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DOI:
10.3390/su14169896

Citation for published version (Harvard):
Tamasiga, P, Miri, T, Onyeaka, H & Hart, A 2022, 'Food waste and circular economy: challenges and opportunities', *Sustainability*, vol. 14, no. 16, 9896. https://doi.org/10.3390/su14169896

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Review

Food Waste and Circular Economy: Challenges and Opportunities

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Abstract: The world's population is expected to grow at an increasing rate, leading to increased food consumption and waste production. Even though food waste represents one of the most challenging economic and environmental issues of the 21st century, it also provides a vast array of valuable resources. To address the challenge, this study uses resource recovery from food waste to close the supply chain loop, which is the cornerstone of a circular economy. By applying the bibliometric review technique, trends and patterns in food waste and circular economy were studied. The analysis of frequent keywords in the field provided insights into further research directions. A Boolean search of the keywords in the Scopus database resulted in 288 articles, published between 2015 and 2021. Further screening of titles, keywords, and abstracts resulted in 155 journal articles. Bibliometric coupling, including authors' co-citation data, co-occurrence, and the occurrence of keywords, was graphically mapped using VOSviewer software. From the analysis of the publications, eight broad themes emerged: (1) anaerobic digestion of food waste for circular economy creation; (2) food waste systems and life cycle assessments for circular economy; (3) bio-based circular economy approaches; (4) consumer behavior and attitudes toward circular economies; (5) food supply chains and food waste in a circular economy; (6) material flow analysis and sustainability; (7) challenges, policies, and practices to achieve circularity; and (8) circular economy and patterns of consumption. Based on the eight themes, we emphasize an urgent need to promote the collaboration of governments, the private sector, educational institutions, and researchers, who should combine efforts to promote, integrate and accelerate acceptance of circularity, which will potentially mitigate greenhouse emissions associated with food loss and waste. We also highlight an opportunity to encourage consumer acceptance of upcycled food in the food waste hierarchy. In addition, we deduce that there is a need to quantify food waste and emissions of greenhouse gases due to this waste along the food value chain; this is important as it is one pathway of examining the 'food leaks' along the food supply chain. This can then inform optimal strategies targeting specific areas of the food supply chain experiencing food leaks. Lastly, food wastage affects the entire globe; however, future studies and funding need to be channeled towards investigating the possibility of implementing circularity in developing countries.

Keywords: food waste; circular economy; recycling; organic waste

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Citation: Tamasiga, P.; Miri, T.; Onyeaka, H.; Hart, A. Food Waste and Circular Economy: Challenges and Opportunities. *Sustainability* **2022**, *14*, 9896. https://doi.org/10.3390/su14169896

Academic Editor: Piergiuseppe Morone

Received: 24 May 2022
Accepted: 8 August 2022
Published: 10 August 2022

1. Introduction

Food consumption and waste generation are expected to increase as the world population increases. Hence, managing food waste is one of the global challenges of the 21st century due to its adverse effect on the environment and economy. In addition to government policies and legislation, the continuous growth of food waste has led to a significant change in waste management approaches, from landfill disposal to waste treatment through reduction, recycling, and reuse, and a shift to energy and resource recovery from waste. The focus has been on the recovery of materials and energy from food waste, as well as their applications in electricity generation, fuel production, and agriculture in the context of sustainability, circular economy, and environmental protection. According to the Food and

Agriculture Organization (FAO), approximately one-third of all food produced for human consumption is lost or wasted [1]. The three dimensions to investigate the impacts of food waste include environmental, social, and economic. Nevertheless, the main challenge is that the magnitude of food waste and its impacts have not been well investigated and quantified. Understanding the scale of food waste can help develop informed policies and strategies that aim to reduce food waste. FAO asserted that the causes of food waste are country-dependent due to the prevailing local conditions. The report argues that in low-income countries, food waste happens at the production, postharvest handling, storage, and processing stages. This waste is the consequence of mainly managerial and technical limitations [2]. Gustavsson et al. cites poor infrastructure, technology, and financial limitations as some of the causes of food waste and loss [1]. Other causes of food waste, such as overproduction, are cited in the paper of Beretta et al. [3].

On the other hand, in high- and middle-income countries, food waste occurs in the distribution and consumption stages of the food value chain. Over and above that, local consumer behavior and government policies have a bearing on the levels of food waste in both developing and developed countries. Against this background, there is a need for concerted global efforts to measure the magnitude of food wasted along the food value chain; at the farm (agricultural production), distribution channels (transportation and retail), and consumer level, in order to harness the untapped benefits of food waste reduction. More developed countries are shown to have low food waste compared to less developed countries. For example, South Korea has increased its recycled food waste from 2% in 1995 to about 95% in 2021. Dumping food in a landfill was banned in 2005, and compulsory food waste recycling was introduced in 2013. The government has also approved the use of recycled food waste as fertilizer, although some becomes animal feed [4]. The inverse relationship between the composition of organic food waste and Gross Domestic Product (GDP) is illustrated in Figure 1.

According to Figure 2, most sub-Saharan African countries with lower GDP, in the top left corner, have a higher composition of organic food waste. This proves the assertion we made from observing Figure 1, that there is a downward-sloping regression line that indicates a negative inverse relationship between GDP and the composition of organic food waste. This is a bleak picture because the FAO states that about 220 million people are undernourished in sub–Saharan Africa. The FAO has asserted that the scale wasted in the African continent is sufficient to feed about 300 million people. One of the causes of this alarming food waste is the loss during food harvest, and as such, farmers ought to be supported with the requisite harvest technologies to reduce food waste and loss.

A continuous and growing literature supports implementing a circular economy to stem the problem of food waste. In principle, the circular economy is an economic model that aims to cut resource use and deliver low carbon, and low environmental impact, through reducing waste and preserving resources (raw materials, energy, and water). This would imply that food products and inputs to food products are circulated within the context of food waste. In the same line of thought, Sellito and Hermann investigated ways of prioritizing green practices of companies along the supply chains to improve the entire chain's eco-efficiency, and an environmentally friendly corporate image [5]. On the contrary, in the linear model, food products and input materials to food products are discarded as waste after use. The Circularity Gap Report finds that circular economy strategies can cut global greenhouse gas emissions by 39% and help avoid climate breakdown [6]. Figure 3 shows the relationship between the GDP, population, and composition of food organic waste per world region.

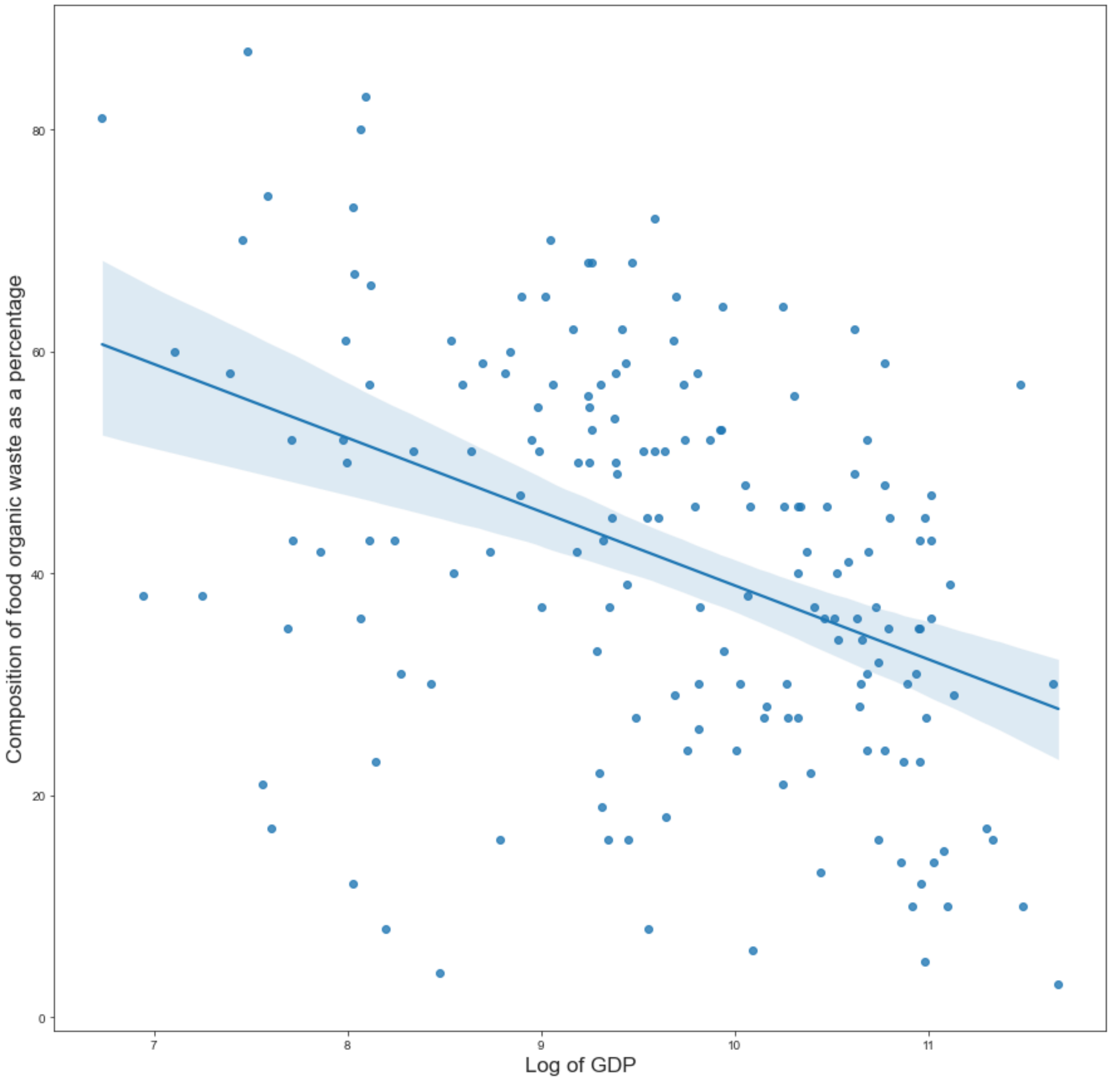

Figure 1. A regression plot of GDP versus food waste. Source: Illustration by Authors based on data retrieved from What a Waste Global Database-Data Catalog (worldbank.org) (accessed on 24 November 2021).

It is evident from Figure 3 that the Europe and Central Asia (ECS) region has the highest composition of organic food waste, as shown by its highest peak in the normal distribution graph, which is orange in color. In comparison, the sub-Saharan African region has a lower organic food waste composition, as shown by the purple normal distribution graph. Moreover, Figure 3 illustrates the inverse relationship between GDP across regions and the composition of organic food waste. For example, a careful analysis of the scatter plot of the log of GDP, and the composition of organic waste shows the purple points of sub-Saharan Africa to the top left of Figure 3, which indicates that countries with lower GDP also have a higher composition of organic waste. In contrast, the developed regions of the world, e.g., East Asia and Pacific (EAS) and ECS are to the bottom right corner of Figure 3 (indicated by green and red points, respectively).

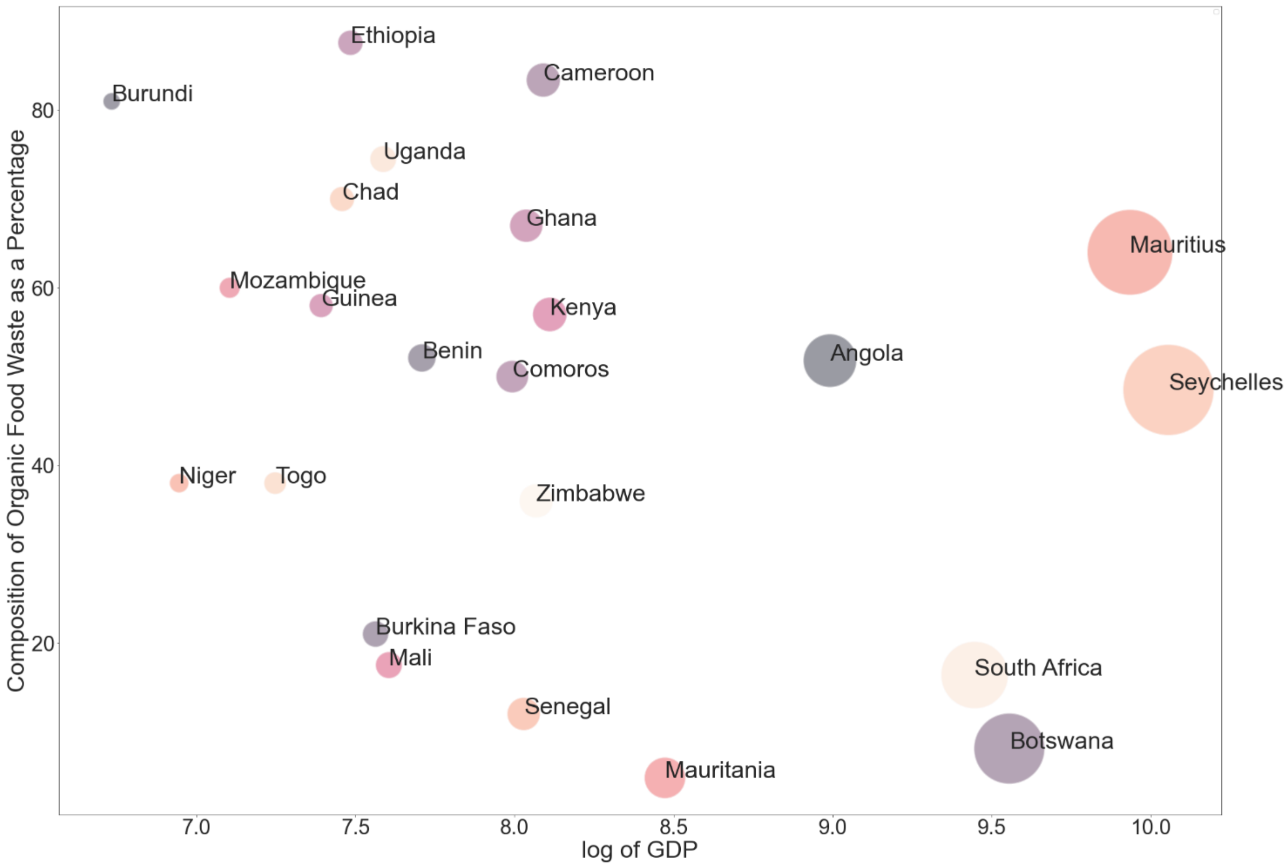

Figure 2. Scatter plot showing GDP and food waste across the world. Source: Illustration by Authors based on data retrieved from What a Waste Global Database-Data Catalog (worldbank.org) (accessed on 17 May 2022).

In addition to increasing pressure on scarce natural resources, the current linear economic model will also lead to an increase in waste as the population grows and industrialization occurs, negatively affecting the environment, ecosystem, and human health. In order to reduce waste and promote the effective use of resources, Boulding [7] proposed the circular economy concept. The European Commission asserted that the circular economy aims to' boost global competitiveness, foster sustainable economic growth, and generate new jobs [8]. The United Nations Environment Programme (UNEP) estimates that the circular economy would account for 8.6 percent of the global economy [9]. Geissdoerfer explained that the circular economy concept reduces the entry and waste of resources, emissions, and energy expenditure by closing and slowing down material and energy circuits [10]. The circular economy is a product of concerted efforts of various stakeholders, including consumers, governments, and sectors of the amiable cooperation between different sectors or industries of the economy. It requires behavioral and mindset change to varying levels of stakeholder interaction with the environment, its natural resources, and raw materials. In the same line of thought, Chizaryfard et al. argued that implementing the circular economy requires a radical shift in societal values, norms, and behaviors/mindsets [11]. The precise correlations are indicated on the heat map in Figure 4. A further deduction from Figure 4 is a negative correlation of about (−0.55) between the composition of organic food waste and waste treatment recycling. This implies an inverse relationship between waste and recycling for the given dataset. This suggests that the more a country recycles, the less the composition of organic food waste. For example, South Korea now recycles about 95% of its food waste [4].

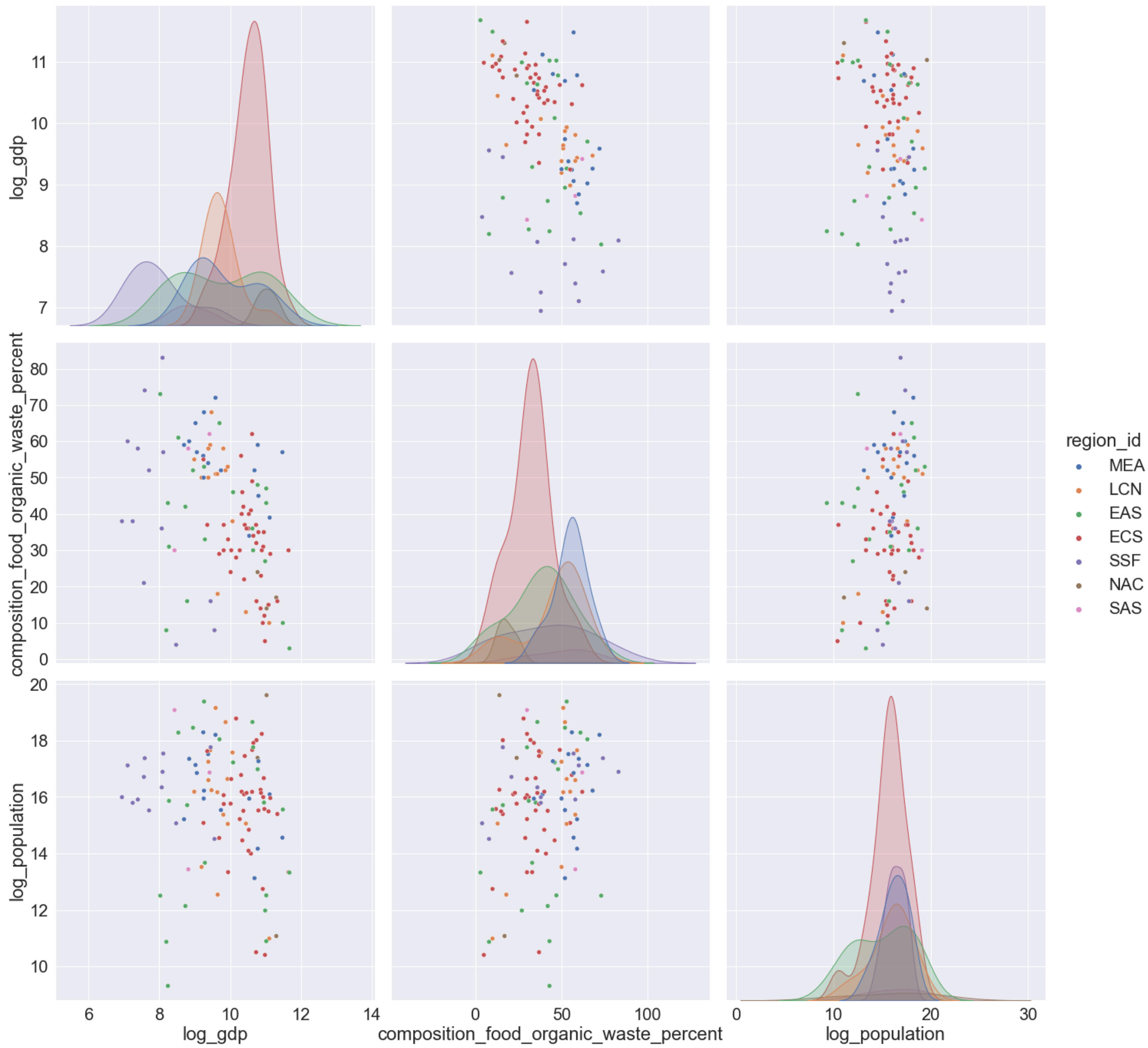

Figure 3. Sub-plots of food waste, population, and GDP across world regions showing the distributions and the regional regression plots. Region IDs are MEA: Middle East and North Africa, LCN: Latin America and Caribbean, EAS: East Asia and Pacific, SSF: Sub Saharan Africa, ECS: Europe and Central Asia. Source: Illustration by Authors based on data retrieved from What a Waste Global Database-Data Catalog (worldbank.org) (accessed on 17 May 2022).

On the other hand, there is a strong positive correlation of about 0.62 between the GDP and waste treatment recycling. This means that high- and medium-income countries recycle more than lower-income countries. Moreover, there is an inverse relationship of 0.54 between GDP and organic food waste. The lower the GDP, the more organic food because there are low recycling capabilities, as indicated by the negative waste treatment recycling correlation.

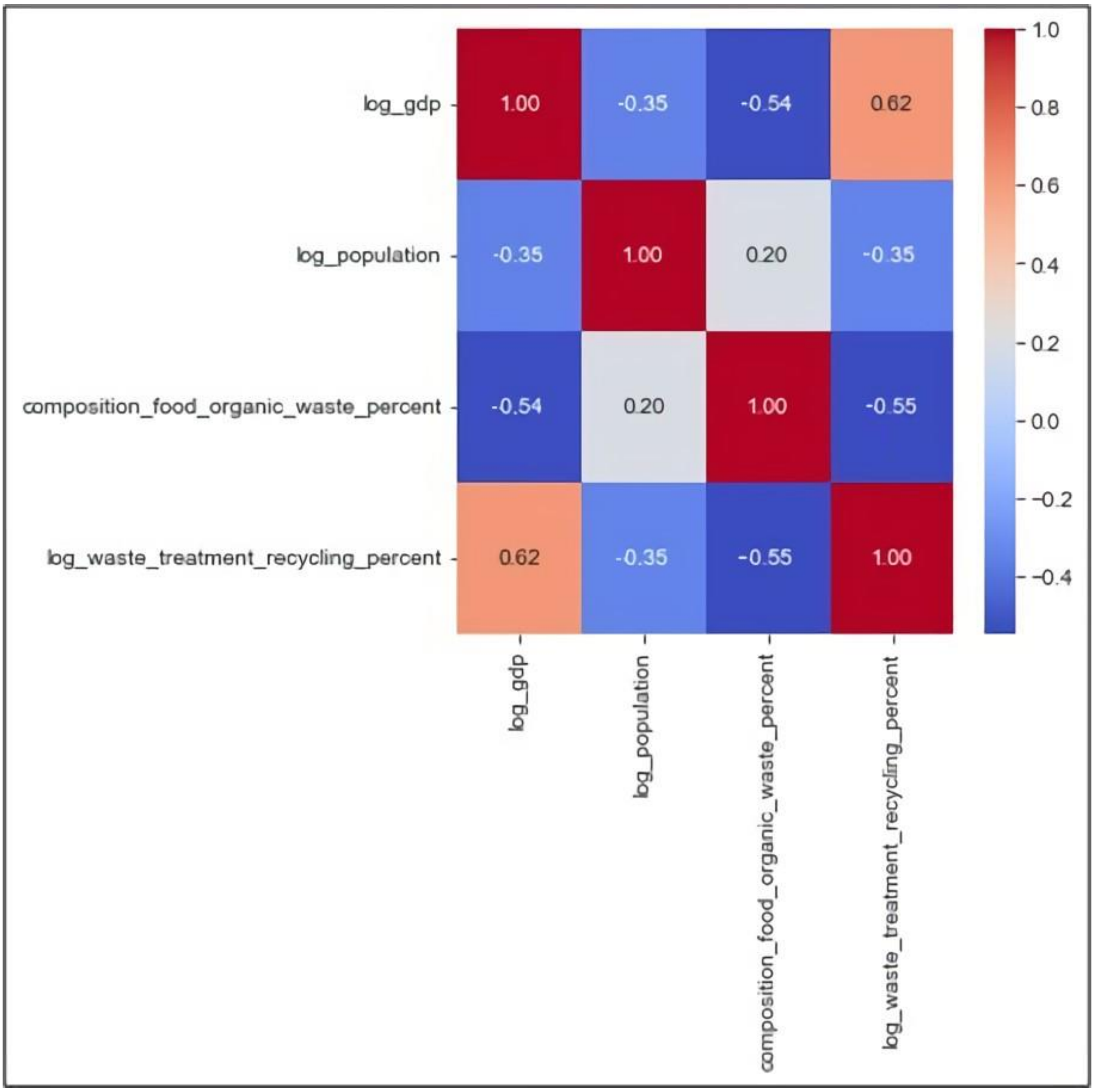

Figure 4. Correlation heat map for composition of organic waste, waste treatment recycling, population, and GDP. Source: Illustration by Authors based on data retrieved from What a Waste Global Database-Data Catalog (worldbank.org) (accessed on 24 November 2021).

According to the UN Sustainable Development Goals Report 2021, food security is one of the pillars of the United Nations 2030 Agenda for Sustainable Development Goals (i.e., SDG #2), which serves as a blueprint to achieve a better and more sustainable future for all [12]. Coupled with high levels of food waste (about one third of all food production), the continuously rising demand for energy and materials to supply the population's food demands is forcing many countries to consider the circular economy as a parsimonious solution to the food waste problem. The EU has already started to employ the Sustainable Development Goal (SDG) 12.3, which aims to reduce by half the per capita food by reducing food wastages along the food value chain, from producers to retailers and consumers. Table A1 in the Appendix A shows that the entire set of countries considered has higher levels of food waste and very low levels of waste treatment recycling.

A further observation from Table A1 is that there is a higher composition of food waste compared to the recycling efforts across all the countries in the data set. For instance, Tunisia, Thailand, Vanuatu, Uganda, Yemen, and Iran have the highest composition of organic food waste (more than 60%) and a very little percentage of recycling, indicating a need to reinforce the implementation of circular economy principles that will see higher recycling efforts.

The main aim of this bibliometric review was to study the challenges and opportunities of food waste and a circular economy. Our goals are: (1) to investigate the status quo of food waste and circular economy by reviewing previous scientific literature; (2) to investigate the main themes that arises in the application of circular economy principles; and (3) based on the themes that arise, to determine possible opportunity to implement circular economy and reduce food waste and loss.

2. Methodology

This paper reviewed the continuously growing literature on food waste and the circular economy nexus. A three-step approach was followed to collect the data sample. First, we performed a Boolean search for articles on the Scopus database using a combination of the keywords: (a) food waste = ("food waste" OR "food-waste") AND (b) circular economy = ("circular economy" OR "circular-economy"). The Scopus database search was limited to the topic, which covers the title of articles, their abstracts, and keywords. The results were then filtered by language (English), document type (articles), publication stage (final), and research areas (engineering, environmental sciences, ecology, business economics, science technology, other topics), resulting in 288 articles initially. In the second step, we removed two duplicate articles resulting in 286. In the third step (through a review by two authors), 155 out of these 286 articles were identified as relevant to the topic by reviewing their titles, abstracts, and keywords. In the final step, for these 155 articles, article title, author name(s) and affiliation, journal name, number, volume, pages, date of publication, abstract, and cited references were extracted for bibliometric analysis.

We used Microsoft Excel to generate bar charts of top 10 journals with the most citations and trend lines related to total citations and number of publications. We also used Microsoft Excel to determine the top 10 most cited authors and the top 10 most cited articles by title. As part of the visualizations, we used VOS viewer to generate a graphical visualization of clusters of keywords and a co-authorship network. The flow chart illustrated by Figure A1 in the Appendix A gives a summary of the methodology.

3. Results

3.1. Descriptive Analysis

As illustrated in Figure 5, while the number of academic publications on food waste and circular economy progressively increased from 2015 to 2021, there have been fluctuations in citations. The first article was only published in 2015. Since then, there has been an increase in broader interest in circular economy and food waste. The number of publications has been on the rise since 2015; in contrast, the number of citations on the theme has declined from 783 in 2020, to 158 in 2021, as of October 2021. A total of 155 publications were recorded from the search criteria, and the corresponding total of citations observed is 2809.

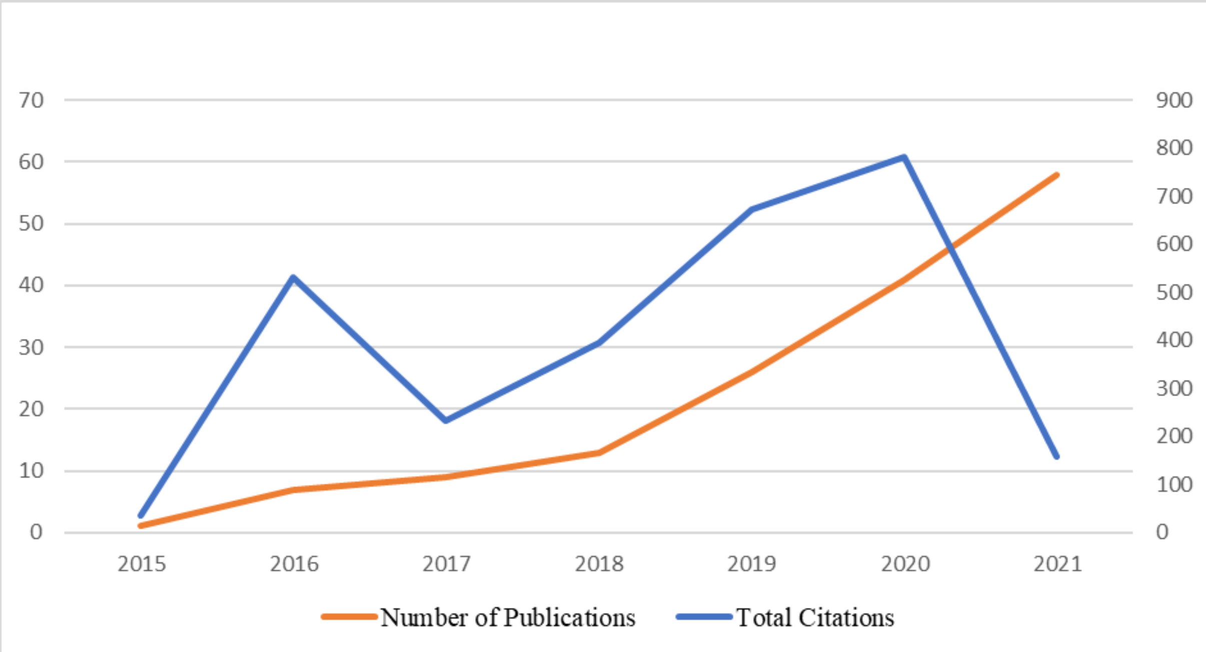

Figure 5. Academic publications on food waste and circular economy.

The increase in the number of publications from 2015 to 2021 can be due to several factors, such as the availability of funding for research projects on food waste and circular economy; the development of new policies as a result of the rising importance of the circular economy; and commitment to international and regional agreements on the move towards a circular economy, as opposed to the linear economy. However, it is not clear why the citation in 2021 is decreased. It might be linked to the COVID-19 pandemic.

Figure 6 shows publications in the top 10 journals obtained from the search, whereas the corresponding citations are presented in Figure 7. The complete yearly citations per journal, from 2015 to 2021, is Table A2.

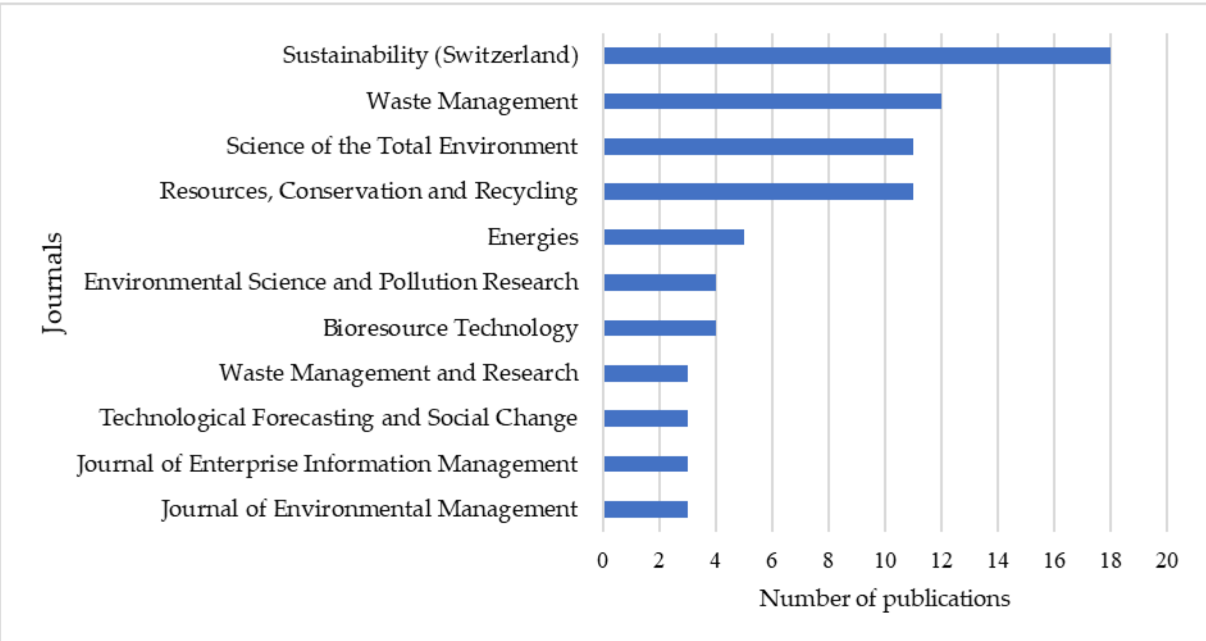

Figure 6. Top 10 journals with the highest citations.

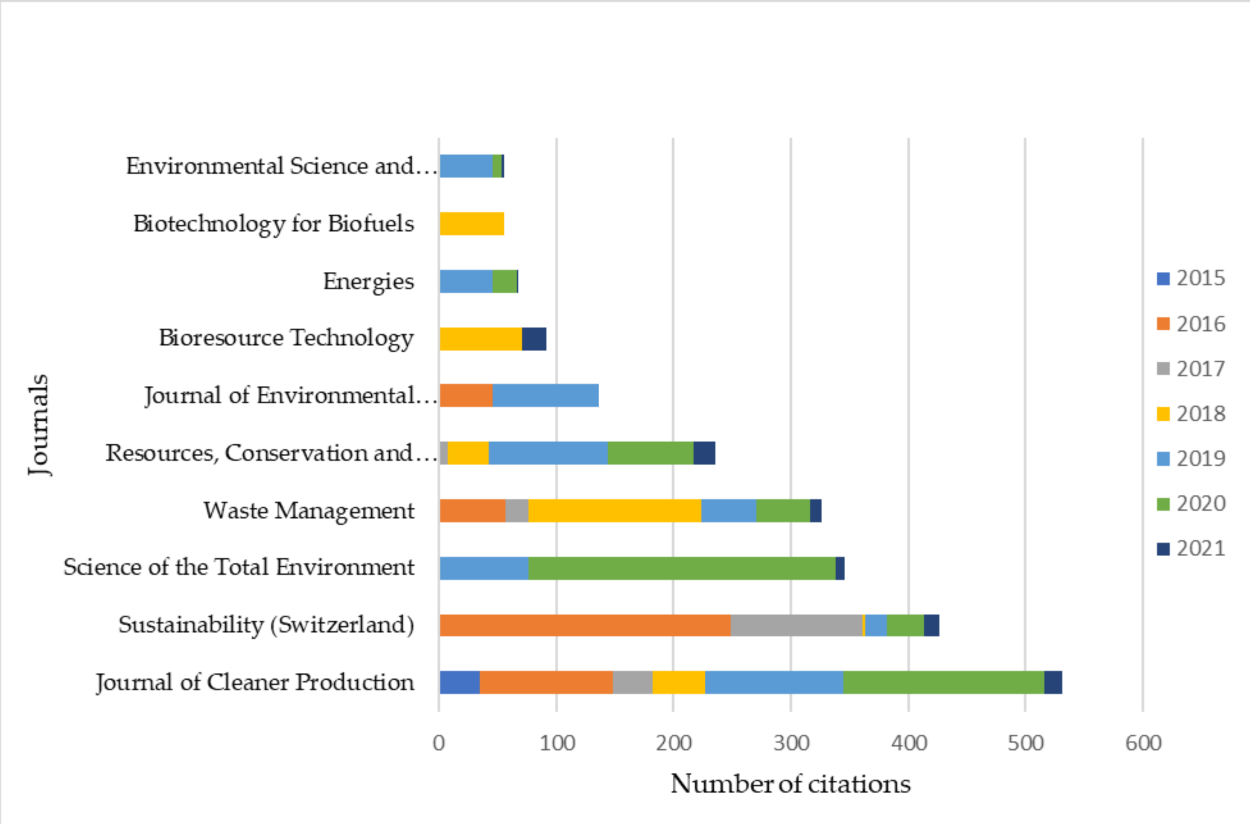

Figure 7. Citations of top 10 journals, 2015–2021.

The result shows that the journal *Sustainability* accounted for 18 publications, which is the highest compared to other journals. The least number of publications is three recorded by the journal of Waste Management and Research, Technological Forecasting and Social Change.

On the other hand, the journal of *Cleaner Production* recorded the highest citation impact, with over 500 citations in the period 2015 to 2021. Whereas, *Sustainability*, which had the highest number of publications, produced the second-highest citation impact, with over 400 citations from 2015 to 2021. The fact that these two journals have a leading citation impact is trivial, because the core of their mandate is to publish articles that address how to measure and monitor sustainability at theoretical and practical levels. Moreover, these two journals also publish articles that address waste and cleaner production; therefore, it would be odd had the results been otherwise. However, the *Environmental Science and Pollution Research* journal had the lowest citation impact from 2015 to 2021, with only about 50 citations. Notably, the journal of *Biotechnology for Biofuels* recorded citations only for the year 2018.

As shown in Table 1, the article entitled 'Transition towards a circular economy in the food system' had 204 citations, accounting for 7.2% of the total citations from 2015 to 2021. This article was published in 2016 in the journal of *Sustainability*. The article applied the circular economy phenomena in discussing the challenges and solutions at various stages of the food supply chain (from production to consumption stages). On average, there were about 18 citations per article, per journal. The top 10 researchers in the field are shown in Table 2. The authors were ranked based on the number of publications recorded, while their publications' impact is indicated by the total number of citations received.

Table 1. Top 10 most cited articles.

Title	Citations (N)	Key Findings	Ref.
Transition towards circular economy in the food system	204	A circular economy sustainability resolution should include supportive local food supply chains, pricing the actual expense of resource utilization, and making policy processes to stimulate the reduction and recovery of critical raw materials.	[13]
From the table to waste: An exploratory study on behavior towards food waste of Spanish and Italian youths	113	Behavioral models are applicable for explaining youths' behavior towards food waste. Marketing and sales tactics adversely affect conservative food waste behavior.	[14]
Consumers' perspective on circular economy strategy for reducing food waste	112	Italian households reacted positively to this study and were willing to participate in closed loops to reduce food waste actively.	[15]
Waste-to-energy nexus for circular economy and environmental protection: Recent trends in hydrogen energy	89	This paper reviewed bio-hydrogen production from waste materials and analyzed its economic aspects.	[16]
Environmental Sustainability of anaerobic digestion of household food waste	71	Electricity from anaerobic digestion (AD) of food waste has 43% lower global warming potential than the UK grid. However, it has a higher global warming potential than solar PV and wind electricity.	[17]
Techno-economic and profitability analysis of food waste biorefineries at European level	71	A techno-economic and profitability analysis of a food waste biorefinery was studied. Four relevant products were analyzed: potato, tomato, citrus, and olives. Food waste from product processing was quantified at the European level. The value-added product market price was identified as a critical element for profitability. A market analysis is necessary prior to the biorefinery implementation.	[18]
Adopting the circular economy approach on food loss and waste: The case of Italian pasta production	64	The pasta supply chain was analyzed as an example of a circular economy. 1kg of pasta produces about 1.98 kg of food loss and waste throughout its entire lifecycle. Approximately 94% of Food loss and waste per kg of produced pasta is reused in alternative sectors.	[19]
Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy	59	They created six categories distinguishing edibility and level of avoidance. Also, they expanded the waste hierarchy through material recycling and nutrient recovery.	[20]
Efficiency of a novel "Food to waste to food" system including anaerobic digestion of food waste and cultivation of vegetables on digestate in a bubble-insulated greenhouse	57	They proposed digeponics as a novel approach for processing organic waste into new food and demonstrated a new closed low-energy greenhouse system. The system was 80% energy demand reduction compared to conventional greenhouses.	[21]
Environmental and economic implications of recovering resources from food waste in a circular economy	57	They investigated and compared the anaerobic digestion, in-vessel composting, incineration, and landfill systems.	[22]

Though Slorach had the highest number of publications in terms of citation impact, Jurgilevich (Helsinki University) was the most cited with about 204 citations, followed by Slorach with 151 citations, and at the bottom of the top 10 list is Procentese (University of Manchester), with 56 citations from 2015 to 2021. It is worthy to note that the difference in citations can be attributed to journal impact factors, as well as the publication type, whether open access or otherwise. This is because Jurgilevich, with a single publication, produced the highest citation against Slorach, who had three research outputs. Nonetheless, Zhang et al. [23] argued that counting citations cannot objectively indicate the impact of authors, but Parmar et al. [24] assert that the number of citations of an author indicates the relevance of that author in the field as a result of recognition, which enhances visibility.

Table 2. Top 10 most cited authors.

Authors	Total of Citations	Number of Publications
Jurgilevich A.	204	1
Slorach P.C.	151	3
Mondéjar-Jiménez J.-A.	113	1
Borrello M.	112	1
Teigiserova D.A.	97	2
Sharma S.	89	1
Cristóbal J.	71	1
Principato L.	64	1
Stoknes K.	57	1
Procentese A.	56	1
	1014	**13**

3.2. Analysis Bibliographic Coupling

In this bibliometric review, VOSviewer software was utilized for bibliometric coupling. VOSviewer was used to make graphical mappings and illustrations of authors based on co-citation and co-occurrence data. Also, it is used to construct maps of keywords in a particular bibliometric study field. This process examines numerous shared references between two articles to measure the extent of their similarities. The software can also cluster the main themes of food waste and circular economy.

The results from keywords co-occurrence, in Figure 8, shows that the main keywords on the food waste and circular economy nexus include: food supply chain, organic waste, material flow analysis, environmental impact, sustainable development recovery, and food loss.

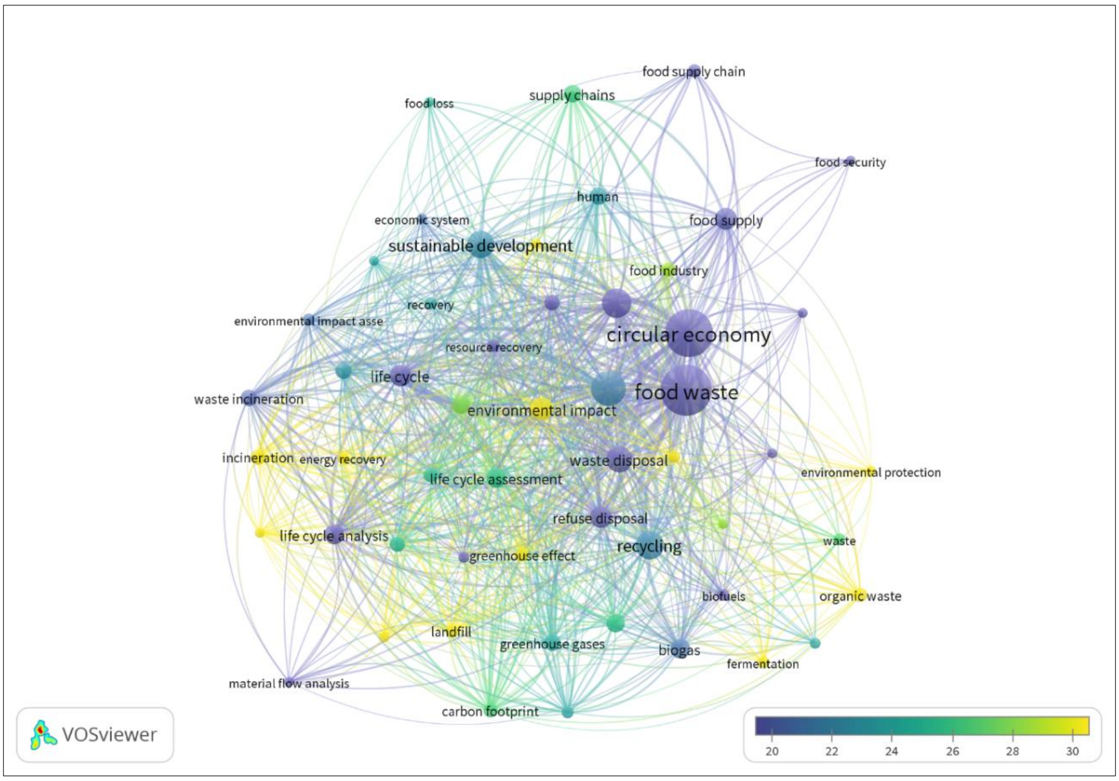

Figure 8. Network of co-occurrence of keywords in the field of food waste and circular economy.

Figure 9 illustrates the co-authorship network from 2015 to 2021, and the colors of the nodes reveal the publication year of the articles. The figure shows more network linkages in yellow color, indicating an increase in citations/authorship activity from 2021.

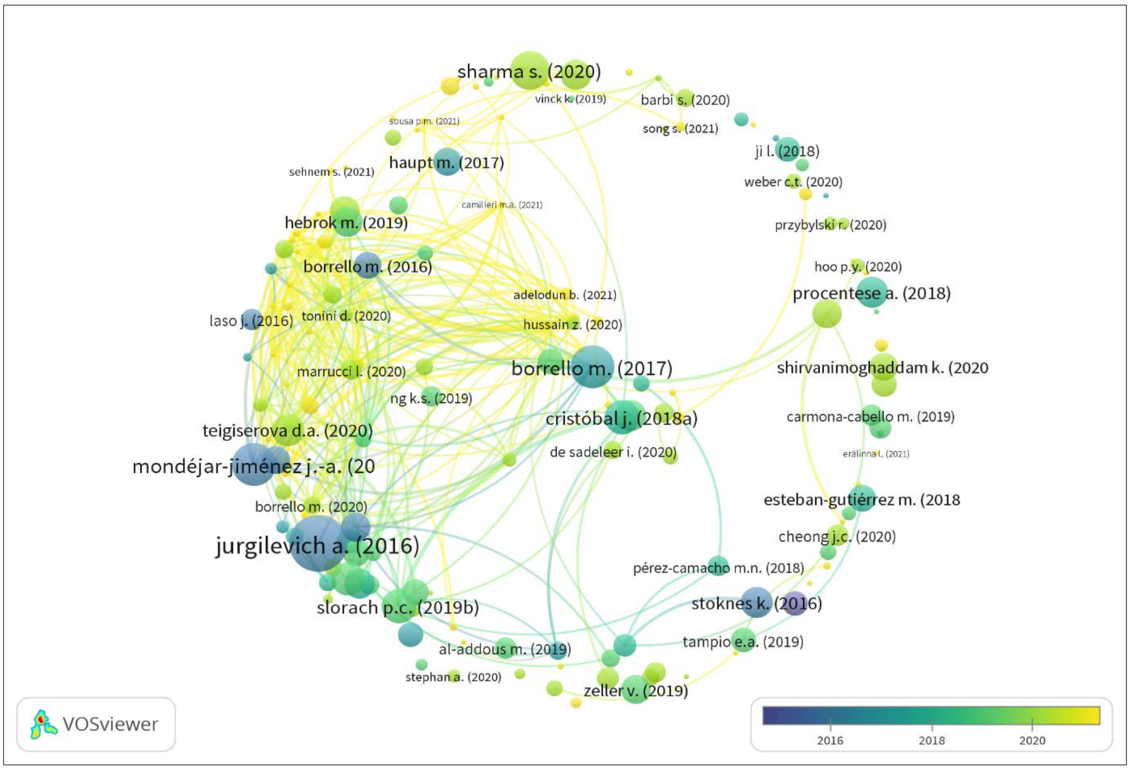

Figure 9. Co-authorship network of authors with a minimum of one publication and at least 10 citations during 2015–2021.

All articles were analyzed irrespective of the number of citations. This process attributed a minimum of five articles per cluster. The 155 articles formed eight clusters, as shown in Table 3 below.

Table 3. Authors per eight clusters identified from n = 155 articles.

Cluster 1 (n = 34)	**Cluster 2 (n = 29)**	**Cluster 3 (n = 17)**	**Cluster 4 (n = 16)**	**Cluster 5 (n = 15)**
Al-Addous et al. (2019) [25]	Albizzati et al. (2021) [26]	Boccia et al. (2019) [27]	Barbi et al. (2020) [28]	Aschemann-Witzel et al. (2021) [29]
Allegue et al. (2020) [30]	Alias et al. (2021) [31]	Buss (2019) [32]	Borrello et al. (2017) [15]	Bhakta Sharmaet al. (2021) [33]
Cărpuş et al. (2020) [34]	Badgett et al. (2021) [35]	Campagnaro et al. (2017) [36]	Borrello et al. (2016) [37]	Coderoni et al. (2021) [38]
Cecchi et al. (2019) [39]	Brenes-Peralta et al. (2020) [40]	Chang et al. (2018) [41]	Carmona-Cabello et al. (2019) [42]	Coderoni et al. (2020) [43]
Chen H. et al. (2019) [44]	Cristóbal et al. (2018) [18]	Cicculllo et al. (2021) [45]	Cristóbal et al. (2018) [46]	Dora et al. (2020) [47]
Chen T. et al. (2020) [48]	de Sadeleer et al. (2020) [49]	de Souza et al. (2021) [50]	Czekala et al. (2020) [51]	Fassio et al. (2019) [52]
Cheong et al., (2020) [53]	Edwards et al. (2017) [54]	Erälinna et al. (2021) [55]	Ebeneezar et al. (2021) [56]	Holmberg & Ideland (2021) [57]

Table 3. *Cont.*

Cluster 1 (n = 34)	Cluster 2 (n = 29)	Cluster 3 (n = 17)	Cluster 4 (n = 16)	Cluster 5 (n = 15)
Dora et al. (2021) [58]	Fujii et al. (2018) [59]	Hamam et al. (2021) [60]	Gligorescu et al. (2020) [61]	Kakadellis et al. (2021) [62]
Esteban-Gutiérrez et al. (2018) [63]	Garske et al. (2020) [64]	Ji L. et al. (2018) [65]	Hussain et al. (2020) [66]	Kazancoglu et al. (2021) [67]
Fuldauer et al. (2018) [68]	Gómez-Sagasti et al. (2021) [69]	Marino & Pariso (2020) [70]	Jagtap et al. (2021) [71]	Leipold et al. (2021) [72]
Hoo et al. (2020) [73]	Guerra-Oliveira et al. (2021) [69,74]	Neves et al. (2019) [75]	Lee et al. (2021) [76]	Moggi et al. (2021) [77]
Irani et al. (2018) [78]	Haupt et al. (2017) [79]	Oyelola et al. (2017) [80]	Ncube et al. (2021) [81]	Sousa (2021) [82]
Keng et al. (2020) [83]	Hoehn et al. (2019) [84]	Procentese et al. (2018) [85]	Przybylski et al. (2020) [86]	Spartano et al. (2021) [87]
Khatami et al. (2021) [88]	Johansson (2021) [89]	Russo et al. (2019) [90]	Sadhukhan et al. (2020) [91]	Usmani et al. (2021) [92]
Kliopova et al. (2019) [93]	Jurgilevich et al. (2016) [13]	Shirvanimoghaddam et al. (2020) [94]	Sharma (2020) [16]	Yakovleva et al. (2021) [95]
Moretto et al. (2020) [96]	Kowalski et al. (2021) [97]	Trento et al. (2021) [98]	Song et al. (2021) [99]	
Moure et al. (2021) [100]	La Scalia et al. (2021) [101]	Umeda et al. (2020) [102]	Weber et al. (2020) [103]	
Pap et al. (2020) [104]	Laso et al. (2018) [105]	Zilia et al. (2021) [106]		
Paul et al. (2018) [107]	Laso et al. (2018) [108]			
Pérez-Camacho et al. (2018) [109]	Matrapazi et al. (2020) [110]			
Principato et al. (2019) [19]	Oldfield et al. (2016) [111]			
Provin et al. (2021) [112]	Patel et al. (2021) [113]			
Rolewicz-Kalińska et al. (2020) [114]	Schmidt Rivera et al. (2020) [115]			
Secondi et al. (2019) [116]	Slorach et al. (2019) [17]			
Siddiqui et al. (2021) [117]	Slorach et al. (2019) [22]			
Slorach et al. (2020) [118]	Tedesco et al. (2019) [119]			
Stoknes et al. (2016) [21]	Tonini et al. (2020) [120]			
Tampio et al. (2019) [121]	Wohner et al. (2020) [122]			
Udugama et al. (2020) [123]	Yeo et al. (2019) [124]			
Uwineza et al. (2021) [125]				
Valentino et al. (2021) [126]				

Table 3. *Cont.*

Cluster 1 (n = 34)	Cluster 2 (n = 29)	Cluster 3 (n = 17)	Cluster 4 (n = 16)	Cluster 5 (n = 15)
Wilinska-Lisowska et al. (2021) [127]				
Woodard et al. (2021) [128]				
Woon et al. (2021) [129]				
Cluster 6 (n = 14)	**Cluster 7 (n = 11)**	**Cluster 8 (n = 9)**		
Adelodun et al. (2021) [130]	Agapios et al. (2020) [131]	Borrello et al. (2020) [132]		
Amicarelli et al. (2021) [133]	Aramyan et al. (2021) [134]	Cooper et al. (2017) [135]		
Andreopoulou (2017) [136]	Bas-Bellver et al. (2020) [137]	Fogarassy et al. (2020) [138]		
Batista et al. (2021) [139]	Camilleri (2021) [140]	Marrucci et al. (2020) [141]		
Gretzel et al. (2019) [142]	Ezeudu et al. (2021) [143]	Miliute-Plepiene & Plepys (2015) [144]		
Gruia et al. (2021) [145]	Loizia et al. (2019) [146]	Mylan et al. (2016) [147]		
Hebrok et al. (2019) [148]	Manca et al. (2020) [149]	Rijal et al. (2021) [150]		
Kuisma et al. (2017) [151]	McCarthy et al. (2019) [152]	Stephan et al. (2020) [153]		
Lang et al. (2020) [154]	Ng et al. (2019) [155]	Zeller et al. (2019) [156]		
Mondéjar-Jiménez et al. (2016) [14]	Rashid et al. (2021) [157]			
Mu'azu et al. (2019) [158]	Vinck et al. (2019) [159]			
Sarti et al. (2017) [160]				
Teigiserova et al. (2020) [20]				
Teigiserova et al. (2019) [161]				

4. Discussion

Based on the articles in the clusters, we provide an overview and discussion on the main themes.

- **Theme 1: Anaerobic Digestion of Food Waste for the creation of a circular economy**

One efficient use of food waste recorded in the articles reviewed is fertilization, which has been an increasing focus of research in recent years. According to the literature studies, the method utilized in producing fertilizer from food waste has been anaerobic digestion. The food waste is broken down in this process, releasing biogas, while producing organic matter, thereby contributing to a circular economy. Pérez-Camacho et al. [109] investigated the lifecycle environmental impacts of substituting feedstock with food waste in traditional anaerobic digestion. They found out that the substitution resulted in less green house gas emissions (GHG) and argued that this benefits the circular economy policies, especially the tax on landfilling with food waste. In another study reported by Stoknes et al., a novel technological approach was developed for processing organic waste into new food [21]. Organic waste is first converted into digester residue, subsequently used as the main mushroom and vegetable fertilizer component. As a result of using the digestate and substrate as a fertilizer for the first time, the commercial crops produced higher yields. To corroborate the study of Stoknes et al. [21], there was an investigation by Cheong et al. [53], in which the use of food waste as a digestate fertilizer for the cultivation of leafy vegetables was studied. The result showed improved yields when food waste was used as a digestate fertilizer, and also observed an increase in chlorophyll content. More recent studies have investigated the bioconversion of food waste into fatty acids [88,121,125,126]. They argued that bioconversion of food waste through anaerobic digestion is an invaluable aspect of the circular economy, and supports the implementation of a food waste management hierarchy.

- **Theme 2: Food Waste Systems and Life Cycle Assessment in the Circular Economy**

Literature on this theme offers direction on the lifecycle assessment of food waste, and the challenges that impede attempts to employ closed-loop designs in food waste management. Kowalski et al. [97] carried out a study that quantified material recovery from meat waste in incineration. They used a material flow analysis approach to assess the incineration process of creating hydroxyapatite (HA) ash from meat bone waste. They also suggest that the recovery of HA can be used to produce food-grade phosphoric acid, and the production of food-grade mono and di-calcium feed phosphates. Tonini et al. [120] reported that food waste constitutes the largest proportion of the municipal waste generated in Europe, and quickly pointed out that suboptimal environmental performance is associated with its management. They quantify the sustainability and investigate five alternative household food waste management scenarios for the case of the Amsterdam metropolitan area. Their results indicate that separate collection of food waste and anaerobic digestion are the most preferred strategies to improve the sustainability and circular economy. Results from de Sadeleer et al. [49] analyzed and compared two waste management systems for household food waste: recycling by anaerobic digestion and incineration. Their study employs material flow analysis in combination with lifecycle analysis. They found that recycling food waste using anaerobic digestion performs better in recycling rates and GHG emissions than incineration. In a similar manner, Laso et al. [108], Haupt et al. [79], and Edwards et al. [54] all investigated the lifecycle component of the food waste and circular economy nexus. These studies highlight the challenge that food waste systems are incapable of quantifying the efficiency of a system to turn food waste into a valuable resource.

- **Theme 3: Bio-Based circular economy approaches**

In contrast to theme 1, which considered how to deal with waste disposal by using aerobic digestion, this theme examines how to turn low-value waste into high-value food ingredients. For example, Jagtap et al. [71] studied the use of black soldier fly larvae (BSFL) as a bioreactor to convert organic food waste into high-value animal feeds. They postulated that zero waste could be achieved by localized conversion of in-field crop losses to an animal feed using BSFL, which offers opportunities to develop a circular economy. Other studies that investigated converting low-value waste to high-value waste include Przybylski et al. [86], and Song et al. [99]. In the same line of thought, Ebeneezar et al. [56] conducted a systematic evaluation investigating how including food waste can be converted through biological processes into proteins and lipid-rich animal feeds. They concluded that sustainability targets could be achieved by adopting innovative and cost-effective technologies for rearing BSFL.

Moreover, they assert that using BSFL for food valorization would help stem climate change and provide a pathway towards achieving a green and circular bio-economy. Furthermore, Barbi et al. [28] investigated the use of insects for the valorization of seasonal agri-food. Their study aimed to investigate "specific combinations of agri-food leftovers, focusing on their availability in a defined geographical area (Regione Emilia-Romagna, Italy), as rearing substrates for Black Soldier Fly (BSF) larvae". They concluded that the use of BSF in bioconversion of food waste could be improved by "using tailored combinations of available leftovers, calculated through Mixture Design, thus overcoming the negative effects of nutritionally unbalanced substrates".

- **Theme 4: Consumer's behavior, attitudes towards circular economy**

Consumers' behavioral responses toward food waste, interest in the circular economy concept, and cultural norms, are essential indicators of whether circular economy initiatives will succeed [162]. In other words, for a circular economic agenda to be promoted, advanced and actualized changes are required from the consumers themselves. In support of these assertions, Borrello et al. [15] hypothesized that consumer willingness is important in closed food loops to reduce food waste. In their study, the questionnaire methodology approach was adopted to gather knowledge and establish an understanding of consumers' attitudes towards active participation in a circular economy. They found out that many consumers were willing to participate in a circular designed loop. Interestingly, it was discovered that some reward schemes, such as an increase in discounts of animal products, indicated a positive willingness of consumers to take part in a circular economy. This suggests that consumers need to be motivated through incentives/rewards in order to participate in a circular designed loop.

On the contrary, consumers indicated that they are ready to give away a significant portion of the discount in exchange for collecting organic waste from their homes, instead of bringing the organic waste to retailers. In a complementary study, Sadhukhan et al. investigated the life cycle environmental impacts of moving from livestock to a plant-based diet [91]. Their analysis indicated that the highest environmental impact saving could be achieved through the displacement of livestock by plant-based (beans and lentils), for protein sourcing. This suggests that consumers should be encouraged to adopt more vegan/vegetarian diets instead of meat-based ones. Through an exploratory approach, Sousa et al. investigated consumers' perception of the circular economy to identify consumers' recognition of products from the food industry [82]. Their results suggested lack of a clear understanding of consumers' attitudes towards the circular economy, hence a need to promote and disseminate circular economy principles to the general populous for better integration, participation, and acceptance. In another study by Aschemann et al. the consumers' perspective on the upcycle by-product use in agri-food systems was investigated [29]. They found that the acceptance of waste-to-value food products among consumers depends on the individual person, the context, and the product. An interesting study by Coderoni et al. analyzed millennials' willingness to buy food with upcycled ingredients [38]. They argue that upcycled food as a new food category faces several challenges in the food waste management hierarchy, and is not readily accepted by the public.

- **Theme 5: Food Supply Chain and Food Waste in the Circular Economy**

This section will cover literature that examines food waste as it is produced, processed, distributed, retailed, and consumed, along the food value chain. The food value chain also consists of all other key stakeholders, such as policy makers who influence food waste along the food value chain. Dora et al. investigated the leading causes of food loss and waste along the food value chain [58]. They proposed and developed a waste utilization framework through the circular economy and proposed a model for achieving depollution. Batista et al. identified the barriers to implementing circular in the food supply chain [139]. Moreover, they underscored the importance of digital technologies, such as blockchains to removing circular economy barriers in the food supply chain. A performance evaluation study by Kazancoglu et al. showed that reverse logistics activities in the food supply chain could contribute to green performance by reducing food waste and losses [67]. The authors argue that companies must distinguish between value-adding and non-value-adding activities, and should set targets to reduce the non-value activities of the reverse-logistics processes, such that environmental impacts are reduced. Other investigations which focused on the interrelations of the food supply chain and the circular economy were conducted by Russo et al. [90], and Secondi et al. [116]. Respectively, these studies investigated the use of waste products in closed-loop supply chains, reuse of food waste in manufacturing, and the recovery and optimal design of the food value chain for sustainability.

- **Theme 6: Material flow analysis and sustainability**

This theme addresses material flow analysis as a method that can be implemented to manage natural resources, co-products, and by-product valorization. The Italian meat industry accounts for 15% of national agri-food value and produces different types of waste, of which food loss and waste constitute a substantial and increasing proportion [133]. The authors concluded that material flow analysis assists in the analysis of material cycles and eco-efficiency indicators, and in assessing the efficiency and circularity of agri-food systems. Andreopoulou documented that in view of attaining sustainability, food actors need to adopt digital sharing platforms such as the "Internet of Things" (IoT) to promote a circular economy [136]. Gretzel et al. pointed out that the environmental sustainability of tourist destinations is an issue of concern, because of increasing food waste in the tourism sector [142]. Hebrok and Heidenstrøm [148] investigated how the material infrastructure of food handling practices presents opportunities for reducing food waste. They focused on five food handling practices that cause food waste: acquiring, storing, assessing, valuing, and eating. Teigiserova [161] conducted a systematic review that focused on the use of inedible and unavoidable food residues and waste that can be used in the production of bio-based compounds, which could substitute synthetic chemicals.

- **Theme 7: Challenges, policies and practices to achieve circularity**

This theme focuses on the challenges, policies, and practices that can be put into practice to achieve circularity. Camilleri [140] argued that there is scope for regulatory authorities and policymakers to encourage hospitality practitioners to engage in a circular economy. Their study suggested that catering businesses can implement several responsible initiatives by introducing preventative measures and recycling practices to curb food loss and waste. McCarthy et al. [152] discussed the challenges of waste management in the horticultural sector and presented the circular economy as a possible solution to curbing food waste. They specifically focused on value adding as a potential remedy to transform food waste for reuse. Bas-Bellver et al. [137] studied revalorizing vegetable waste (carrot, leek, celery, and cabbage) from the fresh and ready-to-eat lines of the cooperative into functional ingredients. They used hot air drying or freeze drying, and considered other factors, like storage conditions, before drying. They obtained about 25 vegetable powders, and hot air drying produced stable powders, which could then be used in the food industry as coloring and flavoring. Loizia et al. [146] investigated how the circular economy can be applied in optimizing the production of biogas using food waste. Their study is important in encouraging the use of food waste in treatment plants, diversion of food waste from landfills, and the use of food waste as a secondary energy resource.

- **Theme 8: Circular economy and patterns of consumption**

This theme summarizes the nexus between consumption patterns that can foster circular economy practices. Fogarassy et al. [138] studied the pro-circular behavior that can increase the consumption of organic food. Mylan et al. [147] argued that it is important to understand why people use or consume particular goods or services, how this might be altered, and what drives waste production. Central to their study is the mobilization of insights from a socio-technical perspective on consumption, which underscores interactions between routine activities, mundane technologies, and culture in reproducing patterns of consumption. Another important aspect is to gain insights into how carbon footprint could be used to understand the tendencies of sustainable consumption better [141].

5. Limitations of the Study

This bibliometric review considers literature within the confines of the criteria used to search for articles in the Scopus database. This implies that the Boolean search criteria used do not permit the generalizations of results out of the scope of the study. Furthermore, the bibliometric review considered the final version of published journal articles. There is a possibility to search further for articles not in a final publishable state, and for conference papers and reports. Further studies may also expand the search scope and include granulated aspects of food waste recycling such as 'anaerobic digestion and food waste', 'food valorization and circular economy' etc. Furthermore, studies with resources could consider using other databases such as the Web of Science.

6. Conclusions and Way Forward

There is a severe food security challenge due to surging demand as the world population grows. The FAO predicted that the world population will grow by over a third (around 2.3 billion people by the year 2050), with the fasted growth rate of 110 percent being experienced in sub-Sahara Africa. On the other front, rising food waste is challenging worldwide. FAO also indicated that almost one-third of food produced is wasted yearly, with about 1.3 million tons of food waste and loss at various stages of the food supply chain [1]. On the other hand, about 3.3 billion tons of carbon dioxide emissions are produced from food waste. Therefore, the pressure that the growing population mounts on world food production systems, the greenhouse emissions associated with food waste and loss, and the volume of food waste, requires urgent adoption of sustainable food production techniques to ensure sustainable consumption paths and climate mitigation. A plausible solution is to implement the circular economy principles, which offer closed loop designs to recycle food waste, mitigate climate change due to greenhouse emissions from food waste, and achieve zero waste targets.

Based on the discussion of the main themes of the existing literature, we observed that the majority of the studies were carried out in developed countries. However, food security is a topical issue for developing countries, with sub-Saharan Africa having the highest population growth of around 110% by 2050. Moreover, most studies lack a gender dimension in understanding consumer perspectives and behavior towards circularity. A gender and age lens on circularity could help target policies to different demographic groups. Furthermore, we recommend the consideration and proper definition of the upcycled food category and stakeholder engagement to speed up its uptake and acceptability by the public.

Moreover, the fourth industrial revolution comes with opportunities for optimally using technology and digitization to overcome some barriers that inhibit the implantation of the circular economy. Blockchain technology is one point of departure that can offer transparency and traceability in the food supply chain and can be used to trace food losses, wastages, and fraud, from the farm to the fork. Another critical dimension is the interrelationship between the circular economy and the food value chain. Further studies need to quantify value-adding and non-value adding activities, from the farm to the retailers along the food value chain. This will help estimate levels of greenhouse gases associated with the volumes of food loss and waste for the two activities at every stage of the food supply chain.

Author Contributions: Conceptualization P.T., H.O. and T.M.; methodology, P.T.; software, P.T. and T.M.; writing—original draft preparation, P.T.; writing—review and editing, P.T., T.M., A.H. and H.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

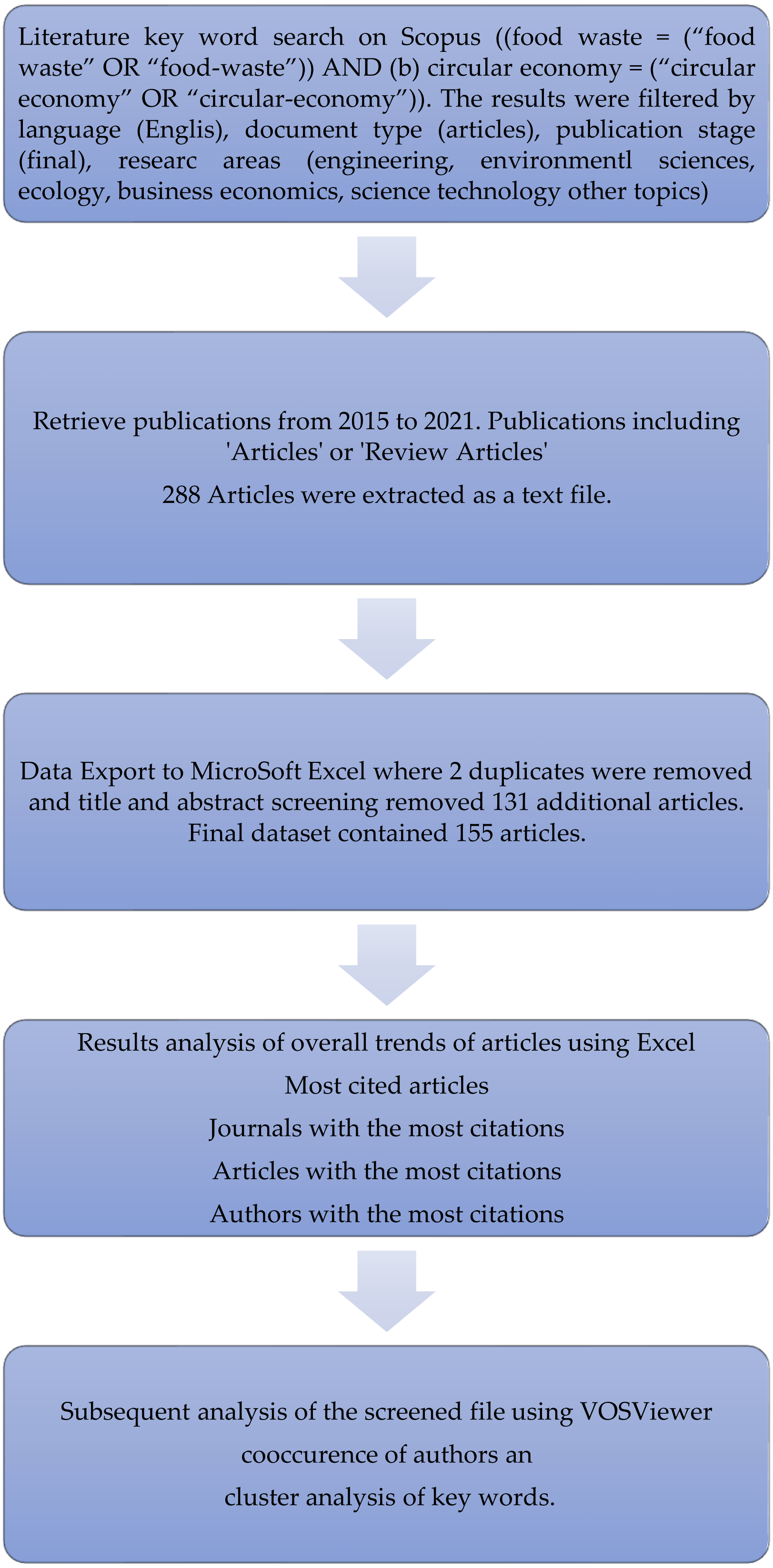

Figure A1. Flow chart of the methodology.

Table A1. Food waste and recycling across countries.

Country	Waste Treatment Recycling in Percentage	Composition of Food Organic Waste in Percentage
Liechtenstein	64.6	37.6
Singapore	61.0	10.5
Korea. Rep.	58.0	30.0
Iceland	55.8	10.0
Germany	47.8	30.0
San Marino	45.1	5.4
Australia	42.1	48.4
French Polynesia	39.0	47.0
Vanuatu	37.0	73.4
Samoa	36.0	42.6
Northern Mariana Islands	36.0	43.6
United States	34.6	14.9
Belgium	34.3	14.2
Hong Kong SAR. China	34.0	35.0
Ireland	33.0	16.6
Sweden	32.4	23.3
Switzerland	32.0	29.0
Marshall Islands	30.8	8.0
Luxembourg	28.4	30.0
Finland	28.1	35.9
South Africa	28.0	1.6
Philippines	28.0	52.3
Denmark	27.3	12.8
United Kingdom	27.3	16.7
Poland	26.4	37.3
Norway	26.2	15.5
Hungary	25.9	22.5
Italy	25.9	34.4
Austria	25.7	31.4
Czech Republic	25.5	62.3
Israel	25.0	34.0
Benin	25.0	52.1
Estonia	24.7	36.7
Netherlands	24.6	35.0
Vietnam	23.0	61.9
Lithuania	22.9	40.4
France	22.3	32.0
Latvia	21.2	46.7
Cayman Islands	21.0	10.9
Canada	20.6	24.0

Table A1. *Cont.*

Country	Waste Treatment Recycling in Percentage	Composition of Food Organic Waste in Percentage
Macao SAR. China	20.0	3.1
United Arab Emirates	20.0	39.0
Thailand	19.1	65.5
Bulgaria	19.0	24.4
Greece	19.0	40.0
Guam	17.9	27.3
Malaysia	17.5	46.0
Colombia	17.2	59.6
Spain	16.8	49.0
Croatia	16.3	30.9
Portugal	16.2	36.5
Belarus	16.0	30.0
Zimbabwe	16.0	36.0
Moldova	15.3	55.0
Tuvalu	15.0	43.6
Saudi Arabia	15.0	45.5
Puerto Rico	14.0	13.1
Cyprus	13.3	41.5
Ecuador	12.9	58.7
Sri Lanka	12.8	62.0
Egypt. Arab Rep.	12.5	56.0
Bolivia	12.1	5.5
Burkina Faso	12.0	21.0
Lao PDR	10.0	16.9
Cuba	9.5	68.9
Barbados	9.0	18.3
Dominican Republic	8.2	51.0
Mauritania	8.0	4.8
Pakistan	8.0	30.0
Lebanon	8.0	52.5
Uruguay	8.0	53.5
Algeria	8.0	54.4
Kenya	8.0	57.0
Bahrain	8.0	59.1
Morocco	8.0	60.0
Yemen. Rep.	8.0	65.0
Slovak Republic	7.6	42.0
Jordan	7.0	50.0
Indonesia	7.0	53.8
Malta	6.7	52.0

Table A1. *Cont.*

Country	Waste Treatment Recycling in Percentage	Composition of Food Organic Waste in Percentage
Argentina	6.0	38.7
Uganda	6.0	74.5
Romania	5.7	56.3
Fiji	5.5	33.2
Montenegro	5.4	33.8
Mexico	5.0	52.4
Guinea	5.0	58.0
Iran. Islamic Rep.	5.0	72.9
Japan	4.9	36.0
Russian Federation	4.5	28.4
Niger	4.0	38.0
Peru	4.0	50.4
Tunisia	4.0	68.0
Ukraine	3.2	37.0
Qatar	3.0	57.0
Kazakhstan	2.9	30.0
Syrian Arab Republic	2.5	57.0
Bermuda	2.0	17.0
Papua New Guinea	2.0	31.0
Togo	2.0	38.0
Brazil	1.4	51.4
Costa Rica	1.3	58.0
Botswana	1.0	8.1
Mozambique	1.0	60.0
Bhutan	0.9	58.0
Serbia	0.8	37.6
Guyana	0.5	50.1
West Bank and Gaza	0.5	59.1
Cameroon	0.4	83.4
Chile	0.4	53.3
Macedonia. FYR	0.2	29.3

Source: Illustration by authors based on data retrieved from What a Waste Global Database-Data Catalog (worldbank.org) (accessed on 7 July 2022).

Table A2. Yearly citations per journal from 2015 to 2021 (Scopus).

	Year of Citations							
Journal	2015	2016	2017	2018	2019	2020	2021	Total Citations Per Journal
Journal of Cleaner Production	35	113	34	45	118	171	15	531
Sustainability (Switzerland)		249	112	2	19	31	14	427
Science of the Total Environment					76	262	8	346

Table A2. *Cont.*

	Year of Citations							
Journal	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Total Citations Per Journal**
Waste Management		57	19	147	47	46	10	326
Resources, Conservation and Recycling			7	35	102	73	18	235
Journal of Environmental Management		46			90			136
Bioresource Technology				71			20	91
Energies					46	20	2	68
Biotechnology for Biofuels				56				56
Environmental Science and Pollution Research					46	7	2	55
Water Research						46		46
International Journal of Life Cycle Assessment			44				1	45
Journal of Enterprise Information Management				15		28		43
Recent Patents on Food, Nutrition and Agriculture		42						42
GCB Bioenergy					35			35
The Science of the total environment						33		33
Waste Management and Research		25			2		1	28
Fuel					24			24
Resources, Conservation and Recycling: X					24			24
Business Strategy and the Environment							22	22
Land						18		18
Waste and Biomass Valorization				14			2	16
Food and Bioproducts Processing						15		15
International Journal of Environmental Research and Public Health					13			13
Rural Society					13			13
Journal of Material Cycles and Waste Management					12			12
Industrial Marketing Management							11	11
Agronomy						10		10
Food Chemistry						10		10
Proceedings of Institution of Civil Engineers: Energy				10				10
Economics and Policy of Energy and the Environment			9					9
Frontiers in Chemistry					7			7
Journal of Hazardous Materials							7	7
Chemosphere							6	6
Scientific Reports						6		6
Tourism Review						5		5
Rivista di Studi sulla Sostenibilita			4					4

Table A2. *Cont.*

Journal	Year of Citations							
	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Total Citations Per Journal**
Sustainable Production and Consumption							4	4
Technological Forecasting and Social Change							4	4
Frontiers of Environmental Science and Engineering							3	3
Ecological Economics							2	2
Energy							2	2
Management of Environmental Quality: An International Journal							2	2
Procedia Environmental Science, Engineering and Management			2					2
Biomass and Bioenergy						1		1
Environmental Quality Management							1	1
Future Foods							1	1
International Journal of Food Design			1					1
Journal of Ecological Engineering						1		1
Environmental Science and Policy								0
Environmental Technology and Innovation								0
Food Technology								0
Foods								0
Industria Textila								0
International Journal of Automation Technology								0
Journal of Environmental Chemical Engineering								0
Journal of Material Culture								0
Microorganisms								0
Processes								0
Quality—Access to Success								0
Resources Policy								0
Total Citations Per Year	**35**	**532**	**232**	**395**	**674**	**783**	**158**	**2809**

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