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Building new paths for responsible solid waste management

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Abstract The amount of solid waste produced across the planet in the past decade was 1.3 billion tons (1.2 kg/year per person). Also, the significant number of publications on solid waste management (SWM) draws attention to the importance of discussing the topic to improve public health and to mitigate environmental impacts. The objectives of this article are to identify the state of the art and the scientific gaps on SWM and to propose a framework to promote it in the coming years. For this, a content analysis was carried out with the support of a bibliometric study, considering articles published in the Scopus database. The field of SWM study was classified into 12 different themes, and from this division, it was sought to identify the evolution of each of them between the 2005 and 2018 period. Content analysis and bibliometric study indicate that thermal and biological treatments are a promising trend to improve the performance of SWM. Its most important applied contribution is the generation of qualified information about SWM that can support the decision-making of public and private managers to reduce environmental impacts and improve life in urban spaces. The main academic contribution of the paper is the articulation of the most important themes on SWM, identifying the individual impact of each one of them in this field of study and the indication of the scientific trends that should guide the development of future research.

Keywords Solid waste management · Waste management · Environmental impact · Conservation of resources · Sustainability

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Introduction

Every year, one million people have died worldwide as a result of chemical contamination by inappropriate disposal of solid waste (United Nations, 2019). In the 2000s, the amount of solid waste produced worldwide was 0.68 billion tons (0.64 kg/year per person), reaching 1.3 billion (1.2 kg/year per person) in the current decade and with expectation of reaching 2.2 billion tons at 2025 (Word Bank Group, 2014). All materials when discarded become a waste regardless of its intrinsic value, which may be leftovers, surplus materials, and products that are useful or not (Johari et al., 2014). The main causes for disposing materials are related to the cost of its storage and management, which often proves to be disadvantageous, or to the fact that there is no prospect of exchanging or selling them (Christensen, 2010; Metin et al., 2003). Solid waste can be classified into food waste, paper, cardboard, plastic, PET, glass, textile, metal, wood, leather, diaper, and ash, among others and can be disposed of in residential, commercial, or industrial areas

(Tan et al., 2015). The heterogeneity of solid waste makes collection and treatment difficult (Wallace et al., 2017). The factors that influence the composition and amount of solid waste in a municipality are the climate, average income, social behavior, industrial production, and the capacity for reuse (Gupta et al., 2015). Urbanization, population growth, and improving people's living standards are the main reasons for the significant increase in waste generation (Fei et al., 2016; Parastar et al., 2017).

As the increase in garbage production causes environmental impacts and a series of disorders in people's daily lives, it is essential to identify the main stakeholders in solid waste management (SWM) to diagnose the participation and responsibility of each one of them (Tan et al., 2010). The main stakeholders are federal governments, municipalities, industries, experts in the field, citizens, etc. For waste management to achieve satisfactory results, it is essential that these stakeholders interact (Henry et al., 2006; Soltani et al., 2015). In order to reduce the amount of solid waste in nature, it is important that there is a multidisciplinary effort, aimed at protecting the environment and conserving natural resources through an integrated waste management system with a focus on sustainable urban development (Cucchiella et al., 2014; Liu et al., 2014). The Waste Hierarchy developed by the European Union institutes that the priority of waste management should follow a sequence. The suggested order is prevention, preparing for reuse, recycling, recovery of waste (e.g., using its energy), and as a last option, waste should be sent to landfills (European Commission, 2012). To conduct SWM services in municipalities, four essential steps are performed. The first stage consists of the classification and identification of solid waste. The second stage addresses waste collection and transportation. The third stage consists of waste treatment, and the fourth stage is about the final destination of the waste, which can be sent for recycling, reuse, or a landfill destination (Christensen, 2010). The first stage consists of the classification and identification of solid waste. The second stage addresses waste collection and transportation. The third stage consists of waste treatment, and the fourth stage is about the final destination of the waste, which can be sent for recycling, reuse, or a landfill destination (Christensen, 2010).

There is a concentration of studies in the literature focused on management tools, laws, and regulations and solid waste treatments (Ferri et al., 2015; Herva et al., 2014; Li & Zhao, 2015). The management tools contribute to improving the results of the SWM by increasing the efficiency of the processes in order to meet the established goals (Herva et al., 2014). The regulations allow companies and their stakeholders to have their obligations instituted, encouraging taking responsibilities and inspection assignments (Ferri et al., 2015). The most appropriated type of waste treatment is chosen in function of minimizing as much as possible the environmental damage and public health problems (Li & Zhao, 2015).

Among the most widely used tools for solid waste management are the cost–benefit analysis (CBA), multiple-criteria decision analysis (MCDA), risk assessment (RA), benchmarking, and, mainly, the life cycle assessment (ACL). They allow the quantification of environmental impacts and assist in the elaboration of strategies for their mitigation. These tools are more commonly used in European countries, but if they were more extensively implemented in developing countries, the negative socio-environmental impacts of solid waste disposal would significantly decrease in such nations (Laurent et al., 2014).

The management of solid waste is regulated based on laws that establish the obligations of public agencies, citizens, companies, and other stakeholders and that cover compliance (Bing et al., 2016). The creation and enactment of laws aim at adapting waste management to sustainability elements, seeking to facilitate its integration with other services in the municipality, such as urban cleaning, public health administration, and environmental preservation (Christensen, 2010). There is a significant variation in the composition and enforcement of SWM laws between countries. For example, Germany has implemented laws that are stricter than those in force in other European Union countries (Mühle et al., 2010). There are countries that started implementing laws on solid waste in 2000, as is the case in Japan, while in Brazil, the first national law was enacted only in 2010 (Bonjardim et al., 2018; Shekdar, 2009).

The waste can be subjected to treatments that aim to recover recyclable materials, harness energy, or improve their characteristics (Rada et al., 2009). Waste can also be used as an important source of energy, reducing emissions and environmental pollution (Alwaeli, 2011a). The treatments can be mechanical, thermal, or biological and implemented isolated or combined with each other (Christensen, 2010). Mechanical treatment involves reducing the size of solid waste, followed by its classification and compacting through unitary operations that alter their physical characteristics but do not alter their chemical characteristics (Christensen, 2010). This treatment can be classified into: "fuel" element, known as refuse derived fuel (RDF); "wet" element, produced from organic waste and the "mineral" element, usually sent to landfills (Panepinto et al., 2015). The heat treatment aims to reduce the volume of waste through exposure to high temperature, which turns the pathogenic waste into harmless chemical waste. This procedure is performed mainly through incineration, gasification, and pyrolysis (Yan et al., 2016). Waste incineration is the thermal conversion of waste into heat, with an excess of air that allows the release of flue gas released into the atmosphere (Christensen, 2010; Kalyani & Pandey, 2014). Gasification is a partial thermochemical oxidation process that converts solid waste into combustible gases (Arena, 2012; Kumar, 2000; Rada & Ragazzi, 2014). Pyrolysis is a method that produces a series of hydrocarbons, allowing a reduction in dependence on fossil fuels and a possible resolution of landfill problems (Chen et al., 2014; Hossain et al., 2011; Kalyani & Pandey, 2014; Tozlu et al., 2016). The biological treatment is applied to organic waste and is carried out mainly by composting and aerobic digestion (Colón et al., 2012). Composting is a sustainable and clean procedure that can be associated with intermittent aeration and earthworm insertion techniques (vermicomposting) aimed at reducing carbon dioxide emissions (Lim et al., 2016; Yay, 2015). The biological oxidation of carbon-rich molecules releases energy, which is then consumed by organisms, while the released nutrients are consumed by plants. The practice of anaerobic digestion involves the degradation and stabilization of organic materials in anaerobic conditions. It is an attractive technique because it allows pollution controls and energy recovery (Chen et al., 2010; Kizito et al., 2017). The choice of the type of solid waste treatment varies according to the priorities of public managers and the availability of technology (Tan et al., 2015; Yay, 2015).

The importance of solid waste management for public health and the mitigation of environmental impacts have reflected a significant number of publications on the subject in the scientific literature research on the SWM. It started in the mid-1960s and currently covers several areas of knowledge (Scopus, 2019; Zyoud et al., 2015). "The state of the art" consists of all types of knowledge shared with the public through various types of communication channels, such as writing, speech, observation, etc. (European Patent Office 1973). Research gaps are key questions for a particular area of knowledge that have not been answered until the time of carrying out a particular research. They are fundamental for pointing out the possibility for future studies and for indicating topics that require greater academic efforts to reach their maturity (Nunhes et al., 2016).

Bibliometric studies on solid waste have been conducted since 2010. Fu et al. (2010) analyzed the periods from 1993 to 2008 using the Science Citation Index (SCI) database. The same database was used by Ma et al. (2011), whose study period ranged from 1991 to 2010 and by Yang et al. (2013) through analyses carried out between 1997 and 2011. Mesdaghinia et al (2015) conducted a study focused on publications from Iran in the period between 1982 and 2013 using the Scopus database. Zyoud et al. (2015) also used the SCI database in Arab countries. Wang et al. (2016) analyzed publications from 1999 to 2015 with focus on the topic of heat treatment of waste from incineration. Chen et al. (2017) particularly studied kitchen waste in publications from 1997 to 2014 in the Web of Science database. Bonjardim et al. (2018) selected 447 articles presented in Brazilian conferences on SWM laws. Gonçalves et al. (2018) selected articles through the Web of Science and analyzed SWM in BRICs countries (Brazil, Russia, India, China, and South Africa). Li et al. (2018) conducted studies on reuse and recycling between the periods of 1992 to 2016 through the SCI database.

Compared to these previous studies, this article deepens and expands the state of the art on SWM, from the verification of scientific trends and the proposition of new paths that add to the literature a set of guidelines for developing future researches on SWM. This work is relevant because it thoroughly demonstrates the development of research topics from 2005 onward in SWM, providing insights into areas that can be explored by researchers. At the same time, it indicates to public managers and entrepreneurs some paths that can be taken to make waste management more sustainable. The great novelty of this article is, therefore, to provide a transdisciplinary framework for the technical and scientific development of SWM to support strategic actions to decrease and end the surplus of waste that accumulates annually on the planet, proposing actions for governments, non-governmental organizations, and companies. Given this, the following research question was posed: how is the panorama of the research on solid waste management and what are opportunities and challenges for developing this field of research? In order to respond to these questions, the main objectives of this article are to map the state of the art and identify the scientific gaps about solid waste management so that the academic community and those responsible for waste management in governments and companies could have relevant and updated information to guide scientific and technological investments, public and private, for the development of this theme and to propose a framework to develop SWM research in the next years. The achievement of this objective will contribute to the investigation of some important gaps identified in this research, among them: strategic integration of solid waste management processes in a long-term perspective (Ghiani et al., 2014), implementation of strategies aimed at raising awareness of the importance of getting used to recycling (Yay, 2015), and use of management tools to measure impacts on sustainability (Al-Salem et al., 2017), as the recommendations were proposed to increase the utilization of solid waste and improving metrics for measuring impacts across the entire cycle of waste management, from the stages of collection and transportation to final disposal. The article is organized as follows: following the introduction, the research method is presented, which is followed by the results and discussions, and finally, the section of conclusions and references close the paper.

Research method

Figure 1 presents the methodological flow that guided the development of this research.

As shown in Fig. 1, the methodological flow was developed following four phases that aimed at (1) establishing the objectives and methods to be used; (2) conducting the bibliometric study; (3) identifying the gaps, and (4) elaborating the conclusions and proposing suggestions for future studies.

In the first phase, the research objective and method were established taking into account the relevance of

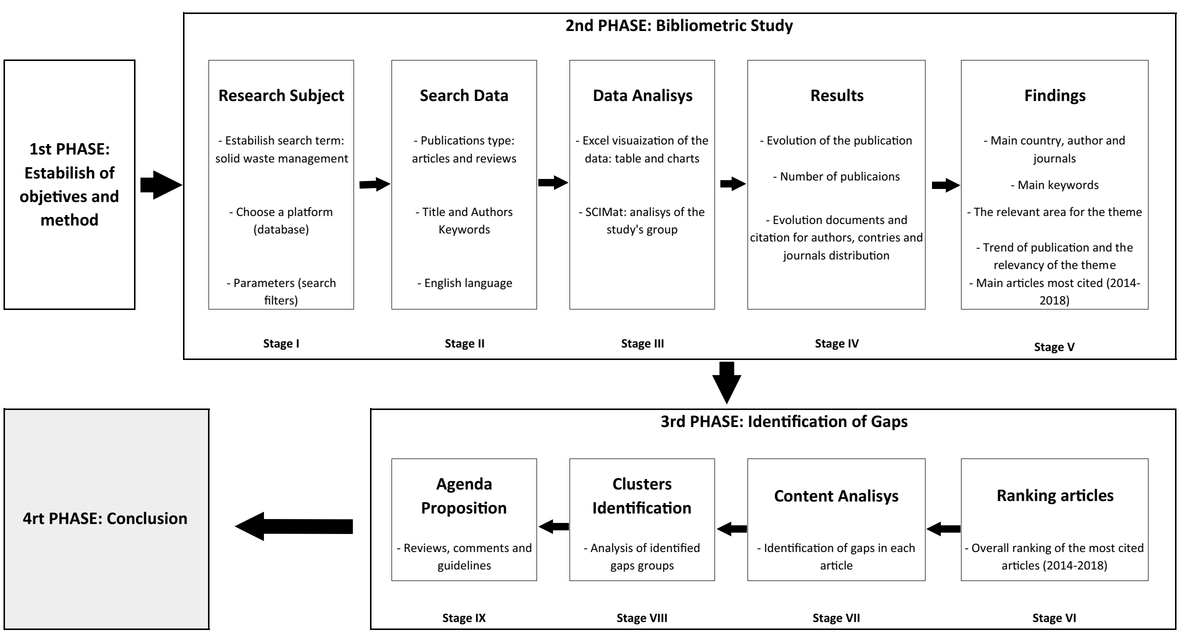

Fig. 1 Methodological flow of research

the topic and the need to conduct a research like this, as highlighted in the introduction to this work. The objective was to identify the state of the art and the scientific gaps in solid waste management. To achieve this purpose, the research method chosen was a mixed method of content analysis and bibliometrics. Bibliometric studies aim to analyze a given research topic, by means of the analysis of quantitative information such as the number of citations and publications in a given field of knowledge. The analysis may include observations on the main countries, journals, universities, keywords, research funds, and patents, among other factors (Nunhes et al., 2021; Reis et al., 2020a, b). Content analysis complements the bibliometrics once it is a method that seeks to identify trends in publications on a given subject based on a systematic interpretation of data (Alvarenga et al., 2021; Nunhes et al., 2021).

The second phase consisted of five stages. In Stage 2.1, it was sought to delimit the most relevant articles for this research, by applying a search that contained the most important terms, among solid waste management, waste treatment, recycling, composting, biogas, etc.; according to "Step A" presented in Fig. 2. The search returned 45,321 articles.

In Stage 2.2 (Data search), only articles and reviews were selected, with the addition of the term "solid waste management," under the limitation of articles containing five or more citations, reducing the number of articles to 3.126; as shown in "Step B" in Fig. 2. In the last filter, the search was restricted to the articles produced from 2005 to 2018, resulting in 1986 articles (Step C). In Stage 2.3 (Data Analysis), information was organized using tables and graphs. Data refinement was performed using Microsoft Excel and SCIMat software packages. The Stage 2.4 (Results) obtained the evolution of the publications presented between 1973 and 2018, general information regarding the countries, the authors, and the journals that stood out in the publications on solid waste management. In Stage 2.5 (Findings), the main countries, authors, journals, and keywords

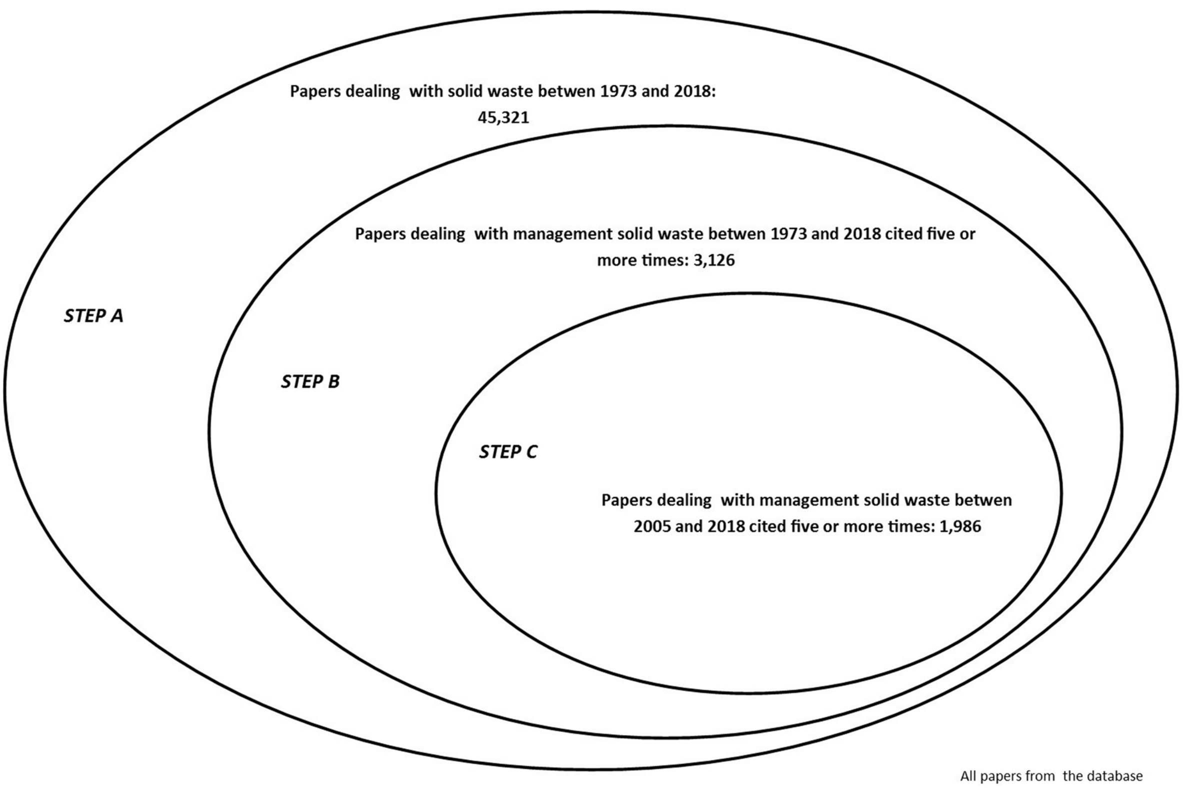

Fig. 2 Overview stage I and stage II

related to publications on solid waste management were identified and discussed. Then, the most relevant themes in the field of study were identified and discussed. The most relevant groups were created according to the similarity of the terms identified, as recommended by Scott (2006).

The third phase consisted of four stages: (3.1) ranking articles, (3.2) content analysis, (3.3) identification of groups, and (3.4) group analysis. On Stage 3.1 (Ranking Articles), the articles published between 2014 and 2018 were ranked according to their number of citations. On Stage 3.2 (Content Analysis), the research gaps were identified in each article. The gaps were identified by analyzing the publications selected for the bibliometric study, specifically, it was analyzed the indications for future studies found in the conclusion section of the papers (explicit gaps) and in cases where these notes were missing, the studies were strategically analyzed in order to find implicit gaps throughout all the other sections of the papers. In Stage 3.3 (Identification of Groups), the gaps identified were categorized into five main trend groups, according to the adherence of the gaps. In Stage 3.4 (Group Analysis), the identified trends were analyzed and the framework for SWM was proposed, considering the two previous phases, in order to allow the mapping of the state of the art on the theme and the indication of the most promising paths for SMW research in the coming years.

Results and discussions

Publications lifecycle

According to Price's law (Cristino et al., 2018), the scientific production of a given field tends to grow exponentially, and this growth can be decomposed into four phases, as shown in Fig. 3.

According to Price's law, scientific development in general follows an exponential growth, and its epistemological domain goes through four phases (Dabi et al., 2016). In Fig. 4, it is possible to observe the differences between the precursor, exponential growth, and linear growth and maturity domain phases. The first phase, which began in 1973 until 1980, is the period characterized by the precursor authors of this field of knowledge who presented a small number of publications on the topic (Dabi et al., 2016). In the second phase (1981–2004), the expansion of the scientific field tends to attract a significant number of researchers. In this period, the number of publications reaches approximately 35% of the total published articles, and it can be said that the number of articles has doubled in approximately every 5 years. In the third phase (2005–2018), this field of knowledge is consolidated and publications grow linearly until in 2018 it seems to reach a turning point, which suggests that this field of knowledge has reached or is close to reaching its

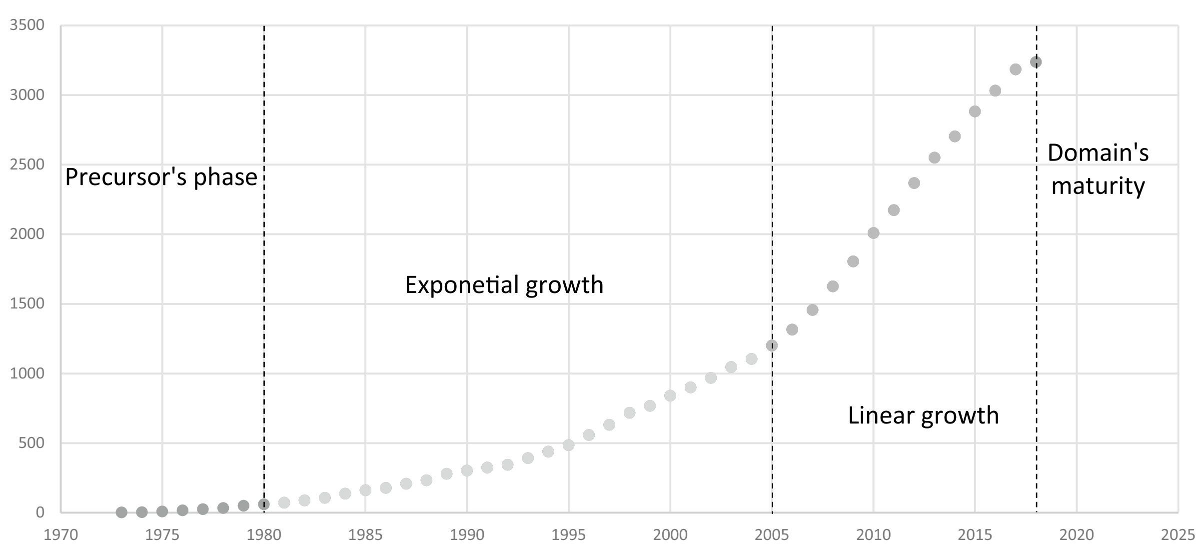

Fig. 3 Phases of growth of the SWM domain according to Price's law. Based on Dabi et al. (2016)

Nº	Country	H-Index	Citations - Scopus (2005-2018)	Documents - Scopus (2005-2018)	Citações 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	China	48	8745	295	1	1	30	92	272	357	493	544	716	892	991	1168	1443	1745
2	North America	42	7714	199	0	9	47	139	254	294	408	501	727	785	979	1023	1219	1329
3	India	40	6993	186	3	15	38	136	221	291	372	437	564	665	803	928	1145	1375
4	Italy	38	3916	120	0	3	4	13	45	94	154	216	322	423	529	561	763	789
5	United Kingdom	37	5425	115	0	3	13	57	121	181	276	372	494	586	642	793	865	1022
6	Canada	37	3702	128	2	2	19	74	225	251	307	275	324	404	176	474	580	589
7	Spain	34	3267	99	2	20	28	54	103	129	179	269	292	330	404	412	492	553
8	Malaysia	28	2524	83	0	0	1	2	25	55	73	91	152	240	270	444	556	615
9	Japan	24	2235	92	0	10	20	51	105	96	118	167	188	234	267	278	316	385
10	Turkey	12	516	24	0	0	2	4	18	25	31	46	59	58	62	50	69	92

Nº	Country	Publicações 2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	China	2	14	12	25	37	36	26	27	18	25	30	22	16	5
2	North America	13	14	17	18	10	16	17	24	22	14	15	12	5	2
3	India	15	9	9	19	15	23	14	14	11	8	16	16	14	3
4	Italy	3	1	6	7	10	12	10	9	19	16	13	7	7	0
5	United Kingdom	3	10	10	7	11	10	10	16	8	8	6	8	7	1
6	Canada	6	7	16	13	20	15	7	7	12	10	4	9	2	0
7	Spain	3	8	5	11	6	13	8	12	5	9	7	5	4	3
8	Malaysia	1	6	3	0	7	3	12	11	7	8	14	4	6	1
9	Japan	7	9	8	8	8	6	12	10	7	4	5	4	4	0
10	Turkey	1	1	3	4	5	2	2	1	1	1	1	0	2	0

Fig. 4 Major countries (2005–2018)

maturity, which it would be the fourth phase established by Price (Cristino et al., 2018).

Territorial predominance

This subsection presents the bibliometric performance of some countries that have excelled in the SWM field. The period covered in this analysis refers to the period corresponding to the linear phase of growth of publications, that is, from 2005 to 2018, as shown in Fig. 4. Table 1 shows the ten countries with the largest number of publications. It can be seen that China (295), USA (199), and India (186) stand out. Italy (120) and the UK (115) share fourth and fifth place among the most productive countries.

Between 2005 and 2018, there were 110 countries with which the publications on the SWM theme were affiliated. Of these, 62 countries were related to at least 5 documents. For this analysis, the 10 countries with the best performance were highlighted, and it was observed that 4 members of this group are from the Asian continent, 4 belong to Europe, and 2 from North America. China stands out in relation to the H-Index and number of documents (H-Index 48 and 295 articles), as shown in Fig. 5, but in terms of average citation per document, the UK stands out with 47.17, USA with an average of 38.76, and India with an average of 37.60. The ten countries listed among the most important of the studies are responsible for approximately 72% of the total citation (45,037 citations).

Among the main countries that published on SWM, China presented an outstanding number in the production of documents from 2008 and maintained a significant pace of publications until 2015. In this case, the number of citations started to be expressive from 2007 and lasts until 2018. The scientific production in the USA began in 2005 and remained significant until 2013. India started to stand out in the production focused on solid waste between 2008 and 2013. Italy gained prominence in 2009 and had a number of considerable publications until 2015. There was a shortage of relevant studies between the African and Latin American continents.

Main influencers

The 108 authors who published articles on SWM between 2005 and 2018 are presented. Figure 5 shows the list of the 10 authors with the highest number of citations, who have produced at least five articles. It can be observed the authors from Europe and Asia stand out.

The 10 authors ranked in Fig. 6 published 198 articles, which in turn obtained a total of 8616 citations. Huang obtained the highest H-Index (30) in SWM, although he obtained the ninth highest average among the listed authors. Lettiere was the author with the highest number of citations, obtaining an average of 124 citations per document. In the scenario of the annual production of articles and citations, it was observed that in 2009, according to Fig. 6, the largest amount of documents was produced, with a total of 38 publications. After this year, the downward trend became visible, with only five publications in the last 3 years. In 2018, the publication of only one author (Lettieri) of those on the list of the 10 most productive in the period of 14 years that the research is being carried out. It was also noted that in 2016, only five articles were published and in 2017, none were produced, which reinforces the hypothesis that this field of knowledge has reached its maturity or is very close

Table 1 Categorization of keywords in subgroups

Theme type	Research theme	Keywords
1.Main themes	a.Generation	Generation-rate, characterization, volatile-organic-compounds, waste-characteristics, waste-generation, organic-fraction-of-municipal-solid-waste, waste-composition, organic-solid-waste, composition, waste-characterization, solid-waste-characterization, solid-waste-composition, solid-waste-generation
	b.Collection and transport	Solid-waste-collection, location, waste-collection, separate-collection, selective-collection, collection, transportation, reverse-logistics, site-selection, source-separation
	c.Treatment	Adsorption, gasification, thermal-treatment, incineration, treatment, composting, anaerobic-digestion, vermicompost, wastewater-treatment, pyrolysis, mechanical–biological-treatment, biological-treatment, vermicomposting, pretreatment, municipal-solid-waste-incinerator, waste-treatment, co-digestion, material-recovery, anaerobic-co-digestion, co-composting, waste-incineration, recirculation, digestate, resource-recovery
	d.RUL recycling-utilization-landfilling	Compost, landfill, recycling, landfilling, landfill-leachate, landfill-gasfly-ash, waste-disposal, solid-waste-recycling, landfills, disposal, bioreactor-landfill, bottom-ash, solid-waste-disposal, waste-recycling, landfill-site-selection, reuse, recyclables, landfill-mining
2.Adjacent themes	e.Energy	Waste-to-energy, renewable-energy, energy, solid-recovered-fuel, waste-to-energy-(wte), refuse-derived-fuel. energy-recovery, combustion, biogas-production, biogas
	f.Emission gas	Activated-carbon, greenhouse-gas, greenhouse-gases, greenhouse-gas-emissions, methane, methane-oxidation, ghg-emissions, methane-emission
	g.Sustainibility	Developing-countries, sustainable-development, sustainability, environment, privatization, environmental-impacts, environmental-impact, eco-efficiency, environmental-management, climate-change, industrial-ecology
	h.Waste economics	Informal-sector, cost–benefit-analysis, waste-pickers, cost, circular-economy
	i.Legislation and regulation	Governance, public–private-partnership, policy
	j.LCA	Life-cycle-assessment, lca, life-cycle-assessment-(lca)
	k.Waste hierarchy	waste-hierarchy, waste-minimization
	l.Issues associated	Groundwater-contamination, toxicity, public-health, sanitation, urbanization

to reaching it. It is observed that the authors continued to be cited even after they ended their production in the area, suggesting that their publications are quite relevant both for the area of SWM and related areas, such as sustainability and circular economy.

Main forums

The main forum for disseminating knowledge in environmental science is journals that publish scientific articles. They stand out from the other media for presenting content evaluated in the blind review evaluation system. Of 3,508,894 documents (including articles, books, conferences and others) available on SWM, a total of 2,796,870 corresponded to scientific articles, which represents 79.71% of the total production. The 1986 articles identified in this research were published in 310 journals, highlighting the fact that 58% of these articles were published in 10 journals, as shown Fig. 6. The most productive magazine in this area is the "Waste Management," which published 516 articles, also being the most cited and with the highest H-Index.

Among the 310 journals with publications on the SWM between 2005 and 2018, only 22 of them have an H-Index greater than 10. As shown in Fig. 7,

	Authors	Country	H-Index	Citations - Scopus (2005-2018)	Documents - Scopus (2005-2018)
1	Huang G. H.	Canada	30	2063	78
2	Christensen T. H	Denmark	18	1349	22
3	Li Y. P.	China	16	906	31
4	HE L.	China	14	428	18
6	Chang N.B.	United States	13	1117	14
5	Wilson D. C.	United Kingdom	9	714	10
7	Gheewala S. H.	Thailandv	8	421	7
9	WU T.Y.	Malaysia	7	378	7
8	Lettieri P.	United Kingdom	5	748	6
10	Bernstad A.K.	Brazil	5	492	5

Citações	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Huang G. H.	2	1	5	50	184	182	226	164	199	256	170	218	216	190
Christensen T. H	0	3	7	16	55	77	78	91	109	112	176	158	229	238
Li Y. P.	2	0	5	30	124	93	109	75	74	106	73	77	81	57
HE L.	0	0	0	15	37	39	48	38	41	44	32	42	48	44
Chang N.B.	0	0	6	20	44	58	82	85	123	131	130	135	150	153
Wilson D. C.	0	0	1	6	19	15	22	39	75	83	98	105	116	135
Gheewala S. H.	0	0	0	0	21	20	27	40	42	40	45	55	56	75
WU T.Y.	0	0	0	0	0	0	3	5	19	30	34	78	104	105
Lettieri P.	0	0	0	0	1	21	33	51	87	75	86	108	138	148
Bernstad A.K.	0	0	0	0	0	0	0	1	11	32	95	90	125	138

Publicações	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Huang G. H.	3	4	6	8	18	13	8	5	4	7	0	2	0	0
Christensen T. H	1	3	2	0	4	4	2	3	0	2	1	0	0	0
Li Y. P.	2	4	4	4	7	6	3	1	0	0	0	0	0	0
HE L.	0	0	0	5	6	1	2	1	0	1	1	1	0	0
Chang N.B.	2	1	1	3	0	1	4	1	1	0	0	0	0	0
Wilson D. C.	0	1	0	1	0	0	0	5	1	1	1	0	0	0
Gheewala S. H.	0	0	1	2	1	1	0	2	0	0	0	0	0	0
WU T.Y.	0	0	0	0	0	1	1	1	0	2	1	1	0	0
Lettieri P.	0	0	0	0	2	0	0	1	0	1	0	1	0	1
Bernstad A.K.	0	0	0	0	0	0	1	1	1	2	0	0	0	0

Fig. 5 Top 10 authors (2005–2018)

citations of the 10 largest journals have been growing steadily since 2008, reaching stability in the last few observed years. The journal Waste Management shows a marked growth between the years 2008 and 2016. The journal "Bioresource Technology" presented a considerable number of publications from 2008 and extending until 2013. The journal that maintains a constant distribution in the longest period of time is the "Resources Conservation and Recycling," which extends from 2005 to 2016. The "Waste Management and Research" and "Journal of Cleaner Production" journals show stability in the publication of articles from 2005 to 2015. The "Hazardous Materials" and "Environmental Monitoring and Assessment" had a considerable average of citations, among the highest in the selected journals.

Keyword analysis

In this subsection, the keywords most used in this field of study were identified, considering the frequency that they were used in the articles. Before the classification of the keywords, all words that were mentioned less than five times were excluded. It is worth remembering that only the keywords provided by the authors were considered, and the words indexed by scientific journals were not considered. The number of expressions used to be distributed among the themes, according to Table 1, was 116 words, out of a total of 4320. For the survey of keywords, the term solid waste management was identified with expressiveness. As this is the name of the research field, this expression was not considered. Words with little contribution to research were also eliminated, such as mathematical methods (exemplified with the "Theory of Uncertainties" with 53 documents) or names of places and countries (whose "China" has 25 notes). From this identification, it was possible to understand the most relevant expressions in the SWM.

The most used keyword was "anaerobic digestion," found in 111 articles (Fig. 7). Anaerobic digestion is a process characterized by biochemical transformations

Journal	H-Index	Number of publications (2005-2018)	Citation count (2005-2018)	Avarege (2005-2018)
Waste Management- JCR 4,723	71	519	20192	38.91
Bioresouce Technology- JCR 5,807	41	102	4252	41.69
Journal of Hazardous Materials- JCR 6,434	37	78	4816	61.74
Resources Conservation And Recycling- JCR 5,120	36	120	3694	30.78
Journal of Environmental Management- JCR 4,005	33	66	3145	47.65
Waste Management And Research- JCR 1,631	31	201	3915	19.48
Journal of Cleaner Production- JCR 5,651	23	45	1240	27.56
Environmental Monitoring And Assessment- JCR 1,334	19	34	1196	35.18
Chemosphere- JCR 4,427	19	32	1074	33.56
Habitat International- JCR 3,000	17	36	1169	32.47

Evolution paper for year from 2005 to 2018	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Waste Management- JCR 4,723	17	28	38	43	47	43	38	48	47	30	54	42	35	9
Bioresouce Technology- JCR 5,807	1	1	5	17	12	17	8	11	9	4	8	4	4	1
Journal of Hazardous Materials- JCR 6,434	5	12	11	11	14	11	4	4	4	1	1	0	0	0
Resources Conservation And Recycling- JCR 5,120	5	5	8	9	4	19	10	10	15	10	12	7	4	2
Journal of Environmental Management- JCR 4,005	3	2	5	9	9	7	9	6	5	5	2	2	2	0
Waste Management And Research- JCR 1,631	19	15	11	14	16	24	17	19	20	19	12	10	5	0
Journal of Cleaner Production- JCR 5,651	0	0	0	3	0	2	0	2	5	2	5	10	11	5
Environmental Monitoring And Assessment- JCR 1,334	0	2	6	2	2	4	4	5	3	2	2	2	0	0
Chemosphere- JCR 4,427	6	3	4	3	1	2	2	3	1	4	0	2	1	0
Habitat International- JCR 3,000	2	7	1	1	3	1	3	2	3	2	7	3	1	0

Evolution citation for year from 2005 to 2018	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Waste Management- JCR 4,723	1	20	79	262	509	666	979	1184	1593	1905	2522	2751	3513	4208
Bioresouce Technology- JCR 5,807	0	1	4	36	111	171	257	326	392	446	508	629	662	709
Journal of Hazardous Materials- JCR 6,434	0	12	42	119	196	297	364	383	495	507	566	571	658	606
Resources Conservation And Recycling- JCR 5,120	1	4	22	44	103	126	202	254	311	367	430	491	601	738
Journal of Environmental Management- JCR 4,005	0	2	5	30	107	123	177	216	300	334	358	417	521	555
Waste Management And Research- JCR 1,631	2	15	24	66	112	149	196	293	347	373	479	483	647	729
Journal of Cleaner Production- JCR 5,651	0	0	1	0	10	10	15	34	42	65	75	156	338	494
Environmental Monitoring And Assessment- JCR 1,334	0	2	5	14	20	48	69	96	106	152	135	169	176	204
Chemosphere- JCR 4,427	1	7	19	43	70	57	70	78	85	82	106	137	152	167
Habitat International- JCR 3,000	2	3	5	21	38	47	78	76	132	105	159	157	176	170

Fig. 6 Top 10 journals in SWM (2005–2018)

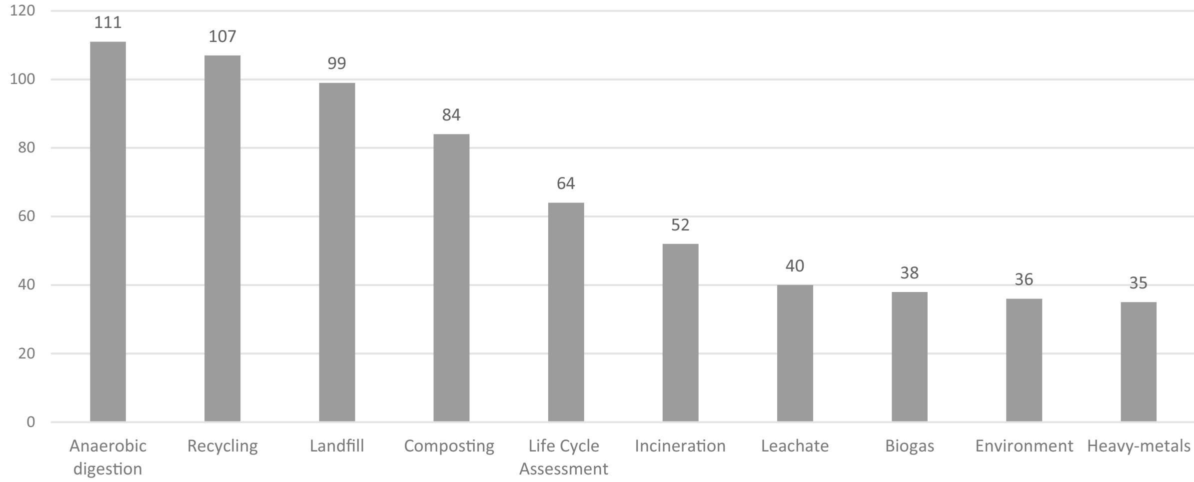

Fig. 7 Main keywords

from a junction of microbes, transforming complex macromolecules into low molecular weight compounds (Ariunbaatar et al., 2014). Then, the keyword "recycling" was used 107 times. Recycling is the use of materials to produce equivalent or similar products from discarded waste resulting in an economic and social development (Alwaeli, 2011b; Christensen, 2010). In the third position, the keyword "landfill" was used 99 times. A landfill is an easily accessible area and a common waste treatment technique used in the world, designed for the safe disposal of solid waste (Gupta et al., 2015; Tozlu et al., 2016).

The fourth most cited keyword was "Composting" (cited 84 times), which is a treatment that converts organic waste into a biologically stable form, both through aerobic and anaerobic decomposition (Wu et al., 2014). The keyword "Life Cycle Assessment" was cited 64 times. It is a decision support tool that assists in the quantification of environmental impacts and can provide appropriate solutions for the improvement of solid waste management (Laurent et al., 2014). Sixth, the keyword "Incineration" (cited 52 times) is the thermal conversion of waste into heat (Christensen, 2010).

Seventh, the keywords "leachate" (cited 40 times), which means contaminated liquid derived from waste disposal facilities, such as landfills, which contains soluble organic and inorganic compounds, as well as suspended particles (Naveen et al., 2017). The word "Biogas" was cited 38 times, being the eighth most used word in articles. Biogas refers to the production of gas from the decomposition of organic matter with the absence of oxygen (Fernández-Nava et al., 2014). The penultimate word was "Environment" (cited 36 times), characterized as a set of physical, chemical, and biological components that can directly or indirectly impact human life (United Nations, 1972). Finally, the last selected keyword was "Heavy Metals" (35), which are metals so named when they weigh more than 5 mg per m^3. Some of the heavy metals are essential for the survival of plants or animals (Fe, Mn, Zn, among others), while others have levels of toxicity even at low concentrations (Cd, Hg, and Pb) (Christensen, 2010).

Hot topics

In this subsection, the keywords were organized into research themes that have similarities between them, in order to quantify the terms existing in each theme. With this quantification, it became possible to verify the participation of each of the themes in the field of knowledge as a whole, as well as to observe the variations of the respective percentages in different periods, as can be seen in the later section. The formation of clusters of keywords inserted in publications can map the main themes of a scientific field. The terms that were previously organized should reflect the similarity of a field of scientific research (Phillips et al., 2015). For the analysis of keywords, the clustering technique was used, which consists of grouping words with similar meanings into themes to verify trends within the research knowledge area (Cobo et al., 2012).

As can be seen in Table 1, terms directly related to SWM were used, dividing them into: (I) main themes and (II) adjacent terms, as recommended by Christensen (2010). The attribution of keywords to the research themes took into account the adherence of the expression to the specific theme, as well as the possibility that there was some ambiguity in the interpretation, that is, words that contained a double meaning were eliminated so as not to harm or bias the organization of the proposed themes.

Table 1 shows that the main themes describe the stages of the SWM, while the adjacent themes group issues that are not directly related, but that interact with issues of waste management, such as issues related to the environment, the economy, legislation, among others. Among the main themes, there is (a) generation of waste, in which its visibility is due to the uncontrolled increase in the production of solid waste, especially in the last decades (Laurent et al., 2014).

Added to this theme are questions that address the characteristics of waste and its composition (Christensen, 2010). In the theme (b) "collection and transport," the importance of reducing energy expenditure for a less polluting and effective service provision is presented (Nabavi-Pelesaraei et al., 2017; Rızvanoğlu et al., 2020). The (c) "treatment" of waste is of strategic importance for SWM to become successful and reduce environmental impacts (Soltani et al., 2015). The theme (d) "RUL" is approached to trace the final destination of the waste, which can extend to recycling, use, or landfill. It refers to the last stage that a waste will go through: either it can be used again in a supply chain or it will be used as raw material or it will still be disposed of in a specific space (Christensen, 2010).

Adjacent themes include (e) "energy," since the need for clean and renewable energy is of great importance to everyone, since the scarcity of fossil resources and the concern with the state of the environment are highlighted by international community (Basso et al., 2015; Zarea et al., 2019). As for (f) "gas emission," there is a significant concern about the increase in the production of greenhouse gases resulting from the disposal of waste, which increased by 54% in a time span of just 18 years (Tan et al., 2015). The theme (G) "sustainability" is highlighted in this field of study due to the fact that the stakeholders that participate in the decisions about the SWM take into account the economic, social, and environmental criteria (Soltani et al., 2015). The (h) "waste economy" becomes relevant because it identifies the commercial and logistical organization of workers (mostly informal) that make waste reduction possible through business formulation, even in slow institutional processes (Lim et al., 2016). In (i) "legislation and regulation," there are procedures for the inspection of residues and the elaboration of targets for the reduction of pollution (Allesch & Brunner, 2014; Fernández-Nava et al., 2014). The (j) "LCA" methodology has been widely used because it allows an understanding of the complexity that SWM has, including allowing the identification of interdependencies of integrated systems (Abduli et al., 2011; Fernández-Nava et al., 2014). The (k) "waste hierarchy" formulated by the European Community is an important strategy that allows reflection on conscious consumption even in the product creation phase (Allesch & Brunner, 2014; Tan et al., 2015). In (l) "associated issues," various topics that influence waste management are grouped, such as urbanization and sanitation (impacted by inappropriate waste management), public health, contamination by diseases or toxicities, etc. (Christensen, 2010; Johar et al., 2020; Pandey et al., 2012).

In this subsection, the evolution of each of the 12 themes that make up solid waste management was analyzed. In total, 116 keywords were identified, adding up to 1546 repetitions. The field "others" was added considering the keywords that could not be used for the proposed themes. The evolution of the themes was analyzed starting in 2005, a period in which this field of knowledge is considered fully established, according to Fig. 4. To analyze the variations in which the expressions were distributed over the last 14 years, two consecutive periods were established 4 years and the last 5 years. The purpose of this analysis was to map the research trends in this field of knowledge by identifying the most relevant topics at the moment in order to verify which are the main research opportunities in this field.

Table 2 shows the percentage of documents that present keywords related to the respective themes. The final three columns show the evolution of each theme, in percentage points, from one period to the next. The themes that showed the greatest growth over the period were energy, treatment, emission gas, and life cycle assessment. Waste hierarchy reached its peak in the second period. The percentage information for the three periods (from 2005 to 2018) was inserted to verify the trend that the research themes present, as shown in Fig. 8. Note that the "others" field obtained a significant decline in keywords, demonstrating that the 12 research themes have become increasingly relevant over the analyzed period.

Table 2 shows that the themes that stand out the most are "treatment" and "collection and transport." In relation to the adjacent themes, the most impacting themes are "energy," "emission gas," "life cycle assessment," "sustainability," and "waste economics." Among the adjacent themes, Fig. 8 suggests that the academic community has been giving less importance to "generation," "RUL" (among the main themes), "associated issues," and "waste hierarchy."

Research topics with an increasing trend were: energy, waste treatment, sustainability, waste economy, gas emissions, and life cycle assessment. As for the most relevant trends, it was found: new methods of thermal and biological treatment, assessment of the solid waste management life cycle, tools for the improvement of solid waste management, renewable energy production, and sustainable alternatives that provide resource savings. It is noted that there is a strong relationship between waste treatment, energy, gas emission, and life cycle assessment (LCA), as burning or organic decomposition guides strategies to decrease gas production and are crucial for energy production. The greater participation of adjacent areas in SWM research can demonstrate that there is an effort to implement transversal actions that involve and integrate the technical, economic, and legal spheres, in order to seek solutions to the problems faced in waste management (Fig. 9).

Top articles

More recent articles can indicate the most current research trends in the most diverse themes that make up a field and, therefore, are the best sources to detect the scientific gaps in each theme. However, as important as the contemporary nature of the article is its number of citations (Nunhes & Oliveira, 2018). Thus, in order to combine these two aspects, it was decided to research the research gaps in this scientific field based on the 15 most cited articles in the last 5 years. Table 7 presents the article with the respective authors, the year of publication, the journal in which it was published, the number of

Table 2 Evolution of the research theme

Research themes	(1) Documents 2005–2008	% (1)	(2) Documents 2009–2013 (%)	% (2)	(3) Documents 2014–2018 (%)	% (3)	Variation (2)–(1) (%)	Variation (3)–(2) (%)	Variation (3)–(1) (%)
RUL recycling-utilization-landfilling	95	18.4	173	19.5	116	19.9	1.2	0.4	1.5
Treatment	79	15.3	172	19.4	127	21.8	4.1	2.4	6.5
Sustainability	27	5.2	86	9.7	55	9.4	4.5	−0.3	4.2
Emission gas	20	3.9	69	7.8	51	8.7	3.9	1.0	4.9
Life cycle assessment	16	3.1	47	5.3	45	7.7	2.2	2.4	4.6
Generation	24	4.6	38	4.3	31	5.3	−0.4	1.0	0.7
Energy	9	1.7	32	3.6	50	8.6	1.9	5.0	6.8
Collection and transport	14	2.7	38	4.3	34	5.8	1.6	1.5	3.1
Waste economics	3	0.6	12	1.4	25	4.3	0.8	2.9	3.7
Issues associated	5	1.0	17	1.9	6	1.0	1.0	−0.9	0.1
Legislation and regulation	2	0.4	7	0.8	10	1.7	0.4	0.9	1.3
Waste hierarchy	0	0.0	10	1.1	1	0.2	1.1	−1.0	0.2
Others	223	43.1	185	20.9	32	5.6	−22.3	−15.3	−37.6
Total (documents)	517	100%	886	100%	583	100%			

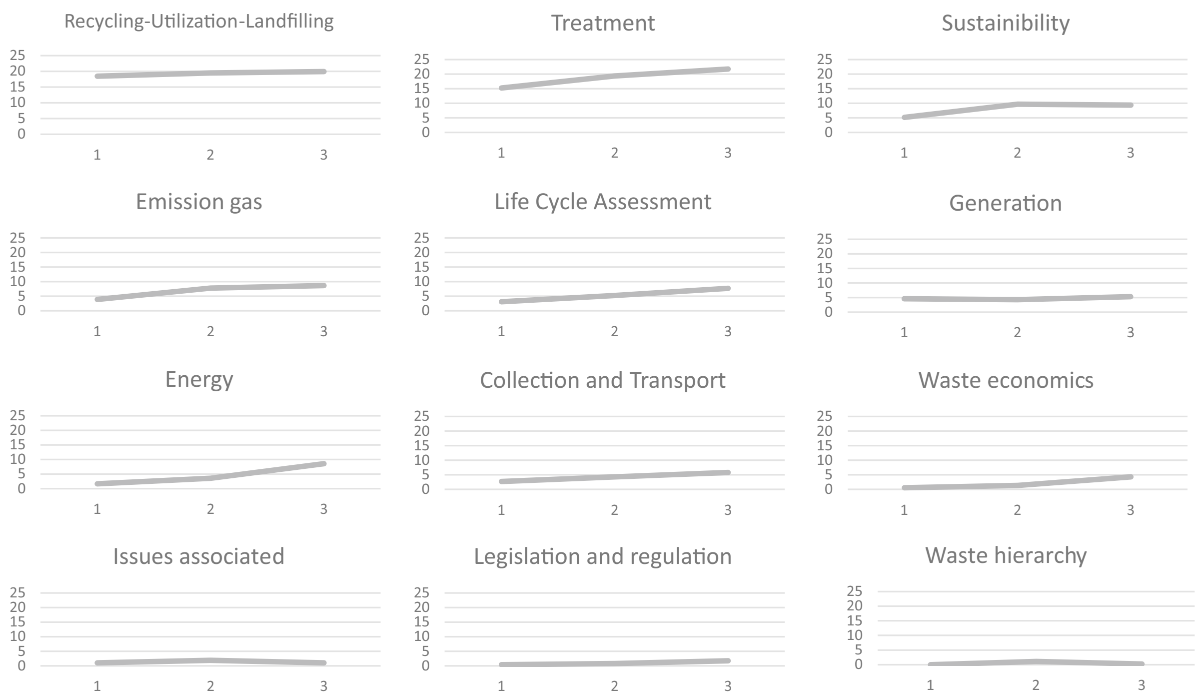

Fig. 8 Trends of research themes

citations in the article, the annual average of citations, and the evolution of citations between 2014 and 2018. The 15 selected articles received 1228 citations out of a total of 9671 received for all articles produced in this period (583).

The number of citations for the 15 articles has grown over the past 5 years, as shown in Table 7. Among the journals with the highest number of articles in the analyzed period are Waste Management (6), Journal of Cleaner Production (2), and Journal of Environmental Management (2). Articles 1 and 3 achieved an expressive growth between the years 2016 and 2017. The most expressive increase in the number of citations occurred from 2016, even considering the eight articles that were published in the year of 2014. Among the authors cited, only two are present in the list of the main authors (Christensen and Bernstad) as shown in Fig. 6.

Proposed framework for the technical and scientific development of solid waste management

The identification of research gaps was carried out based on the 15 most cited articles between 2014 and 2018, as shown in Table 3. This procedure sought to analyze the contents embedded in the most relevant articles in this field of knowledge for the composition of groups with similar gaps.

In the 16 gaps observed, there is an important trend toward management tools, with a special focus on life cycle assessment, as well as a frequency of gaps aimed at waste treatment. The two most recent studies that are included in the analyses among the 15 most relevant articles, by Lim et al. (2016) (# 3) and Al-Salem et al. (2017) (# 15), concern studies aimed at the modalities of treatment, being directed respectively to biological and thermal treatments. The content presented in Table 3 subsidized the proposition of the framework presented in Table 4.

The first item of the framework addresses the use of thermal and biological treatments, which are two alternatives that aim to degrade the waste, both being better than the disposal in dumps and landfills (Alwaeli, 2015; Tan et al., 2015). Regarding this, it is necessary to investigate the pros and cons of thermal and biological treatments considering the points of view of different agents, such as population and government. The second item suggests conducting

#	Most cited aticles	Author	Year	Journal	Citations	Average citation / year	Evolution citation for year from 2014 to 2018				
							2014	2015	2016	2017	2018
1	Review of LCA studies of solid waste management systems - Part I: Lessons learned and perspectives	Laurent A. et al.	2014	Waste Management	182	36.40	7	32	33	52	58
2	Review of LCA studies of solid waste management systems - Part II: Methodological guidance for a better practice	Laurent A. et al.	2014	Waste Management	140	28.00	7	28	29	30	46
3	Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: Recent overview, greenhouse gases emissions and economic analysis	Lim S.L. et al.	2016	Journal of Cleaner Production	119	39.67	0	1	20	45	53
4	Pyrolysis technologies for municipal solid waste: A review	Chen D. et al.	2014	Waste Management	96	19.20	0	8	15	35	38
5	Multiple stakeholders in multi-criteria decision-making in the context of municipal solid waste management: A review	Soltani A. et al.	2015	Waste Management	80	20.00	0	8	18	20	34
6	Anaerobic co-digestion of food waste and dairy manure: Effects offood waste particle size and organic loading rate	Agyeman F.O., Tao W.	2014	Journal of Environmental Management	70	14.00	3	8	15	21	23
7	Operations research in solid waste management: A survey of strategic and tactical issues	Ghiani G. et al.	2014	Computers and Operations Research	69	13.80	3	9	16	21	20
8	Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation	Edjabou M.E. et al.	2015	Waste Management	69	17.25	0	6	15	21	27
9	Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia	Tan S.T. et al.	2015	Energy Conversion and Management	65	16.25	0	2	8	24	31
10	Overview of household solid waste recycling policy status and challenges in Malaysia	Moh Y.C., Abd Manaf L.	2014	Resources, Conservation and Recycling	65	13.00	0	8	15	17	25
11	Application of life cycle assessment (LCA) for municipal solid waste management: A case study of Sakarya	Erses Yay A.S.	2015	Journal of Cleaner Production	62	15.50	0	1	12	21	28
12	Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials	Alibardi L., Cossu R.	2015	Waste Management	56	14.00	0	3	9	18	26
13	Energy and emissions benefits of renewable energy derived from municipal solid waste: Analysis of a low carbon scenario in Malaysia	Tan S.T. et al.	2014	Applied Energy	56	11.20	2	6	12	22	14
14	Assessment methods for solid waste management: A literature review	Allesch A., Brunner P.H.	2014	Waste Management and Research	54	10.80	2	3	11	21	17
15	A review on thermal and catalytic pyrolysis of plastic solid waste (PSW)	Al-Salem S.M. et al.	2017	Journal of Environmental Management	45	22.50	0	0	0	6	39

Fig. 9 The 15 most cited articles on solid waste management between 2014-2018

studies to improve the methods used for solid waste management, eliminating the systematic flaws that may exist in its implementation. In this sense, it is highlighted the lack of effective surveillance in each of the phases, since there is no certification, for example, along the lines of the ISO to support the processes in their entirety (Laurent et al., 2014). With regard to the third item, difficulties arise in reconciling the interests of several stakeholders for the adoption of strategic procedures in SWM from a long-term perspective. In this sense, it is suggested that future studies propose more resilient methods, which are measurable and can be replicated in other environments (Ghiani et al., 2014; Soltani et al., 2015). In this item, in addition to the treatment itself, it includes the adoption of public policies and the involvement of the population (Moh & Abd Manaf, 2014). In the fourth item, studies are suggested to use the energy produced from waste, both from incinerators and from landfills (Tan et al., 2014). In the fifth item, the research guidance is aimed at taking advantage of surplus waste to generate business. The focus is on understanding how to save the extraction of elements from nature for energy generation (Lim et al., 2016; Soltani et al., 2015).

The content analysis indicates a strong convergence with bibliometric studies, since the groups of gaps that obtained the most points were new alternatives for thermal and biological treatments. Life cycle assessment was highlighted both in bibliometric studies and in content analysis. It is also worth noting that the possibility that SWM is undergoing a transition from leading authors is quite plausible, since among the main researchers identified in the 15 most cited articles in the last 5 years, only two of them were part of from the selection that identified the 10 most cited authors in the last 14 years, a period characterized by the 3rd phase (linear growth) of SWM research.

Finally, the findings of this research were compared to the latest publications on the theme. In order

Table 3 Scientific gaps

No	Author	Gap
1	Laurent et al. (2014)	Conducting further studies on life cycle assessment of specific waste flows, such as in civil construction and electronic waste
2	Laurent et al. (2014)	Search for standardized procedures in LCA implementation focused on solid waste management so as to reduce possible methodological flaws in case studies
3	Lim et al. (2016)	Application of composting and vermicomposting techniques for producing organic fertilizers aimed at agricultural application
4	Chen et al. (2014)	Identification of municipal solid waste for pyrolysis that minimizes pollution
5	Soltani et al. (2015)	Use of MCDA techniques for Urban Solid Waste Management
6	Agyeman and Tao (2014)	Conducting further studies on anaerobic digestion focused on energy consumption
7	Ghiani et al. (2014)	Strategic integration of solid waste management processes in a long-term perspective
8	Edjabou et al. (2015)	Conducting studies aimed at social issues related to impacts of solid waste on the population
9	Tan et al. (2015)	Screening food waste in groups such as plant and animal derivatives
10	Moh and Manaf (2014)	3E analysis on energy recovery technologies from waste materials, including landfills
11	Yay (2015)	Implementation of strategies aimed at raising awareness among the population about the importance of becoming accustomed to recycling
12	Alibardi and Cossu (2015)	Implementação da avaliação do ciclo de vida para análise da política de gestão municipal de resíduos sólidos. Implementation of life cycle evaluation for analysis of municipal solid waste management policy
13	Tan et al. (2014)	Identifying the potential of hydrogen in different types of waste
14	Allesch and Brunner (2014)	Municipal solid waste incineration as an economic and reducing alternative to environmental impacts
15	Al-Salem et al., (2017)	Using management tools to measure impacts on sustainability

to do this, the latest papers that contained the search terms "bibliometrics" (4 articles) and "content analysis" (2 articles) and associated with "solid waste management" published in 2020 in Scopus were selected. Tsai et al. (2020) identified that there are few studies conducted in Africa regarding solid waste management in the context of the circular economy. These findings corroborate with the results of this work, in which no relevant participation of scientific publications on SWM was identified among the African countries. This information can be seen in "Territorial predominance" (analysis of territorial predominance). Tsai et al. (2020) also highlighted some critical issues in solid waste management, such as incineration, life cycle assessment, plastic waste, waste sorting, and sustainability. All these critical elements of SWM

Table 4 Proposed Framework for SWM

Group	Item	Comments	Articles
I	New heat and biological treatment methods	It is suggested studies that can improve treatment techniques, with the objective of combining the best methods for each specific material	No. 3, no. 4, no. 6, no. 12, no. 13, no. 15
II	Life cycle assessment of solid waste management	Analysis of each process for devising methodologies and basing public policies	No. 1, no. 2, no. 11
III	Tools for improving solid waste management	Implementation of qualitative and quantitative methods for solid waste management	No. 5, no. 7, no. 14
IV	Renewable energy production	Harnessing the potential of waste energy itself for treatment and take advantage of the same processes to produce surplus energy	No. 9
V	Sustainable alternatives that conserve resources	Harnessing raw materials inherent in solid waste so as to reduce impacts of natural resources scarcity	No. 8, no. 10

were addressed in this article, except plastic waste because it is covered in RUL (recycling, utilization, and landfill). Medina-Mijangos and Seguí-Amórtegui (2020) and Fernández-González et al. (2020) observed that there is significant growth in energy recovery, while the number of publications that address the waste hierarchy is low (Medina-Mijangos & Seguí-Amórtegui, 2020). These findings reflect the same results presented in "Hot topics," where the area of energy in the context of waste has the highest variance (6.8%), and the waste hierarchy has the second-worst variance (0.2%). Wong et al. (2020) investigated, through a bibliometric study, the ash produced in the incineration of municipal solid waste in order to identify the negative environmental impacts of this form of treatment. Although the bibliometric study was conducted with articles from the Web of Science database and the authors filtered the results in the thermal treatment of waste, some similarities with this study can be noted. For instance, in the proposed framework of this work ("Proposed framework for the technical and scientific development of solid waste management"), there is a group of gaps regarding waste treatment techniques, which include thermal treatment and biological treatment. The relevance of this topic of thermal treatment of waste can also be observed in the publications from China ("Territorial predominance").

Esae et al. (2020) identified the potential for the insertion of renewable energy in solid waste in Nigeria. The main difficulty encountered in the installation of this energy matrix was the informal work, as part of the resources are retained by waste pickers, reducing the amount of waste sent to thermal and biological treatment plants. The authors mention that there is a great potential for renewable energy generation in the rural villages in Nigeria and that to achieve it, it is necessary to strengthen environmental policies, funding sources, and environmental education. These results are in line with the framework proposed in this paper, especially in groups I, IV, and V (Table 4). Babazadeh et al. (2020) addressed household waste separation in Iran. The main challenges identified for household waste separation were low citizen involvement, waste theft, lack of resources, poorly formulated policies, little private sector participation, and lack of integrated management. These findings converge with the propositions of this paper discussed in groups II, III, and V (Table 4).

Conclusions

The objective of mapping the state of the art on SWM was achieved through the identification of hot topics and scientific gaps that added to the authors' experience subsidized the proposition of the framework. This framework enriches the state of the art on SWM, deepening and expanding five main thematic groups. Therefore, according to the results of the framework, it is recommended that future studies investigate new thermal and biological treatment methods for decreasing waste disposal to landfills, evaluate the life cycle of solid waste management to promote circular economy and sustainability, and develop tools to improve SWM by using renewable energy and other sustainable alternatives to conserve natural resources. The deepening of these thematic groups contemplated the proposition of solutions to overcome the challenges and develop the opportunities identified.

The main academic contribution was to deepen and expand the state of the art on SWM, from the verification of scientific trends and the proposition of new paths that add to the literature a set of guidelines for developing future researches on SWM. The new paths proposed in this paper also bring important applied contributions, once they can support the decision-making of researchers, public and private managers; reduce environmental impacts; and improve life in urban spaces.

The main novelty of this study was the organization of a framework that can be implemented and adapted transdisciplinary by the main SWM actors, therefore involving governments from different instances, staff responsible for the direction of schools and universities, non-governmental organizations, and private companies. This study provides an initial direction so that the complex dilemmas of waste can be solved sustainably. Future studies could develop bibliometrics comparing the performance of different cities in SWM by their number of inhabitants, technological development, HDI index, etc. Other studies could also deepen the five thematic groups identified in this paper as well as propose specific guidelines to serve as a basis for the formulation of public policies, technological development, and investments in SWM.

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