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Review

Renewable Energy Problems: Exploring the Methods to Support the Decision-Making Process

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Abstract: In the current scenario of increasing energy demand and encouraging sustainable development in countries, the energy sector's planning has become more complex, involving multiple factors, such as technical, economic, environmental, social, and political. The decision process plays a vital role in structuring and evaluating complex decision situations related to the sector, considering various criteria and objectives, encouraging adopting policies to promote energy efficiency actions by increasing research on renewable energy sources and strategic energy decisions. The high number of multi-criteria decision support methods (MCDM) available and their efficiency in solving highly complex problems results in an impasse with their selection and application in specific decision situations. Thus, the scientific community requires methodological approaches that help the decision-maker select the method consistent with his problem. Accordingly, this paper conducts a Systematic Literature Review (SLR) of renewable energy problems associated with MCDM methods based on a final set of 163 articles. We identified five categories of problems solved by MCDM techniques: Source selection, location, sustainability, project performance, and technological performance. We separate the MCDM process into five evaluation steps (alternative selection, criteria selection, criteria weighting, evaluation of alternatives, and post-assessment analyzes), and we extract the methods used in each MCDM step from papers. This paper's main contribution is identifying the most common MCDM methods in the renewable energy area and the energy problem they solve. Accordingly, this manuscript helps energy decision-makers, entrepreneurs, investors, and policy-makers to improve their ability to choose the proper MCDM methods to solve energy problems.

Keywords: multi-criteria decision analysis (MCDA); clean energy; problem class

1. Introduction

In the last two decades, world demand for electricity doubled [1], contributing to natural resources collapse. Environment pollution and energy crisis are two significant problems controlling modern society's sustainable development [2]. In this topic, energy is one of the most critical and pervasive issues that will confront decision-makers globally during this century. The importance of electricity to maintain economic growth has led governments to ensure that their growing energy demands are adequately attempted [3]. Thus, it is necessary to research the energy and sustainable development of nations. Relating to this, worldwide adopted policies to promote the introduction of energy efficiency actions and energy generation from renewable and sustainable sources [4–6], increasing the investigations about clean sources and strategy energy decisions.

The concern about the environment since the 1980s changed the decision-making structure of unique criteria [7]. Hence, environmental protection encompasses more factors (not only economic ones), forcing decision-makers to use Multiple Criteria Decision Making (MCDM) methods to solve energy problems [8]. So, it is essential to reconcile contradictory objectives, make decisions based on multiple criteria, and investigate the optimal solution. Thus, rational decision making in the management of the energy supply system is decisive for sustainable development. For this, the MCDM methods are effective. In this context, Wang et al. (2009) [7] reviewed the corresponding methods in different MCDM stages for sustainable energy. Their article discusses energy supply systems' factors from technical, economic, environmental, and social aspects. However, the study does not provide an overview of the leading renewable energy problems associated with MCDM methods. It is significant to provide a material that helps decision-makers choose the technique to be used, saving them from too long a search to understand each method applied to renewable sources' problems.

Selecting renewable energy sources is a complex problem involving different criteria and alternatives [8]. In this process, Büyüközkan et al. [8] measure the evaluation of renewable energy alternatives through an MCDM method, which is a flexible tool to deal with complex situations and assist decision-makers (DMs). MCDM methods allow considering opposing objectives and diverse stakeholders' opinions in the decision process [9]. Objectives are metrics that indicate decision-makers' desires. MCDM methods aid decision-making recommending actions to decide what to do from a sequence of steps [9,10]. Martins et al. [11] present an overview of decision-support tools applied to decommission, focusing on the oil and gas sector and multi-criteria decision analysis methods. The paper investigates deeply into the considerable aspects before reaching a decision, examining the experiences and methods found in industrial reports and academic papers. However, this research examined the experiences and methods of MCDM applied to the oil and gas sector. This evidence proves the current importance of explaining the use of multi-criteria techniques in complex scenarios, such as the current discussions on diversification of the electrical matrix.

The high number of potential MCDM methods available for use results in an impasse with their selection and application in specific decision situations. Thus, methodological approaches to selecting the MCDM method are required from an academic and practical perspective. Even though the literature recognizes the importance of adequately defining MCDM methods for solving renewable energy problems [7], most research presents the problem already associated with a particular MCDM method to guide the solution. However, researchers must deepen the justification for using the method to the studied problem, enriching the decision-making process.

There are many methods available in the literature, which sometimes confuses the researcher when deciding which one would give him or her a better result according to the problem situation. Moreover, each MCDM method has its advantages and disadvantages, and neither method dominating other methods [12]. Accordingly, scientific guidance on the essential aspects of MCDM techniques applied to renewable and sustainable power generation problems is a gap to be filled by this study. This paper conducting a systematic literature review (SLR) of renewable energy problems associated with MCDM methods, addressing the following Research Questions (RQ):

RQ1. What are the energy problems associated with the use of MCDM methods?
RQ2. What are the energy sources associated with the use of MCDM methods?
RQ3. What are the MCDM methods applied in each renewable energy problem and decision step (alternative selection, criteria selection, criteria weighting, evaluation of alternatives, and post-assessment analyzes)?

This investigation provides an overview of the leading renewable energy problems associated with MCDM methods, based on a final set of 163 articles, identifying the problems, the related sources, and the authors' techniques. To provide a material that helps decision-makers choose the technique to be used, saving them from too long a search for a better understanding of each method's behavior applied to renewable sources' problems. This paper has six sections. The second section presents related works. The third section presents the study's methodology. The four-section contains the research questions' results, encompassing sources, classes of problems, and MDCM methods. The fifth section presents the discussions, and the sixth section manifests the conclusions of this study.

2. State of the Art

Considering the variety of MCDM methods and the importance of renewable energy area some review studies are published. The reviews related to the methods and their applications emphasize the multi-criteria methods and the growing use of them. Table 1 presents ten review articles on the topic addressed by this study. The papers are from 2004 to 2020 and have different approaches and results. All documents have a significant number of citations. This citation number means that researchers use these articles as a source to support and discuss their method choices.

Table 1. Related works.

References	Study's Description	Journal	Scopus Citations *
Pohekar and Ramachandran (2004) [13]	A review of 90 articles analyzing MCDM methods in the power generation planning area. They concluded that several methods are based on priority setting, weighted averages, and overcoming fuzzy principles. They focused on the mathematical explanation methods, lacking a discussion about the problems.	Renewable and Sustainable Energy Reviews	1090
Wang et al. (2009) [7]	A review of the corresponding methods in different MCDM stages (criteria selection, weighting methods, MCDA methods, aggregation methods) for sustainable energy. They discuss energy supply systems' factors from technical, economic, environmental, and social aspects. The study does not provide an overview of the leading renewable energy problems associated with MCDM methods.	Renewable and Sustainable Energy Reviews	1101
Mardani et al. (2015) [14]	Conducted a review to provide an overview of several critical approaches and techniques proposed by MCDM over the years. Their study investigated 54 articles from 2003 to 2015 and examples approaches and techniques for sustainable and renewable energy issues. This study focuses on the methods by article.	Sustainability	119
Arce et al. (2015) [15]	A review of appropriated methods and three stages of MCDA (criteria selection methods, weighting methods, and MCDA methods) using grey relation methods (i.e., criteria selection and weighting methods).	Renewable and Sustainable Energy Reviews	64
Strantzali and Aravossis (2016) [16]	A review of 183 articles about energy planning and life cycle assessment (LCA), cost-benefit analysis (CBA), and multicriteria decision aid (MCDA). Their approach is broad and did not explain every step of the MCDM methods.	Renewable and Sustainable Energy Reviews	152
Mardani et al. [17] (2017)	A Systematic review of 196 articles by 2015, covering all energy sources in 13 fields. Their approach is broad and did not explain every step of the MCDM methods.	Renewable and Sustainable Energy Reviews	121
Kumar et al. (2017) [18]	Presented a narrative review of methods (their strengths and weaknesses), method application software, criteria, and indicators. However, they offer no connection between studies and do not discuss their practical applications.	Renewable and Sustainable Energy Reviews	360

Table 1. *Cont.*

References	Study's Description	Journal	Scopus Citations *
Kaya, Çolak, and Terzi (2018) [19]	A review of traditional MCDM papers and renewable and non-renewable energy alternatives. They focus on the criteria utilized by the paper. Their approach did not explain every step of the MCDM methods.	International Journal of Energy Research	23
Ilbahar, Cebi and Kahraman (2019) [20]	A review of 150 papers using MCDA methods and renewable energy. They classified the purposes of the articles into four categories and pointed out the methods used. They do not treat methods per MCDM step.	Energy Strategy Reviews	21
Siksnelyte-Butkiene, Zavadskas and Streimikiene (2020) [21]	A review of multiple-criteria decision-making (MCDM) methods as a key tool to evaluate renewable energy technologies in households. They focus on the technology source choose the problem.	Energies	6

* The number of documents cited by November 2020.

The researchers in Table 1 were concerned with providing a review of the application and use of energy management decision-making approaches. Our review paper differs from previous studies in two main points: dividing the renewable energy problems into five classes (source selection, location, sustainability, technologies performance, and project performance); and studying which MCDM method was used by MCDM steps (alternative selection, criteria selection, criteria weighting, evaluation of alternatives, and post-assessment analyzes). These two points were related, bringing greater clarity to the scientific community. Our review article brings the following contributions for researchers and society: It addresses the recurring problems about MCDM methods' choice and the possibility of reflection and learning by decision-makers; it proposes the five problem classes about renewable sources; It discusses the sustainability of clean energy sources; it brings a way to understand the MCDM general process through a flowchart that encompasses the five steps and the different methods.

3. Review Method

The review method is mainly based on the authors' Systematic Literature Review (SLR) guidelines [22,23], and Figure 1 presents the research procedures. In the first stage, we develop the reviews' questions in the introduction section. We selected three databases of relevant scientific articles in the energy area: SCOPUS, Web of Science, and IEEE. It was possible to cover the significant publishers (Elsevier, Emerald, Springer, Taylor and Francis, IEEE, and Wiley) [23]. Based on the initial readings, it was possible to identify all the words related to the research questions and create the search algorithm: TITLE-ABS-KEY ((“Multi Criteria Decision aid” OR “Multicriteria decision aid” OR “Multi Criteria Decision Analysis” OR “Multicriteria Decision Analysis” OR “Multi-Criteria Decision Making” OR “Multicriteria Decision Making” OR “Multi-Criteria Decision Method*” OR “Multicriteria Decision Method*” OR “MCDM” OR “MCDA”) AND (“Renewable Energy” OR “Sustainable Energy” OR “Cleaner Energy”)). The period for collecting articles was between 2009 and 2019 because the seminal study of Wang et al. [7] encompasses up to 2008, and the decision scenarios changed in that occurred in the last few years. The search was filtered from only articles without considering conferences, books, chapters, and thesis.

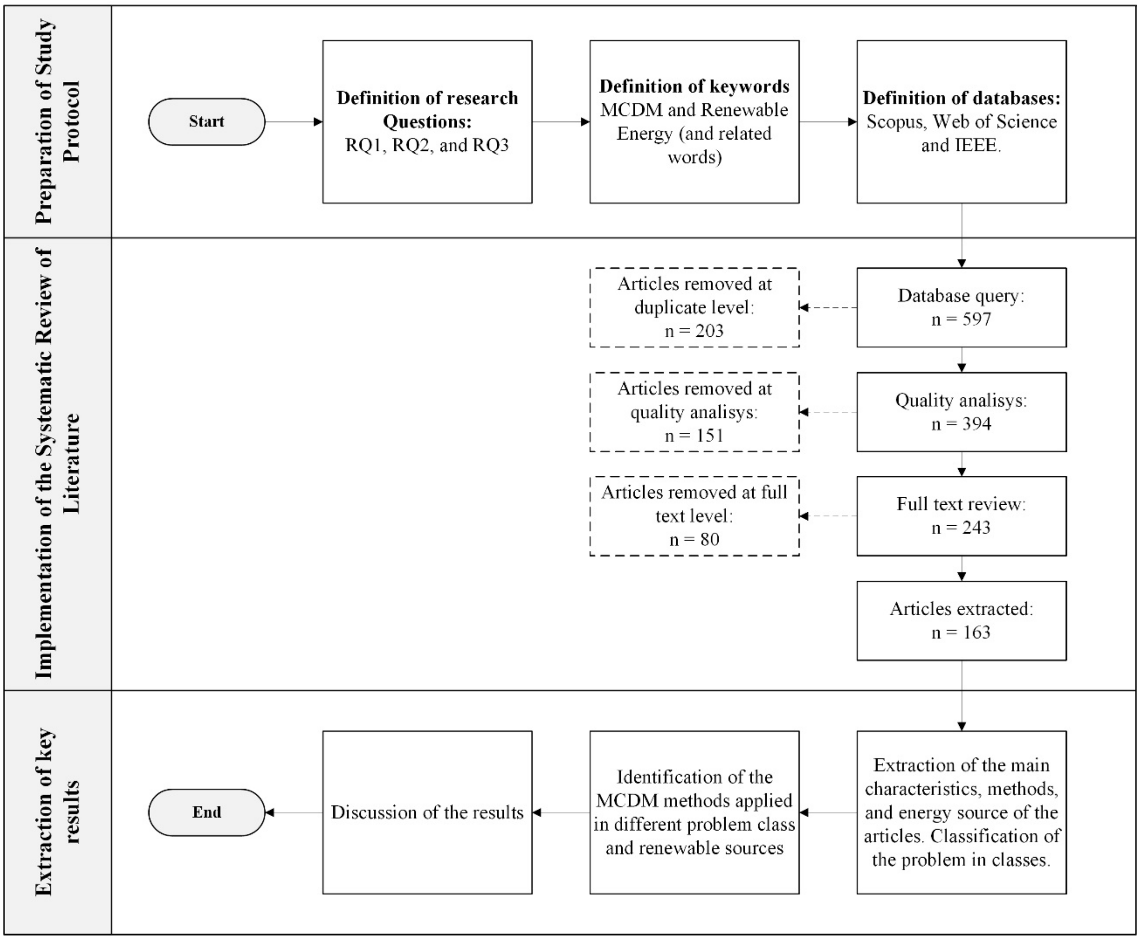

Figure 1. Review process.

According to Figure 1, all procedures were described. The database search resulted in 394 articles (we excluded the duplicated article using software Mendeley). Considering the high number of articles for content evaluation, we selected the most relevant articles considering *Scimago* classification, that only quartile one journals (Q1, high-quality researches), totaling 243 articles for the review. With a sample of 243 articles, we applied the first evaluation, responding to the following questions of each article: (1) Do the objectives of the article involve renewable energy? (2) Do the procedures of the article involves MDCM methods? (3) Is the article not a review? If one response to these questions is "No," the article was excluded from the next review stage. So, 80 articles were excluded in this analysis, and a total of 163 articles compose the final database.

The 163 articles were organized using a reference manager software Mendeley, and we analyzed their years, authors, title, journal, and country of the study application. The results are presented in subsection "Preliminary Findings" of the results section. The country of application has been carefully extracted from the articles because it is essential for the studying of energy problems using MCDM methods. Sequentially, each of the RQs was answered with a complete reading of the articles. So, for RQ1 "What are the energy problems associated with the use of MCDM methods?", each of the objectives of the articles was studied, until we understand that many problems could be associated with a class of problems, with five classes of problems being created to classify the articles. Their results are presented in the subsection "Problem Class" of the results section. For RQ2, "What are the energy sources associated with the use of MCDM methods?", each energy source studied in the articles was selected, be it a clean, renewable, sustainable, or fossil-fuel source. Their results are presented in subsection "Sources" of the results section. For RQ3 "What are the MCDM methods applied in each renewable energy problem and decision step (alternative selection, criteria selection, criteria weighting, evaluation of alternatives, and post-assessment analyzes)?", each article was critically evaluated for the MCDM process, and the different methods used in each step were identified. This was a critical process, as we had to use our expertise to identify which methods were used at each stage because this information was not always objective in the papers. Their results are presented in subsection "Multicriteria Methods" of the results section.

4. Results

The systematic literature review results were separated into four steps: Preliminary findings; classes of research problems; energy sources; and multicriteria methods.

4.1. Preliminary Findings

The number of articles per year observed a substantial increase from 2015 and 2016, both with 18 articles, to 2017 with 31 articles and 2018 with 41 articles. In 2019, 15 articles were published by the first semester. There was a predominance of six journals: Energy (26 articles), Renewable Energy (22), Energy Policy, Energies and Journal of Cleaner Production (14 each), and Applied Energy (11). The trend is for the number of publications to increase. Another relevant point for studies in the area of electric power is its country of application. Figure 2 shows the ranking with the ten countries with the most articles in a total of 55 countries. A few articles have not been applied in specific countries, such as across the European continent or Asia.

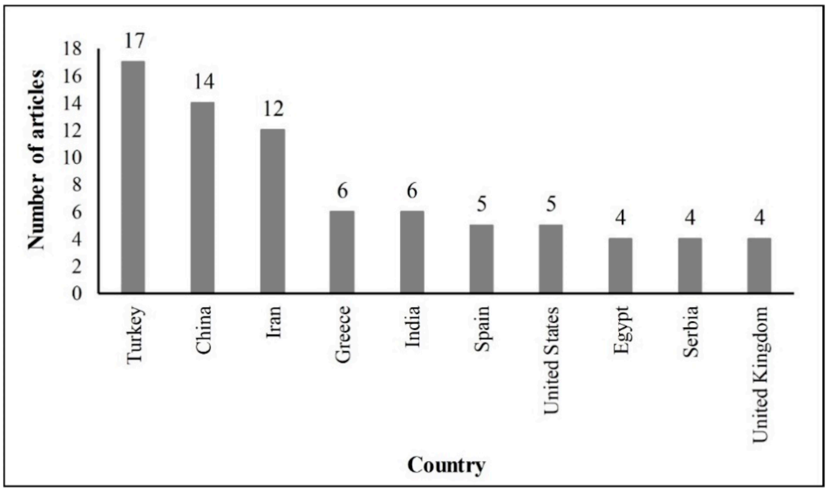

Figure 2. Distribution of articles by country.

Figure 2 shows that three countries are noteworthy in applying MCDM methods in renewable energy management: Turkey, China, and Iran. Turkey is in accelerated economic development and subsequently demands more electricity [1]. This rising electricity demand is being met by less carbon-intensive technologies [8]. Therefore, government policy development aims to increment the percentage of renewable energy resources by approximately 30% in total installed capacity by 2023 [24]. This scenario motivates researchers about the choice of renewable energy sources. China is a highlight in several scientific knowledge areas. China's intense economic development has led to numerous problems relating to energy production and environmental aspects [25]. So, the country has limited resources and limited reserves of traditional energy, and it was urgent to establish a strategy for the sustainable development of electricity generation [25]. In 2013, Iran was among the countries responsible for two-thirds of global carbon dioxide emissions, where the ratio of CO_2 (kg) to GDP was 2.17, very high compared to the world average of 0.57 [26]. Still, Iran donates diverse potential scenarios of renewable energy generation due to climatic diversity [27]. New government policies have been developed to expand scientific knowledge on renewable energy sources to meet energy demand, reducing dependence on fossil fuels [28].

4.2. Problem Class

The decision-making around renewable energy queries permeates the sustainability concept's multidimensionality and the socioeconomic and biophysical factors complexity involved in these decisions [7]. Even knowing the level of problem difficulty, it was possible to identify synergy between several problems and could be included in a homogeneous problem class. So, the problems were classified into five categories. Those that did not fit into these five categories were debated in the "other" category. The five problem classes are: (a) Source selection with 44 articles; (b) Location with 35 articles; (c) Sustainability with 31 articles; (d) Technologies performance with 26 articles; (e) Project Performance with 13 articles; and (f) Others, with 14 articles. The main aspects of each problem class are presented below, and Table 2 presented the problem class and the 163 references of the database.

4.2.1. Source Selection

Recently, several researchers and professionals have conducted studies to select the best renewable energy sources for their region of study (A novel approach to extended fuzzy TOPSIS based on new divergence measures for renewable energy sources selection). The decision-making process that determines the better energy sources involves many contradictory conditions at different levels, such as economic, technical, environmental, political, and social [29–31]. Different power generation technologies have different advantages and disadvantages [32]. With the use of multicriteria methods, it is possible to identify which one has a more satisfactory return for the region of application. MCDM methods are among the most helpful analyzes for energy source selection troubleshooting [29,33–35] and can be successfully implemented in power planning problems, particularly in complex scenarios within uncertainty, conflicting objectives, multiple interests, and different points of view [8].

4.2.2. Location

There is a visible increase in studies on locational aspects of power generation facilities. These studies vary widely concerning energy sources, applied methodologies, and the area's spatial scale [36]. Identifying optimal locations is a complex task that involves several criteria that can influence decision making [37,38]. The application of multicriteria methods is indicated in the solution of these problems [39,40]. Several of the environmental impacts of renewable energy technologies are directly associated with the renewable energy systems' geographical location and can be reduced by appropriate site selection [41]. Determining where a power generation system will be installed is a crucial step that precedes the technical project's development. Location optimization provides knowledge of the modeling problems related to configuration facilities in some specific regions based on specific factors considered (Investigation of accurate location planning for wind farm establishment: a case study). Factors that affect the environment, the economy, and the viability of energy production over the system's life must be considered.

4.2.3. Sustainability

Historically, countries' energy planning has focused only on energy costs [42]. However, with increasing awareness of the non-renewable scarcity resources, sustainable energy planning is critical. Sustainability research encompasses aspects such as Incentive policies for renewable energy development, which may involve concepts of the Energy Action Plan (EAP) [43], Renewable Energy Portfolio Standards (RPSes) [42], and Clean Development Mechanism (CDM) [44]; Strategies for increasing renewable energy participation [45–47]; Green building options using renewable energy such as Net Zero Energy Building (NZEB) [48]; and Selection of indicators and development of models for sustainability assessment [49–51]. Sustainability is inherently a multi-criteria concept, thus it is appropriate to use multi-criteria decision analysis (MCDA) [43]. In this scenario, MCDM techniques are used to choose among the various alternatives, assist public and private managers to rank priority policies and strategies, and/or eliminate low-performing sustainable alternatives.

4.2.4. Technologies Performance

When technology alternatives exist, technology performance assessments are relevant in improving renewable energy [52]. Various researches are aiming for a better sustainable performance regarding energy storage systems considering economic and technical factors [53]. Most studies address issues such as: developing assessment techniques to prioritize multiple-energy storage system (ESS) [54–56]; choose an appropriate turbine from multiple perspectives that best suits the wind power station [26,57,58]; decision criteria analysis to be used in the examination for the best photovoltaic cell [59]. Technologies are essential for a business' success. Therefore, managers must carefully evaluate and select the technologies [60], requiring a complex process that involves varying degrees of technical, economic, and environmental criteria. MCDM can cover the relevant factors and deal with the uncertainty and inaccuracy inherent in the technology evaluation problem.

4.2.5. Project Performance

The renewable energy project's performance consists of verifying the best energy project to minimize environmental impact and resource use, contributing to the local economy, employment, and technology transfer. Project performance evaluation should not be based on one perspective, such as cost or benefit [61]. It is necessary to observe the relevant aspects of the decision support models. The best configuration depends on socioeconomic factors, environmental concerns, design parameters, technical restraints, and the policymakers' interests [62]. So, the use of MCDM allows a broad understanding of whole system performance by decision-makers, throughout a range of weighting processes, uncertainty, and criteria sensitivity [62].

4.2.6. Other Problems

Some articles used MCDM methods related to renewable energy but did not fit into the problem classes above, such as low carbon providers' progress, which proposes a model for suppliers to improve their carbon performance [63]. In this category were found problems related to policy evaluation and investigated the factors affecting energy security [64,65]. Besides, difficulties related to clean energy scenarios were investigated [66,67]. Table 2 presents the description of the problem class definition and the respective references that specific studies.

Table 2. Problem class definition and references.

Problem Class	Definition	References	Total References
Source Selection	Decision-making process that aims to select a better energy source or a mix of sources	[1,8,29–35,68–101]	44 articles
Location	Decision-making process that aims to select the better location of energy generation of a source	[27,28,36,39–41,102–129]	35 articles
Sustainability	Decision-making process that aims to evaluate sustainable energy planning (rank priority policies and strategies, and/or eliminate low-performing sustainable alternatives)	[42,44–46,49–51,130–149]	31 articles
Technologies Performance	Decision-making process that aims to select the better technology (technical component, material, etc.)	[52,54–60,118,150–165]	26 articles
Project Performance	Decision-making process that aims to evaluate the project's performance	[61,62,166–176]	13 articles

4.3. Sources

The main focus of this study is renewable energy. Renewable energy is derived from naturally replenished sources in a short time [28]. We extract the renewable sources studied in the 163 papers. Some articles involve only one source and the other two or more sources. The most common sources in the documents are: Solar in 88 (Photovoltaic in 68, Solar Thermal in 15, Concentrated Solar Power (CSP) in 5); Wind in 82; Biomass in 47 (4 them about biogas); Hydro in 39; Geothermal in 30. Figure 3 was developed to explain which papers relate to more than one source, we use the Venn Diagram to do this. The diagram consists of five sets, each representing a source and the possible unions. We counted the articles that present the relationship with more than one source and display in the diagram if the link is observed in more than one article. We find the five sources' relationship in 18 articles, investigating the "source selection" problem class.

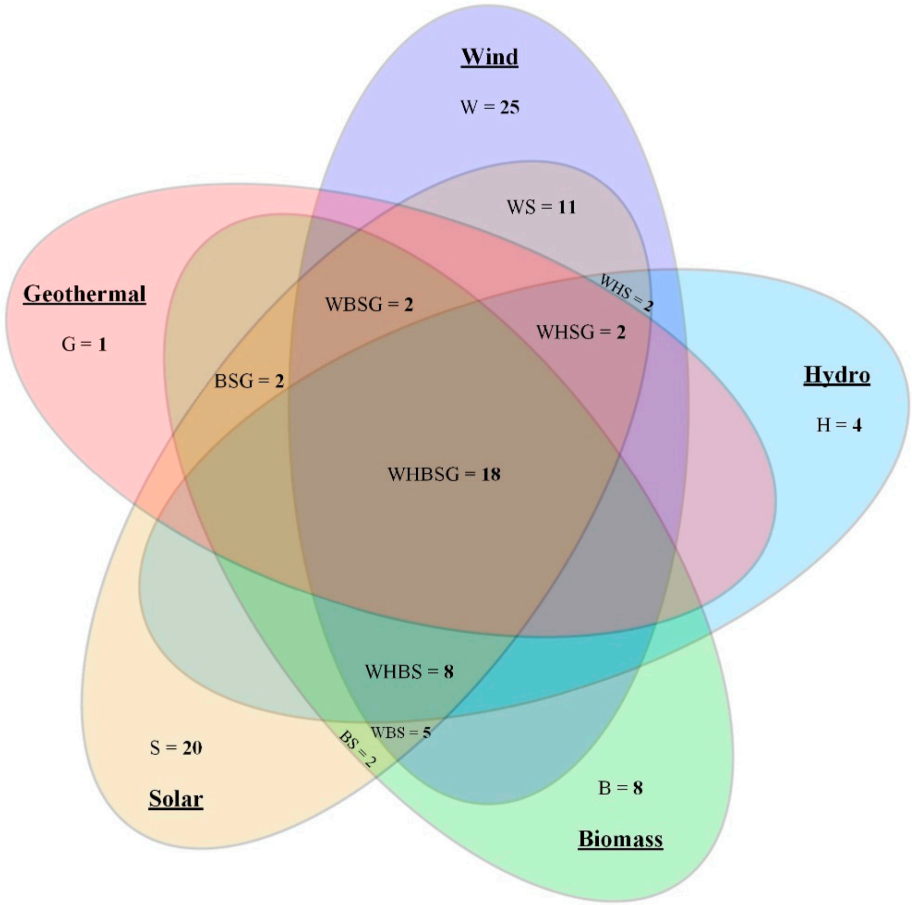

Figure 3. Venn Diagram of articles' renewable sources.

A total of 25 papers study exclusively wind source. Power generation from wind is advantageous because of its technological maturity, excellent infrastructure, and relative cost competitiveness. In the "source selection" problem class, 30 articles encompass wind in comparing sources to determine which is the best, resulting in the wind usually among the decision-makers' choices. Considering the wind turbine represents about 60% of a land wind farm costs [56], fourteen articles studied the wind turbine technology, associated with the "Technologies Performance" problem class. The combination of wind and solar sources appeared in 11 articles. Wind and Solar power generation are free and abundant clean energy that can be converted to other forms of energy without emitting air pollutants [28].

A total of 20 articles studied exclusively solar sources. Solar PV papers select the most suitable renewable energy for a given region, as it is abundant everywhere [46,100]. Solar thermal energy is present in studies aiming to increase sustainability, evaluating various power system options for hot water production in heating plants that produce and supply domestic hot water and home heating energy [131]. The Concentrated Solar Power (CSP) technology is constituted by adopting reflectors or mirrors to concentrate solar radiation on the heat transfer fluid used to generate electricity [34]. Found in studies that seek to analyze the best location for installation of CSP generation plants, as it is a technology that needs several factors in its performance, beyond solar radiation, the optimal location is essential for project performance and viability [112].

Among the 47 articles that related biomass, only 8 studied this source exclusively. Despite being an abundantly available source, generating biomass energy demands high investment and maintenance costs [94]. Of the 41 studies listed in the database, 30 are classified in the "source selection" and 7 in "sustainability". Also, studies related to biomass were applied in 38 different countries, with Turkey and China being the most relevant with, respectively, 10 and 5 studies.

Among the 39 articles that related to hydro power, only 4 studied this source exclusively. Hydro power plants are considered the most increased renewable energy worldwide [73]. The main advantage of hydroelectric power plants is their dependence on a freely available source, obtained free of charge [94]. Among the researchers, 29 are linked to the "source selection" problem class. Studies analyzing hydropower had applications in 20 different countries, highlighting Turkey and China with 11 and 5 studies. China has excellent water resources potential and also ranks first concerning hydropower [177]. All researches applied in Turkey are classified in the source selection problem class. For the authors [31,49,78] hydropower was rated as the best energy alternative for Turkey.

All studies with geothermal energy that analyze the problem class "source selection" are always compared to other sources. A significant number of studies have been conducted in Turkey, the world's seventh-richest geothermal potential country for direct use and electricity generation [94]. For this country, [31,35,69] rated it as the first, second, and third best energy sources respectively. The geothermal source is consolidated in Mexico, with the potential for development as it has a reliable power supply [79]. Then [44] shown to the geothermal resource as non-competitive in Chile, China, Israel, Kenya, and Thailand. Further, to the countries, Algeria [86] and Saudi Arabia [34], the geothermal source was not considered a priority for implementation.

4.4. Multicriteria Methods

Many MCDM techniques are available in the literature, which can be combined and personalized to specific needs, bringing considerable advantages to complex problems [8]. A methodological process of MDCM application can be developed in five steps: (i) selection of alternatives; (ii) selection of criteria; (iii) weighting of criteria; (iv) evaluation of alternatives; (v) final treatment, such as reliability and sensitivity analysis of the decision-making process. The decision-making process may require different methods for each step. This way, different methods can be chosen in each step or for more than one step. Not using methods in some steps is also acceptable.

The starting point of the process is objective development. In most of the papers analyzed, the goal structuring was already accompanied by the selection of alternatives. Therefore, in applying the MCDM process in the energy area, alternative selection methods are generally not necessary, because the decision-makers define the alternatives (sources, locations, technologies, policies). The step "select the criteria" lists the relevant factors to evaluate alternatives, supported by Selection Criteria Methods. The validity of the MCDM process correlates with the quality and quantity of selected criteria [33]. So, the decision-maker needs to make sure that the set of criteria matches the characteristics of the analyzed context [104].

With the alternatives and criteria established, it is necessary to select the weighting method to define each criterion's importance in evaluating the alternatives. In this case, there are two sets of methods, the subjective and the objective [7]. The characteristic of subjective methods is the sensitivity to the judgment of decision-makers, stakeholders, experts, and other respondents. Subjective methods are the most used because, in various cases, it is not possible to collect quantitative data to decide the relevance of one criterion to another. In objective methods, quantitative data are required. Sequentially, analysis of the options is viable throughout the evaluation of alternatives methods. Finally, the quality of the decision process can be done through a sensitivity analysis, regarding the weights used, and reliability analysis, comparing the results found with one method about others. We developed Figure 4 to elucidate the MCDM general process.

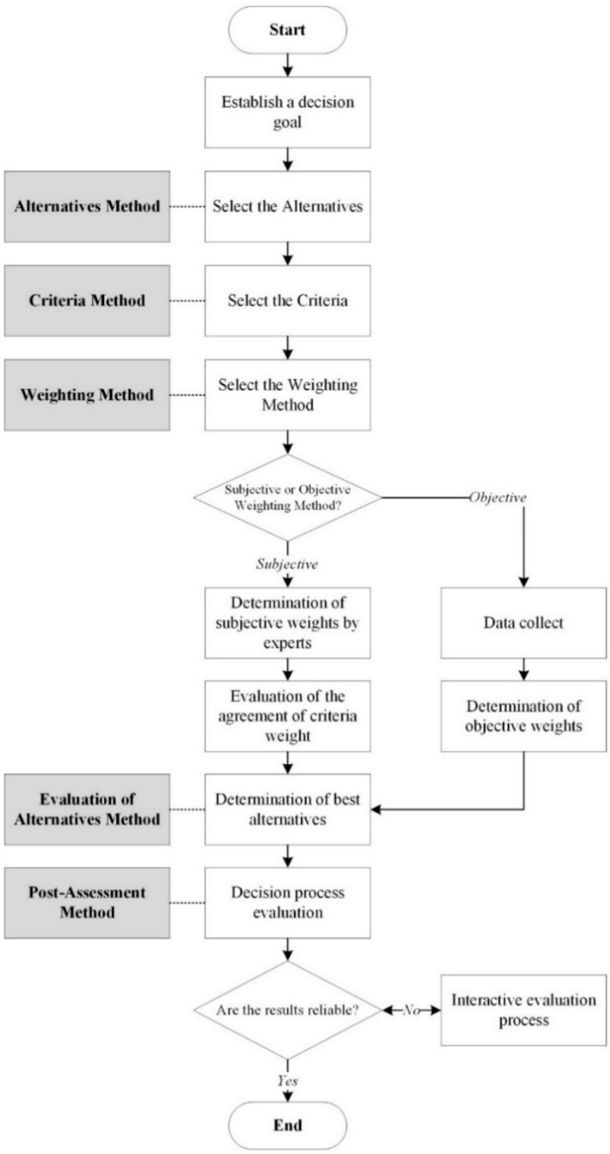

Figure 4. Multi-criteria decision support methods (MCDM) process.

The MCDM method used in each step of the process was extracted from the 163 articles. In the criteria selection step, a total of 122 papers use 13 different methods. In the criteria weighting step, 158 papers use 43 different methods (or variations of methods). In the alternatives' evaluation step, 159 papers use 52 different methods. Finally, in the post-assessment step, 49 papers use eight types of approaches. Table 3 presents the sum of articles per most used methods by the MCDM step.

Table 3. Methods for each MCDM step in papers.

MCDM Step	Methods	Number of Articles
Criteria Selection	Literature Review	98
	Experts	19
	Delphi and Fuzzy Delphi	4
Criteria Weighting	AHP and Fuzzy AHP	64
	ANP and Fuzzy ANP	12
	ELECTRE	8
	TOPSIS and Fuzzy TOPSIS	6
	PROMETHEE	6
	DEMATEL	4
Evaluation of Alternatives	AHP and Fuzzy AHP	40
	TOPSIS and Fuzzy TOPSIS	29
	ELECTRE	14
	ANP and Fuzzy ANP	9
	PROMETHEE	9
	VIKOR	6
Post-Assessment	Sensitivity Analysis	34
	Reliability Analysis	11
	Monte Carlo Simulation	5

We counted only 39 papers that used a method for alternative selection, but none is an MCDM method. A decision-making problem must start by clearly defining the problem, selecting and applying an MDCM method for evaluating alternatives. Thus, research begins with a problem that needs to be solved, so in most cases, the possible alternatives already exist, defined by the researcher. There are a few situations in which the alternatives do not come directly from the problem. When this occurs, the researcher can query specialists in the area to indicate the alternatives or even resort to the literature, looking for studies already carried out for possible alternatives. A particular problem class is "location" because the researcher generates alternatives through an adequacy analysis. The authors [39,129,178] studied local solar plant imposing the necessary restrictions. They used Geographic Information Systems (GIS) software, as 50% of papers related to problem class "location." GIS excludes the restricted study area, generating a bank of alternatives to be evaluated by multicriteria methods.

Following this section, we explain the methods set out in Table 3. In Section 5, we discuss the application of these methods to the different problem classes of papers.

4.4.1. Criteria Selection Methods

Literature Review

The literature review can be defined as collecting and synthesizing data from previous research [179]. The sample of the articles analyzed shows that 98 used the literature review to identify the criteria. Most articles, such as [31,73,86], do not have a research protocol, as a systematic literature review. When presented in the article, the research protocol allows the scientific community to reproduce its research in the databases, enabling it to be updated with the addition or deletion of criteria.

Experts

A second method of selecting criteria is by consulting experts in the field. In the area of renewable and sustainable energy, experts are professionals involved in the power process, like electricity generation techniques professionals, engineers, economists, environmentalists, and politicians [102]. In 19 surveys, the criteria were chosen by experts. Neves et al. [43] used brainstorming and roundtables, although [35,126] united literature review and expert opinion. The selection of criteria by experts may be associated with selection by literature review. Thus, both experts and literature's criteria are doubly indicated as criteria for the analysis of alternatives.

Delphi Method and Fuzzy-Delphi

Only two papers use the Delphi Method [59,180], and the other two papers used Fuzzy Delphi [52,55] in the criteria selection process. Initially, the Delphi Method was developed to achieve the agreement of opinions from experts into a series of concentrated questionnaires interspersed with controlled feedback from these opinions [181]. However, according to Engelke et al. [182], recent research using the Delphi methodology has dispensed with the search for consensus as a key factor for the method. Delphi is currently a trusted tool for collecting expert opinions. Xu, Nayak, and Gray [180], for example, utilized Delphi to identify energy businesses to achieve demand, considering efficiency and dependence on fossil fuels. Fuzzy-Delphi was used by Acar et al. [52], identifying 15 sub-criteria from the perspectives of technology, economy, environment, performance, and sociality. The Fuzzy-Delphi is a more advanced version of the Delphi Method because it employs triangulation statistics. The traditional Delphi model requires experts to get feedback and reconsider their previous judgments through rounds of consultation [183], which is ambitious, redundant, and difficult to collect unanimous opinions through consulting. Thus, the Fuzzy-Delphi model, integrating the conventional Delphi model and fuzzy theory, was put forward to solve the above demerits.

4.4.2. Weighting Criteria and Evaluation of Alternatives Methods

AHP

Analytic Hierarchy Process (AHP) is the most used method by the studies and decision-makers. A total of 64 papers used AHP (11 are fuzzy AHP) in the weighting criteria step, and a total of 40 papers used AHP (4 are fuzzy AHP) in the evaluation of alternative steps. AHP method has three principles: decomposition, comparative judgments, and priority synthesis [184]. For Saaty [185], AHP theory reflects the natural technique of the human brain function so that in a large number of factors, the mind aggregates them into common groups. The brain repeats this process and reassembles the elements at a "higher" level, based on common properties in the level immediately below. The repetition of the systematic reaches the maximum level when it represents the objective of the decision-making process [185]. The authors Kumar et al. [147], for example, applied AHP to consider, at stratified levels, many criteria, and opinions of the multiple stakeholders involved in sustainable micro-grid design scenarios. The three principles (decomposition, comparative judgments, and priority synthesis) can be accomplished by the following steps: modeling or structuring of the decision problem, valuation and aggregation of weight, and sensitivity analysis [186]. Expert comparative judgments weight the criteria of the hierarchical structure and permit a check of consistency by a proportion scale [187]. The alternative prioritization vector is calculated by assigning values that describe the degree to which a given alternative meets the criteria. Additive aggregation with the normalization of the sum of local priorities determines the overall option priorities at the last level of the hierarchical structure [186]. Hence, the AHP method permits divided the problem into its smaller parts, helping decision-makers organize the critical aspects of a problem [28,171]. The AHP was the most used method among the researched methods, besides being the most combined method to other techniques [9,188–191]. This statement is confirmed by [7] that AHP is most popular when considering multiple criteria by a hierarchical division of the problem.

ANP

The Analytic Network Process (ANP) was popularized by Saaty in 1996 [185]. The basis of ANP is the same as AHP because it is needed to make pairwise comparisons between the criteria linked to the same criteria. However, ANP considers all the existing connections between the network criteria [162]. So, the ANP technique is like the AHP, but the hierarchies are replaced by networks to consider all interactions between the clusters and elements within a cluster [192]. The applications observed were: [122] used the Fuzzy ANP to modeling a system for prioritizing sites in ocean energy sources; [166] used Fuzzy ANP to evaluate wind farm performance; [35] used an integrated DEMATEL-ANP approach for renewable energy sources selection.

TOPSIS

The Technique for Order of Preference for Similarity Ideal Solution (TOPSIS) is based on the idea that the selected alternative must have the shortest distance from the Positive Ideal Solution (PIS) and the longest distance from the Negative Ideal Solution (NIS) [31,128]. Alternatives are sorted in descending order by proximity index [118]. This method has been broadly adopted to resolve MCDM problems in many different areas [31]. One of the areas highlighted in the use of this method is in the decision making of renewable energy problems [193]. [118] applied the method to estimate and prioritize multiple technology transfer strategies for wind turbines. In Denmark, the method was used to prioritize renewable energy home heating technologies [98]. The TOPSIS method is also commonly used in decision making to identify optimal locations [40,112,128].

PROMETHEE

The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) is an outranking method capable of supporting different criteria, if any, as well as a mix of quantitative and qualitative measures of such criteria. The basic principle of PROMETHEE is on ranking and is well-suited to problems in which there is a finite number of actions to be assessed based on a range of conflicting criteria [150]. This method is regularly used for problems in renewable energy planning. [13,165] used the PROMETHEE method to analyze alternative heating energy systems for remote communities in Nunavik. In Vancouver, Canada, a study was conducted to help choose the source to use in a district heating system, where sources were classified based on six important criteria using the PROMETHEE method [68]. In 2017, Ziemba et al. [123] show the method's applicability in sustainability evaluation decision problems.

ELECTRE

The Elimination EtChoix Traduisant la REalite'(ELECTRE) is used to select the best activity from the set [194]. ELECTRE is constructed on the study of overcoming ratios and agreement and disagreement indices to examine overcoming ratios between alternatives, which makes the results more efficient [110]. There are several versions of the method ELECTRE (I, II, III, IV, IS e TRI), however, they all start from the same principle, differing only in the final mathematical procedures, making each version have a specific result. This method effectively supports decision making on new energy investments and performs well compared to other existing methods [24]. The authors Grujić, Ivezić, and Živković [77] proposed a model for the selection of the ideal district heating system comparing different options to meet the expected new heat demand, applying the ELECTRE to obtain the ideal system. Peng et al. [25] presented an applicable decision support model established by integrating the Z numbers, regret theory and, ELECTRE III to assess the risk of investing in new energy sources. In Greece, an analysis using ELECTRE has been applied to evaluate public policy mechanisms promoting energy efficiency and renewable energy sources in the Greek construction sector [139].

VIKOR

The method Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), focuses on developing a ranking based on a set of contradictory alternative criteria present, according to the proximity analysis of the "ideal" solution [72]. The evaluation principles of VIKOR can be originated from the Lp-metric employed as an aggregate function [55]. The authors Büyüközkan and Karabulut [35] proposed a performance appraisal model for power generation projects as a decision support tool for investors using VIKOR. [170] joined Fuzzy VIKOR and Fuzzy TOPSIS to select proper fuel mix to achieve maximum engine performance and environmental benefits while reducing harmful emissions. This method is commonly used in the evaluation of renewable energy project alternatives [35,72,81].

4.4.3. Post-Assessment Methods

Sensitivity Analysis

Sensitivity analysis occurs when the researchers have done alterations to the criteria weighting system to measure the intensity that the weighting has on the result of the MCDM process. In all, we account that 34 articles that made this type of analysis. The sensitivity analysis that we highlight are: [56] investigate the weights of the nine metrics, resulting in the same order in four alternatives analyzed; Maimoun, Madani, and Reinhart [82] analyzed the sensibility including and excluding criteria; Harkouss, Fardoun, and Biwole [48] compared the ELECTREE III with AHP weighting process, proving the robustness of the model. Finally, a study carried out in Brazil developed three cases of weight strengthening the same conclusions obtained [88].

Reliability Analysis

Reliability analysis occurs when the authors realize the alternative evaluation step by other methods to discover different ranking alternatives. This method comparison process serves as a validation of the MCDM process. In all, we counted only 11 articles that have done this kind of analysis. The comparisons between methods we highlight are: AHP and PROMETHEE, resulting in the same alternatives in first and second positions [156]; ANP and AHP, resulting in the ranking of the same alternatives [192]; ANP and MACBETH, had given the same ranking order of energy alternatives [74]; ELECTRE III and TOPSIS, it was observed that for the 33 best alternatives obtained by both methods there are 21 coincident alternatives [112].

Monte Carlo Simulation

The Monte Carlo Simulation is also conducted by modifying the weighting system, but differs from the sensitivity analyzes mentioned earlier by using the probabilistic method. Monte Carlo is a statistical simulation technique that approximate solutions to problems expressed mathematically, utilizing a sequence of random numbers to perform the simulation [96]. Thereby, the Monte Carlo simulation is implemented to ensure the robustness of the results assuming that the underlying weights are perturbed [32]. In the analysis scope, only five articles used this method to analyze the MCDM process's robustness. This procedure can be a differential in the analysis of the weighting system.

5. Discussion

Energy is necessary for economic growth, social development, and improved quality of life worldwide. Thus, the increased demand and consumption of electricity resulting from technological progress and the advancement of human development are seen as the most critical factors in the acceleration of climate and environmental changes observed and described by the scientific community. This scenario requires governments and decision-makers to make appropriate energy demand plans, including source assessment, exploration of alternative energy sources, and the definition of appropriate locations, and technical specifications.

In this sense, several studies consider how the community interacts to cooperate in favor of sustainable energy generation. Several organizations have been meeting in conferences to discuss our planet's future. These debates bring to the forefront measures that must be taken by countries. This decision-making entails numerous factors that directly impact the life of society. Sustainable decision making is understood based on behavioral society, the economy, and the environment. To support these combinations of decisions, the Multicriteria Decision Making Methods have emerged as useful mathematical tools for problem-solving configured with conflicting criteria.

This section presents the relationship of the results described in the third chapter: the relation problem class and source and the relation between problem class and MCDM methods, considering the different MCDM steps.

5.1. Problem Class and Source

The relationship between renewable energy sources and problem class is diverse. It is impossible to state that a source is always associated with only one problem class, except geothermal source, because, in all articles, it is in problem class "source selection", being compared to other sources. The "source selection" problem class has the most articles, comparing different energy sources. Thus, it is positive evidence that the energy sector is mobilizing to invest in renewable sources and uses the MCDM methodologies available to choose the source. In these comparisons, the important factor is choosing the best technical feasibility, maximizing the energy generation through the renewable sources' efficiency. This maximization seeks the source's sustainability, because the more competitive and assertive choices by the designers and managers, the greater its diffusion in the countries.

In addition to the choice between renewable sources, there is also a choice between non-renewable and renewable sources. In this case, the environmental sustainability factor enters into discussing the impacts arising from the countries' choices to maintain their energy matrixes based on exhaustible sources. The environmental criteria, when applied in the MCDM techniques, help in the rationalization of the decision. Faced with this, the "sustainability" problem class also compares different sources, except studies about political issues in general. Unlike the "source selection" problem class, the comparison between the sources in the "sustainability" problem class deepens the discussion of cleaner energy production. Reducing the emission of polluting gases and ending the use of exhaustible sources becomes the main objective behind each article's objectives.

The other three classes of problems—"location", "technologies performance" and "project performance"—become less comparative between sources, but the studies go more in-depth into just one renewable source. Regarding the "location" problem class, the most common are the clean sources, solar and wind. Even though these are clean sources in the electric energy transformation process, many environmental impacts can occur in installation locations. Photovoltaic plants require an extensive area of land, which, if not properly evaluated, can remove habitat for wild animals or agricultural areas. Wind farms can modify the natural landscape, in addition to interfering with migration routes and bird habitats. The best location choice, taking into account environmental and social criteria, increases the generation's sustainability through these sources. These articles are showing positive examples for the world community, driving the spread of these clean sources.

In the "technologies performance" problem class, the most common sources are the clean sources of solar and wind. These studies highlight the scientific community's relentless pursuit of making the efficiency of these sources ever greater. MCDM techniques seek to maximize generation in the face of less use of resources, increasing technologies' sustainability. The "project performance" class problem does not present a source of energy that stands out. In this type of problem, the main objective is to evaluate the projects' performance considering minimizing environmental impact and resource use, contributing to the local economy, employment, and technology transfer.

5.2. Problem Class and MCDM Method

An analysis of which methods are most commonly used to solve a specific problem class was investigated. For this, the total number of articles relating the problem class to a weighting method and an alternative evaluation method was accounted for, as shown in the bubble chart in Figure 5. Figure 5 shows the bubble chart with all relations of the problem class to the weighting method.

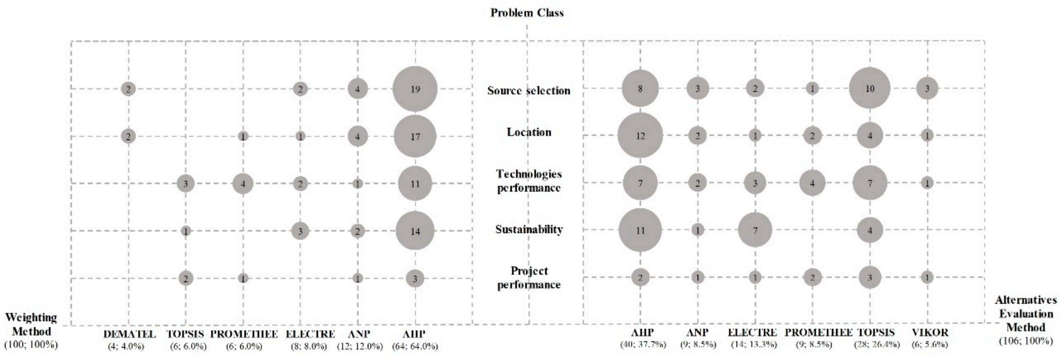

Figure 5. Methods-problem class combination in a bubble chart.

The central vertical axis shows the problem classes; the left horizontal axis shows the weighting methods; the right horizontal axis shows the alternative evaluation methods; the bubbles represent the number of articles per iteration.

A clear tendency of researchers to choose AHP can be noticed because, in all problem classes in this scenario, AHP is the most used method. AHP is highly recommended for weighting the criteria because it can transform expert opinion with accuracy and robustness. The good results in weighting motivate the extensive use of AHP. Besides the advantages in the weighting process, it can also be used to evaluate alternatives. However, it highlights paired weighting, where the method is most common in weighting.

Another aspect related to the excessive use of AHP is its flexibility regarding the practical application, without losses in the results' analysis robustness. AHP can efficiently deal with extracting qualitative data from, for example, the opinion of decision-makers about the importance of criteria, or even criteria that have inherent factual attributes. According to AHP's methodological assumptions, qualitative data can easily be transformed into a quantitative dataset using standardized value scales. Even when the nature of the criteria is quantitative, AHP allows, through scales, as the standard scale proposed by Saaty, to standardize attributes represented by different measurement units. For interpretative and managerial purposes, numerical results can be converted back to qualitative format to facilitate understanding of the application context. Thus, the application of AHP in different contexts of energy management problems is justified and reflected in the bibliometric research results conducted during the presented study.

If AHP brings the hierarchical view of problems, the ANP broadens this relationship by considering all possible connections between criteria with the network view. Even represented by 12 articles, ANP is still little explored compared to AHP. The cause of the least use may be the level of consistency ratio required for ANP results to be considered adequate because when the criteria are paired in a network, the number of pairs that an expert should judge will be higher and may bring more substantial inconsistency levels of the judgment matrix. Thus, the cost-benefit of the application of ANP should be evaluated by the researcher.

In the alternatives evaluating methods, TOPSIS is also a method that stood out in solving energy problems. The possibility of evaluating the performance of alternatives through similarity to the ideal solution makes the method easy for the researcher to understand, favoring the application of TOPSIS. Its similarity methodology also enables the researcher to gauge and validate the results obtained by presenting a clear and coherent logic.

There is a highlight in the relationship between the Sustainability problem class and the ELECTRE method, where there are seven articles, a high number when compared to the others. Neves et al. [43] argue that the application of MCDA using the ELECTRE III method is very popular at the regional and national levels for sustainability and renewable energy deployment purposes. In sustainability problem class articles, the goal has always been to select a better scenario, planning, or strategy to increase sustainability. The ELECTRE method was used due to the need for a method that systematically selects a unique and robust solution [44,148].

The use of ELECTRE in its traditional format is generally not trivial because the analysis of the results occurs focusing on excluding alternatives considered as not sufficient for the context of the studied problem. Besides, how ELECTRE was developed does not require that ordering of alternatives be performed, which compromises the achievement of quantitative results and more accurate conclusions about the relationship between the listed criteria and the evaluated alternatives. Given this feature, the method was more present in the choices of sustainability, which is the most subjective problem class for such decision analysis.

Another aspect discussed in Figure 5 is null or unique iterations between methods and problem class, such as PROMETHEE and Source Selection and Sustainability; ELECTRE and Project Performance; Weighting with TOPSIS and Source Selection and Location; among others. The non-recurrence of these iterations can be understood from two conclusions: (1) The methods are not considered appropriate to solve renewable and sustainable energy problems adequately; or (2) They were not used due to the unfamiliarity of the researchers about the results that these methods are capable of providing. Thus, they were opting for the most known and recurring methods for solving problems, such as AHP, a well-established method in the area of energies.

6. Conclusions

This study identified the most often used MCDM methods in renewable energy and its purpose. The systematic literature review outlines the main problems that researchers seek to solve sustainable and renewable energy sources related to these problems, and the MCDM methods used in each decision-making stage. We concluded that MCDM methods had been widely employed in sustainable energy decision-making, considering multi-criteria. We identified five categories of problems solved with MCDM techniques: Source selection, location, sustainability, Project performance, and technological performance. There is a high concentration on using AHP to solve multi-criteria problems found in this area (64% in the weighting process and 37.7% in the evaluation alternatives process), followed by TOPSIS and ELECTRE (26.4% and 13.3% in the evaluation alternatives process). There are relevant MCDM techniques that are little explored in this area, such as PROMETHEE, VIKOR, and DEMATEL. This article suggests the problems in which methods can be used effectively to contribute to the method application. The article provides updated references, found according to the proposed search protocol, for the main stage of using the MCDM: Criteria Selection Methods and Weighting criteria and evaluation of alternative methods.

The research proves that the energy sector is increasingly concerned and interested in planning projects related to clean sources, such as Solar, Wind, Hydro, and Geothermal. As they are sources exposed to problems related to multiple conflicting criteria, there is a need for a methodology that makes it possible to incorporate these different criteria in their mathematical model. MCDM becomes a popular tool in the area of energy planning, applied to the most varied types of problems, due to the flexibility it provides decision-makers, providing scientific support, which on several occasions, involves conflicting criteria, inaccurate data, and a challenge to quantify. The complexity of the problems and the characteristics of uncertainty/imprecision of the collected data demands an approach that seeks to address these factors. With this information, when the decision-maker has a problem with many criteria to be analyzed in renewable and sustainable energy, they can choose consolidated MCDM methods because MCDM methods are useful for solving several problems. The present research can motivate future studies aiming at the gaps found, proposing new problem-solving techniques through methods that have not yet been used.

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