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Conceptualizing the Circular Economy: R-framework Question

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Abstract: Despite its rich history, the circular economy (CE) must be more firmly conceptualized. Various definitions of CE are often connected with specific R-frameworks, which differ significantly. This divergence could be caused by the fact that CE is related to other predecessors' concepts, for example, industrial ecology, waste management, cleaner production, and reverse logistics, some of which also used R-frameworks. This article aims to find the most frequently used R-principles in the context of CE, including identifying possible factors influencing the author's choice of the selected R-framework. For this purpose, 128 articles (related to R-frameworks and CE) were analyzed. The potential relationship between selected factors (e.g., authors' nationality, the publication's year, or journal) and the selected R-framework was tested using chi-square tests. The results show that only the nationality of the authors can influence the choice of the R-framework and that the 3R principles (reduce, reuse, recycle) are most often discussed in the context of the CE. Results show that the 3R framework is dominant in Asian publications (which is logical due to the longer recognition of this framework) and also in European publications. However, lately, there is a visible growing trend in using the 10R framework in European publications; thus, it may be a matter of time before other frameworks become dominant. As a result, it can be stated that the 3R and 10R frameworks are well-used frameworks that can serve as the basis for defining and conceptualizing the CE. One official definition of CE that would use a selected R-framework should be stated to clearly define what CE is.

Keywords: circular economy, R-framework, 3R

1. Introduction

The circular economy (CE) has over 200 definitions [1]. Some were stated by official institutions [2, 3] and some by researchers [4–9]. The reason may be that CE is rooted in several theoretical backgrounds or scholarly disciplines, such as ecological economics, environmental economics, waste management, reverse logistics, product design, or industrial ecology [10, 11] and can be interpreted differently by different actors (such as businesses, academics, legislative institutions, etc.) [9]. CE is also viewed differently in terms of the micro (e.g., people, companies), meso (eco-industrial parks), and macro levels (city, region, country) [10]. Even R-principles (or R-imperatives, R-framework, R-strategies) that are closely connected to the CE are defined in various ways. The 3Rs, 4Rs, 6Rs, 9Rs, and 10Rs can be found in the literature, sometimes with different meanings of Rs assigned [11].

These different views make this concept very difficult to conceptualize. This situation affects practice as well as theoretical studies concerning CE. In practice, implementing CE principles could be supported and managed by government bodies, organizations, or individuals more effectively if the rules of what is CE and what is not CE were clearly stated. In the theoretical field, if the research subject is not clearly defined, it is not easy or even possible to study its effects (e.g., its impacts on the economy, environment, or organizations). These types of studies in the field of CE are crucial because they can help promote CE implementation.

In terms of promotion, the general benefits of CE are well known, for example, increase in organizational competitiveness, stimulation of innovations, creation of circa 700,000 jobs by 2030, or saving money for consumers by making products more durable [2]. However, better conceptualization would allow researchers to clearly define their object of study and more elaborate research about the concepts' impact on, for example, individual organizations, their environment, or their management would appear.

For their clarity, the R-principles could serve as an ideal framework to conceptualize CE. However, they need to be defined uniformly. In order to help conceptualize this field of study, this paper studies the R-principles used by researchers in their publications. This paper aims to find the most frequently used R-principles in the context of CE and to reveal what influences the selection of R-principles used in scientific literature. It uses a systematic literature review method (SLR), followed by statistical testing of the possible relationships.

The paper follows with the definitions of CE and R-frameworks, and then the methodological description of the methods used (SLR, chi-square) is presented. The conclusion follows the results and their discussion.

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2. Theoretical Background

2.1. Circular economy: history and its definitions

The formation of a CE was a gradual process with several steps, and its origin is still the subject of debate. Kenneth Boulding is usually denoted as the author of the concept. In his work "The Economics of the Coming Spaceship Earth" [12], he describes the concept of the "spaceship economy" as an economy "without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy" [12]. He compares it with the "cowboy economy" of the past, where production and consumption were seen as a good thing. According to Murray et al. [7], the first reference to a closed-loop economy was drawn from the work of Boulding by Stahel and Reday-Mulvey [13]. Other well-known authors who elaborated on this concept were Pearce and Turner [14], who, according to Ghisellini et al. [10], "explain the shift from the traditional open-ended economic system to the circular economic system as a consequence of the law of thermodynamics."

Several concepts related to CE can be called their predecessors, for example, industrial ecology, waste management, cleaner production, and reverse logistics [10, 11]. The oldest concepts, waste management and waste recycling, have been dealt with in the scientific literature since the 1970s, while industrial ecology emerged in the 1990s, and an overall high increase in scientific publications of other related concepts happened around 2000 [11]. They also highlight that literature on CE and the oldest predecessor concepts (waste management, industrial ecology, cleaner production) emerged in 2004. Concepts such as reverse logistics and closed-loop supply chains connected to CE emerged in 2007, and literature regarding cradle-to-cradle in the context of CE emerged in 2012.

At the national level, the first attempts to include principles of CE in the law and their successful implementation have been made in China. They selected CE as a national policy for sustainable development and enacted related national laws and regulations [15]. This sustainable development strategy was formally accepted in 2002 and aimed "to improve the efficiency of materials and energy use" [16]. Their "Circular Economy Promotion Law [3] describes CE as a generic term for the reducing, reusing, and recycling activities conducted in the process of production, circulation, and consumption."

In Europe, several milestones that helped to develop the CE concept can be found in history. One was the launching of the Ellen MacArthur Foundation in 2010 (established in the United Kingdom but now operating also in other parts of Europe, North and Latin America, and Asia). The story behind the foundation is that in 2005, Ellen MacArthur sailed alone around the world (and broke the world record), during which she realized the fragility of our global economy and that we rely entirely on resources that are not unlimited. After she returned, she started learning about how the global economy works, talked to experts and business leaders, and proposed an economy that maintains materials in use, minimizing waste and regenerating natural systems – the CE. Thus, the foundation[1] was launched, and since then, it has aimed to inspire society (people, businesses, and nations) to accelerate the transition toward the CE concept.

Another milestone was the official recognition of CE by EU institutions. The first official document dealing with CE was "Closing the Loop – An EU Action Plan for the Circular Economy,"[2] the action plan which introduced the transition of Europe to a more CE. It introduced actions at the EU level related to production, consumption, and waste management, with priority areas such as plastics, food waste, critical raw materials, construction and demolition, biomass, and bio-made products. Also, the "European Green Deal,"[3] which was adopted in 2019, helped to support the CE implementation because it aims to make Europe climate-neutral and resource-efficient by 2050, which is the goal that CE can directly help with. As a result, in 2020, "A New Circular Economy Action Plan for a Cleaner and More Competitive Europe" was published, coordinating the CE action plan with the European Green Deal.[4]

There are so many definitions, as pointed out in the introduction. Beginning with researchers who analyzed the existing ones and tried to synthesize or summarize them, Ghisellini et al. [10] based their SLR of 155 publications and, as a result, defined CE as "a way to overcome the current production and consumption model based on continuous growth and increasing resource throughput." According to Kirchherr et al. [4] , who conducted a systematic literature review of 114 definitions of the CE, CE is "a combination of reduce, reuse and recycle activities," with "few explicit linkages to sustainable development," and its main aim of economic prosperity, followed by environmental quality." Geisendorf and Pietrulla [6], on the basis of a review of similar concepts, proposed the following synthesized definition: "In a circular economy, the value of products and materials is maintained, waste is avoided, and resources are kept within the economy when a product has reached the end of its life." Stahel [17], the "father of CE," recently defines the concept as the economy that "manages stocks of manufactured assets, such as infrastructure, buildings, vehicles, equipment and consumer goods, to maintain their value and utility as high as possible for as long as possible." Lacy et al. [18] say that "a circular economy eliminates the concept of waste altogether, fundamentally changing the way we produce and consume, creating a healthier, thriving ecosystem that circulates value throughout the economy and society." For an overview of older definitions, see Rizos et al. [8]. It isn't easy to summarize these definitions because they are very different, and the CE is viewed from different angles. However, they mostly stress the need to keep value in the economy as long as possible and avoid waste. Official institutions propose clearer definitions; for example, China defines CE as a "generic term for the reducing, reusing and recycling activities conducted in the process of production, circulation, and consumption." The circular economy has been defined as "a system where materials never become waste and nature is regenerated. In a CE, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting" [19]. Also, the European Parliament [2] defines CE as "a model of production and consumption, which involves

[1] Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/

[2] Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the loop - An EU action plan for the circular economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614

[3] Communication from The Commission: The European Green Deal. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640

[4] Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee of the Regions: A new circular economy action plan for a cleaner and more competitive Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52020DC0098

sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible." Thus, the R-framework is used, although it has different types of Rs.

2.2. R-frameworks

The origin of R-frameworks can be traced back to the 1970s in the USA, when people became more aware of the environment and worried about pollution, water quality, etc. On April 22, 1970, the first Earth Day was celebrated, and in 1976, the "Resource Conservation and Recovery Act" was approved, and waste started to be perceived as a problem. The slogan "reduce, reuse, recycle" was born [20]. Since then, the R-framework has been used in several fields that were CE's predecessors (e.g., waste management, reverse logistics, closed-loop supply chain management, product design, cleaner production, and industrial ecology). Its connection to the CE concept can be traced back to the 2000s. At first, China based its approach to a CE on the 3R typology. Also, during the 2010s, the first research articles dealing with CE and some R-imperatives were published. Nowadays, R-imperatives are very commonly connected to the CE (see the official definitions of CE above). However, authors differ significantly regarding their opinion on the number of Rs and their meaning. Reike et al. [11] revealed that not only does the number of Rs vary (they mention particularly 3Rs, 4Rs, and 6Rs), but different attributes and meanings to the same groups of Rs are assigned by various authors. Besides the well-known reduce, reuse, and recycle, many other Rs are used. For example, recently, the 10Rs framework, according to Potting et al. [21], is often used [22–25]. The 10R framework contains Refuse (R0), Rethink (R1), Reduce (R2), Reuse (R3), Repair (R4), Refurbish (R5), Remanufacture (R6), Repurpose (R7), Recycle (R8), and Recover (R9). R0–R2 represent strategies for smarter product use and manufacture, R3–R7 represent strategies for extending the product and its parts' lifespan, and R8–R9 represent strategies for the practical application of materials [21]. These R-strategies are characterized in Table 1. These and other R-imperatives will be discussed more in the results section.

The R-framework represents an excellent framework for conceptualizing CE. However, it is necessary to state the most suitable R-framework (thus the correct number and types of R-imperatives/R-principles, which in this paper is collectively referred to as R-framework). To contribute to this field of study, this research, marginally inspired by Reike et al. [11], aims to review the literature to find the most frequently used R-principles. In addition, the possible factors influencing the author's choice of the selected R-framework will be identified and statistically tested. Thus, the research questions are:

RQ1: What are the most frequently used R-principles in the CE-related existing research?

RQ2: Are any factors influencing the author's choice of R-framework type?

3. Research Methodology

To answer the research questions, an SLR was performed, followed by statistical testing of the data. SLR was based on the approach used by Baltazar et al. [26] and Tomašević et al. [27], and it aimed to find all papers that deal with CE and some R-imperative. Its research question was, "What are the most frequently used R-principles in the CE-related existing research?" The keywords were defined accordingly (see Table 2), and as a database, the Web of Science was selected to obtain only the high-quality and well-cited papers. Additional search conditions are seen in Table 2.

Initially, 152 articles were found (8 were unavailable). The resulting articles were screened for quality and relevance [27], and 24 were discarded for irrelevance. On the other hand, using the snowballing technique, eight were added as they were considered very important and often cited (e.g., Reike et al. [11], Potting et al. [21], and Morseletto [22]) and the final sample contained 128 papers. The SLR procedure is visualized in Figure 1. From the final sample of publications, the data necessary for further analysis were filled into the Excel sheet for further statistical analysis.

Table 1
R-strategies definition (according to the 10Rs framework)

Strategies		Definition
Smarter product use and manufacture	R0 Refuse	Make a product redundant by abandoning its function or offering the same function with a radically different product.
	R1 Rethink	Make product use more intensive (e.g., by sharing products or putting multifunctional products on the market).
	R2 Reduce	Increase product manufacture or use efficiency by consuming fewer natural resources and materials.
Extend the lifespan of products and their parts	R3 Reuse	Reuse by another consumer of a discarded product, which is still in good condition and fulfills its original function.
	R4 Repair	Repair and maintain defective products to be used for their original function.
	R5 Refurbish	Restore old products and bring them up to date.
	R6 Remanufacture	Use parts of discarded products in a new product with the same function.
	R7 Repurpose	Use discarded products or parts in a new product with a different function.
Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality.
	R9 Recover	Incineration of materials with energy recovery.

Table 2
Article sourcing protocol

Database	WoS
Year of publication	No restriction
Search field	Topic (title, abstract, author keywords, and KeyWords Plus)
Combination of keywords	" circular economy" and ("3R" or "4R" or "5R" or "6R" or "7R" or "8R" or "9R" or "10R")
Link	https://www.webofscience.com/wos/woscc/summary/a8223f37-19ad-47be-bbce-99aa8cfd06dd-ecf40da0/relevance/1
Date of search	10. 6. 2024
Criteria for article inclusion	Written in the English language

Figure 1
SLR procedure

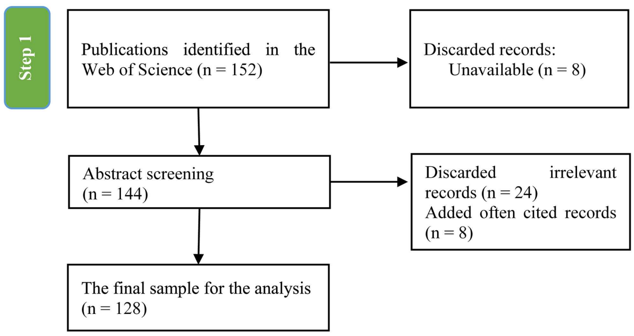
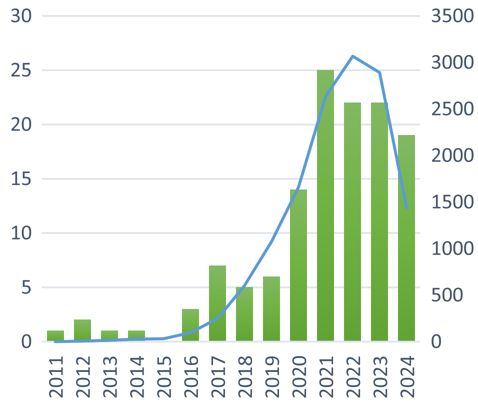


Figure 2
Number of publications and their citations



As input data for the analysis, the used R-imperatives, name of the journal, country of the authors, year of the publication, and WoS Category were selected.

Pearson's chi-square test and contingency tables were used to analyze the data statistically. The calculations were performed using the Tibco Statistica 14.0 software.

4. Results

Descriptive analysis and content analysis of the publications, together with the statistical results, will be introduced in this section.

4.1. Descriptive analysis of the publications

The analyzed publications are shown in Table 3. The oldest paper is from 2011; the highest number of papers was published in 2021 (25 papers), and the highest cited paper is Kirchherr et al. [4], with 2,939 citations (by July 2024). These 128 papers were cited 13,786 times, indicating this topic's importance. For more details regarding this topic, see Figure 2.

As to the WoS Category, the most significant number of articles (74) was categorized as "Environmental Sciences," 47 to "Green & Sustainable Science & Technology," 34 to "Engineering Environmental," 30 to "Environmental Studies," and only 10 to "Business" and 9 to "Management" (journals are usually in several categories; thus, the sum here is not 128).

Regarding the types of journals where articles were published, see Table 3 (the top five journals are shown in more detail). Most papers (20, thus every sixth) were published in the *Journal of Cleaner Production*.

As to the country of authors, 20 publications were written by Chinese authors, 13 by Italians, eight papers by authors from India, followed by six publications written by authors from the Netherlands, five written by authors from Germany, five by Australians, five by authors from England, and the rest is from other countries (in case of several authors from different countries, the country was assigned according to the first author).

Table 3
Top 5 journals with the most publications

Journal name	Number of papers	JIF (2023)	Publisher
Journal of Cleaner Production	20	9.7	Elsevier
Sustainability	14	3.3	MDPI
Resources Conservation and Recycling	8	11.2	Elsevier
Journal of Material Cycles and Waste Management	6	2.7	Springer
Sustainable Production and Consumption	5	10.9	Elsevier

The last descriptive analysis studied the keyword co-occurrence. The full counting method of VOSviewer was used. Altogether, 954 keywords were found, of which 45 fulfilled the criteria to appear at least in 5 of these 128 papers. The most often appearing keywords are "sustainability" and "China." The keywords "3Rs" are most often connected to "management" and "China."

4.2. Content analysis of the publications

The found publications were categorized according to the R-framework used in the paper. As visible in Table 4, in the highest number of publications (72), the 3R framework was used. The second most often used framework is the 10R framework (24 papers), followed by the 4R framework as the third most used (17), and then 5R (6), 6R (5), 9R (3), and 8R (1). The following subchapters will describe these categories and the papers in more detail.

Table 4
Categorization of publications

R-framework	Publication
3R (n = 72)	[10, 15, 16, 28–96]
4R (n = 17)	[1, 4, 97–111]
5R (n = 6)	[112–117]
6R (n = 5)	[118–122]
8R (n = 1)	[123]
9R (n = 3)	[124–126]
10R (n = 24)	[11, 21–25, 127–144]

In the publications, 23 R-principles were found, fewer than the 38 found by Reike et al. [11] (however, they did not aim their paper solely to CE) but still a large number. The most often used R-imperatives are Recycle (in 127 papers), Reuse (124), Reduce (116), Recover (47), and Remanufacture (42).

4.2.1. 3R framework (n = 72)

In the case of 3Rs, most of the found publications used the well-known reuse-reduce-recycle principles (in 60 cases); however, some used different ones. For example, Lieder and Rashid [28], Ayati et al. [44], Kurdve et al. [62], Kampker et al. [66], Liao et al. [74], and Sergio et al. [87] used Reuse, Remanufacture, Recycle. Barmparitsas et al. [47] use Reuse, Recycle, Recover; similarly, Ignatyeva et al. [56] used Reduce, Recycle, Recover. Prajapati et al. [50] used Resell, Refurbish, Recycle; Ma et al. [36] used Rethink, Reduce, Reuse; Towa et al. [65] used Reuse, Repair, Remanufacture; and Debnath and Sarkar [71] used Reduce, Recycle, Restore.

4.2.2. 10R framework (n = 24)

The second biggest group is formed by papers that used the 10R framework. There is a more significant agreement between authors on what Rs should be included in 10R. In fact, there are only two groups of authors with different definitions. The authors in the first group (19) used the 10Rs defined by Potting et al. [21] (see Table 1). The authors of the second group [11, 137, 142, 144] used the R-framework defined by Reike et al. [11]: Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover, Re-mine. Pegorin et al. [135] have their definition of 10R: Refuse, Rethink, Reduce, Reuse, Repair, Reform, Remanufacture, Repurpose, Recycle, Recover. However, their definition of Reform ("recondition old products to bring in updated them" [135]) reminds a lot of the definition of "refurbish" (see Table 1). Thus, it can be classified into the first group. The only difference between Potting's and Reike's definitions is that Reike's has no Rethink, and Re-mine is added. Reike et al. [11] claim that re-mine "forgotten or ignored in operationalizing CE is the retrieval of materials after the landfilling phase."

4.2.3. 4R framework (n = 17)

In the case of 4Rs in 11 articles, the authors used the Reduce, Reuse, Recycle, Recover framework. Bressanelli et al. [100, 101] used Reduce, Reuse, Remanufacture, Recycle; Rodrigo-González et al. [97] used Reuse, Refurbish, Remanufacture, Recycle; Liu et al. [30] used Reduce, Reuse, Repair, Recycle; Mutuku et al. [102] used Reuse, Redesign, Recycle, Recover; and Popescu-Arges et al. [105] used Reduce, Reuse, Recycle, Restore. Thus, Reuse and Recycle are used in all cases, but Reduce and Recover are sometimes replaced by different Rs.

4.2.4. 5R framework (n = 6)

In the case of 5R, almost no same Rs were used. Only Nandi et al. [113] and Selvan et al. [117] used the same first four: Refuse, Reduce, Reuse, and Recycle, where Nandi et al. [113] added the Rot as the fifth and Selvan et al. [117] the Replace. Tserng et al. [112] used Rethink, Reduce, Reuse, Repair, Recycle; Chen et al. [114] used Reduce, Reuse, Redesign, Recycle, Recover; Silva [115] used Reduce, Reuse, Recycle, Recover, Reclaim; and Korsunova et al. [116] used Refuse, Reduce, Reuse, Repair, Recycle.

4.2.5. 6R framework (n = 5)

The 6Rs framework is defined almost the same way: Reduce, Reuse, Remanufacture, Redesign, Recycle, and Recover [118–121]. Only Ding et al. [122] define it as Reduce, Reuse, Repair, Remanufacture, Redesign, and Recycle.

4.2.6. 9R framework (n = 3)

The definition of the 9Rs in each publication is different. Van Buren et al. [124] used Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover. De Oliveira et al. [125] used Refuse, Rethink, Reduce, Reuse, Repair, Reform, Remanufacture, Recycle, Recover as well as Mesa and González-Quiroga [126], who called the strategies as 9Rs strategies, even though the last two do not start with R: Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover, Cascade (to another product system), Upgrade (as a strategy for extending use-lifecycle).

4.2.7. 8R framework (n = 1)

Cabrales Salazar et al.'s study [123] is the only one that uses and defines 8R as Reflect, Reject, Reduce, Reuse, Recycle, Redistribute, Claim, and Social Networks (even though the last two do not start with R).

4.3. Factors influencing the selection of R-framework

To answer RQ2, it was logically deduced that the factors influencing the final use of the R-framework could relate to the form used in the country where the publication's authors lived, the time at which the publication was written, or the usual usage in the field of study.

Table 5
Contingency table (observed and expected values) for continents and R-frameworks

Continent/R-framework	3R	10R	4R	5–9R	total
Asia (observed)	40	4	2	7	53
Europe (observed)	24	15	13	3	55
Asia (expected)	31.407	9.324	7.361	4.907	53
Europe (expected)	32.593	9.676	7.639	5.093	55
Total	64	19	15	10	108

Thus, the tested factors were identified as follows: the authors' country, the publication's year, and the journal. Initially, the WoS Category was also intended to be tested. However, no relationship can be revealed because the categories do not differ much (most relate to the environment, sustainability, etc.).

As to the country of the authors, the result needed to be merged to fulfill the conditions of the chi-square test that at least 80% of the expected counts have a value of five or more, and all individual expected counts have a higher value than 1. Thus, it was decided to merge the publications according to the continent of the authors (and include only Asia and Europe). Also, 5–9R frameworks were merged into one category. The observed and expected values are shown in Table 5. The null hypothesis was set as "There is no significant association between the continent and the selected R-framework." The results are $\chi 2 = 20{,}0049$, with 3 degrees of freedom. Moreover, with the p-value of 0.000159, the hypothesis was rejected, and it can be assumed that there is a relationship between the author's continent and the selection of the R-framework.

As is visible in Table 5, in Asia, the 3R concepts were primarily used (in 40 cases out of 53). In Europe, there is a higher difference in the selection, and although 44% of European publications used the 3R framework, 27% and 24% used 10R and 4R, respectively. From a different angle, in the case of 3R, the publications were 63% from Asia and 38% from Europe; conversely, in the case of 10R and 4R frameworks, they were more often European (79% and 87%, respectively) than Asian. As category 5–9R has already been merged and is the smallest category, no results have been concluded.

As to the expected relationship between the journal and the selected R-framework, it could not have been tested by using the chi-square test because the primary condition that more than 80% of expected values have to be higher than five was not fulfilled (see Table 6). No meaningful merge could be done.

In the case of testing the relationship between the publication's year and the selected framework, there was no point in it for the same reason as above. Even when only publications for the last five years were considered, and R-frameworks were merged into three categories (3R, 4–9R, and 10R), the essential condition of chi-square testing (more than 80% of expected values have to be higher than 5) was not fulfilled. However, if it were fulfilled, the null hypothesis would not be rejected as the p-value was 0.949; thus, no relationship can be found here. Still, it is interesting to look at this data (see Table 7) (unmerged), where it is visible that at first, the publications with the 3R concept emerged and then gradually, the others (in the last few years, the rise of the 10R concept is visible).

Table 7
The rise of R-frameworks during the years

	3R	4R	5R	6R	7R	9R	10R
2011	1						
2012	2						
2013	1						
2014	1						
2016	2	1				1	
2017	5	1					1
2018	3			1			1
2019	5	1					
2020	7	2	1	1			3
2021	11	4	2		1		7
2022	14	3	1	1			3
2023	11	3	2	1		1	4
2024	9	3		1		1	5

Table 6
Contingency table (observed and expected values) for journals and R-frameworks

Journal title/R-framework	3R	4–9R	10R	Total
Journal of Cleaner Production (observed)	14	1	5	20
Sustainability (observed)	6	5	3	14
Resources Conservation and Recycling (observed)	3	3	2	8
Journal of Material Cycles and Waste Management (observed)	5	1	0	6
Sustainable Production and Consumption (observed)	1	3	1	5
Journal of Cleaner Production (expected)	3.434	2.906	7.660	3.434
Sustainability (expected)	4.906	4.151	10.943	4.906
Resources Conservation and Recycling (expected)	1.962	1,660	4.377	1.962
*Journal of Material Cycles and Waste Managemen*t (expected)	1.472	1.245	3.283	1.472
Sustainable Production and Consumption (expected)	1.226	1.038	2.736	1.226
Total	29	13	11	53

It is also interesting to study the relationship between the continent and the publication year more closely. Logically, the first publications were written by Asian authors, up to 2016, when the first articles were published by European authors (in North America, only three publications were found, with the first published in 2018).

5. Discussion

The results of this review show several exciting findings. The emergence of the 3Rs concept (as the first R-framework defined as Reduce, Reuse, Recycle) can be traced back to the USA and was incorporated into the Chinese laws at the beginning of the Millennium. At this time, China was also the first to connect the 3R framework with CE (even though some predecessors' concepts used the 3R framework, and at the same time, the CE had already existed for several decades, but without the connection to the 3Rs). The connection between R-frameworks and the CE in the research emerged after 2010, when Chinese authors started to publish their research regarding CE and 3Rs. The Ellen McArthur Foundation was founded then, which sparked interest in CE in Europe. The first three scientific papers from European authors on CE that mentioned the R-framework were found in 2016 (two of them mention the 3R concept, and one 9R, the first mention of a different R-concept found by this research). Since then, other R-frameworks emerged; from those, the most interesting (and well-cited) is the 10R framework stated by Potting et al. [21]. Since its first citation in 2020, it has been cited in 18 other publications (12 from Europe) related to the CE. As to America (notably the USA), the scientific research of CE and R-framework is occasional. Two papers written by authors from the USA were found: one from 2018 and the second from 2022. This can be explained by the missing relevant federal policy regarding CE [10], which can cause the researchers to lack interest. To compare, nine papers were recently published by authors from South America (mainly from Colombia or Brazil). Thus, the topic seems more attractive in Latin America (however, they do not tend to use only one type of R-framework).

The similar overall development is confirmed by the official institutions' definitions of CE. Except for China, CE definitions have only recently mentioned R-imperatives. The previous definition mentioned only the "reuse" principle. However, the current definition [19] uses reuse, refurbishment, remanufacture, and recycling. Also, the European Parliament [2] uses reusing, repairing, refurbishing, and recycling R-imperatives. However, no definition particularly mentions some specific R-framework (e.g., 3R, 4R, 10R).

Thus, to answer the first research question (RQ1), the most frequently used R-principles are those from the 3R framework, found in 72 publications. Within all the R-frameworks, the most often used R-principles are Recycle (in 127 papers), Reuse (124), Reduce (116), followed by Recover (47), and Remanufacture (42). In the last five years, the 10R concept has also been used (especially in Europe). However, the number is still relatively low (24 publications) for making any conclusions.

To summarize, this article revealed similar results to Reike et al. [11], who also, as a part of their article, did an SLR on R-frameworks and proved that not only do R-imperatives vary (3Rs, 4Rs, and 6RS) but also authors assign them different meanings. The same finding was revealed in this SLR, with fewer different Rs (23 vs Reike's 38, but they did not focus only on the CE literature). They revealed that the 3R framework is the most often used concerning CE, which was also confirmed by this research. On the other hand, their research was done before 2018. Thus, the rise of the 10R typology is a value that this research adds.

To answer RQ2, three possible factors were tested regarding the factors influencing R-framework selection. The relationship between the R-framework and year and journal was not found; however, in the case of the continent, it was confirmed. Thus, the 3R concept is used more by Asian (specifically Chinese) authors than European, and vice versa; 10R and 4R frameworks are used more by Europeans than Asians. Of course, it is a logical finding due to the incorporation of the 3Rs into Chinese law and the gradual inclusion of more Rs into the official definitions made by the EU. As to the other continents or countries, no specific relationships were revealed. Thus, to answer RQ2, only the authors' countries (continents) could influence the authors' choice of R-framework type.

6. Conclusion

This study confirmed that the 3R framework has a solid, unchangeable place in several concepts dealing with the environment and its protection. When the concept of CE began to be the center of attention, the R-frameworks started to be used in its context, especially in China, which included the 3R framework in its laws regarding CE. The European Union does not officially recognize any connection of the R-framework to CE. However, some R-principles started to appear in some official definitions of CE. On the other hand, although the USA was the cradle of the 3R framework, the CE concept is not well developed there, which was confirmed by the finding of only two publications written by American authors.

To conclude, this study reveals that the 3R framework is the most often used, even nowadays. However, other frameworks (mainly 10R by Potting et al. [21]) started to be used a lot. Thus, it may be a matter of time before other frameworks become dominant. Also, the choice of R-framework depends mainly on the country/continent from which the author/s comes.

This study aimed to contribute to the scientific literature to research the R-frameworks in more detail and to examine its potential as a framework that could be used to conceptualize the CE better. As a result, it can be stated that the 3R and 10R frameworks are well-used frameworks that can serve as the basis for defining CE.

Regarding practical implications, one officially recognized definition of CE using a selected R-framework should be stated to end the confusion about what CE is and what is not. It can contribute to a better management of CE implementation. Policymakers should consider the 3R or broader 10R framework, as these are the two most often used concepts (in the case of the EU, the 10R concept would be more logical, as it started to appear more recently in publications made by European authors). In the case of the EU, better conceptualization is necessary when a higher level of CE implementation is wanted (due to the Green Deal). The R-framework can also serve as a base from which indicators that measure the level of CE implementation would be derived. Thus, using the R-framework can contribute to an efficient implementation of CE in organizations or regions because the proper actions or projects can be supported.

In terms of theoretical implications, this study contributes to the ongoing discussion about CE by confirming that R-frameworks are an unforgettable part of it and that the 3R framework is the most often used one. It shows that CE and R-frameworks are concepts that are under constant development. The findings of this study can be seen as the basis for further research. They should be subjected to follow-up research that would assess the further development of the R-framework's use, especially the confirmation of 10R's increase in scientific research. Additionally, the same methodology could be used to examine CE frameworks implemented in businesses or governments to give more practical results to practitioners. However, the data necessary for this type of research would be challenging to find (businesses don't usually share these types of data). Perhaps only data for some countries could be found. Another direction for future research is studying the drivers that lead to the implementation of selected R-frameworks in individual countries or regions (e.g., some laws, industrial priorities, etc.).

The limitation of this study can be seen in the use of a single scientific database for the SLR. However, it aimed to study the highest quality publications, and a more significant number of papers would not be possible to process. Regarding the content analysis of SLR, the R-principles were always clearly defined. Thus, no subjective assessment could occur.

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Conflicts of Interest

The author declares that she has no conflicts of interest to this work.

Data Availability Statement

Data are available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Marta Nosková: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision.

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