Vol. 61, p. 161-182, jan./jun. 2023. DOI: 10.5380/dma.v61i0.80307 e-ISSN 2176-9109

UFPR
DeMA
DESENVOLVIMENTO E MEIO AMBIENTE
BIBLIOTECA DIGITAL DE PERIÓDICOS BDP | UFPR
revistas.ufpr.br

Assessment of sustainability for wastewater treatment plants: a bibliometric review

Avaliação de sustentabilidade para estações de tratamento de esgoto: uma revisão bibliométrica

Renata Carlos FREIRE[1]*, Marianna de Andrade SARAIVA[1], Eduarda Maria Farias SILVA[1], Patrícia Verônica Pinheiro Sales LIMA[1]

[1] Universidade Federal do Ceará (UFC), Fortaleza, CE, Brasil.

* E-mail of contact: renata.carlosfreire@gmail.com

Article received in March 30, 2021, accepet in August 18, 2021, published in April 5, 2023.

ABSTRACT: The 2030 Agenda adopted as one of its Sustainable Development Goals (SDGs): "ensuring the availability and sustainable management of water and sanitation for all". This is a claim that requires the involvement of actors, managers, researchers, private sector, and civil society. Science can be engaged in this agenda through the production of knowledge and subsidies to managers. The present study aims to perform a bibliometric analysis of publications related to sustainability in the treatment of effluents from 2015 to 2020. For this, the Scopus database was used, seeking to characterize the publications with the themes “sustainability”, “wastewater treatment” and “assessment”, considering the quantity, year, main authors, magazines, main countries, keywords and main articles. The study identified an increasing number of publications on the topic and some important methodologies such as Life Cycle Analysis (LCA) and Multicriteria Analysis. In addition, it was concluded that, although there are several publications on the subject, in some articles and methodologies, not all pillars of sustainability are addressed.

Keywords: bibliometry; sewage treatment; sustainable development; WWTP; sanitation.

RESUMO: A Agenda 2030 adotou como um dos seus Objetivos de Desenvolvimento Sustentável (ODS): “assegurar a disponibilidade e gestão sustentável da água e saneamento para todas e todos”. Trata-se de uma pretensão que requer o envolvimento de atores, gestores, pesquisadores, setor privado e sociedade civil. A ciência pode se engajar na referida agenda por meio da produção de conhecimento e subsídios aos gestores. O presente estudo tem como objetivo realizar uma análise bibliométrica das publicações relacionadas à sustentabilidade no tratamento de efluentes do período de 2015 a 2020. Para isso, utilizou-se a base de dados *Scopus*, buscando caracterizar as publicações com os temas “*sustainability*”, “*wastewater treatment*” e “*assessment*”,

considerando a quantidade, ano, principais autores, revistas, principais países, palavras-chave e principais artigos. O estudo identificou uma crescente quantidade de publicações sobre o tema e algumas metodologias importantes como a Avaliação de Ciclo de Vida (ACV) e a Análise Multicritério. Além disso, concluiu-se que, embora existam várias publicações sobre o tema, em alguns artigos e metodologias não são abordados todos os pilares da sustentabilidade.

Palavras-chave: bibliometria; tratamento de efluentes; desenvolvimento sustentável; ETE; saneamento.

1. Introduction

The pollution and degradation of water resources are global problems intensified by the lack of sanitation in many cities. Data on hygiene, sanitation, and water supply monitoring indicate that one in every three individuals worldwide does not have access to drinking water and over half of the global population lack safe sanitation (UNICEF & WHO, 2019).

The Agenda 2030 for Sustainable Development of the United Nations set targets to ensure the availability and the sustainable management of drinking water and basic sanitation. The Sustainable Development Goals (SDG) sets six objectives that include the improvement of water quality; the treatment and safe reuse of wastewater; increased efficiency of water use; guaranteed supply of freshwater; implementation of water reuse management; and the protection and restoration of water-related ecosystems (Delanka-Pedige *et al.*, 2020; United Nations, 2020). The SDG 11 - Sustainable Cities and Communities also sets goals related to the infrastructure of wastewater, namely: provision of essential services; reduction of the negative environmental impact of cities, including the air quality and municipal waste management; and increased resource efficiency.

To achieve the goals of universal and safe sanitation by 2030, the rate of sanitation coverage needs to increase fourfold (UNICEF & WHO, 2020), making it necessary, therefore, to act on five main strategies: governance with effective leadership, funding, development of capabilities, support of reliable data and innovative solutions.

The premises where the wastewater is processed on a large scale are called Wastewater Treatment Plants (WWTP). They are key for the success of the sanitation plan because their purpose is to ensure the final quality of the wastewater in compliance with the current environmental laws (Neves *et al.*, 2019). Maninna et al. (2019) discuss that in order for WWTPs to be considered sustainable, they must have a low discharge of pollutants, protect human health, and viable construction and operation costs.

However, WWTPs generally use a lot of energy and generate large amounts of both greenhouse gases and water pollutants (Chai *et al.*, 2015). This scenario of either a lack of or inefficient wastewater is not only a key issue to protect human health and environmental sustainability (IOC & UNESCO, 2011) but has drawn attention the attention of sanitation managers and authorities to the performance of WWTPs (Piao *et al.*, 2016).

More sustainable solutions for WWTPs management are being studied worldwide (Mannina

et al., 2019). This field of study is in constant improvement, and the results obtained can offer further opportunities for the scientific community to find innovative and universal solutions for WWTP problems, covering increasingly more aspects of the process, from security to sustainability, efficient operation, cost optimization, treatment of emerging pollutants, reduction of emissions and other by-products in a way that is flexible enough to be adaptable to the rapidly changing context of the WWTPs.

In this perspective, the following questions arise: How has the scientific production on sustainability for wastewater treatment been developing? What are specific areas of science usually approached in the works? What are the trends for and gaps in knowledge? Considering these issues, this article aims to present a bibliometric analysis of publications related to sustainability for wastewater treatment from 2015 to 2020 to support different ways of managing and assessing the sustainability of WWTPs and guide new research on the topic.

A bibliometric study can show in a more objective and complete way what has been written about a particular subject, presenting some studies that, oftentimes, are not seen because they are not part of the groups of most-cited authors, but which can be of great value for research on the subject. In this case, we carried out a bibliometric analysis using the Scopus database with the aid of VOSviewer.

2. Sustainability in wastewater treatment: key element in the pursuit of sustainable development

Sustainability is a term that expresses human actions and activities that aim to meet the current needs of human beings without compromising the future of coming generations. The concept is based on three main pillars: economic, social, and environmental support.

In order to promote sustainability in sewage treatment systems and incorporating these main pillars in the infrastructure of wastewater, it is possible to highlight the use of specific local solutions, the implementation of a economically viable system, the absence of polluting substances in the WWTP products, and by-products, adaptability, and the non-induction of irreversible distortions in environmental cycles (Brostel, 2002).

Energy efficiency and biofuel recovery allow for a smaller carbon footprint and decrease energy costs, in addition to providing local economic development. The reduction of emissions during processing minimizes odors and the emission of greenhouse gases (GHG), contributing to the reduction of climate change impacts and promotion of improved quality of life for populations. Obtaining high-quality water prevents the eutrophication of water bodies, thus reducing human, animal, and aquatic toxicity (Delanka-Pedige *et al.*, 2020).

The current goal of WWTPs is to improve the quality of the final effluent, seeking greater sustainability during the treatment, i.e., processing as much sewage as possible, with the lowest cost associated with the treatment, causing less environmental impact, being environmentally effective, economically affordable, and socially acceptable (Garrido-Baserba *et al.*, 2014; Mannina *et al.*, 2019).

In addition, the processing must be safe for the workers and community involved to minimally affect all the stakeholders (Amaral *et al.*, 2018). The optimal operation of the plants requires inte-

gration between various factors of different natures: technical and economic, environmental, health and hygiene, and sociocultural, which makes this a very challenging issue (Mannina *et al.*, 2019).

Sustainability is difficult to measure, a fact that was acknowledged during the United Nations Conference on Environment and Development, Rio 92, which took place in 1992 and was documented in Agenda 21, Chapter 40. This chapter states the need to create ways to assess sustainability, including scientific and technological cooperation (United Nations, 1996).

Following the guidelines of Agenda 21, since the end of the 1990s, different methodologies have been proposed aimed at assessing and monitoring the sustainability of various objects of interest: cities, communities, economic activities, public policies, and companies. According to Abreu & Rodrigues (2011), considering WWTPs, the establishment of sustainability assessment indicators and criteria is relevant since, in most cases, during the choice and design of projects, only the deployment, operational, and maintenance costs are considered.

According to the authors, in addition to the economic aspect, it is essential to consider the social and environmental ones because these involve problems of environmental degradation, health, and quality of life. By incorporating these criteria, the concern regarding sustainability in wastewater treatment is solidified, and the development of methodologies that make its measurement possible is immediately accepted.

3. Methodology

Bibliometrics is the use of quantitative and statistical techniques to measure the production and transmission of scientific knowledge, in addition to informing standards of written communication and literature aspects (Koseoglu *et al.*, 2016). It refers to a quantitative and statistical technique that allows measuring knowledge production and dissemination indexes, monitoring the development of various scientific areas and authorship patterns, as well as the publication and use of research results (Araújo, 2006).

Bibliometric indicators are tools that allow the assessment of scientific production on an issue under different aspects: the perception or opinion of peers who assess the content of the publications; the volume of scientific activity developed in terms of the number and geographical distribution of the studies published, the authors' productivity, the network of collaboration in the authorship of works, number of citations received; impact factor on journals, immediate citation index, journal influence; most important topics and topics of lesser interest (Lopes *et al.*, 2012). Table 1 shows the methodology steps adopted in this study.

TABLE 1 – Methodological sequence adopted in the bibliometric analysis.

Phases of Metodology	Descriptions and activities
1– Research Structuring	- Establishing and assessing the research objective to structure the theoretical framework; - Selection of words or terms based on the literature review; - Definition of the search targeting papers.
2 – Retrieval of papers	- Analysis of the words and terms agreed upon; - Saturation of the papers found in the Scopus database; - Papers found up to 11 June 2020.
3 – Analysis of the sample of papers	- Extraction of the references of all indexed items; - List of the relevant citations in the works retrieved.
4 – Data tabulation and analysis	- Tabulation of the metrics chosen for the documents; - Creation of maps using VOSviewer; - Creation of tables and graphs to analyze the data using Excel.

SOURCE: Changed from Schmitt *et al.* (2013).

To develop the theoretical foundation for the paper, we used books, dissertations, theses, and papers from journals.

All the papers collected for this study, for the bibliometric analysis, were obtained only from the Scopus database. This search was carried out only on Scopus because it features several papers on environmental sciences and technology. The keywords used in the search were: "assessment", "sustainability", and "wastewater treatment", in addition, we used the connective "AND" to narrow down the search for the chosen words. All search words were used in English so that the largest number of papers could be found since most papers in journals are written in this language. In addition, we adopted the period from 2015 to 2020 in the search filter mechanisms, up until the date when the research was carried out, 11 June 2020, and added a filter for journal papers, i.e., we excluded books and other types of documents. Another filter applied to the database was the exclusion of areas related to medicine, immunology, mathematics, computer science, astronomy, and pharmaceutics. Using these criteria, we identified 332 documents.

Part of the bibliometric indicators was obtained from the very Scopus database. The other part, as well as the maps, were drawn up with the aid of the VOSviewer software. The information analyzed in this study were: evolution of the total number of publications on the subject, the number of the publications per journal, the journals with the most publications, the most influential authors on the subject, the countries with the most publications, and the most influential ones on the subject, the subtopics of the papers, the main keywords, the main papers on the subject, and the evaluation of these papers regarding sustainability.

Considering the papers chosen for an in-depth analysis, three criteria were used: number of citations, "link" value on VOSviewer, co-occurrence

of keywords, and analysis of co-citation. These criteria were used in addition to the number of citations because sometimes a given document has many citations, but they are not very relevant to the subject chosen for research because the work may have been cited by other studies on different topics. For this reason, the VOSviewer software has a criterion named "link", which classifies the document in relation to the chosen subject; thus, the greater the number of the "link," the greater the relevance to the subject at hand.

We chose some prominent papers using the criteria of the number of citations and "link" value. Of these articles that were chosen, we identified characteristics such as the methodology used to measure the sustainability, if there was a specific focus on a particular step of wastewater treatment, the sustainability pillars discussed, and the presence or not of case studies.

4. Results e discussion

The bibliometric analysis and description of the main papers are presented below. Among the criteria discussed in this section are: the evolution of the scientific production in the field studied, and the production of the main countries, analyses of the scientific fields and keywords found, and gaps identified in the research.

4.1. Evolution of production in the field of study and production by country

Sustainability is a topic that is being increasingly discussed, and the same can be said about sustainability in sanitation. This is shown in Figure 1 by the increase in the number of publications per year in journals from the Scopus database.

FIGURE 1 – Documents published on Scopus on the topic from 2015 to 2020.
SOURCE: Prepared by the authors (2020).

The growing interest in sustainability and wastewater treatment is observed in the greater number of papers in journals from 2020, even when considering only the first six months of the year (76 papers and approximately 23% of the total 332 papers published from 2015-2020).

However, the greater growth of published documents, considering these five years, was observed from 2016 to 2017, which is made evident by the steep increase of the curve in Figure 1. There was an increase of 17 papers in comparison to the previous year, while the difference in the number of papers from other years in relation to their previous ones was nine additional papers, at most (2019-2020). Considering 2015 and 2020, in 2020, there was an increase by 44 papers in comparison to 2015, which is equivalent to a 137.5% increase.

Of the 332 papers, 70 of them (21%) were produced in the United States, and 60 (18%) in China, as shown in Figure 2. These two countries alone are responsible for around 40% of all published papers. Graph 2 shows only the top 10 countries in the number of publications since they are responsible for 93% of all published papers; the other countries together published 23 papers in the five years analyzed. The United States was responsible for double the number of publications of the 3rd country with the most publication, i.e., Spain (35 papers, which corresponds to 10.5% of all publications).

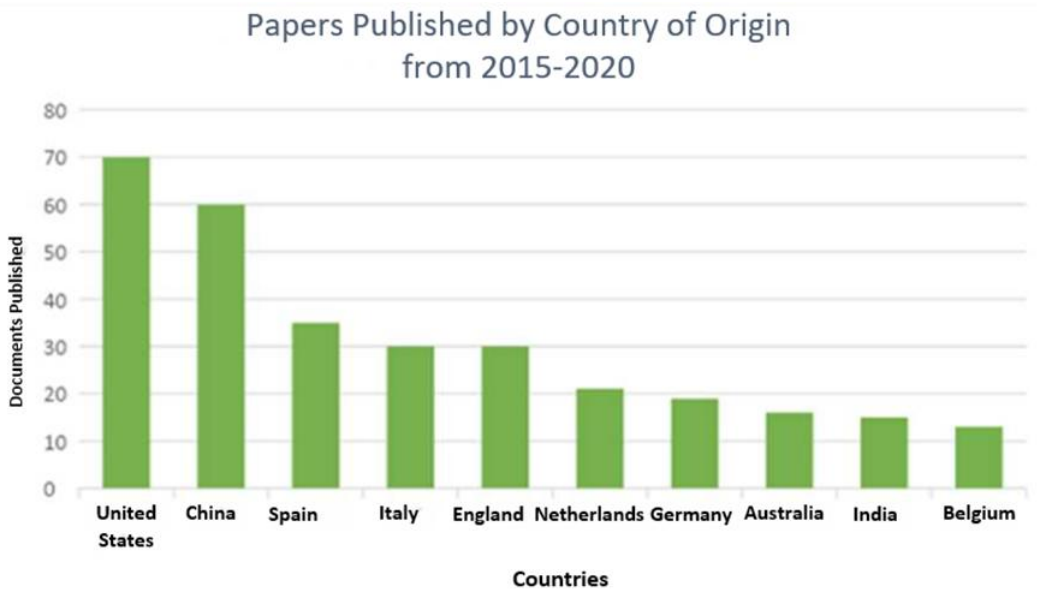

FIGURE 2 – Papers published by country in 2015-2020.
SOURCE: Prepared by the authors (2020).

Figure 3 shows a map generated using VOSviewer that illustrates the importance of each country in relation to the number of citations. In addition, the map shows the relationships between countries and the documents produced and the period when there were the most publications in each country.

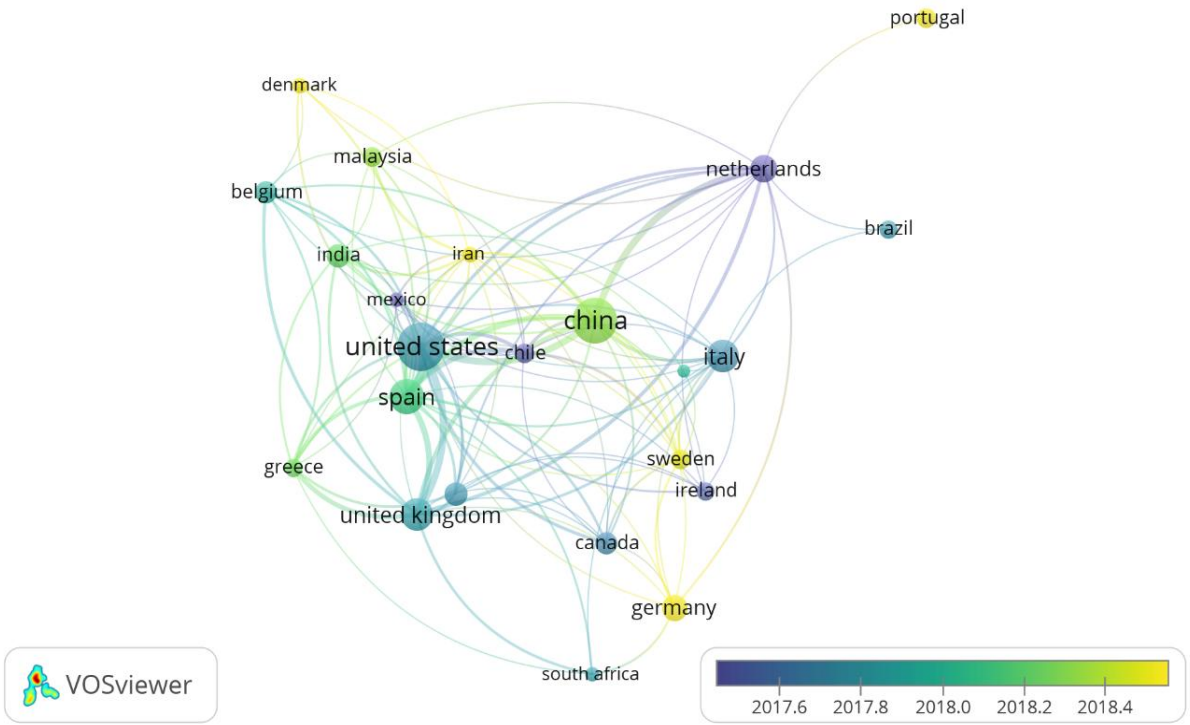

FIGURE 3 – Countries with the most documents cited during 2015-2020.
SOURCE: Prepared by the authors (2020).

Spain and China hold a similar number of citations, although China has almost twice the number of papers (60) published in comparison with Spain (35). Still, in Figure 3, considering the color that represents Spain and the one that represents China, is it possible to say that the Spanish publications are older than the Chinese ones, which explains the close number of citations of both countries. The United States remains in the lead both in number of documents published and number of citations, something which is reaffirmed by the number of connections (number of lines in the figure) and the strong relationship of discussion and citation with some countries (demonstrated by the proximity to some countries and increased thickness of the line in the figure).

Some countries do not feature among the top 10 with the most publications; however, they seem to be as cited as some of the countries that feature in Figure 2, which is the case of Brazil, Greece, Malaysia, and Canada.

4.2. Author and journal productivity

Regarding the Journals with the most papers on sustainability and wastewater treatment, as shown in Figure 4, the one with the highest number of publications was the Journal of Cleaner Production with 48 papers published (approximately 14.5% of publications), followed by the Science of the Total Environmental with 29 papers (about 8.7%). It is possible to see that, with the exception of the Journal of Cleaner Production, the number of documents on the subject of sustainability indicators for wastewater treatment is well distributed among a few journals. This is a positive point because it gives room for different approaches, providing a range of options for researchers and a likely reduction in the time for publication.

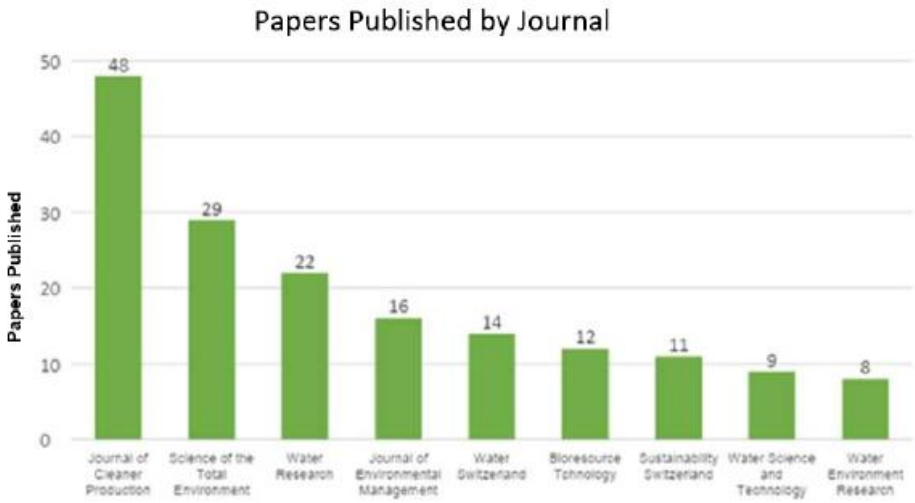

FIGURE 4 – Papers published on Scopus in 2015-2020 per magazine.
SOURCE: Prepared by the authors (2020).

Considering the authors with the most publications during the five years analyzed in this study, shown in Figure 5, is it possible to see that the most productive authors were Xu Wang, María Molinos-Senante, and Q Zhang. The first works at the Chinese Academy of Sciences, the second at the Pontifical Catholic University of Chile, and the last at the University of South Florida. It is also possible to see that, among the twelve authors presented, the numbers of papers produced by these scholars were very close to each other. Furthermore, it is possible to see that the number of papers created by each author was not exorbitant nor scarce.

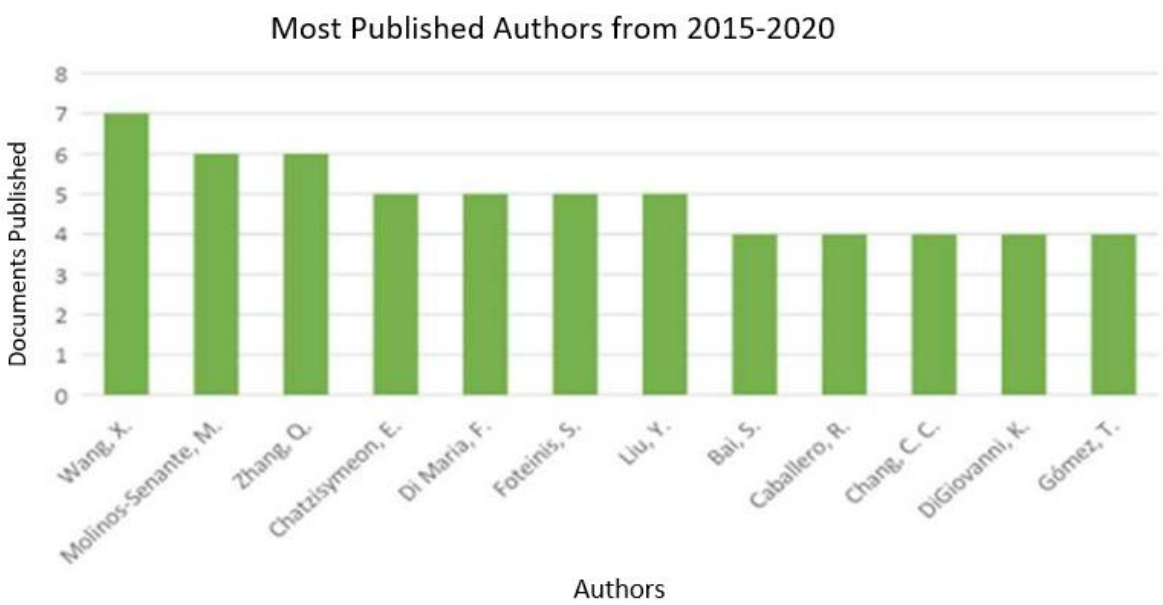

FIGURE 5 – Authors who published the most papers on Scopus on the topic studied in 2015-2020.
SOURCE: Prepared by the authors (2020). Prepared by the authors; Scopus (2020).

Still considering the publications by authors, we created a map using VOSviewer, represented in Figure 6, which shows the publication relationships between authors (the thicker the line, the greater the relationship) and the authors with the most citations (the bigger the circle, the greater number of citations).

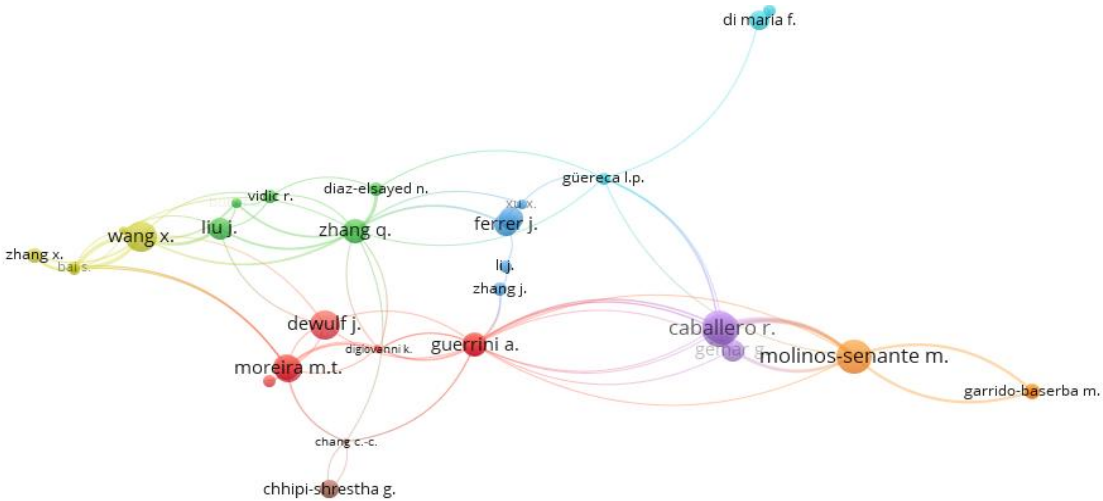

FIGURE 6 – Map representing the most cited authors in publications from 2015-2020.
SOURCE: Prepared by the authors with the help of VOSviewer (2020).

It is possible to see, based on Figures 5 and 6, that some authors, such as Molinos-Senante and Xu Wang, have a greater number of publications on the subject and are some of the most cited. In addition, it is possible to observe a correlation between all clusters (groups of colors), showing them that authors from different places and institutions cite each other and that some authors have thicker lines and with greater proximity, because they have worked together in some papers, as is the case of Caballero and Molinos-Senante. Another conclusion is that there are no authors with a highly discrepant number of citations, which is in line with the similar number of papers written by the 12 authors shown in Figure 5.

4.3. Analysis of the areas of study and keywords found

Each document published can be classified into one or more areas of knowledge that this study discusses. All areas of the 332 papers analyzed are shown in Table 2. Since sustainability is a very comprehensive subject with three pillars (social, environmental, and economic), we admitted different areas of knowledge. Among the areas of study classified, Environmental Science held, in numbers of documents, most of the research (296 of the 332 papers, approximately 89% of the total). This result shows that the papers selected are assertive regarding the topic of research because wastewater treatment and sustainability are both issues studied by environmental sciences.

TABLE 2 – Areas of study of the papers analyzed from 2015-2020.

Area of study	**Number of documents**
Environmental Science	296
Energy	95
Engineering	74
Business	48
Social Sciences	43
Agriculture and Biological Sciences	34
Chemical Engineering	31
Biochemistry, Genetics and Molecular Biology	28
Chemistry	22
Economy and Finance	8
Decisions in science	4
Earth and Planetary Sciences	4
Materials Science	2
Multidisciplinary	2

SOURCE: Prepared by the authors (2020).

Another way of analyzing the assertiveness of the papers selected regarding the subject is through their keywords. Naturally, the keyword "wastewater treatment" was the most recurrent one (in 83% of the papers) because it was one of the search words used in the systematic analysis; thus, this shows that the papers retrieved are consistent with the research carried out. The second most recurrent expression was "sustainable development" (in 53% of the articles) which is closely related to the word "Sustainability" (in 40% of the articles) that was also used in the search. This confirms that there

should not be many articles on discrepant topics to the one proposed herein. Other terms stood out, such as: "wastewater management" and "wastewater", with approximately 30% of recurrence in the papers selected; these terms were directly related to the "wastewater treatment' keyword.

We drew up a wordmap using VOSviewer (Figure 7) with the 35 most recurrent keywords in the 332 papers analyzed.

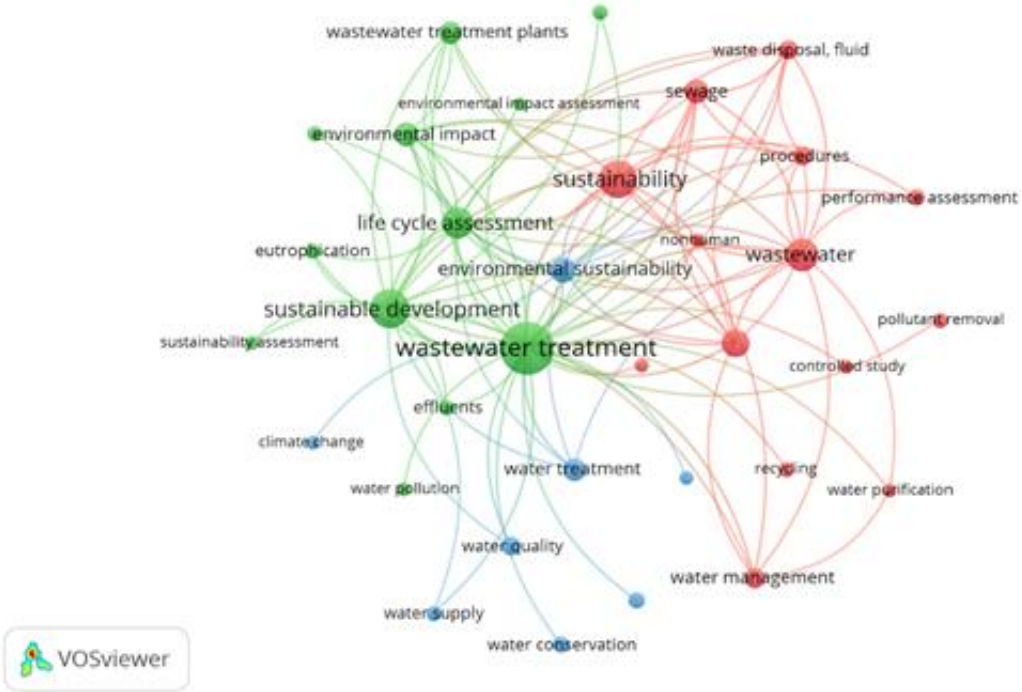

FIGURE 7 – Most cited keywords in the journals from 2015-2020 on the subject.
SOURCE: Prepared by the authors with the help of VOSviewer (2020).

The keyword map was organized into 3 clusters. The green cluster gathers the terms of a more direct relationship established with the keywords used in the data survey for this study: "assessment", "wastewater treatment", and "sustainability", the latter better represented in the network by the term "sustainable development". The blue cluster gathers items related to water resources, such as: "water treatment', 'water quality', 'water supply', 'water conservation", and "climate change". Finally, the red cluster gathers some terms related to the management of wastewater treatment: "performance assessment', 'procedures', 'water management' and "controlled study".

It is worth noting that the terms "effluents", "sewage", and "wastewater" are all commonly used to refer to sewage. However, among these terms, the most widely used in papers analyzed was 'wastewater', featuring in 50% of the papers selected. Of the keywords analyzed as a whole, only two have no direct connection with the subject: copper and coal; however, they are related to some sewage treatment analyses.

4.4. Analysis of the main articles

As previously presented, some authors stand out in their publications on the subject. Some papers stand out due to the number of citations and/or high "link" as defined by VOSviewer. Knowing the most cited and important papers on the subject can help assess whether the scientific production has succeeded in its choice of research. Table 3 brings some of the main papers on WWTP sustainability.

Some of the papers by the main authors already cited, shown in Figure 6 and Figure 5, María Molinos-Senante and Xu Wang, also feature among the papers selected and shown in Table 3. Most papers selected are from 2015 and 2016 because, since they are older, they are usually more cited in comparison with papers from 2019, which can only be cited by papers written in 2019 and 2020, for example.

TABLE 3 – Main papers on the subject from 2015-2020.

Title	**Authors and year**	**Objective**	**Number of Citations**	**Link VOSViewer**	**Journal**
Sewage sludge disposal strategies for sustainable development	Małgorzata Kacprzaka, Ewa Neczaja, Krzysztof Fijałkowskia, Anna Grobelaka, Anna Grossera, Małgorzata Worwaga, Agnieszka Rorata, Helge Brattebo, Åsgeir Almåsc, Bal Ram Singhc (2017)	Develops a review focused on the existing solutions for sustainable sewage sludge management considering in particular the Life Cycle Assessment as the methodology for decision-making.	185	1	*Environmental Research*

Multi-criteria group decision-making based sustainability measurement of wastewater treatment processes	Jingzheng Ren, Hanwei Liang (2017)	Develop a method for a Multicriteria sustainability assessment on wastewater treatment to assist in decision-making.	23	5	*Environmental Impact Assessment Review*
Eco-efficiency assessment of wastewater treatment plants using a weighted Russell directional distance model	María Molinos-Senante, Germán Gemar, Trinidad Gómez, Rafael Caballero, Ramón Sala-Garrido. (2016)	This study analyzed the eco-efficiency of effluent treatment stations also considering the removal of pollutants and the production of greenhouse gases.	60	2	*Journal of Cleaner Production*
Probabilistic evaluation of integrating resource recovery into wastewater treatment to improve environmental sustainability	Xu Wang, Perry L. McCarty, Junxin Liu, Nan-Qi Rend, Duu-Jong Lee, Han-Qing Yuf, Yi Qiang, and Jiuhui Qu (2015)	This work conducts a calculation of the net environmental benefit to assess the wastewater treatment in various scenarios in 50 countries.	50	3	*Proceedings of the National Academy of Sciences of the United States of America*
Sustainability assessment of tertiary wastewater treatment technologies: a multi--criteria analysis	K. V. Plakas, A. A. Georgiadis and A. J. Karabelas (2016)	Aimed at developing a Multicriteria analysis to choose the best sewage treatment technology to reuse the treated effluent.	28	1	*Water Science and Technology*
Benchmarking wastewater treatment plants under an eco-efficiency perspective	Yago Lorenzo-Toja, Ian Vázquez-Rowe, María José Amores, Montserrat Termes-Rifé, Desirée Marín-Navarro, María Teresa Moreira, Gumersindo Feijoo (2016)	Analyzed 22 WWTP in Spain based on eco-efficiency criteria and using the Life Cycle Assessment (LCA).	52	1	*Science of the Total Environment journal*
Economic and environmental sustainability of submerged anaerobic MBR-based technology as compared to aerobic-based technologies for moderate-/high-loaded urban wastewater treatment	R. Pretel, A. Robles, M.V. Ruano, A. Seco, J. Ferrer (2016)	This study assessed economic and environmental sustainability for choosing the best technology for wastewater treatment using the Life Cycle Assessment (LAC).	37	3	*Journal of Environmental Management*

SOURCE: Prepared by the authors (2020).

Part of the articles commented (approximately 42.85% of those in Table 3) was published in journals with a greater number of publications on the subject, which are shown in Figure 4. It is worth noting that, in the papers chosen, there was no repetition of journals, i.e., all the studies were published in different journals. As already mentioned, with the exception of the "Journal of Cleaner Production", the number of publications is well distributed among all the journals.

To better understand the proposal of the main articles published on sustainability and wastewater treatment, we present below their most relevant points. According to Ren & Liang (2017), several studies have been conducted to investigate and compare different processes of wastewater treatment, and there were two predominant ones: Life Cycle Assessment (LCA) and Multicriteria Decision Analysis, LCA being the most popular one (Ren & Liang, 2017). This methodology, according to Hellweg & Canals (2014), can quantify the environmental impacts related to the entire life cycle of goods and products and can monitor a wide variety of environmental categories.

Regarding the main papers selected, in the first one, by Kacprzaka *et al.* (2017), the authors use the Life Cycle Assessment methodology to carry out an environmental, technical, social, and economic assessment. The three pillars of sustainability have their criteria for selecting the best technology for the treatment and disposal of sewage sludge. There are 14 criteria used to choose the technology: five social, four economic, and five environmental. The social criteria are related to protecting public health and safety, minimizing disturbances to the community, and land requirements. The environment criteria focus on greater energy efficiency, local emissions, and the production of secondary waste. The economic ones refer to technology status and accessibility.

Another one of the main articles presented in Table 3 is by Ren & Liang (2017). According to it, the objective of the proposed tool is to assist decision-makers by selecting a more sustainable technology through a Multicriteria Decision Analysis. This methodology consists of a technique that allows for decisions guided by criteria deemed relevant to the problem by decision-makers, with the level of importance of the criteria defined by them in an interactive process with other technical-political players using a qualitative and quantitative technique. In the study by Ren & Liang (2017), the experts tested the methodology in four different treatment technologies. The study proposed ten criteria in the economic, technical, socio-political, and environmental pillars, namely: maintenance and operation costs, deployment cost, effects on the improvement of the quality of water, area occupied, simplicity of operations, maturity, public acceptance, governmental support, reliability, and jobs created. In this article of 2017, the Fuzzy model is used because there are not always accurate data available; thus, this model works with the imprecision and ambiguity of human judgment.

In the work by Molinos-Senante *et al.* (2016), the weighted Russell's directional distance model is applied to estimate the eco-efficiency of a sample of actual sewage treatment plants. This eco-efficiency is the ratio between the value of the products or services and the environmental impacts caused, whether by the economic activity or the consumption of resources. This ratio implies the removal of more pollutants from wastewater incurring in cost savings and lower greenhouse gases emission (Gómez *et al.*,

2018). In the work by Molinos-Senante *et al.* (2016), the approach used in the research allowed to obtain a score of inefficiency for each criterion involved in the proposed model. The first objective of this study was to evaluate the efficiency of some WWTP, and the second goal was to explore the factors that affect the efficiency analyses. This model was used in 30 Spanish WWTP. In the paper of 2016 uses parameters such as operational and maintenance costs, amount of organic matter removed, amount of suspended solids removed, and greenhouse gases produced in the WWTP.

Wang *et al.* (2015) used a model that calculates the Net Environmental Benefit of a station, taking into account the impacts and the benefits to society. The Net Environmental Benefit is obtained considering the total gains from the integration of the capture of resources and best practices for wastewater treatment, minus the adverse environmental effects of these actions. The authors created various scenarios for 50 countries and presented discussions showing them that recovery of resources can bring greater benefits for developed countries than for developing countries. In addition, in the work of 2015, they used the Monte Carlo statistical method to analyze the scenarios and benefits. The researchers also concluded that developing countries should have a different management approach from developed countries, i.e., more situation-specific management instead of replicating the strategies used by developed countries. Still, the work by Wang et al. (2015) used as parameters the emission of greenhouse gases, the consumed energy, the use of chemicals, the reuse of bioenergy, the sludge recycling, and the removal of struvite.

Considering the work by Plakas *et al.* (2016), it defined a Multicriteria Decision Analysis methodology to choose the best technology for wastewater treatment, in addition to using the "Triple Bottom Line" (TBL) method for approaches to sustainability. This study evaluated four tertiary treatment technologies for the development of effluents reuse in stations. This approach was carried out along with decision-makers in Greece. In a case study conducted by Plakas and coauthors, twelve criteria were selected to implement a multicriteria analysis for the needs of the sustainability assessment. Among the variables chosen are: investment costs, operational and maintenance costs, energy consumed, the area required, removal of xenobiotics, the impact of odors, impact of noise, visual impact, reliability, job creation, complexity, and public acceptance.

The paper by Lorenzo-Toja *et al.* (2016) presents an analysis of 22 Spanish stations regarding the Life Cycle Assessment, the impacts generated, and the Life-Cycle Cost Assessment, the latter being a variation of the first. The impacts analyzed were global warming and the potential for eutrophication. They proposed an ecological label to classify the effluent treatment stations. This work did not address the three pillars of sustainability, only two: the environmental and economic. It analyzed the main maintenance and operational costs of the stations, in addition to analyzing the estimated amount of carbon dioxide emitted. Other parameters analyzed were the quality of the effluent released, considering the variables of quality of the final effluent: the total phosphorus, total nitrogen, final Biochemical Oxygen Demand, and Total Suspended Solids. These parameters comprised the impact analysis regarding eutrophication.

Pretel *et al.* (2016) used approaches such as the Life Cycle Assessment and Life-Cycle Cost Assessment to compare the treatment technologies:

anaerobe membrane bioreactors (AnMBR), anaerobic membrane bioreactors (AeMBR), and conventional activated sludge. Regarding environmental sustainability, it considered the global warming potential and the eutrophication of the end water body as the main impacts of the treatment. These approaches aim to design WWTPs with specific technology for real-scale treatment, considering the key parameters that affect the process performance. However, the selection of appropriate schemes for the treatment should consider not only economic items (investment costs, operation, and maintenance) and environmental concerns (eutrophication, global warming potential, marine ecotoxicity, etc.), but also the social and political aspects; thus, this work did not cover all the sustainability pillars. This study observed that the technology of anaerobic membrane bioreactors with post-treatment of conventional activated sludge was the most sustainable for affluents with moderate/high rates.

Considering these seven documents, the papers by Lorenzo-Toja *et al.* (2016), do Pretel *et al.* (2016) and by Kacprzaka *et al.* (2017) were the ones that presented a Life Cycle Assessment and Life-Cycle Cost Assessment as their methodologies. Of these three, only the first considered the aspects of the social pillar of sustainability. In addition, the objective of the first and third was to choose the best treatment technology for stations that would be built. Unlike Lorenzo-Toja et al. (2016), who analyzed 22 existing stations.

Regarding the Multicriteria Decision Analysis methodology, the works that applied it were those by Plakas *et al.* (2016) and Ren & Liang (2017). These two studies addressed all the pillars of sustainability to choose the best technology for future effluent treatment plants. Although, the one by Plakas et al. (2016) focused on the choice of technology-specific for tertiary treatment. Whereas in the work of 2017, in addition to the Multicriteria Analysis, the Fuzzy model is also considered for handling more imprecise and subjective data.

Like the works by Lorenzo-Toja *et al.* (2016) and Pretel *et al.* (2016), the paper by Wang *et al.*(2015) does approach the social aspect. However, it is understandable that the latter does not mention this aspect since it encompasses a global scale, considering the analysis of 50 countries, and social data related to WWTP are difficult to measure on a larger scale. The work by Wang *et al.* (2015) uses an unusual model, the Net Environmental Benefit and the Monte Carlo simulation.

Lastly, the work by Molinos-Senante *et al.*(2016) uses the WWTP Ecoefficiency methodology, which in most papers does not address all aspects of the treatment environmental impacts, focusing on technical and economic aspects. However, the work by Molinos-Senante *et al.* (2016) considers the main environmental impacts and economic aspects. However, the authors do not address the social pillar of the 30 plants analyzed.

All the works analyzed in Table 3 address the topic of this review, i.e., the assessment of sustainability in wastewater treatment plants; however, some do not analyze all sustainability pillars, presenting an incomplete assessment of the subject. In addition, there were some differences regarding the objective of choosing the best treatment technology for plants to be built, while others aimed at measuring the sustainability of existing plants.

5. Conclusion

The bibliometric analysis of the papers retrieved from the Scopus database on wastewater

treatment sustainability from 2015 to 2020 indicated a significant increase in the number of papers on the subject, with an increase, up until June 2020, of 137.5% in comparison with the scientific production from 2015.

Considering the publications and their countries of origin, it is possible to see that the United States and China led in terms of the number of papers published, with approximately 40% of the 332 articles. It is possible to observe that countries like Brazil, Malaysia, and India, which have deficient sanitation coverage, lack studies addressing their specificities, which highlights the importance of investments in research on the subject.

There is a considerable number of journals interested in publishing research on sustainability and sewage treatment, which can be seen as positive under two perspectives: (i) increased dissemination of research results, which may support strategies by decision-makers, and (ii) shorter time between the preparation and publication of the research. The study also showed that Environmental Sciences lead the research on the subject, and few authors stand out in these studies.

Although there are different methodologies, such as Life Cycle Analysis and Multicriteria Analysis, to assess the sustainability in Wastewater Treatment Plants, not all dimensions of the concept were discussed. This was seen especially in the omission of the social pillar. Thus, without the joint analysis of the social, environmental, and economic pillars, it is possible to conclude that several studies did not assess comprehensively and effectively the sustainability of the wastewater treatment activity. However, although some articles do not approach all the sustainability pillars, it is possible to see a growing search for the improvement of the work already published, either by the same authors or by others. Thus, the adaptation of these already consolidated methodologies to include social and institutional aspects is essential for a more complete assessment of sustainability in future work.

The bibliographic survey allowed the identification of some gaps in the knowledge related to wastewater treatment sustainability. This identification is of the utmost importance because it suggests possible improvements and points to be better addressed in future works. One of the gaps observed during the analysis of the seven papers discussed in this study was that only 3 of them (Molinos-Senante et al., 2016; Wang *et al.*, 2015; Lorenzo-Toja *et al.*, 2016) has as their goal to assess the sustainability of existing treatment plants. The other four papers aimed at choosing the most sustainable technology for a plant to be built. Not only in this small selection, but most of the papers on wastewater treatment sustainability focus primarily on choosing the technology for future treatment. However, there is a need for new research focused on the assessment of current WWTP sustainability and the possibility to make such equipment more sustainable and efficient as feasible. This assessment of the current situation of wastewater treatment must be integrated with methodologies to aid in decision-making so that, in addition to measuring the sustainability for the treatment, actions may be developed for the effective improvement of the WWTPs.

Another shortcoming is that out of all the works analyzed, only the one by Wang *et al.* (2015) managed to compare completely different sanitation scenarios, examining the situation in different countries. This shortage of studies with such focus is justified since the availability and access to WWTP data, particularly in developing countries,

is oftentimes scarce and impracticable considering the situation of these sites. However, acquiring data for a better assessment of the sustainability of such equipment is of the utmost importance and, therefore, must be sought by wastewater treatment companies and managers. A suggestion for future work is to pursue case studies focused on the implementation of plant monitoring and sustainability assessment, showing the improvements observed in each case study.

We deem it relevant for future research studies to focus on the efficiency of the plants regarding environmental, economic, and technical aspects, in addition to social aspects, in the assessment of WWTPs already in operation and in the design of new ones. Additionally, we emphasize the importance of addressing the topic in studies by Brazilian scholars.

Acknowledgments

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico (FUNCAP), and the Conselho Nacional de Desenvolvimento Científico e Tecnológico for financialy supporting this study.

References

Abreu, P. D.; Rodrigues, M. B. Proposta de arranjo de indicadores para avaliação da sustentabilidade de estações de tratamento de esgoto por zona de raízes. *Synergismus Scyentifica*, 6(1), 1-8, 2011. Disponível em: http://revistas.utfpr.edu.br/pb/index.php/SysScy/article/view/1250/0

Amaral, K. G. C. D.; Aisse, M. M.; Possetti, G. R. C. Avaliação da sustentabilidade no gerenciamento do lodo e biogás, em estação de tratamento de esgotos, utilizando a técnica de ACV. *Revista Ambiente & Água*, 14(5), 2018. doi: 10.4136/ambi-agua.2371

Araújo, C. A. Bibliometria: evolução histórica e questões atuais. *Em Questão*,12(1), 11–32, 2006. doi: 10.19132/1808-5245121

Brostel, R. D. C. *Formulação de modelo de avaliação de desempenho global de Estações de Tratamento de Esgotos Sanitários (ETEs)*. Dissertação (Mestrado em Tecnologia Ambiental e Recursos Hídricos) – UnB, 2002.

Chai C; Zhang D; Yu Y; Feng Y; Wong MS. Carbon footprint analyses of mainstream wastewater treatment technologies under different sludge treatment scenarios in China. *Water*, 7(3), 918-938, 2015. doi: 10.3390/w7030918

Delanka-Pedige, H. M. K.; Munasinghe-Arachchige, S. P.; Abeysiriwardana-Arachchige, I. S. A.; Nirmalakhandan, N. Wastewater infrastructure for sustainable cities: Assessment based on UN sustainable development goals (SDGs). *International Journal of Sustainable Development & World Ecology*, 1-7, 2020. doi: 10.1080/13504509.2020.1795006

Garrido-Baserba, M.; Hospido, A.; Reif, R.; Molinos-Senante, M.; Comas, J.; Poch, M. Including the environmental criteria when selecting a wastewater treatment plant. *Environmental modelling & software*, 56, 74-82, 2014. doi: j.envsoft.2013.11.008

Gómez, T.; Gémar, G.; Molinos-Senante, M.; Sala-Garrido, R.; Caballero, R. Measuring the eco-efficiency of wastewater treatment plants under data uncertainty. *Journal of environmental management*, 226, 484-492, 2018. doi: 10.1016/j.jenvman.2018.08.067

Hellweg, S.; Canals, L. M. Emerging approaches, challenges and opportunities in life cycle assessment. *Science*, 344, 1109–1113, 2014. doi: 10.1126/science.1248361

Kacprzak, M. et al.Sewage sludge disposal strategies for sustainable development. *Environmental research*, 156, 39-46, 2017. doi: 10.1016/j.envres.2017.03.010

Koseoglu, M. A., Rahimi, R., Okumus, F., Liu, J. Bibliometric studies in tourism. *Annals of Tourism Research*, 61, 180-198, 2016. doi: 10.1016/j.annals.2016.10.006

Lopes, S.; Costa, M. T.; Fernández-Llimós, F.; Amante, M. J.; Lopes, P. F. A Bibliometria e a Avaliação da Produção Científica: indicadores e ferramentas. *In: Anais do Congresso Nacional de bibliotecários, arquivistas e documentalistas* (No. 11), 2012. Disponível em: https://www.bad.pt/publicacoes/index.php/congressosbad/article/view/429

Lorenzo-Toja, Y.; Vázquez-Rowe, I.; Amores, M. J.; Termes-Rifé, M.; Marín-Navarro, D.; Moreira, M. T.; Feijoo, G. Benchmarking wastewater treatment plants under an eco-efficiency perspective. *Science of the Total Environment*, 566, 468-479, 2016. doi: 10.1016/j.scitotenv.2016.05.110

Mannina, G.; Rebouças, T. F.; Cosenza, A.; Sànchez-Marrè, M.; Gibert, K. Decision support systems (DSS) for wastewater treatment plants–a review of the state of the art. *Bioresource technology*, 290, 121814, 2019. doi: 10.1016/j.biortech.2019.121814

Molinos-Senante, M.; Gémar, G.; Gómez, T.; Caballero, R.; Sala-Garrido, R. Eco-efficiency assessment of wastewater treatment plants using a weighted Russell directional distance model. *JournalofCleanerProduction*, 137, 1066-1075, 2016. doi: 10.1016/j.jclepro.2016.07.057

Neves, A. P. N.; Ferreira, D. S.; Castro, D. A.; Cavallini, G. S. Avaliação da eficiência de remoção de matéria orgânica em efluente sanitário em função da idade do lodo de reator UASB: um estudo de caso. *Journal of Biotechnology and Biodiversity,* 7(4), 449–456, 2019. doi: 10.20873/jbb.uft.cemaf.v7n4.neves

Piao, W.; Kim, Y.; Kim, H.; Kim, M.; Kim, C. Life cycle assessment and economic efficiency analysis of integrated management of wastewater treatment plants. *Journal of Cleaner Production*, 113, 325-337, 2016. doi: 10.1016/j.jclepro.2015.11.012

Plakas, K. V.; Karabelas, A. J.; Georgiadis, A. A. Sustainability assessment of tertiary wastewater treatment technologies: a multi-criteria analysis. *Water Science and Technology*, 73(7), 1532–1540, 2016. doi: 10.2166/wst.2015.630.

Pretel, R.; Robles, A.; Ruano, M. V.; Seco, A.; Ferrer, J. Economic and environmental sustainability of submerged anaerobic MBR-based (AnMBR-based) technology as compared to aerobic-based technologies for moderate-/high-loaded urban wastewater treatment. *Journal of Environmental Management*, 166, 45–54, 2016. doi: 10.1016/j.jenvman.2015.10.004.

Ren, J.; Liang, H. Multi-criteria group decision-making based sustainability measurement of wastewater treatment processes. *Environmental ImpactAssessmentReview*, 65, 91–99, 2017. doi: 10.1016/j.eiar.2017.04.008.

Schmitt, C. S.; Hayde, C. T. V., Dreher, M. T. Sustentabilidade como vantagem competitiva: uma análise bibliométrica. *Estratégia & Negócios*, 6(2), 157-174, 2013. doi: 10.19177/reen.v6e22013157-174

The Intergovernmental Oceanographic Commission of United Nations Educational, Scientific and Cultural Organization (IOC & UNESCO). *A Blueprint for Ocean and Coastal Sustainability*, 2011. Disponível em: <https://tamugir.tdl.org/bitstream/handle/1969.3/28970/interagency_blue_paper_ocean_rioPlus20[1].pdf?sequence=1>Acesso em: jan. 2021.

UN – United Nations. *Conferência das Nações Unidas sobre Meio Ambiente e Desenvolvimento*: Agenda 21. Senado Federal, Subsecretaria de EdiçõesTécnicas, 1996.

UN – United Nations. *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*, 2020.Disponível em: <https://unstats.un.org/sdgs/indicators/indicators-list/> Acesso em: jan. 2021.

UNICEF – United Nations Children's Fund; WHO – World Health Organization. *Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities, 2019*. Disponível em: <https://www.who.int/water_sanitation_health/publications/jmp-report-2019/en/>. Acesso em: fev. 2021.

UNICEF – United Nations Children's Fund; WHO – World Health Organization. *State of the World's Sanitation:* an urgent call to transform sanitation for better health, environments, economies and societies, 2020. Disponível em: <https://washdata.org/sites/default/files/2020-11/UNICEF-WHO-state-of-the-worlds-sanitation-2020.pdf>. Acesso em: fev. 2021.

Wang, X. et al. Probabilistic evaluation of integrating

resource recovery into wastewater treatment to improve environmental sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, 112(5), 1630–1635, 2015. doi: 10.1073/pnas.1410715112.