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Systematic Review

Review of Water Reuse from a Circular Economy Perspective

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Abstract: In the last three decades, water shortages have become more common and have left an increasing and significant mark on the world economy. The lack of water in arid and semi-arid regions, along with the interest in water security in areas where the demand for water exceeds its availability, has caused water reuse to be considered as an alternative source in these areas and has prompted the authorities to change from the usual linear, take–make–use management approach to the circular management of resource preservation. This new approach to sustainable management, using the management of reduction, reuse, recycling, and recovery, is called the circular economy (CE). However, although the potential for the reuse of treated wastewater is still insipient, CE in the water sector has gained a lot of attention lately. The aim of this paper is to systematically examine existing research published in the last five years on CE implementation in the water and wastewater sector. A sample of 64 articles was found through interactive keyword selection. Using the dynamic reading technique, data were extracted, and articles were classified according to five research motivations, which include, political, economic, legal, institutional, technical, and environmental. Most publications were from institutions in Europe, followed by North America and Asia. A similar trend was observed in terms of the distribution by authors, countries, and regions.

Keywords: circular economy; reuse; wastewater; water-scarce countries

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1. Introduction

In addition to water being vital for life on earth, it plays a central role in almost every sector of the economy. However, water resources are under increasing pressure due to industrialization [1]. According to the International Resource Panel (IRP), due to rapid urban growth, the world's population residing in urban areas will grow by 23% by 2050 [2,3], and this growth will result in increased demand on available water resources. The gap between demand and supply is exacerbated in large part due to prolonged droughts and climate change [4]. Agriculture continues to be the activity that exerts the greatest pressure on freshwater resources, reaching values as high as 90% in some developing countries [5].

Industries in Europe account for 57% of global water consumption, while in Asia, this figure is 10%. According to the World Economic Forum, water scarcity is one of the major global risks [6], and if there are no changes in the way water is managed, it is estimated that by 2030, there will be a 40% shortfall in the world's water supply. The concern of water scarcity affects not only the regions historically known as arid [7] but also regions where demand is greater than availability. In accordance with UNESCO, 4 billion people are affected by water shortages for at least one month annually [5].

For many, the most reliable solutions to the gap between water availability and demand are desalination technologies [8]; nevertheless, when widely used, desalination is seen as an expensive solution with harmful impacts on the environment [9] and its use does not solve problems related to wastewater management. Furthermore, it should be emphasized that the goals of the 2030 Agenda for Sustainable Development will only be achieved if

the environmental and social issues of wastewater reuse are adequately addressed [5]. In most developing countries, wastewater is discharged without proper treatment, causing damage to the environment. Therefore, it is not surprising that there is a consensus around the importance of wastewater reuse, as it provides important environmental gains such as resilience and reduced energy consumption in water production [10].

However, it is important to emphasize that the growth in wastewater reuse does not yet reflect the dimension of its potential, since only a small percentage of wastewater is still regenerated. China and the United States of America are the countries with the largest growth in reuse capacity [5].

It is also important to emphasize that many of the existing initiatives associated with the circular economy (CE) model are not advancing because of a lack of user acceptance and inadequacies in existing regulations and laws [11].

The aim of this paper is to systematically examine the existing research published in the last five years on CE implementation globally and to describe the motivating factors for research as they relate to the implementation of a circular economy in the water and wastewater sector. Given the level of heterogeneity of research in this sector, it will be useful to bring the studies together to better understand when, what, and where articles have been published, and which results are most relevant for decision-making. Section 2 presents the main research characteristics that appear in the literature; Section 3 presents the data produced by systematic, semantic, and narrative analysis; and Section 4 identifies the issues addressed by the studies reviewed. Finally, section five provides some concluding remarks.

Circular Economy

Pearce and Turner pioneered the introduction of the concept of circular economy in environmental and natural resource economics [12]. In 2010, the Ellen MacArthur Foundation made a major contribution to the evolution of CE practice in various sectors [13] Despite the extensive work performed within the scope of the concept CE in many countries and in different sectors, the supervision of the strategies to implement CE is still not very clear [12]. According to Saidani et al. [14], there is no agreement on how to evaluate the materialization of CE in practice and on a large scale.

According to Sekulić et al. [15], the requirements for implementing a CE in a developing country make it a slow, complex, challenging, and intangible process in many cases. In an attempt to understand and agree on a definition of the circular economy, Geissdoerfer et al., 2017 [16], conducted a study in which they compiled the various existing definitions. They proposed a definition that they felt was the most comprehensive: "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" [17]. A CE allows the interaction between markets, customers, and natural resources to be made in a sustainable way, with greater efficiency in water use, combined with permanent incentives for increased resilience in water availability. Nevertheless, there are aspects of CE yet to be achieved, such as improving the negative public perception, as well as technological and regulatory limitations that still exist [12]

The documents that exist on CE demonstrate a deficit in issues related to the water sector, the advantages related to the potential of CE, and the legal framework. To fill this gap, a review of CE in the water and wastewater sector is of utmost importance [12]

In the opinion of Del Borghi et al. [18] the changes in CE from a theoretical perspective to a more practical framework remain a challenge [16]. It is advisable that the entities that manage the water supply always strive for the management of their resources towards CE, thus eliminating waste through recycling and intentional reuse of secondary waste [19].

2. Research Methods and Data

This review followed the standard principles normally used in a systematic review and meta-analysis (PRISMA) process [20]. PRISMA focuses on ways authors can ensure transparency in the reporting of systematic reviews and meta-analyses [20]. According to Paula et al. [21] and Lima et al. [22], the progressive selection of articles follows four stages: planning, collection, treatment, and data analysis. In the first stage, the objectives and keywords are defined. In the second stage, a search engine is selected, always considering the rapid updating of search tools. Stage 3 includes searching for articles with continuous adjustment of the keywords and other available filters, and finally, stage 4 is the visual analysis of the search results, where we try to identify errors and duplication of the results. The documents were obtained from web-hosted search engines such as Google Scholar and Scopus. The search terms were related to the Boolean operators "OR" and "AND", employing the following search criteria: Circular AND Economy AND wastewater OR sanitation OR sewage OR wastewater OR reuse OR reclamation.

The designation of water reuse varies depending on the study. Technically, the understanding of regenerated water is treated wastewater ready for safe use [23]

We found that many authors in their writings do not differentiate between the terms "recycled", "reclaimed", and "reused". In our case, although in this paper, search terms such as "reclaimed water" and "water recycling" were used, we decided to use the terminology "water reuse" generally, referring to the different ways of recycling water.

The design of the literature review (Figure 1) contains three forms of search, (a) grey literature information, (b) custom search tools, and (c) web features, in order to minimize the possibility of excluding documents relevant to our research.

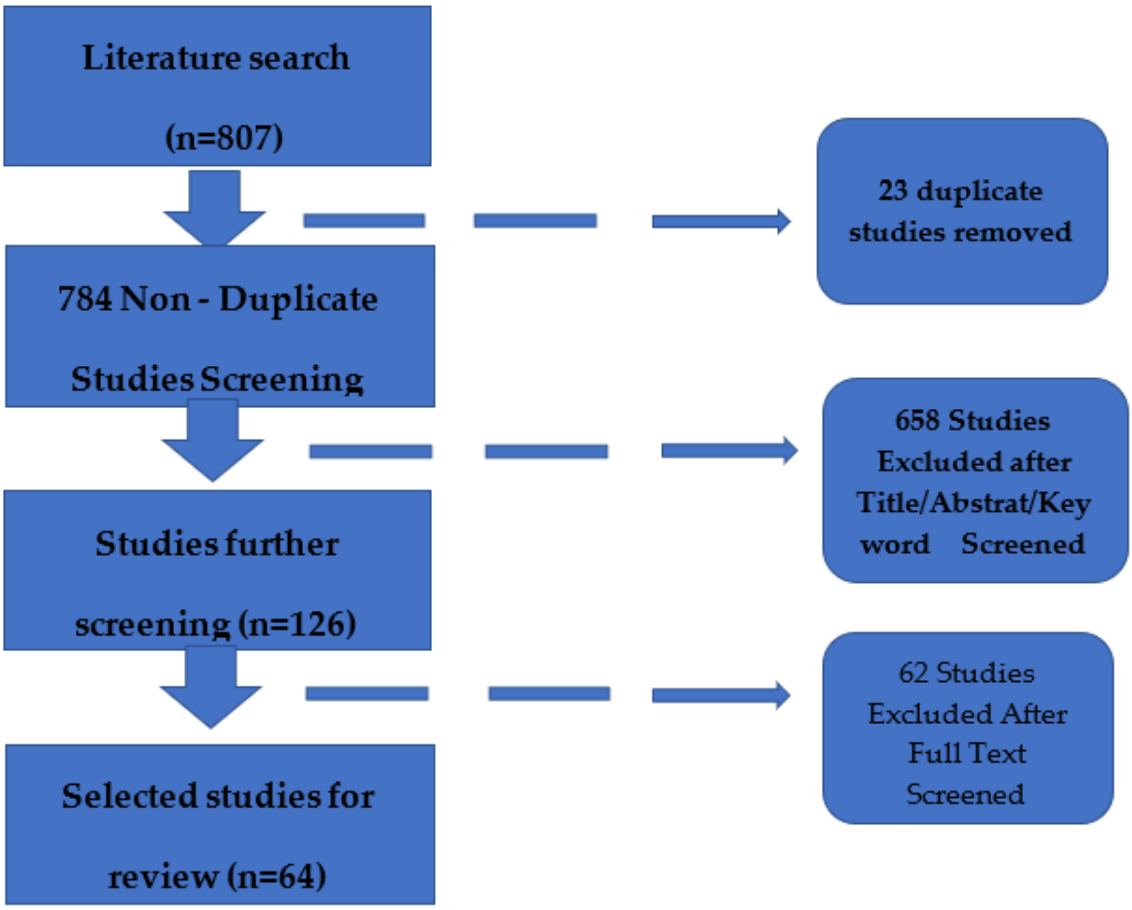

Figure 1. The PRISMA flowchart used in this review.

Initially, 807 studies were generated from the three data platforms used and then refined by excluding repeated documents and by applying filters such as titles, year, type of document, and phase of publication, thematic area, and abstract, which resulted in 126 selected documents, and after full-text scrutiny, 64 studies were obtained and served as the basis for this review. We used research methods based primarily on quantitative systematic review and narrative analysis [9]. While the quantitative systematic review analyzed aspects such as distribution of publications by region and time, the number of publications per journal and author, type of document, and thematic areas, while the narrative analysis analyzed the main motivations behind the 64 selected articles.

3. Results

3.1. Systematic Quantitative Review

3.1.1. Publications by Regions and Time

The analysis of the literature review indicates the timeliness and relevance of the theme (Figure 2) and allows visualization that the theme of this research was boosted from 2020, since the number of publications increased from 11 in 2020 to 15 in 2021 and 11 in 2022. Considering the incomplete data from 2022 (up to July 2022), 66% of the research was conducted from 2020 to 2022; this suggests a growing interest by the scientific community in the adoption of CE in the scope of wastewater management.

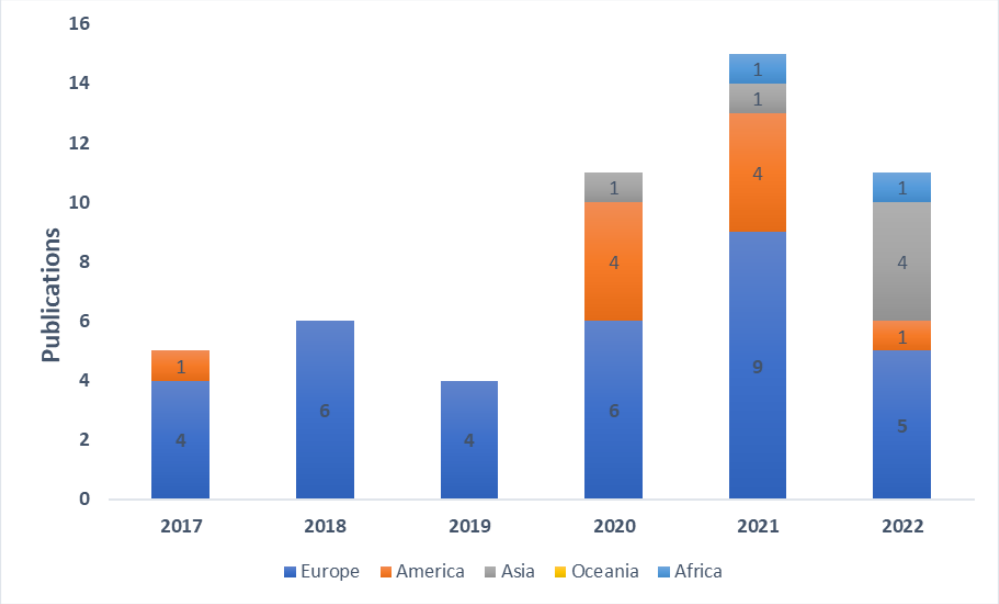

Figure 2. The number of studies analyzed by year and region. Source: Prepared by the authors.

The European continent accounts for 64% of the publications, with Italy (9) and Spain (7) having the most publications.

It is important to mention that when the studies are characterized by region and the period considered (2017–2022), the largest numbers of publications are in European countries, which demonstrates a deficit of studies in countries with water scarcity, highlighting the need for further research, as a mechanism to disseminate and promote the adoption of CE in the water sanitation service (WWS).

3.1.2. Number of Publications by Journal and Author

As shown in Table 1, of the 64 articles reviewed, 10 were published in the journal *Water*, making it the leading journal in CE research in the water sector. The most productive authors are Fabio Masi, Marzena Smol, Oliver Maaß, and Águeda Bellver-Domingo (Table 2).

Table 1. Leading journals.

Journal	Number of Studies
Water	10
Journal of Environmental Management	5
Sustainability Switzerland	3
Journal of Cleaner Production	3
Current Opinion in Environmental Science & Health	3
Others	22
Total number of journals out of 64 Studies	

Table 2. Leading authors in terms of number of publications.

Authors	Number of Studies
Masi, F	3
Smol, M	3
Bellver-Domingo, Á	3
Maaß, O.	3
Collivignarelli, M	2
Others	34
Total number of authors out of 44 Studies	

3.1.3. Document Type

According to Figure 3, it can be observed that of the 64 documents reviewed, 79.5% are articles, 16.0% are book chapters, and 4.5% are conference papers.

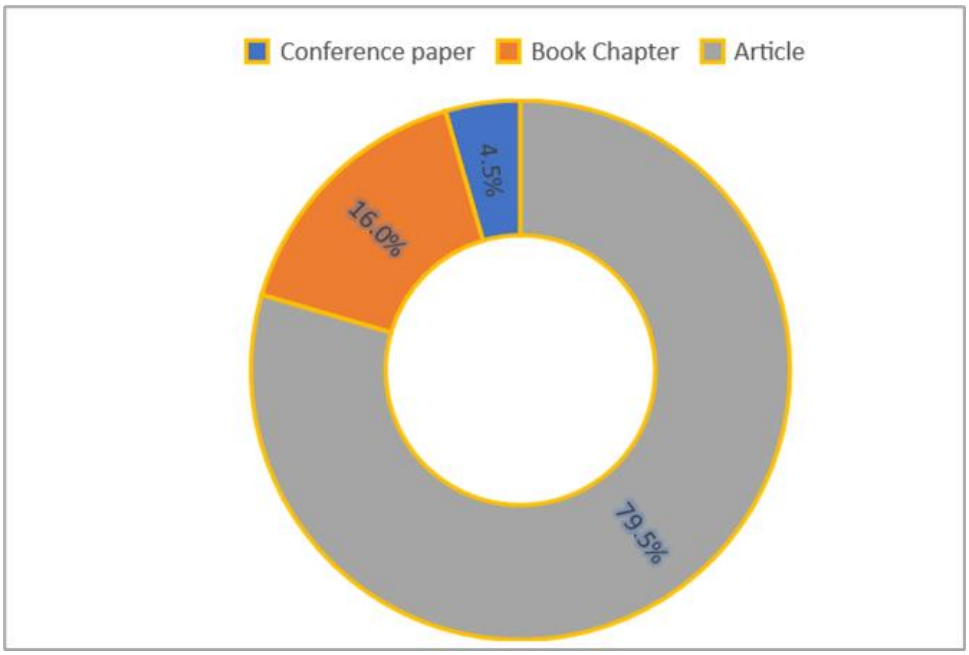

Figure 3. Distribution of data by document type.

3.1.4. Subject Areas

The subject areas in these articles come directly from Scopus. The 64 papers reviewed were related to 10 subject areas (Figure 4). The top two subject areas were Environment Science and Engineering, with 38.3% and 17.0%, respectively. Energy was ranked third, with 15.6%. This is acceptable, considering that CE always involves environmental issues.

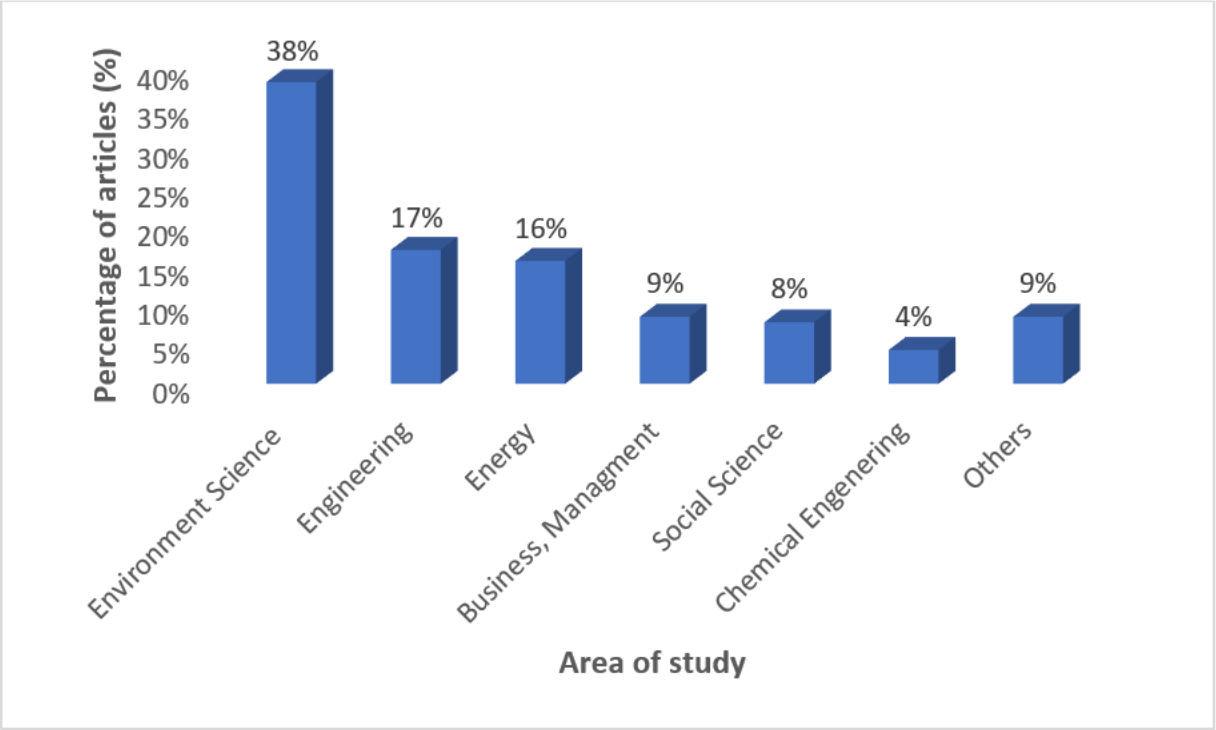

Figure 4. Distribution of data by area of study.

3.2. Narrative Analysis

From the study sample, it is possible to categorize five research motivations—Political, Economic, Legal and Institutional, Technological, and Environmental—which are shown in Table 3 and discussed below.

Table 3. Total documents per research motivation.

Reseach Motivations	Papers	Total
Economic	Colella et al. [3], Kakwani et al. [12], Saidani et al. [14], Hagenvoort et al. [19], Lima et al [22], Chen et al. [23], Rogers et al. [24], Vij et al. [25], Giakoumis et al. [26], Dzidic et al. [27], Hartley et al. [28], Sgroi et al. [29], Bellver-Domingo et al. [30], Watari et al. [31], Berbel et al. [33], Grundmann et al. [35], Stoller et al. [36], Shuo Chan et al. [37], Collivignarelli et al. [38], Rodríguez-Villanueva et al. [39].	20
Technological	Hagenvoort et al. [19], Stoller et al. [36], Shuo Chan et al. [37], Rodríguez-Villanueva et al. [39], Bichai et al. [40], Ishii et al. [41], Lane et al [42], and others	23
Legal and institutional factors	Lima et al [22], Lane et al. [42], Al-Saidi et al. [45], Watson et al. [46], Martínez-Fernández et al. [48], van Zyl et al. [50] . . .	6
Political	Saidani et al. [14], Rogers et al. [24], Vij et al. [25], Giakoumis et al. [26], Dzidic et al. [27], Hartley et al. [28], Sgroi et al. [29].	7
Environmental	Chen et al. [23], Kunz et al. [51], Sridhar et al. [52], Asano et al. [53], Tortajada et al. [54], Smol et al. [55], Maaß et al. [56], Jodar-Abellan et al. [57].	8

3.3. Political Motivation

One of the crucial factors to promote a shift from a linear to a circular economy is the political will and sensitivity of decision-makers, given that it is impossible to change the status quo without changing the legal framework that will allow leveraging the necessary changes, while keeping in mind the political gains achieved in recent decades in the water sector [24]. There are different planning policies, and it is necessary to analyze, for each system, what levels of water reuse planning can be implemented. For integration at the

regional and municipal levels, it is particularly important to implement holistic approaches and thus integrate sources of water reuse and possible application areas [25]. In most countries, these approaches do not exist. The countries of the European Union believe that to drive a shift towards an efficient and climate-neutral economy, this transition must be supported by specific wastewater reuse policies. For Iberian countries, the European water policy is still seen as a tool for progress to overcome the inertia of the hydraulic paradigm, while in the case of Australia, what was particularly decisive for an increase in wastewater reuse was the involvement of all stakeholders in the process of developing incentive policies for wastewater reuse [24,26]. In the case of the United States, the "California Recycled Water Policy" played a decisive role in the development of the water recycling process in California, despite its deficiency with regard to the policies that encourage the change to a CE [24,27,28]. There is a consensus among the various authors that, to boost the progress of wastewater reuse projects, it is essential to have a clear public policy for the sector.

To be effective, this policy needs to be framed within a legal and institutional framework to create a receptive environment for investment in wastewater reuse. For this to happen, it is imperative that there is political, regulatory, and legislative support in several key sectors, such as health, agriculture, and energy [14,29].

3.4. Economic Motivation

Economic motivation is the third most common topic in the sample, addressed in 31% of the selected articles. From a CE perspective, wastewater reuse is a good investment [30] The basic principles of CE aim to avoid waste and increase the validity of resources [31] Water reuse is only feasible for a given region when the price to pay for reuse is lower than the price to pay for other forms of water management [32]. In Portugal, as in Spain, there are taxes and fees associated with different types of water use [33], and in the United Arab Emirates, price discounts and tax incentives are used to encourage water reuse, whereas in Germany, the municipal water reuse project depends on subsidies [34,35]. However, according to Maaß et al. [19], the economic sustainability of wastewater reuse is very sensitive to regulation, especially when the regulation is very demanding with regard to end-user protection.

3.5. Technological Motivation

According to Harris et al., technological developments are opening up new avenues to facilitate CE through resource recovery from industrial wastewater, directly impacting the quality of the regenerated waters, which is largely dependent on the development of wastewater recovery technology [36,37]. Stoller et al. believe that achieving CE with membrane technology is therefore not a simple task and requires an appropriate design and process. According to existing studies, modern wastewater treatment technologies will always have a say in aspects related to the cost and quality of the regenerated water, thus influencing the choice of treatment system by the management entities. It is noteworthy that technologies such as reverse osmosis and light ultraviolet [38,39], have played a major role in the quality of the final product, extending the purpose of its use [40,41]. Legal and Institutional Factors

Existing studies on the change from a linear economy to a CE indicate that it is a very complex and time-consuming process, and these obstacles jeopardize the sustainability of wastewater-treatment plants (WWTPs) [11]. The gains made so far regarding the need to focus on wastewater reuse are largely due to the evolution of legal and institutional concepts related to aspects of water law and water quality [42,43]. In the case of California, in order to continue to operate legally, the wastewater treatment plants had to adapt to the regulatory standards imposed by the Department of Public Health regarding the discharge of wastewater [44,45]. In the case of Sydney, there have been government guidelines for increased use of regenerated water in the city's green spaces and also on golf courses [46]. There are indications that wastewater reuse can also be promoted through increased institutional collaboration between the managing entities for water and sanitation

services [47,48]. Existing studies have also shown that forms of water governance can also influence the promotion of wastewater reuse, i.e., the more centralized water management is, the more likely wastewater reuse projects are to materialize, as it happens in most cities in Australia, where water is managed by state-owned companies [49,50].

3.6. Environmental Factors

For many regions, water scarcity is a decisive element for reuse to be considered as an alternative to conventional water sources [51]. In countries considered to be water-stressed, regenerated water can be considered a credible source in the medium and long term, taking into account the role that the water and sanitation sector plays in public health and the economic development of a country [52,53].The issue of regulating the supply of reclaimed water to the population remains a grey area in the water and sanitation sector, as many of the aspects related to the impact of reclaimed water on the environment and its marketing to the end consumer remain unregulated [54,55]. In addition to the issue of the economic and environmental gains of wastewater reuse, it is necessary to emphasize aspects related to the appropriate governance of regenerated wastewater [56]. As one of the pioneers in the circular economy in wastewater reuse, Singapore opted for a closed reuse system very early on, where the regenerated water is used directly for industrial purposes and indirectly for human consumption. It must be stressed, however, that all this is possible if there is a well-structured legal framework that takes public health and environmental protection into consideration [57].

4. Conclusions

The purpose of this study was to carry out a systematic review of the CE in the water and wastewater sector. It is clear that even though there are countries with wide experience in the area of CE in the water and wastewater sector, its implementation is insipient, and there is a lack of understanding concerning the need to work on consensual indicators to facilitate its application in a more comprehensive way. The Scopus and Google Scholar tools were used giving the best conditions for data analysis. We affirmed that most of the articles were published in Europe, followed by America and Asia. Five global motivations were identified, three of which were Economic, Technological, and Environmental, which were present in 78.1% of the publications in the study sample, demonstrating a common concern about the application of CE to wastewater reuse.

Throughout this review, it became evident that the transition to CE in the water sector is a priority for most countries, despite the challenges that this entails, particularly in economic, political, and environmental terms. In terms of the limitations of this review, we highlight the scarcity of studies portraying the CE from the perspective of wastewater reuse. Given that we restricted our search to Scopus and Google Scholar, using other databases could have altered the current result. Moreover, since this subject is a very current theme undergoing constant development and considering that the date limit of our search was July 2022, articles with important contributions to this subject matter could have been excluded. In addition, we must highlight the fact that the wastewater was discussed as a whole, when it is known that there are several types of wastewaters and that the level of treatment differs from one type to another. Furthermore, there is a need for further analysis of the barriers still existing in society regarding the reuse of wastewater, and finally, there is a deficit of publications from countries with water-scarcity problems, highlighting the need for studies to be conducted in these countries. A future review on this subject should consider the limitations pointed out [58]. It should also analyze the impact of the circular economy on people's lives, the public perception of reuse, the effectiveness of existing regulations, water reuse approached through a holistic perspective, and the work that the World Bank, the International Water Association (IWA), and other institutions have been developing on this subject.

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