sustainability

MDPI

Review

Digitalization and Digital Applications in Waste Recycling: An Integrative Review

Neslihan Onur [1], Hale Alan [2,*], Hüsne Demirel [3] and Ali Rıza Köker [4]

[1] Department of Gastronomy and Culinary Arts, Manavgat Faculty of Tourism, Akdeniz University, Antalya 07600, Turkey; neslihanonur@akdeniz.edu.tr
[2] Manavgat Faculty of Social Sciences and Humanities, Akdeniz University, Antalya 07600, Turkey
[3] Department of Social Work, Faculty of Health Sciences, Gazi University, Ankara 06490, Turkey; husnedem@gazi.edu.tr
[4] Turkish Patent and Trademark Office, Ankara 06560, Turkey; alikoker@gmail.com
* Correspondence: halealan@akdeniz.edu.tr; Tel.: +90-0534-551-06-10

Abstract: The rapid growth of urbanization and industrialization has brought the issue of waste management to the forefront. Industrial, household, and medical waste management and disposal are major issues affecting the whole world. The adoption of digital technologies across society is largely a result of the increasing processing power of waste and decreasing costs. Waste management and recycling is also benefiting from emerging digital technologies. The Internet of Things, cloud computing, artificial intelligence, robotics, and data analytics are a few examples of specific digital technologies that are currently in use and are predicted to have a significant impact on the efficiency of the waste recycling industry in the future. The objective of this review, which was conducted using the bibliometric method and visualized with scientific mapping, is to demonstrate how the digital transformation of waste recycling has evolved over the last decade and to identify which issues have been overlooked or have become more prominent. The scope of the research is based on studies carried out all over the world and on digital applications and works in the field of waste recycling. In this review, bibliometric analysis was used to scan the entire field and the results were classified and interpreted according to the PRISMA (preferred reporting of systematic reviews and meta-analyses) methodology.

Keywords: waste recycling; waste management; digitalization; mobile application; internet + recycling

check for updates

Citation: Onur, N.; Alan, H.; Demirel, H.; Köker, A.R. Digitalization and Digital Applications in Waste Recycling: An Integrative Review. *Sustainability* **2024**, *16*, 7379. https://doi.org/10.3390/su16177379

Academic Editor: Paolo S. Calabrò

Received: 31 July 2024
Revised: 19 August 2024
Accepted: 24 August 2024
Published: 27 August 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In recent years, there has been an increase in waste management practices as part of sustainability activities. The main reason for this is the emergence of legal obligations to recycle and dispose of the waste produced by manufacturers and the spread of businesses that generate income from using waste. While developing countries still use the landfill method, developed countries recycle almost all their waste to produce raw materials and energy. Although the number of studies on waste management has increased all over the world, the use of technology and digitalization in waste management and recycling has not reached a sufficient level. A total of 2.1 billion tons of municipal solid waste will be generated globally each year [1]. Traditional waste collection systems are becoming increasingly inefficient and expensive as population growth and rapid urbanization lead to massive increases in waste generation. The widespread practice of open dumping in many parts of the world makes solid and liquid waste from households, businesses, consumption, and construction a source of danger and potential environmental damage. The concept of zero waste, which is a current approach to waste management, is being adopted more and more every day, and many countries around the world have defined their zero waste strategies and visions [2].

The advent of an increasingly digitalized 21st century is affecting every aspect of daily life, including the environmental technology sector. The utilization of digital technologies offers more effective waste management practices. The term "digitalization" refers to the method of employing digital technologies to enhance organizational processes. Examples of digital technology include facial recognition, blockchain, Internet of Things applications, and the use of artificial intelligence [3,4]. The implementation of these measures will facilitate the recovery of valuable materials from waste streams in each country, thereby reducing the reliance on raw materials extracted or imported and mitigating the associated environmental and climate impacts. The optimal solution for this considerable volume of waste is the implementation of an intelligent waste management system. The objective of smart waste management is to address the previously mentioned solid-waste management issues using sensors, intelligent monitoring systems, and mobile applications. The increased utilization of digital technologies is vital to the transition of waste management toward a more sustainable approach to material management. Such technologies enhance the recycling process, facilitate the utilization of recycled waste by producers, enable consumers to make more informed purchasing and sorting decisions, and improve the options available to recyclers for the sourcing of waste materials [5]. The current phase of development in the field of digitalization in waste management and recycling is characterized by a focus on innovation. New business models have emerged, including waste e-commerce platforms, waste-specific software, and business analytics. The application of digital technologies is becoming increasingly prevalent across the entirety of the waste collection sector, with the potential to transform the way in which waste is managed.

The digitalization of logistics, in particular, has brought about significant changes in the field of waste collection. The process of organizing, planning, and dispatching tasks, personnel, and vehicles has been transformed by the advent of digital technologies. The utilization of digital tools has the potential to enhance the process by facilitating the storage, processing, analysis, and optimization of the specific information that is required [6]. The information generated during the collection process can be monitored in real time, thus facilitating the identification of any anomalies or irregularities. Another aspect of waste collection is the documentation, communication, and billing process. As evidenced in other sectors, the transition from paper-based management systems to digital systems will serve to enhance the efficiency of processes and the flow of information. Related technologies include the utilization of digital ID tags for the purpose of identifying smart bins and containers, the implementation of digital order processing, the introduction of digital billing and payment, the development of digital user interfaces for the facilitation of communication with consumers, and the establishment of a network connecting public waste collection providers to other relevant government databases. The utilization of digital technologies in documentation processes enables the collection of data pertaining to waste generated by the public. The conversion of this information into valuable data through the process of data analytics can facilitate the advancement of the circular economy through the enhancement of our comprehension of the spatial and temporal patterns of waste production.

The quantity of waste, encompassing both industrial waste (construction and demolition materials, hazardous waste, sludge) and local solid waste (food waste, paper, cardboard, plastic, textiles), is becoming an increasingly significant challenge for scientists, organizations, and companies across the globe. In response, a range of innovative solutions and technologies have emerged with the aim of mitigating this issue [7]. Digital technologies are employed at each stage of the waste management process, with some already being utilized extensively. It is imperative that the digital transformation of the waste management sector should be aligned with the plans for the increased utilization of digital technologies in the development of a circular economy. The initial significant studies on the advantages of waste within the context of the circular economy, in both practical and academic terms, emerged during the early 2000s. Consequently, there is a divergence of opinion as to the most appropriate methodology for addressing this new commitment to

the economic and productive system. It is evident that there is a necessity for the implementation of novel construction and production methodologies that can eliminate products that have a detrimental impact on the environment, and furthermore, that there is a requirement for the reduction in the harmful effects of production through the enhancement of efficiency in the design of products and systems. The fundamental concept of the circular economy has undergone a process of conceptual evolution in response to the emergence of new studies that have sought to define its scope and parameters. A considerable quantity of waste has yet to be recycled. In addition to the environmental benefits, the recycling of waste materials provides a new source of income for producers and contributes to the country's economy. The recycling of waste products through the utilization of digital applications will enhance their value, capitalizing on the advancements in technology. Technology plays a pivotal role in facilitating waste management. The fulfilment of crucial functions through the exploitation of technological opportunities represents the most pivotal instrument of the circular economy in the context of the present era. Despite the multitude of reviews on waste recycling and waste management in the existing literature, studies and research tend to focus on a single type of waste. It has been observed that the existing literature reviews examine waste management and recycling from a narrow perspective. This study, however, presents a comprehensive evaluation of digitalization and digital applications in the field of waste management and recycling and highlights the development and trends in this field to provide a more comprehensive understanding.

This study looks at the topic from different perspectives, including business management, environmental science, and industrial production. This method fills a gap in the existing knowledge. The study examines the future of the circular economy within the context of business management, with a particular focus on recycling and waste management. This study has four research topics and the following research questions.

RQ1: What are the concepts most associated with digitalization in waste recycling in the literature?

RQ2: What are the most-used digital technologies in waste recycling?

RQ3: What types of waste have been subjected to digital recycling in the most significant volume over the past decade?

RQ4: What are the digital applications and business models used in digital-based waste recycling?

The objective of this review is to analyze the existing literature about digitalization in waste recycling on a global scale. Furthermore, it seeks to identify and examine the various digital works or applications that have been developed in the field of waste recycling and to highlight any issues that have been overlooked in previous studies. The objective of this study is to employ scientific methodology to map the thematic structure of digital waste management and recycling research as well as related research outputs. Additionally, the study examines digital applications in waste recycling within the context of the literature accumulation. The second objective of the study is to identify technology-based themes within the context of waste management and recycling. It is expected that determining the seminal works and digital applications in this domain will function as a fundamental study area for scholars, society, and companies working in the same industry. Gaining knowledge about waste management advancements and current technology-driven solutions is positive since it opens the door to future research on unresolved challenges and underappreciated problems. For the economy and development, the effectiveness and high performance of digital business models or applications that prioritize trash recycling are crucial. The research questions of this review also aim to demonstrate the levels of awareness and sensitivity regarding waste processing from the past to the present. These research questions should be explained in published studies in a manner that is both scientifically rigorous and reliable, to facilitate further research in this field.

2. Materials and Methods

The primary aim of this review is to analyze the existing literature about digitalization in waste recycling on a global scale. To achieve this objective, an attempt was made to identify the answers to the research questions and to map the thematic structures of the concepts that are the subject of digital applications, and the research outputs related to this. Based on the integrated literature review methodology, this study uses bibliometric analysis. An integrative review enables a deeper comprehension of a particular phenomenon and the integration of quantitative and qualitative data [8]. The researcher can receive a synthesis of relevant data from an integrated literature study, which can also clarify theoretical frameworks and arrange conceptual structures [9]. In addition to providing the researcher with a synthesis of relevant data, an integrated literature search can also help to organize conceptual structures and make theoretical frameworks more transparent [10]. The bibliometric method is selected for its ability to integrate performance analysis tools and science mapping tools for the comprehensive examination of a research field. This approach facilitates the identification and visualization of conceptual subdomains, encompassing specific topics, themes, and thematic areas, as well as the visualization of the thematic evolution.

The number of scientific publications has increased markedly in recent years, particularly over the past decade. These publications encompass a diverse range of formats, including research articles, reviews, and reports. The condition in question presents a significant challenge for field researchers. It has highlighted the need for bibliometric methodologies that employ a range of filtering strategies to provide insights into scientific advancements, the characteristics and structure of the field, and its core research areas. In comparison with more conventional methodologies such as meta-analysis and structured literature reviews, the bibliometric approach offers a more substantial and comprehensive contribution to the subject matter. However, given the time-consuming nature of meta-analyses and systematic literature reviews, the number of studies that can be included is restricted [8–12].

In conducting an integrative review, the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines facilitated the illustration of the choices made in the inclusion and exclusion of articles to be searched and selected for review [13]. Bibliometric studies provide researchers with a practical tool for identifying the most compelling studies and mapping the relevant research area without the potential for subjective bias [14]. The analytical techniques to be employed to address the research questions have been selected. To answer the research questions, it is necessary to employ common word analysis and bibliographic matching.

The bibliometric research process comprises the following steps: (1) defining the research problem; (2) reviewing the literature in line with the stated purpose; (3) selecting the appropriate database, determining the relevant terms, and establishing inclusion and exclusion criteria; (4) choosing the most suitable bibliometric method and software for analyzing the data; (5) gathering and organizing the data in a manner that aligns with the research question and the chosen bibliometric method; (6) importing the data into the software and conducting the analysis; (7) visualizing the data, reporting the findings, and writing the impact and recommendations. To analyze the data, it was first necessary to load the bibliometric data into the R program Biblioshiny. The analyses were performed using both the R program version 4.3.1 and the Vosviewer version 1.6.20 [15].

The search strings were formulated to encompass a comprehensive range of the literature. They were not combined into a single search string, allowing the number of results for each term to be determined separately. The initial literature searches yielded 989 articles, as illustrated in Figure 1. The papers were filtered to retain only those in the English language that were journal articles and related to the research field. This process resulted in a total of 678 publications (see Figure 1).

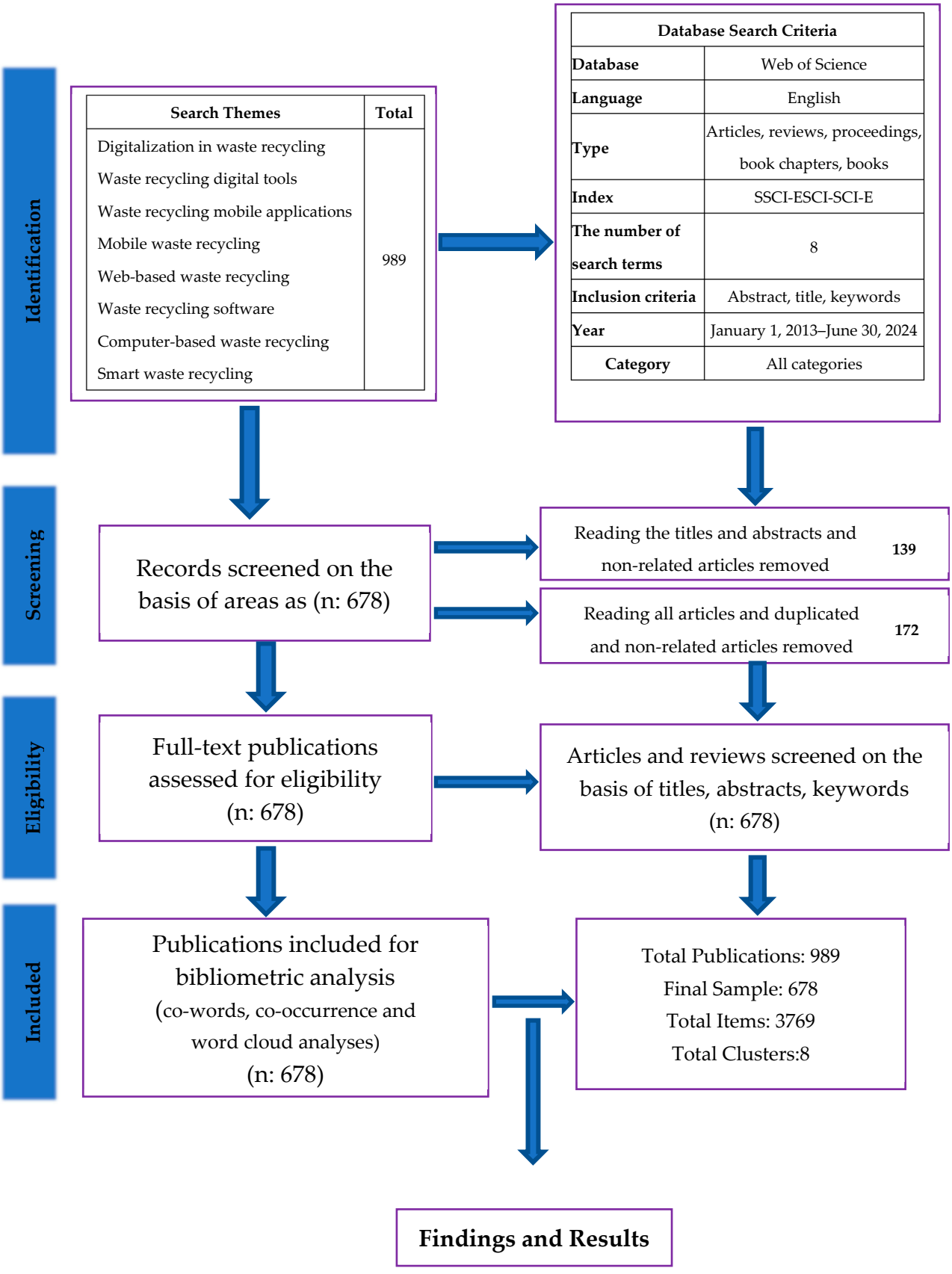


Figure 1. PRISMA flowchart.

2.1. Data Collection for Bibliometric Analysis

The Web of Science is regarded as the most significant data sources globally for bibliometric analysis, exhibiting greater consistency and standardization in their records than other databases [16]. The specified time frame encompasses the period between January 2013 and June 2024. The document type was identified as "articles, proceedings papers, reviews, book chapters, and books" and the search was conducted across all subject categories. To ensure the integrity of the data, the analysis focused on articles written in English and covering all subject categories. A comprehensive review of the literature was conducted to identify themes and research foci related to waste recycling and digitalization. After conducting the integrative literature review, the researchers identified the keywords to be used in the analysis. The sources of literature consulted for each research query or key theme were identified, as illustrated in Figure 1.

2.2. Data Analysis

This review, which falls under the category of explorer-defining research, employed the bibliometric approach to examine the academic and scientific output of the field. The bibliometric approach involves an analysis of the number of scientific publications with specific parameters for statistical purposes. This study is an analysis of publications on the topic of digitalization in waste recycling, with a particular focus on the use of datasets in the research process. Because of the research, the authors determined which keywords would be employed. The study began with the definition of research terms and how they are used in the literature. These terms are related to digitalization and waste recycling. All data from the database using these terms are in Table 1.

Table 1. Main description of the dataset.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2013:2024
Sources (journals, books, etc.)	376
Documents	678
Annual growth rate %	25.02
Document average age	3.17
Average citations per doc	21.23
References	29,407
DOCUMENT CONTENTS	
Keywords plus (ID)	3769
Author's keywords (DE)	3769
AUTHORS	
Authors	2248
Authors of single-authored docs	28
AUTHORS COLLABORATION	
Single-authored docs	38
Co-authors per doc	4.38
International co-authorships %	33.67
DOCUMENT TYPES	
Article	501
Book chapter	5
Proceedings paper	172

According to Table 1, the main information in the research data consists of the annual growth rate in the area over the past decade and in details from the publications. The annual production rate of documents has increased by 25.02%. In our analysis of the authors of the papers, most of the research has been carried out by more than one author. The average number of authors per document is 2.7, and the international co-authorship rate is 33.67%. The most prevalent document types in the literature are articles and proceedings.

Annual scientific production is a graph showing the change in the literature from year to year, as shown in Figure 2. The graph presents a linear increase in the number of publications over the duration of 2023. A total of 147 publications were produced in 2023, and this number is expected to decline again in 2024. This is due to the inclusion of publications in the first eight months of the study. There are 104 publications in 2021, 117 in 2022, and 70 in the first 8 months of 2024.

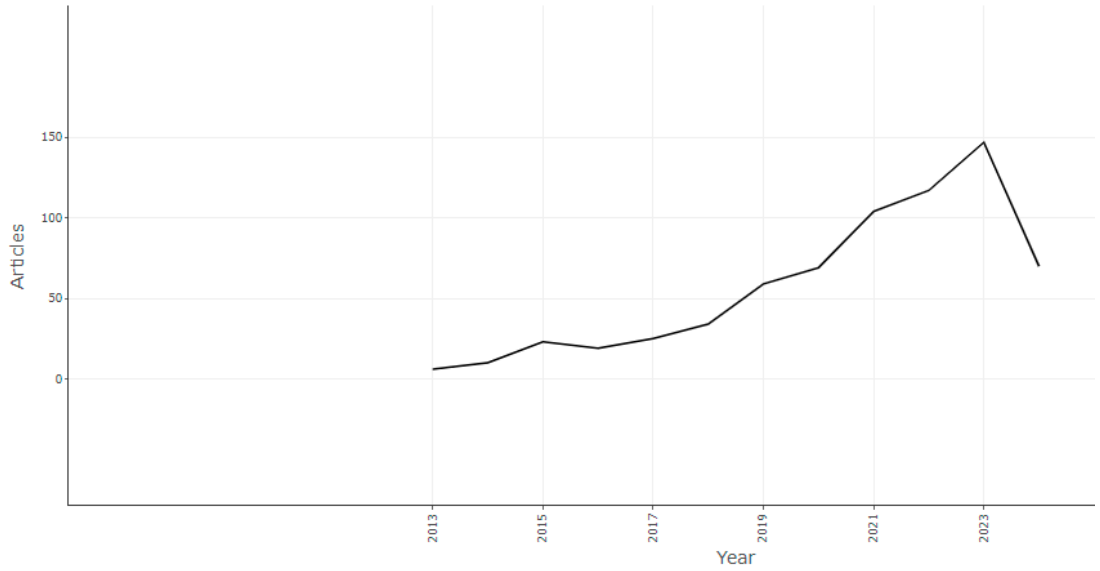


Figure 2. Annual scientific production.

Figure 3 shows the top ten most-published journals on digitalization in waste management and recycling. The most widely published journal is the *Journal of Cleaner Production*. *Sustainability* is ranked second and third is *Waste Management*. These journals are prominent in the fields of waste management, recycling, environment, and sustainability.

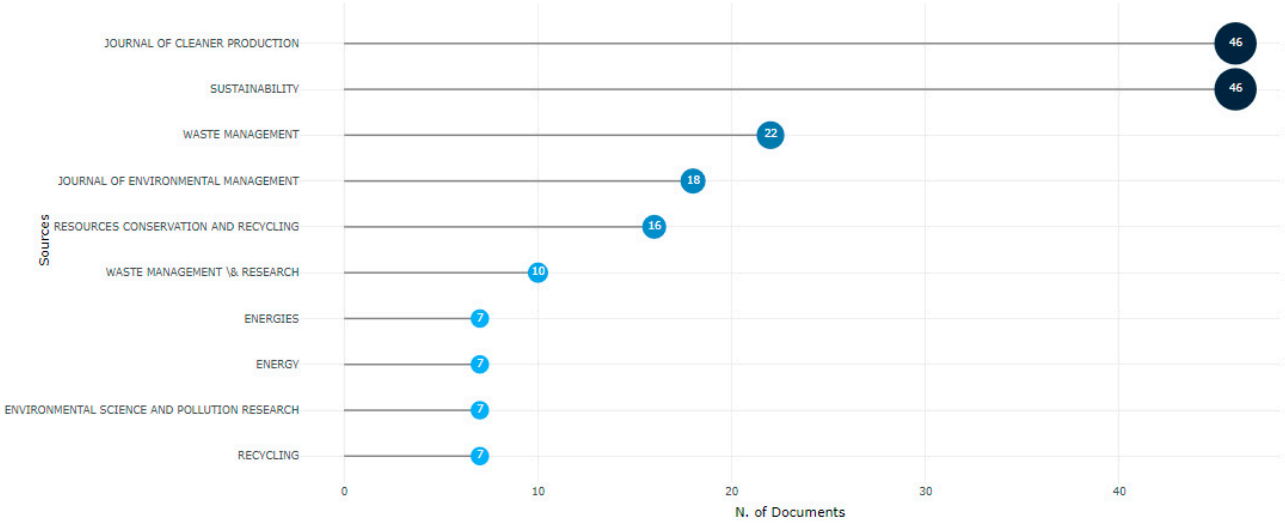


Figure 3. Most relevant sources.

Figure 4 lists the top ten most relevant authors according to their publication numbers. These authors have made significant contributions to the literature in the field of waste management and recycling.

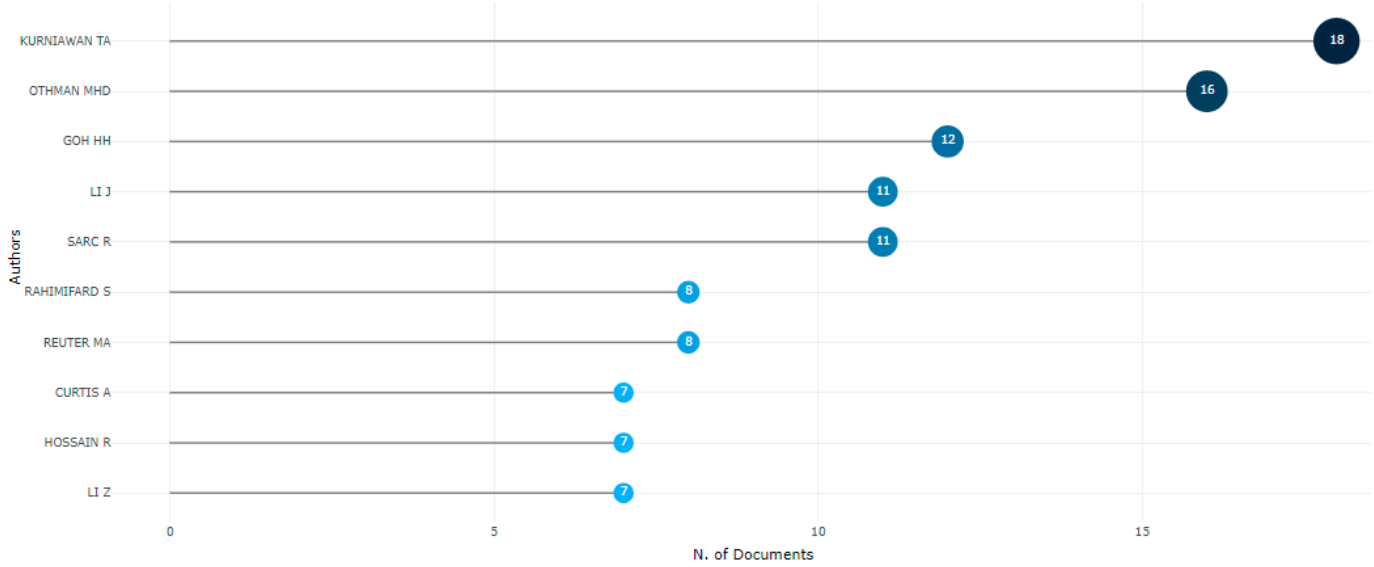


Figure 4. Most relevant authors.

Figure 5 lists the top ten most locally cited authors. Local citations measure how many times an author (or a document) included in the literature has been cited by the documents. In terms of the number of citations, Sarc, R. (140) is in the lead, followed by Curtis, A. (132) and Khoider, K. (122).

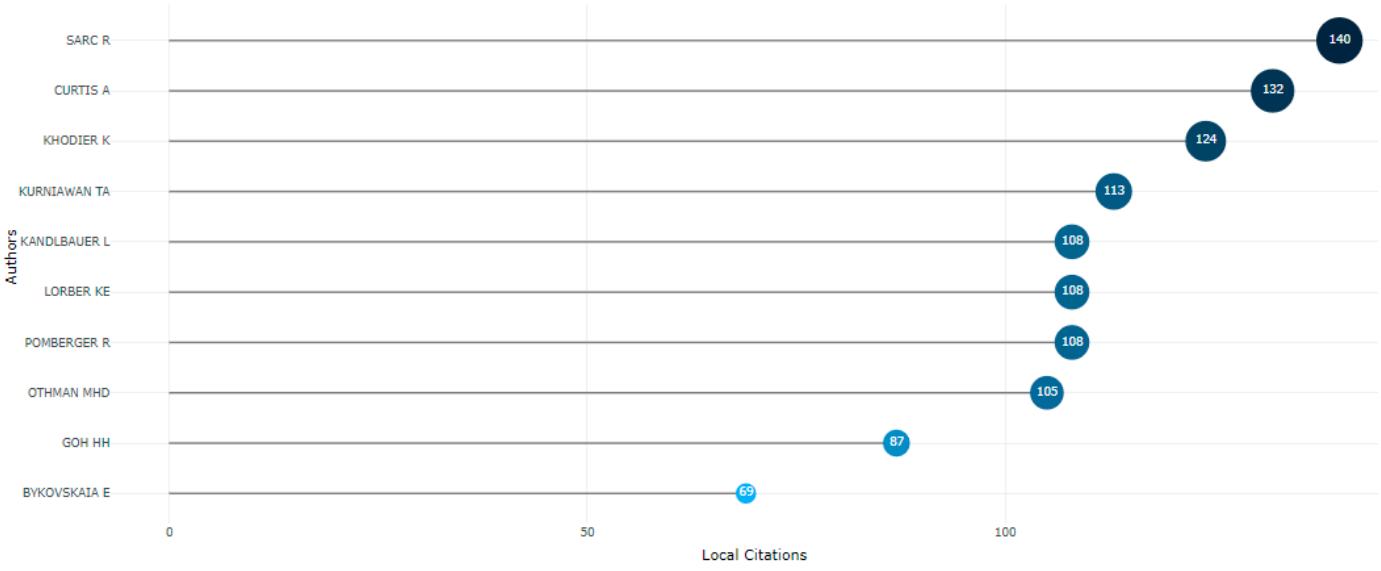


Figure 5. Most locally cited authors.

3. Bibliometric Findings

3.1. Word Cloud Analysis

According to R's word cloud analysis of the Bibliometrix package, Figure 2 shows the word cloud visually. Word clouds are useful tools for illustrating audience sentiment on a certain subject, where tags represent single words, and font size or color indicates their importance.

According to Figure 6, a word cloud is a visual representation of the most frequently occurring terms in each corpus of text. These graphical representations, also known as tag clouds, are designed to highlight the most prevalent words in each text, thus offering a visual representation of word frequency. The relative size of each word in the visual representation indicates its frequency of occurrence in the document(s) [17]. The most concentrated areas of our work are management, sustainability, waste, optimization, technology, challenges, and municipal solid waste. Words displayed in smaller font sizes indicate potential future research directions [18]. Smaller terms include electronic waste, printed circuit boards, business models, cost-benefit analysis, big data, cobalt, China, and adoption. Word clouds do not just represent word frequency; they can also help explain relationships between terms.



Figure 6. Word cloud of the literature.

3.2. Co-Word Analyses of Digitalization in the Waste Recycling Literature in the Period 2013–2024

The technique of co-word analysis has been employed by numerous researchers to gain insight into conceptual work across a range of domains [19]. It is a valuable approach for mapping the degree of association between information items in textual data and gaining insight into the relationships between concepts within a corpus [20]. It is an effective method for identifying and analyzing the relationships between various fields of scientific inquiry [21]. Co-word analysis is also a valuable method for reducing the number of descriptors (or keywords) in each space and synthesizing them into a network of graphs that illustrate the most significant correlations between descriptors [22]. Its utility is particularly evident in a longitudinal framework, which allows us to analyze and track the evolution of a research field along consecutive time periods [23].

Figure 7 shows that over the past decade, the literature on digitalization in recycling consists of 3769 keywords, 162 nodes, and 8 clusters. It turns out that the themes of recycling, waste management, and circular economy have the largest nodes and are centered on the most important and intense connections on the network. Among the largest clusters, central recycling is the clustering, which is closely related to recovery. The themes in the literature include solid waste, food waste, wastewater, valuable metals, plastic, electronic waste, biomass, fiber, heavy metals, and composites. The themes that stand out according to the common occurrences because of co-word analysis can be categorized under three groups.

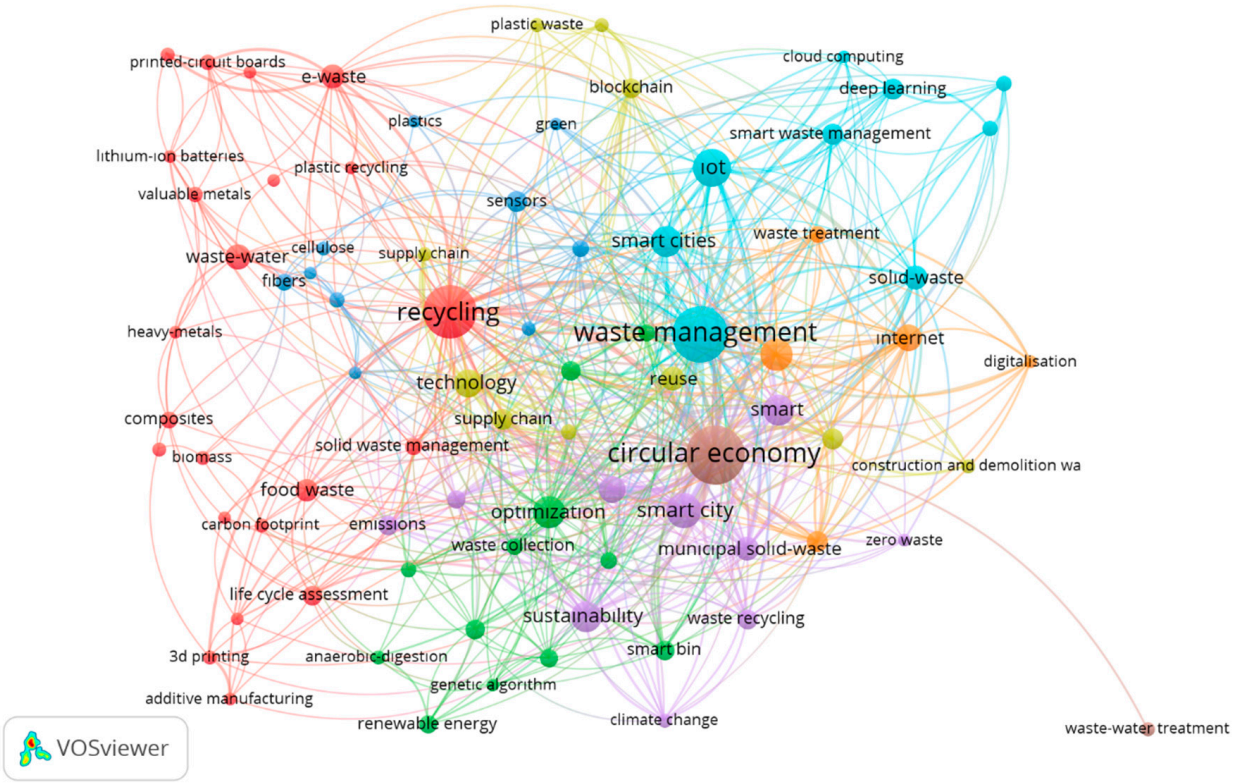


Figure 7. Keywords co-occurrence clustering map.

Firstly, smart cities, smart bin, zero waste, circular economy, Industry 4.0, sustainability, supply chain, waste collection, life cycle assessment, climate change, renewable, optimization, sustainable development, innovation, carbon footprint, and nanoparticles are the most associated themes in the literature. Secondly, in the literature on digitalization in recycling, the main concepts related to digitalization are as follows: digitalization, internet, IoT, cloud computing, deep learning, blockchain, sensors, 3D printing, machine learning, genetic algorithm, and artificial intelligence. The last grouping, of waste types that are most affected by digitalization, consists of: solid waste, municipal solid wastes, water waste, heavy metals, valuable metals, cellulose, fibers, food waste, construction and demolition waste, plastic waste, e-waste, biomass, printed circuit boards, and lithium-ion batteries.

4. Discussion and Implications

The bibliometric analysis has revealed that the literature can be classified as comprising three distinct dimensions. This classification emerged in accordance with the scope of the research and studies conducted within the literature. The concepts most frequently associated with digitalization literature in waste recycling are those that have the most common formations because of the co-word analysis. These are classified according to the characteristics and clustering of these concepts. Furthermore, 678 scientific publications comprising the metadata were examined, and web- and mobile-based applications published in the scientific literature were collated. The groupings identified as responses to the research questions posed by this study, along with the comparative analysis of the applications most frequently utilized in waste recycling within the literature, are presented in Table 2.

4.1. The Following Themes Are Most Associated with the Waste Recycling and Digitalization Literature

The field of waste recycling is a rapidly evolving area of study that is closely related to the concept of the circular economy. The circular economy represents a novel circular model that has been developed as an alternative to the conventional economic order, which is based on the traditional "produce, use, dispose" methodology. The objective of the circular economy model is to reduce the consumption of natural resources and to obtain economic gain from them. This is achieved by designing products in a reusable way and by giving importance to recycling and zero-waste practices. Waste management has become a significant concern within the context of CE, particularly for municipalities, public institutions, managers, and researchers. The proliferation of the literature on this topic can be attributed to the integration of eco-design principles in product design within the scope of zero waste, waste reduction and recycling, and the reduction in greenhouse gas emissions into the atmosphere. This is done with the dual objective of accelerating economic growth and preventing environmental disasters. One of the key objectives of research that links waste recycling with the circular economy is to achieve effective zero-waste management. Zero waste is a crucial aspect of CE, offering economic benefits through material savings, waste resale, repurposing of waste in other materials, and avoidance of environmental damage [24].

Waste recycling is frequently regarded as a means of attaining sustainability through CE. CE is a comprehensive concept that is promoted as a strategy for sustainable development [25]. Waste represents a significant strategic challenge within the context of supply chain management. Organizations are seeking to reduce costs by minimizing all forms of waste within their internal and external supply chains. The impact of products and services on the environment is becoming an increasingly important consideration for businesses. This is reflected in the growing number of national and international laws and regulations governing waste management. The life cycle assessment (LCA) technique is a valuable tool for identifying the root causes of environmental issues and enabling decision-makers to enhance the environmental performance of waste management practices. It is a widely used technique in the waste management and recycling literature.

The considerable number of innovative initiatives in the field of waste recycling is notable. It can be asserted that the management and processing of waste is currently undergoing a complex process of innovation and transformation with the objective of enhancing the efficiency, profitability and environmental compatibility of the collection, classification, and recycling of waste. The final stage of this long-distance race, which is waste management, is treatment. Efficient management is a crucial factor in reducing the number of landfills, minimizing CO_2 emissions, saving water and energy, reducing raw material extraction, and creating sustainable employment, among other benefits. It is crucial to consider the environmental impacts of alternative waste management strategies in addition to the socio-economic aspects. A comprehensive policy for sustainable waste management must take all these factors into account, recognizing that climate change represents only one element.

To achieve the recycling targets set out in the European Circular Economy Package, it is necessary for member states to implement a series of measures with the aim of optimizing national waste management practices in a way that is consistent with the principles of a circular economy [26]. A comparison of waste management with other industrial sectors reveals that digitalization and the utilization of robots in the context of the circular economy and waste management are still in their relatively early stages of development. However, as digitalization and Industry 4.0 approaches rapidly develop across all sectors, an increasing number of applications for these technologies is emerging, particularly in the field of waste management. The incorporation of innovative solutions provides a means of alleviating waste disposal issues and offers opportunities for the recovery of resources and the production of renewable energy. To fully realize the potential of recycling

technologies, it is essential that cooperation between recycling professionals, politicians, and stakeholders is established to meet the challenges and drive sustainable practices in the field of waste management. The term "digitalization" describes the use of digital technology in waste management. This is called "Industry 4.0" because it is the fourth industrial revolution [26]. This means that more and more modern technology is being used in local waste management systems [27]. I4.0 technologies help create smart cities, smart businesses, and smart factories that manage waste smartly [28].

Concurrently with the emergence of new waste management challenges, innovative waste management strategies are being devised through the utilization of advanced technological tools [29,30]. The significance of these factors in the context of the implementation of the smart city concept is acknowledged by numerous scientists [31,32]. The implementation of the previously discussed solutions will facilitate more efficient waste management practices. This will facilitate the preparation of superior-quality raw materials for recycling.

Waste management has improved a lot recently. This is because we need to reduce the impact of waste on the environment and make waste management more efficient. The spectrum of approaches encompasses a diverse range, spanning traditional techniques such as composting or landfilling to cutting-edge, advanced solutions leveraging the potential of Internet of Things (IoT) technologies. The concept of "smart cities" represents a novel approach to urban planning, whereby the use of cutting-edge electronics is employed to enhance the quality of life for residents while simultaneously safeguarding the environment from detrimental overgrowth [33]. The significance of these factors in the context of the implementation of the smart city concept is acknowledged by numerous scientists [31]. The potential for digital technology to enhance the current waste management system has been identified by lawmakers, experts, and academics. This includes the use of smart bins, artificial intelligence for material identification, and robotic automation. The introduction of these innovations will facilitate a more computerized future for waste collection, separation, and recycling [3]. The objective of developing a smart bin is to provide an efficient solution for the management of waste bins in urban environments. The smart bin is equipped with a range of sensors and technologies that facilitate more efficient waste management [34].

The implementation of an optimized, technology-enabled waste management solution has been proven to reduce the potential for global warming and the negative impacts of climate change. The reduction in carbon emissions can be significantly facilitated by the streamlining of waste management procedures and the pursuit of a net-zero future. Over the past few decades, a considerable number of nanoparticles have been created using a range of techniques and employed in the development of technologies for environmental applications, including soil and water remediation, water purification, and the detection of persistent contaminants. There is an increasing focus within the fields of materials science and engineering on enhancing the sustainability of the procedures used to produce nanoparticles.

4.2. Prominent Themes Related to Digital Tools in the Waste Recycling and Digitalization Literature

The second category of instruments utilized in the digitalization process is that of digital instruments. Recycling studies focus on the digital tools and platforms that have emerged and gained prominence in the literature because of Industry 4.0 and evolving technology. The ease and efficiency with which digital platforms match users with offers, and users who want these offers, means that they play a crucial role in fostering user interaction [35]. Digital platforms and tools that are designed to reduce food waste are conceptualized as two-sided marketplaces with the principal objective of facilitating connections between retailers and consumers [36]. In the future, the process of digitalization will facilitate the fulfilment of electronic invoices, the elimination of paperless orders, and the utilization of service portals [37]. To realize the full potential of the industry 4.0 movement,

a plethora of technologies must work in concert, including cloud computing, mobile technologies, blockchain, artificial intelligence (AI), big data and analytics, and cyber-physical systems [38,39]. Additionally, the designation "4.0" was derived from the recognition that the impact of drivers and technologies within the I4.0 context has been evaluated across numerous industrial sectors. Moreover, the potential of deep-learning applications in waste collection, transportation, and final cleaning was investigated [30].

The digitalization of waste management provides access to safe and affordable drinking water and sanitation, which are essential for sustainable development [3]. Digitalization helps the transition to a low-carbon economy. It encompasses a range of factors, including energy and resource efficiency, digital infrastructure, and the utilization of renewable energy sources [40]. AI, robotics, IoT, and blockchain make it easier to recycle and track waste from collection to treatment. This means waste management can be fully digitalized and linked to Industry 4.0, offering solutions that increase control, efficiency, and profit and optimize all stages in the process.

Artificial intelligence is important for creating new ways of managing waste. This is especially true when we think about the social, economic, and environmental factors [41]. Artificial intelligence is important for waste management, especially for recycling. Waste management should be considered when examining problems in different areas and sectors, including smart cities.

The Internet of Things (IoT) lets us monitor, collect, and analyze data in real time. This helps us to improve waste collection and reduce inefficiency. Machine vision and AI can identify the materials. Further research could investigate the potential for utilizing robots and blockchain technology in the context of waste management, particularly in conjunction with digitalization [3]. The application of robot technology for the classification of specific waste materials could help to increase current recycling rates and reach the requested rates [26]. Sensing helps collect and produce data in Industry 4.0 such as up-to-date information on where waste is produced and what it is made of. Artificial intelligence, especially chatbots, could help solve waste problems in the context of the circular economy. A chatbot is a computer program that can talk to people like a human, usually through text or voice [42].

4.3. The Types of Waste Most Relevant to the Waste Recycling and Digitalization Literature

The third group, formed because of bibliometric analysis, comprises the types of waste that are subject to recycling. The most prominent of these are the types of waste that are perceived as problematic on a global scale. "Solid waste" is the unwanted solid material created by humans in homes, workplaces, and shops. The issue of solid waste has been the subject of considerable attention in recent years, particularly in developing countries, in the context of efforts to promote sustainable development. The term "municipal solid waste" (MSW) encompasses a range of waste materials, including household waste, non-hazardous industrial waste, and biodegradable materials such as food waste, leaves, and wood. The generation of municipal solid waste is increasing because of rapid population growth, rising levels of economic development and industrialization, urbanization, and an escalating consumption trend within society [42]. It is for this reason that it is widely included in the literature. Municipal waste is just one of the waste types and requires significant investment in technology research (material, energy, chemical recycling), access, and information to significantly reduce its production share. However, there is much that can be done by an individual; therefore, it is possible to gain new knowledge through information and to reach assistive technology in reducing waste production. The recovery of materials (recycling) represents a single avenue through which municipal waste can be repurposed to produce new products, compost, or biofuels [43]. It is possible to recycle or recover municipal waste [27]. An additional option for the management of these materials is thermal conversion in incinerators [44], which can be combined with energy recovery. The best way to get rid of waste is to put it in a landfill. All these methods affect the

environment. But the best ways to manage waste are recycling and recovery. These can make useful products from waste.

The contamination of soil with heavy metals has emerged as a significant concern for agricultural scientists, particularly considering the advancements made in the field of agricultural product safety. Heavy metals, including lead, mercury, cadmium, and copper, are recognized as mass poisons, environmental hazards, and highly toxic substances. Heavy metals represent one of the most pervasive and detrimental types of pollutants in the environment. The recovery of precious metals from solid waste is an environmentally beneficial process that allows for the utilization of waste with high added value. E-waste presents a duality, serving as both a potential source of valuable materials, including gold, silver, copper, and rare earth metals, and a challenge to the environment.

Agro-industrial waste is a byproduct of agro-based industries, which are typically rich in lignocellulosic materials and bioactive compounds. Cellulose is one of the most prevalent natural resources in the natural world. Cellulose is the primary component of plant cell walls, and its widespread occurrence makes it a potentially valuable product. Cellulose can be extracted from a variety of agricultural byproducts, including pea pods, rice straw, cucumber peels, eggplant stalks, and coconut shells. Significant research has been conducted with the objective of recovering usable compounds from these wastes. The economic and cultural importance of agricultural waste fibers is evidenced by their utilization as building materials, decorative products, and versatile raw materials on a global scale. Agricultural waste fibers are a highly promising material for use in composites. They offer several key advantages, including high strength, an environmentally friendly structure, low cost, availability, and sustainability. The issue of agricultural waste represents a significant challenge for the protection of the global environment. The recycling of waste fibers not only renders cement composites more cost-effective and durable, but also facilitates the reduction in pollution. Agricultural and plantation wastes are regarded as prospective and suitable materials for meeting the rising demand for renewable resources. Biomass material represents a significant alternative material source for the manufacture of bio-composite products.

Food waste is a growing problem. It harms the environment, economy, and society. This makes it harder to sustain our planet [45,46]. The food sector is responsible for about a third of all greenhouse gas emissions in the EU. More food-sharing models are being developed to solve food waste [47]. Digital platforms match users with offers. Digital platforms let grocery stores share last-minute discounts with consumers. This helps stores attract more customers and connect with local shoppers. It also helps solve the problem of information asymmetry. Digital platforms for reducing food waste are two-sided marketplaces connecting stores and consumers.

Construction and demolition waste is a big problem around the world. There is a lot more of it than there used to be. Construction and demolition waste is one of the world's largest sources of solid waste. About 90% of C&DW comes from demolished concrete, bricks, and masonry. The rest comes from construction waste [48].

The term "e-waste" is used to describe electronic devices that have reached the end of their effective use, including computers, mobile phones, and other electronic equipment [49,50]. When these devices are discarded, their components can become a significant source of environmental contamination, gradually seeping into the soil and harming the atmosphere [51]. The growing quantity of electronic waste (e-waste) has resulted in considerable burdens on society and the environment, particularly regarding waste printed circuit boards, which play a pivotal role in electronics manufacturing. Printed circuit boards represent a significant technological waste stream within the electronics industry. The complexity of their composition, comprising a multitude of materials and components, poses a significant challenge to recycling, making it both costly and difficult to process. Printed circuit boards constitute the foundation of the electronics industry and are regarded as the most valuable and intricate components of waste electrical and electronic equipment streams.

Lithium-ion batteries represent a rapidly growing industry, as they are a source of numerous valuable materials and are integral to meeting the rising demand for metals and achieving a sustainable circular economy. It is inadvisable to dispose of lithium-ion batteries and devices containing them in household waste or recycling bins. Given that manufacturers require access to strategic items and critical materials to produce electric vehicles, used batteries may also present an opportunity. The recycling of lithium-ion batteries from electric vehicles could provide a valuable source of secondary materials. Plastics are used in many fields, including agriculture, medicine, electronics, packaging, transportation, aviation, and more [52]. The global community faces a big challenge in managing plastic waste. There is a global consensus that we need to control plastic waste [53–56].

Finally, wastewater contains a variety of potentially harmful materials originating from diverse sources, including sewage, industrial and commercial waste, agricultural waste, and more. These materials can be characterized by their physical appearance, chemical composition, and load of microorganisms.

4.4. Digital Applications Used in Digital-Based Waste Recycling

This research emphasizes the growing importance of digital technology in promoting environmentally friendly business practices. The study presents a compilation of digital applications, developed to address the issue of waste recycling, which have been incorporated into databases (Table 2). Digital apps are the solution for accelerating the registration, tracking, and reporting process during waste collection. The barcode reader feature integrated into these apps makes them the ideal choice for streamlining this process. The process of digitalization has the potential to enhance the efficiency of waste collection by enabling the prompt identification of waste types, quantities, and owners. This can be achieved through the utilization of mobile phone barcode scanning, which obviates the necessity for face-to-face interactions during the prevailing period of physical and social distancing [57]. While enhanced sorting procedures enhance the quality of recyclable fractions and reduce residual waste, the advent of the digital age has necessitated the digitalization of the waste sector. This has enabled market participants to interact online via digital platforms, thus facilitating the transfer of data and information. Furthermore, the digitalization of the waste recycling sector has the potential to completely transform the waste management industry, resulting in significant social upheaval and offering the prospect of environmental and economic benefits [58]. Web-based and mobile applications designed to reduce food waste can be classified into two principal categories: those concerned with food redistribution and those concerned with the management of food within the household [59]. A variety of food redistribution applications have been developed with the objective of preventing food waste by redirecting it toward those who require it. These applications encompass sale-to-purchase, peer-to-peer sharing, and donation models [47]. A new way of managing waste is being introduced. It is called “Internet + Recycling”, and this allows people to arrange online to have their waste collected. It is thought that this could help to make it easier for people to dispose of their waste [60]. “Internet + Recycling” is an online platform for individuals and recycling experts to make appointments for local waste collection or trade.

Table 2. Digital applications for waste recycling.

No	App. Name	Type	Publication Type	Cites	User	Type of Waste	Country	Usage Status and Descriptives
1	Aibolv	AI-based/web-based/mobile app/mini program	Article	[60]	Individual users	Municipal solid waste/household food waste	China	One of the most widely used social networking applications globally, with over 963 million active users per month [61].
2	Wasteapp	Android application	Proceeding	[62]	Supporting better recycling behavior for users	Municipal solid waste/household food waste	Italy	The design and preliminary implementation of a mobile application for the support of waste recycling, based on the principles of user-centered design, for use on mobile phones and tablets [62].
3	Ecowaste	IoT-based platform and mobile application	Proceeding	[63]	For waste pickers and dispensers	Municipal solid waste/household food waste	Brazil	The system enables the implementation of a circular economy through the utilization of waste recycling and the development of enhanced logistics systems. The Internet of Things (IoT) platform facilitates the interconnection of waste pickers and dispensers.
4	1millionbot	IoT-based chatbot	Article	[41]	For all citizens	Municipal solid waste/household food waste	Spain	The chatbot has the potential to enhance and optimize waste collection procedures through the application of AI technology, offering users tailored information and pragmatic guidance to streamline the process.
5	Litterbot	IoT-based chatbot	Article	[41]	For users' local needs and regulations	Municipal solid waste/household food waste	USA	The system helps users identify items for recycling. It educates users about recycling's environmental impact and encourages sustainable waste management.
6	GOA Plastic Waste Chatbot	IoT-based chatbot	Article	[41]	For users	Plastic waste	India	The application employs the geographical positioning system (GPS) to determine the location of the waste, and users can transmit photographic documentation of the waste in question. The chatbot guides users through a series of predetermined questions to elicit the necessary information. The source further stated that, although alternative applications exist for addressing similar issues, users are not required to download additional software, thereby conserving valuable storage space on their mobile devices, due to the chatbot's functionality.

Table 2. *Cont.*

No	App. Name	Type	Publication Type	Cites	User	Type of Waste	Country	Usage Status and Descriptives
7	No Waste Ukraine	Web-based chatbot	Article	[41]	For municipal recycling system	Municipal solid waste	Ukraine	The chatbot has been developed with the objective of being user-friendly and intuitive, with the aim of assisting users in comprehending the fundamentals of waste management. It provides prompt advice on waste sorting, the location of the nearest waste disposal station, and information regarding its operating hours.
8	SCC Chatbot	IoT-based chatbot	Article	[41]	For users	Garbage waste	United Kingdom	SCC has introduced an intelligent chatbot service that employs natural language processing to convert spoken queries into text, thereby facilitating the efficient and effective handling of customer inquiries.
9	Bota	Mobile application	Proceeding	[64]	Individual users	İmproper disposal waste	Canada	The design of the application was informed by an iterative design process, which commenced with a review of existing applications in the field of waste management. The objective of this process was to develop an application that would promote environmental awareness.
10	Beeco	Mobile application	Proceeding	[65]	Children	Garbage disposal	Malaysia	The design of the application was informed by an iterative design process, which commenced with a review of existing applications in the field of waste management. The objective of this process was to develop an application that would serve to promote environmental awareness.
11	RecycHongs	Mobile application	Proceeding	[66]	Hong Kong residents	Food, paper, and textile. The second one covers metal, glass, and plastic. The third category contains poisons, oil, and biohazardous waste.	Hong Kong	The case of RecycHongs illustrates how a smart city can facilitate collective action among its citizens through the implementation of recycling initiatives.

Table 2. *Cont.*

No	App. Name	Type	Publication Type	Cites	User	Type of Waste	Country	Usage Status and Descriptives
12	Seva	Mobile application	Proceeding	[67]	Suppliers and consumers	Food waste	USA	The platform enables users to visualize the food resources available in their local area, thereby facilitating access to food and addressing two significant issues: hunger and food waste.
13	Flashfood	Mobile application	Proceeding	[67]	Suppliers and consumers	Food waste	USA and Canada	The sale of foods approaching their expiration dates at a discounted price allows retailers to guarantee the sale of these items in a relatively short period of time.
14	Food for All	Mobile application	Proceeding	[67]	Suppliers and consumers	Food waste	Boston and NYC areas	This application facilitates connections between restaurants and users, enabling the purchase of discounted meals for personal consumption or donation to those in need.
15	Perazuhan	Mobile application	Proceeding	[68]	Household members	Solid wastes	Philippines	This technologically driven approach provides a viable and accessible method for the sale of recyclable materials, including bottles, newspapers, paper, and plastics, to junk shops.
16	OLIO	Mobile application	Article	[69]	Organizations and consumers	Food waste	U.K.	The app is a free resource that facilitates connections between neighbors and local businesses, enabling the sharing of surplus food rather than its disposal.
17	Foodsaveshare	Mobile application	Article	[70]	Chain markets and consumers	Household food waste	Greece	It has the potential to significantly reduce household food waste.
18	Mysuscof	Mobile application	Article	[71]	Organizations and consumers	Household food waste	Europe	The objective of the app is to assist consumers in reducing the amount of food waste they generate.
19	Eatchafood	Mobile application	Proceeding	[72]	For all members of a household	Household food waste	Australia	The eatchafood mobile application has been developed with the objective of encouraging users to consume their food items prior to their expiration dates.

Table 2. *Cont.*

No	App. Name	Type	Publication Type	Cites	User	Type of Waste	Country	Usage Status and Descriptives
21	Relix	Mobile application	Article	[74]	Waste pickers	Recyclable waste	Northeast Brazil	The initiative fosters the practice of recycling and facilitates communication between the local population and waste pickers through the utilization of a mobile application.
20	Compostnet	Mobile application	Proceeding	[73]	For all members of a household	Meal waste	USA	The system categorizes the types of waste produced after eating a meal, which can be used in apps to encourage users to sort waste correctly.
22	Emetsi	Mobile and website applications	Article	[75]	The samplers, laboratory technicians, and client	Solid waste	South Africa	It is conceivable that emetsi and ML-GUI could be employed in other sectors, including municipal wastewater treatment plants, water resource management, and agriculture.
23	Foodreduction app	Android mobile application	Proceeding	[76]	Restaurants and unfortunate people	Food waste	United Arab Emirates	This application is designed to facilitate a mutually beneficial relationship between the restaurant and the less fortunate members of society. Rather than discarding food, these individuals will be able to collect it from the restaurant at the end of the day.
24	WM-HAS	Mobile and website applications	Proceeding	[77]	All stakeholders (waste generators, pickers, collectors, and recyclers)	All kinds of waste	Nigeria	The Waste Management and Hazard Alert System (WM-HAS) web application represents a novel business model that facilitates seamless participation in the waste management ecosystem for all stakeholders.
25	Foodscover	Mobile application	Proceeding	[78]	Retail sector	Food waste	Singapore	The Foodscover application provides a digital marketplace for consumers to source from retailers' food items that are at risk of being discarded and to purchase these items at discounted prices.
26	Spoonful	Mobile application	Proceeding	[79]	For all members of a household	Household food waste	Indonesia	This mobile application is designed to influence human consumption behavior.

Table 2. *Cont.*

No	App. Name	Type	Publication Type	Cites	User	Type of Waste	Country	Usage Status and Descriptives
27	Foodernity	Mobile and website applications	Proceeding	[80]	Donors and people in need.	Food waste	Philippines	The objective is to reduce food waste by redistributing surplus food in a socially responsible manner and to facilitate connections between food donors and beneficiaries through donations.
28	Foodwise	Mobile and website applications	Proceeding	[81]	University campus	Food waste	China	The system consists of a mobile web application that encourages users to document their actions with the objective of reducing food waste. It also provides incentives to those who actively participate in this process. In addition, it comprises a data storytelling dashboard that presents information on food waste from university canteens in a graphical format.
29	Dumpster	Mobile and website applications	Proceeding	[82]	The farmers and all stakeholders	Agricultural waste	India	The principal objective of this smartphone application is to facilitate the transportation of waste materials and to act as an intermediary between farmers and other relevant parties who require agricultural waste for productive purposes. This is done to prevent farmers from incinerating their agricultural waste.
30	Recycling	Mobile and website applications	Proceeding	[83]	Generators and recyclers	All kinds of waste	Peru	The application is designed to meet the needs of its users, facilitating more effective waste segregation using a barcode scanner integrated into the Android interface.

As illustrated in Table 2, a review of the literature reveals that digital applications for waste recycling have proliferated in the last decade. These applications, which systematize and organize waste recycling, are experiencing a rapid increase in usage across the globe. A total of 678 publications related to digital waste recycling were identified through a manual search and review process conducted in chronological order between 2013 and 2024. These publications were selected based on specific research criteria and are listed in Table 1. The list includes only those publications that were designed or developed using scientific and reliable methods for waste recycling. Most of these applications have been developed within the last five years and are web- and mobile-based. It is evident that the literature on these applications primarily comprises highly current articles and conference proceedings. Most of these conference proceedings focus on food and household food waste. In addition to these waste materials, most applications developed to facilitate the classification and recycling of garbage wastes are designed to do so. The applications developed are typically confined to a specific locality or country. The applications that have the greatest potential for global reach are those developed for the USA and Europe. Furthermore, it is evident that applications are being developed in China and India, the countries with the largest populations globally, and that new digital applications are still being created. It can be posited that the collective objective of these applications, derived from the extant literature, is to facilitate access to these wastes, irrespective of their classification, and to guarantee both economic advancement and that those in need derive benefit from the wastes. A multitude of applications have been developed with the objective of preventing food waste and donating food to those in need. The recycling of municipal solid waste represents a significant global challenge. The utilization of digital applications, developed with the aid of digital tools and the convenience afforded by the advent of technology and internet access, has become a prevalent means of addressing this issue. The applications under consideration in this study are those that have been the subject of scientific activities and publications and have been developed in accordance with scientific and systematic methods.

The development and implementation of these applications based on scientific foundations provides benefits to waste owners, recyclers, and those who need waste and generate commercial income from waste. The development of these applications with a well-designed system infrastructure is important for the continuity and sustainability of the applications. There is a growing need for applications that have been studied and developed according to the needs of the target audience across the globe. The level of importance that each country ascribes to waste can be gauged by the degree of emphasis they place on digitalization in recycling. The successful application of recycling techniques will inform the development of applications to meet future needs. It is for this reason that applications that have reached a significant level of success in the field of waste recycling serve as a useful point of reference and exemplar. Limiting the applications to a single region can reduce transportation and accessibility costs, as the waste is confined to that region. Plastic and electronic waste, which present a global challenge, require support from political and administrative bodies rather than individual applications. It can be observed that the parties responsible for developing applications vary according to the quantity and type of waste. While the objective of each application may differ, the scope of access is expanding in applications designed for the disposal of all wastes.

5. Conclusions and Future Directions

The management and recycling of waste materials represents a significant challenge in both developed and developing countries. The conventional methods of waste collection have proven to be inadequate and financially burdensome [6]. The most efficacious method for resolving this considerable quantity of waste is to employ technology and digital tools that have been developed in conjunction with technology. The existing literature on the digitalization of waste recycling over the past decade has elucidated the pivotal role of digital tools, particularly those utilizing artificial intelligence. This literature review reveals

which types of waste present the greatest challenges and which digital technologies are used for waste recycling. In line with this, the most frequently occurring themes in the literature are smart cities, smart bins, zero waste, circular economy, Industry 4.0, sustainability, supply chain, waste collection, life climate change, renewable, optimization, and sustainable development. Secondly, the literature on digitalization in records covers the following areas: digitalization, the internet, IoT, cloud computing, deep learning, blockchain, sensors, 3D printing, and AI. The waste materials most affected by digitalization are biomass, printed circuit boards, and lithium-ion batteries.

It is crucial to develop and expand artificial intelligence-based mobile and web applications to prevent the further contamination of waste and to facilitate access to those who can benefit from its reuse. Additionally, such applications can be utilized to ensure that waste materials gain economic value [77–83]. In this paper, web-based and mobile applications developed for this purpose were compiled. These applications are of critical importance for each country. Countries that have recognized the gravity of the issue are striving for success and efficiency in waste recycling with a multitude of analogous applications. In addition to the practices outlined in this study, there are numerous non-governmental organizations, nonprofit individuals, and smaller local units. This review is in alignment with the findings of previous studies that have demonstrated the efficacy of the circular economy (CE) approach, which emphasizes the utilization and preservation of resources for an extended period through the utilization of information technology (IT) applications within the context of smart city infrastructure [41]. The CE has emerged as a pivotal concept in recent years, with the objective of ensuring sustainable urban development. As urban centers experience an increase in waste volumes, the necessity for sustainable waste management practices has become a pivotal aspect of the ecological resilience of smart cities (see [41,63,67,83]).

In the future, following the completion of this review, it will be possible to devise a long-term plan for the creation of an eco-design of plastics. This will facilitate the development of waste management and energy production as well as the utilization and recycling of developing technologies, which are collectively referred to as recycling technologies. The development of a more resilient and sustainable waste management system is contingent upon the implementation of a range of strategies, including the advancement of recycling technology, the establishment of zero-waste policies, the development of intelligent waste management systems, the promotion of a circular economy, and the expansion of volunteerism. The construction of a cleaner, healthier, and more sustainable environment necessitates the utilization of innovative approaches and collaborative efforts to facilitate the advancement toward a sustainable future. Furthermore, it is imperative to address the issue of waste management.

Given the objective of this review, which is to analyze the orientation of scientific production and accumulation, the data were collected from the scientific database WOS due to its reliability and standardization. Also, since WOS is a very large database, other databases were not examined. Other databases are planned to be examined in the future. Since this article is a large and comprehensive study, further reviews are concluded.

Author Contributions: Conceptualization, H.A., A.R.K. and N.O.; methodology, H.D., A.R.K. and N.O.; software, N.O., A.R.K. and H.D.; validation, H.A., A.R.K. and N.O.; writing—original draft preparation, H.A. and A.R.K.; writing—review and editing, H.D., N.O. and A.R.K.; supervision, H.A. and N.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.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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

References

1. Camón Luis, E.; Celma, D. Circular Economy. A Review and Bibliometric Analysis. *Sustainability* **2020**, *12*, 6381. [CrossRef]
2. Ahmed, F.; Hasan, S.; Rana, M.S.; Sharmin, N. A conceptual framework for zero waste management in Bangladesh. *Int. J. Environ. Sci. Technol.* **2023**, *20*, 1887–1904. [CrossRef]
3. Seyyedi, S.R.; Kowsari, E.; Gheibi, M.; Chinnappan, A.; Ramakrishna, S. A comprehensive review integration of digitalization and circular economy in waste management by adopting artificial intelligence approaches: Towards a simulation model. *J. Clean. Prod.* **2024**, *460*, 142584. [CrossRef]
4. Jahani, N.; Sepehri, A.; Vandchali, H.R.; Tirkolaee, E.B. Application of industry 4.0 in the procurement processes of supply chains: A systematic literature review. *Sustainability* **2021**, *13*, 7520. [CrossRef]
5. Mohamed, N.H.; Khan, S.; Jagtap, S. Modernizing Medical Waste Management: Unleashing the Power of the Internet of Things (IoT). *Sustainability* **2023**, *15*, 9909. [CrossRef]
6. Borchard, R.; Zeiss, R.; Recker, J. Digitalization of waste management: Insights from German private and public waste management firms. *Waste Manag. Res.* **2022**, *40*, 775–792. [CrossRef]
7. Czekała, W.; Drozdowski, J.; Łabiak, P. Modern Technologies for Waste Management: A Review. *Appl. Sci.* **2023**, *13*, 8847. [CrossRef]
8. Torraco, R.J. Writing integrative literature reviews: Using the past and present to explore the future. *Hum. Resour. Dev. Rev.* **2016**, *15*, 404–428. [CrossRef]
9. Gough, D.; Thomas, J.; Oliver, S. Clarifying differences between review designs and methods. *Syst. Rev.* **2012**, *1*, 28. [CrossRef] [PubMed]
10. Soares, C.B.; Hoga, L.A.; Peduzzi, M.; Sangaleti, C.; Yonekura, T.; Silva, D.R. Revisão integrativa: Conceitos e métodos utilizados na enfermagem [Integrative review: Concepts and methods used in nursing]. *Rev. Esc. Enferm. USP* **2014**, *48*, 335–345. [CrossRef]
11. Ariaa, M.; Cuccurullo, C. Bibliometrix: An r-tool for comprehensive science mapping analysis. *J. Informetr. J.* **2017**, *11*, 959–975. [CrossRef]
12. Whittemore, R.; Knafl, K. The integrative review: Updated methodology. *J. Adv. Nurs.* **2005**, *5*, 546–553. [CrossRef] [PubMed]
13. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Group, T.P. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef]
14. Zupic, I.; Cater, T. Bibliometric methods in management and organization. *Organ. Res. Methods* **2015**, *18*, 429–472. [CrossRef]
15. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
16. Birkle, C.; Pendlebury, D.A.; Schnell, J.; Adams, J. Web of Science as a data source for research on scientific and scholarly activity. *Quant. Sci. Stud.* **2020**, *1*, 363–376. [CrossRef]
17. Atenstaedt, R. Word cloud analysis of the BJGP. *Br. J. Gen. Pract.* **2012**, *62*, 148. [CrossRef]
18. Mulay, P.; Joshi, R.; Chaudhari, A. Distributed incremental clustering algorithms: A bibliometric and word-cloud review analysis. *Sci. Technol. Lib.* **2020**, *39*, 289–306. [CrossRef]
19. Chen, X.; Chen, J.; Wu, D.; Xie, Y.; Li, J. Mapping the Research Trends by Co-word Analysis Based on Keywords from Funded Project. *Procedia Comput. Sci.* **2016**, *91*, 547–555. [CrossRef]
20. De la Hoz-Correa, A.; Muñoz-Leiva, F.; Bakucz, M. Past Themes and Future Trends in Medical Tourism Research: A Co-Word Analysis. *Tour. Manag.* **2018**, *65*, 200–211. [CrossRef]
21. Muñoz-Leiva, F.; Viedma-del-Jesús, M.I.; Sánchez-Fernández, J.; López-Herrera, A.G. An application of co-word analysis and bibliometric maps for detecting the most highlighting themes in the consumer behaviour research from a longitudinal perspective. *Qual Quant.* **2012**, *46*, 1077–1095. [CrossRef]
22. Coulter, N.; Monarch, I.; Konda, S. Software engineering as seen through its research literature: A study in co-word analysis. *J. Am. Soc. Inf. Sci.* **1998**, *49*, 1206–1223. [CrossRef]
23. Garfield, E. Scientography: Mapping the tracks of science. *Curr. Contents Soc. Behav. Sci.* **1994**, *7*, 5–10.
24. Nizar, M.; Munir, E.; Irvan, I.; Amir, F. Examining the economic benefits of urban waste recycle based on zero waste concepts. In *1st Aceh Global Conference*; Atlantis Press: Amsterdam, The Netherlands, 2019; pp. 300–309.
25. Blomsma, F.; Brennan, G. The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. *J. Ind. Ecol.* **2017**, *21*, 603–614. [CrossRef]
26. Sarc, R.; Curtis, A.; Kandlbauer, L.; Khodier, K.; Lorber, K.E.; Pomberger, R. Digitalisation and intelligent robotics in value chain of circular economy-oriented waste management—A review. *Waste Manag.* **2019**, *95*, 476–492. [CrossRef]
27. Czekała, W.; Pulka, J.; Jasiński, T.; Szewczyk, P.; Bojarski, W.; Jasiński, J. Waste as substrates for agricultural biogas plants: A case study from Poland. *J. Water Land. Dev.* **2023**, *56*, 45–50. [CrossRef]
28. Kannan, D.; Khademolqorani, S.; Janatyan, N.; Alavi, S. Smart waste management 4.0: The transition from a systematic review to an integrated framework. *Waste Manag.* **2024**, *174*, 1–14. [CrossRef]
29. Sharma, S.; Basu, N.P.; Shetti, M.; Kamali, P.; Walvekar, T.M. Aminabhavi Waste-to-energy nexus: A sustainable development. *Environ. Pollut.* **2020**, *267*, 115501. [CrossRef]
30. Lin, K.; Zhao, Y.; Kuo, J.-H.; Deng, H.; Cui, F.; Zhang, Z.; Zhang, M.; Zhao, C.; Gao, X.; Zhou, T.; et al. Toward smarter management and recovery of municipal solid waste: A critical review on deep learning approaches. *J. Clean. Prod.* **2022**, *346*, 130943. [CrossRef]

31. Goutam Mukherjee, A.; Ramesh Wanjari, U.; Chakraborty, R.; Renu, K.; Vellingiri, B.; George, A.; CR, S.R.; Valsala Gopalakrishnan, A. A Review on Modern and Smart Technologies for Efficient Waste Disposal and Management. *J. Environ. Manag.* **2021**, *297*, 113347. [CrossRef]
32. Mingaleva, Z.; Vukovic, N.; Volkova, I.; Salimova, T. Waste Management in Green and Smart Cities: A Case Study of Russia. *Sustain. Sci. Pract. Policy* **2019**, *12*, 94. [CrossRef]
33. Kumar, S.; Singh, D. Smart cities waste minimization, remanufacturing, reuse, and recycling solutions using IoT and ML. In Proceedings of the 2024 IEEE International Conference on Computing, Power and Communication Technologies (IC2PCT), Greater Noida, India, 9–10 February 2024; IEEE: Piscataway, NJ, USA, 2024; pp. 1546–1552.
34. Shyam, G.K.; Manvi, S.S.; Bharti, P. SmartWaste Management Using Internet-of-Things (IoT). In Proceedings of the 2017 2nd International Conference on Computing and Communications Technologies (ICCCT), Chennai, India, 23–24 February 2017.
35. Rangaswamy, A.; Moch, N.; Felten, C.; van Bruggen, G.; Wieringa, J.E.; Wirtz, J. The role of marketing in digital business platforms. *J. Interact. Mark.* **2020**, *51*, 72–90. [CrossRef]
36. Frishammar, J.; Cenamor, J.; Cavalli-Björkman, H.; Hernell, E.; Carlsson, J. Digital strategies for two-sided markets: A case study of shopping malls. *Decis. Support Syst.* **2018**, *108*, 34–44. [CrossRef]
37. The Digitalisation of Waste Management; Survey Reveals Uncertainty among Disposal Companies. Available online: https://www.netwaste.de/blog/waste-5-0/die-digitalisierung-der-abfallwirtschaft-umfrage-deckt-unsicherheit-bei-entsorgern-auf/#more-496 (accessed on 1 March 2024).
38. Ghobakhloo, M.; Fathi, M.; Iranmanesh, M.; Maroufkhani, P.; Morales, M.E. Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants. *J. Clean. Prod.* **2021**, *302*, 127052. [CrossRef]
39. Alidoosti, Z.; Sadegheih, A.; Govindan, K.; Pishvaee, M.S. Sustainable network design of bioenergies generation based on municipal solid waste (MSW) management under uncertainty. *J. Renew. Sustain. Energy* **2023**, *15*, 013103. [CrossRef]
40. Usman, M.; Jahanger, A.; Makhdum, M.S.A.; Balsalobre-Lorente, D.; Bashir, A. How do financial development, energy consumption, natural resources, and globalization affect Arctic countries' economic growth and environmental quality? An advanced panel data simulation. *Energy* **2022**, *241*, 122515. [CrossRef]
41. Zota, R.D.; Cîmpeanu, I.A.; Dragomir, D.A.; Lungu, M.A. Practical Approach for Smart and Circular Cities: Chatbots Used in Waste Recycling. *Appl. Sci.* **2024**, *14*, 3060. [CrossRef]
42. Ndou, V.; Rampedi, I.T. Bibliometric Analysis of Municipal Solid Waste Management Research: Global and South African Trends. *Sustainability* **2022**, *14*, 10229. [CrossRef]
43. Luić, L.; Krešimir, L. Information Practices and Digital Perspectives of Municipal Waste Recovery Providers in Europe. *Teh. Glas.* **2021**, *15*, 392–400. [CrossRef]
44. Matuszewska, A.; Owczuk, M.; Biernat, K. Current Trends in Waste Plastics' Liquefaction into Fuel Fraction: A Review. *Energies* **2022**, *15*, 2719. [CrossRef]
45. Cane, M.; Parra, C. Digital platforms: Mapping the territory of new technologies to fight food waste. *Br. Food J.* **2020**, *122*, 1647–1669. [CrossRef]
46. Bonadonna, A.; Matozzo, A.; Giachino, C.; Peira, G. Farmer behavior and perception regarding food waste and unsold food. *Br. Food J.* **2019**, *121*, 89–103. [CrossRef]
47. Michelini, L.; Principato, L.; Iasevoli, G. Understanding food sharing models to tackle sustainability challenges. *Ecol. Econ.* **2018**, *145*, 205–217. [CrossRef]
48. Li, Q.; Sun, P. Research trend of construction debris reclamation home and abroad. *China Build. Mater. Sci. Technol.* **2009**, *4*, 119–122.
49. Arya, S.; Kumar, S. E-waste in India at a glance: Current trends, regulations, challenges and management strategies. *J. Clean. Prod.* **2020**, *271*, 122707. [CrossRef]
50. Farjana, M.; Fahad, A.B.; Alam, S.E.; Islam, M.M. An IoT- and Cloud-Based E-Waste Management System for Resource Reclamation with a Data-Driven Decision-Making Process. *IoT* **2023**, *4*, 202–220. [CrossRef]
51. Mahipal, S.S.; Mayuri, K.; Manisha, N.; Shriyash, M.; Gaurav, S.; Bhaskar, C.; Rajeev, K. Effect of Electronic waste on Environmental & Human health-A Review. *IOSR J. Environ. Sci. Toxicol. Food Technol. (IOSR-JESTFT)* **2016**, *10*, 98–104.
52. Ali, S.S.; Elsamahy, T.; Koutra, E.; Kornaros, M.; El-Sheekh, M.; Abdelkarim, E.A.; Zhu, D.; Sun, J. Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal. *Sci. Total Environ.* **2021**, *771*, 144719. [CrossRef]
53. Dris, R.; Agarwal, S.; Laforsch, C. Plastics: From a success story to an environmental problem and a global challenge. *Glob. Chall.* **2020**, *4*, 2000026. [CrossRef]
54. Wang, Z.; Huo, J.; Duan, Y. The impact of government incentives and penalties on willingness to recycle plastic waste: An evolutionary game theory perspective. *Front. Environ. Sci. Eng.* **2020**, *14*, 29. [CrossRef]
55. Shin, S.K.; Um, N.; Kim, Y.J.; Cho, N.H.; Jeon, T.W. New policy framework with plastic waste control plan for effective plastic waste management. *Sustainability* **2020**, *12*, 6049. [CrossRef]
56. Ding, Q.; Zhu, H. The Key to Solving Plastic Packaging Wastes: Design for Recycling and Recycling Technology. *Polymers* **2023**, *15*, 1485. [CrossRef] [PubMed]
57. Rajput, S.; Singh, S.P. Industry 4.0 Model for circular economy and cleaner production. *J. Clean. Prod.* **2020**, *277*, 123853. [CrossRef]

58. Kurniawan, T.A.; Oliveira, J.P.; Gamaralalage, P.J.D.; Nagaishi, M. City-to-city level cooperation for generating urban co-benefits: The case of technological cooperation in the waste sector between Surabaya (Indonesia) and Kitakyushu (Japan). *J. Clean. Prod.* **2013**, *58*, 43–50. [CrossRef]
59. Hanson, V.; Ahmadi, L. Mobile applications to reduce food waste within Canada: A review. *Can. Geogr./Géographe Can.* **2022**, *66*, 402–411. [CrossRef]
60. Gu, F.; Zhang, W.; Guo, J.; Hall, P. Exploring "Internet+ Recycling": Mass balance and life cycle assessment of a waste management system associated with a mobile application. *Sci. Total Environ.* **2019**, *649*, 172–185. [CrossRef] [PubMed]
61. Statista. Number of Monthly Active WeChat Users from 2nd Quarter 2010 to 2nd Quarter 2017 (in Millions). 2018. Available online: https://www.statista.com/statistics/255778/number-of-active-wechat-messenger-accounts/ (accessed on 15 May 2024).
62. Bonino, D.; Alizo, M.T.D.; Pastrone, C.; Spirito, M. WasteApp: Smarter waste recycling for smart citizens. In Proceedings of the 2016 International Multidisciplinary Conference on Computer and Energy Science (SpliTech), Split, Croatia, 13–15 July 2016; pp. 1–6. [CrossRef]
63. Ambrosio, L.; Siqueira Paulino, P.L.; Antiquera, J.; Aquino, G.P.; Cesar Vilas Boas, E. EcoWaste: A Smart Waste Platform Enabling Circular Economy. In Proceedings of the 2021 IEEE 19th Student Conference on Research and Development (SCOReD), Kota Kinabalu, Malaysia, 23–25 November 2021; pp. 411–415. [CrossRef]
64. Suruliraj, B.; Olagunju, T.; Nkwo, M.S.; Orji, R. Bota: A Personalized Persuasive Mobile App for Sustainable Waste Management. In Proceedings of the International Conference on Persuasive Technology, Aalborg, Denmark, 20–23 April 2020.
65. Nadzir, M.M.; Seowfuddin, N.F.A.S. Reduce, Reuse, Recycle (3Rs) Awareness App: Mobile Learning Application for Supporting Environmental Awareness Initiatives. In Proceedings of the 2019 IEEE Conference on e-Learning, e-Management & e- Services (IC3e), Pulau Pinang, Malaysia, 19–21 November 2019; pp. 31–34. [CrossRef]
66. Naskova, J. RecycHongs: Mobile App Co-design. In Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems (DIS'17 Companion), Edinburgh, UK, 10–14 June 2017; Association for Computing Machinery: New York, NY, USA, 2017; pp. 337–340. [CrossRef]
67. Varghese, C.; Pathak, D.; Varde, A.S. SeVa: A Food Donation App for Smart Living. In Proceedings of the 2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC), Virtual, 27–30 January 2021; pp. 0408–0413. [CrossRef]
68. Ballaran, P.M.; Corpuz, C.B.A.; Paras, L.A.R.; Fabito, B.S.; Rivera, E.R. Perazuhan: A Mobile Application for Solid Waste Micro-Management Framework, 2019. In Proceedings of the IEEE Student Conference on Research and Development (SCOReD), Bandar Seri Iskandar, Malaysia, 15–17 October 2019; pp. 17–20. [CrossRef]
69. Harvey, J.; Smith, A.; Goulding, J.; Branco, I.I. Food Sharing, Redistribution, and Waste Reduction via Mobile Applications: A Social Network Analysis. *Ind. Mark. Manag.* **2019**, *88*, 437–448. [CrossRef]
70. Mastorakis, G.; Kopanakis, I.; Makridis, J.; Chroni, C.; Synani, K.; Lasaridi, K.; Abeliotis, K.; Louloudakis, I.; Daliakopoulos, I.N.; Manios, T. Managing Household Food Waste with the FoodSaveShare Mobile Application. *Sustainability* **2024**, *16*, 2800. [CrossRef]
71. Haas, R.; Aşan, H.; Doğan, O.; Michalek, C.R.; Karaca Akkan, Ö.; Bulut, Z.A. Designing and Implementing the MySusCof App-A Mobile App to Support Food Waste Reduction. *Foods* **2022**, *11*, 2222. [CrossRef]
72. Farr-Wharton, G.; Foth, M.; Choi, J.H. EatChaFood: Challenging technology design to slice food waste production. In Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication (UbiComp'13 Adjunct), Zurich, Switzerland, 8–12 September 2013; Association for Computing Machinery: New York, NY, USA, 2013; pp. 559–562. [CrossRef]
73. Frost, S.; Tor, B.; Agrawal, R.; Forbes, A.G. CompostNet: An Image Classifier for Meal Waste. In Proceedings of the 2019 IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 17–20 October 2019; pp. 1–4. [CrossRef]
74. Coelho, T.R.; Hino, M.R.M.C.; Vahldick, S.M.O. The use of ICT in the informal recycling sector: The Brazilian case of Relix. *Electron. J. Inf. Syst. Dev. Ctries.* **2019**, *85*, e12078. [CrossRef]
75. More, K.S.; Wolkersdorfer, C. Intelligent Mine Water Management Tools—eMetsi and Machine Learning GUI. *Mine Water Environ.* **2023**, *42*, 111–120. [CrossRef]
76. Hajjdiab, H.; Anzer, A.; Tabaza, H.A.; Ahmed, W. A Food Wastage Reduction Mobile Application. In Proceedings of the 2018 6th International Conference on Future Internet of Things and Cloud Workshops (FiCloudW), Barcelona, Spain, 6–8 August 2018; pp. 152–157. [CrossRef]
77. Amadi, E.C.; Chukwudebe, G.; Ayogu, I.; Ikerionwu, C.; Okafor, K.C. Implementation of a Web Application for Stakeholder Inclusion for Sustainable Waste Management. In Proceedings of the 2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON), Lagos, Nigeria, 5–7 April 2022; pp. 1–5. [CrossRef]
78. Wong, W.T.; Fernando, O.N.N.; Panchapakesan, C.; Jia, J.K.S. Foodscover: Eliminating food waste in the retail sector through technology. In Proceedings of the 2021 International Conference on Cyberworlds (CW), Caen, France, 28–30 September 2021; pp. 85–92. [CrossRef]
79. Akmal, M.; Niwanputri, G.S. Spoonful: Mobile Application for Reducing Household Food Waste using Fogg Behavior Model (FBM). In Proceedings of the 2021 International Conference on Data and Software Engineering (ICoDSE), Bandung, Indonesia, 3–4 November 2021; pp. 1–6. [CrossRef]
80. Morilla, J.A.R.; Bagsic, F.C.; Dela Cruz, M.K.; Patio, C.D.A.; Yabut, E.R. Foodernity: A Mobile and Web Application for Food Sharing. In Proceedings of the 2021 1st International Conference in Information and Computing Research (iCORE), Manila, Philippines, 11–12 December 2021; pp. 90–95. [CrossRef]

81. Yu, Y.; Yi, S.; Nan, X.; Lo, L.Y.; Shigyo, K.; Xie, L.; Wicaksana, J.; Cheng, K.T.; Qu, H. FoodWise: Food Waste Reduction and Behavior Change on Campus with Data Visualization and Gamification. In Proceedings of the 6th ACM SIGCAS/SIGCHI Conference on Computing and Sustainable Societies (COMPASS'23), Cape Town, South Africa, 16–19 August 2023; Association for Computing Machinery: New York, NY, USA, 2023; pp. 76–83. [CrossRef]
82. Kanmani, A.; Karthicka Priyadharshni, J.K.; Praharsha, S.; Mano Dharshan, M.P.; Deeraj Kumar, K.K.; Abirami, A.M. Dumpster: Predictive Model to trade Bio-waste from Agricultural Lands. In Proceedings of the 2020 International Conference on Innovative Trends in Information Technology (ICITIIT), Kottayam, India, 13–14 February 2020; pp. 1–6. [CrossRef]
83. Manrique, S.; Eulogio, L.; Armas, J. Recycling: A User-Friendly Oriented Mobile and Web Solution for Generators and Recyclers in the City of Lima. In *BTSym 2020, Proceedings of the 6th Brazilian Technology Symposium (BTSym'20), Campinas, Brazil, 26–28 October 2020*; Iano, Y., Saotome, O., Kemper, G., Mendes de Seixas, A.C., Gomes de Oliveira, G., Eds.; Smart Innovation, Systems and Technologies; Springer: Cham, Switzerland, 2021; Volume 233. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.