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A review on multiplicity of methods, criteria and data sources for multicriteria decision making on energy transition environment

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RESUMO

Muitas empresas e governos têm avaliado soluções energéticas para seus negócios e regiões, buscando a diversificação energética e a descarbonização para reduzir seus impactos nas mudanças climáticas que já testemunhamos em diversas partes do mundo. A análise destas soluções energéticas consideram uma grande diversidade de energias provenientes de fontes renováveis, que requerem a avaliação de uma multiplicidade de critérios, muitas vezes conflitantes. Para isto, um caminho que tem se mostrado robusto é a adoção de métodos de tomada de decisão multi-critério. Nesse contexto, esta pesquisa faz uma revisão sistemática da literatura sobre a adoção de métodos de tomada de decisão multicritério na busca de soluções de diversificação energética e descarbonização, buscando identificar os principais métodos empregados nesta análise, os critérios de avaliação mais considerados para cada tipo de energia, e os tipos e abrangência das fontes que disponibilizam os dados utilizados nos processos de tomada de decisão.

PALAVRAS CHAVE. Métodos de decisão multi-critério, Critérios de avaliação, Fontes de dados, Transição energética, Energias renováveis

Tópicos: Cidades e Regiões Inteligentes e Sustentáveis; P.O. em Energia, Petróleo e Gás.

ABSTRACT

Many companies and governments are evaluating energy solutions within their businesses and regions, seeking both the energy diversification and the decarbonization to reduce its impacts on the climate changes that we witnesses in different parts of the world. The analysis of these energy solutions considers a wide diversity of energies from renewable sources, which requires the evaluation of a multiplicity of criteria, often conflicting. To achieve this goal, a path that has proven to be robust is the adoption of multi-criteria decision-making methods. Within this context, this research carries out a systematic literature review on the adoption of multi-criteria decision-making methods in the search for energy diversification and decarbonization solutions, aiming identify the main methods adopted in those analysis, the most considered evaluation criteria for each type of energy, and the types and coverage of sources that provides the criteria data considered on the decision-making processes.

KEYWORDS. Multicriteria decision methods, Evaluation criteria, Data sources, Energy transition, Renewable energies

Topics: Smart and sustainable cities and regions; O.R. in Energy, Oil and Gas.

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1. Introduction

When it comes to economic development, especially regarding countries industrial development, energy is the most important component. And it comes even more important if we consider that the world's population is rising at positive rates, as so as its energy demand. And forecasts foresee it will continue growing for the next decades. [Aslam et al., 2024]

In this context, fossil fuels still provide the very most of energy sources consumed in the globe recently. Even though, it's remarkable to notice that renewable energy (RE) resources are expanding more quickly within countries energetic matrix, and that comes from the growing concern with the raising of carbon emissions at accelerated rates, which exacerbates global warming caused by fossil fuels consumption. [Krozer, 2019]

Due to the greenhouse gases (GHG's) emission at concerning levels resulted from indiscriminate use of fossil fuels, countries have realized the need to swift it's source of energy from fossil fuels to RE sources, considering that a low CO2 emitting country's environmental quality is largely sensitive to the consumption of renewable energy. [Rahman et al., 2024]

The proportion of renewable energy resources in electricity matrix production is experiencing a huge increase, due to its cleaner production and high energy efficiency. [Lotfipour e Mohtavipour, 2024]

Organizations and governments are growing investments on renewable energy systems (RESs) as wind energy, solar energy, geothermal energy, biomass etc. considered alternatives for conventional fossil fuels. For this, it's necessary to assess the sustainability level of RESs regarding long-term viability guarantee, progress and track advancements monitoring, the possible chances for improvement and decision-making supporting capacity. So, this sustainability assessment is itself a multicriteria decision making (MCDM) problem because several factors must be evaluated, many of which are sometimes in conflict with one another. Hendiani e Walther [2023]

This sustainability assessment of the impacts and opportunities of RESs incorporates sustainability principles in the decision-making, which is often a complex and multifaceted problem. For this, MCDM is a systematic methodology capable of synthesizing these heterogeneous considerations to evaluate and prioritize different alternatives. [Boix-Cots et al., 2022]

Therefore, the present study aims to conduct a Systematic Literature Review (SLR) to assist the community to better deal with – and get ready for – the energy transition challenges. For that, a systematic search will be made upon researches about MCDM methods applied for assessment on renewable and clean energy adoption, aiming to identify the main methods adopted in those analysis, the most considered evaluation criteria for each type of energy, and the types, scope and availability of sources that provides criteria data for the decision-making processes.

The main contributions of the present study are the findings on the following tree MCDM aspects within studies on the energy transition context: the identification of the most adopted decision-making methods, the understanding of the need to observe the study context when picking a criterium up, and the listing of sources[1] that provides criteria data with global coverage.

The present study is structured as follows: Section 2 presents the integrated research method for identifying, refining, and selecting publications within databases, with the scope and research protocol adopted for articles search. Section 3 brings information from similar or related works about MCDM studies on energy context. Section 4 investigates the findings extracted from the literature review made after the search undertaken through tables and charts, in order to find the answers for the research questions previously made. Lastly, Section 5 provides discussions and research limitations upon the findings, leaving conclusions to Section 6.

[1] In final version an Annex will be given on authors website (omitted during peer-review to preserve anonymity)

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2. Research method

In the systematic literature review process, the existence of a predefined protocol, which is strictly followed, reduces existing biases among researchers and increases its rigor and reproducibility. [Keele et al., 2007]

When it comes to plan the review protocol, it is necessary to elaborate a list of research questions and then describe its scope, search method and search string for the systematic review, in addition to describing the inclusion criteria and exclusion of the bibliography to finally define the quality assessment criteria of the selected studies. [Van Dinter et al., 2021]

In order to ensures the work's methodological accuracy and completeness, and also the uniformity and thoroughness of research, this study adopts the PSALSAR approach, which has six main steps: Protocol, Search, Appraisal, Synthesis, Analysis, and Report [Mengist et al., 2020]

The methodology for conducting this systematic literature search considering the PSALSAR approach is presented on Table 1.

Approach	Steps	Tasks	Article's item
P	Research Protocol	Study scope: identifying the MCDM methods, criteria and data sources used in energy adoption analysis	2.1 - 2.2
S	Searching	Searching for publications related to the research goals	2.3 - 2.4
AL	AppraisaL	Selecting eligible studies	2.5
S	Synthesis	Classification information from included articles	4.2
A	Analysis	Analyzing the search process and the classified information extracted from articles to propose a new approach	5
R	Report	Summarizing the results of analyses in the form of an article	This article

Table 1: Methodology for this systematic literature review.

2.1. Research questions

This systematic review aims to answer the following questions, in the context of MCDM methods applied for assessment on renewable and clean energy adoption:

1. Which are the most applied MCDC methods in energy studies?
2. Which evaluation criteria are being most adopted within these MCDM assessment?
3. How many data sources are being considered by making criteria data available for decision-making process, and what is the coverage of available data?

2.2. Search scope

The search scope is defined following the PICOC methodology. For each PICOC's section, the related terms have been defined as: *Population:* Renewable energy; *Intervention:* Multi-criteria decision-making; *Comparison:* Oil & gas industry, fossil fuel, petroleum; *Outcome:* evaluation criteria, variables; *Context:* Energy transition, decarbonization.

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2.3. Search method

The search method consists in adopting the PICOC terms on the search string at each articles database considered. The databases that were considered for this search are those collections that can be accessed trough "Periodicos CAPES" [Periodicos, 2024] and are classified as a Computing Science database. The following seven libraries or database were selected for the research search: ACM Digital Library, IEEE Digital Library, ISI Web of Science, Science@Direct, Scopus, Springer Link and Wiley.

2.4. Search String

The search string may not be too specific, therefore having many terms on it that makes the search inefficient, neither can be too generic, with just few terms resulting in large lists of articles with no relevance for the study.

The base search string for handle this study search is:

```
[ ("MCDM") AND ("Energy transition" OR "decarbonisation" OR
"Renewable energy") AND ("criteria" OR "variables") AND
("Oil & gas industry" OR "fussel fuel" OR "petroleum") ]
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Nevertheless, variations ware necessary to be applied, due to specific search requirements that each database adopts. This search string was applied on the seven databases, finding a total of 1.127 articles.

2.5. Literature selection criteria

Upon the article's lists returned from the databases searches, a two-step selection procedure is proposed: a cutting-off adherence step is applied first, followed by a relevance-evaluation step. Both procedures are executed having as input the three main article's information: title, keywords and abstract. At first step, the following three criteria are applied on the complete list:

- Criterion 1: Terms from 3 out of the following 4 PICOC sections are mentioned at least once in the title, keywords or abstract: Population, Intervention, Comparison or Context. Terms from section 'Outcome' have not been considered for selection criteria due to its high appearance frequency observed.
- Criterion 2: Terms from 2 PICOC sections are mentioned at least once in the title, keywords or abstract, being one of these the 'Intervention' section necessarily, for it being considered de most relevant section within this study, and the other section any of the following three: Population, Comparison or Context.
- Criterion 3: Terms from 2 out of the following 4 PICOC sections are mentioned at least once in the title, keywords or abstract: Population, Intervention, Comparison or Context, plus 1 of the following two terms related to this research focus: 'gis' or 'map'.

The articles that doesn't attempt to any of the 3 criteria are cut-off from the list for next step.

At second step, the remaining articles are categorized as per it's expected relevance, accordingly to the terms found on its title, keywords and article. For this, a deeper evaluation of the articles' information is made considering a wider list of research related terms, having a relevance grade being assigned for each article.

This grade is composed by the sum of specific values assigned for each aspect evaluated, which can be: 1 – if one or more terms from the aspect evaluated appears on the article's title or

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keyword; 0,5 – if one or more terms from the aspect evaluated appears on the article's abstract; 0 – if the terms from the aspect evaluated don't appear on any of the article's main information.

The specific values described above are assigned to the following article's aspects:

1. Appearance of terms related to PICOC's Population section: Renewable energy; clean energy; green energy; sustainable energy; renewable energy; renewable source; energy sources; biomass; biogas; bioenergy; biofuels; pumped hydro; hydro storage; critical minerals; CCS; CCUS; carbon capture; lithium; mineral; solar; wind; geotherm; hydrogen.

2. Appearance of terms related to PICOC's Intervention section: MCDM; multi-criteria; multi-criterion; decision parameter; evaluation of metric; evaluation criteria; data envelopment; multicriteria; multi-variable; multi-indicator; decision support.

3. Appearance of terms related to PICOC's Comparison section: oil & gas; fossil fuel; oil exploration; oil industry; gas industry; natural gas; petroleum; traditional industry.

4. Appearance of terms related to PICOC's Context section: Energy transition; decarbonization; decarbonizing; low carbon; sustainability; climate-change; environmental sustainability; ecosystem; circular economy; life cycle assessment; LCA; energy transition; climate change; GHG; greenhouse gas; low-carbon; net zero.

5. Appearance of terms related to spatial analysis: GIS; map.

6. Appearance of terms related to data source availability: data source; data envelopment.

7. Appearance of terms related to geoscientific related renewable energy: hydrogen; geothermal; mineral; CCS; CCUS; carbon capture; lithium.

8. Appearance of terms related to other renewable energy: bioenergy; biomass; biogas; biofuels; tide; tidal; pump hydro; wind; solar; photovoltaic; PV.

After carrying out the evaluation defined on second step, the relevance grade assigned to each article shall be between 8 (eight), if all its aspects are assigned with the individually maximum grade, and 0 (zero), when we are in the opposite situation. Articles with relevance grade higher than 4.0 are considered relevant for this study and will be assessed regarding the research questions, due to their relevance grade.

3. Related work

A wide range of studies are found in literature about MCDM methods seeking for energy transition solutions. Solar studies, for example, mainly establish criteria for solar power plant site selection. [Van Dinter et al., 2021] Energy matrix studies usually makes quantitative analysis for select the most sustainable energy production methods. [Genco e Genco, 2021]

Hydrogen studies sometimes investigates the selection of sustainable hydrogen production technologies. [Mei e Chen, 2021] In other cases, it investigates the most appropriate site for establishing a hydrogen plant. [Seker e Aydin, 2020] Hydrogen studies are also associated with solar energy, evaluating land suitability for hydrogen production from solar energy site selection. [Messaoudi et al., 2019] And in the case of hydrogen storage studies, they look for the most suitable storage alternative. [İlbahar et al., 2022] Hydrogen studies also are associated with CCUS (Carbon Capture, Use and Storage) technologies in few cases, proposing multi-criteria frameworks to select suitable sources of carbon dioxide and hydrogen, both for the carbon dioxide conversion process. [Lopes et al., 2021]

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Geothermal energy studies, in most cases, tries to identify promising areas for geothermal exploration, usually through favorability maps. [Jara-Alvear et al., 2023] Sometimes, these studies are associated with other energy, as hydrogen, evaluating the electricity generated from a geothermal source. [Ramazankhani et al., 2016]

Offshore wind studies approach usually considers location alternatives assessment. [Gil-García et al., 2022] This energy studies can also be associated with solar energy, having, though, the same location assessment focus. [Elkadeem et al., 2022] Biomass and biofuels studies commonly finds optimum locations for its facilities. [Ghose et al., 2019] Finally, natural gas studies investigate potential decarbonization strategies for the natural gas industry value chain. [Kotagodahetti et al., 2023]

4. Research findings

4.1. Research process findings

Within the systematic literature review process applied on this research, the article selection starts applying the defined search string on each of the 7 libraries and databases chosen for this research. The total of articles returned from each database searched is presented on Table 2.

The cutting-off adherence procedure step selected 355 articles that are expected to have relatively high adherence to the study, according to the 3 criteria previously defined, which were formulated from PICOC fundamentals and some few other terms also related to this research objective. The article's quantity selected by each criteria is presented on Table 3.

ACM Digital Library	0 articles
IEEE Digital Library	2 articles
ISI Web of Science	0 articles
Science@Direct	397 articles
Scopus	718 articles
Springer Link	0 articles
Wiley	10 articles
TOTAL	1.127 articles

Table 2: Articles from database

Selected by criterion 1	24 articles
Selected by criterion 2	325 articles
Selected by criterion 3	6 articles
TOTAL SELECTED	355 articles

Table 3: Articles selected by criterion

Following, the relevance-evaluation step procedure evaluated 8 aspects on each of the 355 selected articles and assigned a grade for each article.

From this step procedure, we have that the maximum grade actually assigned to an article is 6.0 and the minimum is 1.0. Also, 26 (7.3%) of the selected articles have been assigned with a grade higher than 4.0, being, then, considered relevant, and were assessed regarding the research question. Table 4 presents the quantity of selected articles assigned with each relevance grade.

Relevance Grade	8	7,5	7	6,5	6	5,5	5	4,5	4
Selected Articles	0	0	0	0	1	0	9	16	28
Cumulative Percentual (%)	0	0	0	0	0,3	0,3	2,8	7,3	15,2

Relevance Grade	3,5	3	2,5	2	1,5	1	0,5	0
Selected Articles	43	56	54	68	60	20	0	0
Cumulative Percentual (%)	27,3	43,1	58,3	77,5	94,4	100,0	100,0	

Table 4: Selected articles per each relevance grade

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4.2. Research objective findings

From the 26 relevant articles assessment, the study brings to light some important information. For this, the first concern is to group them according to the type of energy or technology focus of each selected article, as presented on Table 5.

Type of energy / technology	Articles
bioenergy	2
decarbonization technologies	4
energy matrix	4
geothermal	3
hydrogen production	5
hydrogen storage	2
solar and wind	3
"Not possible to assess"	3
TOTAL RELEVANT	**26**

Table 5: Articles' quantity per energy-technology focus

Then, it analyzes the criteria considered on each study. It finds 195 different criteria, grouped according to the type of data source used for the MCDM proposed in the article and also its energy-technology focus. On Table 6, it presents the quantity of criteria on each of these groups.

Type of energy / technology	Articles	Calculated	Expert judgem.	Local institute	Website	Other	TOTAL
bioenergy	1			4	4	3	12
decarbonization technology	25				2		27
energy matrix	9		9	6	1		25
geothermal	6		12	9	15		42
hydrogen production	5	4	33	1	6		49
hydrogen storage	2			1			3
solar and wind			6	1	30		37

Table 6: Quantity of criteria per criteria data source type and energy-technology focus

Another information captured is the coverage of each criteria data source, checking if the data available has a global coverage or a limited or local one. Limited data are those which the information available are limited within the article's scope. Local ones are those which the source makes available information only for the country or region from where it is located. Global data source, in fact, have information regarding the criteria for everywhere in the globe. Table 7 presents the quantity of criteria with each coverage by each data source type.

Finally, this study analyzes the MCDM method adopted by the articles of each energy type focus. Table 8 presents the quantity of works on each energy type focus that have adopted each MCDM method listed.

5. Discussion

The main goals of this research are the answers it can find for the research questions. Within this objective, it seeks for information upon the selected literature regarding the decision-

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Criteria data source type	Global	Limited	Local (country)	TOTAL
Articles	17	17	14	48
Calculated		4		4
Expert judgement		60		60
Local institute			22	22
Website	46		12	58
Other		3		3
TOTAL	63	84	48	195

Table 7: Quantity of criteria per Coverage and type of criteria data source

MCDM method	ENERGY TYPE RESEARCH							Tot.
	bio-energy	Decarb. tech-nologies	energy matrix	geo-thermal	H2 prod.	H2 storage	solar / wind	
AHP	1		1	2	2	1	1	8
Best–worst method			1					1
Boolean Logic			1					1
CoCoSo				1				1
cognitive mapping						1		1
DEA	1		1	2	1			5
DEMATEL						1		1
Entropy					1			1
Favorability maps				1				1
GIS	1		1	1	1	1	2	7
IVPF					1			1
LCA	1							1
MILP			1					1
MultiMOORA					1			1
OPA							1	1
rough-fuzzy number					1			1
SVM			1					1
TOPSIS		1		1	2		1	5
VIKOR								4
Z-numbers			1				1	

Table 8: Articles adopting MCDM software/technique for each energy type research

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making methods adopted on each work, the evaluation criteria considered on those methods and, lastly, the sources from where the criteria data were obtained.

The first analysis comes from the MCDM methods. This study lists twenty different softwares or techniques adopted by the works assessed, although 15 methods (75% of them) are found in only one article, which means they are not widely adopted. 3 methods (DEA, TOPSIS and VIKOR) are adopted in 4 or 5 studies, and the 2 most adopted of them (AHP and GIS) are observed in 7 or more different works. Taking into account the different articles that a method is found, a total of 44 decision-making softwares or techniques are observed over this literature review. If we analyzes the energy type that most uses a decision-making method for its specific studies, we verify that Hydrogen production is the most adopter type (11 articles), followed closely by Geothermal energy (9 articles).

Regarding the evaluation criteria being adopted, a total of 210 different criteria is listed[2]. Most of them (a total of 181, or 86,2%) are observed only once over the decision-making processes adopted on the studies assessed, while 29 criteria (13,8%) are observed more than once, being ”land use” the criteria most adopted, in 7 different works. When we focus our analysis on the criteria adopted per each type of energy research, we find the distribution presented on Table 9, where DMPCQ means Decision-making Process Criteria Quantity.

Energy type research	bio-energy	Decarb. technologies	energy matrix	geo-thermal	H2 prod.	H2 storage	solar wind	Total
DMPCQ	12	27	35	41	62	38	39	210

Table 9: Total of criteria adopted per each type of energy study

Finally, the criteria data sources are assessed seeking to understand the coverage of their available data and the usability of the source. The first step, then, is to classify the types of data source as following: data collected from other articles, data calculated from other data already collected, data obtained from experts' judgment, data collected directly from local institutes, data collected from websites or web services, and other source of data. In total, 33 articles, 16 local institutes and 31 different websites have been used to collect all the 195 data criteria considered on the MCDM methods.

From the 210 criteria listed, 15 of them did not present its data source. The other criteria data are obtained mostly from experts' judgment (60) or websites (58), followed by specific articles (49) and local institutes (22). Calculated data and other sources provides respectively only 4 and 3 criteria data. And regarding the source coverage of the available data, this study found that 63 data available (32,3%) have a global coverage, being 46 of them (23,6%) obtained from websites. Data that are limited within the article's scope or are locally available represent, respectively, 84 (43,1%) and 48 (24,6%) of the criteria assessed.

6. Conclusion

This work's goal is to evaluate the multiplicity of MCDM methods, data source and criteria adopted in decision-making studies considering the energy transition context. For that, it adopted the PSALSAR approach in order to ensure the work's methodological accuracy and completeness. A base search string was defined and used to search literature within 7 different libraries or databases, returning a total of 1.127 articles, from which 355 of them were selected and classified. The 26 most relevant articles were, then, assessed regarding the research questions.

[2]In final version an Annex will be given on authors website (omitted during peer-review to preserve anonymity)

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On this assessment, the study listed 7 categories of energy or technology that were the study focus of the relevant literature, and also 195 different criteria adopted within 20 different MCDM methods, being the most adopted methods the AHP and GIS, followed by DEA, TOPSIS and VIKOR. The large number of criteria found comes from the need to observe that context is crucial when picking a criterium.

The criteria data applied on those methods were obtained from 81 different sources, besides experts' judgement and calculated date, some of those sources providing data with local or limited coverage only, while others sources provides data with global coverage.

Regarding the criteria data with global coverage, 46 of them are collected from websites and 17 from articles. Important is to note that these global criteria data can be applied in any other MCDM studies on the energy transition context. On the other hand, the 60 expert's judgment data and 22 data from local institutes, and also the 12 criteria data from websites or 32 from articles with non-global coverage, are not possible to be used in almost any other studies, unless its scope be limited within the coverage area of the criteria data applied on the chosen MCDM method adopted in the research.

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