Analysis of scientific production of refused derived fuel through scientometric and bibliometric indicators

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ARTICLE INFO	ABSTRACT
	Constant urbanization has intensified the volume of solid urban waste generated, in addition to causing the exhaustion of landfills and the elevation of carbon in the atmosphere. New treatment technologies allow waste to be transformed, having economic value and, consequently, increasing the useful life of landfills. Energy recovery as a solution for the recovery of waste, through conversion to Refused Derived Fuel (RDF), to be used, for example, in industries. This study aimed to analyze the current state of scientific production on RDF production through scientometric and bibliometric indicators. The distribution of study sites suggests a global interest from both developed and developing countries. The most frequent terms analyzed in the word cloud of the article titles focus on the energy recovery of waste. The main words in the abstracts emphasized the methods of energy recycling, life cycle, and incineration. The analysis of networks by the co-occurrence of words showed that the synergy occurs around the term waste, with terms that demonstrate a tendency to use solid waste as an energy source to contribute to the municipal management of these materials. In addition, one of the energy conversion processes, gasification, was highlighted, pointing out that this process is one of the most applied. Finally, the potential collaborations of the factor analysis that verified two clusters focused on energy issues and related to the management of urban solid waste. **Keywords:** Waste, energy, management, cement, Refused Derived Fuel.

Introduction

Population growth contributes to an increase in the generation of solid urban waste, and this issue is a challenge present worldwide. The protection of the environment against the anthropic impacts caused by urbanization and inadequate solid waste management has been debated through multidisciplinary knowledge, including civil engineering combined with other areas of expertise, such as chemistry and biology.

Waste management must be carried out according to the waste hierarchy so that there is an evolution towards a stronger focus on the recovery of material as an energy source. The technology is an essential determining factor in the most appropriate time to value the waste stream before disposal in landfills (Bosmans et al., 2013).

New treatment technologies allow waste to be transformed, having economic value and, consequently, reducing the disposal in landfills, in addition to respecting the socio-environmental and economic aspects of the place to be implanted (Berticelli, Pandolfo & Korf, 2016). In the hierarchy of waste destinations, a technology used is the recovery and energy recovery by heat treatment, based on a conversion process that occurs at relatively high temperatures, causing changes in the material's chemical structure (Lombardi, Carnevale, & Corti, 2015).

Energy recovery through waste treatment has a significant effect on increasing the landfill's useful life, which are the main means of final disposal of waste generated in cities (Havukainen et al., 2017). Thus, a solution to this problem would be the recovery of waste through

conversion to Refused Derived Fuel (RDF) to be used, for example, in the cement production industries. In the cement industry, RDF is used as an exchange for non-renewable fossil fuels, such as petroleum coke. Araújo (2020) states that the cement industry is fundamental for the world economy; however, the production process consumes large amounts of fuel and electricity, being responsible for up to 7% of CO_2 emissions.

In recent years, there has been an increase in the number of literature reviews using bibliometric analyses to assess research trends (Ellegaard & Wallin, 2015). Bibliometrics makes it possible to statistically evaluate the technical-scientific literature from different perspectives, enabling the approximation between the researcher and the field of study and connecting and aligning the research objectives to the relevance of the restored content (Ensslin et al., 2015). Bibliometric studies are part of scientometry, which is defined as a study of measurement and quantification of the scientific process, based on bibliometric indicators, and an

academic field that has established lines of questions and methodologies, and distinct identities (Ramy et al., 2018).

In this context, a review of the literature on emerging technologies is indispensable to define the problem, and inform about the current state of the issue, identifying the trends, and the gaps in the area. Therefore, this study aimed to understand the current state of scientific production on the treatment of solid waste to produce refused-derived fuel used in industrial ovens.

Material and Methods

The research is characterized as descriptive with a quantitative focus through bibliometric and scientometric analysis. Thus, bibliometric indicators were analyzed considering quantitative aspects of scientific production and scientometric indicators in the quantitative aspects of science. Thus, the investigation was divided into two phases: (1) Data collection and (2) Analysis (Figure 1).
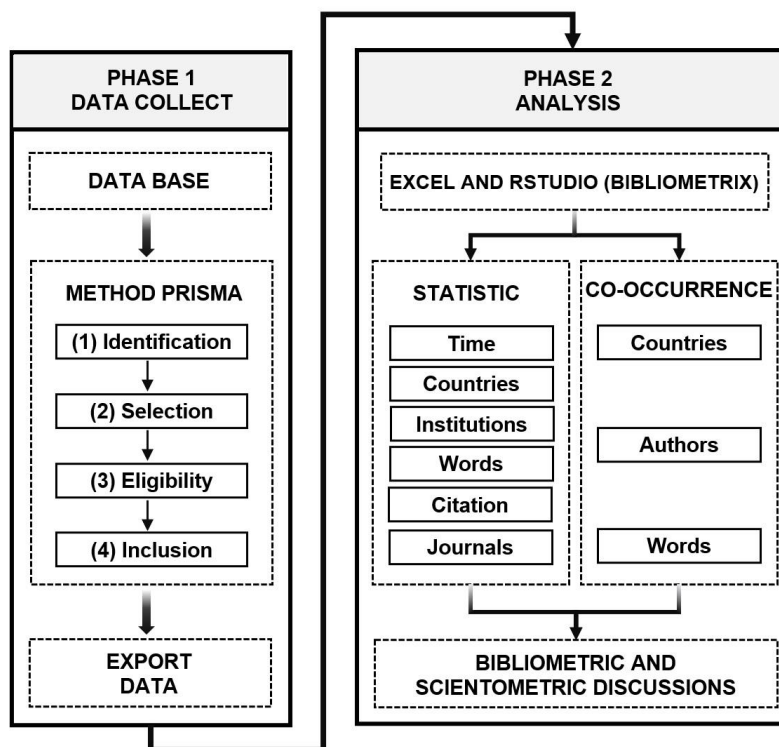

Figure 1. Flowchart used in the bibliometric and scientometric analysis. Source: Guedes et al. (2021).

Data collection

The analyze bibliometric and scientometric indicators were made using published scientific articles on the topic of refused derived fuel, waste energy, and coprocessing to investigate how the scientific community is treating such issues.

For data collection, we used the Scopus database, which, according to Paula et al. (2017),

is considered one of the largest databases among citations and abstracts of scientific literature with review by peers, offering tools to track, analyze and visualize research from the most diverse areas of knowledge, allowing a broad view of what is being published in the world. The Scopus platform annually covers a greater number of bibliographic records, totaling more than 55 million records dating from 1823, representing a

consistent alternative to a global source of scientific information (Mongeon & Paul-Hus, 2015).

The delimitation was carried out through the systematization of four stages, Identification, Selection, Eligibility, and Inclusion, defined by the methodology known as the Main Items for Reporting Systematic Reviews and Meta-Analysis - PRISMA (Moher et al., 2010). According to Pacheco et al. (2018), PRISMA is widely used to analyze studies published in different science segments.

In the Identification stage, the query on the platform was applied through Title - Abstract - Keywords, with the simultaneous application of the terms "refused devived fuel", "waste energy" and "coprocessing", to try to achieve a wider range of studies related to Solid Waste Management and RDF production. Then, in the Selection stage, the following filters were applied: space-time (2009 to 2019); type of journal (scientific journals); type of scientific production (research article); the language of the manuscript (English). Then, in the Eligibility stage, the titles and abstracts of the articles were read to screen the papers directly related to the topic addressed. All papers were read to guarantee, let only those restricted with the issue of this study. Read all papers guaranteed, let only those restricted with the issue of this study. Then, the data containing information about the articles were exported in bib format, which is read by bibliometrics software.

Thus, the analysis of the content of scientific productions focused on the production of RDF from the urban environment and RDF from the industrial sector. This study explored scientific research on the proposed theme worldwide.

Analyzes

The bibliometric data of the selected scientific articles, from the application of the systematization of the PRISMA methodology, were exported and inserted in the stages of data treatment and scientometric and bibliometric analysis of the collected data. Thus, a bibliometric and scientometric survey was carried out with the free software R Studio - Bibliometrix package. According to Geng et al. (2017), this methodology is recognized as a research mechanism established in information science, using analysis by quantitative, qualitative, and statistical methods to analyze information from a data set.

Subsequently, the following steps were adopted: data treatment and quantitative and textual/qualitative analysis. was made possible by

using the R Studio software - Bibliometrix package, which provides a vast field of importing bibliographic data from different databases, which help carry out bibliometric analyses, facilitating data construction.

After processing the data, the graphs and tables' elaboration proved necessary to explain the results. The quantification and identification of works on the scientific production of RDF over the years informed the development of literature on the subject, in addition to the spatialization of the works developed (Liu et al., 2019). The textual analysis of the texts covered the terms present in the titles and abstracts of the selected articles through the elaboration of the frequency of words by word cloud, the co-occurrence network, and the dendrogram. Lexical analysis is of great importance for understanding the word cloud (Ramos, Rosário-Lima & Amaral-Rosa, 2018), as it performs the grouping of terms due to the amount of repetition of these in the textual body, with larger and smaller words depending on the frequency (Melchior & Zanini, 2019).

Results and Discussion
Database search

The search was carried out in March 2020 in the Scopus database, applying the PRISMA methodology (Figure 2). In the first stage, identification, the keywords refused to derived fuel, waste energy, and coprocessing were simultaneously searched, resulting in the location of 904 publications. Then, in the second stage, selection, and exclusion criteria were applied to the initial sample using filters, leaving only scientific research articles published in journals, in the English language, between the years 2010 and 2019. Thus, the sample has been reduced to 298 scientific articles.

Subsequently, in the third stage, eligibility, the titles, and abstracts of the articles selected in the previous stage were read, resulting in 96 scientific articles' ineligibility because they did not address the issues investigated in this study. Thus, we proceeded with a sample of 202 articles. Finally, in the fourth stage, inclusion, the full articles were read, culminating in the removal of 78 articles, as they were not within the focus of this research. Soon, 124 scientific articles were included to analyze scientific production, exporting the bibliometric data of these articles.

The difference between the number of documents located between the identification and inclusion phase points to the relevance of the initial methodology for analyzing bibliometric and scientometric indicators. It allows for a systematization that minimizes the appearance of

bias in the production of literature reviews. In addition, the PRISMA method allows for greater speed in reading, analyzing, and processing

existing information and investigating the state of the art of related studies (Pacheco et al., 2018).
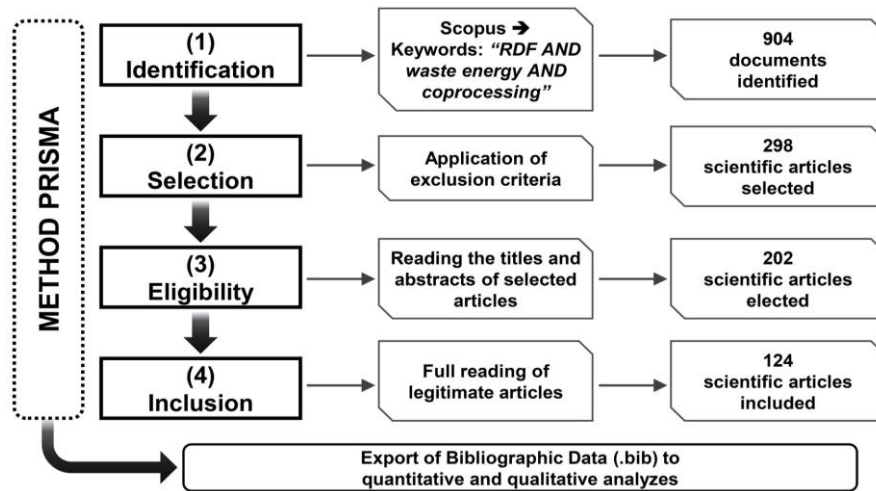

Figure 2. Systematic flowchart of the search in Scopus database. Source: Guedes et al. (2021).

Temporal evolution of publications

Analyzing the evolution of the number of publications over the years, a gradual increase is noted, except for the years 2018 and 2019 (Figure 3). Thus, it can be said that this study area is in evidence, being the object of study by researchers due to the possibility of scientific discoveries that contribute to the application of this technology for

the disposal of solid waste. The number of works related to the years 2016 and 2017 had a greater contribution. The year 2011, on the other hand, had the least number of scientific articles on RDF. Still, there is a drop in the number of publications analyzed in the last two years, 2018 and 2019. However, it is believed that this does not represent a reduction in interest in the topic studied.
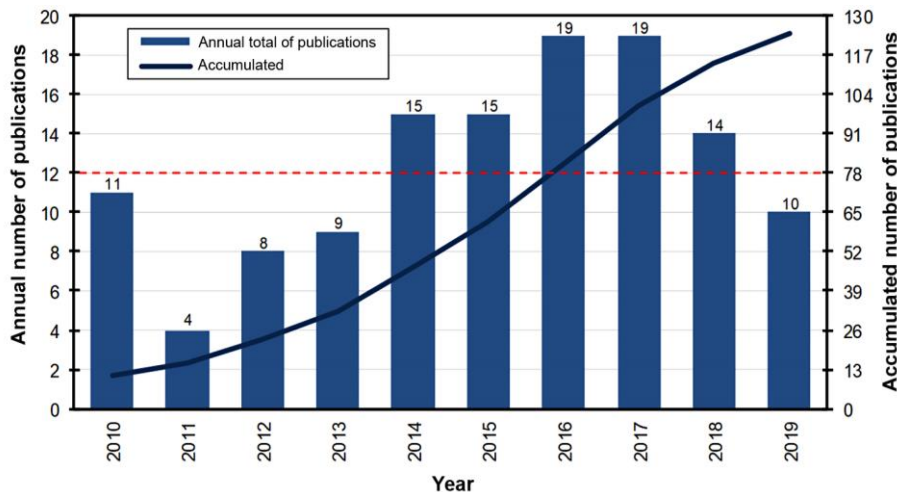

Figure 3. Evolution in the number of publications on RDF in the world over the years. Source: Guedes et al. (2021).

The average of annual publications was equal to approximately 12, so it is noted that the years 2014, 2015, 2016, 2017, and 2018 had an above-average amount, causing an increase in the growth of the line corresponding to the accumulated number of published articles. The continued rise in the number of publications related to the disposal of waste through RDF production indicates that the field of study research has been extensively explored. It can be

predicted that the number of publications related to this study area will continue growing with the development of new research that proves the efficiency of fuel generation from solid waste (Liu et al., 2019).

Distribution of publications

Considering the corresponding authors of the 124 articles, only 10 countries have two or more publications: Thailand with 11, the United

Kingdom with seven, Denmark and Spain with four, Brazil with three, and Finland, Iran, Italy, Poland, and the United States with two, totaling 39 articles (Figure 4). Still considering the 10 countries that have two or more publications, it is noted that the European continent was the one that had the greatest contribution, with 21 publications, followed by the Asian continent, with 13 publications, and the American continent, with five. The results obtained are consistent with

the history of the RDF since they point out that the first use was during the late 19th century, apparently in England, and quickly adopted in the United States, Germany, and Japan (Harvey, 1987). In the past decade, countries worldwide have explored ways to use better RDF production technology, especially in developed countries, such as the United States, and European and Asian countries (Mukherjee et al., 2020).
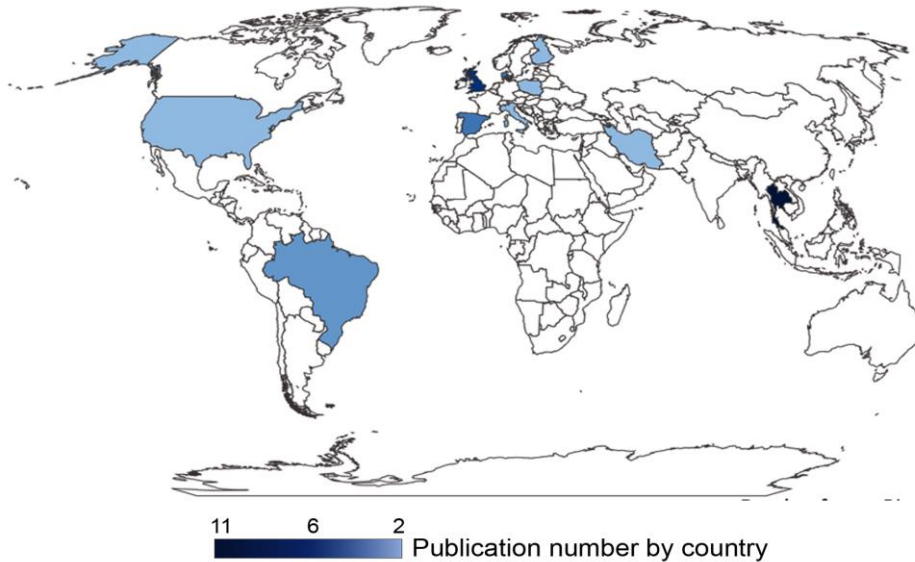

Figure 4. Main countries with publications on the theme. Source: Guedes et al. (2021).

Still considering the corresponding authors of the articles, seven institutions have two or more publications (Table 1). The distribution of institutions across the continents of the study sites suggests a global interest in the subject, mainly in higher-income economies - Denmark, United

States, Spain, Finland, and England; and middle-income economies - Thailand and Brazil. It is important to highlight that a large part of them focus on RDF production through solid waste treatment, applied in coprocessing.

Table 1. Leading institutions with publications on RDF in the world. Source: Guedes et al. (2021).

Institution	Country	Number of articles
Chiang Mai University	Thailand	5
Technical University of Denmark	Denmark	3
Center of Excellence on Energy Technology and Environment	Spain	2
Lappeenranta University of Technology	Finland	2
NC State University	United States	2
Newcastle University	England	2
University of São Paulo	Brazil	2

According to Boonpa & Sharp (2017), the government of Thailand considers the production of RDF as a renewable technology. In addition, it reduces the quantity and improves the quality of waste to meet the control of pollution needed standards also generates a substantial amount of power. Such public management policies for RDF production may have increased the number of research on the subject in that country. This fact

may have contributed to the production of scientific articles from Chiang Mai University in Thailand. The articles are distributed in 26 journals, with approximately 71% published in only five (Table 2).

The prominent magazines were Waste Management with 48 articles, Journal of Cleaner Production with 16 articles, Waste Management and Research with 10 articles, Resources

Conservation and Recycling, and Waste and Biomass Valorization, both with seven articles. Considering the high impact factor of these highlighted journals, most of the analyzed papers are of good quality since they were subjected to

rigorous evaluation processes for publication in reputable journals concerning the impact metrics, which for these newspapers correspond on average to approximately 5,280 for the Impact Factor (2019) and 8.8 for the Citescore (2019).

Table 2. Breakdown of journals by total publications and impact metrics. Source: Guedes et al. (2021).

Journals	Distribution of articles		Impact metrics	
	Quantity	Contribution (%)	CiteScore 2019	Impact Factor 2019
1 Waste Management	48	38.71	9.6	5.448
2 Journal of Cleaner Production	16	12.90	10.9	7.246
3 Waste Management and Research	10	8.06	3.9	2.771
4 Resources Conservation and Recycling	7	5.65	10.7	8.086
5 Waste and Biomass Valorization	7	5.65	-	2.851
Total	88	70.97		

Analysis of article citations

When analyzing the 10 articles with the highest number of citations and the 10 articles with the highest average of citations by the time of publication of the study (Figure 5), it appears that these nine are in both analyzes, proving the importance of these articles and the corresponding authors for the topic addressed in this study.

Considering these widely cited articles categorized by the Scopus database, they stood out with greater contribution in the two categories

analyzed: Bosmans et al. (2013) and Lombardi et al. (2015). These authors brought comprehensive reviews of concepts, characteristics, and factors that are basic in the study of refused derived fuel, serving as a basis for research that addresses the theme. Still, in terms of the research area, these two authors analyzed the issue of waste energy through a review of technologies and the performance of the heat treatment systems for recovering waste energy.
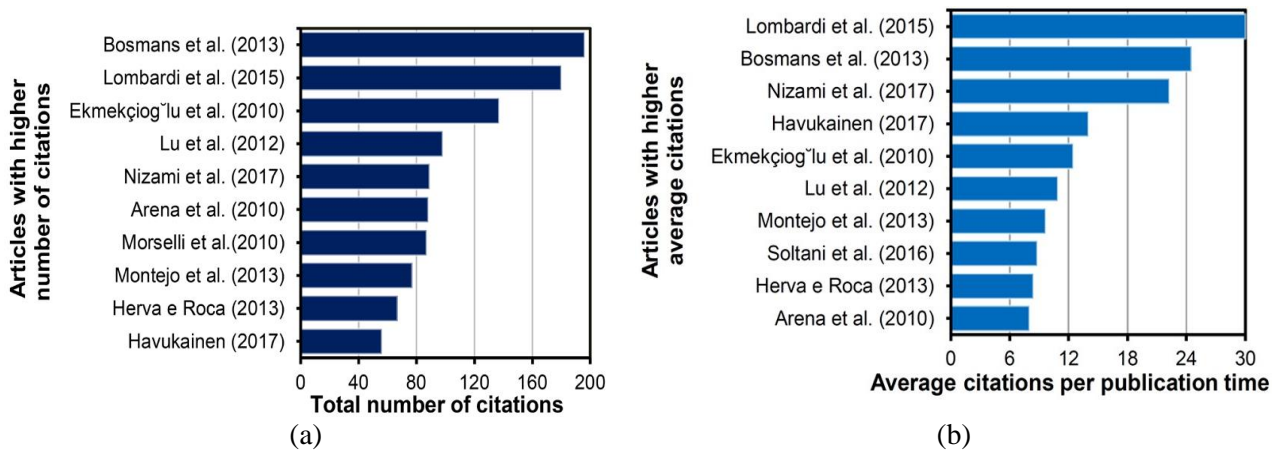

(a)   (b)

Figure 5. Analysis of article citations: (a) the 10 articles with the highest number of citations; and (b) the 10 articles with the highest average of citations per publication time. Source: Guedes et al. (2021).

Word frequency

An ordered list of predominant words was generated by the frequency of repetition of the words in the analyzed documents. In this perspective, the words that showed a greater emphasis on textual analysis stand out in the central area and are more extensive (Figure 6). Most of the words in the titles of the articles focus on words related to the theme and context of the

study, the main ones being waste, solid, fuel, energy, and management. The most frequent terms in the cloud referring to the words used in the abstracts emphasize methods, highlighting the energy recycling industry, life cycle, and incineration, the main ones being life cycle, incineration, recycling, solid waste, and waste treatment.

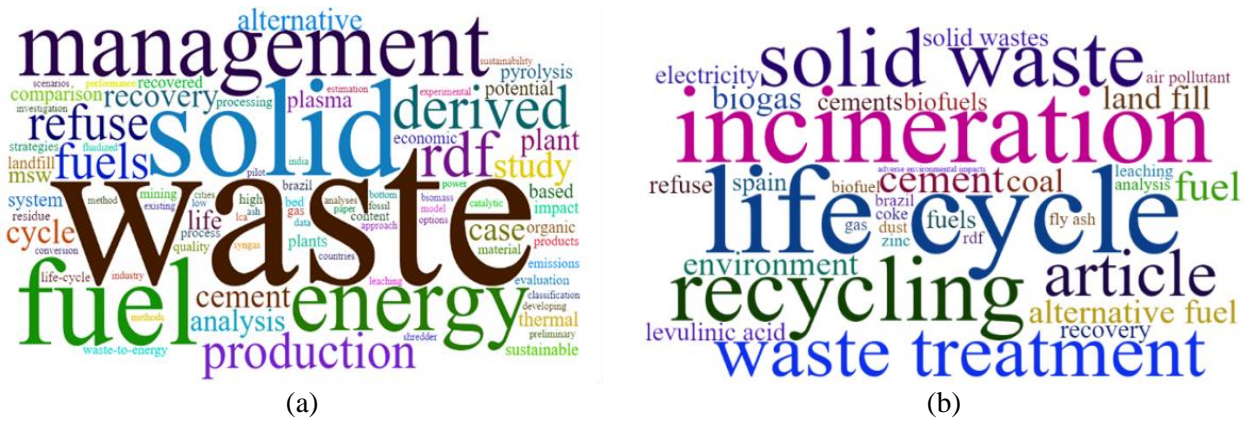(a)   (b)

Figure 6. Word cloud formed from: (a) the titles; (b) the abstracts. Source: Guedes et al. (2021).

Regarding the analysis of networks by the co-occurrence of terms located in the titles and abstracts (Figure 7), it is observed that the synergy between the words occurs around the term waste, which is interconnected with all other words that had greater repetitions. Still, there is a stronger link between the word waste and the terms solid, energy, management, and municipal, demonstrating that the research deals with the use of solid waste as an energy source to contribute to the municipal management of these materials. Secondarily, the words fuel and derived stood out,

which together with the word refused to form the object of this study, refused derived fuel. In addition, one of the energy conversion processes from different sources, gasification, was highlighted, showing that this process is one of the most applied worldwide.

Thus, identifying the co-occurrence of words reinforces the results of the filters applied in the search and selection stages, as these terms have the same semantic content, that is, related to the treatment of solid waste in the production of RDF.

Figure 7. Co-occurrence network of words. Source: Guedes et al. (2021).

Factor analysis

Through the analysis of the co-occurrence matrix in the words of the abstracts, it is observed through the tree diagram or dendrogram, which shows the groups formed by grouping observations in each step and in their levels of

similarity, how the words correlate and form factors that can determine a field of study (Figure 8). For Hair et al. (2006), factor analysis is a data reduction technique that correlates items to factors.
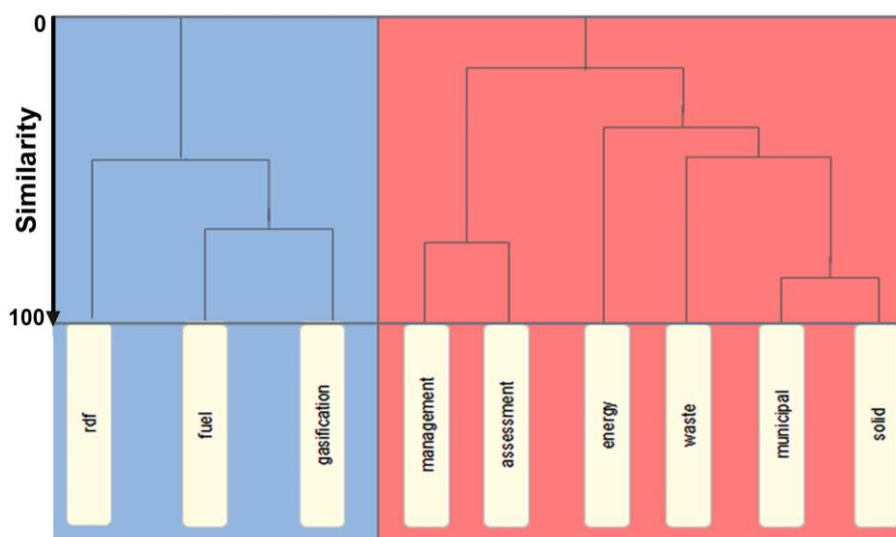
Figure 8. Dendrogram analysis at similarity levels. Source: Guedes et al. (2021).

The dendrogram was used to visualize the process's niches and analyze the distance levels of the formed clusters. Following the analysis, it is possible to observe two clusters. The first is characterized by approximating the terms RDF, fuel, and gasification, which focus on energy issues. The second is related to the management of urban solid waste. The level of similarity is measured along the vertical axis, and the different observations are listed along the horizontal axis. These main terms found in the factor analysis are considered latent variables, which are not observed in everyday life but are important for implementing a study or model (Leme et al., 2020).

Conclusion

The research made it possible to observe the scenario of scientific productions over 10 years on the energy use of solid waste through refused derived fuel with an emphasis on coprocessing, based on analysis of scientometric and bibliometric indicators. The 124 articles analyzed indicated that this area of study is in evidence, being the object of study by researchers due to the possibility of scientific discoveries that contribute to the application of technology. The most productive nations were those on the European and Asian continents, emphasizing Thailand, the United Kingdom, Denmark, and Spain.

The distribution of institutions across the continents of the study sites suggests a global interest from both developed and developing countries such as Thailand and Brazil. The sample of 124 articles taken from the Scopus database is distributed in 26 journals. Approximately 71% of the articles are distributed in only five journals, Waste Management; Journal of Cleaner Production; Waste Management and Research; Resources Conservation and Recycling; and Waste and Biomass Valorization. Thus, considering the high impact factor of these highlighted journals, most of the studies analyzed are of good quality since they have undergone rigorous evaluation processes for publication.

Analyzing the 10 articles with the highest number of citations and the 10 articles with the highest average citations by the time of publication of the work, it was found that nine are in the two analyzes, indicating a level of knowledge of the author in a specific way for with the theme of this study. Still, in terms of the research area, the main authors analyzed the issue of waste energy through a review of technologies for recovering energy from waste.

The most frequent terms analyzed in the word cloud from the titles of the articles focus on words related to the theme and context of the study, such as waste, solid, fuel, energy, and management. The most frequent words in the abstracts emphasize methods, highlighting the energy recycling industry, life cycle, and incineration, such as life cycle, incineration, recycling, solid waste, and waste treatment.

The analysis of networks by the co-occurrence of words showed that the synergy occurs around the term waste, having stronger links with the terms solid, energy, management, and municipal, demonstrating the trend of using solid waste as an energy source to contribute to the municipal management of these materials. In addition, one of the energy conversion processes, gasification, was highlighted, pointing out that this process is one of the most applied.

Finally, two clusters were verified in the factorial analysis using the dendrogram. The first was characterized by the approximation of terms

related to energy issues and the second related to the management of urban solid waste. These main terms found in the analysis are considered latent variables that are important for implementing the research.

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