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Resumo Energy management (EM) is important for the competitiveness and profitability of companies. EM has become essential in the current global political-economic context. Commitment to social aspects, goals to reduce pollutant emissions, and policies for responsible use of natural resources also favoured the search for new methods and tools such as the Multi-Criteria Decision-Making (MCDM). MCDM is a flexible approach and has the potential to harmoniously cooperate with other tools that have been app...

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Energy management in industry: Multi-criteria decision-making applications

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Abstract. Energy management (EM) is important for the competitiveness and profitability of companies. EM has become essential in the current global political-economic context. Commitment to social aspects, goals to reduce pollutant emissions, and policies for responsible use of natural resources also favoured the search for new methods and tools such as the Multi-Criteria Decision-Making (MCDM). MCDM is a flexible approach and has the potential to harmoniously cooperate with other tools that have been applied in the most diverse areas, such as energy efficiency and management, plant selection, project evaluation, equipment evaluation and selection, and construction of indicators, among others. The growing number of works relating EM to MCDM is evidence of the increased use of these tools to support organizations in problems related to the themes, especially in complex scenarios, where several qualitative and quantitative variables are considered in a broad context organizational. To expand this frontier of knowledge, we must first understand where the current frontier is. This view can be obtained with one literature review. In this context, this work aims to present a literature review on MCDM application by EM in the industry. Specific objectives include the analysis of which MCDM methods have been applied, which areas of the industry, and

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which are the main barriers, challenges, and future trends.

Keywords: Decision making; Energy management; Industry; Literature review.

1. Introduction

The decision-making process is a subdiscipline of Operations Research and has been widely used when two or more alternatives need to be formally examined [1–3]. The main objectives of using multicriteria decision methods are the classification and selection of alternatives to support decision-making based on mathematical formulations and systematic methodologies [4–5]. Multicriteria decision-making, MCDM can be defined as the study of methods and procedures that allow the evaluation of criteria (qualitative and quantitative) that often conflict with each other, allowing their inclusion in decision-making processes [6]. The development of multicriteria decision-making methods was motivated not only by the variety of practical problems that require consideration of various aspects but also by the need to provide modern decision-making techniques that make use of advances in mathematical models and computational technology [7–8]. Multicriteria decision methods can be ranked based on the number of alternatives considered. Differences can be noted between multi-attribute decisions and multi-objective decisions, but both share similar characteristics. Multi-attribute decision methods are designed to select discrete alternatives while multi-objective decision methods are better suited to deal with multi-objective planning problems when a theoretically infinite number of continuous alternatives is defined by a set of constraints on a vector of decision variables [1, 9–10].

The multi-criteria analysis is a flexible approach and has the potential to harmoniously cooperate with other tools that have been applied in the most diverse areas, such as energy efficiency and management, plant selection, project evaluation, equipment evaluation and selection, and construction of indicators, among others [11–13]. Several multicriteria decision methods have been proposed in recent decades considering the issue of measuring priorities of conflicting tangible or intangible criteria. In order to allow the evaluation of the best alternatives for a decision, some of the most popular methods are: Analytic Hierarchy Process (AHP),Analytic Network Process (ANP),Additive Ratio Assessment (ARAS),Complex Proportional Assessment of Alternatives (COPRAS),Compromise Programming (CP),Data Envelopment Analysis (DEA), Decision Making Trial and Evaluation Laboratory (DEMATEL), Dominance Based Rough Set Approach (DRSA), Elimination Et Choice Translating Reality (ELECTRE), Evidential Reasoning (ER), Goal Programming (GP), Grey Relational Analysis (GRA), GUESS method , Inner Product of Vectors (IPV), Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH),Multi-Attribute

Global Inference of Quality (MAGIQ),Multi-attribute utility theory (MAUT),Multi-attribute value theory (MAVT),Maximal Entropy Ordered Weighted Averaging (ME-OWA),New Approach to Appraisal (NATA), Nonstructural Fuzzy Decision Support System (NSFDSS), Potentially All Pairwise Rankings of All Possible Alternatives (PAPRIKA), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE),Simple Additive Weighting (SAW), Superiority and Inferiority Ranking Method (SIR),Technique for Order Preference by Similarity to Ideal Solution (TOPSIS),Utility Additive (UTA),Value Analysis(VA),Value Engineering (VE),VIKOR method, Weighted Product Model(WPM), and Weighted Sum Model (WSM) [14–15].

Several types of MCDM methods have been developed or improved by different authors in recent decades. The main differences between these methods in summary are related to the level of complexity of the numerical models, the criteria weighting methods, the form of representation of the evaluation criteria of the preferences, the possibility of incorporating uncertainties into the models and the type of data aggregation [8]. MCDM methods can be classified by value measurement methods, (for example, MAUT and SAW), reference level methods (TOPSIS and VIKOR), outranking methods (ELECTRE and PROMETHEE), pairwise comparison (AHP and ANP) and combined approaches (MULTI-MOORA and Goal Programming) [16–17] (Figure 1).

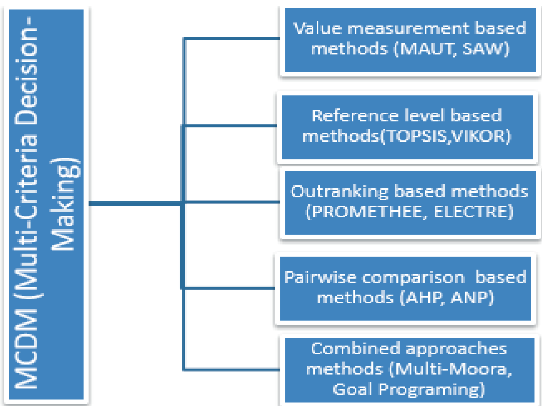

Figure 1 - Classification of MCDM methods

AHP, Fuzzy, and TOPSIS methods are among the most applied in MCDM problems, mainly in energy management [15–17]. Energy management is a crucial issue for society and has gained prominence in scientific research every year. Several economic, social, political, and environmental factors have significant effects on energy management practices, leading to a variety of uncertainties in decision-making on the subject [17–18]. Models that support energy management are increasingly sought after due to their great importance in the world economic scenario.

Decreasing the consumption of sources that generate pollutants and the search for renewable and sustainable energy sources is essential for the evolution of society, especially for the responsible development of industrial activities [19]. The combination of energy management and sustainable behavior in organizations is seen as a key element for global competitiveness and growth. The evaluation of these themes in different regions and sectors is of great importance for identifying several factors and quantitative bases for improvements [21–22]. There are several criteria and objectives to be considered in the decision-making process. In this context, decision-making has increasingly resorted to methods and tools that allow them to have a better perception and understanding of scenarios in a rational, efficient, and explicit way. Issues related to energy management and the increase in its demand have been considered critical by authorities and governments, as they can lead to several impacts, including public health and the sustainable development of a region, in addition to affecting economic growth [1, 29].

The need for studies and techniques that allow better use of energy resources is justified in several initiatives to encourage sustainable development, renewable energy sources, and commitment to society by reducing the emission of polluting gases mainly from fossil fuels [18,30–31]. Global documents such as the Agenda 2030 [32] (which establishes 17 goals and targets for sustainable development considering the balance between economic, social, and environmental aspects) are examples of encouraging research on the subject. They consider the importance of studies focused on clean and accessible energy by encouraging new research and technologies, the gradual increase in the use of clean energy and renewable sources, and the search for improvement in the energy efficiency of existing technologies. International standards, such as ISO 50001 [33] regarding policies and objectives for organizations to achieve more efficient energy consumption and ISO 55001 [34] on asset management, also highlight the importance of the energy consumption and energy efficiency factor for companies and society.

2. Literature Review

The literature review is one way to analyze the development of a theme in a scientific field allowing the identification of contributions, main data, and gaps that can be explored in new research. It is constituted by an explicit and reproducible method allowing to summarize results of existing studies, evaluation of their contents, and consistency between different studies on the same subject, helping in the construction of answers and new questions [35–36]. In this article, studies were selected considering the filters and terms of the advanced search performed in the Scopus database (Figure 2).

Advanced Search	*Search-results*
(TITLE-ABS-KEY ("energy management") AND TITLE-ABS-KEY ("mcdm" OR "mcda" OR "DECISION MAKING" OR "MULTI-CRITERIA" OR "MULTIPLE CRITERIA") AND TITLE-ABS-KEY ("industry")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "re")) AND (EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "PSYC")) AND (EXCLUDE (PUBYEAR , 2023))	**295**

Figure 2- Search results on Scopus.

Document types were articles (55%), conference papers (38%), and reviews (7%). We excluded documents from the following sub-areas: Biochemistry, Genetic and Molecular Biology, Medicine, Physics and Astronomy, and Psychology (because these documents were not directly related to the selected topic), resulting in 295 documents, being cited 5,290 times with document *h*-index 36. This large number of citations evidences the growth of the study area and the importance of combinations of themes that have been frequently addressed in several areas including Business Management and Accounting, Chemistry, Computer Science, Decision Sciences, Energy, Engineering, Environmental Science, Mathematics, and Social Sciences, among others (Figure 3).

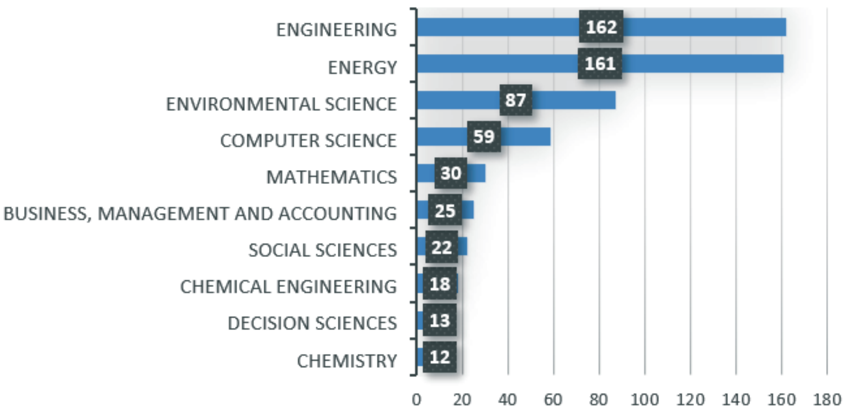

Figure 3 - Documents by subject area

Several journals have published research referring to energy management in the industry because of relevance of topics to different areas. About 10 journals concentrated 37.17% of the published works: Applied Energy, Energies, Energy Conversion and Management, Energy Policy, Energy Procedia, Energy Strategy Reviews, Energy, Journal of Cleaner Production, Renewable and Sustainable Energy Reviews, and Sustainability (Figure 4). In total about 100 journals have published in the field of energy management in industry.

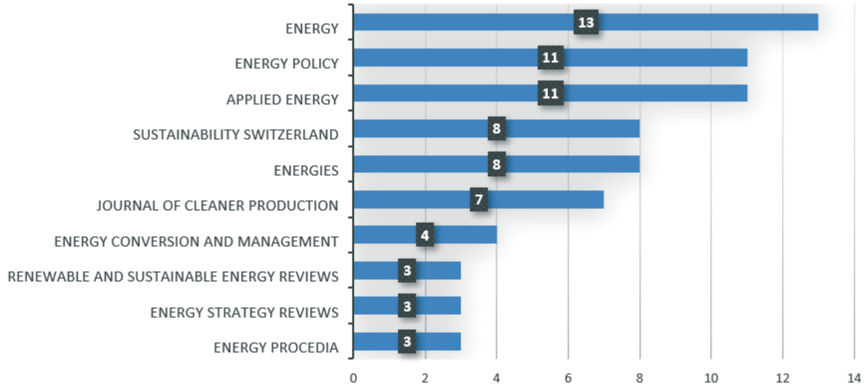

Figure 4 - Sources with more numbers of publications

The number of published works has increased each year as shown in Figure 5. Among the years of publication of the works considered, it can be noted, for example, that in 2004, 2008, 2013, and 2016 the trend of increasing relevance of the theme was observed. Just as the last decade stood out both in a number of works and in citations of existing works. This growth comes in line with the increase in policies and discussions about the economic, environmental, and social impact of energy management on the world stage and the need to develop models to support these initiatives.

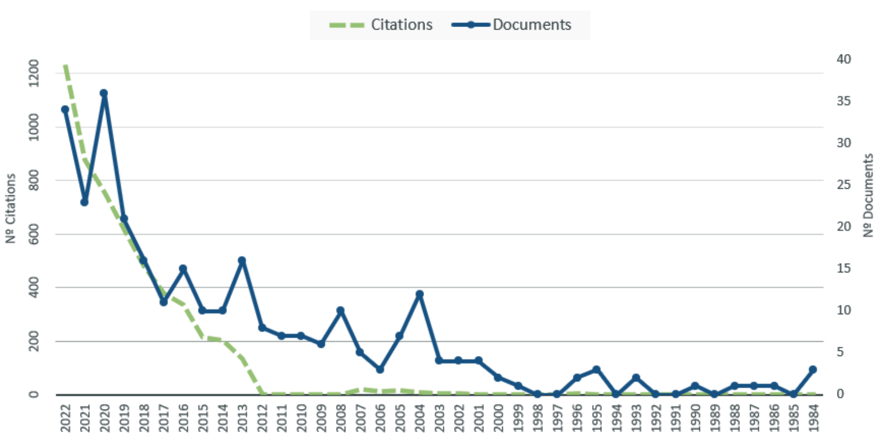

Figure 5 - Number of articles and citations by year.

Analyzing the keywords of the papers, it is possible to observe 7 clusters according to the emphasis of incidence in the papers. In the red and green group, there is a strong connection between the keywords: costs reduction, decision making, decision theory, economic and social effects, energy management, energy saving, industrial economics, law and legislation, and mathematical models, highlighting aspects related to economic impacts, social and legal aspects in the works presented. The orange and blue groups highlight specific approaches and techniques applied to improve energy use in industrial facilities such as: Automation, big data, energy management systems, energy planning, maintenance, Industry 4.0, Internet of things, manufacturing, and smart grids. The yellow group is related to keywords addressing sustainability and climate impacts of the emission of polluting gases and the need to control emissions and benchmarking: Carbon footprint, climate change, fossil fuels, gas emissions, greenhouse gas emissions, and water management. The models most applied in the works mentioned in abstracts or keywords were Algorithms, Analytic Hierarchy Process, Data Envelopment Analysis, Fuzzy Logic, Linear Programming, Monte Carlo Methods, Multi-Objective Optimization, and TOPSIS among others. Finally, it can also be noted that the analyzed studies were mostly in manufacturing industries: automotive, chemical, construction, electric, energy generation, iron and steel, and others incidence in the papers, as shown in Figure 6.

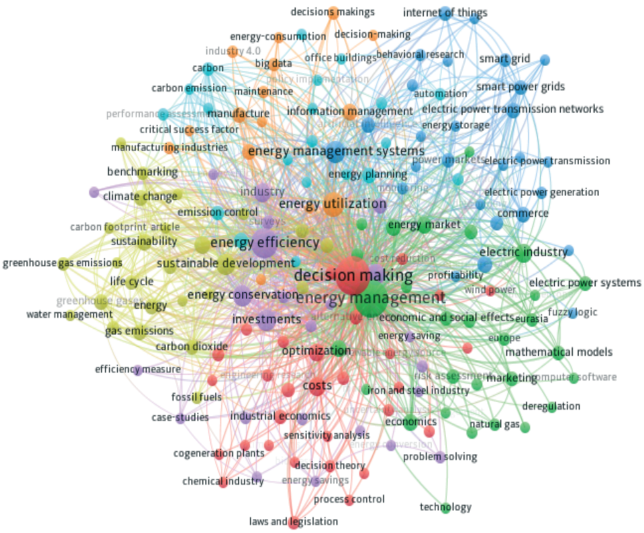

Figure 6- Bibliometric visualization for the author keywords (*VOSviewer Software*).

On the publication by country, the most developed regions and those with the greatest demand for energy resources have invested more in research on the subject, as well as the wide range of interest in the subject, which already involves research in more than 60 countries, highlighting Australia, Brazil, Canada, China, Germany, India, Iran, Italy, Spain, Sweden, United Kingdom, United States, with greater numbers of documents (Figure 7).

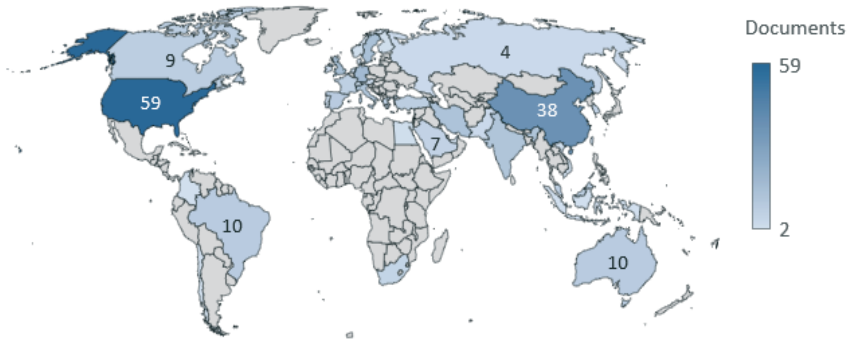

Figure 7 - Publications by countries

3. Conclusions

This paper aimed to answer research questions from the context of publications on the combination of energy management and MCDM topics. Data such as the number of papers, citations, regions, authors of publications, most applied models, and industry areas were presented. Analysis of the keywords and abstract of the works also allowed an understanding of the current context.

Clusters of topics within this area of study on energy management were identified, such as renewable energy, sustainable development, alternative energy sources, costs, and energy management policies. The main barriers mentioned in the studies ranged from bureaucratic problems, financial restrictions, interference with future costs, lack of technological innovation, lack of organization culture, search for opportunities for conservation, and conscious consumption of energy.

Although there is an expressive number of published works, it is observed that there was still no specific connection between energy management, guidelines, and MCDM methods, highlighting the research gap in the area. Most of the studies are still focused on specific models of measuring the energy efficiency performance of equipment or industrial systems. More detailed research on the needs, specifications, and difficulties encountered in establishing parameters for choosing MCDM methods to be associated with emerging issues in energy management may contribute to a better understanding of this knowledge field.

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