the most renewable energy supply system. San Cristóbal [25] conducted VIKOR in the selection of a RE project in Spain. Their results show that a biomass plant is the best choice, followed by the wind and solar power. Klein and Whalley [26] proposed a multi-criteria method in order to compare the sustainability of U.S. electricity options, considering 8 criteria such as GHG emissions, land use, jobs, and capacity factor. Their results across several preference scenarios indicated that biomass and geothermal score highest for the US. Georgopoulou et al. [27] and Beccali et al. [28] employed ELECTRE for assessment and ranking of RE technologies. Troldborg et al. [29] assessed the sustainability of RE technologies using PROMETHEE. They considered nine criteria including technical, environmental and socio-economic criteria. Their results indicated that PV is the best option when all criteria are considered equally important.

In the past several years, the applications of integrated MCDM methods in energy, renewable and sustainable energy have increased dramatically. Kabak and Dağdeviren [30] integrated BOCR (benefits, opportunities, costs and risks) and ANP to prioritize RES for Turkey. Streimikiene et al. [31] employed AHP and ARAS (additive ratio assessment method) to rank electricity generation technologies considering economic, technological, environmental, social, and political aspects. Kahraman et al. [32] also conducted a comparative analysis for multiattribute selection among RE alternatives using fuzzy axiomatic design and fuzzy AHP. Streimikiene et al. [33] ranked sustainable electricity production technologies by utilization of TOPSIS and MULTIMOOR approaches. Nigim et al. [34] integrated AHP and SIMUS for prioritizing RES. The various MCDM methods and criteria related to sustainable or renewable energy are shown in Table 1.

In past studies, most RE research in Taiwan has mainly focused on energy policy [5,13,45,46] and location selection for wind farms and solar plant [47,48]. Few studies have used real data to analyze and rank RE. Table 2 presents various MCDM approaches that have been used in Taiwan's RE case study. As seen in Table 2, three papers are applied AHP, FAHP, and PROMETHEE approaches to rank RES in Taiwan. Therefore, this paper focuses on how to use MCDM methods to rank RE and obtain a better solution for Taiwan. The ranking result can provide the government with a reference for the development of RE.

The ranking results are not same due to consideration of different aspects and criteria by using various MCDM methods, even in the same country. For example, as shown in Table 3, hydro, solar PV, and wind energy are the three mostly preferred RES in Taiwan. Especially, the abundant hydropower resources, the more mature technology cause a competitive cost of generation electricity. Hydro is also a first priority RES in China, follow by wind energy. However, hydropower is the least preferred RES in Turkey. In addition, biomass is considered the most preferred RES in Spain, Pakistan, and Lithuania.

This paper has three contributions: the identification of criteria for selection of RES; review of the literature to guide the research on RES by using MCDM methodologies, especially, for Taiwan RE case study; and the recommendations for Taiwan's RE development policy. Additionally, sensitivity analysis is conducted to analyze the ranking results, considering technical, financial, environmental, and social aspects.

3. Evaluation criteria

According to the literature review above, the evaluation criteria for RE research can be divided into four main categories: financial, technical, environmental, and social dimensions. The financial dimension refers to cost-related criteria (e.g., investment cost, fix and variable O&M cost, and electric cost). The technical dimension refers to power generation (e.g., energy efficiency, technical mature, and installed capacity). The environmental dimension refers to negative impact for the environment (e.g., CO_2 emissions, and destruction of the ecological environment). The social dimension specifies the maximization of the social-welfare of people (e.g., job creation, and social benefit). The selected criteria for the study are presented in Table 4.

The data sources of this study are summarized in Table 5. As seen in the Table 5, two criteria (technical maturity and social acceptance) are evaluated using a qualitative scale ranging from 1 to 5, where 1 is the lowest score and 5 is the highest score. Social acceptance was identified by a questionnaire survey. In order to obtain the value of each

Table 1
Review of studies using MCDM to evaluate the selection of renewable energy.

Author	Method	Financial criteria	Technological criteria	Environmental criteria	Social criteria
[27]	ELECTRE	Investment cost O&M Cost	Safety Operationality Stability	Air quality Noise Visual amenity Climate change Ecosystem's protection	Employment Economic activities
[35]	AHP	hardware cost Fuel Costs Maintenance cost	Efficiency Reliability Availability Safety		Social benefits National economy
[36]	PROMETHEE	NPV	Energy consumption Risk		Jobs
[28]	ELECTRE III		Technical maturity Reliability	Greenhouse emissions Land requirement	Labor impact Market maturity
[34]	AHP SIMUS	Capital cost Payback time Government incentives	Technology mature Resource availability	Ecological impact Land requirement	Employment Local development Social benefits
[21]	AHP			CO_2 NOx SO_2 Land requirement	Job creation Social acceptance Accident fatalities
[32]	fuzzy AD fuzzy AHP	Implementation cost Availability of funds Economic value	Feasibility Risk Reliability	Pollution emission Land requirement	Social acceptance Labor impact
[37]	AHP PROMETHEE	Investment cost Running cost	Primary energy consumption	CO_2 emissions	
[38]	AHP	Capital Costs O&M Cost Fuel Costs	Efficiency Availability Capacity Reserves/Production Ratio	External Costs	
[39]	PROMETHEE	Investment costs O & M costs Conventional fuel savings	Maturity of technology Safety of supply	CO_2 emissions	Local development and welfare Social acceptance
[40]	VIKOR AHP	Investment cost O & M cost	Technical efficiency Exergy efficiency	NOx emisLand use	Social acceptability Job creation
[41]	FAHP	Investment cost	Technical maturity	Carbon emission Sox, NOx Land requirement Environmental sustainability	Local development Employment Market size
[22]	AHP	R& D cost Capital cost O & M cost Electricity cost	Maturity Efficiency Reliability Availability Resource available	Land requirement Emission Eco-system	Social benefits Job creation Social acceptance
[25]	VIKOR	Investment Ratio Implementation Period O & M Costs	Operating Hours	CO_2	Useful Life
[33]	MULTIMOORA TOPSIS	Investments and operation costs Costs of grid connection	Load factor Security of supply peak load response	GHG emissions Human Health impact External costs	Job opportunities Fatal accidents
[42]	AHP	Investment Cost O&M Cost Payback Period	Energy Production Capacity Technological Maturity Reliability Safety	Impact on Ecosystem CO_2 Emission	Social Benefits Social Acceptability
[43]	COPRAS AHP	Power, investment ratio Implementation period O&M costs	Operating hours	CO_2	Useful life
[19]	AHP	Total overnight cost Variable O&M Fixed O&M Fuel cost	Production efficiency Capacity factor	External costs Loss of Life Expectancy	Fuel reserve years Job creation Net import of consumption
[23]	AHP	Technology cost Operational life Resource potential	Maturity Efficiency Lead time	CO_2 Emission Impacts on environment Land requirement	Public acceptance Job creation
[30]	ANP	Economic value Implementation cost Investment cost O&M cost	Technical feasibility Reliability Security Immaturity	Global effect Land use Ecological damage	Human wellbeing Job creation Social resistance
[29]	PROMETHEE	Initial investment O&M Cost Fuel Costs	Potential power generation Technology maturity Reliability	GHG emissions Impacts on amenity Area requirements	social acceptance
[44]	AHP TOPSIS				Social acceptability Government support

(*continued on next page*)

Table 1 (*continued*)

Author	Method	Financial criteria	Technological criteria	Environmental criteria	Social criteria
			Technological maturity Reliability Security Installed capacity Electricity generation		
[26]	MCDA	LCOE	Capacity factor	GHG emissions Air pollution Land use Water use	Fatalities Jobs
[24]	FTOPSIS	Investment cost O & M cost Payback period	Efficiency Installed capacity Amount of energy produced	Land use CO_2 emission	Job creation
[31]	AHP ARAS	Production cost Economic efficiency Technology's competitiveness	Capacity Reliability Innovativeness Durability of technology	Climate change Pollution (SO_2, NOx)	Job Public acceptance

alternative in the social acceptance criterion, the mean score was calculated from a total of 131 samples. The initial data on Taiwan's RES, based on the source in Table 5, is shown in Table 6.

All criteria are explained briefly as follows.

3.1. Economic criteria

- Investment cost (C1): The components of investment costs are the purchase of mechanical equipment, technological installations, construction of roads and connections to the national web, engineering services, drilling and other incidental construction work [18]. The investors must consider the costs and the benefits of investments. Investment cost is the mostly used economic criterion to evaluate energy systems.
- O&M cost (Operation & maintenance cost) (C2): it consists of two parts; (1) operation cost including employees' salaries, and the funds spent for energy, products and services for energy system operation [18], and (2) maintenance cost.
- Electric cost (C3): In the process of electrical power generation, the cost of the whole system includes the land cost, construction costs, operation costs, fuel costs, equipment depreciation and interest costs. This is also a vital financial indicator.

3.2. Technical criteria

- Efficiency (C4): This is the widely used technical criterion to evaluate energy systems. Efficiency refers to how much useful energy can be obtained from an energy source. The efficiency coefficient which is one of the most frequently used measures of efficiency, is defined as the ratio of the output energy to the input energy.
- Capacity factor (C5): The capacity factor of a power plant is the ratio of the electrical energy produced by a generating unit for the period of time that could have been produced at continuous full power operation during the same period [19]. The capacity factors of different types of power plants vary widely. The capacity factor of RE is affected by the weather; for example, in summer, the average power generation capacity of hydropower plants is higher, leading to a higher capacity factor. Geothermal and biomass energy operate almost 24 h a day, but solar energy is affected by sunshine, while wind energy is affected by the wind speed.
- Capacity factor = Annual total generation / (Installed capacity × 365 days × 24 h/days)× 100%
- Technical maturity (C6): This criterion refers to the reliability degree of the adopted technology and its spread at a national level. In this study, it is assessed with a qualitative 5-point scale ranging from 1 indicating very low maturity (i.e. the technology is only tested in laboratory) to 5 indicating very high maturity (i.e. commercially mature technology with a solid market position) [39].

3.3. Environmental criteria

- GHG emission (C7): This criterion refers to the amount of GHG emissions from a given RE system, which is one of the most widely used criteria in evaluating the sustainability of renewables. Here, the life-cycle of GHG emissions from different renewable technologies should be estimated. Emissions are measured in equivalent

Table 2
Taiwan case study in renewable energy based on MCDM method.

Author	Year	Research purpose	Method	Results
[49]	1992	The evaluation of new energy system development	AHP PROMETHEE	The scores for solar PV, wind energy and geothermal energy are similar. Ocean energy and hydrogen energy are ranked at the bottom.
[41]	2010	An assessment of renewable energy sources	FAHP	Hydropower is the most preferred, followed by solar, wind, geothermal, biomass and ocean energy.
[50]	2011	The evaluation of wind farm performance	ISM BOCR FANP	Lowest buy-back price is the most important concern in selecting a wind farm.
[3]	2011	The portfolio of renewable energy sources	AHP	Non-pumped storage hydropower, wind energy, and solar energy are three sources that could meet the three policy goals at the same time.
[51]	2012	A wind turbine evaluation model	ISM FANP	Economic aspect is the most important criterion. Under the economic aspects, net present value is the most important objective. The most suitable turbines for installation can be generated.
[48]	2013	The location selection of the sites for wind farms	FANP BOCR	The results show the rankings: Taoyuan, Changbin, Taichung Harbor, and Daan wind farm. By adopting the method, the most suitable wind farm can be determined.
[47]	2017	Photovoltaic solar plant location selection	ISM FANP VIKOR	The most important criterion is costs. Land utilization is the most important sub-criteria. By applying the proposed model, the overall ranking of the alternatives can be obtained through the model.

Table 3
The ranking results of RES based on country and method.

Author	Nationality	Method	Results
[49]	Taiwan	AHP PROMETHEE	Solar thermal > PV = Wind = Geothermal > Ocean
[35]	Jordan	AHP	Solar > Wind > Hydro > Fossil > Nuclear
[34]	Canada	AHP SIMUS	Solar Thermal > Wind > PV > Ground Thermal > Micro Hydro
[32]	Turkey	FAD FAHP	Wind > Solar > Biomass > Geothermal > Hydro
[40]	Turkey	VIKOR AHP	Solar > Biomass > Geothermal > Hydro
[41]	Taiwan	FAHP	Hydro > Solar > Wind > Geothermal > Biomass > Ocean
[22]	Pakistan	AHP	Biomass > Wind > Solar thermal > Solar PV
[25]	Spain	VIKOR	Biomass > Wind > Solar Thermo > Hydro
[3]	Taiwan	AHP	Hydro > Solar > Wind > Geothermal > Ocean > Biomass
[33]	European Union	MULTIMOORA TOPSIS	MULTIMOORA: Hydro M > Hydro L > Solar thermal > Hydro S > Wind onshore > Wind offshore > PV roof > PV open TOPSIS: Solar thermal > Hydro L > Hydro M > Hydro S > Wind onshore > Wind offshore > PV open > PV roof
[42]	Turkey	AHP	Wind > Biomass > Geothermal > Solar > Hydro
[43]	Spain	COPRAS AHP	Biomass(co-combustion in conventional central)≻ Wind(10 ≤ P ≤ 50 MW)≻ Solar Thermo > Hydro (25 ≤ P ≤ 50 MW)≻ Wind (5 ≤ P ≤ 10 MW)≻ Hydro(10 ≤ P ≤ 25 MW)≻ Biomass(forest industrial wastes) > Biomass (farming industrial wastes) = Biomass (forest and agricultural wastes)≻ Wind power(P ≤ 5 MW)≻ Hydro(P ≤ 10 MW)
[19]	USA	AHP	Wind > Solar > Hydro > Geothermal
[52]	Turkey	MACBETH FAHP	Wind > Solar > Biomass > Geothermal > Hydro
[23]	Malaysia	AHP	Solar > Biomass > Hydro > Wind
[30]	Turkey	ANP	Hydro > Solar > Wind > Geothermal > Biomass
[29]	UK	PROMETHEE	PV > Wind offshore > Solar thermal > Hydro > Wind onshore > Tidal > Wave > Geothermal > Biomass
[44]	China	AHP TOPSIS	Hydro > Wind > Biomass > Solar > Nuclear
[26]	USA	MCDA	Biopower > Geothermal > Nuclear > Wind onshore > Wind offshore > Solar CSP > Solar PV > Hydro
[24]	Turkey	FTOPSIS	Hydro > Geothermal > Wind
[31]	Lithuania	AHP ARAS	Nuclear > Biomass > Hydro > Geothermal

emissions of CO_2 per energy unit produced (g CO_2eq/kWh) [58]. In a life-cycle assessment (LCA) of emissions, all the stages of the energy production system, from raw material extraction, refining, processing, transportation, construction, to operation and maintenance, and dismantling, were considered.

- Land use (C8): As the environment and landscape are directly affected by the energy system, the land required by each plant is a matter of great concern for evaluation. Different energy systems may occupy different land areas, while the products are same. Hence, land use must be considered.

3.4. Social criteria

- Job creation (C9): An energy supply system can employ many people during its life cycle, from construction to operation. Hence,

Table 5
Sources of data for this study.

Criteria	Unit	Source
Investment cost	US$/kW	[53]
O&M cost	US$/kW/y	[53]
Electric cost	$/kWh	[54]
Efficiency	%	[19]
Capacity factor	%	[55]
Technical maturity	1–5 scale	
GHG emission	gCO_2/kWh	[56]
Land use	m^2/kW	[29]
Job creation	person/kWh	[57]
Social acceptance	1–5 scale	questionnaire

Table 4
The selected criteria.

Criteria	Criteria type	Description	Reference
Economic			
Investment cost	Cost	Expenditure on equipment and installation	[24,29,30,33,35,37,38,40,42]
O&M cost	Cost	Employees' wages, the funds spent for energy, and products and services for energy system operation	[19,24,25,27,29,30,33,35,38–40,42,43]
Electric cost	Cost	The cost of various energy generation systems	[18,21,32,34]
Technical			
Efficiency	Benefit	Efficiency is defined as the ratio of the output energy to the input energy	[24,35,38,40]
Capacity factor	Benefit	The ratio of annual total generation and install capacity	[19,33]
Technical maturity	Benefit	Technology refers to the reliability degree of the adopted technology and its spread at national level	[28–30,39,42,44]
Environmental			
GHG emission	Cost	The life-cycle GHG emissions (in equivalent emission of CO_2) from the technology	[28,29,33,42]
Land use	Cost	Land area needed for the technology	[24,28–30,40]
Social			
Job creation	Benefit	Potential of employment opportunities to be created by energy project	[19,27,28,30,33,36,40,43]
Social acceptance	Benefit	Public acceptance of the RE technology/project	[29,30,39,40,42,44]

Table 6
Initial data on Taiwan's renewable energy sources.

Criteria	Alternatives				
	Solar PV A1	Wind A2	Hydro A3	Biomass A4	Geothermal A5
Investment cost	4550	3005	2040	3370	3920
O&M cost	30	60.86	14.85	99.4	112.6
Electric cost	6.74	2.4	1.7	3.25	4.93
Efficiency	20	35	90	25.3	11.4
Capacity factor	15	27	25	54	71.7
Technical maturity	5	4	5	3	2
GHG emission	85	26	26	45	50
Land use	150	200	500	222	100
Job creation	0.87	0.17	0.27	0.21	0.25
Social acceptance	4.76	4.51	4.19	3.78	4.11

the development of RE should take into account the local residents by assessing improvement of quality of life and job creations.

- Social acceptance (C10): This criterion refers to the extent of public acceptance of the RE, which is recognized as an important issue shaping the implementation of RE technologies and the achievement of energy policy targets [59]. It is extremely important since the opinion of the population and of pressure groups may heavily influence the amount of time needed to complete an energy project. It should be noted that social acceptance is not a directly measurable indicator. In this study, the measurement of social acceptance is based on a qualitative scale ranging from 1 indicating strong opposition to 5 indicating strong support.

4. A brief review of the main MCDM approaches

After determining the evaluation criteria and alternatives, this study integrates entropy and MCDM methods to rank the priority of RES for Taiwan RE development. In order to determine the importance of each criterion, the weights of each criterion are calculated using Shannon's entropy. Then, four MCDM methods are utilized to rank the RE alternatives. Finally, the recommendations for Taiwan's RE development are provided. The research framework is shown in Fig. 1.

4.1. The calculation of criteria weight

The calculation of weight can be divided into subjective weight and objective weight. Subjective weight is mainly determined by an expert opinion based on experiences and subjective judgments, such as with AHP and Delphi; objective weight is directly drawn from the real data of the alternative, such as with the entropy weight method. The advantage of entropy weight method reduces the subjective impact of decision makers and increases objectivity.

Entropy was originally a concept in thermodynamics and was used to calculate the disorder of a system, that is, to calculate the degree of confusion. Shannon applied it to solve problems of information theory, making it one of the ways to deal with uncertainty [60]. According to the entropy theory, the less the entropy value, the more the information that can be provided. Therefore, the criterion can be assigned a bigger weight [61]. The concept of entropy weight has been widely used in several fields. For example, Mohsen [62] proposed a fuzzy model by combining entropy and fuzzy VIKOR for the risk assessment of equipment failure in geothermal power plants. Sengül et al. [24] used interval Shannon entropy to determine the weights of criteria and employed the fuzzy TOPSIS approach for ranking RE supply systems. Shad et al. [63] combined entropy with AHP and GIS in green building assessment. Hafezalkotob [64] integrated entropy and subjective weight, and MULTIMOORA for the engineering design and production process of the most appropriate material selection problem. And finally, they compared the ranking results with other MCDM methods.

The calculation of Shannon's entropy weight is presented as follows [65].

Assuming that m alternatives $(A_1, A_2, \dots, A_m)$ and n criteria $(C_1, C_2, \dots, C_n)$ for a decision problem. Then initial decision matrix is

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} = [a_{ij}]_{m\times n}$$

where its elements a_{ij} denote i th alternative of j th criterion.

Step 1: Normalize the decision matrix

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}},\ i = 1, 2, \dots, m$$

Step 2: Compute entropy

$$e_j = -K \sum_{i=1}^{m} r_{ij} \ln r_{ij},\ j = 1, 2, \dots, n$$

where $K = 1/\ln m$

Step 3: The weights of each criterion are calculated

$$w_j = \frac{1-e_j}{\sum_{i=1}^{n}(1-e_j)},\ j = 1, 2, \dots, n$$

4.2. MCDM methods

In this section, some brief comments on four MCDM methods for ranking RE are presented. A general review of MCDM for IM and the type of infrastructure applications have been addressed by Kabir et al. [66].

- Weighted sum method (WSM) [67]
- TOPSIS [68]
- VIKOR [69]
- ELECTRE [70]

Brief discussion of MCDM methods for IM is provided as follows.

4.2.1. Weighted sum method (WSM)

The weighted sum method, also called the simple additive weighted method, is one of the simplest and most widely used MCDM methods. In general, WSM deals with benefit criteria, i.e. the cost criteria are transformed into benefit criteria. After the transformation, the lowest cost criterion becomes the largest and the largest cost becomes the lowest. Then, a normalized matrix can be created by dividing each criterion value by the sum of all criteria [20]. Finally, the total score of each alternative is multiplied by its weight. The best alternative is the highest total score among all the alternatives. Bagočius et al. [71] applied the aggregated WSM and weighted product method (WPM) to assess the best wind power plant in considering technical, economic, and environmental criteria.

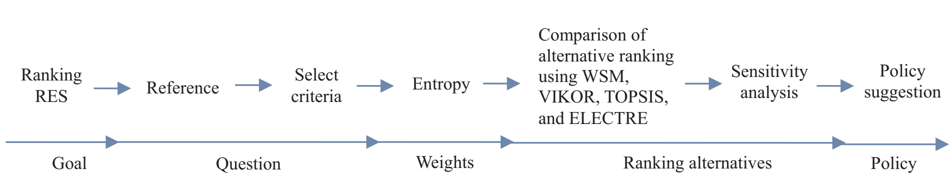

Fig. 1. Research framework.

4.2.2. TOPSIS

TOPSIS is also a popular MCDM method, which was proposed by Hwang and Yoon [68] to determine the best alternative. The main rule of TOPSIS is that the best alternative should have shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution [72].

This method has been widely adopted to solve MCDM problems in many different fields. In the application of energy, several studies have used TOPSIS to rank the sustainable electricity production technologies [24,33] and to evaluate offshore wind turbines [73].

The algorithm of the TOPSIS method is presented as follows, according to Huang and Yoon [74].

Step 1: Construct the normalized decision matrix R

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}$$

Step 2: Construct weighted normalized decision matrix V

$v_{ij} = w_j r_{ij}$, $\sum_{j=1}^{n} w_j = 1$, w_j is the weight of j th criterion

Step 3: Determine the positive-ideal solution (PIS) and negative-ideal solution (NIS), denoted respectively as A^* and A^-, are defined in the following way.

$$A^* = \{(\max v_{ij} | j \in J) or (\min v_{ij} | j \in J')\},\ i = 1, 2, ..., m$$

$$= \{v_1^*, v_2^*, ..., v_n^*\}$$

$$A^- = \{(\min v_{ij} | j \in J) or (\max v_{ij}) | j \in J')\},\ i = 1, 2, ..., m$$

$$= \{v_1^-, v_2^-, ..., v_n^-\}$$

where J and J' are sets of benefit and cost criteria, respectively.

Step 4: Calculate the distances of each alternative from PIS and NIS

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2},\ for\ i = 1, 2, ...m$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2},\ for\ i = 1, 2, ...m$$

Step 5 : Calculate the closeness coefficient and rank the order of alternatives

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-},\ 0 < C_i^* < 1,\ i = 1, 2, ..., m$$

Where $C_i^* \in [0; 1]$ with $i = 1, 2, ..., m$. The best alternative can therefore be found according to the preference order of C_i^*. The value is the more the better. If C_i^* is close to 1, it indicate the alternative A_i is closer to the PIS.

4.2.3. VIKOR

VIKOR was developed to solve decision problems with conflicting and noncommensurable (different units) criteria. In the VIKOR model, compromise ranking can be performed by comparing the measure of closeness to the ideal solution [72]. This method has been used for the assessment of sustainable and renewable energy system problems over the past several years. For instance, VIKOR has been used to assess renewable energy projects considering technical, environmental, and economic circumstances [25,40,75].

The algorithm VIKOR has the following four steps [40].

Step 1 : Determine the positive-ideal solution f_j^* (PIS) and negative-ideal solution f_j^- (NIS)

$$\begin{matrix} f_j^* = \left\{\max_i f_{ij} | j \in I_1\right\} & f_j^* = \left\{\min_i f_{ij} | j \in I_2\right\} \\ f_j^- = \left\{\min_i f_{ij} | j \in I_1\right\} & f_j^- = \left\{\max_i f_{ij} | j \in I_2\right\} \end{matrix},\ \forall j$$

where I_1 and I_2 are sets of benefit and cost criteria, respectively.

Step 2 : Compute the values S_i and R_i

$$S_i = \sum_{j=1}^{n} w_j (f_j^* - f_{ij})/((f_j^* - f_j^-)$$

$$R_i = \max_j \left[w_j (f_j^* - f_{ij})/((f_j^* - f_j^-) \right]$$

where w_j are the weights of criteria.

Step 3 : Compute the value Q_i

$$Q_i = v(\frac{S_i - S^*}{S^- - S^*}) + (1 - v)(\frac{R_i - R^*}{R^- - R^*})$$

where $S^* = \min S_i$, $S^- = \max S_i$, $R^* = \min R_i$, $R^- = \max R_i$ and v is identified as a weight for strategy of maximum group utility, whereas (1-v) is the weight of the individual regret. Normally, the value of v is set as 0.5. However, v can set any value from 0 to 1.

Step 4 : Rank the alternatives, sorting by the values of Q_i in decreasing order.

4.2.4. ELECTRE

The concept of outranking relations to introduce ELECTRE was first developed by [70]. Since then, various ELECTRE models have been developed based on the nature of the problem. However, ELECTREIcannot derive the ranking of alternatives. ELECTREIIwas proposed by Roy and Bertier to overcome the defect of ELECTREI to produce a ranking of alternatives [74]. Therefore, ELECTREIIwas adopted as a comparative method in this paper. ELECTRE method is widely applied in many fields such as the selection of sustainable energy action plan [76], location selection [77,78] and the performance assessment [79]. Beccali et al. [28] used ELECTRE method to assess a group of actions for RE technology based on environmental and technical criteria.

The algorithm of the ELECTRE method is presented as follow [80].

Step 1 : Construct the normalized decision matrix

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}$$

Step 2 : Construct weighted normalized decision matrix V

Step 3 : Determined the concordance and discordance set

If the value of preference for the alternative A_k is better than that of alternative A_i, under the jth criterion, then the element k is classified in the concordance set (C_{ij}). Otherwise, it is classified in the discordance set (D_{ij}).

$$C_{ij} = \{k | V_{ik} \geq V_{jk}\},\ D_{ij} = \{k | V_{ik} < V_{jk}\}$$

Step 4 : Sum the weight of the criteria by each element discordance set, and obtain the concordance matrix

$$c_{ij} = \frac{\sum_{k \in c_{ij}} w_k}{\sum_{k=1}^{n} w_k}$$

Step 5 : Calculate the discordance matrix and revise

$d_{ij} = \frac{\max_{k \in D_{ij}} \{|v_{ik} - v_{jk}|\}}{\max_{k \in S} \{|v_{ik} - v_{jk}|\}}$, $d'_{ij} = 1 - d_{ij}$, S is the set of all criteria

Step 6 : Calculate the revised total matrix (Y), $y_{ij} = c_{ij} \times d'_{ij}$

Step 7 : Compute the net advantage value

Since the traditional ELECTREII method may only provide partial ranking and be overly dependent on the threshold, therefore, this study employed the concept of the net advantage value to compute C_k; it is calculated as follows:

$$C_k = \sum_{\substack{i=1 \\ i \neq k}}^{n} y_{ki} - \sum_{\substack{j=1 \\ j \neq k}}^{n} y_{jk},\ k = 1, 2, ..., n$$

Finally, rank alternatives, sorting by the values of C_k in increasing order.

Table 7
The comparisons of four MCDM methods.

	WSM	TOPSIS	VIKOR	ELECTRE
feature	Simple and easy to deal with multiple criteria decision-making problems.	Consideration of both the positive and negative ideal solutions.	Maximize group benefits and minimize individual regret, so compromise solutions are more easily accepted by decision makers.	When the number of alternatives is large, and each criterion under alternative can be established through objective assessment.
calculation procedure	easy	medium	medium	complex
criteria	quantitative	quantitative	quantitative	quantitative and qualitative

Table 8
Shannon's entropy weight.

Dimension	Criteria	Weight	Rank	weight	Rank
Finance	(C1) Investment cost	0.026	9	0.269	2
	(C2) O&M cost	0.154	3		
	(C3) Electric cost	0.089	6		
Technology	(C4) Efficiency	0.199	1	0.353	1
	(C5) Capacity factor	0.115	5		
	(C6) Technical maturity	0.039	8		
Environment	(C7) GHG emission	0.080	7	0.203	3
	(C8) Land use	0.123	4		
Social	(C9) Job creation	0.172	2	0.175	4
	(C10) Social acceptance	0.003	10		

Table 9
The ranking of RES in different methods.

Rank	WSM	TOPSIS	VIKOR	ELECTRE
1	Hydro	Hydro	Hydro	Hydro
2	Solar PV	Solar PV	Wind	Solar PV
3	Wind	Wind	Solar PV	Wind
4	Biomass	Geothermal	Biomass	Geothermal
5	Geothermal	Biomass	Geothermal	Biomass

4.2.5. *Summary of MCDM methods*

The MCDM helps decision makers to evaluate all alternatives according to various criteria to obtain the more suitable solutions. Each approach may have advantages and disadvantages. It cannot be claimed that a particular approach is preferred the others. The selection of an appropriate approach is mostly dependent on the preferences of the analyst. The procedure of these four MCDM methods has some common rules: (1) collected the value of alternative for each criterion; (2) multiplied by corresponding weights; (3) obtained the total score of each alternative. Table 7 presents the comparisons of four MCDM methods. The selected methods for the comparative analysis differ in their basic principles. VIKOR and TOPSIS are based on an aggregating function representing closeness to the reference point. These two MCDM methods use different kinds of normalization to eliminate the units of criterion functions: the VIKOR method uses linear normalization, and the TOPSIS method uses vector normalization.

5. Results of MCDM

Based on the initial data in Table 6, Shannon's entropy was used to calculate the relative importance of each criterion. The weights of all criteria and ranking were obtained, as shown in Table 8. As seen in Table 8, technology is the most important consideration for the development of RE, followed by finance, environment and society. In addition, the most important of the criteria is efficiency, followed by job creation, O&M cost, land use, capacity factor, electric cost, GHG emission, technical maturity, investment cost and social acceptance.

The MCDM methods (WSM, TOPSIS, VIKOR and ELECTRE) were applied to the data. The ranking results are presented in Table 9. Hydro was the optimal alternative in all methods. The rankings of these four methods were similar, although not entirely equal. All of the approaches, except for VIKOR, ranked solar PV 2nd and wind 3rd. Biomass and geothermal were the low-ranking alternatives. TOPSIS and ELECTRE produced equal rankings of the alternatives. The ranking results of these two methods were similar to WSM, with three of the

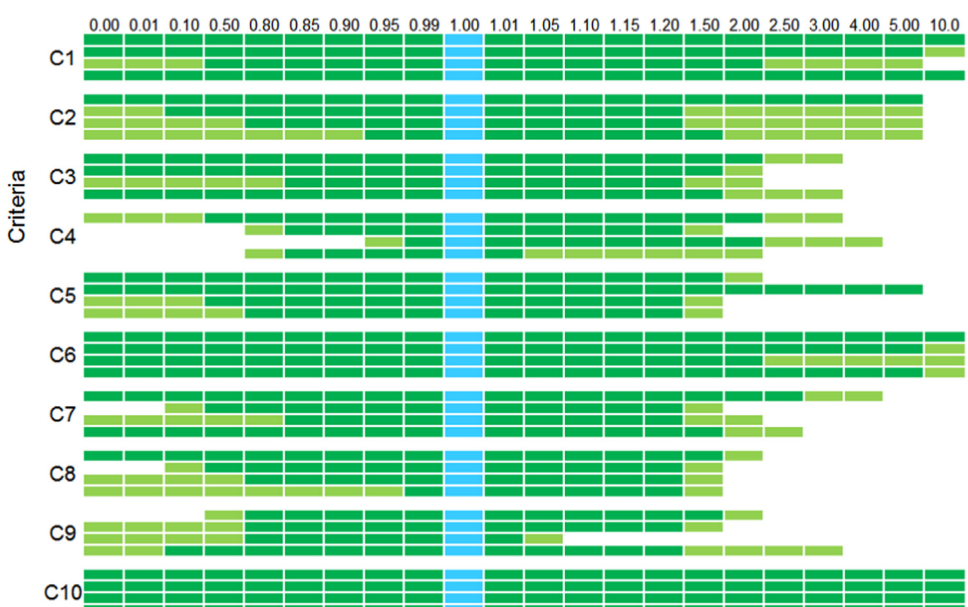

Fig. 2. the sensitivity analysis by change weight.

Table 10
sensitivity coefficient.

	Change criterion weight											
	- 5%			+ 5%			- 50%			+ 50%		
	Sensitivity coefficient											
	0	2	> 2	0	2	> 2	0	2	> 2	0	2	> 2
WSM	10	0	0	10	0	0	9	1	0	10	0	0
TOPSIS	10	0	0	10	0	0	8	1	1	6	4	0
VIKOR	9	1	0	9	1	0	4	5	1	4	4	2
ELECTRE	9	1	0	9	1	0	6	3	1	6	3	1

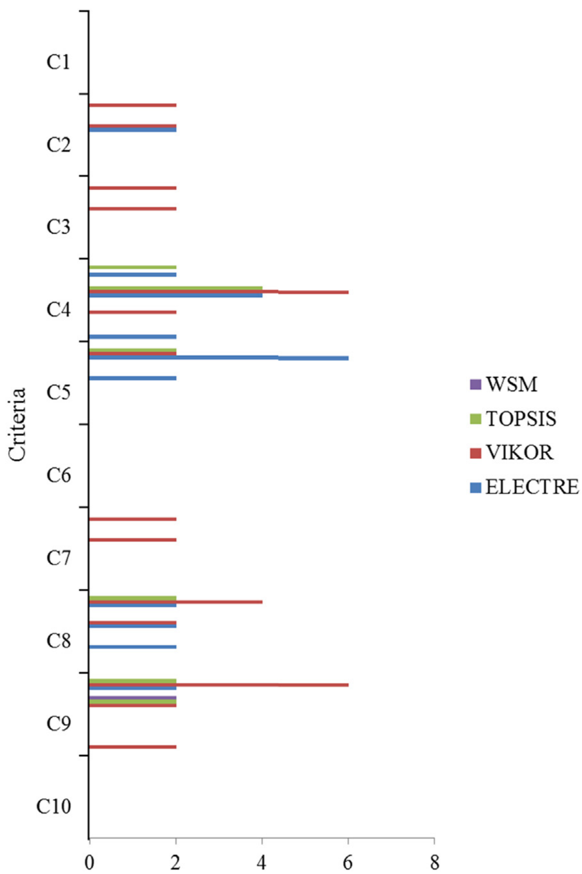

Fig. 3. sensitivity coefficient for each criterion in different MCDM methods.

Table 11
Criteria weights under different scenarios.

Criteria	Scenario 1 Equal weight	Scenario 2 Financial	Scenario 3 Technical	Scenario 4 Environmental	Scenario 5 Social
Financial	0.25	0.5	0.167	0.167	0.167
Technical	0.25	0.167	0.5	0.167	0.167
Environmental	0.25	0.167	0.167	0.5	0.167
Social	0.25	0.167	0.167	0.167	0.5

alternatives (60%) in identical positions. VIKOR was also similar to WSM, with both methods ranking three of the alternatives (60%) in identical positions.

6. Sensitivity analysis

Since the criteria weight significantly affects the rank, the change of the weight value should be evaluated. In this paper, two types of sensitivity analysis were performed to reveal how the ranking of alternatives changes due to variation of criteria weights. First, the weight value was adjusted with a 5% or 50% increase or decrease of the criterion weight. Results of sensitivity analysis for each individual criterion are compared in Fig. 2. In order to fix the criteria weight equal to 1, the remaining criteria must be proportionally reduced when a criterion weight increases. In Fig. 2, the dark green bars indicate that the ranking was not changed after adjusting the criterion weight and the light green bars indicate that the ranking has a slight change. The bar length presents the tolerable degree of the criterion weight. Longer bar length implies less sensitivity of the criterion weight. Each criterion was analyzed using the four MCDM methods, WSM, TOPSIS, VIKOR, and ELECTRE, in that order. Fig. 2 shows C10 (social acceptance) has the least sensitivity. That is, the ranking result is not changed when changing weights using the four MCDM methods. C1 (Investment cost), C2 (O&M cost) and C6 (Technical maturity) are also stable, whereas C4 (Efficiency) is the most sensitive, particularly when using the ELECTRE method.

The sensitivity coefficient was calculated to compare the sensitivity for all four MCDM methods. The value of sensitivity coefficient indicates that a 5% or 50% increase or decrease of the criterion weight leads to single, double or multiple changes in ranking of alternatives. That is, if the ranking is not changed, the sensitivity coefficient is equal to 0. If the ranking of one alternative increases, the ranking of another alternative decreases, so the sensitivity coefficient is equal to 2. As shown in Table 10, the 4–7 columns (blue) present how many criteria change ranking in each of the four methods after adjusting one criterion weight. The result shows that the ranking of alternatives did not have any influence for WSM and TOPSIS and had some effect on the ranking with VIKOR and ELECTRE method, when weight increased (decreased) by 5%. The ranking of the WSM method was least affected by the 50% change in the criterion weight, while VIKOR had the most significant change (60% change) and ELECTRE showed a change of 40%. This means that when the weight changes significantly (50%), only the WSM ranking result remains almost unchanged, while the remaining three methods change by about 40–60%.

Fig. 3 presents the sensitivity of each criterion in a simpler way. The horizontal axis represents the sensitivity coefficient when the weight of one criterion increases or decreases by 5% or 50%. For instance, when the weight of criterion C2 increases 50%, the ranking result from A3 ≻ A2 ≻ A1 ≻ A4 ≻ A5 changes to A3 ≻ A2 ≻ A4 ≻ A1 ≻ A5. The criterion weight is increased (or decreased) 5% or 50% to calculate the number of changes in ranking. As can be clearly seen from Fig. 3, the ranking results of C1, C6, and C10 are not affected by changes of criterion weight. On the contrary, C4, C5, and C9 are the most sensitive, especially when using the VIKOR method.

Second, five scenarios listed in Table 11 are taken into account. In scenario 1, every dimension is treated as equally important. The following four scenarios focus on the financial, technical, environmental, or social dimensions. The weights for certain criteria were obtained by dividing dimension weight by the number of criteria.

Table 12
The ranks in terms of different methods and scenarios.

	Method	Rank				
		1	2	3	4	5
Scenario 1	WSM	Hydro	Solar PV	Wind	Biomass	Geothermal
Equal weight	TOPSIS	Solar PV	Hydro	Wind	Geothermal	Biomass
	VIKOR	Geothermal	Hydro	Wind	Solar PV	Biomass
	ELECTRE	Solar PV	Geothermal	Wind	Hydro	Biomass
Scenario 2	WSM	Hydro	Wind	Solar PV	Biomass	Geothermal
Financial	TOPSIS	Hydro	Wind	Solar PV	Biomass	Geothermal
	VIKOR	Hydro	Wind	Biomass	Solar PV	Geothermal
	ELECTRE	Hydro	Wind	Solar PV	Biomass	Geothermal
Scenario 3	WSM	Hydro	Wind	Solar PV	Biomass	Geothermal
Technical	TOPSIS	Hydro	Geothermal	Biomass	Wind	Solar PV
	VIKOR	Hydro	Wind	Biomass	Solar PV	Geothermal
	ELECTRE	Hydro	Geothermal	Biomass	Solar PV	Wind
Scenario 4	WSM	Wind	Hydro	Solar PV	Geothermal	Biomass
Environmental	TOPSIS	Wind	Geothermal	Biomass	Solar PV	Hydro
	VIKOR	Wind	Geothermal	Biomass	Hydro	Solar PV
	ELECTRE	Wind	Geothermal	Solar PV	Biomass	Hydro
Scenario 5	WSM	Solar PV	Hydro	Wind	Geothermal	Biomass
Social	TOPSIS	Solar PV	Hydro	Geothermal	Wind	Biomass
	VIKOR	Solar PV	Hydro	Wind	Geothermal	Biomass
	ELECTRE	Solar PV	Wind	Geothermal	Hydro	Biomass

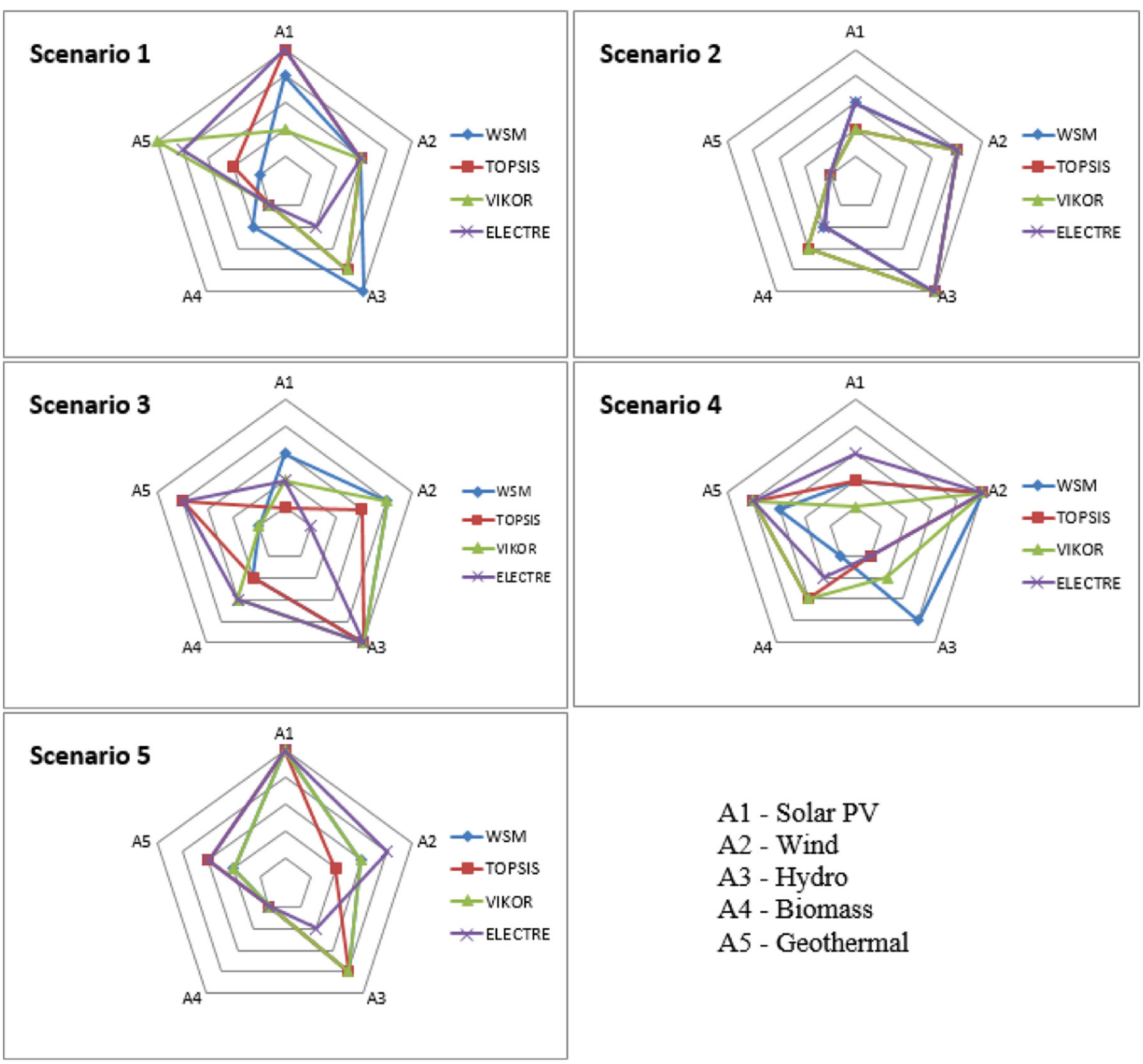

Fig. 4. Radar chart for the ranking in terms of different methods and scenarios.

Table 13
Aggregate ranking in different scenarios.

Rank	Scenario 1 Equal weight	Scenario 2 Financial	Scenario 3 Technical	Scenario 4 Environmental	Scenario 5 Social
1	Solar PV	Hydro	Hydro	Wind	Solar PV
2	Hydro	Wind	*Wind*	Geothermal	Hydro
3	*Wind*	Solar PV	*Biomass*	*Hydro*	Wind
4	*Geothermal*	Biomass	Geothermal	*Solar PV*	Geothermal
5	Biomass	Geothermal	Solar PV	Biomass	Biomass

Note. Italic indicated the ranking is the same.

The ranks in terms of different methods and scenarios are shown in Table 12 and the radar chart in Fig. 4. The ranking results are different under various scenarios. In scenario 1, solar PV is the most attractive. Biomass is the least attractive. From a financial perspective, hydro provides the best solution, followed by wind, solar PV, biomass and geothermal. From a technical perspective, hydro is still the best choice. In scenario 4, the emphasis is on minimizing environmental impact. The results show that wind power is the best choice, and geothermal ranks 2nd. In scenario 5, solar PV is the best choice, while biomass is the least desirable choice from this perspective.

The aggregation method is used to determine the best alternative because of various MCDM have different ranking results. If there are k alternatives, each alternative receives k points for being the first choice, k-1 points for being the second choice, and so on. The alternative with the highest number of points is the best. The aggregated ranking results are illustrated in Table 13.

7. Discussion and conclusion

This paper reviewed the related literature on RE studies to identify ten criteria and used four MCDM (WSM, TOPSIS, VIKOR and ELECTRE) methods to rank the priority of five RES in Taiwan. The data were collected from various official institutions or related studies. The results of analysis show that technology is the most important factor for the evaluation of RES, followed by financial, environmental, and social factors. In addition, efficiency, job creation, and O&M cost are identified as the first, second, and third priorities within all criteria. These results imply that the development of Taiwan's RE should consider whether the technology is mature and stable, and power generation is efficient enough. It is necessary to evaluate the capability of electricity generation to decrease the reliance on fossil fuel. Additionally, cost is another critical factor for decision makers in the evaluation of a RE program. However, by improving the RE technology, the cost will be decreased. The environmental factor is becoming increasingly important due to the rise of environmental protection awareness in recent years. The social factor is usually the last consideration.

The calculated weight of each criterion obtained in this paper is partially consistent with the results of past studies using AHP subjective weights. Ahmad and Tahar [22] found efficiency is considered to be an important criterion, while social acceptance and land use criteria are less important. Except for land use, their weight rankings are consistent with ours. Theodorou et al. [81] indicated that investment cost is the most important criterion, followed by efficiency, technological implementation potential, maturity and people's acceptance. Their results also indicate that efficiency is important and residents' acceptance is the least important. Büyükozkan and Karabulut [82] considered environmental, social and economic dimensions, finding that the economic dimension is the most important, followed by the environment and, lastly, the social dimension. Based on the overall consideration of all criteria, air pollution was the most important criterion, followed by investment cost, social acceptance, production and variables costs, and job creation. From the above discussion, it is obvious that the importance of criteria determined using Shannon entropy in this study is same as in previous studies using AHP. Furthermore, the ranking results of four MCDM methods are roughly the same, i.e. hydro should be given highest priority for developing RE in Taiwan, followed by solar PV, wind, biomass, and geothermal. Only the VIKOR method (which ranked wind 2nd and solar PV 3rd) is slightly different in the ranking. The ranking results of this study are consistent with those of Shen et al. [41].

Subsequently, sensitivity analysis was performed by taking each criterion and changing its weights. VIKOR had the highest sensitivity among these four MCDM methods, followed by ELECTRE and TOPSIS. WSM was almost unaffected by changing weight so the sensitivity is the lowest. The result of sensitivity analysis using five different scenarios and the possible reasons are presented in Table 14.

Hydro power is the RE that was developed earliest; its cost is lower, and the technology is mature. However, the impact on the environment is negative. Due to terrain and natural conditions in Taiwan, the development of large-scale reservoirs has been rare. The future trend will move towards small and medium-sized hydro power to reduce the destruction of the ecological environment. Biomass, which currently utilizes waste, can cause air pollution, and the acceptance of residents is lower. In the future, the development of technology should reduce carbon emissions. Geothermal is still in its infancy, the technology is not mature and the development costs are high. However, unlike other RE, such as solar or wind power, which are affected by the weather, it can operate 24 h a day. Experts predict the future of geothermal technology will continue to reduce the cost of power generation. Geothermal will become the cheapest RE. Therefore, Geothermal has great potential for the development of clean energy.

Finally, this study proposes the following recommendations for Taiwan's RE development policy.

1. Improvement of energy efficiency: technology is the most critical factor in the development of RE in Taiwan. In particular, efficiency is the most important criterion. Therefore, solar, wind, biomass and geothermal RE must use advanced technology or innovation to improve efficiency and reduce cost.

Table 14
The result of sensitivity analysis using different scenarios and reasons.

Scenario	Best alternative	Description of possible reasons
scenario 1 - four dimensions are considered equally important	Solar PV	The value of technical maturity, job creation and social acceptance for solar PV are better than for other alternatives (the only exception being cost).
scenario 2 - financial dimension is the most important	Hydro	The technology of hydro power is the most mature and the cost is the lowest out of all the alternatives.
scenario 3 – technical dimension is the most important		
scenario 4 – environmental dimension is the most important	Wind	The carbon emissions of wind are lower. In addition, land use is lower than for hydropower and biomass.
scenario 5 – social dimension is the most important	Solar PV	Solar PV is generally the most popular RE. The destruction of environment is the least and people can install PV or lease idle land. Solar PV will become the star industry in future and as technology advances costs will be greatly reduced, making the installation of PV more popular.

2. Integration of the upstream, middle and downstream industrial chain: solar and wind energy can be integrated through the industrial chain to enhance the technical advantages. In addition, Taiwan is the world's second largest solar PV producer. Taiwan can use this competitive advantage to promote the overall PV industrial development, and then create a sizable domestic market and employment opportunities.
3. Encourage enterprises to engage in green energy industry-related technology research and development (R&D): to help enterprises replace energy-consuming equipment or transformation of energy-saving industries, provide enterprise subsidies, concessional loans and counseling to train technology R&D personnel. The government could organize technical seminars, build information sharing platforms, and combine promotion policies to achieve sustainable development of industrial policy aims.
4. Adjustment of electricity price structure: compared to other countries, Taiwan's electricity price is relatively low, and does not really reflect the cost of power generation. According to the latest statistics of 2016 by IEA, electricity price for households was ranked the third lowest worldwide and the price for industry was ranked the eighth lowest [83]. For example, in the neighboring Asian countries, such as Japan and South Korea, the electricity prices for households are 7.18/kwh and 3.49/kwh, respectively. However, in Taiwan the price is only 2.84/kwh. This may indirectly obstruct the development of RE because people or enterprises do not have incentives to install high cost solar energy and power generation equipment. Therefore, adjusting the electricity price structure is a critical issue.
5. Learning from successful foreign experience: nowadays, there are many countries where RE accounts for more than 50% of power generation, including Iceland (100%), Norway (96%), Brazil (85%), New Zealand (73%), Colombia (70%), Austria (68%), and Sweden (55%). Based on Taiwan's geographical advantages, the Taiwan government can refer to successful foreign cases to identify feasible implementation plans and accelerate the promotion of RE.
6. For sustainable development in the future, although the development of RE is an urgent task, reducing the reliance on fossil fuels is also very important to reduce the damage to the environment. The energy consumption of the transport sector is second, following industrial sector. Therefore, promoting the use of electric vehicles is a good solution for reducing energy consumption. The current price of electric vehicles is still high after government subsidies. If the government can intervene to reduce the price, people will intend to use electric vehicles.
7. In the past, the common duct is never implemented in Taiwan. Currently, electric power company, tap water, and telecom companies dig the road depending on their own projects. It is often found that the asphalted road was dug again that led to increased maintenance costs. Highly excavating frequency of pipeline have caused traffic jam, noise pollution, and road safety. Therefore, construction of the transmission lines of wind and solar power, and construct the common duct is a good way to solve this problem.

The development of RE is often accredited a positive image in the world due to the connection with environmental sustainability. However, in the setting of RE infrastructure, the environmental, technical, and financial support become the key factors for the success of RE development. There are several challenges in the development of RE and IM in Taiwan. Although Taiwan has the top 40 wind farms in the world, 60% of its wind potential is actually more than 50 m deep. The installation of offshore wind turbine, electricity transmission, and maintenance of operation are huge challenges. Moreover, Taiwan has a limited land to construct reservoir, develop wind power, which lead to the problem of land acquisition. Wind power is a new clean and green energy, while protests against wind turbine installations have arisen in Taiwan due to wind turbines are a source of noise. Therefore, Taiwan plans to establish off-shore wind farm in Taiwan strait. However, Taiwan lacks the experience of building the off-shore wind farm. Thus, the government actively encourages more international companies to participate in this project. The construction of reservoir for hydro power needs large areas of land and deforestation, while it leads to environmental damage. South part of Taiwan has sunny weather, which is suitable for a solar power. However, the main power consumption is in the north of Taiwan. So, it needs a big project to transmit the southern power to the north. In recent years, Taiwan's economy has faced drawbacks and it is difficult to implement many RE infrastructure projects simultaneously. This delayed the time for a nuclear-free homeland. In addition, architectural complexity also reduces the incentive for public participation. The overall financial support measure is not mature. These are Taiwan's technical, economic, and environmental challenges for RE development and IM.

Energy is the basic driving force for economic growth and development. However, due to the development and promotion of energy, a large amount of GHG are produced and cause global warming. Energy, economics, and environment are inseparable. The goal of energy policy should be attained to improve energy efficiency and develop clean energy, as well as a secure energy supply. It is a challenge for policy-makers to determine which energy policy should be promoted and what RES should be utilized. According to geographical advantages, natural resources, economic development, as well as the international situation, and other backgrounds, the energy policy that suits the development of the country is formulated. This study applied various MCDM and sensitivity analysis to realize how different situation lead to corresponding RES, which enables policy-makers to recognize the suitable RES under different policy that could be a reference for the development of RE.

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References

[1] Keyuraphan S, Thanarak P, Ketjoy N, Rakwichian W. Subsidy schemes of renewable energy policy for electricity generation in Thailand. Proced Eng 2012;32:440–8.
[2] Trappey AJC, Trappey CV, Lin GYP, Chang YS. The analysis of renewable energy policies for the Taiwan Penghu island administrative region. Renew Sustain Energy Rev 2012;16(1):958–65.
[3] Shen YC, Chou CJ, Lin GT. The portfolio of renewable energy sources for achieving the three E policy goals. Energy 2011;36(5):2589–98.
[4] Ayoub N, Yuji N. Governmental intervention approaches to promote renewable energies—special emphasis on Japanese feed-in tariff. Energy Policy 2012;43:191–201.
[5] Chuang MC, Ma HW. An assessment of Taiwan's energy policy using multi-dimensional energy security indicators. Renew Sustain Energy Rev 2013;17:301–11.
[6] Liou HM. Comparing feed-in tariff incentives in Taiwan and Germany. Renew Sustain Energy Rev 2015;50:1021–34.
[7] Chang CT, Lee HC. Taiwan's renewable energy strategy and energy-intensive industrial policy. Renew Sustain Energy Rev 2016;64:456–65.
[8] Huang YH, Wu JH. Assessment of the feed-in tariff mechanism for renewable energies in Taiwan. Energy Policy 2011;39(12):8106–15.
[9] REN21. Renewables 2016 global status Report; 2016.
[10] International Energy Agency (IEA). Renewable energy and jobs annual review 2016; 2016.
[11] AmCham Taipei. 2017 AmCham Taipei white paper. ⟨https://amcham.com.tw/advocacy/white-paper/⟩; 2017 [Accessed 26 April 2018].
[12]. Bureau of Energy (BOE). Energy statistics handbook 2015. Ministry of Economic Affairs. 2016.
[13] Chen HH, Lee AHI. Comprehensive overview of renewable energy development in Taiwan. Renew Sustain Energy Rev 2014;37:215–28.
[14] Taiwan Power Company. Introduction to renewable energy power generation; 2016. ⟨http://www.taipower.com.tw/content/new_info/new_info-b36-3.aspx?LinkID=8⟩ [Accessed 6 January 2017].
[15] Dinçer F. The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. Renew Sustain Energy Rev 2011;15(1):713–20.
[16] Bureau of Energy (BOE). Million solar rooftop PVs, ⟨http://www.moeaboe.gov.tw/ECW/english/content/Content.aspx?Menu_id=1761⟩; 2014 [Accessed 23 August 2016].
[17]. Bureau of Energy (BOE). 2016 Energy and industry technology white paper. Ministry of Economic Affairs. 2017.
[18] Wang JJ, Jing YY, Zhang CF, Zhao JH. Review on multi-criteria decision analysis

aid in sustainable energy decision-making. Renew Sustain Energy Rev 2009;13(9):2263–78.
[19] Stein EW. A comprehensive multi-criteria model to rank electric energy production technologies. Renew Sustain Energy Rev 2013;2:640–54.
[20] Mulliner E, Malys N, Maliene V. Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. Omega 2016;59:146–56.
[21] Chatzimouratidis AI, Pilavachi PA. Sensitivity analysis of the evaluation of power plants impact on the living standard using the analytic hierarchy process. Energy Convers Manag 2008;49(12):3599–611.
[22] Amer M, Daim TU. Selection of renewable energy technologies for a developing county: a case of Pakistan. Energy Sustain Dev 2011;15(4):420–35.
[23] Ahmad S, Tahar RM. Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: a case of Malaysia. Renew Energy 2014;63:458–66.
[24] Şengül Ü, Eren M, Eslamian Shiraz S, Gezder V, Şengül AB. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. Renew Energy 2015;75:617–25.
[25] San Cristóbal JR. Multi-criteria decision-making in the selection of a renewable energy project in spain: the Vikor method. Renew Energy 2011;36(2):498–502.
[26] Klein SJW, Whalley S. Comparing the sustainability of U.S. electricity options through multi-criteria decision analysis. Energy Policy 2015;79:127–49.
[27] Georgopoulou E, Lalas D, 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.
[28] Beccali M, Cellura M, 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):2063–87.
[29] Troldborg M, Heslop S, Hough RL. 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;39:1173–84.
[30] Kabak M, Dağdeviren M. Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology. Energy Convers Manag 2014;79:25–33.
[31] Štreimikienė D, Šliogerienė J, Turskis Z. Multi-criteria analysis of electricity generation technologies in Lithuania. Renew Energy 2016;85:148–56.
[32] Kahraman C, Kaya İ, 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):1603–16.
[33] Streimikiene D, Balezentis T, Krisciukaitienė I, Balezentis A. Prioritizing sustainable electricity production technologies: MCDM approach. Renew Sustain Energy Rev 2012;16(5):3302–11.
[34] Nigim K, Munier N, Green J. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources. Renew Energy 2004;29(11):1775–91.
[35] Akash BA, Mamlook R, Mohsen MS. Multi-criteria selection of electric power plants using analytical hierarchy process. Electr Power Syst Res 1999;52(1):29–35.
[36] Goumas M, 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):606–13.
[37] Ren H, Gao W, Zhou W, Nakagami K. Multi-criteria evaluation for the optimal adoption of distributed residential energy systems in Japan. Energy Policy 2009;37(12):5484–93.
[38] Chatzimouratidis AI, Pilavachi PA. Sensitivity analysis of technological, economic and sustainability evaluation of power plants using the analytic hierarchy process. Energy Policy 2009;37(3):788–98.
[39] Tsoutsos T, Drandaki M, Frantzeskaki N, Iosifidis E, Kiosses I. Sustainable energy planning by using multi-criteria analysis application in the island of Crete. Energy Policy 2009;37(5):1587–600.
[40] Kaya T, Kahraman C. Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: the case of Istanbul. Energy 2010;35(6):2517–27.
[41] Shen YC, Lin GTR, Li KP, Yuan BJC. An assessment of exploiting renewable energy sources with concerns of policy and technology. Energy Policy 2010;38(8):4604–16.
[42] Demirtas O. Evaluating the best renewable energy technology for sustainable energy planning. Int J Energy Econ Policy 2013;3:23–33.
[43] Yazdani-Chamzini A, Fouladgar MM, Zavadskas EK, Moini SHH. Selecting the optimal renewable energy using multi criteria decision making. J Bus Econ Manag 2013;14(5):957–78.
[44] Ren J, Sovacool BK. Prioritizing low-carbon energy sources to enhance China's energy security. Energy Convers Manag 2015;92:129–36.
[45] Huang YH, Wu JH. Energy policy in Taiwan: historical developments, current status and potential improvements. Energ 2009;2(3):623–45.
[46] Liou HM. Policies and legislation driving Taiwan's development of renewable energy. Renew Sustain Energy Rev 2010;14(7):1763–81.
[47] Lee AH, Kang HY, Liou YJ. A hybrid multiple-criteria decision-making approach for photovoltaic solar plant location selection. Sustain 2017;9(184):1–21.
[48] Kang MS, Chen CS, Ke YL, Lee AH, Ku TT, Kang HY. Applications of FANP and BOCR in renewable energy—study on the choice of the sites for wind farms. IEEE Trans Ind Appl 2013;49(2):982–9.
[49] Tzeng GH, Shiau TA, Lin CY. Application of multicriteria decision making to the evaluation of new energy system development in Taiwan. Energy 1992;17(10):983–92.
[50] Kang HY, Hung MC, Pearn W, Lee AH, Kang MS. An integrated multi-criteria decision making model for evaluating wind farm performance. Energ 2011;4(11):2002–26.
[51] Lee AH, Hung MC, Kang HY, Pearn W. A wind turbine evaluation model under a multi-criteria decision making environment. Energy Convers Manag 2012;64:289–300.
[52] Ertay T, Kahraman C, 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.
[53] National Renewable Energy Laboratory. NREL open EIdatabase, ⟨http://en.openei.org/apps/TCDB/#blank⟩; 2016 [Accessed 17 November 2016].
[54] Taiwan Power Company. Electricity generation costs for various power generation, ⟨http://www.taipower.com.tw/content/new_info/new_info-a02.aspx?LinkID=22⟩; 2016 [Accessed 17 November 2016].
[55] Bureau of Energy (BOE). Capacity factor. ⟨http://web3.moeaboe.gov.tw/ECW/populace/web_book/WebReports.aspx?Book=M_CH&menu_id=142⟩ [Accessed 17 November 2016].
[56] World Nuclear Association. Comparison of lifecycle greenhouse gas emissions of various electricity generation sources; 2012. ⟨http://www.world-nuclear.org/WNA/Publications/WNA-Reports/Lifecycle-GHGEmissions-of-Electricity-Generation/⟩ [Accessed 17 November 2016].
[57] Wei M, Patadia S, Kammen DM. Putting renewables and energy efficiency to work: how many jobs can the clean energy industry generate in the US? Energy Policy 2010;38(2):919–31.
[58] Amponsah NY, Troldborg M, Kington B, Aalders I, Hough RL. Greenhouse gas emissions from renewable energy sources: a review of lifecycle considerations. Renew Sustain Energy Rev 2014;39:461–75.
[59] E. Moula MM, Maula J, Hamdy M, Fang T, Jung N, Lahdelma R. Researching social acceptability of renewable energy technologies in Finland. Int J Sustain Built Environ 2013;2(1):89–98.
[60] Zou ZH, Yun Y, Sun JN. Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment. J Environ Sci 2006;18(5):1020–3.
[61] Ye J. Fuzzy decision-making method based on the weighted correlation coefficient under intuitionistic fuzzy environment. Eur J Oper Res 2010;205(1):202–4.
[62] Mohsen O, Fereshteh N. An extended VIKOR method based on entropy measure for the failure modes risk assessment – a case study of the geothermal power plant (GPP). Saf Sci 2017;92:160–72. http://dx.doi.org/10.1016/j.ssci.2016.10.006.
[63] Shad R, Khorrami M, Ghaemi M. Developing an Iranian green building assessment tool using decision making methods and geographical information system: case study in Mashhad city. Renew Sustain Energy Rev 2017;67:324–40. http://dx.doi.org/10.1016/j.rser.2016.09.004.
[64] Hafezalkotob A, Hafezalkotob A. Extended MULTIMOORA method based on Shannon entropy weight for materials selection. J Ind Eng Int 2016;12(1):1–13.
[65] Lotfi FH, Fallahnejad R. Imprecise Shannon's entropy and multi attribute decision making. Entropy 2010;12(1):53–62.
[66] Kabir G, Sadiq R, Tesfamariam S. A review of multi-criteria decision-making methods for infrastructure management. Struct Infrastruct Eng 2014;10(9):1176–210.
[67] Fishburn PC, editor. Letter to the editor—additive utilities with incomplete product set: applications to priorities and assignments.Operations research, 15. 1967. p. 37–542.
[68] Hwang CL, Yoon K. Methods for multiple attribute decision making. Multiple attribute decision making. New York: Springer; 1981. p. 58–191.
[69] Opricovic S. Multicriteria optimization of civil engineering systems. Belgrade: Faculty of Civil Engineering; 1998.
[70] Benayoun R, Roy B, Sussman N. Manual de reference du programme electre. Note de synthese et Formation 25, Direction Scientifique SEMA, Paris; 1966.
[71] Bagočius V, Zavadskas EK, Turskis Z. Multi-person selection of the best wind turbine based on the multi-criteria integrated additive-multiplicative utility function. J Civil Eng Manag 2014;20(4):590–9.
[72] Chitsaz N, Banihabib ME. Comparison of different multi criteria decision-making models in prioritizing flood management alternatives. Water Resour Manag 2015;29(8):2503–25.
[73] Lozano-Minguez E, Kolios AJ, Brennan FP. Multi-criteria assessment of offshore wind turbine support structures. Renew Energy 2011;36(11):2831–7.
[74] Tzeng GH, Huang JJ. Multiple attribute decision making: methods and applications. Boca Raton: Chapman and Hall/CRC; 2011.
[75] Büyüközkan G, Karabulut Y. Energy project performance evaluation with sustainability perspective. Energy 2017;119:549–60.
[76] Neves D, Baptista P, Simões M, Silva CA, Figueira JR. Designing a municipal sustainable energy strategy using multi-criteria decision analysis. J Clean Prod 2018;176:251–60. http://dx.doi.org/10.1016/j.jclepro.2017.12.114.
[77] Agrebi M, Abed M, Omri MN. ELECTRE I based relevance decision-makers feedback to the location selection of distribution centers. J Adv Transp 2017;2017:1–10.
[78] Haurant P, Oberti P, Muselli M. Multicriteria selection aiding related to photovoltaic plants on farming fields on Corsica island: a real case study using the ELECTRE outranking framework. Energy Policy 2011;39(2):676–88.
[79] Pinto F, Costa A, Figueira J, Marques R. The quality of service: an overall performance assessment for water utilities. Omega 2017;69:115–25.
[80] Chang SS. Fuzzy multi-criteria decision making for evaluation method. Taipei: Wunan; 2012. p. 2012.
[81] Theodorou S, Florides G, Tassou S. The use of multiple criteria decision making methodologies for the promotion of RES through funding schemes in Cyprus, A review. Energy Policy 2010;38(12):7783–92. http://dx.doi.org/10.1016/j.enpol.2010.08.038.
[82] Büyüközkan G, Karabulut Y. Energy project performance evaluation with sustainability perspective. Energy 2017;119:549–60.
[83] Taiwan power company. Comparison of national electricity prices; 2016. ⟨http://www.taipower.com.tw/content/new_info/new_info-d16.aspx?LinkID=14⟩ [Accessed 18 January 2017].