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Review

A Review of Uncertain Decision-Making Methods in Energy Management Using Text Mining and Data Analytics

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Abstract: The managerial and environmental studies conducted in the energy research area reflect its substantial importance, particularly when optimizing and modifying consumption patterns, transitioning to renewable sources away from fossil ones, and designing plans and systems. The aim of this study is to provide a systematic review of the literature allowing us to identify which research subjects have been prioritized in the fields of energy and sustainability in recent years, determine the potential reasons explaining these trends, and categorize the techniques applied to analyze the uncertainty faced by decision-makers. We review articles published in highly ranked journals through the period 2003–2020 and apply text analytics to cluster their main characteristics; that is, we rely on pre-processing and text mining techniques. We analyze the title, abstract, keywords, and research methodology of the articles through clustering and topic modeling and illustrate what methods and fields constitute the main focus of researchers. We demonstrate the substantial importance of fuzzy-related methods and decision-making techniques such as the Analytical Hierarchy Process and Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS). We also show that subjects such as renewable energy, energy planning, sustainable energy, energy policy, and wind energy have gained relevance among researchers in recent years.

Keywords: uncertainty; decision-making; energy; sustainability; text analytics

1. Introduction

Energy is an important pillar of economic activity and product development, and plays a strategic role in national and economic security [1]. Energy is also an essential tool for global economic growth, with environmental protection gaining relevance in recent years [2]. Energy sustainability is a long-term view of natural resource constraints [3]. Renewable, clean, and efficient energy, such as wind and geothermal power, solar energy, hydropower, and biomass, constitute fundamental determinants of future sustainability [4].

The planning, operation, and management of energy have long been of interest to decision-makers, particularly when dealing with energy demand and the optimal allocation of resources. In order

to help decision-makers select optimal decisions, design energy policies, and support sustainable approaches to energy in uncertain environments, various decision-making tools have been introduced by researchers—and subsequently applied by managers. The purpose of the current paper is to provide an overview of the main decision-making methods implemented to deal with sustainability and energy subjects under uncertainty through the period 2003–2020. We aim to determine the main topics highlighted by researchers and the techniques applied to analyze them within the field of energy. In particular, the main questions we address and try to answer through the current paper can be summarized as follows:

- Q1- What type of research has been performed in the fields of energy and sustainability in recent years?
- Q2- What are the main trends observed and the potential reasons for their emergence?
- Q3- Which techniques have been used to formalize and analyze the uncertainty faced by decision-makers?

The remainder of this paper is organized as follows. In Section 2, we present a general overview of the energy literature, together with the main decision making and text mining methods. Data collection and analytics are introduced in Section 3. Section 4 describes the pre-processing and text mining results. Section 5 discusses potential managerial and policy implications. Section 6 concludes.

2. Literature Review

2.1. Energy Research Methods

Energy—in its various forms, namely, renewable, non-renewable, and fossil—is generally defined as a material resource used in industrial and agricultural production, transportation, and national defense [1]. The energy literature has focused on its environmental impact, particularly climate change, global warming, and the transition to renewable forms of energy.

For instance, [5] assessed renewable energy technologies to generate electricity using fuzzy Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) and proposed effective and efficient solutions for the development of clean and sustainable energy. Similarly, [6] proposed a process for selecting electricity generation technologies considering qualitative and quantitative criteria and political and social dimensions.

Quantitative and qualitative criteria have been defined to evaluate technologies designed for energy planning ([7,8]) and storage [9]. Ref. [10] designed a framework to rank renewable energy supply systems. Ref. [11] suggested an approach for increasing the sustainability of energy systems while considering economic and environmental dimensions.

Given the considerable amount of research published on energy-related topics, we concentrate on the main decision-making methods implemented to deal with uncertain environments and the text mining techniques that will be applied to analyze the publications selected in the current paper.

2.2. Decision-Making Methods Dealing with Uncertainty

Multi-criteria decision making (MCDM) techniques encompass multi-attribute decision making (MADM) and multi-object decision making (MODM) models. MADM methods are used to solve problems involving selection from among a finite number of alternatives, while MODM methods are used to solve problems with decision variable values that are determined in a continuous or integer domain. These methods aim at helping decision-makers in complex environments, so that they can define optimal selection criteria and rank the alternatives accordingly [12,13].

Multi-criteria decision aid (MCDA) provides a suitable framework of analysis in complex problems and conflicting situations while focusing mainly on MADM methods [14,15]. MCDA encompasses several comparative methods, including AHP, ELECTRE, PROMETHEE, and rough set theory [16]. We summarize below the main characteristics of the main MCDM methods implemented in the energy literature when decision-makers are subject to uncertain evaluation constraints.

2.2.1. Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is an MCDM technique proposed by [17]. It is generally applied to rank alternatives using paired comparisons [18,19]. The AHP has been implemented across a wide variety of research areas such as supply chain [20], business and marketing [21], supplier selection [22], engineering and manufacturing [23], environmental management [24], human resources management [25], and sustainable energy [26].

2.2.2. Analytic Network Process

The ANP method was introduced by [27] to extend the AHP approach [28]. In particular, this method analyzes the decision process taking place across different hierarchical levels and considers the interdependencies existing among the elements being ranked [29].

2.2.3. Technique for Order Preferences by Similarity to Ideal Solutions

Ref. [30] introduced the Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) to solve problems where the alternatives are classified according to their relative distances from the positive and negative ideal solutions [31]. Among the multiple applications of TOPSIS, we must highlight those related to the selection of sustainable suppliers [32], banking [33], sustainable supply chain risk management [34], the evaluation of wind turbines [35], and the design of prioritizing barriers [36].

2.2.4. Best–Worst Method

The Best–Worst Method (BWM) is an MCDM technique that specifies the relative importance of criteria by performing pairwise comparisons between the best, the worst, and the rest of the criteria [37,38]. The BWM was introduced by [39] and has been applied to evaluate organizational performance [40], identify and assess the demands of users for smart products [41], evaluate school performance [42], and assess road safety [43].

2.2.5. MULTIMOORA

Multi-objective optimization with ratio analysis (MOORA) was proposed by [44] as an MCDM method to solve complex decision-making problems. MULTIMOORA creates a ranking based on the results obtained from three methods: MOORA, reference point, and the full multiplicative form of multiple objectives [45]. MULTIMOORA has been applied to research problems dealing with sustainable energy [46], personnel selection [47], barriers to renewable energy acceptance [48], risk prioritization in failure modes [49], and site selection of sustainable landfills [50].

2.2.6. Complex Proportional Assessment

Complex Proportional Assessment (COPRAS) is a MADM method proposed by [51] that computes solutions by considering the best solution ratio [52]. COPRAS has been applied to partner-selection problems [53], and the analysis of renewable energy sources [54], including the design of strategies in wind farms [55] and site selection [56].

2.2.7. Weighted Aggregated Sum Product Assessment

The Weighted Aggregated Sum-Product Assessment method or WASPAS was defined by [57] combining two MCDM methods, namely, the weighted sum and weighted product models. WASPAS has been applied to assess renewable energy alternatives [58], sustainable production strategies [59], and the selection of suppliers [60].

2.2.8. PROMETHEE and FPROMETHEE

The preference ranking organization method for enrichment evaluation or PROMETHEE builds on comparisons between difficult to discern alternatives [61,62]. PROMETHEE was introduced by [63] and developed by [64,65], as a decision-making method for solving MCDA problems [66]. The fuzzy PROMETHEE technique integrates the PROMETHEE method and fuzzy number logic [67]. It was introduced by [68], and developed by [69,70].

PROMETHEE has been applied to airport location [71], sustainability assessment [72], engineering design processes [73], material selection [74], site selection for waste-to-energy plants [75], and the ranking of websites for renewable energy [76]. FPROMETHEE has been applied to site selection [62], supplier selection problems [77], start-up businesses selection [78], the evaluation of outsourcing risks [79], industrial robot selection [80], and the ranking of energy projects [70].

2.3. Text Mining Methods

Text mining consists of extracting information from textual data on which to perform subsequent analyses [81]. Textual data is categorized as unstructured (word documents, videos, and images) or semi-structured (coded in XML or JSON), and text mining focuses on text processing both types of data [82]. Text mining encompasses a wide variety of algorithms and techniques for analyzing text, such as natural language processing (NLP), a sub-field of computer science, artificial intelligence, and linguistics commonly applied to analyze text [83].

Text mining consists of the following stages: collecting data, pre-processing data or data cleaning, and implementing analytical processing techniques involving text categorization, clustering, and classification [84]. Applications of text mining include research areas as diverse as biology and biomedicine [85], health care [86], and consumer behavior [87]. The different techniques used for text mining include information recovery, extraction of information, text clustering, topic modeling, and text classification [88].

2.3.1. Text Clustering

Text clustering is a standard text mining method consisting of a multivariate statistical technique that groups texts into clusters with similar themes to be used for information recovery, summarization and classification [89]. Several types of unsupervised text clustering learning algorithms have been defined in the literature, including hierarchical, k-means, and partitioning and probabilistic clustering [83]. Recent applications of text clustering include reverse engineering [90], vehicle marketing [91], supply chains [92], logistic optimization [93], and the analysis of manufacturing capability [94].

2.3.2. Topic Modeling

Topic modeling defines probabilistic clustering algorithms [83] aimed at extracting and uncovering hidden or latent semantic patterns and structures, called topics, from unstructured text documents [95,96]. This technique interprets data using topic labels [97] which are created from the words contained in text documents [95]. The main algorithms used in topic modeling focus on latent semantics and Dirichlet processes, the Latent Dirichlet Allocation (LDA) algorithm being one of the most commonly applied techniques. The “latent” quality of the LDA algorithm is relevant to the structural findings in text documents. Moreover, since LDA uses unsupervised learning, it is useful for finding semantic patterns in massive textual data [95]. Topic modeling has been recently used for identifying and assessing challenges in business [98], finding hidden topics and trends in educational technologies [99], and forecasting technology in the field of healthcare [100].

2.3.3. Text Classification

A common application of machine and deep learning is text classification, which uses neural networks to allocate text to different classes based on the characteristics of the text [101]. This technique is generally employed for sentiment and web page classification, and personalized news recommendation [102]. Standard classification algorithms include Naive Bayes, Nearest Neighbor, Decision Tree Classifiers, and Support Vector Machines [83]. Text classification is currently being applied to image processing [103,104], medical diagnosis [105], tag recommendation [106], healthcare [107], and the analysis of incidents [108].

3. Research Framework

3.1. Data Collection

We concentrate on studies conducted in the fields of energy, sustainability, uncertainty, and decision making. Our research has focused on the titles, abstracts, keywords, and research methods of articles retrieved from several online databases such as ScienceDirect (Elsevier), IEEE Xplore, Taylor and Francis, Emerald, Springer, and Google Scholar. As already stated, the keywords used in the search include decision making, uncertainty, energy, and sustainability. When collecting the data, we considered papers published between 2003 and 2020. The data collection process is summarized in Figure 1.

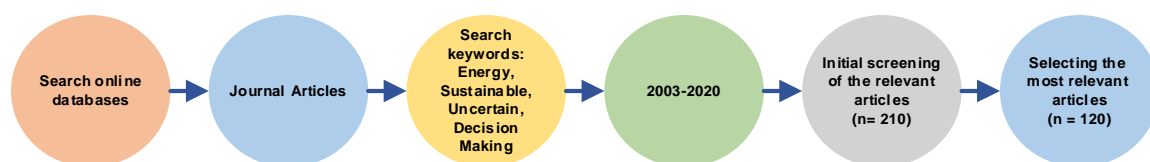


Figure 1. Article collection process.

A total of 210 articles were retrieved from the search, among which we selected 120 articles published in scholarly and academic journals and excluded 90 articles published in professional journals and proceedings. The number of articles and journal specifications are presented in Table 1. We have identified the decision-making methods applied in these studies and followed a text analytics approach, which has been performed on the titles, keywords, abstracts, literature review, research methods, findings, and discussion and conclusion sections of the corresponding articles.

Table 1. Count of the papers gathered.

Journal Name	Number	Impact Factor	h-Index	Q
Renewable and Sustainable Energy Reviews	48	10.556	222	Q1
Energy	13	5.537	158	Q1
Energy Policy	11	4.88	178	Q1
Renewable energy	9	5.439	157	Q1
Sustainability	8	2.592	53	Q2
Energy Conversion and Management	7	7.181	163	Q1
Energy economics	3	4.151	120	Q1
International Journal of Energy Sector Management	3	1.14	17	Q2
Sustainable Energy Technologies and Assessments	2	3.456	25	Q1
Sustainable Cities and Society	2	4.624	34	Q1
International Journal of Environmental Science and Technology	1	2.031	61	Q2
Expert Systems with Applications	1	4.292	162	Q1
Applied Soft Computing Journal	1	4.873	110	Q1
Energy and Buildings	1	4.495	147	Q1
Smart and Sustainable Built Environment	1	1.04	10	Q2
Energy Strategy Reviews	1	2.633	22	Q1
Journal of Modern Power Systems and Clean Energy	1	2.848	23	Q1
Energy Sources, Part B: Economics, Planning, and Policy	1	1.093	28	Q2
Management of Environmental Quality: An International Journal	1	1.4	29	Q3
European Journal of Operational Research	1	3.806	226	Q1

Table 1. Cont.

Journal Name	Number	Impact Factor	h-Index	Q
IEEE Transactions on Systems, Man, and Cybernetics: Systems	1	7.351	111	Q1
Ocean Engineering	1	2.73	80	Q1
Journal of Intelligent and Fuzzy Systems	1	1.637	46	Q1
Processes	1	1.963	16	Q2
Total	120			

3.2. Data Analytics

The data collected has been analyzed, applying both text pre-processing and text mining methods. Text mining allows us to extract information from a wide range of text documents using techniques such as data mining, computational statistics, machine learning, and NLP. The text mining research process is described in Figure 2.

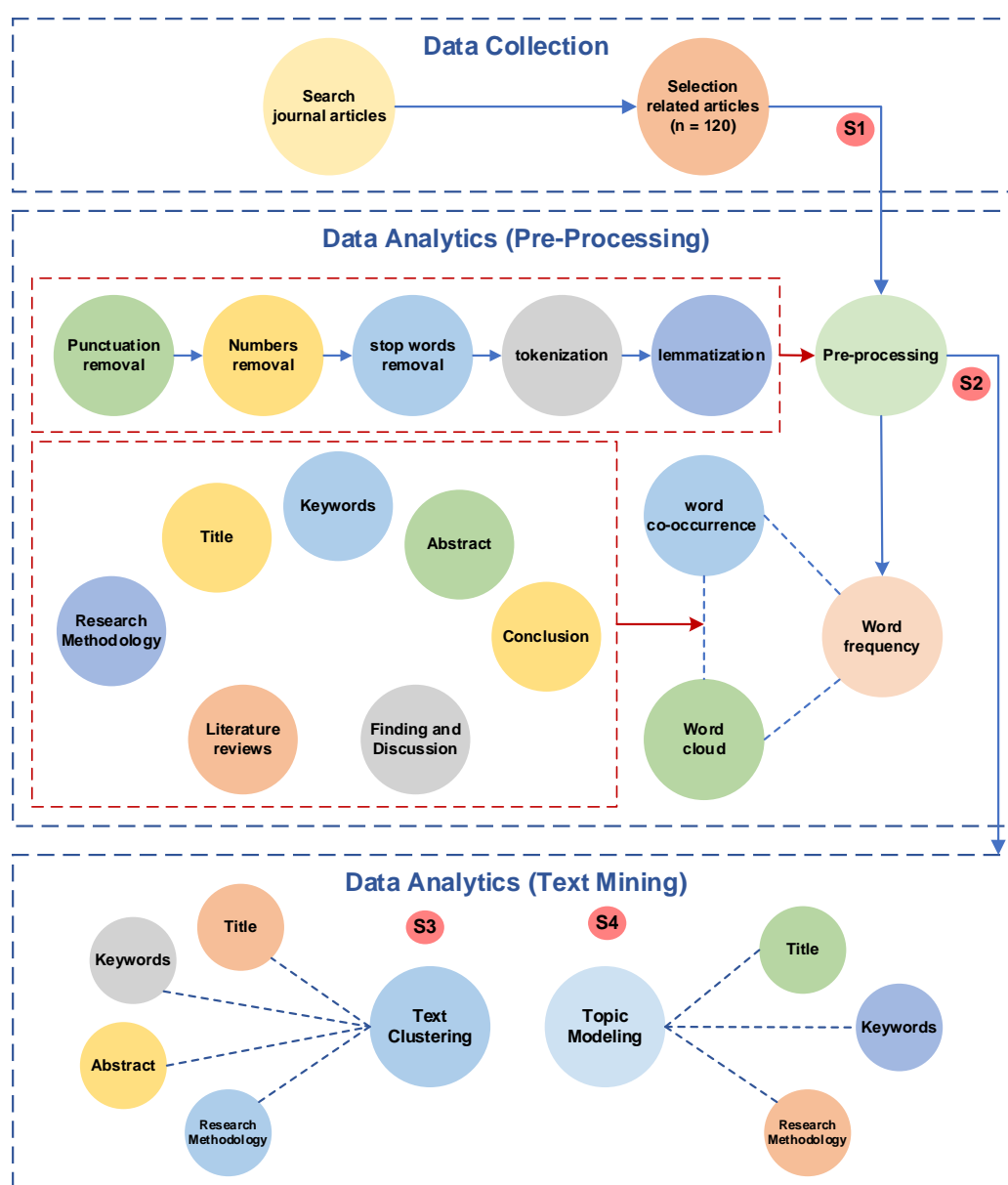


Figure 2. Research methodology.

The following stages summarize the text mining methodologies applied to the different sections of the articles analyzed.

- Through the pre-processing stage, we removed punctuations, numbers, and stop words, and implemented tokenization, lemmatization, and other small improvements. Tokenization is the process of protecting sensitive data by replacing it with an algorithmically generated number called a token, and lemmatization is a text normalization method used to replace the words with root words or words with similar context.
- We identified the most frequent words and applied a word cloud and a word co-occurrence analysis.
- Text clustering is applied to the titles, abstracts, keywords, and research methodologies of the articles.
- Topic modeling focuses on the coherence of article titles and keywords, together with research methods.

4. Findings

In this section, we present the pre-processing, frequency words, and text mining results for the 120 articles collected on decision-making methods in the field of energy management under uncertainty. As an intuitive introduction to the set of results presented through the next sections, Figure 3 depicts the names of the main authors contributing to the research area analyzed.

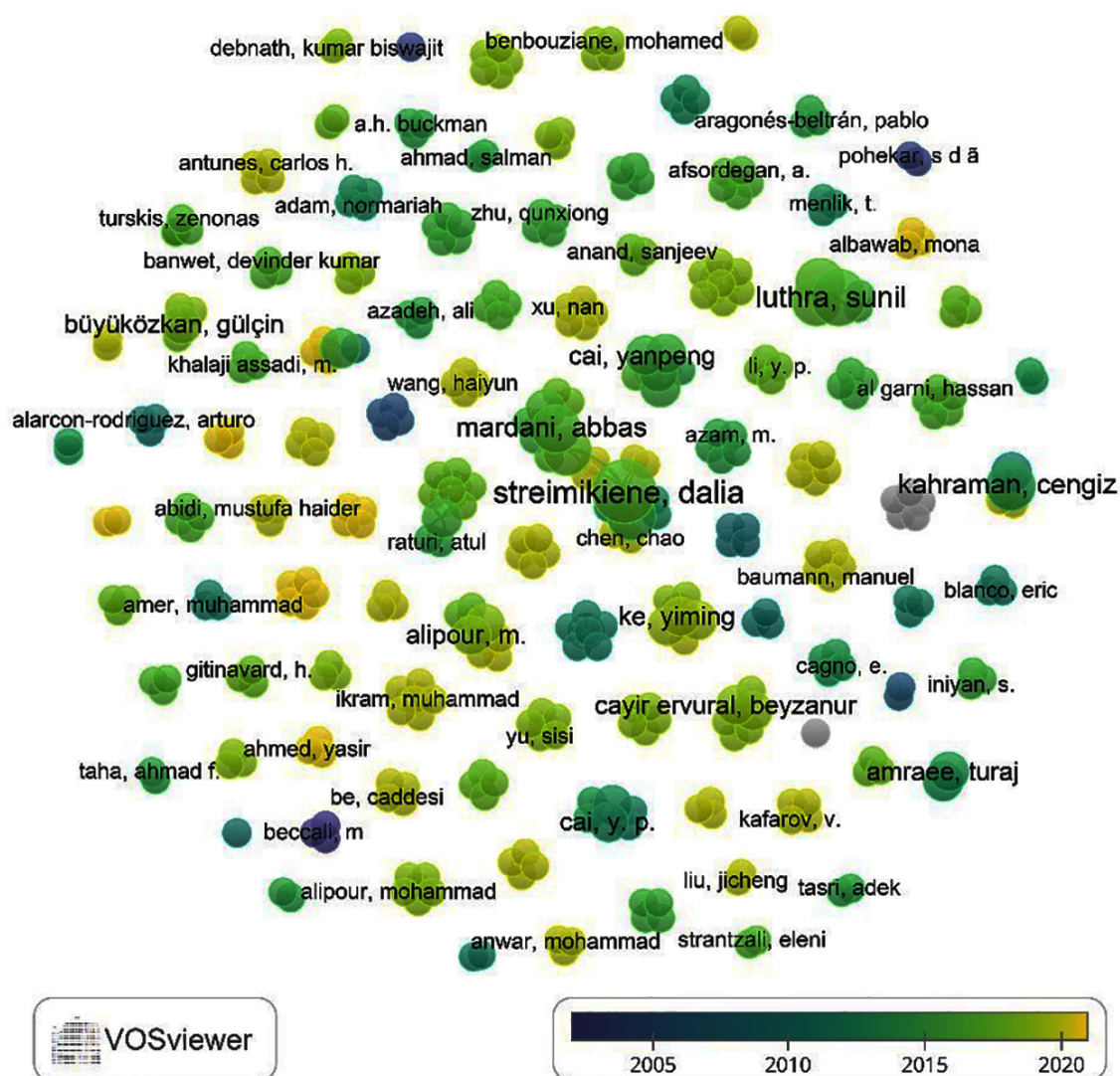


Figure 3. Author names.

4.1. Pre-Processing and Frequency Words

The purpose of the pre-processing stage is to prepare the articles for analysis via text mining. In this stage, we removed all unnecessary punctuations, numbers, and “stop words.” All words have been converted to lower case, tokenized, and lemmatized. Figure 4 describes the four steps performed on the abstracts of the articles.

The next step implements frequency words and word cloud analysis to the title, abstract, keywords, literature review, research methodology, findings and discussion, and conclusion sections of the articles, both separately and collectively. We used frequency words and word cloud to determine whether the selected articles were suitable for analysis regarding the subject and objectives of the research performed. The results obtained, illustrating the number of times different words appear in each of these sections, are presented in Table 2. Note that, together with the standard words expected to arise from the analysis, such as “energy”, “decision”, “sustainable”, and “multicriteria”, the main approaches followed in dealing with uncertainty are found to rely on “fuzzy” methods. Moreover, we observe a clear prevalence of AHP and TOPSIS among the techniques implemented to study the corresponding problems.

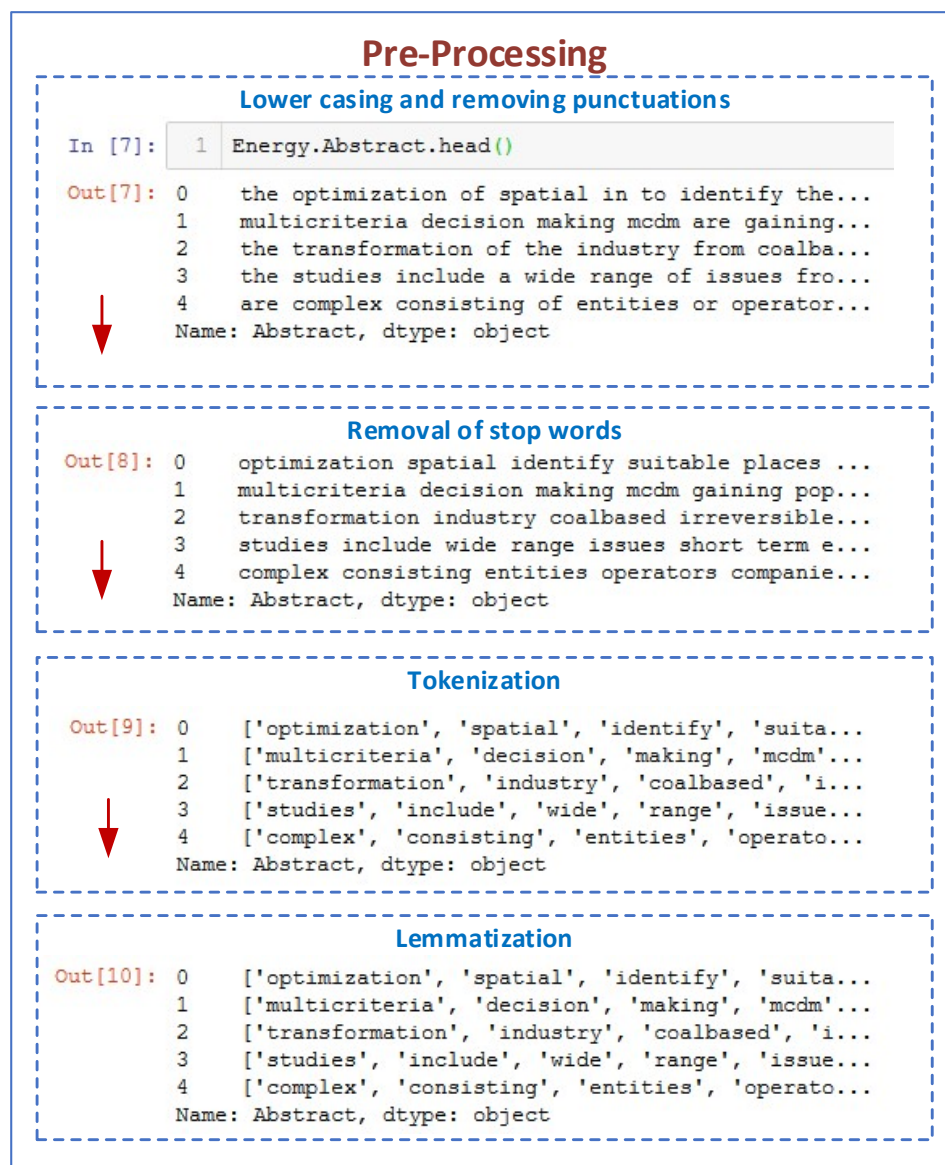


Figure 4. Text pre-processing of the abstracts.

Table 2. Separate word frequency.

Words/Title	Freq.	Words/Abstracts	Freq.	Words/Keywords	Freq.	Words/Literature Review	Freq.	Words/Methodology	Freq.	Words/Finding and Discussion	Freq.	Words/Conclusion	Freq.
'energy'	80	'energy'	538	'energy'	102	'energy'	2069	'energy'	811	'energy'	1050	'energy'	900
'decision'	25	'decision'	152	'decision'	49	'criteria'	494	'fuzzy'	514	'criteria'	411	'criteria'	245
'renewable'	25	'renewable'	130	'fuzzy'	45	'fuzzy'	488	'criteria'	503	'decision'	222	'renewable'	199
'sustainable'	21	'criteria'	108	'making'	34	'decision'	476	'method'	485	'renewable'	208	'decision'	181
'multicriteria'	19	'fuzzy'	101	'multicriteria'	27	'renewable'	428	'decision'	445	'alternatives'	191	'fuzzy'	137
'making'	18	'method'	99	'renewable'	23	'wind'	360	'ahp'	240	'weights'	189	'sustainable'	122
'fuzzy'	18	'analysis'	88	'sustainable'	18	'power'	345	'analysis'	238	'fuzzy'	171	'alternatives'	99
'analysis'	17	'sustainable'	71	'planning'	17	'planning'	313	'alternative'	218	'analysis'	170	'mcdm'	98
'planning'	16	'planning'	64	'topsis'	14	'mcdm'	306	'power'	204	'wind'	169	'policy'	98
'decision making'	10	'decisionmaking'	64	'optimization'	14	'system'	308	'mcdm'	1175	'ranking'	166	'environmental'	92
'multicriteria'	9	'alternatives'	64	'ahp'	13	'analysis'	295	'function'	165	'solar'	148	'decisionmaking'	78
'uncertainty'	8	'multicriteria'	57	'decisionmaking'	13	'environmental'	265	'renewable'	156	'power'	145	'planning'	76
'topsis'	8	'making'	56	'sustainability'	13	'alternatives'	253	'optimization'	148	'efficiency'	145	'resources'	70
'optimization'	8	'policy'	51	'policy'	10	'ahp'	251	'objective'	136	'economic'	133	'ahp'	69
'decision'	6	'makers'	45	'programming'	9	'decisionmaking'	207	'data'	135	'policy'	118	'topsis'	64
'ahp'	5	'mcdm'	41	'mcdm'	7	'optimization'	196	'evaluation'	133	'criterion'	116	'uncertainty'	58
'mcdm'	5	'ahp'	37	'analytical'	7	optimal	165	'topsis'	130	'mcdm'	101	'making'	53
'sustainability'	4	'uncertainty'	38	'multiobjective'	5	making	159	'planning'	129	'sustainable'	91	'sustainability'	49
'decisionmaking'	4	'optimization'	36	'uncertainty'	3	sustainable	155	'criterion'	127	'optimal'	87	'optimization'	45

We now consider the overall word frequency, whose results are presented in Table 3. As was the case with the different sections of the documents, the words “energy”, “criteria”, “decision”, “MCDM”, “sustainable”, together with “fuzzy” and “TOPSIS”, are among the most frequently used ones in the 120 articles. In this regard, the results validate the fact that appropriate articles have been selected for text analytics. Additional representations of the word clouds and frequencies for the different sections of the articles analyzed can be found in Figures 5–12.

Table 3. Overall word frequency.

Words/Title	Frequency	Words/Title	Frequency
'energy'	5602	'optimization'	509
'criteria'	1780	'making'	480
'decision'	1533	'topsis'	457
'fuzzy'	1485	'ranking'	439
'renewable'	1186	'multicriteria'	375
'mcdm'	736	'uncertainty'	307
'planning'	709	'criterion'	350
'sustainable'	537	'sustainability'	322
'decisionmaking'	532	'programming'	277
'policy'	527	'uncertain'	229



Figure 5. “Title” word cloud.



Figure 6. “Abstract” word cloud.



Figure 7. “Keyword” word cloud.

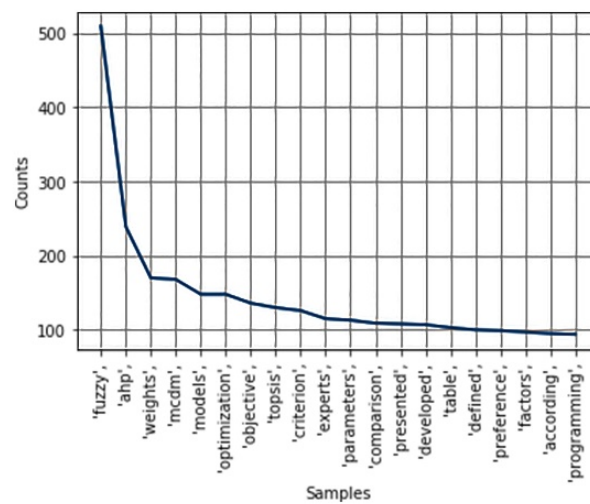


Figure 8. “Research methodology” frequency.

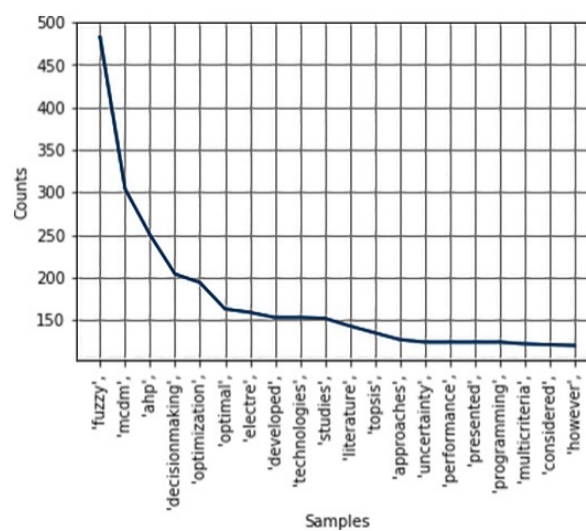


Figure 9. “Literature review” frequency.

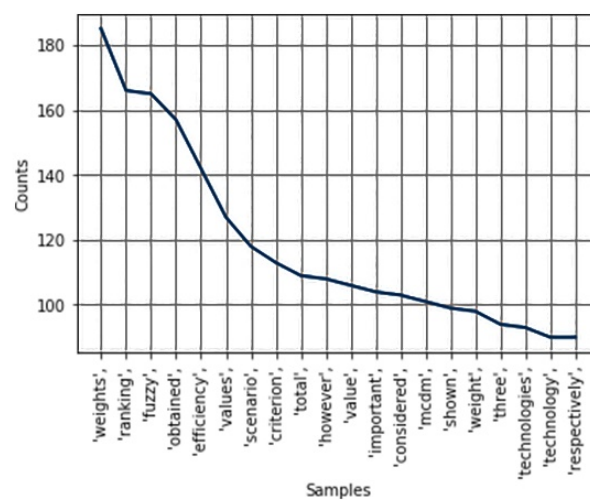


Figure 10. “Finding and discussion” frequency.



Figure 11. Overall word cloud.

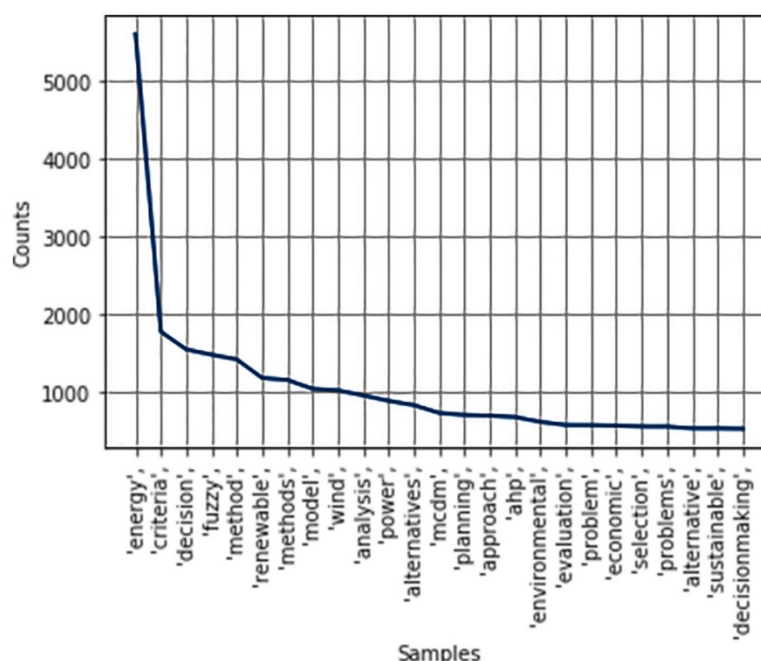


Figure 12. Overall word frequency.

Figures 5–7 and 11 highlight the prominent use of words such as “decision-making”, “MCDM”, “fuzzy”, and “sustainable”, together with the corresponding techniques applied, namely, “AHP”, “TOPSIS”, “ELECTRE”, and “MULTIMOORA”, within the title, abstract and keywords of the papers. Similarly, Figures 8–10 and 12, illustrate that the words “energy”, “fuzzy”, “wind”, “power”, “planning”, “economic”, “environmental”, “AHP”, “MCDM”, “TOPSIS”, “ELECTRE”, and “programming” are used between 100 and 6000 times within these papers.

4.2. Text Mining Analysis

Through the text mining stage, text clustering and topic modeling have been applied to validate (and reinforce) the results obtained in the pre-processing stage. The k-means unsupervised learning clustering algorithm was applied to the title, keywords, abstracts, and research methodology sections. One of the main features of this technique is its capacity to segment and categorize within clusters. As an illustrative example, Figure 13 shows the clustering results for the “Title” section.

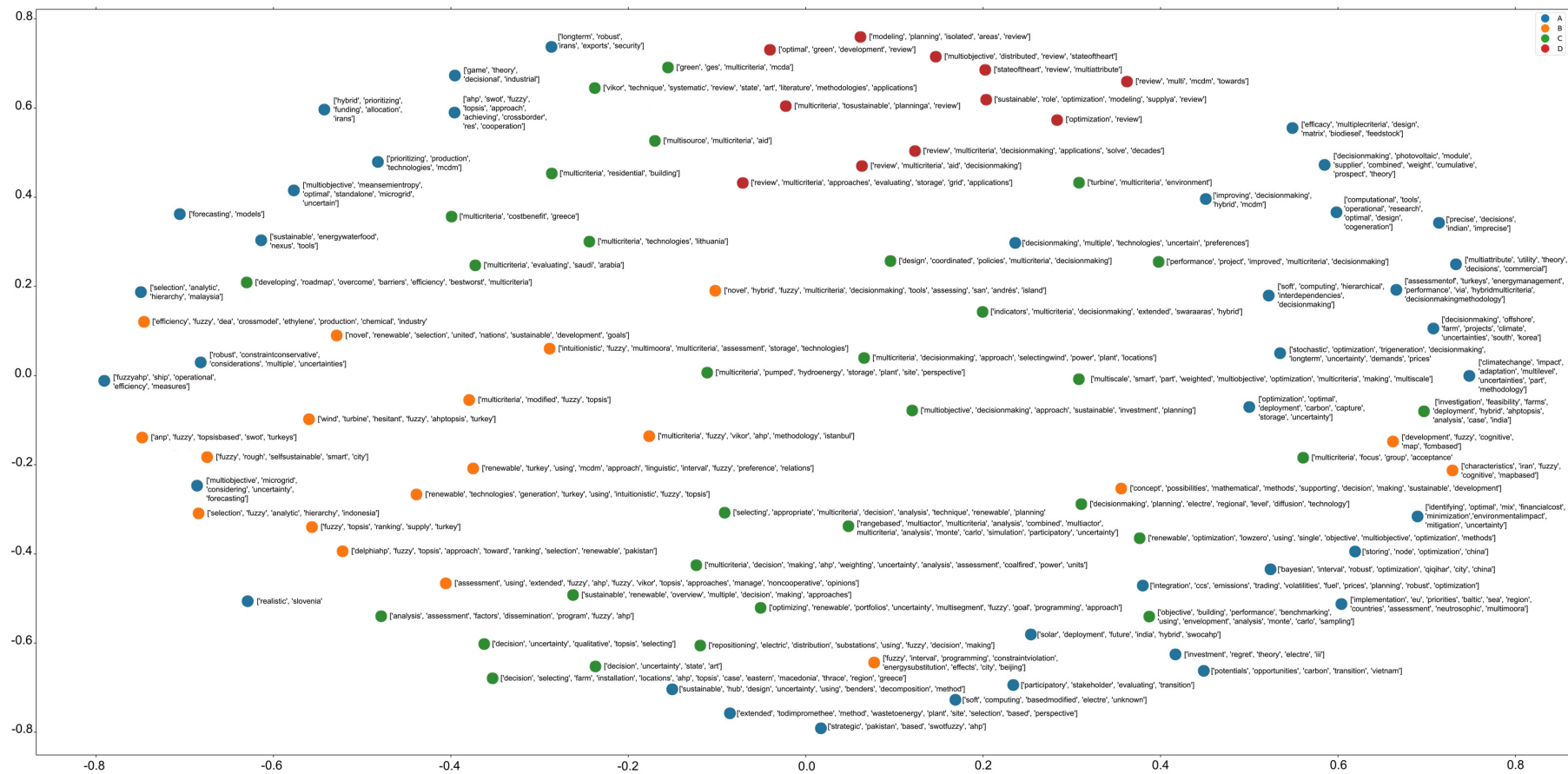


Figure 13. K-means clustering of titles.

The whole set of clustering results are presented in Table 4. As shown in this table, most decision-making methods applied in the articles are related to MADM, MODM, and MCDA. The main analytical techniques implemented within the energy management field include AHP and TOPSIS, together with standard MCDM techniques ranging from PROMETEE to MULTIMOORA. A significant subset of the literature follows a fuzzy approach to deal with uncertainty; the main methods considered including fuzzy interference systems, fuzzy rough sets, fuzzy cognitive maps, and rough theory.

Table 4. Clustering results.

Words	Clusters	Keywords
Title	Clusters 1	(AHP, TOPSIS, FAHP, MULTIMOORA, VIKOR, Optimization, Multi-objective, Game theory, Uncertainties, ANP, Fuzzy, Robust, Programming, Bayesian, Multi-attribute, Cognitive map)
	Clusters 2	(Delphi-AHP, Fuzzy, TOPSIS, AHP, VIKOR, Goal programming, MULTIMOORA, Multi-criteria)
Keywords	Clusters 1	(MCDM, AHP TOPSIS, DSS, ROBUST, Delphi, VIKOR, Multicriteria, SWOT, Shannon Entropy, Game theory, uncertainty, fuzzy, PROMETHEE, COPRAS, MOLTIMOORA)
	Clusters 2	(Multi-objective, Optimization, Multicriteria, decision-making, uncertainty, modelling, optimized, Multicriteria, MCDM, MOLTIMOORA, Optimization, Bayesian, multiple, uncertainties, MCDM, MADM, ELECTRE, ARAS)
	Clusters 3	(Linear, Programming, Optimization, Uncertain, MILP, Single-objective, optimization, Multi-objective)
Abstract	Clusters 1	(Optimization, AHP, TOPSIS, SWOT, VIKOR, Delphi, Fuzzy, Multi-criteria, Decision-making, MCDA, FANP, ISM, ELECTRE, PROMETHEE, FPROMETHEE)
	Clusters 2	(Fuzzy TOPSIS, VIKOR, MOLTIMOORA, Optimization, Multi-objective, Genetic algorithm, Single, Objective, Optimization, Fuzzy logic, ELECTRE iii, MADM, AHP, Multi-attribute, FCM, robustness, uncertainties, Goal programming, ANN, DEA, TODIM, FPROMETHEE, Fuzzy Rough, Delphi Group decision-making, Robust, Linear programming, FAHP)
Research Methodology	Clusters 1	(Fuzzy, AHP, SWOT, Group decision-making, Cognitive map, TOPSIS)
	Clusters 2	(AHP, Multi-criteria, MCDM, Uncertainty, ELECTRE iii, Game-theoretic, Optimization, MADM, Goal programming, Multi-objective, Fuzzy logic, MCDA, FCM, Robustness, VIKOR, Mathematical, Shannon entropy, PROMETHEE, ANP, Programming, Goal programming, Dynamic programming)

Topic modeling was applied to the title, keywords, and research methodology sections. The corresponding results obtained are presented in Table 5. Key topics relate to multicriteria, decision-making, and optimization approaches, along with AHP, TOPSIS, and FPROMETHEE as the main solution techniques. We must also note that subjects such as renewable and power energy have also been highlighted through topic modeling.

Finally, we use VOS-viewer software to depict the main decision-making methods and topics considered in energy management under uncertainty. Figure 14 shows that most research has been conducted on renewable energy, energy planning, and sustainable energy. Figure 15 highlights MCDM, optimization, programming, and fuzzy logic, as the most-used analytical methods. The results also show that the MCDM methods most widely applied through the 2018–2020 period include AHP, MULTIMOORA, BWM, DEMATEL, and PROMETHEE, together with fuzzy goal programming and fuzzy TOPSIS.

Table 5. Topic modeling using the Latent Dirichlet Allocation (LDA) Algorithm.

	Topic	Topic Words
Title	Topic 1	(‘hierarchy’, ‘analytic’, ‘fuzzy’, ‘using’, ‘selection’)
	Topic 2	(‘fuzzy’, ‘forecasting’, ‘planning’, ‘decision-making’, ‘multi-objective’)
	Topic 3	(‘multicriteria’, ‘decision-making’, TOPSIS)
	Topic 4	(‘prioritizing’, ‘optimization’, ‘multiple’, ‘sustainable’, ‘renewable’)
	Topic 5	(‘review’, ‘optimization’, AHP)
	Topic 6	(‘decision’, ‘review’, TOPSIS, ‘uncertainty’, ‘qualitative’)
Keywords	Topic 1	(‘technologies’, ‘decision-making’, ‘renewable’, ‘multicriteria’, ‘programming’)
	Topic 2	(‘planning’, ‘renewable’, ‘multiple’, ‘development’, ‘sustainable’)
	Topic 3	(‘analytic’, ‘hierarchy’, ‘programming’, ‘making’, VIKOR)
	Topic 4	(‘sustainable’, ‘production’, ‘multicriteria’, ‘optimization’, ‘systems’)
	Topic 5	(‘analysis’, ‘power’, ‘fuzzy’, ‘uncertainty’, ‘optimization’)
	Topic 6	(‘policy’, ‘assessment’, ‘analytic’, ‘methods’, ‘renewable’)
	Topic 7	(‘sustainable’, ‘distributed’, ‘fuzzy’, DEA, ‘multi-objective’)
Research Methodology	Topic 1	(MCDM, ‘Alternatives’, ‘Programming’, ‘ranking’, PROMETHEE, ‘Uncertainty’, Optimal)
	Topic 2	(FCM)
	Topic 3	(DEA, FAHP, FPROMETHEE)
	Topic 4	(Rough)
	Topic 5	(Fuzzy, AHP, optimization, TOPSIS, decision-making, multicriteria, ANP)
	Topic 6	(Shannon entropy)
	Topic 7	(TODIM, MADA, PROMETHEE ii)
	Topic 8	(MOORA)

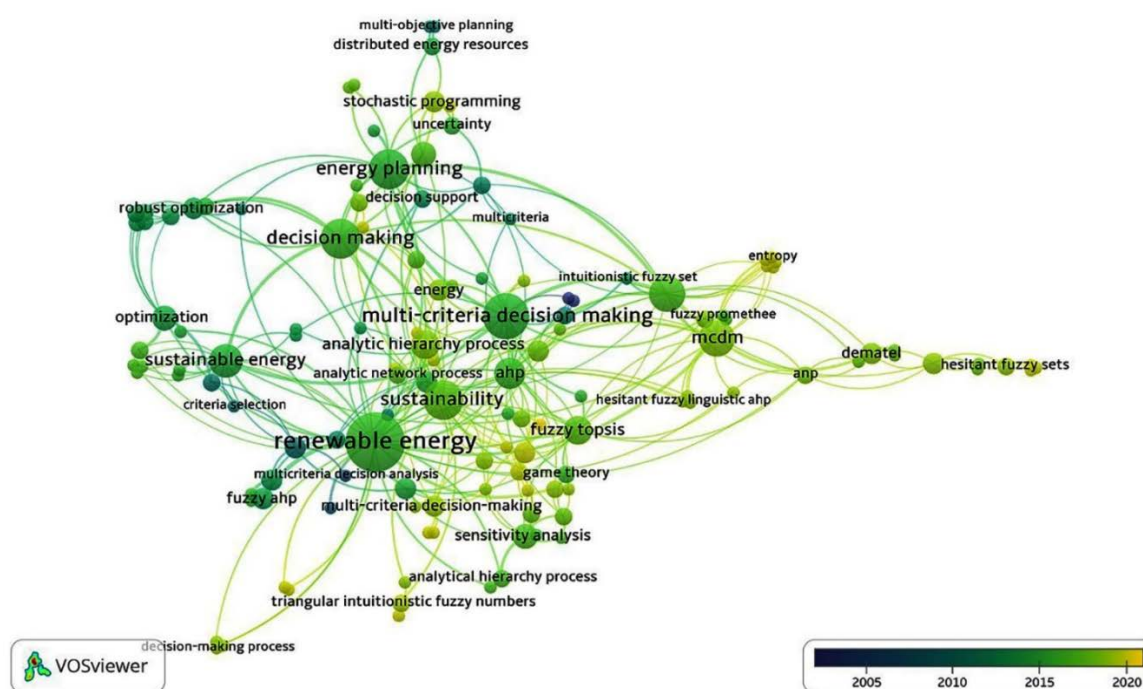


Figure 14. Methods.

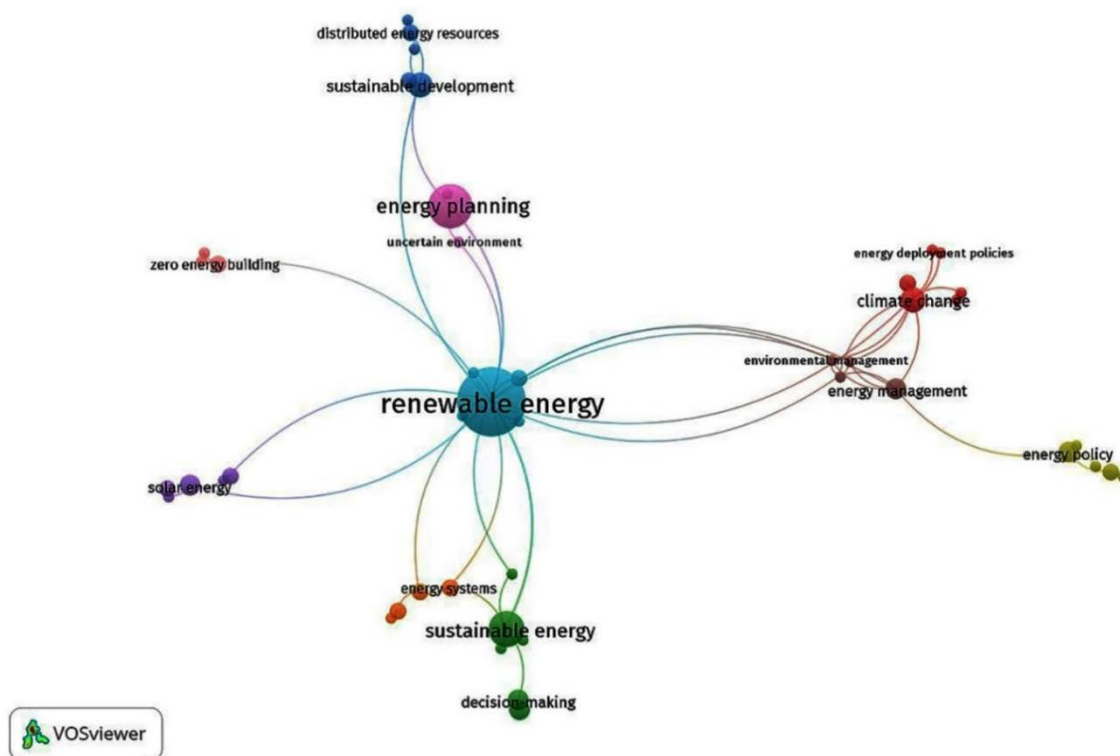


Figure 15. Fields.

5. Discussion and Policy Implications

We have addressed three main questions through the paper, whose answers follow from the text mining analysis applied to the literature reviewed. Figure 16 summarizes the main results obtained through the word cloud and word frequency analyses, together with the clustering and topic modeling techniques. As shown in this figure, subjects such as renewable energy, energy planning, sustainable energy, energy policy, and wind energy have gained relevance among researchers in recent years.

The decreasing availability of traditional energy sources—such as petroleum—as well as the emission of greenhouse gases and their effect on the climate change phenomenon have shifted the focus of the academic literature towards renewable energy sources. The use of renewable energy sources, which can be re-produced and easily replaced by nature shortly after consumption, leads to a reduction in emissions and environmental pollution—together with their associated health costs—and a subsequent increase in economic welfare. Renewable energy sources are available in all geographical areas, implying that developing countries can mitigate their strategic dependence on petroleum and its subsequent price fluctuations.

Governments are investing heavily in renewable energy sources, given their strategic importance as economic development factors. The subsequent planning policies should aim at reducing energy costs and their impact on the environment, with special emphasis being placed on the sustainability problems triggered by intergenerational tradeoffs. That is, planning is conditioned by sustainability, with renewability complementing the development of both policies. Planning, sustainability, and renewability require specific information from the corresponding research fields. In this regard, information ambiguity and uncertainty conditions have increased the importance of decision-making methods as problem-solving tools.

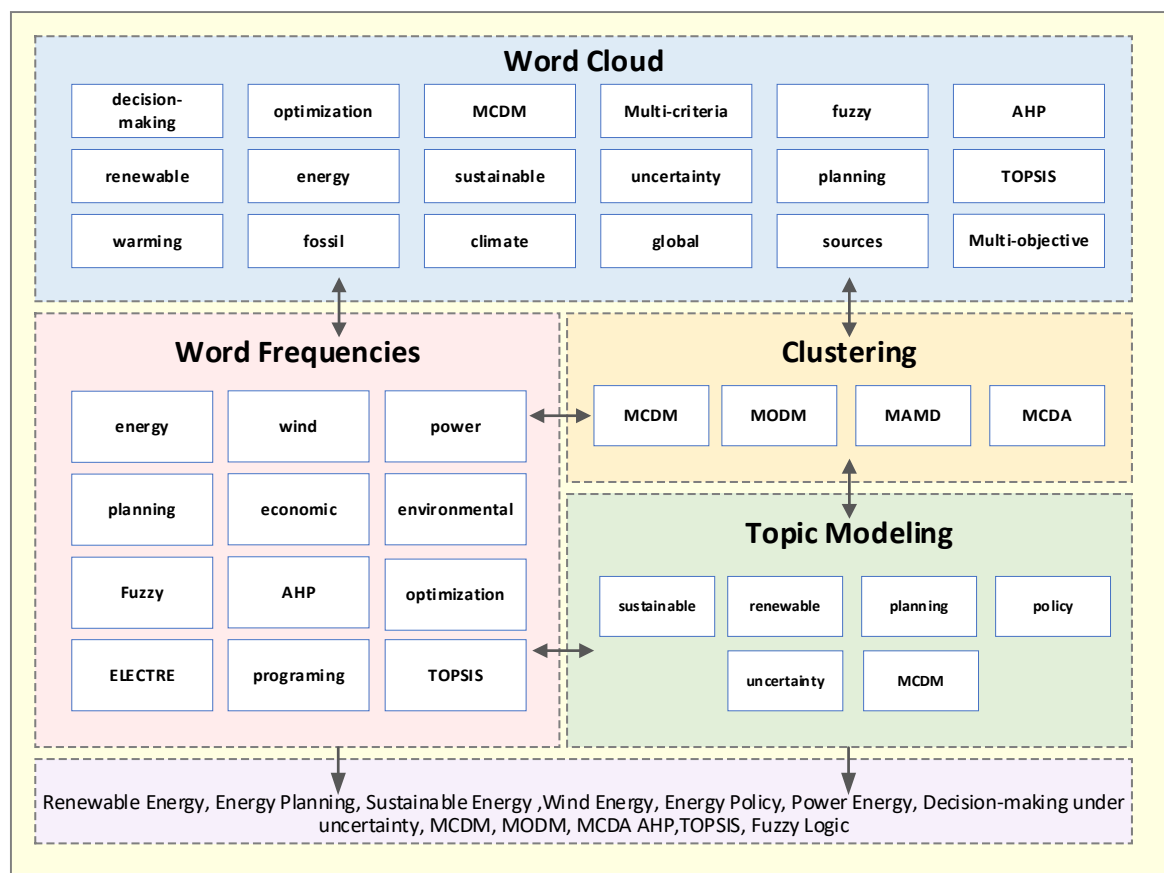


Figure 16. Main findings.

Scope of the Analysis

Several other studies have analyzed the main trends exhibited by the literature in the fields of sustainable and renewable energy and MCDM. For example, [109] reviewed the MCDA methods applied to evaluate sustainable energy sources, with AHP emerging as the preferred decision-making technique. [110] focused on multi-objective planning. They found that the main methods implemented were multi-objective evolutionary algorithms in 2009, MCDM in 2007–2008, and multi-attribute analysis through the 2003–2009 period. [111] reviewed the literature on sustainable energy systems and suggested optimization modeling methods as a good evaluation tool. [112] analyzed 27 papers published within the 2003–2015 period to validate the problem-solving capabilities of MCDM techniques. [113] identified PROMETHE, AHP, and ELECTRE III as the main MCDM methods applied in the field of sustainable renewable energy. [114] concluded that AHP, ANP, and DEA were the most popular MCDM techniques used to solve green energy planning and scheduling problems through the 1957–2017 period.

The main difference between the current paper and other competing reviews is given by the overall scope of our approach to the fields of energy and decision-making. Most studies focus on investigating a unique problem, while we have performed an extensive analysis of the energy research field so as to identify the main techniques implemented to deal with uncertainty within the corresponding decision-making (MCDM, MODM, MADM, and MCDA) scenarios.

6. Conclusions

We have performed a systematic review of the literature within the fields of energy and decision-making under uncertainty. A general keyword approach was initially applied to identify what methods were being implemented within the main academic indexes and publishers (Science direct, Emerald Xplore, Taylor and Francis, IEEE, Springer, and Google Scholar). After selecting 120 articles

from high impact journals, Python 3.8.3 was used to analyze the corresponding texts. To prepare the articles for text mining, we pre-processed all the articles and applied frequency words and word cloud analysis to their main sections. Clustering and topic modeling in text mining was then used to examine the main research methods employed.

Researchers tend to rely on fuzzy reasoning to deal with uncertainty across different MCDM methods, dominated by AHP and TOPSIS. In the field of energy, most research focuses on renewable energy, energy planning, and sustainable energy. In recent years, due to global warming and the overuse of non-renewable resources, the attention given to renewable energy and sustainability topics has increased. In this regard, it is necessary to properly plan energy consumption and develop suitable policies at national and international levels.

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