RESEARCH ARTICLE

Statistical analysis of research in the study of the implementation of the circular economy in the preservation of water resources

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Abstract
Under the current consumption model, the depletion of natural resources, specifically water, is a reality that we will face if we do not promote a paradigm shift: resources can be reused leaving behind the traditional patterns of taking, manufacturing and discarding. Under this premise, in recent years, the concept of circular economy, an economic premise interrelated with sustainability has become an alternative for responsible consumption. The objective is to maintain water sources, if possible, through controlled and responsible collection, increase the reduction of consumption through the reuse of the resource and the appropriate and optimal treatment for its return to nature. Through Research, Development and Innovation, R+D+i, it is possible to define new schemes for the reuse of water, both for industrial sectors and for local governments; for example, in relation to the management of waste water, which goes from being waste to becoming a resource again. A study of information, bibliometrics and scientometry of scientific articles associated with the circular economy of water resources was carried out to identify research trends in this topic, as well as to establish the parameters of sustainability and governance of this resource. In the management of this resource, certain social, economic, environmental processes, among others, have not been considered, which affects the issue of water governance. In the development of this work, the Scopus database (Elsevier, B.V., 2021) and the Text Mining program VantagePoint (Search Technology, Academic Version 12.0) were used. 425 records were identified, during the period 2010 – 2021, in which an increasing trend of 83% is observed. The researchers' interest is focused on applications in environmental science and engineering. As for the countries, Spain and Italy stand out with the highest number of publications. Given the growing interest and importance in the subject, it is necessary to establish which models should be adopted to optimize the use of water resources, contributing to the protection of this natural supply, key to the prolongation of life.

Keywords: Circular economy; Sustainable; water resources; engineering; Cienciometría; Energy efficiency

Introduction

The concept of circular economy has been implemented in the business environment and, more recently, in the development of public policies. His forerunner in the academic literature was Kenneth Boulding, who claimed that the maintenance of human life on Earth requires a circular model of the economy. With this perspective, it is understood that the biosphere is a closed system, while there is a limit to its ability to provide and regenerate resources to meet human needs. This concept arises in contrast to the linear economy model of production and consumption, in which there is a high extraction of raw materials, intensive use of energy and excessive generation of waste, which constitute a risk to human health and ecosystems. From this perspective, the planet is seen as an infinite means of supplying resources and each of its phases contributes to the emission of pollutants. The negative externalities of this productive model have had an impact on the degradation of the planet and have increased the inequality and vulnerability of the most marginalized populations The report Limits to Growth warns for the first time about the consequences of the ecological footprint associated with economic processes and about the carrying capacity of the planet to regenerate. However, the authors claim that it is possible to change this trend by achieving a balance of ecological and economic processes, without affecting the principle that each person can meet their material needs and ensure their individual well-being. In the seventies, the concept of circular economy gained relevance among environmental ecologists, among which Nico-las Georgescu-Roegan, Herman E. Daly, Crawford Stanley Holling, Christian Leipert, Howard T. Odum and José Manuel Naredo stand out. Through their approaches, these theorists promoted the idea that the waste stream can be reintegrated through closed production cycles (closed circuits) to prevent further extraction and reduce the amount of materials discarded. Later, in the early nineties, David W. Pearce and Kerry Turner explained the interdependencies between the ecological and economic system based on four functions of the environment: services, provision of resources, landfill of waste and emissions and life support system (1993). Generally speaking, the circular economy involves three fundamental principles (Figure 1). Water is one of the most valuable and vital resources of the environment, it follows a natural circular model that regulates the flow of water and ensures its quality. However, as proposed in human-managed systems, they follow a linear model of economic growth, where water qualitatively degrades after use, becoming unsuitable for later use by both humans and ecosystems. The stages of a linear system have reached their limits, where the depletion of a number of natural resources and fossil fuels has been demonstrated, from this point, the Circular Economy must begin to be understood as the intersection of environmental and economic issues that allows the global industry in terms of water resources to obtain water supplies, sustainable and quality for the future, proposes a new model of society that uses and optimizes stocks and flows of materials, energy and waste, and whose main objective is the efficiency of the use of resources. According to , the circular economy is a system where the focus is on the efficient use of resources through the minimization of waste, the retention of long-term value, the reduction of primary resources and closed circuits of products, portions of products and materials within the limits of environmental protection and socio-economic benefits, have the potential to lead to sustainable development and energy efficiency, as in the studies proposed by .(Tsalidis et al., 2022)(from Bridges et al., 2022)(Tsalidis et al., 2022)(Hafsi et al., 2022)(Petterson et al., 2022)(Torres-Guevara et al., 2021)(Healthy et al., 2021)(Díaz-López et al., 2021)(Hernández et al., 2021; Moreno Rocha et al., 2022).

Today, many countries are facing a water security crisis, understood as "the availability of an acceptable quantity and quality of water for health, life, ecosystems and production, along with an acceptable level of water-related risks to people, the environment and the economy". Among the issues that affect water security, it is important to highlight: The increase in the demand for basic products associated with changes in consumption patterns (greater number of inhabitants, greater energy expenditure, increase in waste generation, pollution, etc.). Supply failures (a greater number of inhabitants requires a greater infrastructure adequate to that growth). Risks due to extreme hydrological events (due to the absence of adequate contingency protocols).(Arteaga et al., 2019)(Diaz-Perez et al., 2021)

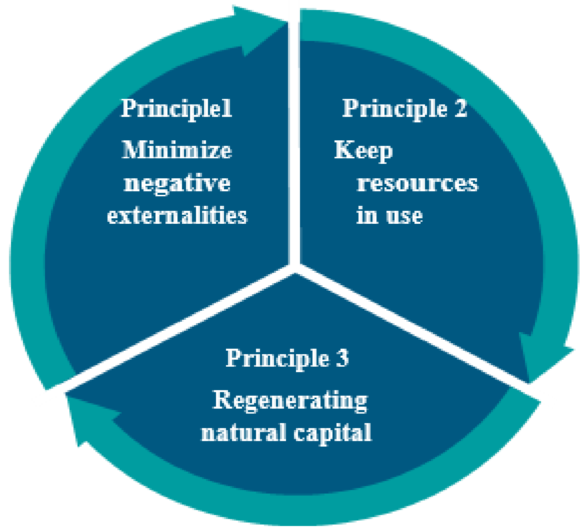


Figure 1: Principles of the circular economy

According to , the circular economy in favor of water would generate an offer of innovative products and technologies, as well as the adoption of effective collaboration models for the integration of water reuse, where norms, criteria and standards related to control and quality are established, reaching the consequent emergency of "new water". After the use of water, a new treatment is carried out, in which the complementary treatment units are organized in cyclical processes, capable of promoting the reuse of water or the new water market, to combat its scarcity. In this way, the introduction of reused water in the current consumption model makes it possible to transform the management of water resources from a linear model to a circular model.(Cervera et al., 2016a)(Cervera et al., 2016b).

The World Bank (2020) conducted the Wastewater report between 2019 and 2020; from waste to resources, in which he addresses the main challenges, opportunities and case studies in Latin America on circular economy. The study highlights the value of wastewater as a source of energy and nutrients, as well as an additional source of water, considering that many countries in the region will face crises of economic water scarcity in the medium term. This implies that, despite the high availability of water resources today, the infrastructure will not be sufficient to meet the growing demand.(Majchrowska et al., 2022)(Cervera et al., 2016c)

Circular economy and water resources

A linear management of water resources contributes to the inefficient and wasteful use of water, increases the use of matter and energy in the phases of water supply among users, increases vulnerability and social inequality in the face of scarcity and affects the degradation of aquatic ecosystems, among many other problems The effects of the linear model on water resources make it necessary to generate technological and management alternatives. The circular model around water resources is presented as a solution that involves the application of sociotechnical tools for the integral solution of these problems(Ahmed et al., 2022)(Mangmeechai, 2022)

The circular economy is proposed as an alternative model of water management, non-obsessive, its implementation depends on institutional support, financial investment for technological innovation, cooperation between key actors and sectors, and the profound socio-cultural transformations around water resources.(Dräger et al., 2022). Water is a critical resource that, while it can be considered a renewable good, is vulnerable to pressures caused by societies. Based on the circular economy perspective, it is necessary to design a closed-loop water management system to meet human needs without compromising the resilience of water-related ecosystems According to Ellen MacArthur FOundation, the principles of the circular economy can be implemented in the management of water systems (Table 1).(Mohammed et al., 2022; Uribe-Toril et al., 2022; Vyhmeister et al., 2017)(Padmanabhan et al., 2022)(Sileryte et al., 2022)

One of the main problems that can be addressed from the Circular Economy in the management of water resources is associated with the conditions of quality, governance, availability of the resource and its different types. For the integral solution of these problems, it is necessary to generate technological and management alternatives, whose objective is to close the resource loops and extend their useful life through greater use, reuse and remanufacturing. From the perspective of the Circular Economy, water reuse is a winning option, the complete wastewater management cycle is a critical component from source to distribution, collection (sewage and sanitation systems (in (Raza et al., 2022)(Pereira & Vence, 2021)(Rödl et al., 2022).

situ) and treatment for disposal and reuse, including the recovery of water, nutrients and energy.(Lambré et al., 2022).

Taking into account the above, it can be concluded that the circular economy linked to the water and sanitation sector has been having a great research interest under the sustainability approach, its incorporation into the sectoral policy seeks the optimal use of resources (water, energy and nutrients) reducing the impacts on the environment. The processes related to the management of the socioeconomic component and the management of water have a relevant impact on the applicability of the mechanisms of participation and governance of this resource, generating business opportunities that give financial sustainability to the services.(Uribe-Toril et al., 2022)(Yamaka et al., 2022).

Table 1: Circular economy principles applied to water management systems. ((Chen, 2022))

Principle 1. Minimize negative externalities	Reduce the amount of energy, minerals and chemicals in the operation of water systems relative to other systems.
	Optimize the consumptive use of water within sub-basins in relation to other sub-basins.
	Implement measures that produce the same result without using water.
Principle 2. Keep resources in use	Improve the management of reserves of different resources (use and reuse of water, energy, minerals and chemicals) within water systems.
	Decrease energy use and resource extraction in water systems and maximize their reuse.
	Optimize the value generated in the interfaces between water service providers and other production systems.
Principle 3. Regeneration o natural capital	Maximize environmental flows by reducing consumptive and non-consumptive uses of water.
	Preserve and improve natural capital (restoration, pollution prevention, effluent quality, among others).
	Ensure minimal disturbance of natural aquatic systems.

Table 2: Application of circular economy approaches around water resources. Own elaboration.

School	Applications	Success stories
Industrial Ecolog	• Wastewater exchange between different sectors for industria use. • Gives a new use to wastewater • Creation of eco-industrial parks to promote synergies between organizations.	- Hai Hua Group (China) Gujarat Maritime Board (India)
Cradle to cradle	• Reuse of wastewater and its by-products to produce goods and services. • Prevention of pollution of water bodies (sources receiving wastewater).	Las Vegas Rock (USA) Ecover (Belgium) Meuse (Netherlands)
Performance economics	• Reduction of the water footprint of industries through the efficient use of water and energy. • Water as a resource to generate goods and energy.	Suez Group (France) HyrdoQuebec (Canada) DuPont (USA) Grundfos (Denmark)
Biomimética	• Technologies and biotechnologies for water treatment. • Clean energy production. • Restoration and conservation of aquatic ecosystems.	WhalePower Corporation (Canada) Aquaporin Inside (Denmark) Applie Biomimetics (USA)
Blue Economy	• Innovation to reduce water consumption in the production o new goods. • Prevention of degradation and restoration of marine ecosystems, using waste for the production of new goods. • Generation of sustainable development around coastal regions.	Aquion emergí (USA) The Blue Circular Economy (European Union) Adidas + Parley (Alemania-EUA) Qingdao Blue Silicon Valley (China

Experimental section

To identify trends and changes in research, a technique called bibliometric analysis is used to determine different patterns related to institutions, topics, countries, and fields, among others. In addition, academic research focused on a specific topic can be quantified over time. The technique consists(Vence & López Pérez, 2021) of the development of a statistical analysis that involves variables such as authors, distribution of journals, keywords and references. For this, certain tools such as Network WorkBench, VOSviewer, HistCite and CiteSpace are available.(Prieto-Sandoval et al., 2021).

In the present work, the HistCite tool was used to perform the statistical analysis, since it has excellent visualization capabilities and is an open access software(Hall et al., n.a.). In addition, this tool is directly focused on the study of trends related to scientific research. For the data collection used in the bibliometric analysis, the Web of Science website was used, since it is one of the main databases used in this type of studies.(Serrano et al., 2020)

The collected data was downloaded from the Web of Science on November 22, 2021, ora scientometric analysis of scientific articles indexed in the Scopus database (Elsevier, B. V., 2021), with the aim of identifying the thematic lines of research of the authors. The following search equation was structured: (TITLE-ABS-KEY ("Circular Economy") AND TITLE-ABS-KEY ("Wastewater Treatment*" OR "Water Treatment*" OR "Water Reuse" OR "Waste Water Recycling" OR "Water Quality" OR "Water Resource*") AND PUBYEAR > 2009 Y (LIMIT-TO (DOCTYPE , "ar") Y (LIMIT-TO (SUBJAREA , "ENVI")). the specialized text mining program VantagePoint (Search Technology, Academic Version 12.0) was used.

Results and discussions

According to the search equation presented above, 425 articles indexed in the Scopus database were identified that relate to "circular economy", "wastewater treatment", "water resources" and "water quality", referring to studies in different fields of knowledge, such as environmental sciences are the ones with the highest activity with 43%, while the area of energy and engineering show a very similar interest of approximately 12% each, (Figure 2).

Using the Law of Solla Prices (ec. 1) (De Solla Price, 1963), the annual growth rate of works related to this topic published from 2010 to 2021 was calculated. According to equation 1, this index was 83.09% with a data correlation of $R2 = 0.974$.

Figure 2: Distribution of articles by areas of knowledge related to the application of the circular economy of water resources.

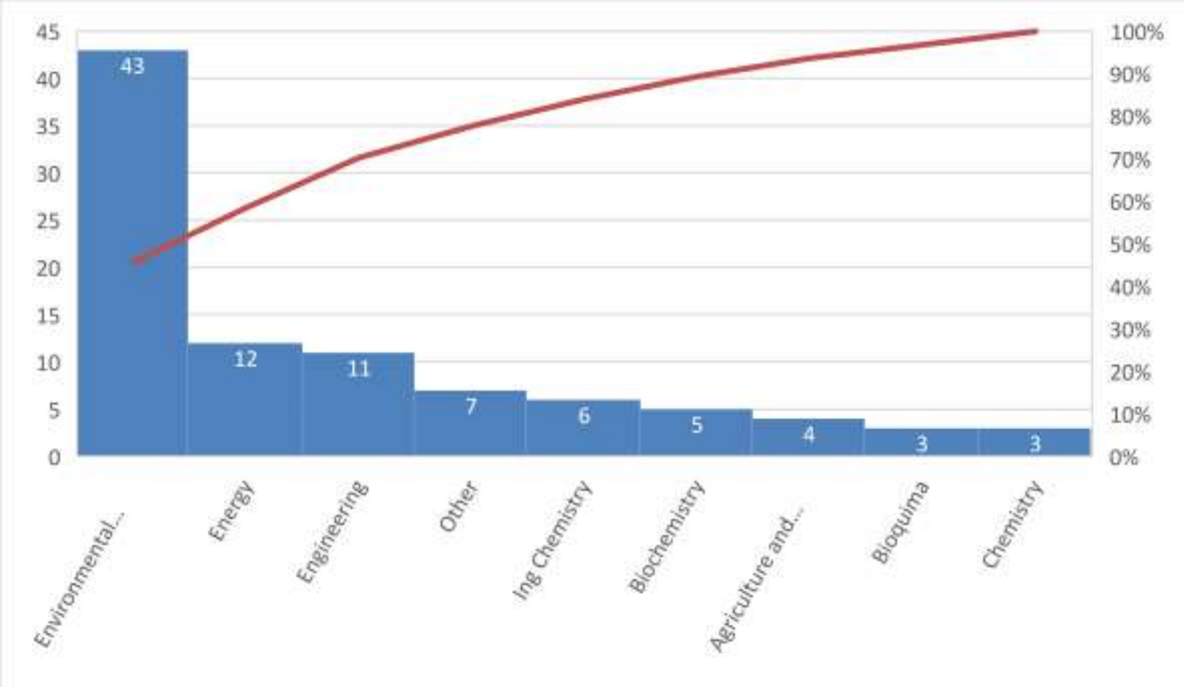
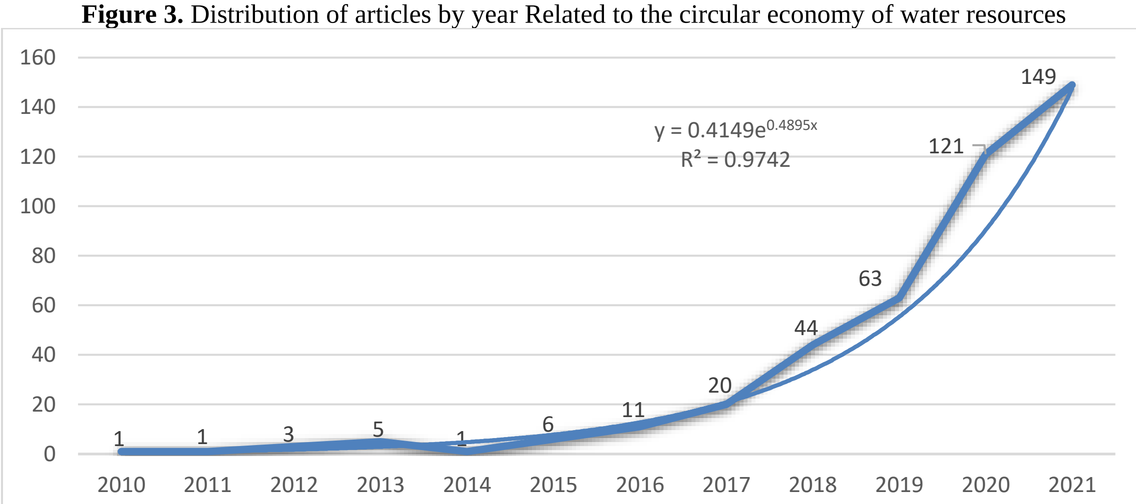


Figure 3 Presents the scientific dynamics (number of articles per year) during the period 2010 – 2021. An increasing trend is observed from the year 2015, the year of greatest activity is 2021 with 149 indexed documents.

Figure 3. Distribution of articles by year Related to the circular economy of water resources



Note. Source: Bibliometrics Unit- CRAI Santo Tomás University Library, Bucaramanga Sectional. Calculations based on information from the Elsevier database (Scopus B.V., 2021), processed with VantagePoint (Search Technology, academic version 12.0).

Ec. 1: $$R = 100\left(e^{b} - 1\right)$$

The performance and scientific output of a country, institution or research centre are directly related to the number of articles published per year (Figure 4). In terms of distribution by country at an international level, Spain stands out with 74 publications related to the circular economy of the water sector. On the other hand, China and Italy present 56 documents indexed in the database, according to the search equation used. At the Latin American level, the country that stands out is Brazil with 21 publications, while these works are related to sludge mixtures from water treatment plants for energy recovery, in these works circular economy indicators were designed as instruments for the evaluation of sustainability and efficiency in wastewater.

The co-occurrence analysis of the keywords allowed to determine the preference in the topic of interest, in this case, the circular economy in the water sector. The free program Vosviewer (2021, Center for Science and

Figure 4: Distribution of scientific production by country between 2010 and 2021 related to the circular economy of water resources

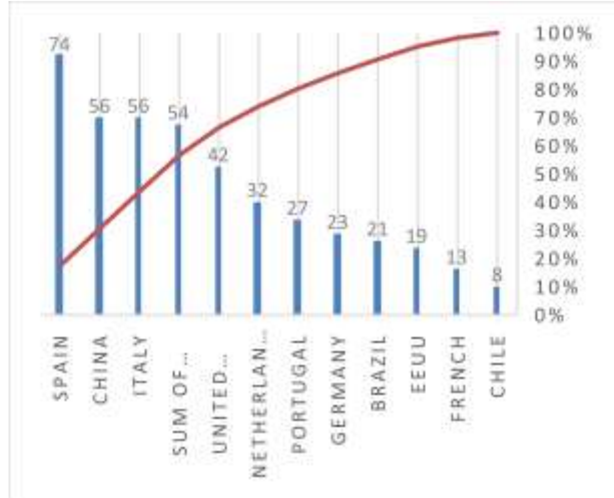
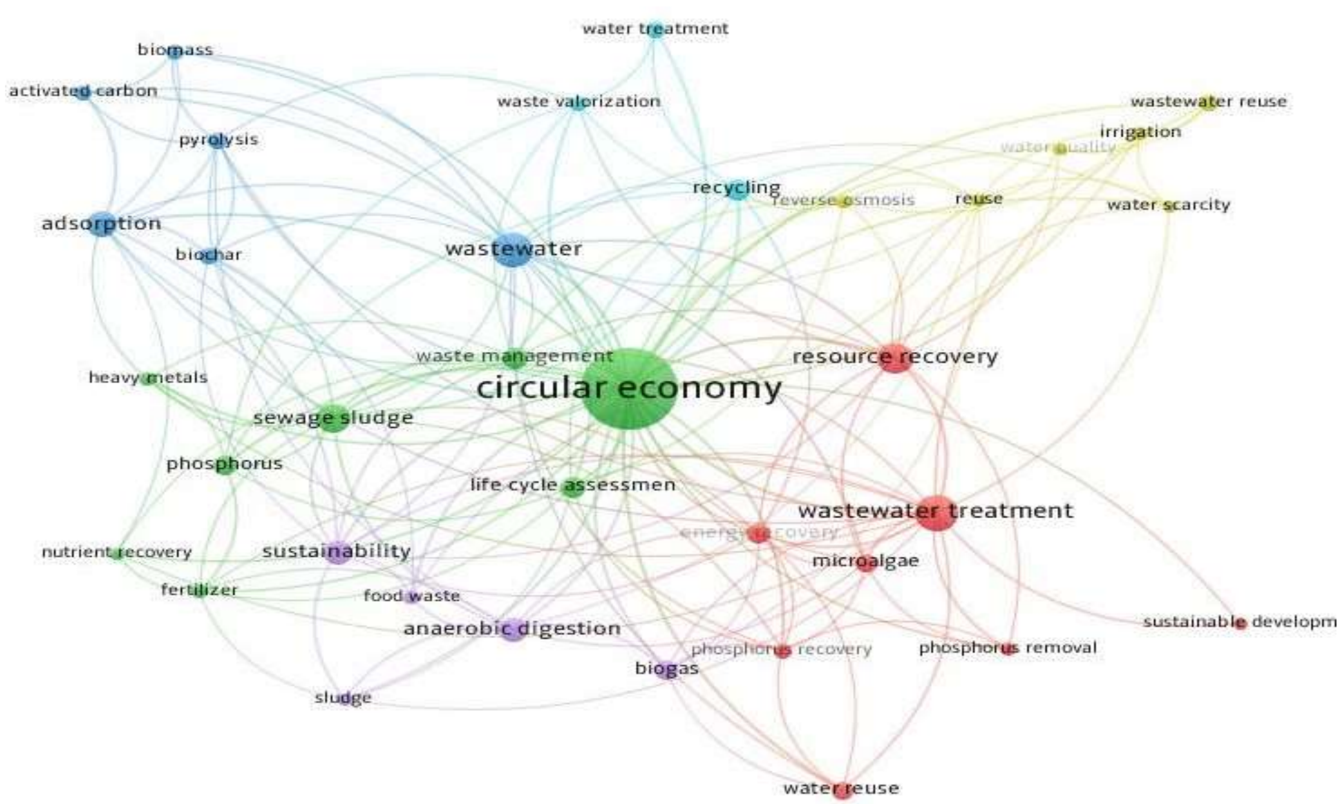


Figure 5: Keywords most used by authors related to the circular economy of water resources



Technology Studies, Leiden University, The Netherlands, version 1.6.15), was used to visualize each of the relationships presented by the keywords (Figure 5). A cluster of words shows an interdisciplinary work and all the topics studied are, for example, development and evaluation of wastewater treatments (235 records), among which reverse osmosis stands out, bioremediation methods for the recovery of water contaminated with heavy metals, pesticides, agrochemicals, among others. 222 documents are associated with the concept of circular economy, especially the recovery of resources such as energy, nutrients among others and a last group (52 documents) are aimed at the management of environmental sciences and sustainable development.

Conclusion

According to the search equation proposed for this work and the number of records obtained, it can be observed that the concept of circular economy applied to water resources is relatively new. However, it presents a high interest, which is verified through Price's law that shows a growth in the number of publications of 83.09% during the period 2010 – 2021, especially in Spain and China, countries where researchers develop work on wastewater treatment methods, the use of resources and the recovery of waste recovered from these same waters. To address water circularity, fundamental changes are needed in the way water is managed and valued, one of the current barriers to truly integrating water. The circular economy of water resources in processes is the lack of indicators, parameters and governance, tools that allow achieving the objective of sustainability by providing economic, environmental and social development. The deployment of a circular economy does not depend solely on cities, it also depends on national policies, private sector participation and a favourable innovation ecosystem. Test the permanent selectivity of ion exchange membranes that is under research consideration.

The linear economy model is not compatible with the sustainable management of natural resources, especially water resources. The principles of the circular economy propose a series of transformations and improvements to reduce pressures on water resources derived from the production, consumption and disposal of goods and services. In addition, it offers the opportunity to improve water management systems and generates development opportunities that have a positive impact on society and ecosystems. The implementation of these principles requires collaboration between producers and consumers, as well as public policies that guarantee the efficient use of materials and energy. It is expected that this work will be of great contribution to future research, which will motivate more scientists from different countries to see in the circular economy a powerful tool in the care and preservation of different energy sources.

Declaration of concurrent interest

The authors state that they have no known competitive financial or personal interest that could have seemed to influence the work re-performed in this article.

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