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Circular economy and sewage sludge from wastewater treatment plants – Review

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Abstract. A problem that humanity is currently facing is pollution. The planet's population is constantly growing and proportionally with it the amount of waste increases. Given the need to manage both resources and waste as efficiently as possible and the need to integrate them into the circular economy, this paper aims to study sludge from sewage treatment plants and the circular economy. Therefore this study aims to review the research carried out between 2021- 2025 that was published on the Web of Science regarding sewage sludge and circular economy. During this period 751 papers were identified that target these topics. In order to summarize and capture as much data as possible, the Vos Viewer software was used and the results of this research are presented below.

Keywords: sludge, sewage treatment plants, circular economy.

1. Introduction

Nowadays, the circular economy represents a goal aimed by all the world, but primarily by the developing countries given global warming and the awareness of the fact that many resources are used and a large amount of waste is produced. Given this fact it is difficult to manage all the waste. In the context of the circular economy, the efficient management of sludge from sewage treatment plants is discussed.

There are several ways to introduce sludge from sewage treatment plants into the circular economy such as their use as fertilizer or drying them and produce biogas. This article aims to review research that studied the connection between the circular economy and sludge from sewage treatment plants published on the Web of Science between 2021-2025.

The circular economy can represent a response of society to current economic systems that emphasize the exploitation of resources. The circular economy

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focuses mainly on finding ways not to affect the environment [1]. In order to achieve it's goals, the circular economy aims to reduce the quantities of pollutants and waste [2]. Moreover, in the context of the circular economy and efficient waste management, sludge from sewage treatment plants represents a resource that can be exploited [3]. Data from the literature supports the need to reuse both wastewater and sludge from sewage treatment plants either in agriculture by creating a compost that facilitates the fertilization of arid lands or energy recovery through thermal treatment [2]. Therefore, given the importance of investigating the introduction of sludge from sewage treatment plants into the circular economy, the following article will analyze the studies published in the last five years that address this topic.

2. Method

A bibliographic analysis is a way of collecting information on a specific topic or discipline [4]. By using bibliographic maps, analyzing relevant data such as the country in which the articles were published, the authors of the studies, the organizations that published them and keywords, relevant data can be obtained that allow a comprehensive analysis of different topics [5].
Therefore, given the need for a more complex understanding of the link between the circular economy and sewage sludge from wastewater treatment plants, this paper reviewed 751 papers published on the Web of Science that addressed these topics.
The first step was to search for studies published on the Web of Science between 2021 and 2025 that investigated sewage sludge from wastewater treatment plants and the circular economy. After this stage, the data was classified according to several criteria such as the countries with the most publications, the journals, the year of publication, the most cited articles and finally, a bibliographic map was created using the VOS Viewer program that emphasized the keywords used in this research.

2.1. Countries with most contributions to the literature

As can be seen in Table 1, most of the research investigating sewage sludge and the circular economy was conducted in England, Switzerland and Netherlands. This indicates a high interest in the topic of these countries. A difference can also be observed regarding continents - most publications were conducted in European countries. North America is the continent that invests the most in research and innovation, but studies show that only 8% of articles investigating sewage sludge and the circular economy were published on the American continent, indicating a low interest of researchers in this area for the topic under investigation.

Table 1. Classification of countries by the number of publications in Web of Science

Classification of countries by number of publications		
Rsnk	**Contry**	**Number of publications**
1	England	225
2	Switzerland	220
3	Netherlands	158
4	United States	64
5	Germany	41
6	Poland	21
7	Italy	4
8	Romania	3
9	Brazil	2
10	Croatia	2
11	Iran	2
12	Singapore	2
13	Belarus	1
14	Belgium	1
15	Bulgaria	1
16	China	1
17	Lithuania	1
18	Slovenia	1
19	Turkey	1

2.2. Journals which present interest for sewage sludge and circular economy

Research on sewage sludge and circular economy has been published in 150 journals, but Table 2 lists the journals that have had at least two publications on this topic. As can be seen, most of the articles on this topic have been published in Energies, Journal of Environmental Management and Journal of Cleaner Production. Energies is a journal published in Basel-Switzerland and the other two are published in London- England. Thus, the interest of the European countries in studying the introduction of sewage sludge into the circular economy also emerges from the perspective of the journals with the most publications.

Table 2. Classification of the number of publications in different journals in Web of Science.

Journals with the highest number of publications			
Rank	**Journal**	**Number of publications**	**Percent of contributions [%]**
1	ENERGIES	39	5.19
2	JOURNAL OF ENVIRONMENTAL MANAGEMENT	39	5.19
3	JOURNAL OF CLEANER PRODUCTION	35	4.66
4	BIORESOURCE TECHNOLOGY	18	2.40
5	CHEMICAL ENGINEERING JOURNAL	15	2.00
6	ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	14	1.86
7	FUEL	13	1.73
8	APPLIED SCIENCES-BASEL	12	1.60
9	AGRONOMY-BASEL	9	1.20
10	JOURNAL OF ENVIRONMENTAL CHEMICAL ENGINEERING	9	1.20
11	CHEMOSPHERE	8	1.07
12	JOURNAL OF HAZARDOUS MATERIALS	8	1.07
13	DESALINATION AND WATER TREATMENT	6	0.80
14	ENVIRONMENT DEVELOPMENT AND SUSTAINABILITY	6	0.80
15	ENVIRONMENTAL RESEARCH	6	0.80
16	CONSTRUCTION AND BUILDING MATERIALS	5	0.67
17	ENERGY CONVERSION AND MANAGEMENT	5	0.67
18	ENVIRONMENTAL TECHNOLOGY	5	0.67
19	ENVIRONMENTAL TECHNOLOGY INNOVATION	5	0.67
20	FRONTIERS IN SUSTAINABLE FOOD SYSTEMS	5	0.67
21	INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH	5	0.67

2.3. Year of publication

The classification of articles according to their year of publication is presented in the table below. A trend of increasing interest in this topic can be observed in recent years, compared to 2021. Considering that other research will be published this year (2025), it should not be considered that researchers concern for studying the link between the circular economy and sludge from sewage treatment plants has diminished.

Table 3. Classification of research according to the year of publication in Web of Science

Year of publication			
Rank	**Year**	**Number of publications**	**Percentage of publications [%]**
1	2025	66	8.45
2	2024	182	24.23
3	2023	174	23.17
4	2022	191	25.43
5	2021	138	18.38

2.4. Most cited articles

Table 4 presents the most cited articles about sewage sludge and circular economy. It can be seen that in this topic the greatest emphasis is placed on introducing sludge into the circular economy by using it in agriculture, especially by transforming it into biochar, which is a vegetable carbon obtained through pyrolysis.

According to the data analyzed, researchers interest in finding ways to utilize sludge from wastewater treatment plants and introduce it into the circular economy, especially in the agricultural field, can be observed.

Table 4. Top of the most cited articles in Web of Science

Top of the most cited articles				
Rank	**Name of the article**	**Author**	**Journal**	**No. citations**
1	How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar	[6]	GLOBAL CHANGE BIOLOGY BIOENERGY	521
2	A critical review on biochar for enhancing biogas production from anaerobic digestion of food waste and sludge	[7]	JOURNAL OF CLEANER PRODUCTION	328
3	Production and beneficial impact of biochar for environmental application: A comprehensive review	[8]	BIORESOURCE TECHNOLOGY	240
4	Conversion of sewage sludge into biochar: A potential resource in water and wastewater treatment	[9]	ENVIRONMENTAL RESEARCH	180
5	Perspective review on Municipal Solid Waste-to-energy route: Characteristics, management strategy, and role in circular economy	[10]	JOURNAL OF CLEANER PRODUCTION	177
6	A review on hydrothermal carbonization of potential	[11]	SCIENCE OF THE TOTAL	159

Top of the most cited articles				
	biomass wastes, characterization and environmental applications of hydrochar, and biorefinery perspectives of the process		ENVIRONMENT	
7	Recent advances and future directions on the valorization of spent mushroom substrate (SMS): A review	[12]	BIORESOURCE TECHNOLOGY	137
8	A sustainable reuse strategy of converting waste activated sludge into biochar for contaminants removal from water: Modifications, applications and perspectives	[13]	JOURNAL OF HAZARDOUS MATERIALS	123
9	Effects of anaerobic digestion of food waste on biogas production and environmental impacts: a review	[14]	ENVIRONMENTAL CHEMISTRY LETTERS	108
10	Phosphorous removal and recovery from urban wastewater: Current practices and new directions	[15]	SCIENCE OF THE TOTAL ENVIRONMENT	103

2.5. Keyword mapping

Keywords were analyzed using the Vos Viewer software. With this program, the keywords could be presented on a map that provides information on the most relevant topics [16]. In this research, keywords from 751 articles published between 2021-2025 that studied sludge from sewage treatment plants and the circular economy were analyzed. Figure 1 shows the keyword map created with Vos Viewer. The size of each node indicates the number of occurrences. It can also be seen that they are grouped according to the relationship between them. According to the figure below, four large clusters were created that include keywords. Some of these show the agricultural subject that concerns soils and their fertilization, another cluster targets the ways in which certain processes can be carried out, a group of keywords is represented by the effective processes that can be carried out to process sludge from sewage treatment plants such as anaerobic digestion, biogas production and the other cluster considers their result.

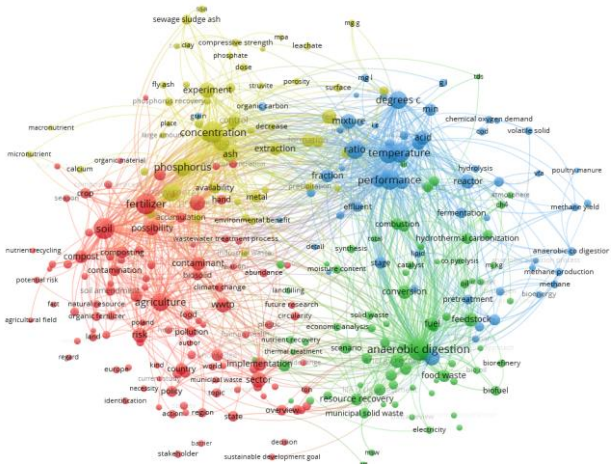

Fig. 1. Keyword mapping using VOS Viewer.

3. Discussions and conclusions

This work analyzed 751 publications displayed on the Web of Science that investigated the sludge from sewage treatment plants and circular economy between 2021 and 2025.

After analyzing the data, it was noted that there is some increase in research on these topics compared to 2021. It was also noted that research investigating these topics is published mainly in countries that are part of Europe, indicating to some extent that there is increased interest in this area for the most efficient management of sludge and for the circular economy.

Given that sewage treatment plants produce a significant amount of sludge, it must be managed as efficiently as possible. Data from the specialized literature indicate that the use of sludge from sewage treatment plants is influenced by the amount and type of pollutants that the sludge contains. On the other hand, if effective methods of removing pollutants are used, then the possibility that sludge from sewage treatment plants to be used increases.

In conclusion, this review aimed to analyze the studies conducted in the last five years that investigated sludge from wastewater treatment plants and circular economy in order to achieve the current state of research and critically analyze them in order to establish the research topics of the doctoral thesis with the theme: ”Theoretical and experimental research on the efficiency of sludge from wastewater treatment plants and their introduction into the circular economy”.

There has been a certain increase in articles that study these topics and this indicates the importance of introducing sewage sludge into the circular economy given the increasing amount that needs to be managed.

In the future, this topic should be further investigated to find the most efficient methods of managing sewage sludge, not only to reduce the amount of waste but also because it represents a resource that must be exploited due to the nutrients it contains.

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