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Research Trends in the Economic Analysis of Municipal Solid Waste Management Systems: A Bibliometric Analysis from 1980 to 2019

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Abstract: This article analyzes state-of the art studies that focus on the economic aspects (EA) of municipal solid waste (MSW) management systems, including an analysis of articles that have developed methodologies for economic analysis (MEA), as well as those which study the economic analysis of the externalities or external impacts related to these systems. The aim of this study was to determine the trends in research and critical points based on the literature available in the Web of Science database from 1980 to 2019. First, we present the statistics and general trends, then perform an in-depth bibliometric study using the VOSviewer software, which allows the results to be grouped according to references, authors, institutions, countries, and journals. The study showed that 563 articles about the economic aspects have been published, 229 about methodology development, and only 21 considered the methodologies for analyzing externalities generated by the MSW management systems. In general, there is great interest in the economic analysis of the systems and technologies that deal with transforming waste into energy.

Keywords: economic assessment; municipal solid waste; externalities; methods; bibliometric analysis; Web of Science (WoS)

1. Introduction

Currently, countries face a serious problem due to the generation and management of greater quantities of waste caused by economic growth and new economic models based on encouraging ever-greater consumption rates in society [1,2]. The large-scale production of waste has led to the development of several operations (i.e., collection, transport, treatment, and elimination) for its management [3]. Specifically, when waste management is centered on the management of domestic waste, or waste of similar characteristics, it is known as municipal solid waste (MSW) management. Depending on the city or country, the complexities and characteristics of these operations may vary; for example, in developed countries, the processes and systems are more complex and use more sophisticated technologies and infrastructures. On the other hand, in developing countries, the processes are generally simpler and the informal waste sector has a notable presence [4,5].

When an MSW management system is implemented it can generate different impacts or consequences, which may be reflected as revenues or costs depending on whether the parties involved are affected positively or negatively. A distinction is usually made between internal and external impacts. In general, the economic-financial analysis of MSW management systems focusses only on studying the internal or private impacts, costs, and revenues related to OPEX (operational

and maintenance costs) and CAPEX (capital costs). The internal or private impacts are those directly related to the MSW treatment process and its later reuse. These costs and incomes are incurred by the project investor or developer [6,7]. In contrast, the external impacts or externalities are those impacts or consequences resulting directly or indirectly from the operation of the MSW management system but whose effects are generally assumed by a party who is neither the owner nor the operator [7,8]. The externalities are generally connected with the social and environmental impacts (for example, effects on third-parties, control of contamination, increase in resources available, or guarantee of service, among others). Although the external impacts are more difficult to calculate, they are nonetheless important, as the impact of these characteristics can cause censorship of the project or its economic viability; therefore, they should be considered in the economic analysis [9–13].

MSW management is an area of increasing interest and concern, as evidenced by the increase in the amount of research carried out in recent years [14]. These studies generally focus on the environmental, social, and economic aspects, individually or combined [14]. Specifically, the economic aspect has acquired great importance due to it being a fundamental aspect in both governmental and national decision making [15], as the majority of decisions relating to the implementation of MSW management systems and technologies in modern society are affected by economic restrictions [9]. Therefore, the development of methods or models that allow the economic valuation of MSW management systems is essential, above all those that facilitate the economic assessment of the possible impacts or externalities (positive or negative) of MSW management systems on society and the environment [16].

To demonstrate the increasing interest in the economic analysis of MSW management systems, a bibliometric analysis was carried out, in which mathematical and statistical methods were applied in order to evaluate the performance of the authors, institutions, or countries, as well as to discover the principal areas of interest and show the future investigative trends [17,18]. The principal aim of this article was to analyze the worldwide dynamics regarding economic studies of MSW management. As such, we sought to: (1) evaluate the performance of authors, institutions, or countries; (2) discover the collaboration networks between journals, authors, and keywords in this field; and (3) discover the main areas of interest and show future investigative trends.

Several authors have carried out bibliometric studies in the field of waste. Among them is a study that examined the research trends in solid waste between 1993 and 2008 [19]. Some studies have focused on specific types of treatment, such as analysis of the reuse and recycling of solid waste between 1992 and 2016 [20], or the study of characteristics and trends of research into the incineration of waste and its conversion to energy [21]. Chen et al. (2017) [22] presented research into a specific type of waste, i.e., the studies of food waste between 1997 and 2014. Finally, some articles have concentrated on analyzing research trends in a specific journal, as in the case of the study into the characteristics and development of the journal *Resources, Conservation, and Recycling*, between 1988 and 2017 [18]. It should be noted that no bibliometric analysis focusing on the economic aspects of MSW management systems has been found.

The present study carried out a bibliometric analysis of the publications that dealt with the economic aspects of MSW management. Next, we conducted a review of the articles that developed methodologies for the economic analysis of MSW management systems. Finally, we analyzed articles that evaluated the possible external impacts (consequences) or externalities caused by the implementation of MSW management systems in economic terms. This study used publications and data obtained from the Web of Science (WoS), using the VOSviewer software to map the data graphically, using tools for co-occurrence of keywords, citations, bibliographic connections, and co-authorship.

The rest of the document is structured as follows: the next section describes the methodology and the data used. Then the bibliometric analysis is presented in Section 3, showing the general trends before viewing and discussing the collaborative networks. Finally, Section 4 contains the conclusions and further areas of research.

2. Materials and Methods

The data was obtained from the Core Collection of the Web of Science (WoS), a tool developed by Thomson Reuters and integrated in the ISI Web of Knowledge. The WoS is one of the most widely-used databases, providing graphics and statistics for the analysis of data about different areas of research, authors, document types, timelines, countries, universities, and institutions, among others. It also permits downloading the complete register of publications in txt format, which is generally used by mapping and data analysis software such as VOSviewer. The database used also included the following indexes: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI), Current Chemical Reactions (CCR-EXPANDED), and Index Chemicus (IC).

One of the most challenging aspects of bibliometric studies is the delimitation of the field of research under study. To obtain a broader view of the publications dealing with the economic aspects of MSW management systems, searches were carried out at three different levels, starting with a general search and becoming more specific. The results were obtained on 29 February 2020. The first search was carried out using the following keywords: Title: (Economic OR Cost OR Valuation) AND Topic: (MSW OR "Municipal Waste" OR "Municipal Solid Waste" OR "Urban Waste" OR "Household Waste") NOT Topic: (Waste-Water OR "Waste Activated Sludge"), limiting the search to the period 1980 to 2019. It was decided to limit the search for terms related to the economic question to the Title field and to refine the results and obtain only those publications that were closely related to this field of research. When the topic field was selected, the search was carried out in the title, abstract, author keywords, and keywords plus. The aim of this search was to determine which articles studied the economic aspects of MSW system management; a total of 563 results were obtained and identified as economic aspects (EA). The second search added other terms to those of the first, such as Topic: (Methodology OR Model) to determine which articles had developed or presented a method or model for the economic analysis of MSW management systems. It obtained 229 results, in this case classified as methodologies for economic analysis (MEA). Finally, the third search added further limits to those of the first and second, such as Topic: (Externality OR External Cost) to determine which articles developed or presented a methodology to evaluate economically the externalities related to the MSW management systems, obtaining only 21 results. The complete register (composed mainly of the authors, titles, sources, and abstracts of the publications), as well as the references quoted, were downloaded in txt format for mapping and network analysis. In Figure 1, the methodology used to search and obtain data and data treatment is presented.

A descriptive analysis was used to investigate and identify the most influential journals, countries, authors, and articles of review database. Taking Seguí-Amortegui et al. (2019) [23] as a reference, this study used bibliometric indicators such as: (1) productivity, based on the number of publications [24]; (2) influence or impact, based on the number of citations [24]; (3) the Hirsch, or H-index, an indicator that shows that at least N publications have been cited at least N times (we aimed to show both the productivity and impact in just one number) [24,25]; (4) impact factor, a measure applied to the journals that represent the average number of citations of the articles published by this source over a period of two years [24].

This research used the VOSviewer software (developed by the University of Leiden) for the mapping and analysis of scientific publication networks, scientific journals, researchers, research organizations, countries, and keywords [26]. The analysis of the networks can be used to create a graphic map of the relationships between the data [18]. The articles in these networks can be connected by authorship, co-occurrence, citations, bibliographic connections, or links to co-citations, allowing maps to be seen and explored [26].

The VOSviewer software uses items (nodes) to represent the objects of interest (publications, researchers, journals, or keywords); the bigger the node, the bigger the weight or importance of the item. A link is the connection or relation between two items, representing the number of articles in

which one specific item appears next to another. The thickest lines of the links show a more regular co-occurrence, in other words, greater intensity of cooperation [23,26]. This co-occurrence between nodes is also reflected in the distance between them. The color of the elements represents a group of items connected by their affinity to the subjects of research, elements of the same color being known as clusters [26].

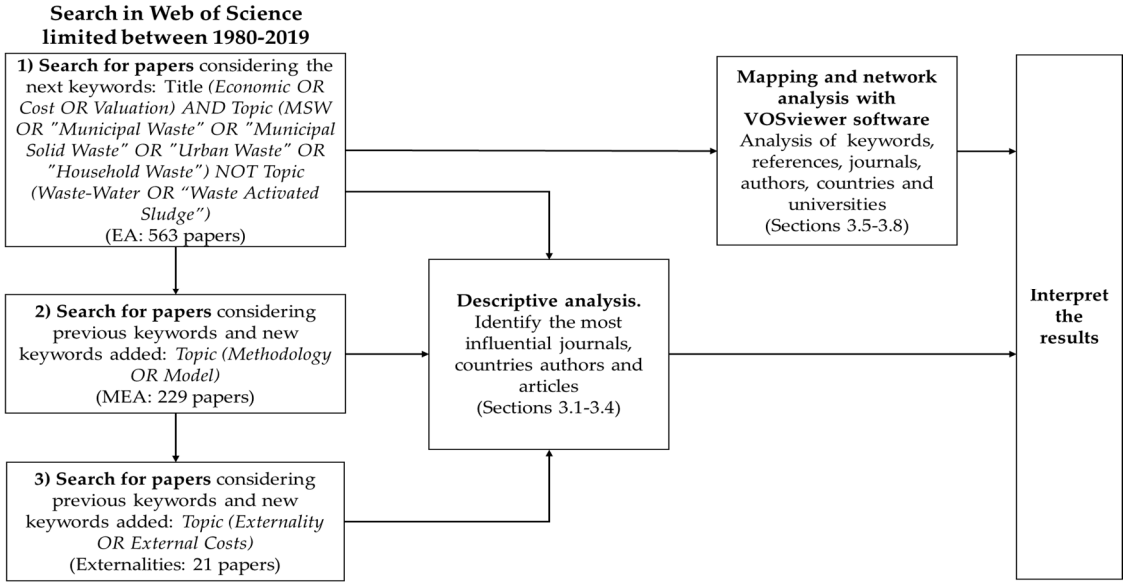


Figure 1. Methodology flowchart for search and analysis of data about economic aspects of Municipal Solid Waste (MSW) systems. Source: Own elaboration. EA: economic aspects; MEA: methodologies for economic analysis.

3. Results

First, we present the general trends in research, which includes the number of publications per year, the number of citations per field and document, the countries with the most publications, and the most representative authors [23]. Then, we analyzed the current situation and the development of research into the economic aspects (EA) of the MSW management systems, which consisted of 563 articles; in addition, we provided information about the articles that contain methodologies for the economic analysis (MEA) of MSW management systems, which consisted of 229 articles. The second part of this section concentrates on the most cited documents regarding the economic analysis of MSW management systems (referring to the themes of EA and MEA). The third analyzes the most representative journals in the field. Next, we give information about the articles that have developed methods for the economic analysis of the external impacts or externalities (this search contained only 21 articles). The fifth part studies the analysis of the coincidence of authors' keywords regarding the economic analysis (EA) of the MSW management systems. Then the article explores the co-citation of references, journals, and authors on the subject of EA. Finally, we studied the co-authorship networks of countries and institutions involved in the research of EA.

3.1. General Trends

The first document about EA appeared in the WoS in 1980. From this year onward there was an intermittent flow of documents, which were not published every year. However, after 1988, documents appeared every year, staring with 1 article in 1988 and rising to 75 in 2019. The annual publications about the economic aspects of MSW management systems are shown in Figure 2, where it can be seen that interest in the research of the subject has grown. Although the search for the economic aspects of the MSW systems only generated 563 results, calculating the increase in the last 10 years (2010 to 2019) shows a rise of more than 294.74%.

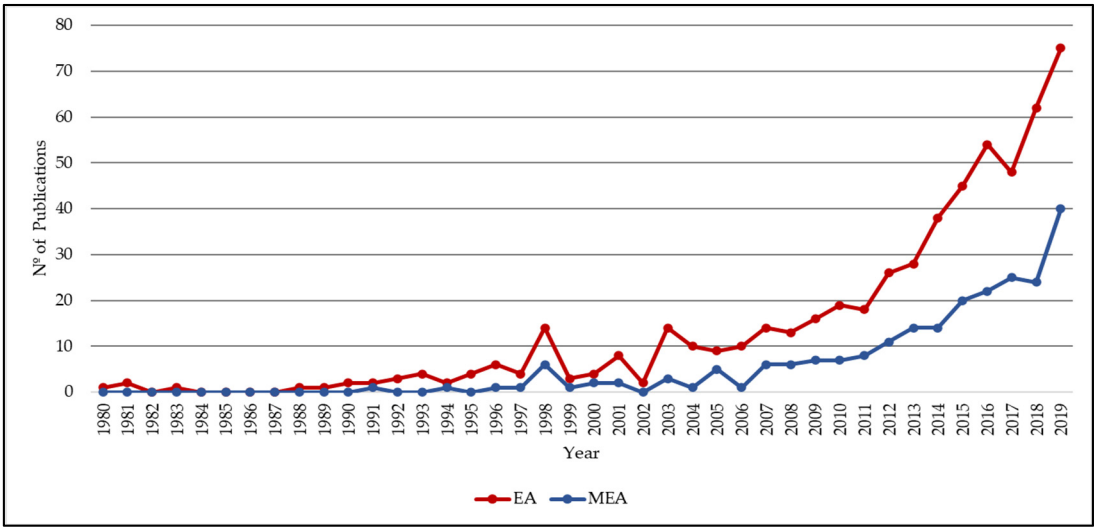
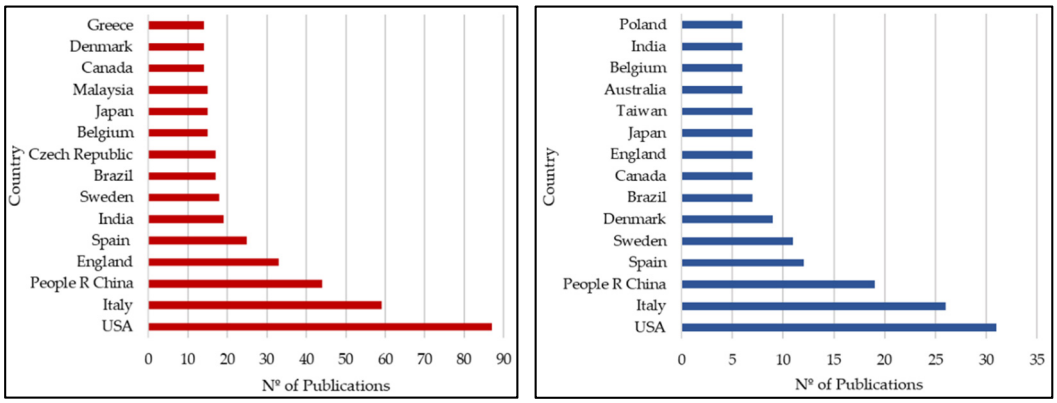


Figure 2. The annual number of publications about economic aspects (EA) and methodologies for economic analysis (MEA) of Municipal Solid Waste systems in Web of Science (WoS). Source: Own elaboration based on data from WoS 2020. The red line in the plot shows the number of publications per year in WoS on EA; the blue line indicates the annual number of research articles on MEA.

In the case of the documents relating to MEA, the first article appeared in 1991, since when there has been an intermittent generation of articles. However, after 2003 more documents appeared every year, starting with 3 in 2003 and reaching a total of 40 in 2019. Although the search for the development of methods for the economic analysis of the MSW systems generated only 229 results, calculating the increase of the last 10 years shows that there has been a rise of more than 471.43%.

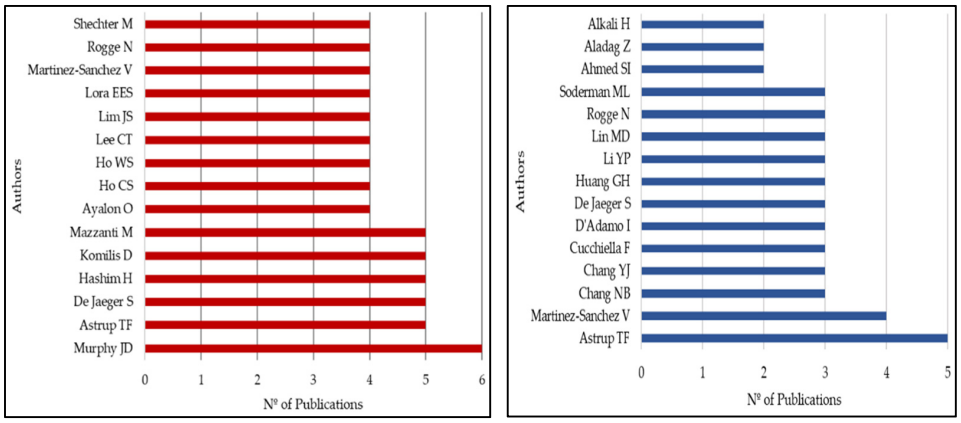
As can be seen in Figure 3, the countries with most publications dealing with EA are the USA with 87 publications, Italy with 59, and China with 44. These represent, respectively, 15.45%, 10.48%, and 7.81% of all publications on the subject. In addition, 80 countries have contributed to the development of the 563 publications. In the case of MEA, the countries with most publications are the USA with 31, Italy with 26, and China with 19. These represent, respectively, 13.53%, 11.35%, and 8.29% of all publications on the subject. It should be noted that the developed countries are to be found among the most representative, which reflects the developing countries' lack of interest in research into the economic aspects of MSW management.



(**a**) (**b**)

Figure 3. Publications in Web of Science (WoS) on economic aspects of Municipal Solid Waste systems, by country. Source: own elaboration based on data from WoS 2020. (**a**) The red bars show the number of publications about economic aspects (EA) research per country. (**b**) The blue bars show the number of publications about methodologies for economic analysis (MEA) per country.

As shown in Figure 4, the authors with the most publications about EA are Murphy, J.D. with 6 publications (total articles in WoS: 151; h-index: 40), Astrup, T. with 5 publications (total articles in WoS: 385; h-index: 57), and Hashim, H. with 5 publications (total articles in WoS: 141; h-index: 28). These represent, respectively, 1.06%, 0.88%, and 0.88% of the 563 publications in this field. The authors with most articles about MEA are Astrup, T. with 5 publications, Martinez-Sanchez, V with 4 publications, and several authors with 3 publications, such as Chang, N.B., Chang, Y.J. and Cucchiella, F., among others.



(**a**) (**b**)

Figure 4. Publications in Web of Science (WoS) on economic aspects of Municipal Solid Waste systems, by author. Source: own elaboration based on data from WoS 2020. (**a**) The red bars show the number of publications about economic aspects (EA) research per author. (**b**) The blue bars show the number of publications about methodologies for economic analysis (MEA) per author.

The influence of the articles can also be measured by analyzing the number of citations. Table 1 shows the level of citations of all the articles published on EA, where it can be seen that only 7.11% (40) of the total (563) have more than 50 citations, 12.43% (70) have between 25 and 49 citations, 22.02% (124) have between 10 and 24 citations, and 58.44% (329) have less than 10 citations. The h-index of the articles about EA is 45 (i.e., 45 articles have at least 45 citations). In the case of articles about MEA, it can be seen that only 6.99% (16) of the total (229) have more than 50 citations, 8.73% (20) have between 25 and 49 citations, 24.89% (57) have between 10 and 24 citations and 59.40% (136) have less than 10 citations. The h-index of the articles related with MEA is 28.

Table 1. General citation structure in EA and MEA.

EA				
Number of Citations	**No. of Articles**	**Accumulated No. of Articles**	**% Articles**	**% Accumulated Articles**
≥150	1	1	0.18%	0.18%
≥100	9	10	1.60%	1.78%
≥50	30	40	5.33%	7.10%
≥25	70	110	12.43%	19.54%
≥10	124	234	22.02%	41.56%
<10	215	449	38.19%	79.75%
0	114	563	20.25%	100.00%
MEA				
≥100	5	5	2.18%	2.18%
≥50	11	16	4.80%	6.99%
≥25	20	36	8.73%	15.72%
≥10	57	93	24.89%	40.61%
<10	90	183	39.30%	79.91%
0	46	229	20.10%	100.00%

Source: Own elaboration based on WoS 2020.

3.2. Analysis of the Most-Cited Articles Related to the Economic Aspects of MSW Management Systems

Table 2 shows the most-cited articles in the fields of EA and MEA, as well as some specific characteristics such as the journals where they were published, the total number of citations (NC), citations per year (CY), and the main results.

Table 2. General citation structure in MSW systems' Economic Assessment.

Most Cited Papers on EA					
R	**Reference**	**Journal**	**NC**	**CY**	**Main Results**
1	Murphy and McKeogh (2004) [27]	RE	176	10.35	Four technologies which produce energy from MSW are researched.
2	Consonni et al. (2005) [28]	WM	138	8.63	Environmental and economic impacts of strategies for energy recovery are examined through LCA.
3	Douskova et al., (2009) [29]	AMB	136	11.33	Flue gas from a MSW incinerator was used as a source of CO_2 for the cultivation of the microalga Chlorella vulgaris to decrease the biomass production costs and to bioremediate CO_2.
4	Reich (2005) [30]	JCP	133	8.31	A methodology for economic assessment of MSW systems that consists of a financial LCC and an environmental LCC.
5	Leme et al. (2014) [31]	RCR	128	18.29	Different alternatives to energy recovery from MSW are compared from a techno-economic and environmental point of view.
6	Murphy et al. (2004) [33]	AE	123	7.24	Different scenarios of biogas use are analyzed from a technical, economic, and environmental point of view.
7	Johari et al. (2012) [32]	RSER	114	12.67	Methane emission from MSW disposed in landfills and its economic and environmental benefits are estimated.
8	Tan et al. (2015) [34]	ECM	107	17.83	Energy, economic and environmental impacts of WtE strategies for MSW management are evaluated.
9	Callan and Thomas (2001) [35]	LE	107	5.35	A multiple-output cost structure, which models the relationship between recycling and disposal activity.
10	Palmer et al. (1997) [36]	JEEM	100	4.17	Three price-based policies for MSW reduction and increased recycling are analyzed.
11	Bandara et al. (2007) [37]	EMA	97	6.93	MSW generation rate, waste composition, and related socio-economic factors are determined though field survey model.
12	Aye and Widjaya (2006) [38]	WM	87	5.8	Environmental and economic assessments to compare the options for traditional market waste disposal are performed through LCA and Cost-Benefit analysis.
13	Dijkgraaf and Gradus (2004) [39]	REE	87	5.12	Effects of unit-based pricing systems on waste collection are estimated.
14	Emery et al. (2007) [40]	RCR	84	6	Environmental and economic impacts of waste management scenarios are evaluated using a LCA computer model.
15	Kollikkathara et al. (2010) [41]	WM	78	7.09	A system dynamic approach that considers landfill capacity, environmental impacts, and financial expenditures.
Most Cited Papers on MEA					
R	**Reference**	**Journal**	**NC**	**CY**	**Main Results**
1	Reich (2005) [30]	JCP	133	8.31	A methodology for economic assessment that consists of a financial LCC and an environmental LCC.
2	Leme et al. (2014) [31]	RCR	128	18.29	Different alternatives to energy recovery from MSW are compared from a techno-economic and environmental point of view.
3	Johari et al. (2012) [32]	RSER	114	12.67	Methane emission from MSW disposed of in landfills and its economic and environmental benefits are estimated.

Table 2. *Cont.*

Most Cited Papers on MEA					
R	**Reference**	**Journal**	**NC**	**CY**	**Main Results**
4	Callan and Thomas (2001) [35]	LE	107	5.35	A multiple-output cost structure, which models the relationship between recycling and disposal activity.
5	Palmer et al. (1997) [36]	JEEM	100	4.17	Three price-based policies for MSW reduction and increased recycling are analyzed.
6	Bandara et al. (2007) [37]	EMA	97	6.93	MSW generation rate, waste composition, and related socioeconomic factors are determined through field survey model.
7	Emery et al. (2007) [40]	RCR	84	6	A LCA computer model for evaluation of environmental and economic impacts of MSW management scenarios.
8	Kollikkathara et al. (2010) [41]	WM	78	7.09	A system dynamic approach that considers landfill capacity, environmental impacts, and financial expenditures.
9	Mazzanti and Zoboli (2009) [42]	ERR	71	5.92	A framework to analyze delinking for diverse waste related trends through a Waste Kuznets Curve.
10	Shmelev and Powell (2006) [43]	EE	65	4.33	A methodology for the regional MSW management modelling that considers spatial and temporal patterns, environmental, and economic impacts (such as public health and biodiversity).

Source: Own elaboration based on data from WoS 2020. EA: economic aspects; MEA: methodologies for economic analysis; R: ranking; NC: total number of citations; CY: citations per year. RE: *Renewable Energy*; WM: *Waste Management*; AMB: *Applied Microbiology and Biotechnology*; JCP: *Journal of Cleaner Production*; RCR: *Resources Conservation and Recycling*; AE: *Applied Energy*; RSER: *Renewable and Sustainable Energy Reviews*; LE: *Land Economics*; JEEM: *Journal of Environmental Economics and Management*; EMA: *Environmental Monitoring and Assessment*; REE: *Resource and Energy Economics*; ECM: *Energy Conversion and Management*; EE: *Ecological Economics*; ERE: *Environmental and Resource Economics*; LCC: Life Cycle Costing; LCA: Life Cycle Assessment; MSW: Municipal Solid Waste; WtE: Waste to Energy.

Regarding research into EA, 33.33% of the 15 most-cited articles were published in the journal *Waste Management* (Table 2). The 3 most-cited articles on this subject are Murphy and McKeogh, (2004) [27] with 176 citations, Consonni et al. (2005) [28] with 138 citations, and Douskova et al. (2009) [29] with 136 citations. In the case of research into MEA, the 3 most-cited articles are Reich (2005) [30] with 133 citations, Leme et al. (2014) [31] with 128 citations, and Johari et al. (2012) [32] with 114 citations. In both cases, these articles focus mainly on the economic analysis of technology and systems for generating energy from waste, waste collection costs, and the assessment of different recycling systems.

3.3. Analysis of the Journals Related to Economic Aspects of MSW Management Systems

Table 3 shows a list of journals with the most articles published regarding the EA and MEA of MSW management systems. In the case of EA, 299 journals contained the 563 articles published on the subject. Of the sources that published articles about economic analysis, 78.59% have published only one article and just 7 journals have published 10 or more articles. In the case of MEA, 136 journals contained the 229 articles published on the subject. Of the sources that published articles about the subject, 78.67% have only published one article and just 4 journals have published 10 or more articles.

The three main sources, according to the articles published on the subjects of EA and MEA are *Waste Management*, *Resources Conservation*, and *Recycling and Waste Management Research*. In addition, 49.91% of the total studies of EA (563) have been published in the top 20 journals. Of the total works on MEA (229), 44.10% have been published in the top 10 journals. Research into EA represents just a small percentage of the total amount of research carried out in the top 20 journals (with coverage varying from 0.01% to 1.19%). In the case of MEA, the research carried out in the top 10 journals represents coverage of 0.02% to 0.55%.

Table 3. The top 20 journals related to EA and top 15 journals related to MEA of MSW Systems.

Journals Related to EA							
R	**Journals**	**AP**	**H-Index**	**TAP**	**AC**	**%AP**	**IF**
1	WM	74	25	6769	23.49	1.09%	5.431
2	RCR	41	19	3619	24.27	1.13%	7.044
3	WMR	35	12	2944	12.74	1.19%	2.015
4	JCP	25	11	17,314	17.04	0.14%	6.395
5	AE	11	8	14,429	32.09	0.08%	8.426
6	E	10	5	17,764	10.10	0.06%	5.537
7	ECM	10	8	13,050	28.80	0.08%	7.181
8	JEM	9	7	10,791	14.67	0.08%	4.865
9	EP	8	5	21,729	7.00	0.04%	-
10	RSER	7	6	9339	40.29	0.07%	10.556
11	WBV	7	4	1462	3.86	0.48%	2.358
12	BT	6	6	22,142	28.83	0.03%	6.669
13	S	6	3	17,777	6.33	0.03%	2.592
14	EE	5	3	5872	17.60	0.09%	4.281
15	EST	5	4	37,941	22.00	0.01%	7.149
16	RE	5	4	11,689	53.00	0.04%	5.439
17	STE	5	5	33,352	23.8	0.01%	5.589
18	B	4	2	6944	2.00	0.06%	0.039
19	CTEP	4	3	1688	10.50	0.24%	2.277
20	EEMJ	4	2	3375	3.75	0.12%	1.186
Journals Related to MEA							
R	**Journals**	**AP**	**H-Index**	**TAP**	**AC**	**%AP**	**IF**
1	WM	29	14	6769	21.00	0.43%	5.431
2	RCR	20	13	3619	27.60	0.55%	7.044
3	WMR	13	5	2944	10.62	0.44%	2.015
4	JCP	11	7	17,314	23.36	0.06%	6.395
5	AE	5	3	14,429	13.60	0.03%	8.426
6	EE	5	3	5872	17.60	0.09%	4.281
7	E	5	4	17,764	8.40	0.03%	5.537
8	EP	5	5	21,729	9.20	0.02%	4.865
9	ECM	4	4	13,050	14.75	0.03%	7.181
10	S	4	3	17,777	5.50	0.02%	2.592

Source: Own elaboration based on data from WoS 2020. EA: economic aspects; MEA: methodologies for economic analysis; R: ranking; AP: articles published about MSW economic analysis; H-index: the h-index in the area; TAP: total articles published; AC: average citations by article in the area. %AP: percentage of articles published (AP/TAP); IF: impact factor (2018). WM: *Waste Management*; RCR: *Resources Conservation and Recycling*; WMR: *Waste Management Research*; JCP: *Journal of Cleaner Production*; AE: *Applied Energy*; E: *Energy*; ECM: *Energy Conversion and Management*; JEM: *Journal of Environmental Management*; EP: *Energy Procedia*; RSER: *Renewable Sustainable Energy Reviews*; WBV: *Waste and Biomass Valorization*; BT: *Bioresource Technology*; S: *Sustainability*; EE: *Ecological Economics*; EST: *Environmental Science Technology*; RE: *Renewable Energy*; STE: *Science of the Total Environment*; B: *Biocycle*; CTEP: *Clean Technologies and Environmental Policy*; EEMJ: *Environmental Engineering and Management Journal*; EE: *Ecological Economics*.

Another measure of the journal's quality is the H index [26], which represents the number (H) of articles for which the author, journal, or institution have received at least H citations. The journal with the highest H-index for EA and MEA is *Waste Management* (25 and 29, respectively).

The journals with the highest average of citations per article published (AC) related to the subject of EA are *Renewable Energy* (53.00), *Renewable Sustainable Energy Reviews* (40.29) and *Applied Energy* (32.09). Regarding MEA, they are *Resources Conservation and Recycling* (27.60), *Journal of Cleaner Production* (23.36), and *Waste Management* (21.00).

The main categories of publications about EA are environmental sciences (54.35%), environmental engineering (42.51%), energy fuels (19.89%), green sustainable science technology (13.14%), economics (7.28%), and environmental studies (7.28%). Regarding MEA, the main categories are environmental sciences (57.20%), environmental engineering (41.48%), energy fuels (18.77%), and green sustainable science technology (14.41%).

3.4. Publications Related to Externalities

The search in WoS using the terms "Methodology" or "Model", as well as "Externality" or "External Costs", produced 21 publications, with 23.80% of the articles published in the journal *Waste Management*. Of all the articles, 23.80% were published before 2010, 38.10% appeared between 2010 and 2015, and 38.10% were published after 2015.

Table 4, shows the most-cited articles that considered external costs or benefits, where the most-cited was Massarutto et al. (2011) [44] with 59 citations. This work developed a model based on the principles of life cycle costing (LCC), which includes externalities such as air emissions (from incineration, landfills and collection vehicles), climate change (CO_2), and disamenities. Rabl et al. (2008) [45], with 55 citations, presented a methodology for evaluating external costs due to pollution from waste treatment is described, based on the ExternE project series of the European Commission. In this case, energy, material recovery, and possible differences in transport distance are considered. Martinez-Sanchez et al. (2015) [9] presented a costs model for the economic valuation of MSW management systems, had 40 citations. This model was based on the principles of LCC and considered the following external costs: environmental emissions and society's willingness to pay to prevent emissions or impacts of the MSW systems.

It must be pointed out that there are some articles that show an extensive review of the principal external impacts generated by MSW management systems [12,46]. They provide a general view of the external costs or externalities associated with several MSW management systems, such as disposal in a landfill and waste incineration, including different valuation methods. These articles are not included in the 21 obtained results because they do not provide methods for the economic valuation of the externalities that would allow them to be identified and their monetary value assessed.

Table 4. General citation structure related to externalities.

Most Cited Papers Related to Externalities or External Costs					
R	**References**	**Journal**	**NC**	**CY**	**Main Results**
1	Massarutto et al. (2011) [44]	WM	59	5.9	External costs and benefits implied by several alternative scenarios based on different combinations of energy and materials recovery.
2	Rabl et al. (2008) [45]	WMR	55	4.23	A methodology for evaluating the impacts and damage costs ('external costs') due to pollution from waste treatment.
3	Martinez-Sanchez et al. (2015) [9]	WM	40	6.67	A cost model that considers externality costs for the economic assessment of MSW management systems.
4	Woon and Lo (2016) [47]	RCR	25	5	Quantifies and compares the private and external costs of a landfill and an incineration facility.
5	Martinez-Sanchez et al. (2017) [48]	EST	20	5	Applicability of societal life-cycle costing to life-cycle optimization of MSW systems.
6	Mavrotas et al. (2015) [10]	RSER	19	3.17	A multi-objective mathematical programming model that considers external costs/benefits of WtE solutions.
7	Agar et al. (2007) [49]	JAWMA	15	1.07	A methodology to estimate heavy duty diesel vehicle emissions thought operational data from vehicle fleets monitored by a global positioning system (GPS).
8	Tonjes and Mallikarjun (2013) [50]	WM	14	1.75	An empirical systems model for recycling systems.
9	Maalouf and El-Fadel (2017) [51]	WM	11	2.75	A model that considers environmental externalities to integrate MSW and wastewater management for waste with high organic food content.
10	Panepinto and Genon (2012) [52]	WBV	10	1.11	A model to determine the optimal destination of MSW that considers monetary costs and environmental externalities.

Own elaboration based on data from WoS 2020. R: ranking; NC: Total number of citations; CY: Citations per year. WM: *Waste Management*; WMR: *Waste Management and Research*; RCR: *Resources Conservation and Recycling*; EST: *Environmental Science and Technology*; RSER: *Renewable and Sustainable Energy Reviews*; JAWMA: *Journal of The Air and Waste Management Association*; WBV: *Waste and Biomass Valorization*; MSW: Municipal Solid Waste; WtE: Waste to Energy.

3.5. Keyword Analysis

The keywords generally indicate the main content and subject of the article's research, showing trends in research and the most important subjects in a specific area [23]. "When working with keywords, the occurrences attribute indicates the number of documents in which a keyword occurs" [26] (p. 36).

Examining the 563 articles about researching the EA of MSW management systems, the analysis reveals the existence of 1493 keywords. Figure 5 shows the principal keywords, organized in 9 clusters, where the most frequent keywords per cluster are as follows: recycling, circular economy (red cluster); MSW, costs (green cluster); MSW, renewable energy (dark blue cluster); biogas, economic analysis (yellow cluster); anaerobic digestion, gasification (purple cluster); MSW, techno-economic analysis (light blue cluster); waste management, waste-to-energy (orange cluster); life cycle assessment, incineration (brown cluster); and landfill, leachate (pink cluster).

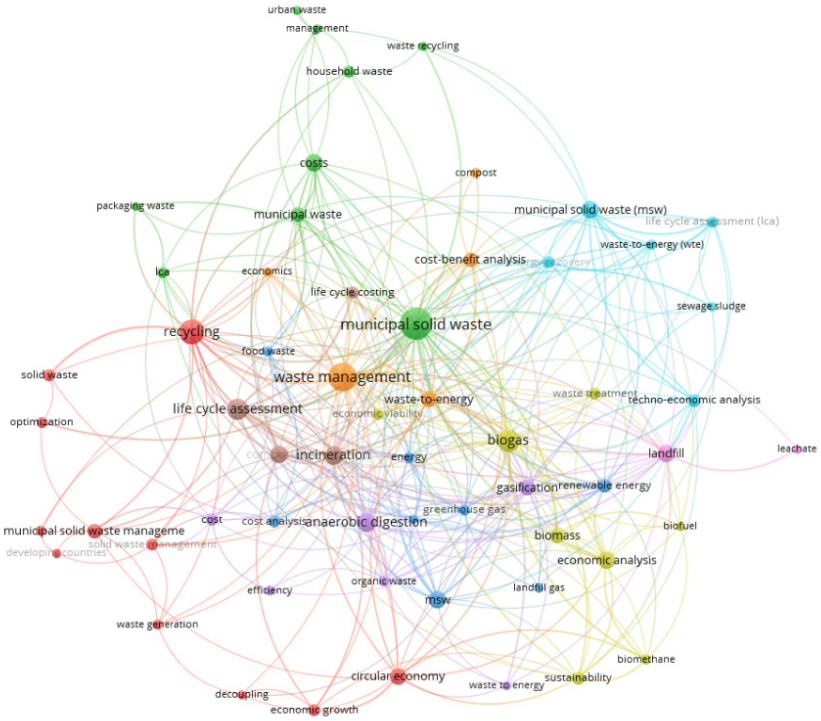


Figure 5. Co-occurrence network of author keywords in publications. The figure includes the 59 keywords with the most frequent occurrences of the 1493 total keywords that meet a minimum threshold of 5 occurrences.

It can be seen that among the top 20 keywords some, related to the transformation of waste into energy, stand out, such as incineration, waste to energy, renewable energy, and biogas. It can also be seen that the most common methods for the economic assessment of MSW systems are the life cycle costing and cost-benefit analysis.

There are also keywords related to some specific types of waste, such as "food waste" and "organic waste"; the importance of the research into these is due to the fact that they are the world's most widely-generated waste types [1,53]. The presence of the keyword "packaging waste" is also noticeable, its importance lying in the several negative impacts (environmental and economic) that can arise if it is not managed adequately, as in the case of "plastic packaging waste" [54,55]. The research and design of viable economic, social, and environmental technologies and MSW systems is essential, as is the development of techniques to improve the management and reduce generation of these wastes, which would lead to a reduction in possible negative impacts.

Table 5 shows the top 20 keywords, as well as the occurrences (frequency) and co-occurrences link (total strength of link). Regarding occurrence, the most important keywords are municipal solid waste,

biogas, and waste management; in the case of the co-occurrence link, the most important keywords are municipal solid waste, waste management, and recycling.

Table 5. The top keywords co-occurrence of publications.

R	Keyword	Co	Oc
1	Municipal solid waste	76	60
2	Biogas	57	29
3	Waste management	56	46
4	Recycling	44	36
5	Incineration	42	20
6	Anaerobic digestion	39	21
7	Life cycle assessment	36	26
8	Municipal solid waste (MSW)	33	18
9	Gasification	33	14
10	Landfill	31	18
11	Composting	30	18
12	Economic analysis	27	17
13	Renewable anergy	27	11
14	MSW	25	17
15	Costs	24	17
16	Waste-to-energy	24	15
17	Circular economy	22	16
18	Waste-to-energy (wte)	22	6
19	Energy	21	7
20	Sustainability	20	10

Source: Own elaboration based on WoS 2020. R: Rank; Co: keyword co-occurrences link; Oc: keyword occurrences.

3.6. Reference, Journal, and Author Co-Citation Analysis

This section analyzed co-citation (cited references, cited sources, and cited authors). Co-citation is defined as the frequency with which documents are cited together; when a third item cites two elements (author, reference, or journal) there is a co-citing relationship [56]. A co-citation link is a link between two elements cited by the same document, in this case the distance between two journals, authors or references shows the relationship of these items in terms of citation links. In general, the closer the nodes the stronger their relationship. The strongest co-citation links between nodes are also represented by lines [26].

First, an analysis was performed on the co-citation of cited references (Figure 6), obtaining three clusters where the most representative articles of each cluster are as follows. Leme et al. (2014) [31] (in red) with 24 citations and a total link strength of 52 (in first place for citations). This work compares different alternatives for generating energy from MSW in Brazil, from a techno-economic and environmental perspective. This cluster also included Murphy and McKeogh (2004) [27], Jamasb and Nepal (2010) [57], and others. Its main focus is the analysis of systems that transform waste to energy.

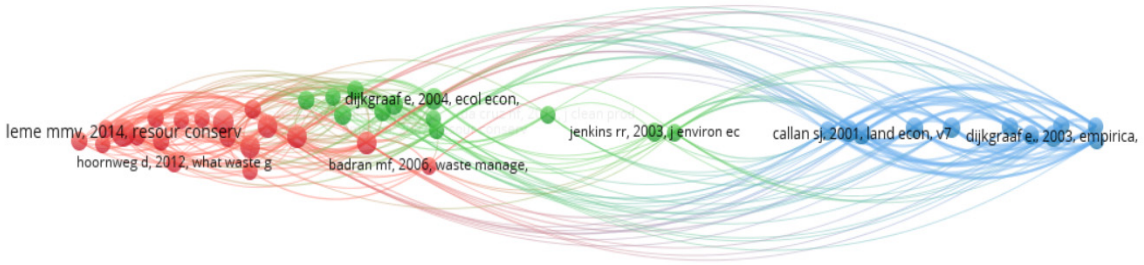


Figure 6. Co-citation of cited references on EA: 42 references of the 16089 cited references that meet the threshold of a minimum number of citations of a cited reference of 10.

Emery et al. (2007) [40] (in green) have 10 citations and a total link strength of 43, developing a model to examine the costs, employment, and recovery rates achieved using various waste recovery methods including recycling and incineration. This cluster also included: Reich (2005) [30]; Eshet et al. (2006) [46], among others. Its main focus is the analysis and comparison of different MSW management systems.

Dijkgraaf et al. (2003) [58] (in blue) have 15 citations and a total link strength of 85 (in first place for total link strength); this work focusses on collection systems in the Netherlands. It can be seen that the blue cluster is further away from the other two clusters, which shows a weaker relationship between the subjects under research. This cluster also included Callan and Thomas (2001) [35], Bel and Warner (2008) [59], and others. Its main focus is the cost analysis of MSW collection services.

Regarding the analysis of the journal co-citation network, there are 3 clusters (Figure 7). The green cluster includes *Waste Management*, the journal with most citations (1557) and the highest link strength (24215). This cluster is composed of journals on subjects related to environmental and sustainability issues, and specifically dealing with waste management (generation, characteristics, reduction, collection, separation, treatment, and elimination). The most representative journal of the red cluster (the most numerous) is *Bioresource Technology* (Citations: 440, Link Strength: 9665); this cluster is mostly made up of journals dealing with subjects such as energy and its generation, conversion, and use. Finally, the most representative journal of the blue cluster is the *Journal of Cleaner Production* (Citations: 492, Link Strength: 10108); this cluster contains interdisciplinary journals focusing on research into the environment and sustainability, as well as the use of resources, water, and energy. In this case, it can be seen that two of the clusters (blue and green) are closely linked, which shows that their subjects of research (waste management, environmental issues, and sustainability) are closer, whereas the red cluster is composed of journals whose principal subjects of research are connected with the generation of energy from waste.

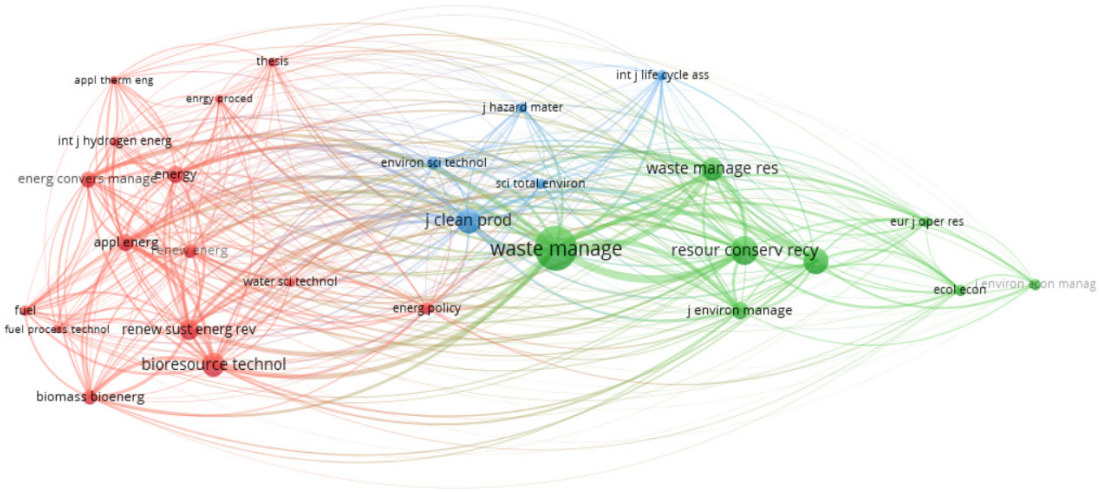


Figure 7. Journal co-citation network on EA: 28 main journals, of the 7542 cited sources, by the 563 documents that meet the threshold of a minimum number of citations of a cited source of 60.

The author co-citation network (Figure 8) shows four clusters: red (the most numerous), composed of 22 authors, among which is the European Commission (73 citations and link strength 326); other authors are Murphy, J.D. (55 citations and link strength 98) and Consonni, S. (35 citations and Link Strength 151) that focus on energy recovery.

The green cluster has 7 authors, of whom Bel, G. stands out (83 citations and link strength 406), having first place in terms of link strength and citations, with 91 documents in WoS about the economic policy of transport and public infrastructure; other authors are Dijkgraaf, E. (51 citations and link strength 361) and Simoes, P. (31 citations and link strength 201).

The blue cluster contains 6 authors, of whom Kinnaman, T.C. stands out (29 citations and link strength 154) with 17 documents in WoS about the economic impact of recycling and incineration. There are also Miranda, M.L. (24 citations and link strength 134) and Rabl, A. (23 citations and link strength 131).

The yellow cluster has 5 authors, where the most noticeably is Chang, N.B. (58 citations and link strength 268) with 355 documents in WoS about MSW management strategies and technologies.

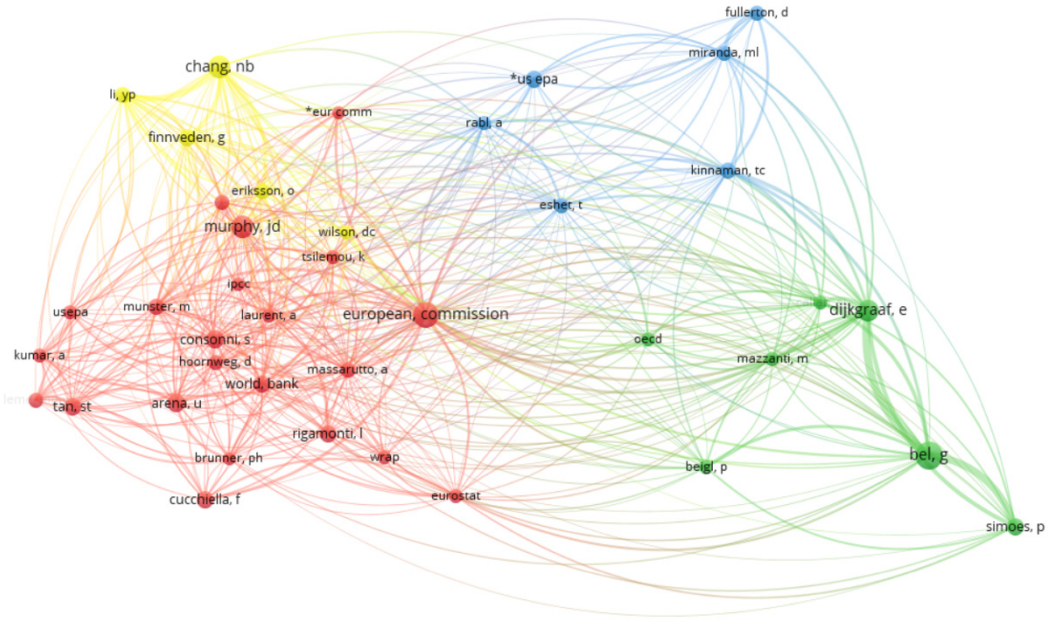


Figure 8. Author co-citation network on EA: 40 authors, of the 11608 cited authors, which meet the threshold of a minimum number of citations of a cited author of 20.

3.7. Bibliographic Coupling of Authors

The bibliographic coupling of authors analysis allowed us to see if authors A and B cite the articles of author C; in other words, two authors with common references are more closely related and have similar research interests [60].

The bibliographic coupling of authors (Figure 9) showed that there were eight clusters composed of 35 authors. Red is the main cluster, with 9 authors, the most representative being De Jaeger, S. Then, the green and dark blue clusters had 6 authors each, yellow had 5 authors, purple had 3, and light blue, brown, and orange clusters had 2 authors each.

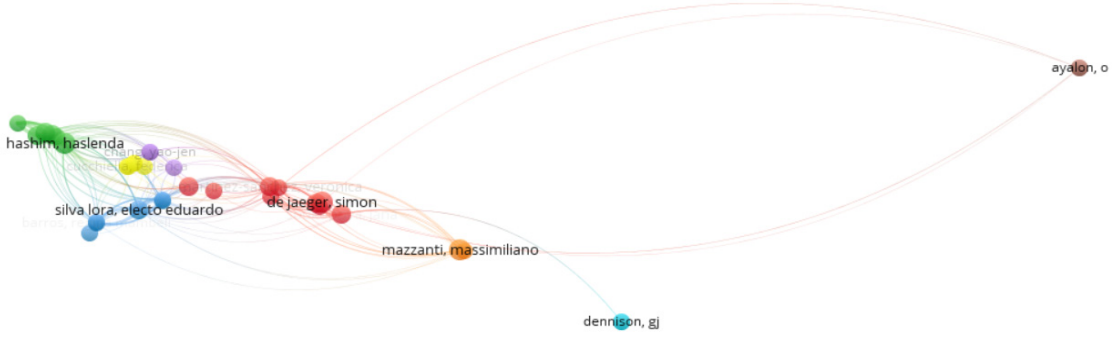


Figure 9. Bibliographic coupling of authors: 35 authors, of the 1702 authors, who meet the threshold of a minimum number of documents of an author of 3.

The authors with most publications are as follows. De Jaeger, S. (5 publications) had a total of 20 publications in WoS about the optimization of transport routes for collecting waste and the recycling systems of packaging waste. Hashim, H. (5 publications) had a total of 141 publications in WoS, which focus on evaluating strategies for converting waste into energy and the use of biogas. Mazzanti, M. (5 publications) had a total of 78 publications in WoS, including research subjects such as the socioeconomic variables that influence waste generation, as well as political influence on the situation.

According to total link strength, the order of authors is Ho, W.S. (731), Silva Lora, E.E. (664), and Hashim, H. (643). For the number of citations, the order of authors is: Murphy, J.D. (329), Hashim, H. (238), and Silva Lora, E.E. (227).

Two clusters can be seen (light blue and brown) further away from the others, which represent recent subjects of research. On the one hand, the cluster formed by authors Ayalon, O. and Shechter, M., whose publications deal with themes regarding the economic valuation of the externalities of the MSW management systems. On the other hand, the cluster composed of Dennison, G.J. and Dodd, V.A., whose works on evaluating the costs of waste recycling focus on Dublin, Ireland.

3.8. Country and University Co-Author Analysis

Finally, co-authorship between cities and universities was analyzed, where item size (nodes) reflects the relevance of the organizations or countries, and the distance reflects the degree of collaboration between them.

Analyzing the co-authorship relationships between countries provides us with a network composed of 19 countries spread over 5 clusters (Figure 10). The red cluster has 5 countries, the most representative being the USA (76 documents, 984 citations), Italy (59 documents, 1128 citations). and Spain (25 documents, 419 citations); the green cluster is made up of 5 countries, with the most representative being Sweden (17 documents, 450 citations) and Belgium (15 documents, 279 citations); the blue cluster has 4 countries, led by the Czech Republic (17 documents, 163 citations) and Malaysia (15 documents, 328 citations); the yellow cluster is composed of 3 countries, led by England (30 documents, 373 citations); the purple cluster includes China (44 documents, 564 citations) and Canada (13 documents, 277 citations). The countries that stand out for the number of publications and citations are the USA, Italy and China. It can also be seen that the different clusters are separated from each other, which indicates little collaboration between them. The presence of developed countries is noticeable, which reflects the low level of collaboration of the developing countries in this field.

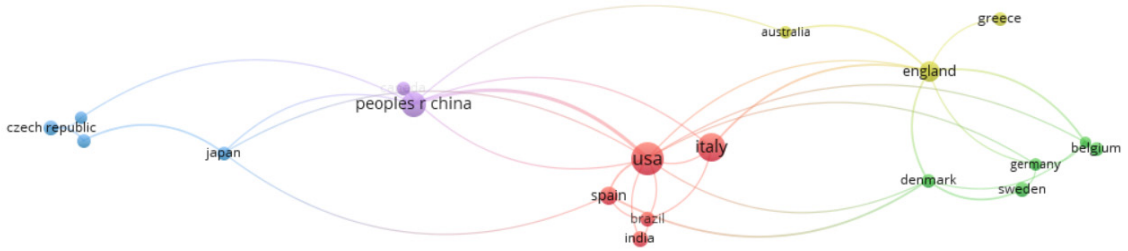


Figure 10. Countries' co-authorship network of EA: 19 countries, of the 80 nations, meet the threshold of a minimum number of papers of a country of 10.

Finally, from the institutions' co-authorship network (Figure 11) of universities or institutions that meet the threshold of at least 2 documents published, it can be seen that there is little collaboration between different universities. This is due to the fact that, of the 700 universities mentioned, the largest group is only 9, organized into three clusters as follows. The red cluster, composed of 4 universities: the IVL Swedish Environmental Research Institute, Sweden (2 documents, 34 citations), Chalmers, Sweden (2 documents, 66 citations), University of Gävle, Sweden (2 documents, 40 citations), and the KTH Royal Institute of Technology, Sweden (2 documents, 20 citations). The green cluster consists

of 3 universities: University of Borås, Sweden (5 documents, 130 citations), Chalmers University of Technology, Sweden (3 documents, 50 citations), and RAM Lose Edb, Denmark (2 documents, 27 citations). The blue cluster has 2 universities: Technical University of Denmark (8 documents, 182 citations) and the Fundación ENT, Spain (2 documents, 32 citations). The importance of the Swedish universities is evident from their positions in all clusters.

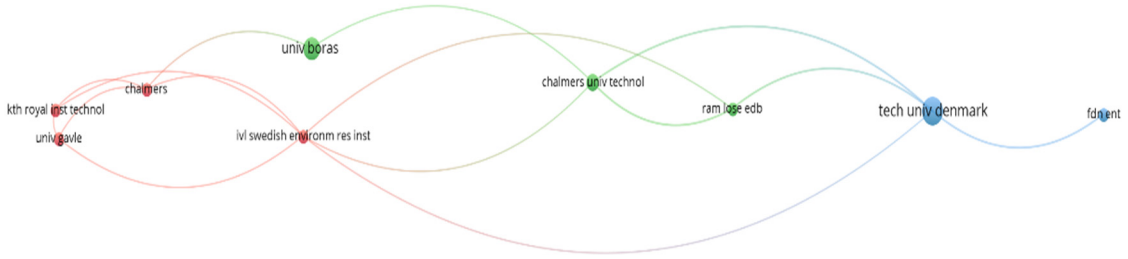


Figure 11. Institutions' co-authorship network of EA: 9 organizations, of 700, meet the threshold of a minimum number of documents of 2.

4. Discussion and Conclusions

Using the bibliometric analysis of the publications in WoS, this article shows the research trends in the economic analysis of MSW management systems, firstly from a general perspective by studying articles that analyze the economic aspects (EA), then more specifically by concentrating on those articles that present or develop a methodology for the economic analysis of these systems (MEA). The importance of this article lies in the fact that, up to now, there have been no bibliometric studies that have analyzed the economic aspects of MSW management systems. Another important point is the analysis of articles that present a methodology for analyzing the external impacts or externalities.

The bibliometric analysis shows the interest in the subjects of EA and MEA, which is evident from the increase in the number of publications. The United States, Italy, and China are the countries with the most publications in both areas. In the developing world, research into this field is scarce. Analysis of the MEA area shows that the LCC and CBA are the principal methods used to analyze the economic aspects, which were also the most representative keywords. The analysis of keywords also shows a greater emphasis on research into specific types of waste, such as "organic waste", "food waste", and "packaging waste". The importance of research into these types of waste is because they represent the most typical waste generated worldwide, along with many possible negative impacts (economic, environmental and social) caused by incorrect management.

In general, an increase can be seen in the number of publications focusing on converting waste to energy. The energy recovery of waste in incineration plants provides an opportunity to reduce the amount of waste sent to landfill. Additionally, it can help reduce the dependency on energy generated by fossil fuels, which usually have to be imported [57]. However, the rise in publications is not in line with the hierarchy of waste, as established by organizations such as the European Parliament. This hierarchy prioritizes the adoption of methods to reduce the generation of waste, increase preparations for reuse and recycling, and discourages the use of incinerators and landfills, practices which are still common in parts of Europe and elsewhere. Analysis of the waste management systems (collection and treatment) is also important as they can reduce the generation of waste and increase the potential for reuse and recycling as opposed to incineration and landfills.

The economic aspect is of great importance, as it is a fundamental part of governmental and national decision making [15], but it is also important for the possible impacts (positive or negative) of MSW management systems, on society, and the environment, to be reflected in the costs and considered by decision-makers [61]. It can also be seen how this work does not consider an economic valuation of the impacts on society, nor the possible effects on public health, of the MSW management systems. Nevertheless, the effects on public health are a very important aspect of waste, as they are associated with every stage of the handling, treatment and elimination of waste, either directly

or indirectly [62]. Therefore, the impacts on public health can be decisive factors in economically evaluating a MSW system.

This work can help researchers highlight different concepts and links between them, leading to further areas of research. In this case, this article reveals several trends in research. The first is the growing importance of the fields of EA and MEA, as shown by the increasing numbers of publications in the WoS. The second is the limited number of studies into developing methodologies for the economic analysis of externalities, which shows the need for more research in this field. In third place, the increasing interest in research into the use of waste to produce energy. The next emphasis is on the need for joint work by different universities (in different countries), as little collaboration has been observed. This collaboration would enable an exchange of knowledge and better management systems. Finally, more research is needed in this field from the developing countries.

Decision-makers will also find this work useful, as its results will help them to find the most economic systems and technologies, as well as the methodologies to evaluate these systems, thereby improving their decisions. Governments can develop policies, incentives, and regulations, based on the economic results of the different studies, to increase or discourage the use of certain technologies or management systems and thereby improve environmental, social or economic sustainability [63].

For the future, it is recommended that the search for articles is widened by the use of other well-known databases, such as Scopus [64]. Next, the search could be limited to a specific journal [18]. The third option would be to focus the bibliometric analysis of EA on treatment systems such as incineration, recycling and landfilling, among others. Finally, another interesting analysis would be to compare the number of results in terms of the three pillars of sustainability, the social, environmental, and/or economic areas.

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