Vol-3 Issue-1 2025
Scientific Research Journal of Environment, Earth and Physical Science
ISSN: 2584-0614, Peer Reviewed Journal

Tech-Driven Circularity: Agile and Lean Synergies

Author[1*]

Henry Efe Onomakpo1*

1 Faculty of Economics and Business, University of Gadjah Mada, Yogyakarta, Indonesia

*** Correspondence:**
Email id: henryonomakpo@gmail.com

Abstract

Background. Growing concerns regarding resource depletion and climate change have elevated the circular economy (CE) to a position of paramount importance. The transition to a CE requires moving away from linear production and disposal models toward regenerative systems. While technological advancements offer unparalleled opportunities, the limited understanding of the integration of agile/lean methodologies alongside these technologies poses a critical research gap. This paper addresses this gap by rigorously analyzing the various techniques for integrating agile/lean methodology with digital technological advancements to enhance CE objectives.

Methods. A systematic literature review was conducted following PRISMA guidelines, leveraging both bibliometric analysis using R's bibliometrix and content analysis. The data sources used for the literature review included Web of Science, Scopus, and ScienceDirect. This involved searching relevant literature, then analyzing those pieces to extract information and come up with a framework.

Results. The analysis ostensibly highlights that artificial intelligence (AI), blockchain, the Internet of Things (IoT), and digital twins are quintessentially key emerging technologies within the CE landscape. The review indicated that agile methodologies support the creation of new CE solutions via iterative processes. The review inherently stresses the importance of collaboration among universities, industry, and governments for knowledge transfer and policy improvements in the transition to a CE. A novel framework integrating agile and lean methodologies with emerging technologies was then synthesized.

This review underscores the potential of integrating agile and lean methodologies with emerging technologies to drive the CE transition. It stresses the need for a systemic approach, underpinned by an appropriate framework and robust policies, alongside consideration of potential ethical and economic impacts relating to the technologies used.

Keywords: Circular Economy, Agile Methodology, Lean Methodology, Artificial Intelligence, Blockchain, Internet of Things, Digital Twins, Sustainability, Technological Innovation.

Introduction

Growing concerns regarding resource depletion, the accumulation of waste, and the pressing need to mitigate climate change have elevated the transition to a circular economy (CE) to a position of paramount importance (Aristi-Capetillo et al., 2022). This transition demands that we move away from a traditional linear model based on extraction, production, and disposal and instead embrace regenerative systems focused on extending the lifespan of resources through continuous use, recovery, and the facilitation of renewal (Rejeb et al., 2023). Addressing this imperative, which is both environmental and economic, necessitates the development of innovative business strategies coupled with the strategic application of technological advancements (Agrawal et al., 2023). The ongoing digital revolution, characterized by technologies such as Artificial Intelligence (AI), Blockchain systems, the Internet of Things (IoT), and Digital Twins (DT), provides unparalleled opportunities for optimizing how resources are managed and for developing effective strategies intended to support circularity.

Nevertheless, realizing the full potential of the circular economy is not solely dependent upon novel technological solutions; it requires the implementation of effective management approaches. Among the many existing approaches, lean and agile methods offer a way of optimizing resources that is not directly related to novel technology. It is, therefore, the position of this paper that the lack of research into the integration of CE technological solutions and existing management strategy is a critical limitation of the current literature.

Therefore, this paper will rigorously consider the various techniques for integrating agile/lean methodology with digital technological advancements to enhance CE objectives. Addressing a clear gap in the literature, the goal of this research is twofold: (1) to identify consistently utilized methodologies and technologies to find potential synergies, and (2) to synthesize existing concepts into a novel framework that helps better apply such systems to the transition of real-world technological systems to a circular economy. These insights will be rigorously integrated through a systematic review, guided by PRISMA guidelines (Page et al., 2021), that leverages both bibliometric analysis using R's biblioshiny() and content analysis (Aria & Cuccurullo, 2017). This process will yield a more developed understanding of critical concepts, identification of challenges, and a more thorough understanding of opportunities that CE methodologies can leverage. The review and resulting framework will then serve as a valuable resource for future research endeavors, policy development, and the practical adoption of technology and agile/lean innovations to more effectively integrate technology and management methodologies into existing CE systems.

Materials & Methods

This study employed a mixed-methods approach, integrating a systematic literature review (SLR) and bibliometric analysis to address the research questions. The methodology adhered to established guidelines for robust and reproducible systematic literature reviews, aligning with the PRISMA flow diagram (Page et al., 2021).

Data Sources and Search Strategy

A comprehensive search was conducted across Scopus, Dimensions, and ScienceDirect databases. Targeted keywords related to agile/lean innovation, the circular economy, and emerging technologies were used. The initial search yielded 6401 articles, limited to publications up to December 2024, without language restrictions, though all articles were indexed in the specified databases and written in English.

Study Selection and Screening

Vol-3 Issue-1 2025
Scientific Research Journal of Environment, Earth and Physical Science
ISSN: 2584-0614, Peer Reviewed Journal

A rigorous multi-stage screening process was applied. Initially, title and abstract screening reduced the articles to 147, followed by manual screening to remove duplicates, resulting in 139 relevant articles. These articles were reviewed for their relevance to the research questions, specifically concerning the intersection of agile/lean methodologies, emerging technologies, and the CE. The PRISMA flow diagram (Figure 1) illustrates the study's selection process. An initial database search (Scopus, Dimensions, and ScienceDirect) yielded 6401 records. After removing 6254 duplicates and 8 ineligible records through automation, 147 records underwent screening. Eight reports were excluded during screening, leaving 139 for full-text retrieval. All 139 retrieved reports were deemed eligible, resulting in a final inclusion of 139 studies in the review.

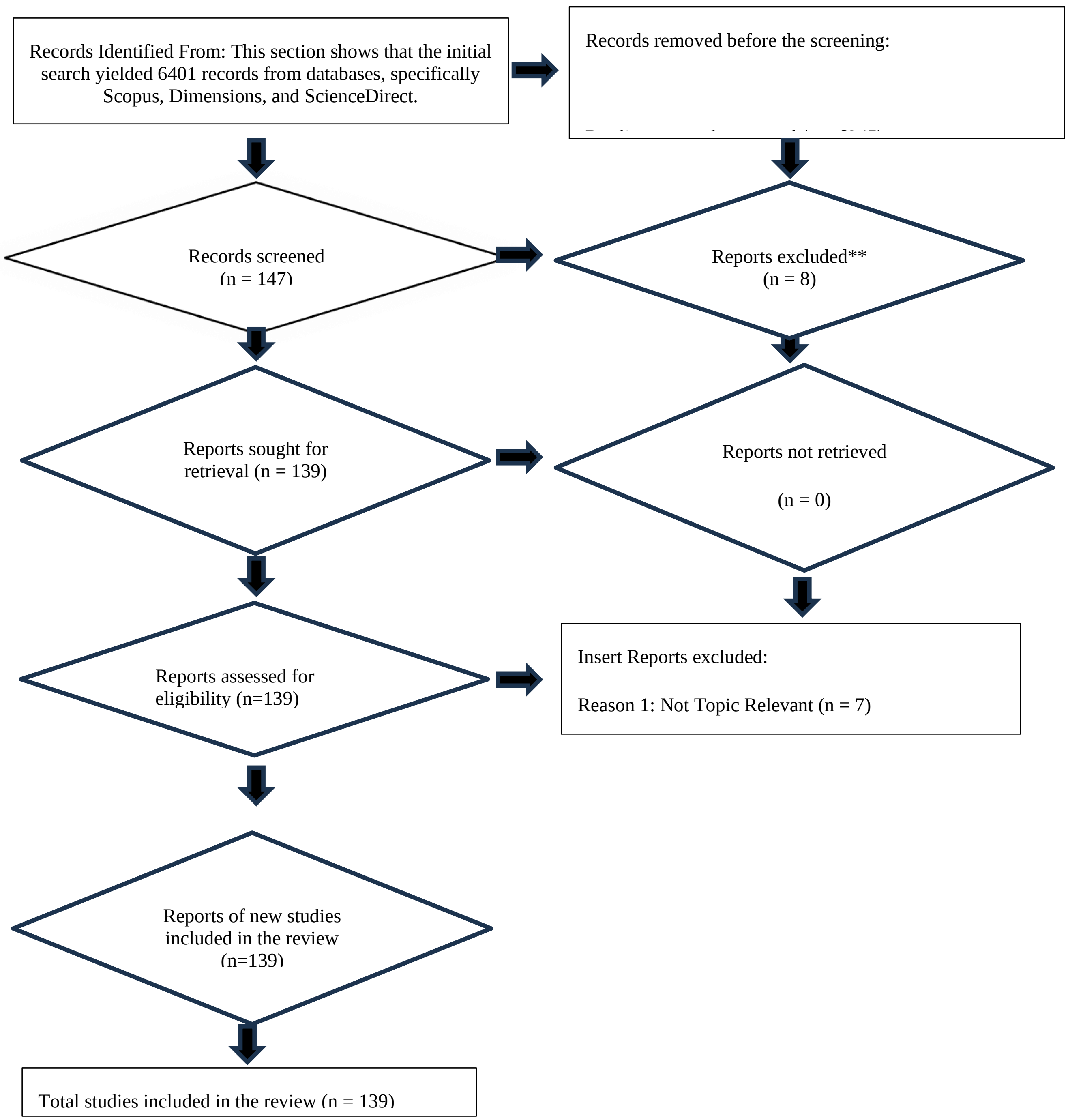

Figure 1. PRISMA Diagram of Search Strategy. The diagram illustrates the systematic review process, detailing records identified, screened, assessed for eligibility, and included in the final analysis. Data sources include Scopus, Dimensions, and ScienceDirect.

Data Extraction and Analysis

Each of the 139 studies was analyzed, extracting data on the title, authors, publication year, journal, key findings, and methodologies. Studies were classified based on emerging themes, practical applications of technologies/methodologies, and encountered challenges.

Bibliometric Analysis

Bibliometric analysis, using R's bibliometrix package with biblioshiny(), mapped the research landscape, identifying trends, sources, and author productivity, employing metrics like citation counts, h-index, and co-occurrence of terms. Visualizations from biblioshiny() helped discern emerging topics and clusters. The data is readily available for replication. The bibliometric analysis informed the SLR and the selection of emerging themes. Data from both analyses was categorized into key themes guided by research objectives and identified trends. This systematic approach coded and classified all collected information.

Study Limitations

This research has limitations, including potential selection bias from keyword combinations, language restrictions (English articles only), and database limitations (Scopus, Dimensions, and ScienceDirect).

Framework Development

Ultimately, the findings from the SLR and bibliometric analysis were integrated to develop a framework for combining agile/lean innovation practices with emerging technologies for effective CE implementation.

Results / Discussion

This section reviews key findings from the 139 selected publications, focusing on the practical implementation of new technologies and the application of agile and lean methodologies to enable circular economy transitions.

The Nexus of Emerging Technologies and Circular Economy

Analysis of the literature revealed key focus areas for emerging technologies in advancing circular economy objectives. AI is primarily leveraged to optimize operations and supply chain management in CE systems to improve overall operation and efficiency as suggested by Alahi et al. (2023) and Delanoë et al. (2023).

While blockchain, as noted in Arvana et al. (2023), enables greater accountability and lifecycle tracking of products, its use, for example, in blockchain networks, has some ethical implications, as indicated by

Cows et al. (2021). The Internet of Things or IoT is also frequently used for material tracking (Ding et al., 2023) and digital twins to support better decision-making and urban planning processes, as highlighted by Alonso et al., 2023 and Tartia & Hämäläinen, 2024. These technologies represent versatile tools that can facilitate both efficiency improvements and enhanced collaboration between stakeholders.

Agile and Lean Methodologies in Circular Economy

The review reveals that applying agile and lean models, including new design aspects and efficient improvements, is crucial for circular economy. As such, Ertz & Gasteau (2023), and Srivastav et al., (2023) find agile implementation enables the development of strategies for changing and improving design, while there is additional support for lean approaches improving resources and sustainability by (Andersen & Halse, 2023; Chopra et al., 2023; Ding et al., 2023; Elia et al., 2018; Magnano et al., 2024; Siddik et al., 2023; Ting et al., 2023).

To continue the progress of efficiency, it is necessary to improve the methods necessary, as this will help reduce costs and increase sustainability (Andersen & Halse, 2023; Chopra et al., 2023; Ting et al., 2023).

Implementation Challenges and Opportunities

The analysis of publications in this area shows a set of shared implementation barriers and also identifies emerging opportunities for improvement. Many authors have cited that negative perceptions and a lack of awareness are common hindrances to the adoption of new technologies. Moreover, the lack of reliable data to assess outcomes and the existence of a digital divide are major challenges, as highlighted by Ahmad et al. (2024), who also raise an ethical concern that new technologies should never undermine equality and justice. In addition, authors such as Ding et al. (2023), Bibri et al. (2023), and Rani et al. (2024) show that governance, ethical, and security concerns also pose a potential obstacle. Authors have also focused on the need to address the environmental costs and social impacts of new technologies to guarantee a transition to net zero that is environmentally and socially sustainable. As such, Cowls et al. (2021) highlighted the carbon footprint of AI-driven research, while Rani et al. (2024) investigated the energy consumption of blockchain networks, and Sharma et al. (2023) explored the potential of "Green AI" to address environmental concerns. Authors have also argued for more robust policy frameworks to foster a more circular economy while also recognizing that new regulations and interventions must be flexible to allow for regional differences. For instance, Aristi Capetillo et al. (2022) and Bibri et al. (2023) emphasized the need to incentivize technology adoption, and authors such as Alonso et al. (2023), Bianchini et al. (2022), and Momete (2021), stressed the need for better collaboration for policy alignment, whereas D'Adamo et al. (2022), and Holzinger et al. (2022) also highlighted that public literacy is essential to ensure the success of this transition. Furthermore, as highlighted by authors such as Hao et al. (2024) and Jugend et al. (2024), policies need to be flexible to adjust to regional specificities.

Other areas of research that are emerging include the need for standardized metrics to evaluate circularity, as explored by Voukkali et al. (2023), the importance of studying the interplay between the digital economy and the CE in developing countries (Liu et al., 2024), and the evaluation of the effectiveness of policy interventions (Bianchini et al., 2022; Jugend et al., 2024). Finally, some authors, such as Samani (2023) and Hassoun et al. (2023), advocated that life cycle assessments must be better integrated with circularity principles.

Quantitative Findings: Bibliometric Analysis of Agile and Lean Innovation in the Circular Economy

This section provides a quantitative overview of the research landscape concerning Agile and Lean Innovation in the Circular Economy, focusing on the integration of technologies like AI, Blockchain, IoT, and Digital Twins.

Table 1. Citation Data and Annual Publication

Year	Articles	Mean TC per Article (citations)	N	Mean TC per Year (citations)	Citable Years
2015	1	127	1	11.55	11
2016	0	0	0	0	0
2017	1	35	1	3.89	9
2018	1	357	1	44.62	8
2019	2	80	2	11.43	7
2020	11	203.82	11	33.97	6
2021	10	90.2	10	18.04	5
2022	34	32.38	34	8.1	4
2023	46	33.87	46	11.29	3
2024	41	3.56	41	1.78	2

Table 1 presents the annual publication and citation analysis. The table includes the following: Year (year of publication), Articles (number of articles published that year), MeanTCperArt (mean total citations per article), N (number of articles included in the bibliometric analysis for that year), MeanTCperYear (mean total citations per year), and CitableYears (number of years since publication).

The early years (2015-2017) saw few publications, with no articles in 2016. A single article published in 2018 had a high MeanTCperArt. A sharp rise in publications occurred from 2020 onward. High MeanTCperArt and MeanTCperYear values were observed in 2018 and 2020. Recent years (2022-2024) showed substantial growth in publications but lower citation rates. Meanwhile, Figure 2 demonstrates the annual distribution of publications and their corresponding average citations, providing insights into the impact and research trends over time.

Vol-3 Issue-1 2025
Scientific Research Journal of Environment, Earth and Physical Science
ISSN: 2584-0614, Peer Reviewed Journal

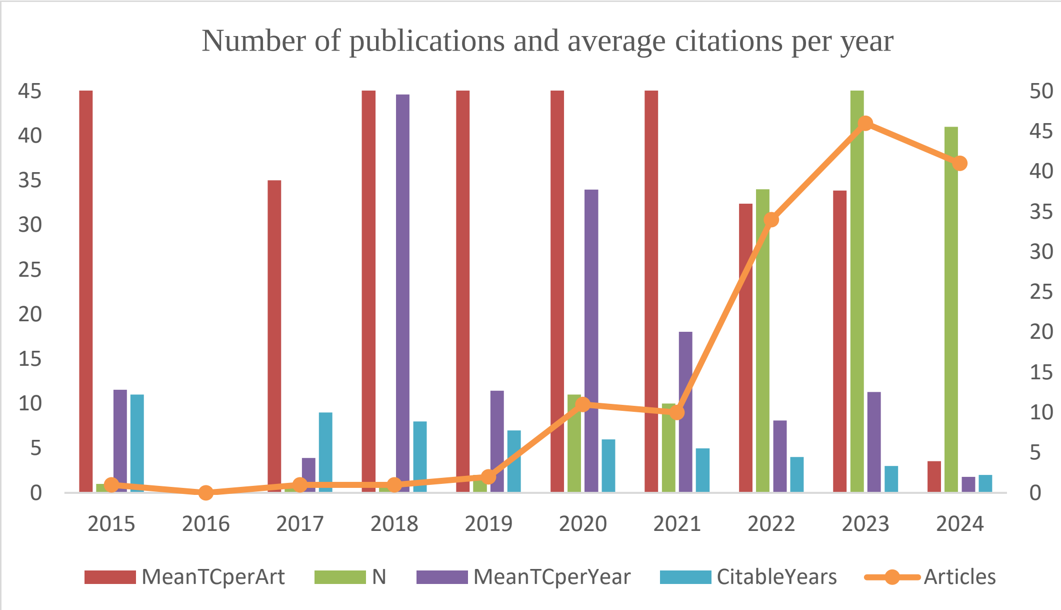

Figure 2. Number of publications and average citations per year. This figure presents the annual distribution of publications and their corresponding average citations, providing insights into the impact and research trends over time.

1.1.1 Most Relevant Sources

The examination of pertinent sources (see Figure 3) reveals a diverse and multidisciplinary research landscape. Notable journals such as Environmental Science and Pollution Research and Journal of Environmental Management dominate, underscoring the environmental emphasis in studies related to the circular economy, agile/lean innovation, and emerging technologies. Additionally, the inclusion of various perspectives from journals like Operations Management Research, Foods, and Waste Management highlights the breadth of the field. Specialized publications such as Circular Economy and Sustainability further indicate the ongoing development and consolidation of this area of research.

The variety of journals, including those that focus on specific applications (e.g., Sensors) and social dimensions (e.g., Frontiers in Psychology), illustrates the applied and interdisciplinary nature of the research. While firmly grounded in environmental sustainability, there is a growing integration of technology and business strategy, as shown by the presence of journals like Sensors, Frontiers in Artificial Intelligence, and Operations Management Research. This diverse array of publications emphasizes the multidisciplinary character of the field and highlights the importance of cross-disciplinary collaboration to tackle the complex issues associated with implementing agile and lean innovations in the context of the circular economy.

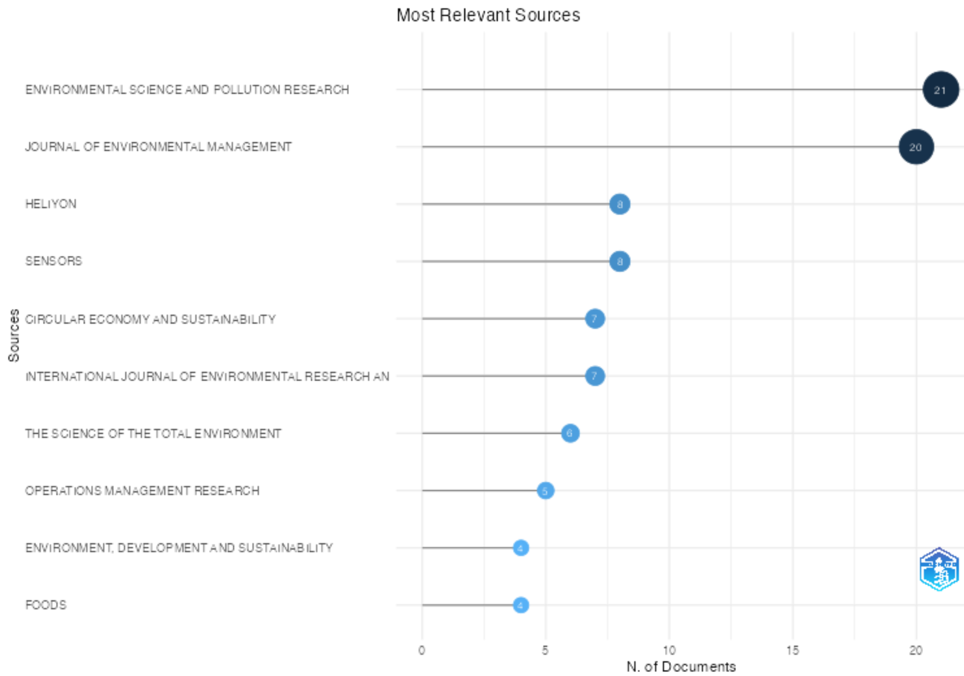

Figure 3. Most Relevant Sources. This figure presents the most frequently cited sources in the study, highlighting their relevance and contribution to the research.

Source: Data compiled by the author from the Scopus database were analyzed using the R package "bibliometrix".

1.1.2 Source's Local Impact

Environmental Science and Pollution Research had a high h-index (13) and total citations (607) (Figure 4). The Journal of Environmental Management demonstrated a strong m-index and h-index. Waste Management had a substantial total citation count (717).

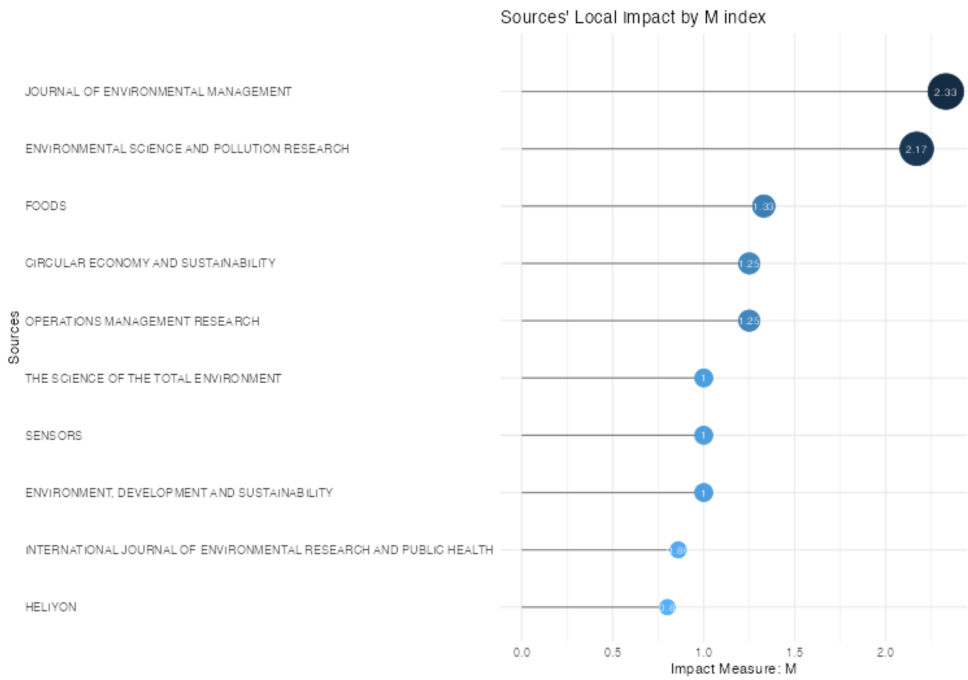

Figure 4. Source’s Local Impact by M-index. This figure illustrates the local impact of sources based on the M-index, which measures the consistency of a researcher's or source’s influence over time.

Source: Data compiled by the author from the Scopus database were analyzed using the R package “bibliometrix”.

1.1.3 Author’s Production Over Time

Yu Z. was a highly active researcher (2022-2024), with the journal Environmental Science and Pollution Research as a primary outlet (Figure 5). Kumar A.'s work explored emerging technologies and green finance.

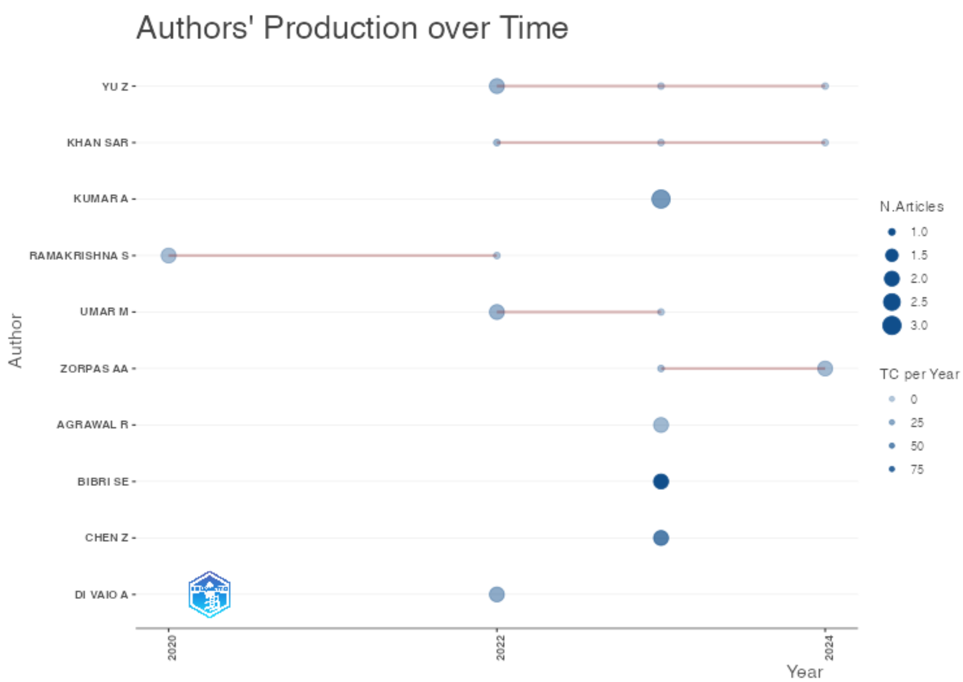

Figure 5. Author's Production Over Time. This figure presents the trend of an author's research output over time, highlighting the number of publications per year and the corresponding citation impact.

Source: Data compiled by the author from the Scopus database were analyzed using the R package "bibliometrix".

1.1.4 Corresponding Author's Countries

China led with 20 articles, equating to 13.6% of the total publications (Figure 6). 70% of these publications involved multiple countries. India and Italy had 10 articles each, representing 6.8% of the total. France, with 8 publications (5.4%), showed a high MCP at 87.5%.

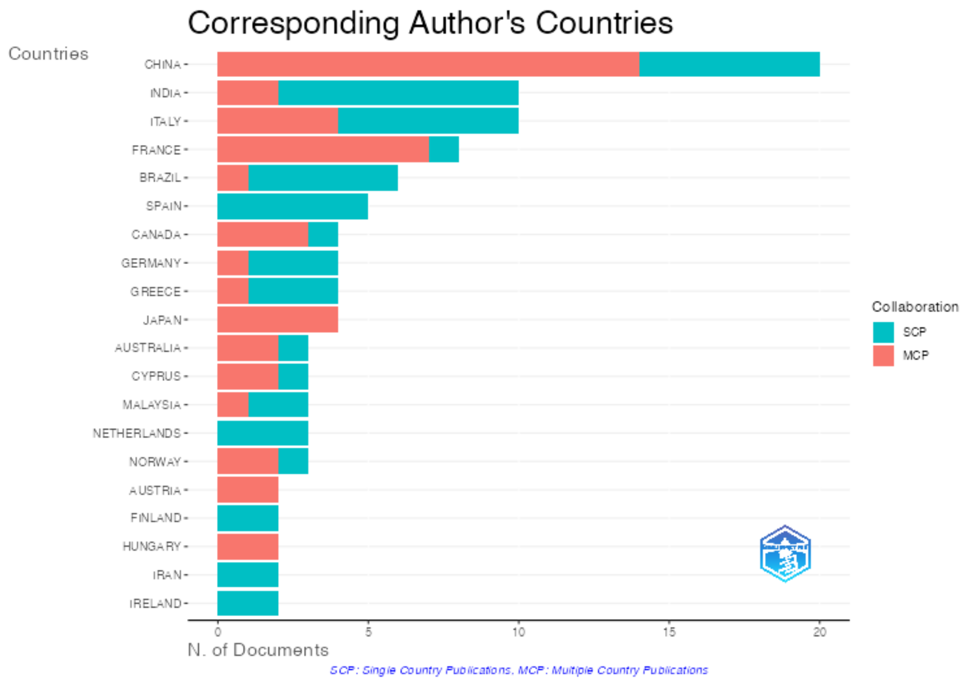

Figure 6. Corresponding Author's Countries. This figure illustrates the geographical distribution of corresponding authors, showcasing the countries with the highest research contributions in the dataset.

Source: Data compiled by the author from the Scopus database were analyzed using the R package "bibliometrix".

1.1.5 Citation Mapping of the Most Influential Papers in Circular Economy Research

Ibn-Mohammed et al. (2021), in Resources Conservation and Recycling, had the highest TC (678), as shown in Figure 7. Nandi et al. (2021), on Sustainable Production and Consumption, also showed a high TC and TC per year. Esmaeilian et al. (2018), in Waste Management, achieved a Normalized TC of 1. Recent publications, like Bibri S.E. (2023) in Environmental Science and Ecotechnology (Normalized TC of 5.7), Alahi E.E. (2023) in Sensors, Fang B. (2023) in Environmental Chemistry Letters, and Raabe D. (2023) in Chemical Reviews, showed high normalized TC values.

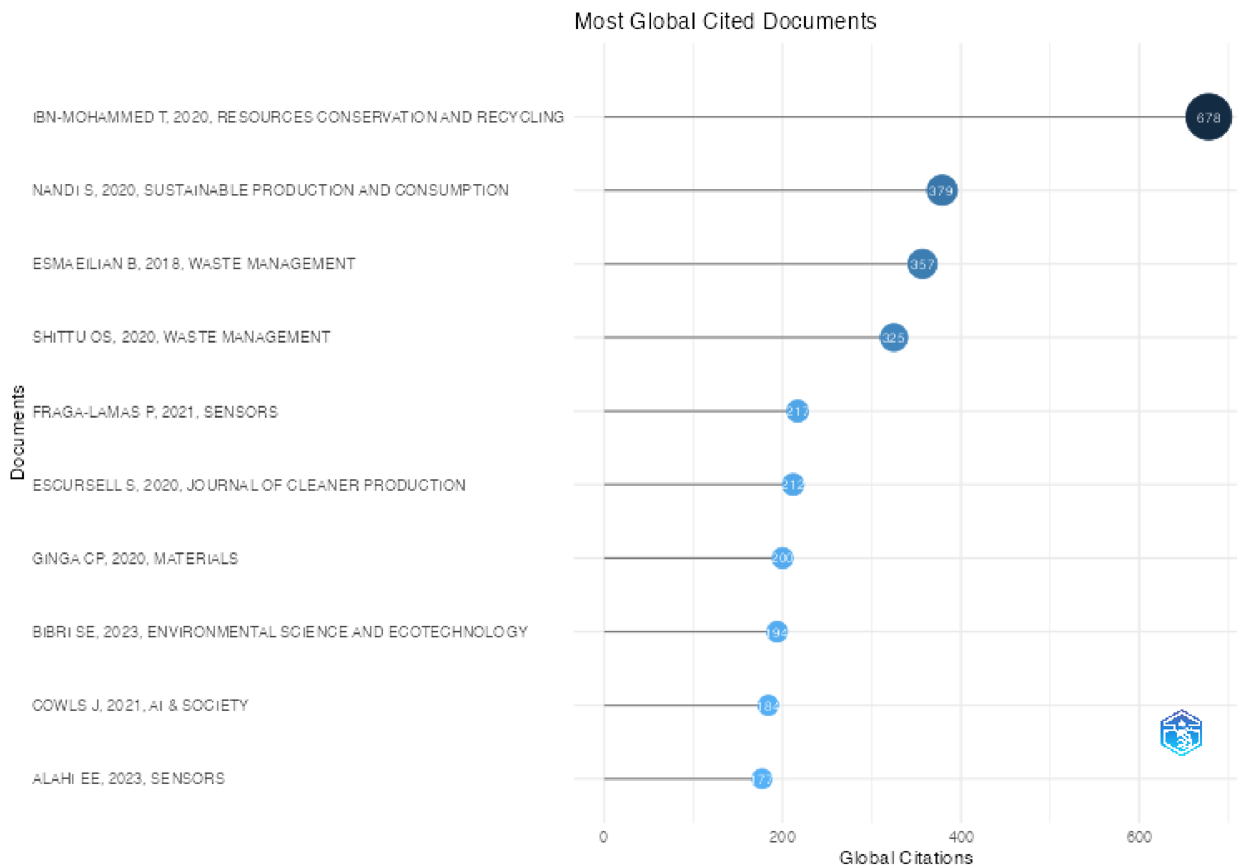

Figure 7. Citation Mapping of the Most Influential Papers in Circular Economy Research. This figure visualizes the citation network of the most impactful papers in Circular Economy research, highlighting key connections and influential works.

Source: Data compiled by the author from the Scopus database were analyzed using the R package "bibliometrix".

1.1.6 Most Relevant Words

"Waste management" (23) emerged as the most frequent term (Figure 8). "Humans" (20) highlighted a user-centered approach. "Recycling" (18) and "industry" (14) linked circularity to industrial processes and waste valorization. "Artificial intelligence" (12), "conservation of natural resources" (11), and "sustainable development" (11) underscored the integration of technology and sustainability, with "economic development" (10) emphasizing economic dimensions.

Figure 8. Most Relevant Words. This figure presents the most frequently occurring words in the analyzed literature, providing insights into key themes and research trends.

Source: Data compiled by the author from the Scopus database were analyzed using the R package "bibliometrix".

1.1.7 Trend Topics

Terms like "electronic waste", "electronics", and "China" showed concentrated publications in 2022-2023 (Table 2). "Waste management, humans, and recycling had a broader distribution with the median year of 2023. "Conservation of natural resources" and "sustainable development" had a median of 2024.

Table 2. Trend topics.

Term	Frequency	Year (Q1)	Year (Median)	Year (Q3)
Electronic waste	9	2022	2022	2023
China	6	2022	2022	2024
Electronics	6	2022	2022	2023
waste management	23	2022	2023	2024
Humans	20	2022	2023	2023
Recycling	18	2022	2023	2024
Conservation of natural resources	11	2024	2024	2024

Sustainable development	11	2023	2024	2024
European union	5	2022	2024	2024

1.1.8 Co-words Network Analysis

Figure 9, a co-occurrence network analysis, reveals the research landscape surrounding the circular economy and its convergence with digital technologies (AI, IoT, blockchain). The analysis organizes concepts into distinct clusters. Cluster 1, featuring “humans,” “artificial intelligence,” “environment,” and “internet of things,” represents the foundational understanding of AI as a key element in a circular economy, particularly for environmental issues. Humans are central, while AI acts as a tool. “Carbon dioxide,” “ecosystem,” and “environmental monitoring” highlight environmental drivers, and “Europe” suggests an EU focus. Cluster 2 emphasizes practical application within the economy, with “industry,” “conservation of natural resources,” “sustainable development,” and “economic development,” linking sustainability and economic activity. “Commerce” and “cities” highlight real-world implementation, and “China” suggests a broader scope. Cluster 3 focuses on water-related aspects, with terms such as “waste disposal, fluid,” “wastewater,” “water,” and “water purification.” Cluster 4 addresses waste management, particularly electronic waste, including “waste management,” “recycling," and “electronic waste,” with “motor vehicles” indicating a sector-specific view and the “European Union” highlighting EU relevance. Clusters 5 and 6 are simpler, focusing on “electric power supplies,” “lithium,” and the “internet,” respectively. Across clusters, AI's pivotal role is highlighted. Sustainability and economic factors are intertwined, and waste management is a major focus, particularly e-waste. “Europe” and the “European Union” repeatedly demonstrate the EU's leadership. The research targets practical applications through specific sectors (automotive urban planning). Key themes include the importance of AI, IoT, and blockchain and the role of agile/lean innovation. The research is committed to leveraging digital technologies for circular economy goals while balancing innovation, environmental concerns, and economic growth and addressing concrete challenges like waste.

Figure 9. Co-words Network Analysis. This figure illustrates the co-occurrence relationships between key terms in the analyzed literature, highlighting thematic clusters and research trends.

Source: Data compiled by the author from the Scopus database were analyzed using the R package "bibliometrix".

1.1.9 Factor Analysis (MCA)

Factor analysis, employing Multiple Correspondence Analysis (MCA), offers a nuanced view of the underlying structure of research on innovating for a circular economy, specifically regarding emerging technologies. The analysis is based on assessing the relationships among multiple categorical variables. As shown in Figure 10, the positions of terms reveal the key elements of this research and highlight the need for a transition to a net-zero society by 2030. The parameters such as n-grams, minDegree, clust and k.max were used to guide the analysis.

The data showing the results of the MCA analysis are presented in two tables of words and documents, revealing clusters and relationships within a factorial space. Terms such as “waste management,” “recycling,” “electronic waste,” and “solid waste” appear closely together (cluster 1), which highlights their role in waste and resource management. “Humans,” “sustainable development,” “economic development”, and “commerce” are also grouped in cluster 1, demonstrating the importance of socio-economic factors. Furthermore, “water,” “waste disposal, fluid”, and “wastewater” are closely connected, indicating a research focus on these particular types of waste, linked to agriculture and renewable energy, which suggests interconnectedness. The coordinates within the two dimensions reveal how the different concepts relate to the overall research field.

The analysis of the documents in the factorial space demonstrates the contribution of each document and how they are grouped in clusters, which is directly linked to the key terms identified above. Notably, the documents with the highest TC tend to be grouped in cluster 1, suggesting they have had a high level of influence in the field. Ultimately, this analysis offers a deeper view into the research and the connections within, highlighting the need for a systematic approach and a transition to a net-zero society by 2030, which is now focused on specific applications that help mitigate the impact of waste and support better production and consumption.

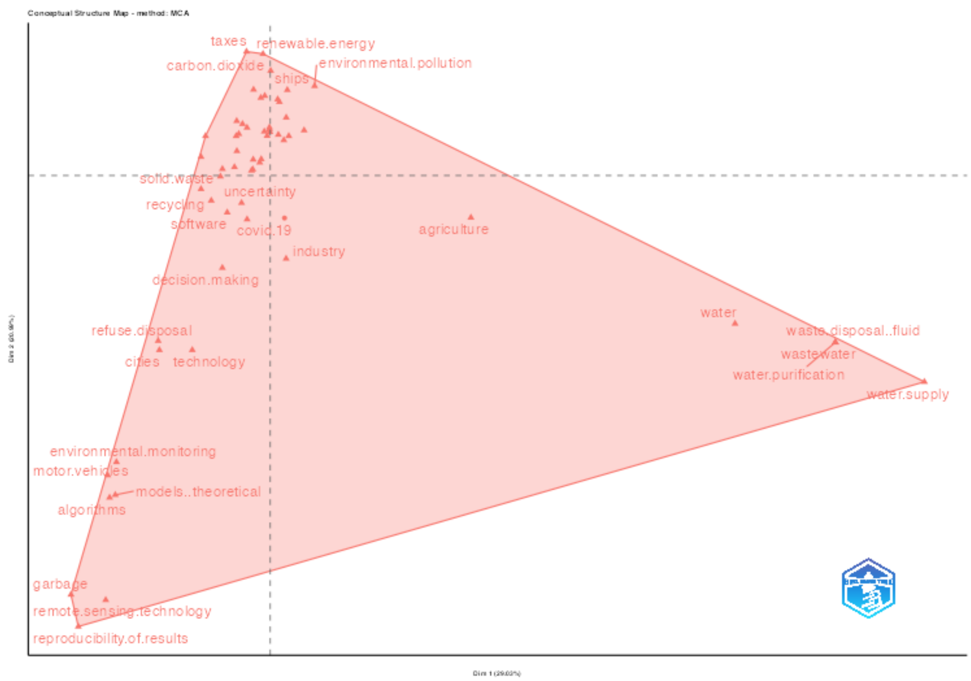

Figure 10. Factorial Analysis. This figure presents the factorial analysis of key terms, identifying the underlying dimensions and structures within the dataset.

Source: Data compiled by the author from the Scopus database were analyzed using the R package “bibliometrix”.

1.2 Framework Setup and the Intersection of Agile/Lean Innovation with Emerging Technologies

The bibliometric mapping, conducted as a network analysis, reveals a research landscape characteristically marked by the prominence of key terms such as “humans,” “artificial intelligence,” “industry,” and “waste management.” This interconnectedness, consequently, underscores the need for strong collaborations between technology, environment, and economics to successfully navigate the transition towards a circular economy.

The diverse clusters that emerge from this analysis reveal different focal areas of research, while a detailed assessment of the relevant journal outlets helps to pinpoint the main channels used for publications. This provides researchers valuable insights into both where to publish and how to better understand the field. The high centrality of the term "humans" suggests future research should prioritize user needs, while the equally high metrics for "artificial intelligence" highlight a need for more research in specific AI-driven solutions. Finally, the emphasis on waste management suggests a need for more specific studies in this area, while also confirming its position as a key area for current scientific publications. Ostensibly, all of these findings have informed the development of the framework.

1.2.1 The Intersection of Agile and Lean Innovation with Emerging Technologies in the Circular Economy

The EU's transition to a CE demands not only significant technological advancements but also a thorough re-evaluation of traditional business and organizational strategies. Agile and lean innovation methodologies are therefore vital for navigating the complexities involved in implementing circular practices and effectively integrating emerging technologies, acting as a means of creating, capturing and distributing value.

The fast pace of technological advancements and a dynamic marketplace make flexible and adaptive approaches vital. Agile methodologies, inherently iterative and focused on user feedback, enable companies to rapidly test and improve circular business models. This inherently improves the capacity to respond to changes with more efficiency (Ertz & Gasteau, 2023). This adaptability is particularly important in the current landscape where the integration of new technologies such as AI and IoT is still developing (Sun & Wang, 2022). Moreover, product lifecycle extension (PLE) and product design can benefit from agile approaches when coupled with smart technologies (Ertz & Gasteau, 2023), which ostensibly leads to enhanced performance and value.

Lean principles, with their focus on efficiency and waste reduction, are undeniably essential for implementing effective circular practices in supply chains. The aim is to minimize all inefficiencies, improve resource utilization, and reduce energy consumption throughout the resource cycle. This includes optimizing logistics, improving reverse supply chain processes, and ensuring that e-waste is managed efficiently (Andersen & Halse, 2023; Sharma et al., 2023). Furthermore, using lean methodologies helps to enable the adoption of circular economy business models and supports more sustainable production practices while reducing material and resource waste (Ting et al., 2023) while also leading to higher profits.

The combination of agile and lean methodologies with the implementation of AI, blockchain, IoT, and DTs not only yields tangible environmental benefits but also produces competitive advantages for businesses within the world's CE framework. Such a combined approach can lead to enhanced resource efficiency, optimized supply chains, and improved waste management while also fostering new circular business models (Ding et al., 2023). Moreover, studies have empirically demonstrated that companies that adopt circular economy principles together with advanced technologies will have better sustainability and financial performance, as shown by authors such as Siddik et al. (2023), Jugend et al. (2024), and Magnano et al. (2024), and further confirmed by Chopra et al. (2023) who highlights the interplay between both agile and lean strategies.

The transition to a CE requires, unequivocally, strong collaboration between universities, industry, and government, which may lead to better knowledge transfer and can foster both technological and policy innovation. Actively engaging SMEs in such collaborations may potentially accelerate the adoption of circular practices by leveraging different areas of expertise and providing diverse approaches for problem-solving (Rejeb et al., 2023; Chopra et al., 2023; Tiwari et al., 2024; Alonso et al., 2023). Such a collaborative approach is necessary for building more robust and sustainable circular business models.

1.3 Framework for a Circular Economy

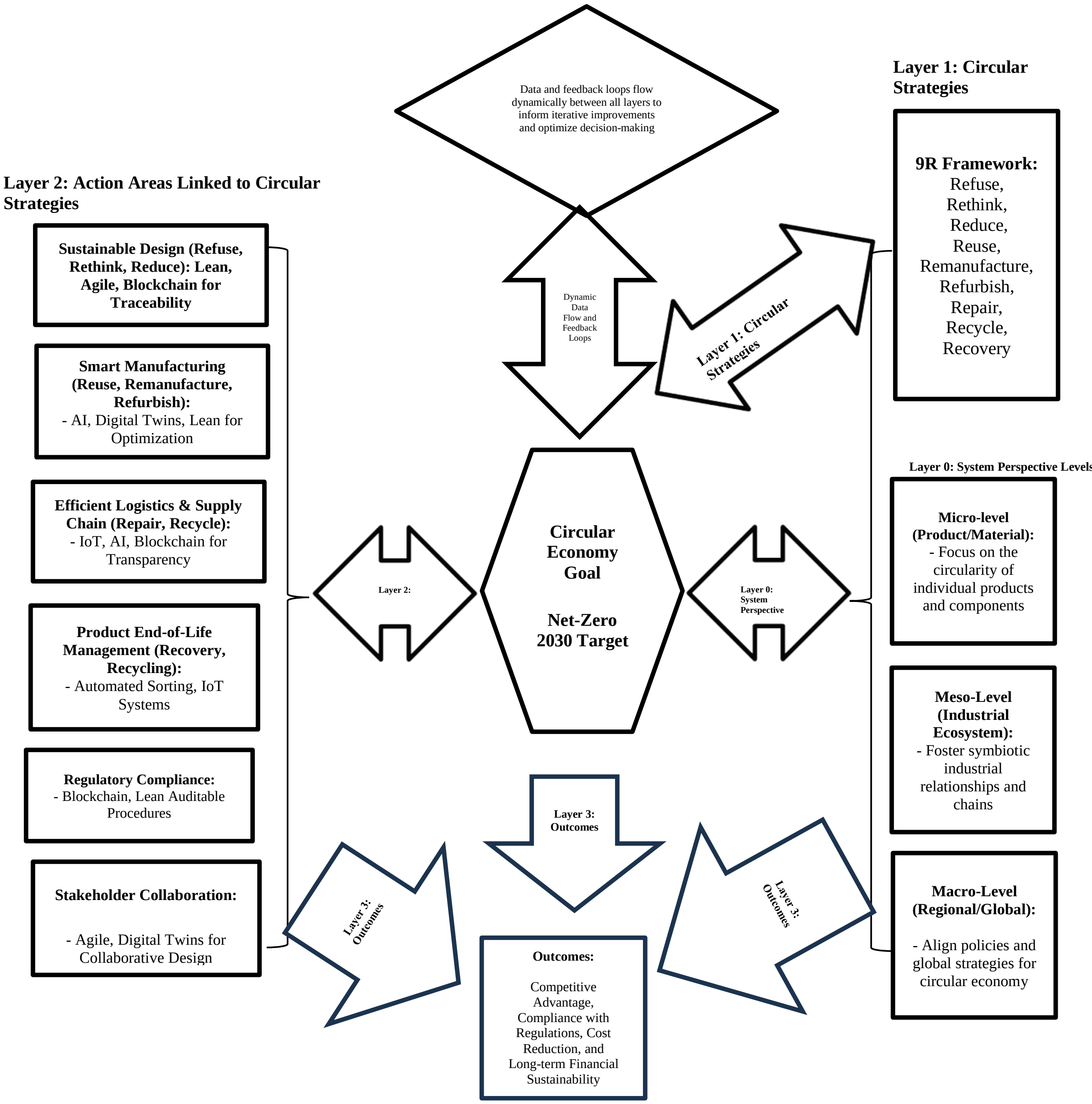

Figure 11. Framework for Circular Economy. The framework illustrates key components and interaction within a circular economy, emphasizing resource efficiency, waste reduction, and sustainable value creation. It integrates CE principles to foster sustainability.

Synthesis and Implications

This section interprets the quantitative findings derived from the bibliometric analysis, juxtaposed with qualitative insights garnered from the literature review. The discussion focuses fundamentally on the roles, challenges, opportunities, and regional nuances of emerging technologies and agile and lean methodologies within the circular economy (CE), ultimately addressing the core question: What do these results effectively mean for advancing the CE?

The analysis ostensibly highlights that Artificial Intelligence (AI), blockchain, the Internet of Things (IoT), and digital twins are quintessentially key emerging technologies within the CE landscape. Although AI applications are increasingly adopted, there's a nuance, and consequently, an associated need to focus on high energy demands, potential biases, and the risk of job displacement, as noted by Mhlanga (2022) and subsequently by other researchers (Alahi et al., 2023; Delanoë et al., 2023; Jovanović et al., 2023). Blockchain is recognized for enhancing supply chain transparency and traceability but faces hurdles invariably related to scalability, regulatory uncertainties, and energy consumption (Cowls et al., 2021). Furthermore, it's arguably critical to ensure that blockchain applications are aligned with ethical considerations and do not undermine equality and justice (Ahmad et al., 2024). The IoT is predominantly used for resource management and streamlining operations, yet data security, privacy concerns, and implementation costs represent significant challenges, seemingly (Ding et al., 2023; Alahi et al., 2023; Ting et al., 2023; Fraga-Lamas et al., 2021). Digital twins can improve decision-making and urban development; however, creating accurate digital twins inherently requires extensive data, expertise, and careful validation to prevent inaccurate outcomes, a point Wang et al. (2023), posits (Alonso et al., 2023; Tartia & Hämäläinen, 2024).

The review empirically indicated that agile methodologies support the creation of new CE solutions via iterative processes (Ertz & Gasteau, 2023; Srivastav et al., 2023), while lean principles pragmatically help refine supply chains and minimize waste (Andersen & Halse, 2023; Ting et al., 2023; Elia et al., 2018). The literature consistently supports the synergistic relationship between agile and lean methodologies, especially when combined with emerging technologies, which, in turn, can enhance both economic and environmental performance (Ding et al., 2023; Siddik et al., 2023; Jugend et al., 2024; Magnano et al., 2024; Chopra et al., 2023).

Nonetheless, the findings also underscored trade-offs and potential conflicts. The inherent focus of agile methodologies on adaptation can clash with lean's emphasis on standardization, leading to potential tensions in recycling efforts. Public blockchains, while purporting transparency, might conversely conflict with data privacy regulations. Furthermore, the increased automation driven by AI and IoT inevitably raises the potential for job displacement, even if it improves recycling efficiency.

Implementing new CE technologies requires addressing negative public attitudes, limited understanding, and the digital divide. Ethical, governance, and security concerns also pose obstacles. The transition to a CE must be environmentally sound and socially equitable, with policies and incentives that foster collaboration and meet local needs. The implementation strategies must carefully consider regional differences in regulations, economic conditions, technology access, and cultural contexts, as policies like Extended Producer Responsibility (EPR) might require adaptations in different regions.

The bibliometric mapping fundamentally revealed a research emphasis on "humans," "artificial intelligence," "industry," and "waste management," underscoring the inextricable interconnectedness of technology, environmental practices, and economic activities. These findings subsequently informed the development of a novel framework integrating agile and lean methodologies with emerging technologies. The framework inherently stresses the importance of collaboration among universities, industry, and governments for knowledge transfer and policy improvements (Rejeb et al., 2023; Chopra et al., 2023; Tiwari et al., 2024; Alonso et al., 2023). This approach builds on existing literature by incorporating agile and lean principles to optimize emerging technology deployment within the CE. It provides a practically adaptable structure for implementation that accounts for unique needs across various industries and regions, addressing a critically identified gap in prior research.

Conclusion

This review unequivocally demonstrates that a systemic, holistic, and well-integrated approach is paramount for the global transition to a circular economy. Ultimately addressing the core research question, the judicious combination of agile and lean methods with emerging technologies, underpinned by robust policy frameworks, demonstrably possesses the potential to accelerate the transition towards a circular economy. While AI, blockchain, IoT, and digital twins offer considerable promise for promoting a circular transition, it is equally paramount to proactively address inherent ethical and environmental concerns. Neglecting these risks inherently carries the potential to undermine efforts to establish a genuinely sustainable and competitive global economy, one that effectively fosters long-term growth, financial stability, and societal well-being.

Moving beyond purely theoretical models, future research must focus on developing demonstrably practical and readily implementable frameworks, informed by empirical evidence and real-world case studies. Policy measures must undergo rigorous evaluation to ensure their effectiveness and relevance across diverse regional and sectoral contexts. Furthermore, this transition necessitates strong collaboration across a diverse range of stakeholders, including academia, industry, government, and civil society organizations, to formulate a unified, inclusive, and participatory approach. Equitable distribution of economic and social benefits, to both reduce disadvantage and ensure the benefits of a circular economy are readily available for all, must also be a primary consideration. Effective management of resources and the implementation of robust circular practices across all sectors are fundamentally vital to achieving ambitious climate targets and are equally essential for enhancing global competitiveness and promoting long-term prosperity.

A multifaceted strategy that seamlessly integrates technological advancements, strategically sound methodologies, proactively designed policies, and an unwavering commitment to sustainability is demonstrably fundamental for ensuring a successful transition to a circular economy. As such, this review makes a clear contribution to the existing body of knowledge, showing the pathway to a more circular and sustainable future.

Conflict of Interest

The author declares that there are no known conflicts of interest associated with this publication, and there were no financial, commercial, legal, or professional relationships that could influence or bias the research.

Author Contributions

Henry Efe Onomakpo Onomakpo conceived and designed the study, conducted the literature review, performed the bibliometric and content analysis, developed the integrated framework, and led the writing and revision of the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. All activities contributing to this work were conducted using the resources of the author's institution.

Acknowledgments

The author gratefully acknowledges the support of the faculty and staff of the Economics and Business department of the University of Gadjah Mada for their invaluable assistance in the preparation of this manuscript. Their guidance and encouragement were instrumental in the successful completion of this research.

Data Availability Statement

The bibliometric data analyzed in this study originates from the Scopus, Dimensions, and ScienceDirect databases. Due to the proprietary nature of these databases, direct access to the raw data is subject to individual subscription agreements with the respective database providers. However, the processed data, along with the analytical code used in this study (primarily utilizing the "bibliometrix" package in R, which can be assessed on https://cran.r-project.org/package=bibliometrix), is deposited on the publisher's website. The materials will remain archived permanently.

Reference

1. Agan, B. (2024). Sustainable development through green transition in EU countries: New evidence from panel quantile regression. Journal of Environmental Management, 365, 121545. https://doi.org/10.1016/j.jenvman.2024.121545
2. Agrawal, R., Priyadarshinee, P., Kumar, A., Luthra, S., Garza-Reyes, J. A., & Kadyan, S. (2023). Are emerging technologies unlocking the potential of sustainable practices in the context of a net-zero economy? An analysis of driving forces. Environmental Science and Pollution Research, 30, 1-19. https://doi.org/10.1007/s11356-023-26434-2
3. Ahmad, A., Liew, A. X. W., Venturini, F., Kalogeras, A., Candiani, A., Di Benedetto, G., Ajibola, S., Cartujo, P., Romero, P., Lykoudi, A., De Grandis, M. M., Xouris, C., Bianco, R. L., Doddy, I., Elegbede, I., Labate, G. F. D., del Moral, L. F. G., & Martos, V. (2024). AI can empower agriculture for global food security: challenges and prospects in developing nations. Frontiers in Artificial Intelligence, 7, 1328530. https://doi.org/10.3389/frai.2024.1328530
4. Aladaileh, M. J., Lahuerta-Otero, E., & Aladayleh, K. J. (2024). Mapping sustainable supply chain innovation: A comprehensive bibliometric analysis. Heliyon, 10(7), e29157. https://doi.org/10.1016/j.heliyon.2024.e29157
5. Alahi, E. E., Sukkuea, A., Tina, F. W., Nag, A., Kurdthongmee, W., Suwannarat, K., & Mukhopadhyay, S. C. (2023). Integration of IoT-Enabled Technologies and Artificial Intelligence (AI) for Smart City Scenario: Recent Advancements and Future Trends. Sensors, 23(11), 5206. https://doi.org/10.3390/s23115206
6. Alonso, R., Olivadese, R., Ibba, A., & Recupero, D. R. (2023). Towards the definition of a European Digital Building Logbook: A survey. Heliyon, 9(9), e19285. https://doi.org/10.1016/j.heliyon.2023.e19285
7. Ameer, W., Ali, M. S. e., Farooq, F., Ayub, B., & Waqas, M. (2023). Renewable energy electricity, environmental taxes, and sustainable development: empirical evidence from E7

economies. Environmental Science and Pollution Research, 31(34), 46178-46193. https://doi.org/10.1007/s11356-023-26930-5
8. Andersen, T., & Halse, L. L. (2023). Product Lifecycle Information Flow in E-waste Handling: a Means to Increase Circularity? Circular Economy and Sustainability, 3(4), 1941-1962. https://doi.org/10.1007/s43615-023-00258-1
9. Ardra, S., & Barua, M. K. (2022). Inclusion of circular economy practices in the food supply chain: Challenges and possibilities for reducing food wastage in emerging economies like India. Environment, Development and Sustainability, 25(12), 13825-13858. https://doi.org/10.1007/s10668-022-02630-x
10. Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007
11. Aristi Capetillo, A., Bauer, F., & Chaminade, C. (2022). Emerging Technologies Supporting the Transition to a Circular Economy in the Plastic Materials Value Chain. Circular Economy and Sustainability, 3(2), 953-982. https://doi.org/10.1007/s43615-022-00209-2
12. Arvana, M., Rocha, A. D., & Barata, J. (2023). Agri-Food Value Chain Traceability Using Blockchain Technology: Portuguese Hams' Production Scenario. Foods, 12(23), 4246. https://doi.org/10.3390/foods12234246
13. Authority, E. F. S., Bronzwaer, S., Kass, G., Robinson, T., Tarazona, J., Verhagen, H., Verloo, D., Vrbos, D., & Hugas, M. (2019). Food Safety Regulatory Research Needs 2030. EFSA Journal, 17(7), e170622. https://doi.org/10.2903/j.efsa.2019.e170622
14. Balcilar, M., Elsayed, A. H., Khalfaoui, R., & Hammoudeh, S. (2024). Technological innovations fuel carbon prices and transform environmental management across Europe. Journal of Environmental Management, 373, 123663. https://doi.org/10.1016/j.jenvman.2024.123663
15. Balsalobre-Lorente, D., Shahbaz, M., Murshed, M., & Nuta, F. M. (2023). Environmental impact of globalization: The case of central and Eastern European emerging economies. Journal of Environmental Management, 341, 118018. https://doi.org/10.1016/j.jenvman.2023.118018
16. Bányai, T., Tamás, P., Illés, B., Stankevičiūtė, Ž., & Bányai, Á. (2019). Optimization of Municipal Waste Collection Routing: Impact of Industry 4.0 Technologies on Environmental Awareness and Sustainability. International Journal of Environmental Research and Public Health, 16(4), 634. https://doi.org/10.3390/ijerph16040634
17. Barbhuiya, S., Das, B. B., & Adak, D. (2024). A comprehensive review on integrating sustainable practices and circular economy principles in the concrete industry. Journal of Environmental Management, 370, 122702. https://doi.org/10.1016/j.jenvman.2024.122702
18. Bhagat, P. R., Naz, F., & Magda, R. (2022). Artificial intelligence solutions enabling sustainable agriculture: A bibliometric analysis. PLoS ONE, 17(6), e0268989. https://doi.org/10.1371/journal.pone.0268989
19. Bianchini, S., Damioli, G., & Ghisetti, C. (2022). The environmental effects of the "twin" green and digital transition in European regions. Environmental and Resource Economics, 84(4), 877-918. https://doi.org/10.1007/s10640-022-00741-7
20. Bibri, S. E., Alahi, A., Sharifi, A., & Krogstie, J. (2023). Environmentally sustainable smart cities and their converging AI, IoT, and big data technologies and solutions: an integrated approach to an extensive literature review. Energy Informatics, 6(1), 9. https://doi.org/10.1186/s42162-023-00259-2
21. Bibri, S. E., Krogstie, J., Kaboli, A., & Alahi, A. (2024). Smarter eco-cities and their leading-edge artificial intelligence of things solutions for environmental sustainability: A comprehensive systematic review. Environmental Science and Ecotechnology, 19, 100330. https://doi.org/10.1016/j.ese.2023.100330
22. Bocean, C. G. (2024). A Longitudinal Analysis of the Impact of Digital Technologies on Sustainable Food Production and Consumption in the European Union. Foods, 13(8), 1281. https://doi.org/10.3390/foods13081281

23. Brodny, J., & Tutak, M. (2021). Assessing the level of digitalization and robotization in the enterprises of the European Union Member States. PLoS ONE, 16(7), e0254993. https://doi.org/10.1371/journal.pone.0254993
24. Bruno, M., & Fiore, S. (2024). Review of lithium-ion batteries' supply-chain in Europe: Material flow analysis and environmental assessment. Journal of Environmental Management, 358, 120758. https://doi.org/10.1016/j.jenvman.2024.120758
25. Cardoso de Oliveira Neto, G., de Jesus Cardoso Correia, A., & Cesar Lucato, W. (2023). Economic and environmental benefits by means of recycling processes grounded in the CE: Case studies in the metal mechanical sector. Waste Management, 164, 250-259. https://doi.org/10.1016/j.wasman.2023.03.017
26. Chang, L., Zhang, Q., & Liu, H. (2022). Digital finance innovation in green manufacturing: a bibliometric approach. Environmental Science and Pollution Research, 30(22), 61340-61368. https://doi.org/10.1007/s11356-021-18016-x
27. Chopra, R., Agrawal, A., Sharma, G. D., Kallmuenzer, A., & Vasa, L. (2023). Uncovering the organizational, environmental, and socio-economic sustainability of digitization: evidence from existing research. Review of Managerial Science, 18(2), 685-709. https://doi.org/10.1007/s11846-023-00637-w
28. Choubey, A., Mishra, S., Misra, R., Pandey, A. K., & Pandey, D. (2024). Smart e-waste management: a revolutionary incentive-driven IoT solution with LPWAN and edge-AI integration for environmental sustainability. Environmental Monitoring and Assessment, 196(8), 720. https://doi.org/10.1007/s10661-024-12854-1
29. Choudhary, D., Sangwan, K. S., & Singh, A. (2024). Blockchain-enabled architecture for lead acid battery circularity. Scientific Reports, 14(1), 16467. https://doi.org/10.1038/s41598-024-67404-z
30. Christidis, P., Ulpiani, G., Stepniak, M., & Vetters, N. (2024). Research and innovation paving the way for climate neutrality in urban transport: Analysis of 362 cities on their journey to zero emissions. Transport Policy, 148, 107-123. https://doi.org/10.1016/j.tranpol.2024.01.008
31. Corsini, F., Gusmerotti, N. M., & Frey, M. (2023). Fostering the Circular Economy with Blockchain Technology: Insights from a Bibliometric Approach. Circular Economy and Sustainability, 3(4), 1819-1839. https://doi.org/10.1007/s43615-023-00250-9
32. Cowls, J., Tsamados, A., Taddeo, M., & Floridi, L. (2021). The AI gambit: leveraging artificial intelligence to combat climate change—opportunities, challenges, and recommendations. AI & Society, 38(1), 283-307. https://doi.org/10.1007/s00146-021-01294-x
33. D'Adamo, I., Di Vaio, A., Formiconi, A., & Soldano, A. (2022). European IoT Use in Homes: Opportunity or Threat to Households? International Journal of Environmental Research and Public Health, 19(21), 14343. https://doi.org/10.3390/ijerph192114343
34. da Rocha, A. B. T., Espuny, M., Kandsamy, J., & Oliveira, O. (2024). Advancing sustainability in the steel industry: the key role of the triple helix sectors. Environmental Science and Pollution Research, 31(31), 43591-43615. https://doi.org/10.1007/s11356-024-33983-7
35. Danciu, C. A., Tulbure, A., Stanciu, M. A., Antonie, I., Capatana, C., Zerbeș, M. V., Giurea, R., & Rada, E. C. (2023). Overview of the Sustainable Valorization of Using Waste and By-Products in Grain Processing. Foods, 12(20), 3770. https://doi.org/10.3390/foods12203770
36. Darzi, M. A. (2024). Evaluating e-waste mitigation strategies based on industry 5.0 enablers: An integrated scenario-based BWM and F-VIKOR approach. Journal of Environmental Management, 373, 123999. https://doi.org/10.1016/j.jenvman.2024.123999
37. das Neves Silva, S., Yamane, L. H., & Ribeiro Siman, R. (2023). Challenges to implement and operationalize the WEEE reverse logistics system at the micro level. Environmental Science and Pollution Research, 30(52), 111693-111713. https://doi.org/10.1007/s11356-023-30207-2
38. de Oliveira Neto, J. F., Candido, L. A., de Freitas Dourado, A. B., Santos, S. M., & Florencio, L. (2022). Waste of electrical and electronic equipment management from the perspective of a

circular economy: A Review. Waste Management & Research, 41(4), 760-780. https://doi.org/10.1177/0734242X221135341

39. Delanoë, P., Tchuente, D., & Colin, G. (2023). Method and evaluations of the effective gain of artificial intelligence models for reducing CO2 emissions. Journal of Environmental Management, 331, 117261. https://doi.org/10.1016/j.jenvman.2023.117261
40. Dhayal, K. S., Giri, A. K., Kumar, A., Samadhiya, A., Agrawal, S., & Agrawal, R. (2023). Can green finance facilitate the Industry 5.0 transition to achieve sustainability? A systematic review with future research directions. Environmental Science and Pollution Research, 30(46), 102158-102180. https://doi.org/10.1007/s11356-023-29539-w
41. Di Vaio, A., Hasan, S., Palladino, R., & Hassan, R. (2022). The transition towards a circular economy and waste within accounting and accountability models: a systematic literature review and conceptual framework. Environment, Development and Sustainability, 25(1), 734-810. https://doi.org/10.1007/s10668-021-02078-5
42. Ding, S., Tukker, A., & Ward, H. (2023). Opportunities and risks of Internet of Things (IoT) technologies for circular business models: A literature review. Journal of Environmental Management, 336, 117662. https://doi.org/10.1016/j.jenvman.2023.117662
43. Dionisio, M., de Souza Junior, S. J., Paula, F., & Pellanda, P. C. (2023). The role of digital social innovations to address SDGs: A systematic review. Environment, Development and Sustainability, 26(3), 5709-5734. https://doi.org/10.1007/s10668-023-03038-x
44. Dou, Q., & Gao, X. (2022). The double-edged role of the digital economy in firm green innovation: micro-evidence from the Chinese manufacturing industry. Environmental Science and Pollution Research, 29(45), 67856-67874. https://doi.org/10.1007/s11356-022-20435-3
45. Economou, F., Chatziparaskeva, G., Papamichael, I., Loizia, P., Voukkali, I., Navarro-Pedreño, J., Klontza, E., Lekkas, D. F., Naddeo, V., & Zorpas, A. A. (2024). The concept of food waste and food loss prevention and measuring tools. Waste Management & Research, 42(8), 651-669. https://doi.org/10.1177/0734242X241237187
46. Elia, V., Gnoni, M. G., & Tornese, F. (2018). Improving logistic efficiency of WEEE collection through dynamic scheduling using simulation modeling. Waste Management, 72, 78-86. https://doi.org/10.1016/j.wasman.2017.11.016
47. Ertz, M., & Gasteau, F. (2023). Role of smart technologies for implementing industry 4.0 environment in product lifetime extension towards a circular economy: A qualitative research. Heliyon, 9(6), e16762. https://doi.org/10.1016/j.heliyon.2023.e16762
48. Escursell, S., Llorach-Massana, P., & Roncero, M. B. (2021). Sustainability in e-commerce packaging: A review. Journal of Cleaner Production, 280, 124314. https://doi.org/10.1016/j.jclepro.2020.124314
49. Esmaeilian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., & Behdad, S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. Waste Management, 81, 177-195. https://doi.org/10.1016/j.wasman.2018.09.047
50. Fair, N., Modafferi, S., Gray, B., Chan, J., & Lelli, F. (2024). An extended approach to impact assessment in the Horizon 2020 digital manufacturing domain. Open Research Europe, 4, 9. https://doi.org/10.12688/openreseurope.16235.1
51. Fang, B., Yu, J., Chen, Z., Osman, A. I., Farghali, M., Ihara, I., Hamza, E. H., Rooney, D. W., & Yap, P.-S. (2023). Artificial intelligence for waste management in smart cities: a review. Environmental Chemistry Letters, 21(4), 1959-1989. https://doi.org/10.1007/s10311-023-01604-3
52. ForouzeshNejad, A. A. (2022). Leagile and sustainable supplier selection problem in the Industry 4.0 era: a case study of the medical devices using hybrid multi-criteria decision-making tool. Environmental Science and Pollution Research, 30(5), 13418-13437. https://doi.org/10.1007/s11356-022-22916-x

53. Fraga-Lamas, P., Lopes, S. I., & Fernández-Caramés, T. M. (2021). Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition towards a Smart Circular Economy: An Industry 5.0 Use Case. Sensors, 21(17), 5745. https://doi.org/10.3390/s21175745
54. Garske, B., Holz, W., & Ekardt, F. (2024). Digital twins in sustainable transition: exploring the role of EU data governance. Frontiers in Research Metrics and Analytics, 9, 1303024. https://doi.org/10.3389/frma.2024.1303024
55. Gennari, F. (2022). The transition towards a circular economy. A framework for SMEs. Journal of Management and Governance, 27(4), 1423-1457. https://doi.org/10.1007/s10997-022-09653-6
56. Getahun, S., Kefale, H., & Gelaye, Y. (2024). Application of Precision Agriculture Technologies for Sustainable Crop Production and Environmental Sustainability: A Systematic Review. The Scientific World Journal, 2024(1), 2126734. https://doi.org/10.1155/2024/2126734
57. Ghalandari, M., Amirkhan, M., & Amoozad-Khalili, H. (2022). RETRACTED ARTICLE: A hybrid model for robust design of sustainable closed-loop supply chain in the lead-acid battery industry. Environmental Science and Pollution Research, 30(1), 451-476. https://doi.org/10.1007/s11356-022-21840-4
58. Ginga, C. P., Ongpeng, J. M. C., & Daly, M. K. M. (2020). Circular Economy on Construction and Demolition Waste: A Literature Review on Material Recovery and Production. Materials, 13(13), 2970. https://doi.org/10.3390/ma13132970
59. Gligoric, N., Escuín, D., Polo, L., Amditis, A., Georgakopoulos, T., & Fraile, A. (2024). IOTA-Based Distributed Ledger in the Mining Industry: Efficiency, Sustainability and Transparency. Sensors, 24(3), 923. https://doi.org/10.3390/s24030923
60. Gonçalves, M. L. M. B. B., & Maximo, G. J. (2022). Circular Economy in the Food Chain: Production, Processing and Waste Management. Circular Economy and Sustainability, 3(3), 1405-1423. https://doi.org/10.1007/s43615-022-00243-0
61. González-Sánchez, R., Alonso-Muñoz, S., & Medina-Salgado, M. S. (2023). Circularity in waste management: a research proposal to achieve the 2030 Agenda. Operations Management Research, 16(3), 1520-1540. https://doi.org/10.1007/s12063-023-00373-0
62. Green, C., Bilyanska, A., Bradley, M., Dinsdale, J., Hutt, L., Backhaus, T., ... & Lynch, I. (2023). A Horizon Scan to Support Chemical Pollution–Related Policymaking for Sustainable and Climate-Resilient Economies. Environmental Toxicology and Chemistry, 42(6), 1212-1228. https://doi.org/10.1002/etc.5620
63. Hao, M.-G., Xu, S.-C., Meng, X.-N., & Xue, X.-F. (2024). How does the digital economy affect the provincial "zero-waste city" construction? Evidence from China. Environmental Science and Pollution Research, 31(12), 18448-18464. https://doi.org/10.1007/s11356-024-32304-2
64. Hassoun, A., Cropotova, J., Trollman, H., Jagtap, S., Garcia-Garcia, G., Parra-López, C., Nirmal, N., Özogul, F., Bhat, Z., Aït-Kaddour, A., & Bono, G. (2023). Use of industry 4.0 technologies to reduce and valorize seafood waste and by-products: A narrative review on current knowledge. Current Research in Food Science, 6, 100505. https://doi.org/10.1016/j.crfs.2023.100505
65. Helbing, D., Mahajan, S., Carpentras, D., Menendez, M., Pournaras, E., Thurner, S., Verma, T., Arcaute, E., Batty, M., & Bettencourt, L. M. A. (2024). Co-creating the future: participatory cities and digital governance. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 382(2285), 20240113. https://doi.org/10.1098/rsta.2024.0113
66. Holzinger, A., Saranti, A., Angerschmid, A., Retzlaff, C. O., Gronauer, A., Pejakovic, V., Medel-Jimenez, F., Krexner, T., Gollob, C., & Stampfer, K. (2022). Digital Transformation in Smart Farm and Forest Operations Needs Human-Centered AI: Challenges and Future Directions. Sensors, 22(8), 3043. https://doi.org/10.3390/s22083043
67. Hoosain, M. S., Paul, B. S., Kass, S., & Ramakrishna, S. (2022). Tools Towards the Sustainability and Circularity of Data Centers. Circular Economy and Sustainability, 3(1), 173-197. https://doi.org/10.1007/s43615-022-00191-9

68. Hoosain, M. S., Paul, B. S., Raza, S. M., & Ramakrishna, S. (2021). Material Passports and Circular Economy. An Introduction to Circular Economy, 131-158. https://doi.org/10.1007/978-981-15-8510-4_8
69. Ibn-Mohammed, T., Mustapha, K. B., Godsell, J., Adamu, Z., Babatunde, K. A., Akintade, D. D., Acquaye, A., Fujii, H., Ndiaye, M. M., Yamoah, F. A., & Koh, S. C. L. (2021). A critical review of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies. Resources Conservation and Recycling, 164, 105169. https://doi.org/10.1016/j.resconrec.2020.105169
70. Imran, M., Jijian, Z., Sharif, A., & Magazzino, C. (2024). Evolving waste management: The impact of environmental technology, taxes, and carbon emissions on incineration in EU countries. Journal of Environmental Management, 364, 121440. https://doi.org/10.1016/j.jenvman.2024.121440
71. Ismail, A. M., Ballini, F., Ölçer, A. I., & Alamoush, A. S. (2024). Integrating ports into green shipping corridors: Drivers, challenges, and pathways to implementation. Marine Pollution Bulletin, 209, 117201. https://doi.org/10.1016/j.marpolbul.2024.117201
72. Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., & Mohiuddin, M. (2021). Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. Heliyon, 7(8), e07753. https://doi.org/10.1016/j.heliyon.2021.e07753
73. Jovanović, M., de J. Mateo Sanguino, T., Damjanović, M., Đukanović, M., & Thomopoulos, N. (2023). Driving Sustainability: Carbon Footprint, 3D Printing, and Legislation concerning Electric and Autonomous Vehicles. Sensors, 23(22), 9104. https://doi.org/10.3390/s23229104
74. Jugend, D., Fiorini, P. D. C., Fournier, P.-L., Latan, H., Chiappetta Jabbour, C. J., & Scaliza, J. A. A. (2024). Industry 4.0 technologies for the adoption of the circular economy: An analysis of institutional pressures and the effects on firm performance. Journal of Environmental Management, 370, 122260. https://doi.org/10.1016/j.jenvman.2024.122260
75. K, V. K. E., K, S., Kandasamy, J., Venkat, V., & Mani, R. S. (2023). Barriers to the adoption of digital technologies in a functional circular economy network. Operations Management Research, 16(3), 1541-1561. https://doi.org/10.1007/s12063-023-00375-y
76. Kahupi, I., Yakovleva, N., Hull, C. E., & Okorie, O. (2024). Factors affecting the adoption of circular economy in mining companies of developing economies — A Namibian stakeholder perspective. Journal of Environmental Management, 361, 121214. https://doi.org/10.1016/j.jenvman.2024.121214
77. Khan, F., & Ali, Y. (2022). A facilitating framework for a developing country to adopt smart waste management in the context of a circular economy. Environmental Science and Pollution Research, 30(22), 61340-61368. https://doi.org/10.1007/s11356-021-18016-x
78. Khan, S. A. R., Tabish, M., Umar, M., & Yu, Z. (2024). A thorough overview of the literature on waste recycling in the circular economy: current practices and future perspectives. Environmental Science and Pollution Research, 31(52), 61377-61396. https://doi.org/10.1007/s11356-024-35329-9
79. Khan, S. A. R., Umar, M., Yu, Z., & Nawaz, M. T. (2023). A Recent Digitalization in Recycling Industry Attaining Ecological Sustainability: A Comprehensive Outlook and Future Trend. Environmental Science and Pollution Research, 30(47), 103760-103775. https://doi.org/10.1007/s11356-023-29537-y
80. Klingström, T., König, E. Z., & Zwane, A. A. (2024). Beyond the hype: using AI, big data, wearable devices, and the internet of things for high-throughput livestock phenotyping. Briefings in Functional Genomics, 23(4), elae032. https://doi.org/10.1093/bfgp/elae032
81. Kolesnichenko, O., Mazelis, L., Sotnik, A., Yakovleva, D., Amelkin, S., Grigorevsky, I., & Kolesnichenko, Y. (2021). Sociological modeling of smart city with the implementation of UN sustainable development goals. Sustainability Science, 16(2), 581-599. https://doi.org/10.1007/s11625-020-00889-5

82. Kostakis, I., Paparas, D., & Tsagarakis, K. P. (2023). Disaggregated energy use and socioeconomic sustainability within OECD countries. Journal of Environmental Management, 334, 117475. https://doi.org/10.1016/j.jenvman.2023.117475
83. Liao, Z. (2023). Supply chain optimization for environmental sustainability and economic growth. Environmental Science and Pollution Research, 30(58), 121599-121613. https://doi.org/10.1007/s11356-023-30521-9
84. Liu, L., Liu, L., Liu, K., & Jiménez-Zarco, A. I. (2024). Double-edged sword of industrial internet of things: Empirical evidence from a green transformation of enterprises. Heliyon, 10(19), e38595. https://doi.org/10.1016/j.heliyon.2024.e38595
85. Liu, T., Zhang, Q., Zheng, Z., Wu, S., & Weng, Z. (2022). Stakeholder Analysis of the Waste Electrical and Electronic Equipment Internet Recycling Industry. International Journal of Environmental Research and Public Health, 19(16), 10003. https://doi.org/10.3390/ijerph191610003
86. MacPherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, I., & Helming, K. (2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review. Agronomy for Sustainable Development, 42(4), 70. https://doi.org/10.1007/s13593-022-00792-6
87. Magazzino, C., Mele, M., Schneider, N., & Sarkodie, S. A. (2021). Waste generation, wealth and GHG emissions from the waste sector: Is Denmark on the path towards circular economy? The Science of The Total Environment, 755(Pt 1), 142510. https://doi.org/10.1016/j.scitotenv.2020.142510
88. Magnano, D. G., Grimstad, S. M. F., Glavee-Geo, R., & Anwar, F. (2024). Disentangling circular economy practices and firm's sustainability performance: A systematic literature review of past achievements and future promises. Journal of Environmental Management, 353, 120138. https://doi.org/10.1016/j.jenvman.2024.120138
89. Mainardis, M., Cecconet, D., Moretti, A., Callegari, A., Goi, D., Freguia, S., & Capodaglio, A. G. (2022). Wastewater fertigation in agriculture: Issues and opportunities for improved water management and circular economy. Environmental Pollution, 296, 118755. https://doi.org/10.1016/j.envpol.2021.118755
90. Mhlanga, D. (2022). The Role of Artificial Intelligence and Machine Learning Amid the COVID-19 Pandemic: What Lessons Are We Learning on 4IR and the Sustainable Development Goals. International Journal of Environmental Research and Public Health, 19(3), 1879. https://doi.org/10.3390/ijerph19031879
91. Molla, A. H., Shams, H., Harun, Z., Kasim, A. N. C., Nallapaneni, M. K., & Rahman, M. N. A. (2022). Adoption of technological innovation and recycling practices in automobile sector: under the Covid-19 pandemic. Operations Management Research, 15(1-2), 298-306. https://doi.org/10.1007/s12063-022-00263-x
92. Momete, D. C. (2020). A unified framework for assessing the readiness of European Union economies to migrate to a circular modelling. Science of the Total Environment, 718, 137375. https://doi.org/10.1016/j.scitotenv.2020.137375
93. Na, C., Khalid, R., Raza, M., Ramirez-Asis, E., Huerta-Soto, R., & Jahanger, A. (2022). The role of age and business coaching in the relationship of lean startup approach and innovative work behavior of women entrepreneurs during COVID-19. Frontiers in Psychology, 13, 946918. https://doi.org/10.3389/fpsyg.2022.946918
94. Nandi, S., Sarkis, J., Hervani, A. A., & Helms, M. M. (2021). Redesigning Supply Chains using Blockchain-Enabled Circular Economy and COVID-19 Experiences. Sustainable Production and Consumption, 27, 10-22. https://doi.org/10.1016/j.spc.2020.10.019
95. Neofotistos, M., Hanioti, N., Kefalonitou, E., Perouli, A. Z., & Vorgias, K. E. (2023). A Real-World Scenario of Citizens' Motivation and Engagement in Urban Waste Management Through a

Mobile Application and Smart City Technology. Circular Economy and Sustainability, 3(1), 221-239. https://doi.org/10.1007/s43615-022-00155-z

96. Noudeng, V., Van Quan, N., & Xuan, T. D. (2022). A Future Perspective on Waste Management of Lithium-Ion Batteries for Electric Vehicles in Lao PDR: Current Status and Challenges. International Journal of Environmental Research and Public Health, 19(23), 16169. https://doi.org/10.3390/ijerph192316169
97. Ntalaperas, D., Christophoridis, C., Angelidis, I., Iossifidis, D., Touloupi, M. F., Vergeti, D., & Politi, E. (2022). Intelligent Tools to Monitor, Control and Predict Wastewater Reclamation and Reuse. Sensors, 22(8), 3068. https://doi.org/10.3390/s22083068
98. Núñez-Cacho, P., Mylonas, G., Kalogeras, A., & Molina-Moreno, V. (2024). Exploring the transformative power of AI in art through a circular economy lens. A systematic literature review. Heliyon, 10(4), e25388. https://doi.org/10.1016/j.heliyon.2024.e25388
99. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. BMJ, 372, n160. https://doi.org/10.1136/bmj.n160
100. Patil, R. A., Ghisellini, P., & Ramakrishna, S. (2021). Towards Sustainable Business Strategies for a Circular Economy: Environmental, Social and Governance (ESG) Performance and Evaluation. In: Liu, L., Ramakrishna, S. (eds) An Introduction to Circular Economy. Springer, Singapore. https://doi.org/10.1007/978-981-15-8510-4_26
101. Piyathanavong, V., Huynh, V.-N., Karnjana, J., & Olapiriyakul, S. (2024). Role of project management on Sustainable Supply Chain development through Industry 4.0 technologies and Circular Economy during the COVID-19 pandemic: A multiple case study of the Thai metals industry. Operations Management Research, 17(1), 13-37. https://doi.org/10.1007/s12063-022-00283-7
102. Pospelova, V., López-Baldominos, I., Fernández-Sanz, L., Castillo-Martínez, A., & Misra, S. (2023). User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe. Sensors, 23(1), 529. https://doi.org/10.3390/s23010529
103. PRISMA. (2020). PRISMA 2020 flow diagram. https://www.prisma-statement.org/prisma-2020-flow-diagram
104. Raabe, D. (2023). The Materials Science behind Sustainable Metals and Alloys. Chemical Reviews, 123(5), 2436-2608. https://doi.org/10.1021/acs.chemrev.2c00799
105. Raheem, D., Soltermann, A. T., Tamiozzo, L. V., Cogo, A., Favén, L., Punam, N. J., ... & Stammler-Gossmann, A. (2022). Partnership for International Development: Finland–Argentina Conference on Circular Economy and Bioeconomy with Emphasis on Food Sovereignty and Sustainability. International Journal of Environmental Research and Public Health, 19(3), 1773. https://doi.org/10.3390/ijerph19031773
106. Rani, P., Sharma, P., & Gupta, I. (2024). Toward a greener future: A survey on sustainable blockchain applications and impact. Journal of Environmental Management, 354, 120273. https://doi.org/10.1016/j.jenvman.2024.120273
107. Rejeb, A., Rejeb, K., Zailani, S., Kayikci, Y., & Keogh, J. G. (2023). Examining Knowledge Diffusion in the Circular Economy Domain: a Main Path Analysis. Circular Economy and Sustainability, 3(1), 125-166. https://doi.org/10.1007/s43615-022-00189-3
108. Riaz, K., McAfee, M., & Gharbia, S. S. (2023). Management of Climate Resilience: Exploring the Potential of Digital Twin Technology, 3D City Modelling, and Early Warning Systems. Sensors, 23(5), 2659. https://doi.org/10.3390/s23052659
109. Rodríguez Furones, A., & Ignacio Tejero Monzón, J. (2023). Blockchain applicability in the management of urban water supply and sanitation systems in Spain. Journal of Environmental Management, 344, 118480. https://doi.org/10.1016/j.jenvman.2023.118480

110. Saliba, M., Frantzi, S., & van Beukering, P. (2022). Shipping spills and plastic pollution: A review of maritime governance in the North Sea. Marine Pollution Bulletin, 181, 113939. https://doi.org/10.1016/j.marpolbul.2022.113939
111. Samani, P. (2023). Synergies and gaps between circularity assessment and Life Cycle Assessment (LCA). The Science of the Total Environment, 903, 166611. https://doi.org/10.1016/j.scitotenv.2023.166611
112. Sharma, M., Shah, J. K., & Joshi, S. (2023). Modeling enablers of supply chain decarbonisation to achieve zero carbon emissions: an environment, social and governance (ESG) perspective. Environmental Science and Pollution Research, 30(31), 76718-76734. https://doi.org/10.1007/s11356-023-27480-6
113. Shittu, O. S., Williams, I. D., & Shaw, P. J. (2021). Global E-waste management: Can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. Waste Management, 120, 549-563. https://doi.org/10.1016/j.wasman.2020.10.016
114. Siddik, A. B., Yong, L., & Rahman, M. N. (2023). The role of Fintech in circular economy practices to improve sustainability performance: a two-staged SEM-ANN approach. Environmental Science and Pollution Research, 30(49), 107465-107486. https://doi.org/10.1007/s11356-023-25576-7
115. Siemieniuch, C. E., Sinclair, M. A., & Henshaw, M. J. D. (2015). Global drivers, sustainable manufacturing and systems ergonomics. Applied Ergonomics, 51, 104-119. https://doi.org/10.1016/j.apergo.2015.04.018
116. Sitadewi, D., Yudoko, G., & Okdinawati, L. (2021). Bibliographic mapping of post-consumer plastic waste based on hierarchical circular principles across the system perspective. Heliyon, 7(6), e07154. https://doi.org/10.1016/j.heliyon.2021.e07154
117. Soeteman-Hernández, L. G., Blanco, C. F., Koese, M., Sips, A. J. A. M., Noorlander, C. W., & Peijnenburg, W. J. G. M. (2023). Life cycle thinking and safe-and-sustainable-by-design approaches for the battery innovation landscape. iScience, 26(3), 106060. https://doi.org/10.1016/j.isci.2023.106060
118. Srivastav, A. L., Markandeya, Patel, N., Pandey, M., Pandey, A. K., Dubey, A. K., Kumar, A., Bhardwaj, A. K., & Chaudhary, V. K. (2023). Concepts of circular economy for sustainable management of electronic wastes: challenges and management options. Environmental Science and Pollution Research, 30(17), 48654-48675. https://doi.org/10.1007/s11356-023-26052-y
119. Sun, X., & Wang, X. (2022). Modeling and Analyzing the Impact of the Internet of Things-Based Industry 4.0 on Circular Economy Practices for Sustainable Development: Evidence From the Food Processing Industry of China. Frontiers in Psychology, 13, 866361. https://doi.org/10.3389/fpsyg.2022.866361
120. Tabish, M., Khan, S. A. R., Yu, Z., & Tanveer, M. (2024). A thorough overview of the literature on waste recycling in the circular economy: current practices and future perspectives. Environmental Science and Pollution Research, 31(52), 61377-61396. https://doi.org/10.1007/s11356-024-35329-9
121. Tanveer, M., Khan, S. A. R., Umar, M., Yu, Z., Sajid, M. J., & Haq, I. U. (2022). Waste management and green technology: future trends in a circular economy. Environmental Science and Pollution Research, 30(5), 13418-13437. https://doi.org/10.1007/s11356-022-23238-8
122. Tao, M. (2024). Digital brains, green gains: Artificial intelligence's path to sustainable transformation. Journal of Environmental Management, 370, 122679. https://doi.org/10.1016/j.jenvman.2024.122679
123. Tartia, J., & Hämäläinen, M. (2024). Co-creation Processes and Urban Digital Twins in Sustainable and Smart Urban District Development - Case Kera District in Espoo, Finland. Open Research Europe, 4, 130. https://doi.org/10.12688/openreseurope.17791.1

124. Tashkeel, R., Rajarathnam, G. P., Wan, W., Soltani, B., & Abbas, A. (2021). Cost-Normalized Circular Economy Indicator and Its Application to Post-Consumer Plastic Packaging Waste. Polymers, 13(20), 3456. https://doi.org/10.3390/polym13203456
125. Ting, L. S., Zailani, S., Sidek, N. Z. M., & Shaharudin, M. R. (2023). Motivators and barriers of circular economy business model adoption and its impact on sustainable production in Malaysia. Environment, Development and Sustainability, 26(7), 17551-17578. https://doi.org/10.1007/s10668-023-03350-6
126. Tiwari, G., Kumar, R. R., Raj, A., & Foropon, C. R. H. (2024). Antecedents and consequents of circular economy adoption: A meta-Analytic Investigation. Journal of Environmental Management, 367, 121912. https://doi.org/10.1016/j.jenvman.2024.121912
127. Troiano, S., Carzedda, M., & Marangon, F. (2023). Better richer than environmentally friendly? Describing preferences toward and factors affecting precision agriculture adoption in Italy. Agricultural and Food Economics, 11(1), 16. https://doi.org/10.1186/s40100-023-00247-w
128. Tseng, M.-L., Chang, C.-H., Lin, C.-W. R., Wu, K.-J., Chen, Q., Xia, L., & Xue, B. (2020). Future trends and guidance for the triple bottom line and sustainability: a data-driven bibliometric analysis. Environmental Science and Pollution Research, 27(27), 33543-33567. https://doi.org/10.1007/s11356-020-09284-0
129. Tucki, K., Orynycz, O., & Dudziak, A. (2022). The Impact of the Available Infrastructure on the Electric Vehicle Market in Poland and EU Countries. International Journal of Environmental Research and Public Health, 19(24), 16783. https://doi.org/10.3390/ijerph192416783
130. Uhlhorn, B., Geißler, G., & Jiricka-Pürrer, A. (2024). Exploring the uptake of advanced digital technologies in environmental assessment practice - Experiences from Austria and Germany. Journal of Environmental Management, 364, 121412. https://doi.org/10.1016/j.jenvman.2024.121412
131. Umar, M., Khan, S. A. R., Yu, Z., & Rehman, S. A. (2022). Adoption of technological innovation and recycling practices in automobile sector: under the Covid-19 pandemic. Operations Management Research, 15(1-2), 298-306. https://doi.org/10.1007/s12063-022-00263-x
132. Ungerman, O., & Dědková, J. (2024). Consumer behavior in the model of the circular economy in the field of handling discarded items. PLoS ONE, 19(3), e0300707. https://doi.org/10.1371/journal.pone.0300707
133. Vărzaru, A. A. (2024). Unveiling Digital Transformation: A Catalyst for Enhancing Food Security and Achieving Sustainable Development Goals at the European Union Level. Foods, 13(8), 1226. https://doi.org/10.3390/foods13081226
134. Vaska, S., Massaro, M., Bagarotto, E. M., & Dal Mas, F. (2021). The Digital Transformation of Business Model Innovation: A Structured Literature Review. Frontiers in Psychology, 11, 539363. https://doi.org/10.3389/fpsyg.2020.539363
135. Velvizhi, G., Shanthakumar, S., Das, B., Pugazhendhi, A., Priya, T. S., Ashok, B., Nanthagopal, K., Vignesh, R., & Karthick, C. (2020). Biodegradable and non-biodegradable fraction of municipal solid waste for multifaceted applications through a closed loop integrated refinery platform: Paving a path towards a circular economy. The Science of The Total Environment, 731, 138049. https://doi.org/10.1016/j.scitotenv.2020.138049
136. Voukkali, I., Papamichael, I., Economou, F., Loizia, P., Klontza, E., Lekkas, D. F., Naddeo, V., & Zorpas, A. A. (2023). Factors affecting social attitude and behavior for the transition towards a circular economy Author links open overlay panel. Sustainable Chemistry and Pharmacy, p. 101276. https://doi.org/10.1016/j.scp.2023.101276
137. Wamba, S. F., Fotso, M., Mosconi, E., & Chai, J. (2023). Assessing the potential of plastic waste management in the circular economy: a longitudinal case study in an emerging economy. Annals of Operations Research, 327, 1-23. https://doi.org/10.1007/s10479-023-05386-3

138. Wang, Z., Wiedenhofer, D., Stephan, A., Perrotti, D., Van den bergh, W., & Cao, Z. (2023). High-Resolution Mapping of Material Stocks in Belgian Road Infrastructure: Material Efficiency Patterns, Material Recycling Potentials, and Greenhouse Gas Emissions Reduction Opportunities. Environmental Science & Technology, 57(34), 12674–12688. https://doi.org/10.1021/acs.est.2c08703
139. Xin, C., Fan, S., Mbanyele, W., & Shahbaz, M. (2023). Towards inclusive green growth: does digital economy matter? Environmental Science and Pollution Research, 30(27), 70348-70370. https://doi.org/10.1007/s11356-023-27357-8
140. Yasmeen, R., Sarfraz, M., Shah, W. U. H., Ivascu, L., & Cifuentes-Faura, J. (2023). The impact of public awareness, infrastructure, and technological development with economic growth on solid waste management of European countries: does governance quality matter? Environmental Science and Pollution Research, 30(53), 113442-113456. https://doi.org/10.1007/s11356-023-30356-4
141. Yu, Z., Umar, M. & Rehman, S.A. (2022). Adoption of technological innovation and recycling practices in automobile sector: under the Covid-19 pandemic. Oper Manag Res 15, 298–306. https://doi.org/10.1007/s12063-022-00263-x
142. Zhang, Y. (2024). Circular economy innovations: Balancing fossil fuel impact on green economic development. Heliyon, 10(18), e36708. https://doi.org/10.1016/j.heliyon.2024.e36708