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Reverse vending machines in the circular economy: A bibliometric analysis of an underexplored enabler (2003–2023)

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ABSTRACT

Deposit Refund Systems (DRS), particularly Reverse Vending Machines (RVM), have emerged as promising tools to foster recycling and close material loops, thus advancing the principles of the circular economy. Yet, the evolution of academic discourse concerning such incentives within the framework of circular economy practices remains an underexplored gap, which justifies a comprehensive analysis such as the one conducted in this study. Through a bibliometric approach, this research explores the evolution of the theme over time (from 2003 to 2023). Drawing on a sample of 755 articles, the results indicate a growing academic interest in the subject, particularly after 2017, driven by global policy shifts and the increasing relevance of circular economy principles. Results also underscore the interdisciplinary nature of sustainable waste management, advocating for the integration of policy frameworks, technological innovations, and financial incentives to achieve long-term sustainability goals. However, the potential of RVM as key enablers in closing material loops, due to their role in material recovery and sustainable waste management, is not sufficiently treated. This highlights not only a gap in the existing literature, but also a missed opportunity to fully explore the transformative potential of RVMs in advancing circular economy goals.

Introduction

The exponential population growth observed in recent decades, along with the corresponding increase in resource consumption and waste generation, has underscored the pressing need for the efficient utilization of resources and the proper management of waste (Amasuomo and Baird, 2016; Kaza et al., 2018). Moreover, increasing wealth and urban migration are correlated with higher per capita waste generation which in turn exacerbates the challenges faced by expanding urban centres, particularly in terms of waste collection and land allocation for treatment and disposal (Kaza et al., 2018). In the European Union (EU), for instance, municipal waste generation per capita increased by 12.9 %[3] between 1995 and 2021 and, globally, the World Bank projects a 70 % rise in waste generation by 2050 if no immediate measures are undertaken (Kaza et al., 2018). Hence, the development and deployment of efficient waste management systems is urgently needed.

Even more crucial is the need to move towards a circular economy model which is, according to Ellen MacArthur Foundation (2015) "restorative and regenerative by design" aiming to maintain products, components, and materials at their highest utility and value for as long as possible. In this context, sustainable waste management and circular economy models extend far beyond the practice of recycling emphasizing that waste prevention and minimization are fundamental. Ultimately, in a closed-loop system, recycling often serves as a remedial measure rather than a central strategy. Nonetheless, increasing recycling rates for materials that have already entered the waste stream remains a vital element of sustainable residual waste management, contributing to the broader goals of resource efficiency and system circularity (Das et al., 2019). This is particularly evident for instance in the case of electronic waste (e-waste), whose rapid growth poses complex environmental and socio-economic challenges. Recent studies focused on the Indian context, where informal recycling practices remain widespread, highlight key challenges to advancing e-waste circularity support (Jaiswal and Mukti, 2024, 2025a, 2025b). These include structural barriers such as limited public awareness, inadequate policy implementation, and infrastructural deficiencies. At the same time, progress depends on promoting sustainable remanufacturing, integrating

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[3] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics

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informal and formal sectors, and ensuring coordinated policy and industry support.

Despite the efforts made to date though, recycling rates remain persistently low in many countries, due to a range of interrelated factors such as the ones just mentioned, either limited public awareness, inadequate infrastructure, weak policy frameworks or insufficient citizen participation (Strydom, 2018; Oluwadipe et al., 2022). The effectiveness of various mechanisms and policy instruments to foster sustainable waste management and circular economy, including tax incentives (Ajayi and Oyedele, 2017), mandatory participation programmes (Jenkins et al., 2003), social influence dynamics (Li et al., 2021), and operational decision-making frameworks decisions (Giovanni and Zaccour, 2014) has been widely studied. Practical considerations such as accessibility and convenience are considered to impact on household recycling behaviours at least as much as financial incentives (Bernstad et al., 2013). As such, behavioural dimensions and citizen engagement may enable a successful transition to circular economy (Vidal-Ayuso et al. (2023) and Zhou et al. (2020)) and the integration of incentive mechanisms must be carefully designed to align with behavioural patterns, user preferences, and systemic goals In this context, incentive-based mechanisms such as Deposit Refund Systems (DRS) and Reverse Vending Machines (RVM) have gained relevance by encouraging consumer participation in waste separation and recycling. These systems allocate value to waste items and reward consumers for their return, thereby reinforcing pro-environmental behaviour and supporting circularity goals (Fullerton and Wolverton, 2000; Laubinger et al., 2022; Walls, 2011).

Although DRS and RVMs are widely implemented across the globe, especially for beverage containers, academic research - particularly from a bibliometric perspective - has rarely addressed their role as incentive-based tools within the circular economy. While previous bibliometric studies have extensively mapped research trends in waste management and circular economy (e.g., Ranjbari et al., 2021; Tsai et al., 2020; Tushar et al., 2023), they tend to focus on broader themes and overlook the specific contribution of reward-based systems like DRS and RVMs in promoting recycling and closed-loop logistics. This omission represents a relevant gap in the literature which justifies the comprehensive analysis conducted in the current study.

To address this gap, the present study conducts a bibliometric analysis focused on the implementation and effectiveness of reward-based recycling mechanisms, particularly DRS and RVMs, as instruments to foster sustainable waste management. It seeks to answer the following research question:

> *To what extent has the academic literature examined the role of incentive mechanisms - such as Deposit-Refund Systems (DRS), Reverse Vending Machines (RVM), and other reward-based systems -in supporting circular economy practices, particularly in the context of recycling and closed-loop logistics?*

By identifying key trends, thematic clusters, and underexplored areas in the past two decades, this study contributes to advancing knowledge on the intersection between behavioural incentives and circular economy, while also informing future research agendas in the field. In fact, DRS incentivize citizens to separate packaging waste for recycling by requiring an upfront deposit at the time of purchase, which is later refunded when the packaging is returned to a designated collection point. This mechanism not only promotes recycling but also strengthens material circularity by keeping resources within the economic loop and reducing negative environmental externalities such as pollution (Laubinger et al., 2022). While there are operational costs associated with these systems, they are generally outweighed by their social, economic, and environmental benefits, including reductions in energy use, landfill dependency, and greenhouse gas emissions (Jadayil and Aqil, 2023). Consequently, the adoption of moderate disposal charges and DRS schemes has been widely recognized as a promising policy approach that aligns market incentives with sustainability goals, contributing directly to the realization of a more circular economy (Calcott and Walls, 2005).

In this context, Reverse Vending Machines (RVMs) emerge as a key technological enabler of DRS implementation. Equipped with advanced sensors and automated sorting technologies, RVMs ensure the accurate segregation of recyclable materials, thereby improving the quality and purity of recovered resources and minimizing contamination in the recycling stream, as illustrated in Fig. 1. This not only facilitates high-value recycling but also supports closed-loop logistics, a cornerstone of circular economy strategies. The recovery of recyclable materials through technologies like RVMs contributes to lowering manufacturing costs for certain products, such as plastic water bottles, by reducing the demand for virgin raw materials (Jadayil and Aqil, 2023). Although the range of packaging accepted by most RVMs remains limited - primarily to beverage containers made of plastic and aluminium, as well as electronic waste (Tong et al., 2018) - some advanced systems are now capable of recognizing and segregating various waste types. This capability enables more precise separation and treatment, which is crucial for supporting circular economy objectives (Rahim and Khatib, 2021; Tong et al., 2018).

Additionally, by offering a convenient and user-friendly interface for material return, RVMs help increase public participation in recycling programs, making sustainable practices more accessible and visible in everyday life (Zhang et al., 2024). Ultimately, the integration of such reward-based systems into waste management infrastructures represents a crucial step toward operationalizing circular economy principles and fostering a more sustainable production and consumption system. However, as Kremel (2024) notes, while financial incentives can play an important role in encouraging sustainable consumer behaviour and participation in circular systems, their effectiveness is not always linear or guaranteed. This underscores the need to consider the social embeddedness as a critical dimension for ensuring the long-term success and resilience of circular strategies (Kremel, 2024).

The effectiveness of deposit-refund systems (DRS) such as the ones operationalized by RVMs depends on an in-depth understanding of user engagement strategies, reinforcing the need for tailored, context-sensitive policy approaches capable of fostering broad participation and long-term commitment to circular waste practices (Bernstad et al., 2013; Timlett and Williams, 2008). In this context, research on this topic remains scarce. The current study addresses this gap by examining how Deposit Return Schemes (DRS) and Reverse Vending Machines (RVMs) have been covered in the academic literature over the past two decades, using a bibliometric analysis to assess their perceived role and relevance in the transition towards a circular economy system.

Data and methods

To develop a comprehensive understanding of the role played by reward-based systems like reverse vending machines and deposit refund systems in promoting recycling and advancing circular economy principles, a bibliometric review was undertaken (Paul and Criado, 2020). This study employed an exploratory and descriptive methodological approach, involving a systematic process for the selection and analysis of peer-reviewed scientific publications addressing this subject.

Scopus and Web of Science (WoS) were selected as the databases due to their extensive indexing of peer-reviewed journals and broad coverage across diverse scientific disciplines (Harzing and Alakangas, 2016; Mongeon and Paul-Hus, 2016; Moral-Muñoz et al., 2020; Paul and Criado, 2020). The specific search strings, filters, and limitations applied during the search process are detailed in Fig. 2. The subject area criteria (also shown in Fig. 2) allowed for a more targeted dataset, ensuring alignment with the study's scope and objectives. By using Web of Science and Scopus for data collection, thorough coverage of peer-reviewed journal articles published from 2003 to 2023 was ensured. By removing duplicates, excluding incomplete records, and applying explicit

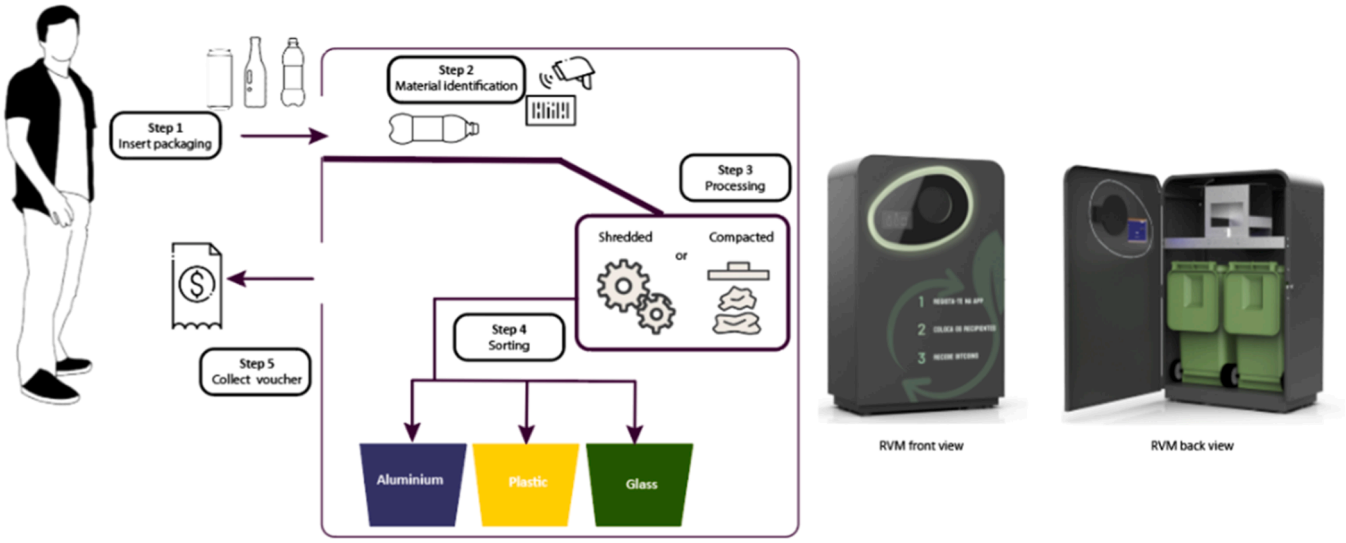

Fig. 1. Schematic Representation of Main Processes and Views of a Reverse Vending Machine (RVM) (Author's own elaboration with Adobe Illustrator2024; RVM images retrieved from https://embalagemdofuturo.pt/subprojetos/pps08/).

inclusion criteria (English language, peer-reviewed, and pertinent subject areas), data quality was ensured using both automated (RStudio) and manual procedures.

The final search resulted in the retrieval of 615 documents from Scopus and 371 from WoS. Subsequently, the datasets were merged using RStudio software (R version 4.2.1), resulting in a combined set of 986 publications. An automated process excluded 218 duplicate entries. A subsequent manual review identified an additional 8 duplicates not detected by the software, as well as 5 records lacking sufficient bibliometric metadata. As a result, a total of 755 publications were retained for the final bibliometric analysis. The sample selection process is depicted in Fig. 2, following the PRISMA guidelines (Page et al., 2021).

Table 1 presents a summary of the dataset used in our analysis, which includes 755 documents published across 282 academic journals. The dataset reflects an annual growth rate of 12.37 %. On average, the documents received 38.44 citations and were 5.69 years old. A total of 1991 authors contributed to these publications. Of these, 84 papers were single-authored, while the average number of co-authors per document was 3.18, indicating a moderate degree of collaboration. Notably, approximately 5.70 % of the publications involved international co-authorship, reflecting limited but present global collaboration.

The analysis was carried out between October and December 2023, using Microsoft Excel and Bibliometrix 4.0.0, a software package specifically designed for bibliometric research (Aria and Cuccurullo, 2017). A quantitative approach was employed to examine annual scientific output, the quality of publication sources (assessed using SJR rankings for journal quartile classification) and the journals with the highest number of publications on the topic over the past two decades (2003–2023). The analysis also identified the top ten authors based on both publications count and total citations, as well as the leading institutions and countries contributing to the field. Additionally, a country collaboration network was constructed to visualize the geographic distribution of scientific output and to highlight key international research linkages. To visualize citation trajectories across disciplines, we used a dual-map overlay generated in CiteSpace 6.4.R1 (64-bit) Advanced, which shows the relationships between citing and cited journals across subject areas.

Beyond mapping the existing body of literature, this bibliometric study uncovers patterns and emerging trends through the identification of co-citation clusters. A content analysis was conducted to explore keyword co-occurrence networks using the Louvain clustering algorithm, while thematic structures within the field were revealed under the use of the InfoMap algorithm to generate a thematic map. Temporal analysis of the results facilitated the detection of evolving research trends and shifts in thematic focus, offering insight into the development of key topics over time. Thematic evolution analysis was based on a corpus comprising the 1000 most frequently occurring terms, with clusters generated using the InfoMap algorithm. Trend topic analysis was conducted by applying a minimum keyword frequency threshold of five and requiring at least two keywords per year.

Results

Topic analysis

As Fig. 3 illustrates, there is clearly an upward trend in the number of annual publications on the topic over the past 20 years. On average, 36 studies were published per year, and 2018 was the first time the annual publications were higher than the historical average. The years of 2012 and 2018 registered remarkable 115 % and 81 % growth in annual publications, respectively. The total number of studies yearly published more than doubled from 2011 to 2012. However, from that year onward, publication growth was not steady (coefficient of variation, CV = 51 % >30 %), which reflects high level of variability in publication counts relative to the mean. This suggests that the growth was characterized by significant fluctuations rather than a steady and sustained increase.

The scientific production on the topic is published in prestigious journals as most publications (72 %) are in first quartile journals (Table 2). The *Journal of Cleaner Production* and *Resources, Conservation and Recycling*, led by a lot the top 10 most productive journals (all classified as Q1, except for "*Land Economics*", which falls under Q2),in terms of number of publications on the topic under analysis, with 144 and 88 articles, respectively (Fig. 4). This great dissemination capacity unveils the interest and relevance attained by the topic covering recycling and circular economy associated to the incentive mechanisms, like the deposit refund systems.

Scientific production in this area is carried out in countries all over the world but the top 10 Universities, with the highest number of scientific publications on this topic, are located essentially in China and in the United States Fig. 5. Nevertheless, a highly intensive collaborative network exists between researchers from these two countries and counterparts across all continents, as evidenced by the red cluster depicted in Fig. 6. Two additional smaller collaboration networks can be

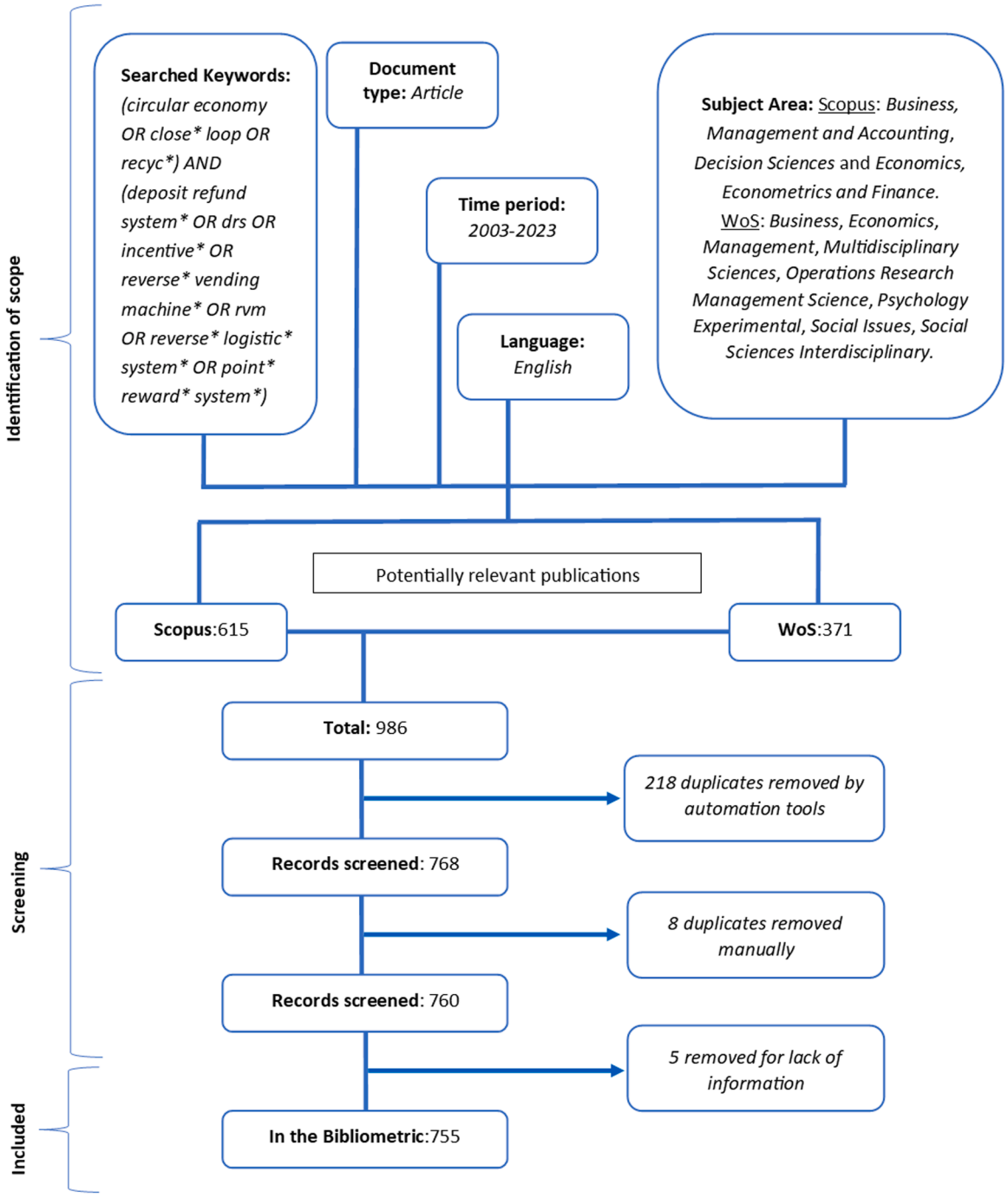

Fig. 2. Sample selection process (Author's own elaboration).

identified, consisting predominantly of European countries—except for Thailand—whose geographical proximity appears to contribute to enhanced research cooperation (green and blue clusters of Fig. 6).

The significance of scientific output is demonstrated not only by the volume of publications, but also by the total number of citations and the average citations per article. Nonetheless, even when considering the last metric, the United States and China emerge as leading contributors, possessing the highest number of cited papers within the sample (Table 3). When assessing impact through the lens of average citations per article, however, Norway distinguishes itself, achieving approximately 89 citations per publication and thereby ranking first according to this criterion (Table 3).

The most highly cited articles within our sample are presented in Table A.1 and A.2 (Appendix). Notably, the study by Savaskan et al. (2004), *'Closed-Loop Supply Chain Models with Product Remanufacturing'*, stands out with a total of 1897 citations, establishing it as a seminal work in the field. Similarly, a more recent contribution by Huang et al. (2018), *'Construction and Demolition Waste Management in China through the 3 R Principle'*, has already garnered 521 citations, underscoring its emerging significance as a key reference in the literature.

To account for the effect of publication age, normalized total citations (TC) provide a more accurate measure of scholarly impact. Using this indicator, the study by Kumar et al. (2022), *'Circular Economy Adoption Challenges in the Food Supply Chain for Sustainable Development'*, emerges as particularly influential, with a normalized TC of 12.54—demonstrating its rapid and sustained academic recognition.

Table 1
Database main information, from final database(n = 755).

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2003:2023
Sources (Journals)	282
Documents	755
Annual Growth Rat%	12,37
Document Average Age	5,69
Average citations per doc	38,44
References	0
DOCUMENT CONTENTS	
Keywords Plus (ID)	3983
Author's Keywords (DE)	2341
AUTHORS	
Authors	1991
Authors of single-authored docs	84
AUTHORS COLLABORATION	
Single-authored docs	89
Co-Authors per Doc	3,18
International co-authorships %	5,70
DOCUMENT TYPES	
Article	755

(Output from Bibliometrix software)

The application of normalized citation metrics reveals the prominence of this and other recent contributions, as detailed in Table A.2 (Appendix), highlighting their role in shaping the current state of the art in the field. Furthermore, the findings suggest a consistent research focus over time on consumer attitudes and behaviours, as well as the impact of incentives in fostering the adoption of circular economy principles- an area examined extensively in earlier works such as Bamberg and Schmidt (2003) and Johansson et al. (2006).

To gain deeper insight into the disciplinary structure and citation dynamics of the literature, a dual-map overlay was generated using CiteSpace software (Chen, 2010). This visualization illustrates the citation trajectories between citing and cited journals across disciplinary domains (see Fig. 7). Two dominant patterns of knowledge flow were identified. The first reflects a model of independent interdisciplinarity, wherein fields such as mathematics, systems, and computing predominantly cite within related technical disciplines, suggesting a more specialized and self-contained trajectory of knowledge development (red line in Fig. 7). The second pattern indicates a disciplinary merge, with journals in the social sciences (including economics, politics, psychology, and education) not only citing each other but also increasingly referencing technical domains such as computing and systems (blue lines in Fig. 7). Overall, the dual-map overlay suggests that knowledge evolution remains largely concentrated within established disciplinary clusters, particularly in areas such as policy, behavioral economics, and systems management, pointing to an incremental rather than disruptive form of interdisciplinary integration.

Thematic analysis

The co-occurrence analysis of authors' keywords, conducted using Bibliometrix version 4.0, is depicted in Fig. 8. This bibliometric technique facilitates the examination of the relational structure among keywords extracted from the studies comprising the sample. The analysis reveals the existence of four thematically distinct yet interconnected clusters: the red cluster, associated with recycling; the blue cluster, centred on the circular economy; the green cluster, focused on closed-loop supply chains; and the purple cluster, pertaining to reverse logistics.

As illustrated in Fig. 8, 'recycling'—represented within the red cluster—emerges as one of the most frequently employed keywords among the authors analysed. It is commonly associated with terms related to waste management, including e-waste, solid waste, and construction and demolition waste, as well as with concepts linked to policy instruments such as incentives, deposit-refund systems, and extended producer responsibility. 'Circular economy', corresponding to the blue cluster, constitutes the second most frequently occurring keyword and is often co-mentioned with terms such as sustainability, sustainable

Table 2
Quality of sources in database.

SJR Rank	Nº of Sources	Nº of publications	%
Q1	132	545	72 %
Q2	62	85	11 %
Q3	41	68	9 %
Q4	28	38	5 %
No information found	19	19	3 %
Total	282	755	100 %

(Authors' elaboration based on Bibliometrix data)

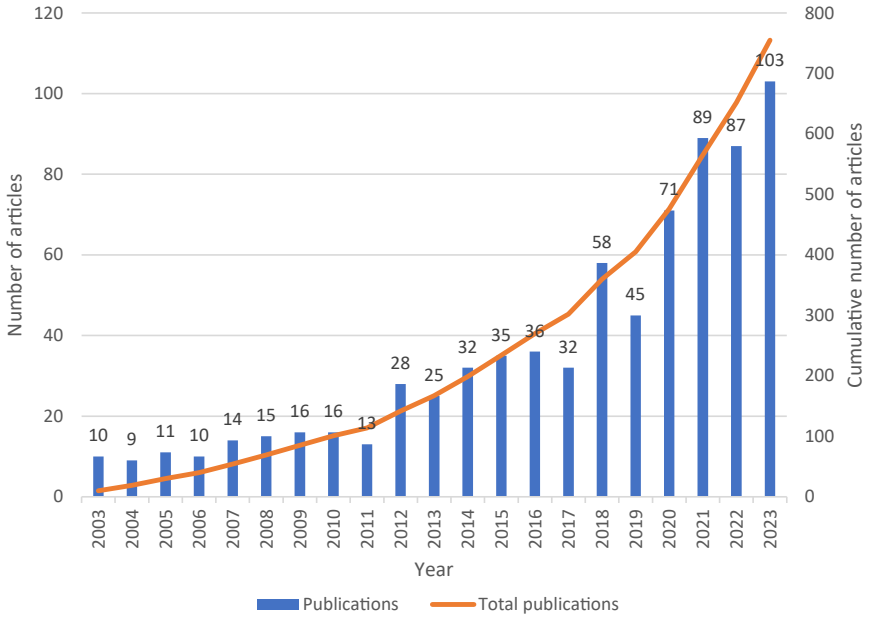

Fig. 3. Annual and cumulative scientific production between 2003 and 2023. (Authors' elaboration based on Bibliometrix data).

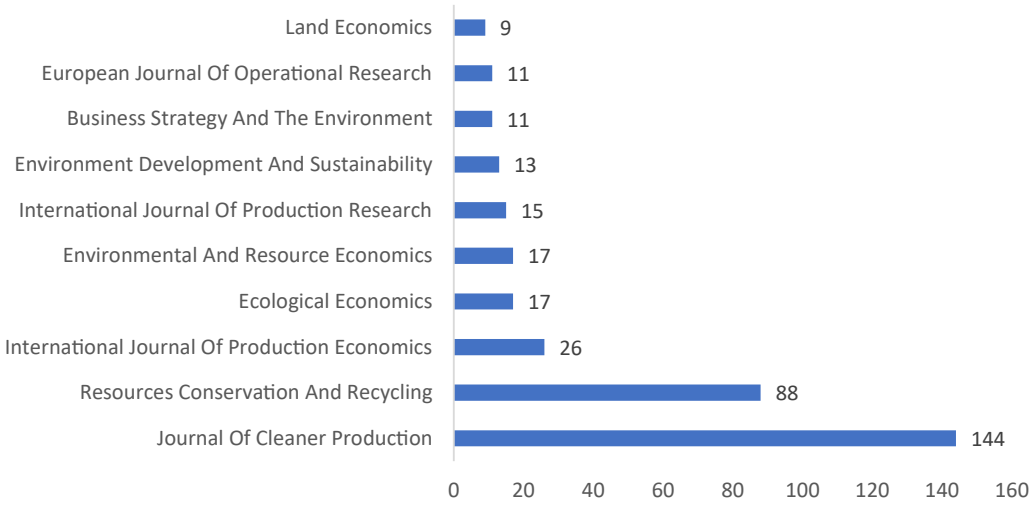

Fig. 4. Top 10 Most productive Journals (in terms of number of publications on the topic under analysis) (Authors' elaboration based on Bibliometrix data).

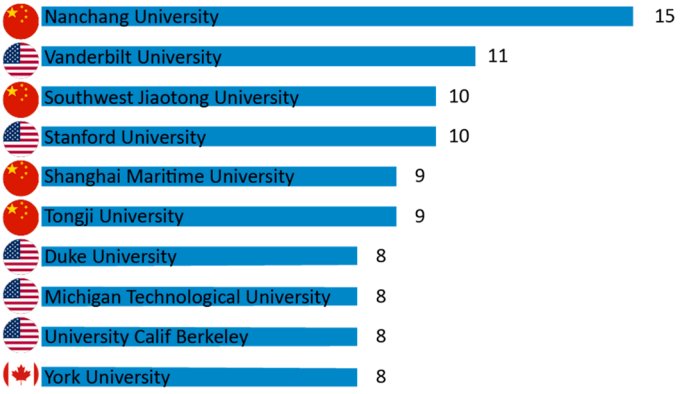

Fig. 5. Top 10 institutions, considering the number of publications on the topic. (Authors' elaboration based on Bibliometrix data).

development, and innovation. Life-cycle assessment' and 'consumer behaviour' also frequently co-occur with the keyword 'circular economy', reflecting their relevance within this research domain. The green cluster in Fig. 8 highlights 'closed-loop supply chains' as a central concept, typically associated with keywords such as 'sustainable supply chain', 'green supply chain', 'economic incentives', and 'willingness to pay'. Lastly, the purple cluster contains studies that emphasize 'reverse logistics' as a key term, which is commonly linked to 'system dynamics', 'reuse', and 'closed-loop' processes.

After the co-occurrence analysis of keywords, a thematic map of author keywords was generated to aid in identifying key trends within the field, their relevance, and their level of maturity, particularly focusing on emerging themes that may represent potential avenues for future research. The results, as presented in Table 4 and Fig. 9, reveal eight distinct clusters. Of these, four are categorized as basic themes (clusters 1–4), indicating that they encompass fundamental topics widely utilized across multiple studies, thereby highlighting cross-cutting themes within the research domain. Within this group, cluster 2 is particularly notable for its centrality and relevance, positioning it as a driving theme. It encompasses 129 relatively recent articles (published on average in 2020) that focus on circular economy, sustainability, and sustainable development, as detailed in Table 4. Cluster 1, which includes a larger number of articles (142), centres on recycling and addresses various aspects of waste management—topics that have been explored for a longer period, as indicated by the average publication year of 2016. Cluster 3, comprising 90 articles (average publication year of 2018), focuses on closed-loop supply chains, remanufacturing, and game theory, while cluster 4, the smallest in this quadrant, with 25 articles, with an average publication year of 2015, is focused on reverse logistics.

The remaining four clusters—clusters 5–8—are classified as niche themes, each addressing more specific aspects within the research domain. Cluster 5, comprising 17 articles, explores the topic of

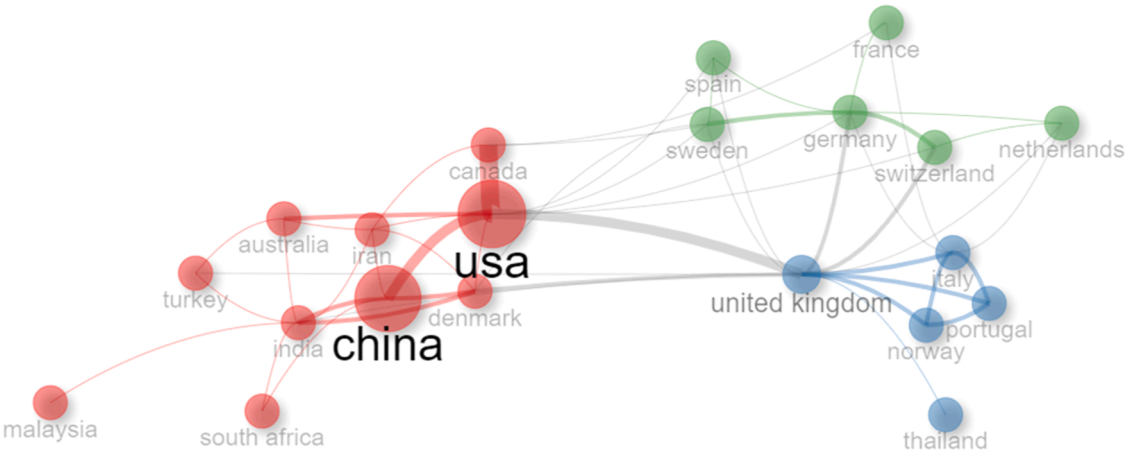

Fig. 6. Country collaboration network (Output from Bibliometrix software).

Table 3
Total citations and average article citations per country (output from bibliometrix software).

Rank	Country	TC*	Average Article Citations**
1st	USA	6152	68.40
2nd	China	5029	35.20
3rd	United Kingdom	2038	63.70
4th	India	1439	35.10
5th	Italy	1270	35.30
6th	Canada	1130	43.50
7th	Australia	959	45.70
8th	Germany	959	56.40
9th	Sweden	890	49.40
10th	Norway	709	88.60

*Total citations received by articles produced in each country.
**The total number of citations received by articles produced by corresponding authors from that specific country divided by the total number of articles produced by corresponding authors from the same country.

incentives, which has been examined for a relatively extended period, as reflected in the average publication year of 2014. A similar temporal pattern is observed in cluster 6, which includes 13 articles focused on environmental policies. Clusters 7 and 8, each consisting of 12 articles, concentrate on system dynamics and deposit-refund systems, respectively, further illustrating the thematic diversity within the field.

The thematic analysis and the resulting cluster classification reveal the diversity of approaches within the field of sustainable waste management research. Although concepts such as Extended Producer Responsibility (EPR) and Deposit-Refund Systems (DRS) are represented within the identified themes, certain terms—most notably 'Reverse Vending Machines' (RVM)—are clearly absent from the clusters. Indeed, only three publications within the entire dataset refer to RVM, whether in their keywords, titles, or abstracts:

- Sambhi, S. & Dahiya, P. (2020). Reverse vending machine for managing plastic waste. (Cluster 1)
- Calcott, P. & Walls, M. (2005). Waste recycling and design for environment: Roles for markets and policy instruments. (Cluster 1)
- Moricz, P. & Drotos, G. (2016). Returpack: The integrator of the beverage can recycling process. (Cluster 4)

Following the identification of thematic groups and clusters, a longitudinal analysis of the sample's keywords was undertaken to examine

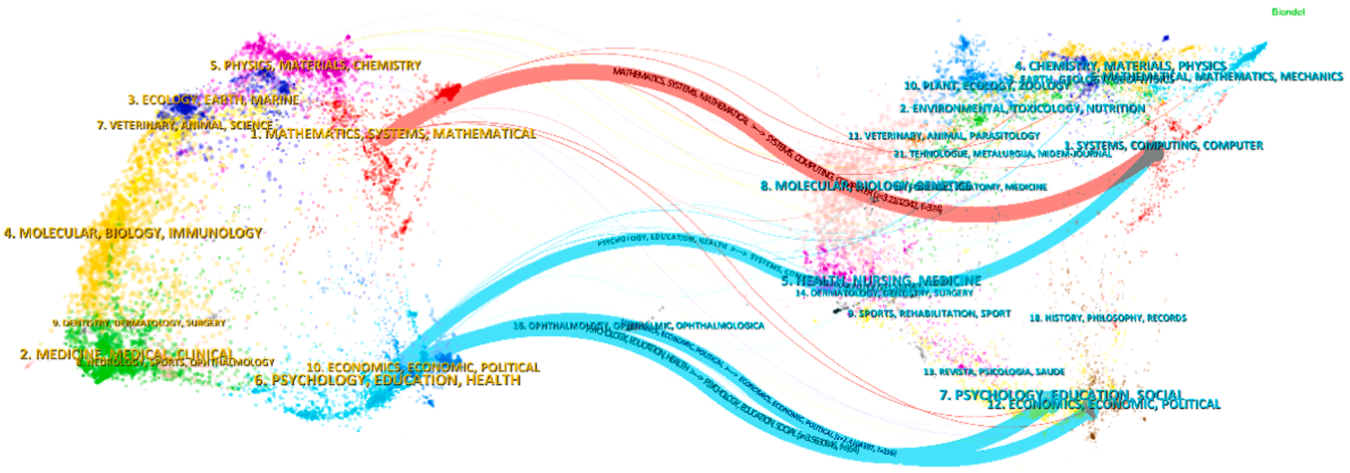

Fig. 7. Dual-map overlay of journal citations, based on z-scores, with citing journals on the left and cited journals on the right. (Output from CiteSpace 6.4.R1 (64-bit) Advanced software).

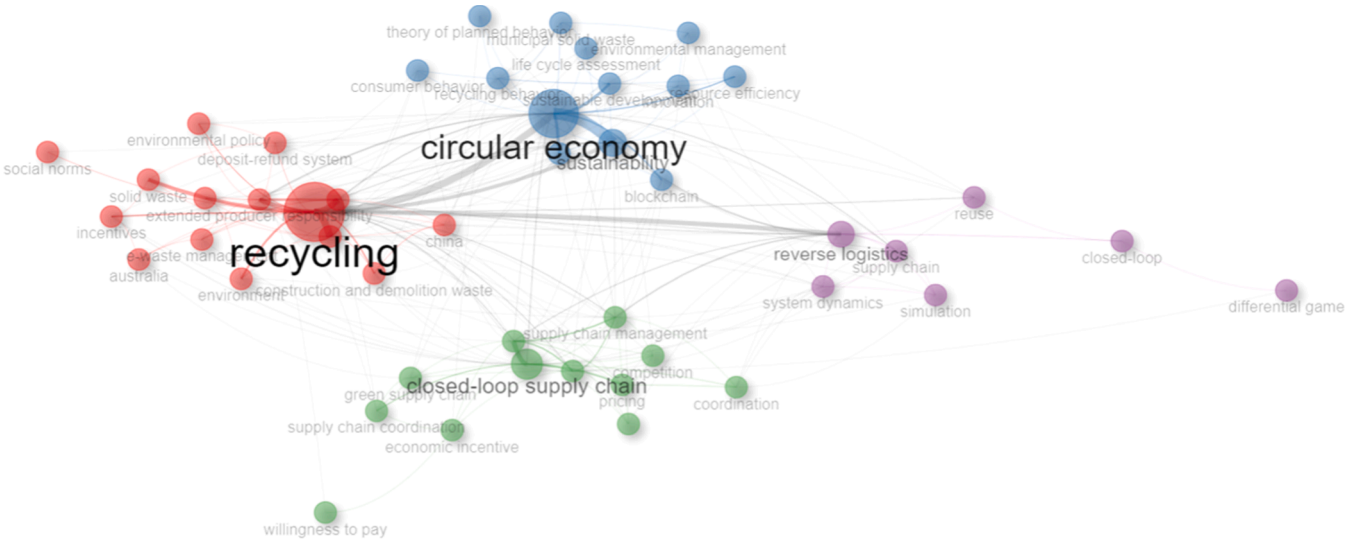

Fig. 8. Author's Keywords co-occurrence analysis (Output from Bibliometrix software).

Table 4
Clusters and associated keywords from thematic map.

#	Cluster	Keywords	Number of articles[(a)]	Average year[(b)]	Main findings[(C)]
1	recycling	recycling, e-waste, waste management, extended producer responsibility, construction and demolition waste	142	2016	Focused on fundamental topics such as waste management and recycling, this cluster covers areas like electronic waste and construction and demolition waste, reflecting a comprehensive and integrated approach to practical solutions and policies in sustainability.
2	circular economy (CE)	circular economy, sustainability, sustainable development, supply chain	129	2020	Explores the intersection of the circular economy with advanced technologies, such as Blockchain and Industry 4.0, highlighting how these innovations can promote sustainability and optimize supply chains.
3	closed-loop supply chain (CLSC)	closed-loop supply chain, remanufacturing, game theory, supply chain management	90	2018	Analyses strategies for recovery and financial intervention in closed-loop supply chains, addressing how policies and economic models can improve the sustainability and efficiency of return and recycling systems.
4	reverse logistics	reverse logistics	25	2015	Focuses on reverse logistics, integrating optimization models, technological advances, and practical case studies to enhance the efficiency of product return and recycling processes.
5	incentives	incentives	17	2014	Investigates niche topics related to incentives and motivational strategies for recycling, addressing how different approaches can stimulate waste management practices in various contexts.
6	environmental policy	environmental policy	13	2014	Emphasizes environmental policies and their effectiveness in promoting recycling and waste reduction, analysing how economic instruments and regulations influence innovation and sustainability.
7	system dynamics	system dynamics	12	2018	Explores the application of system dynamics models to optimize waste and resource management, using simulations to improve efficiency and predict outcomes in different contexts.
88	deposit-refund system	deposit-refund system	12	2017	Examines deposit-refund systems and their effectiveness in waste management, analysing how these mechanisms can improve recycling and influence the behaviour of consumers and industries.

(a) – number of articles in each cluster
(b) – Average year of each cluster
(c) – In the clusters with more than 13 articles, we selected the top 10 for analysis. This selection was based on two factors: their strong association with the cluster (equal to 1) and the highest total citations per year.
(Authors' elaboration based on Bibliometrix data)

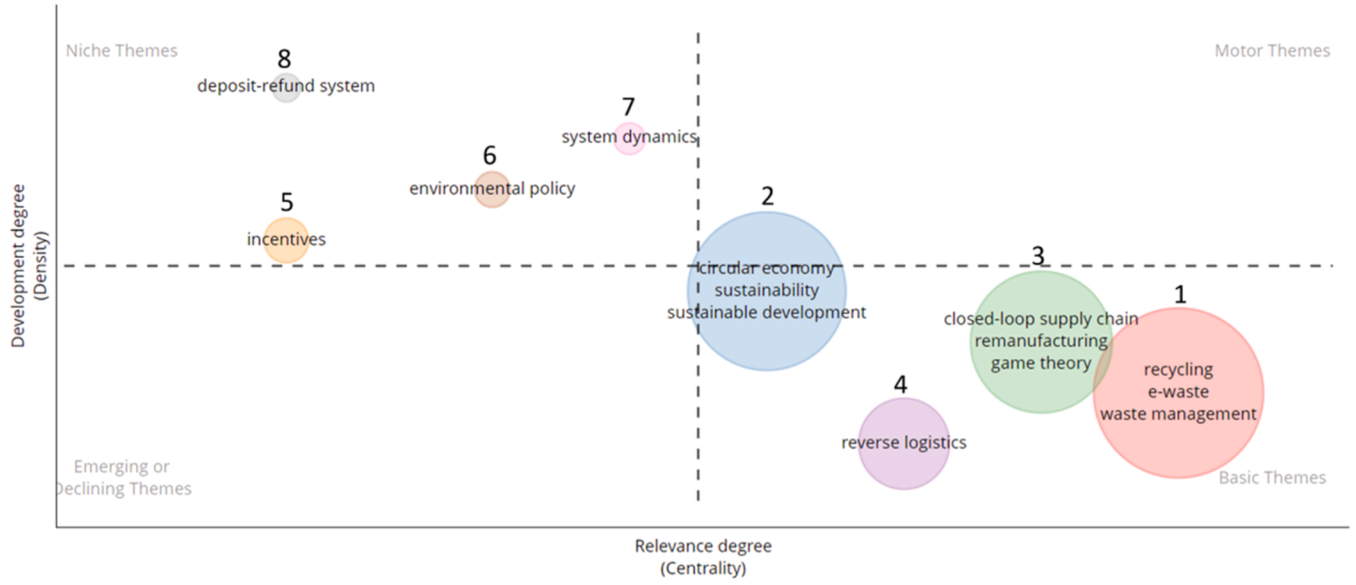

Fig. 9. Thematic map of authors keywords. (Output from Bibliometrix software).

the thematic evolution over the period 2003–2023. The analysis focused on trend topics across two distinct decades: 2003–2013 and 2014–2023. Comparable results were obtained when using either author-defined keywords or abstracts thus, for conciseness, only the findings based on author keywords are reported (Fig. 10).

As illustrated in Fig. 10, distinct thematic emphases can be observed across the two decades analysed, reflecting the evolving landscape of research within the field. Certain topics gained prominence during the earlier period (2003–2013), while others emerged more recently. For instance, terms such as *environmental management* and *reverse logistics* began to gain visibility around 2010, whereas *environmental policy* appeared earlier and has maintained a consistent presence in subsequent

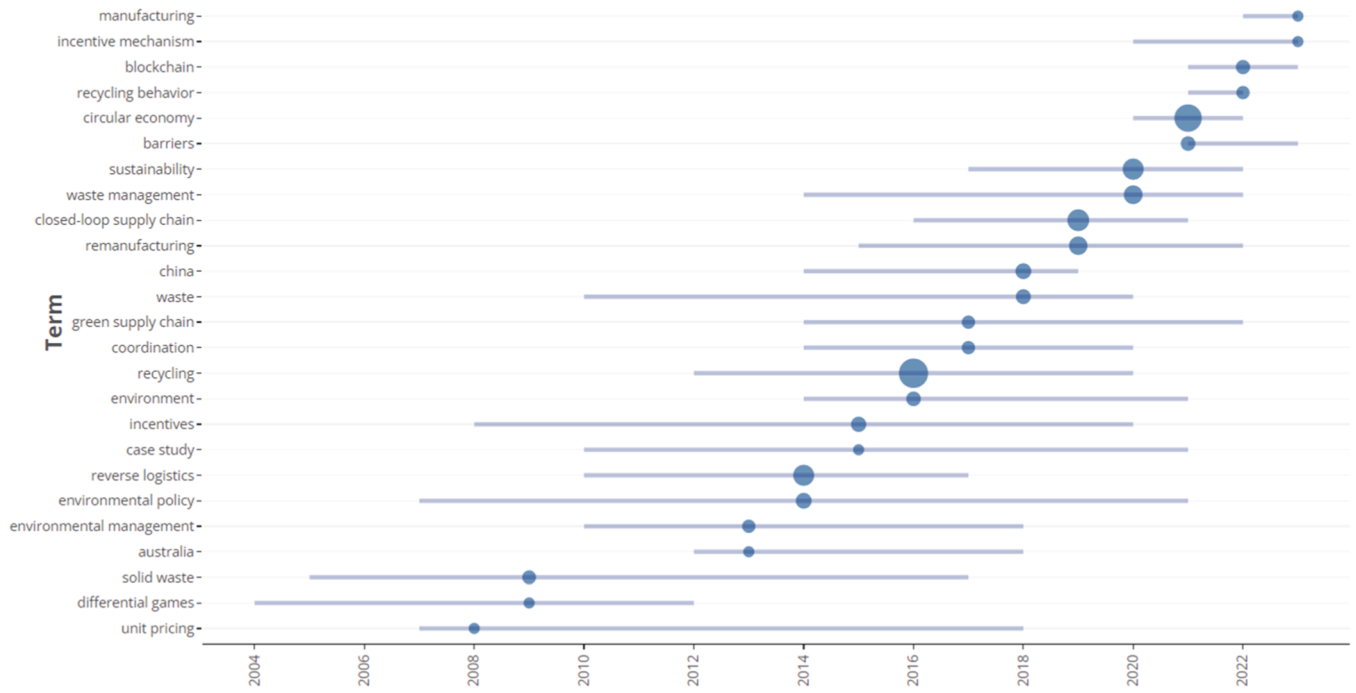

Fig. 10. Evolution of trend topics in authors keywords. (Output from Bibliometrix software).

literature. The theme of *recycling* experienced a notable increase in scholarly attention primarily during the second decade of the sample period (particularly between 2012 and 2020). Similarly, *sustainability* emerged as a central topic in more recent years, predominantly within the 2014–2023 period. The concept of *circular economy* is an even more recent addition, surfacing around 2020, yet rapidly consolidating its position as a dominant research theme.

While the term *incentives* has been present in the literature since approximately 2008, more specific terms such as *incentive mechanism* have only begun to appear in recent years. Likewise, the emergence of terms such as *blockchain* highlights the growing interest in technological innovation to support sustainable practices, reflecting broader shifts in research priorities.

Clustering techniques reveal a progressive thematic convergence over time within the literature. Topics initially explored in isolation—such as economic incentives, facility location, and reverse logistics—have, over the past decade, increasingly joined around the broader framework of the closed-loop supply chain, as illustrated in Fig. 11. Similarly, terms such as *deposit-refund system*, *recycling*, and *e-waste* have gradually aligned with the overarching theme of recycling. Furthermore, Fig. 11 indicates that while *reverse logistics* has maintained its identity as a distinct research topic across both decades, it has more recently been integrated into the broader discourse on the *circular economy*. Lastly, the term *e-waste*, which initially appeared as a standalone focus, now converges with the more encompassing theme of *waste management*, reflecting an evolution toward greater conceptual integration within the field.

Discussion

The present study sought to map the state-of-the-art and its evolution concerning deposit-refund systems and incentive-based mechanisms, with a particular emphasis on Reverse Vending Machines (RVM), within the context of waste management policy, recycling practices and especially circular economy. Among the 755 articles included in the sample, 83 % were published in high-impact journals ranked in Q1 or Q2, highlighting the increasing academic interest and the recognized relevance of this thematic area over the past two decades. The main results presented in the previous section are summarized in Fig. 12.

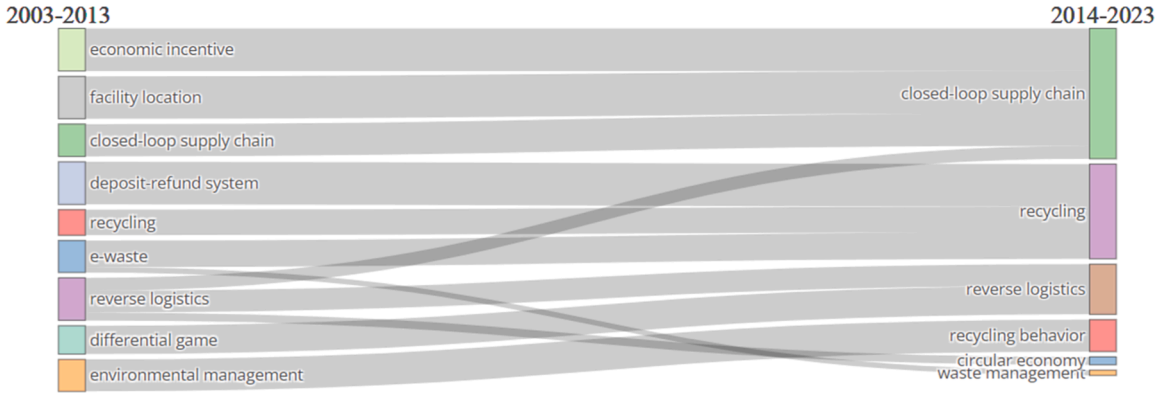

Fig. 11. Thematic evolution of (clustered) authors keywords. (Output from Bibliometrix software).

Global research dynamics

The topic analysis conducted clearly indicates that research in this field is primarily led by Chinese and American institutions. Despite their contrasting economic and political systems, both countries display a comparable and sustained commitment to advancing scholarship on recycling, logistics systems, and the incentive mechanisms that support material recovery within circular economy. The prominence of these nations suggests that the strategic relevance of resource efficiency transcends ideological boundaries, reflecting shared environmental and economic imperatives. Moreover, the global nature of this research agenda is evidenced by contributions from institutions across all continents, reinforcing its multidimensional character and the growing importance of international collaboration. Such cross-national engagement not only enhances the exchange of knowledge and best practices but also contributes to the development of more harmonised and effective policy responses to global sustainability challenges. These findings are consistent with previous bibliometric studies that have identified the UK, Italy, Spain, China, and the USA as leading contributors to the scholarly discourse in this field (Ranjbari et al., 2021; Tsai et al., 2020). However, despite this growing international interest, there remains a notable lack of research focused on RVMs in developing countries, which are the regions that often face the most acute waste management issues and where contextualised, socially informed solutions are urgently needed. Addressing this gap is essential for ensuring that circular economy strategies, including the implementation of RVMs, are inclusive, equitable, and responsive to diverse regional realities. Building on this broad international engagement and leadership in the field, a significant increase in scientific output has been observed since 2018, reflecting the intensifying scholarly interest in issues related to resource efficiency, recycling, and circular economy mechanisms. This upward trend is likely driven by the increasing global urgency to optimise resource use and improve waste management practices. Notably, this surge in academic attention aligns with the timeline of key European Union policy developments, such as the Packaging and Packaging Waste Directive (Directive 94/62/EC; European Commission, 1994) and its subsequent amendments (European Commission, 2015a, 2018a), as well as the "European Strategy for Plastics in a Circular Economy" (European Commission, 2018b). In addition, several major policy frameworks reflect and reinforce the thematic priorities identified in the academic literature and in the findings of this study. Among them are the European Green Deal (European Commission, 2019), the initiatives advanced by the Ellen MacArthur Foundation, and the Sustainable Development Goals (SDGs) established under the United Nations 2030 Agenda (United Nations, 2015). Strategic efforts such as the EU Action Plan for the Circular Economy, articulated in *Closing the Loop* (European Commission, 2015b, 2015c), further underscore this alignment. Together, these developments suggest a growing convergence between academic research and policy agendas aimed at fostering sustainable production and consumption practices.

Thematic clusters

Thematic cluster analysis revealed a multifaceted and evolving research landscape. The identified clusters reflect complementary approaches to circular economy, recycling systems, and sustainable waste management. These approaches range from policy and economic mechanisms to technological innovation and behavioural dimensions. The two largest thematic clusters identified - Recycling (Cluster 1) and Circular Economy (Cluster 2) -represent distinct yet interconnected approaches to sustainable waste management. Cluster 1 adopts a pragmatic, problem-solving focus, emphasizing recycling practices, EPR schemes, and reverse logistics as short-term responses to immediate waste challenges. Foundational studies (e.g., Mazzanti and Zoboli, 2008; Yu et al., 2010) demonstrate the role of policy and incentives in improving recycling systems, while others (e.g., Ghaffar et al., 2020) highlight technological advances enhancing operational efficiency. The interplay between regulatory mechanisms and technological advancement is thus a key enabler of effective circular waste management systems, as also reinforced in recent bibliometric syntheses by Tushar et al. (2023) and Zhou et al. (2020).

In contrast, Cluster 2 reflects a more systemic and long-term vision, focusing on innovation, product redesign, and paradigm shifts driven by tools like Life Cycle Assessment (LCA). It also emphasizes the growing role of digital technologies, such as IoT, blockchain, and Industry 4.0, as enablers of smart circular systems. This is in line with Ranjbari et al. (2021) findings that identify smart sustainable waste management mechanisms as promising opportunities for sustainable CE transition. Closed-loop supply chains, while central to Cluster 3, also feature prominently in Cluster 2, where they are embedded within wider circular strategies. Overall, Cluster 2 illustrates the convergence of policy, technology, and systemic thinking in shaping a forward-looking model of circular production and consumption.

Cluster 3 (Closed-Loop Supply Chains) highlights the strategic role of financial incentives and economic instruments in enabling circular economy practices. Studies in this cluster demonstrate how mechanisms such as green taxation, subsidies, carbon pricing, and return incentives can enhance competitiveness, promote product recovery, and improve environmental performance (e.g., Sheu and Chen, 2012; Fahimnia et al., 2013; Giovanni et al., 2016, Kaya and Urek, 2016; Taleizadeh et al., 2019). By encouraging participation across the supply chain - particularly in reverse logistics - these interventions support the closure of material loops and reinforce sustainability in supply chain operations.

Although considered niche topics in the context of the results of the bibliometric analysis carried out in this study, Clusters 5 (Incentives) and 8 (Deposit-Refund Systems) underscore the critical role of incentive mechanisms in promoting recycling and sustainable waste management. Cluster 8 focuses specifically on Deposit-Refund Systems (DRS), recognized for their effectiveness in improving collection efficiency and encouraging recycling through financial rewards. The growing academic and policy interest in DRS aligns with evolving EU legislation and its expanding global adoption – currently present in at least 46 jurisdictions, including multiple European countries, as well as regions in North America and Australia (Picuno et al., 2025; Zhou et al., 2020; Zorpas, 2024). Cluster 5 addresses a broader array of financial and regulatory incentives, analysing their influence on recycling performance, behavioural change, and system efficiency. While financial tools such as tax incentives and mandatory participation programmes can be effective, studies show that practical factors like convenience often have a stronger impact on recycling behaviour, as also discussed by Bernstad et al. (2013). These findings highlight the need for incentive schemes that are both economically robust and behaviourally informed, supporting citizen engagement and aligning with the broader goals of the circular economy.

Complementing the role of incentives explored in Clusters 5 and 8, Cluster 6 (Environmental Policies) highlights how regulatory frameworks contribute to advancing recycling and waste reduction. Though relatively small, this cluster focuses on case study-based research across diverse national contexts - such as Norway, the US, Taiwan, and several EU countries - and explores a variety of policy instruments, from fiscal measures and tariffs to initiatives promoting material efficiency and technological innovation. Notable examples include Norway's household waste charges (Kipperberg, 2007), the EU's end-of-life vehicle directives (Mazzanti and Zoboli, 2006), and Taiwan's integrated "4-in-1" recycling system (Tsai et al., 2020). The literature also examines market-based tools like permit trading schemes (Peng et al., 2022) and broader strategies for emissions mitigation and energy transition (Annicchiarico et al., 2017). Together, these studies reinforce the importance of well-designed policy instruments - economic, regulatory, and technical - in supporting sustainable waste management and resource recovery.

The thematic clusters identified underscore the complexity of

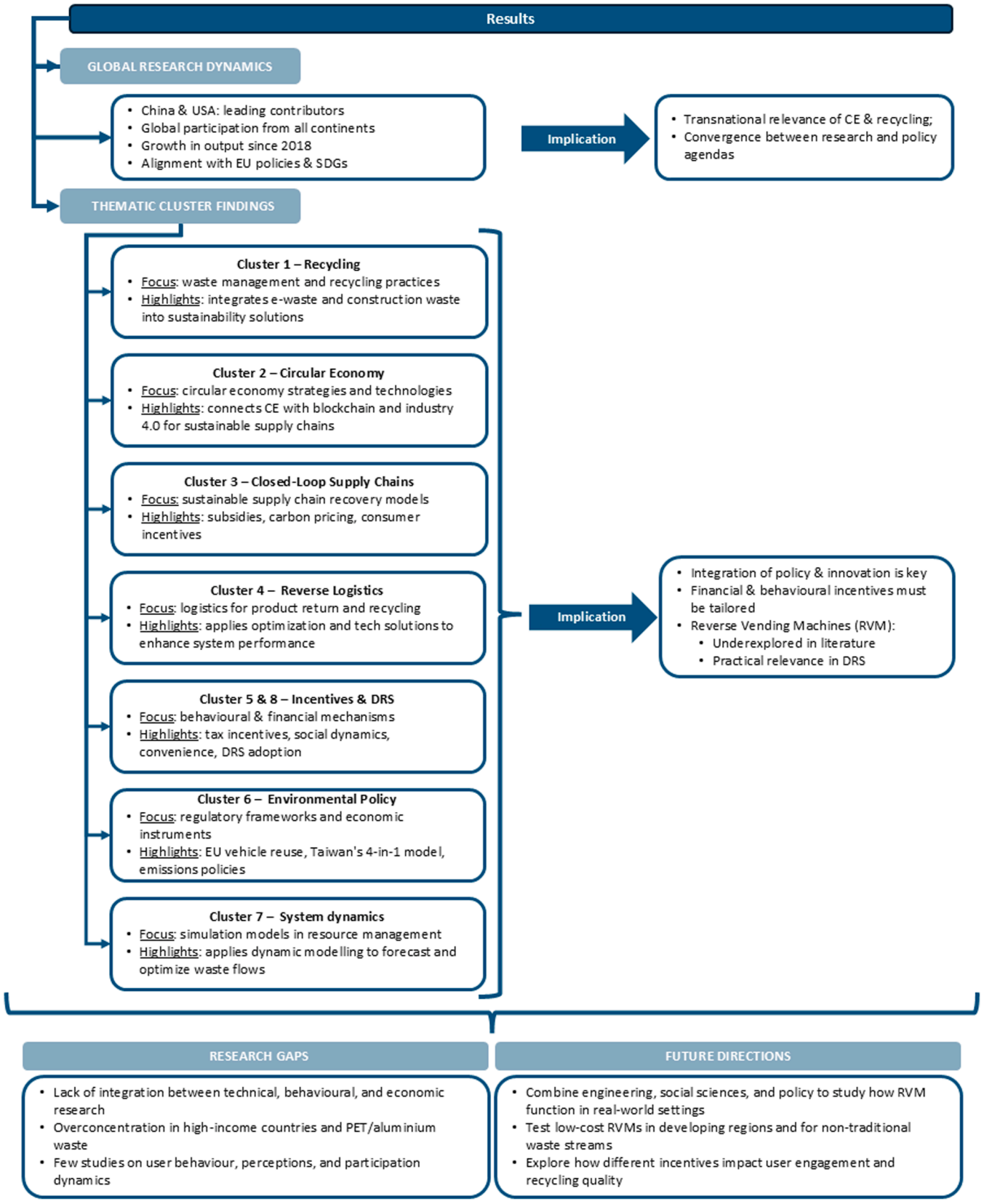

Fig. 12. Summary diagram of key findings from the topic and thematic bibliometric analyses. (Authors' own elaboration).

transitioning to a circular economy, highlighting the need for integrated strategies that combine policy design, financial incentives, technological advances, and citizen engagement. Their convergence suggests that effective waste management solutions must be context-sensitive, systemically coordinated, and grounded in both regulatory frameworks and behavioural dynamics. These results are consistent with those reported by Vidal-Ayuso et al. (2023), Ranjbari et al. (2021), Tsai et al. (2020) and Katoch (2022). Notably, the marginal presence of Reverse Vending Machines (RVMs) within these clusters points to a gap in the academic literature, where their potential as a practical tool to support deposit-refund systems and enhance user participation remains largely underexplored.

RVMs - underexplored enablers of circular economy

The literature underscores the potential of Deposit-Refund Systems (DRS), and by extension, Reverse Vending Machines (RVM), as effective mechanisms for facilitating closed-loop waste management systems, increasing recycling and moving towards a circular economy (Giardullo, 2019; Laubinger et al., 2022; Zhou et al., 2020). However, our bibliometric analysis found that only three studies (accounting for less than 0.4 % of the dataset) explicitly focus on the role of RVMs in the circular economy. One of these studies that explicitly examine the role of RVMs within circular economy frameworks is that of Calcott and Walls (2005). The authors evaluate various household recycling strategies - such as curbside collection, drop-off centres, and RVMs - and argue that an optimal approach may involve the combination of deposit-refund schemes with moderate disposal fees. They also caution that allowing producers to retain unclaimed deposits could undermine the overall effectiveness of the system. While Calcott and Walls (2005) adopt a policy-oriented perspective, Moricz and Drotos (2016) focus on a practical application, analysing the business model of a Hungarian firm that employs RVMs for aluminium can collection. Their analysis highlights the legal, economic, and technological challenges associated with scaling such models internationally, including the influence of global aluminium price volatility. Finally, Sambhi and Dahiya (2020) approach RVMs from a technological and environmental perspective, proposing them as advanced solutions for plastic waste management. Their study highlights the integration of sensor technologies and emphasises the environmental benefits of reducing plastic volume and energy consumption in recycling processes. Within this context, they introduce the concept of "cash-from-trash", whereby recyclable materials are reintegrated into production processes to generate new products, thus contributing to pollution reduction and the mitigation of greenhouse gas emissions.

The reduced number of studies just mentioned highlight the fact that RVMs are rarely conceptualised as instruments that support systemic transitions toward circularity but treated instead in isolation, as technical solutions for waste management. Despite their recognised relevance for enhancing recycling and closing resource loops, academic literature, particularly within the social sciences, seldom establishes an explicit connection between RVMs and broader theoretical frameworks of circular economy or material circularity. Scholarly attention to RVM as a central means to operationalize DRS thus remains limited. Nevertheless, RVMs effectiveness in enhancing beverage container recovery rates has been evidenced in several studies (Cordle et al., 2019; Watkins et al., 2019), and their deployment has, in some contexts, contributed to improved recycling outcomes and progress towards sustainability targets (Picuno et al., 2025).

RVMs are already widely implemented and functioning with notable success across several high-income countries, particularly in Europe and North America, where robust policy frameworks and well-developed infrastructure support national deposit-refund schemes (Laubinger et al., 2022; Stojanov, 2015). For example, Sweden has operated a national DRS with RVMs since 1984, reaching recycling rates of up to 85 %. Similar systems in Denmark, Norway, and Germany report return rates of 89–98 %, supported by extensive RVM networks (Laubinger et al., 2022; Stojanov, 2015). Beyond Scandinavia, countries such as Finland, the Netherlands, Switzerland, Canada, Australia, and several U. S. states have also adopted RVM-based systems with considerable success. In contrast, implementation of RVM infrastructure remains limited in emerging and lower-income regions and the academic work often focuses on prototypes or pilot projects – as it is the case in Kazakhstan (Amantayeva et al., 2021), Colombia (Bedoya et al., 2024), Indonesia (Alfarisi et al., 2022), Pakistan (Zia et al., 2022), Malaysia (Rana et al., 2022; Tomari et al., 2019), and Sri Lanka (Athukorala et al., 2021). Given the scale and complexity of waste-related challenges in developing countries, advancing research on the role of RVMs in supporting circular economy transitions is not only relevant but increasingly essential.

Worth noting is also the fact that RVMs tend to be framed within the beverage and retail sectors, which limits their perceived contribution to circular economy strategies at a systems level. Most research and implementations focus almost exclusively on beverage containers, particularly PET bottles and aluminium cans (Bedoya et al., 2024; Martinho et al., 2024; Rahim and Khatib, 2021; Rana et al., 2022; Stojanov, 2015; Tomari et al., 2019). Although other materials are also mentioned - such as glass (Kim et al., 2021), yogurt cups (Athukorala et al., 2021), or paper (Tomari et al., 2017) - these remain rare and usually restricted to experimental or prototype-level initiatives. Nonetheless, RVMs hold significant unexploited potential. Beyond packaging waste, these technologies could be adapted to new sectors and waste streams. For instance, in the healthcare sector, RVMs could incentivise the return of expired medications or pharmaceutical packaging. While some studies address the challenges of pharmaceutical waste circularity (Fani et al., 2025; Tat and Heydari, 2021), none consider RVMs as part of the solution. Similarly, in the context of e-waste, RVMs could support extended producer responsibility by facilitating the return and recovery of end-of-life electronics such as smartphones or batteries. Expanding the application of RVMs to these domains could enhance material recovery, increase participation, and align more directly with the systemic goals of circular economy frameworks.

Conclusion

The primary aim of this study was to conduct a comprehensive examination of the academic literature on incentive mechanisms—such as reward-based systems, deposit-refund systems and reverse vending machines—within the context of circular economy practices. Our analysis shows that, despite their relevance for material recovery and sustainable waste management, RVMs are seldom recognised in the literature as key enablers of circularity. Their potential to contribute to systemic circular economy goals remains underexplored. On the other hand, our results indicate the existence of substantial thematic interconnections, with incentive-related studies spanning multiple clusters. This highlights the need for an interdisciplinary approach to sustainable waste management within a circular economy: one that integrates policies, tools, incentives, and technological innovations, rather than relying on isolated or one-dimensional solutions.

Based on the findings of our bibliometric analysis, we recommend that policymakers actively support the expansion of RVMs applications through integrated circular economy strategies. This includes the creation of incentive structures (such as deposit-refund schemes) tailored to local contexts, the integration of RVMs into national waste management plans, and the promotion of interdisciplinary research–policy partnerships to assess and adapt RVMs technologies beyond the beverage sector. In regions where RVMs are already well-established, policies should encourage diversification of accepted materials and alignment with extended producer responsibility frameworks. In developing countries, targeted investments in pilot programs, co-designed with local stakeholders and informed by academic research, can foster scalable, socially inclusive solutions. These actionable strategies bridge the current gap

between academic knowledge and practical implementation, aligning RVM deployment with broader circular economy and sustainability goals.

Despite the contributions of the current paper, it is important to acknowledge certain limitations. From a methodological standpoint, the use of longitudinal keyword analysis allows for the identification of temporal patterns and emerging trends, offering valuable insights into the maturation and diversification of the field. However, the reliance on author-defined keywords may introduce biases related to individual authors' framing of their work, potentially overlooking important conceptual overlaps or alternative terminologies. Moreover, more recent publications—despite reflecting current trends—may be underrepresented in terms of visibility due to limited citation accumulation over time. Therefore, while the analysis provides a meaningful overview of thematic evolution, its findings should be interpreted in conjunction with other bibliometric indicators and qualitative assessments to ensure a more comprehensive understanding of the field's development.

Future research can more effectively leverage interdisciplinary approaches by explicitly integrating technical, policy, economic, and behavioural perspectives when analysing Reverse Vending Machines (RVMs) within circular economy frameworks. Interdisciplinary research should seek to bridge policy and practice by analysing how regulatory frameworks, such as deposit-refund schemes, interact with consumer behaviour and infrastructure in diverse contexts. It should also incorporate social science perspectives to investigate public acceptance, equity implications, and cultural dimensions of RVM adoption, especially in developing countries where local governance, informal waste systems, and social norms play a decisive role in shaping outcomes. Cross-sector collaboration is equally important, particularly in exploring how RVMs can be adapted to new material streams—such as pharmaceuticals or e-waste—and integrated into broader waste governance systems.

In addition, co-creation and participatory research methods, engaging stakeholders from government, industry, academia, and civil society, can ensure that RVMs innovations are not only technically effective but also contextually appropriate and socially inclusive. By advancing research that transcends disciplinary boundaries and engages with diverse regional and institutional realities, scholars can contribute to more robust, adaptable, and scalable circular economy strategies that better reflect the complexity of real-world waste management challenges.

CRediT authorship contribution statement

Maria Eduarda Fernandes: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maurício C. João:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT developed by Open AI, to improve the language of the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A.1
Most Cited Documents (based on total citations) (Authors' elaboration based on Bibliometrix data)

Rank	Authors	Year	Title	Journal	Total Citations
#1	R. Canan Savaskan, Shantanu Bhattacharya & Luk N. Van Wassenhove	2004	Closed-Loop Supply Chain Models with Product Remanufacturing	Management Science DOI:10.1287/mnsc.1030.0186	1897
#2	Sebastian Bamberg & Peter Schmidt	2003	Incentives, Morality, Or Habit? Predicting Students' Car Use for University Routes With the Models of Ajzen, Schwartz, and Triandis	Environment and Behavior DOI:10.1177/0013916502250134	626
#3	Beijia Huang, Xiangyu Wang, Harnwei Kua, Yong Geng, Raimund Bleischwitz & Jingzheng Ren	2018	Construction and demolition waste management in China through the 3 R principle	Resources, Conservation and Recycling DOI:10.1016/j.resconrec.2017.09.029	521
#4	Supriya Mitra & Scott Webster	2008	Competition in remanufacturing and the effects of government subsidies	International Journal of Production Economics DOI:10.1016/j.ijpe.2007.02.042	416
#5	Maria Vredin Johansson, Tobias Heldt & Per Johansson	2006	The effects of attitudes and personality traits on mode choice	Transportation Research Part A: Policy and Practice DOI:10.1016/j.tra.2005.09.001	412
#6	Kjell Arne Brekke, Snorre Kverndokk & Karine Nyborg	2003	An economic model of moral motivation	Journal of Public Economics DOI:10.1016/S0047–2727(01)00222–5	347
#7	Behzad Esmaeilian, Joe Sarkis, Kemper Lewis & Sara Behdad	2020	Blockchain for the future of sustainable supply chain management in Industry 4.0	Resources, Conservation and Recycling	343

(*continued on next page*)

Table A.1 (*continued*)

Rank	Authors	Year	Title	Journal	Total Citations
				DOI:10.1016/j.resconrec.2020.105064	
#8	Jiuh-Biing Sheu & Yenming J. Chen	2012	Impact of government financial intervention on competition among green supply chains	International Journal of Production Economics DOI:10.1016/j.ijpe.2012.03.024	287
#9	Rupesh Kumar Pati, Prem Vrat b & Pradeep Kumar	2008	A goal programming model for paper recycling system	Omega DOI:10.1016/j.omega.2006.04.014	287
#10	Navin K. Dev, Ravi Shankar & Fahham Hasan Qaiser	2020	Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance	Resources, Conservation and Recycling DOI:DOI.org/10.1016/j.resconrec.2019.104583	252

Table A.2
Most Cited Documents (based on normalized citations) (Authors' elaboration based on Bibliometrix data)

Rank	Authors	Year	Title	Journal	Normalized TC
#1	Mukesh Kumar, Rakesh D. Raut, Sandeep Jagtap & Vikas Kumar Choubey	2022	Circular economy adoption challenges in the food supply chain for sustainable development	Business Strategy and the Environment DOI:10.1002/bse.3191	12,54
#2	Beijia Huang, Xiangyu Wang, Harnwei Kua, Yong Geng, Raimund Bleischwitz & Jingzheng Ren	2018	Construction and demolition waste management in China through the 3 R principle	Resources, Conservation and Recycling DOI:10.1016/j.resconrec.2017.09.029	10,7
#3	Behzad Esmaeilian, Joe Sarkis, Kemper Lewis & Sara Behdad	2020	Blockchain for the future of sustainable supply chain management in Industry 4.0	Resources, Conservation and Recycling DOI:10.1016/j.resconrec.2020.105064	9,84
#4	R. Canan Savaskan, Shantanu Bhattacharya & Luk N. Van Wassenhove	2004	Closed-Loop Supply Chain Models with Product Remanufacturing	Management Science DOI:10.1287/mnsc.1030.0186	7,89
#5	Navin K. Dev, Ravi Shankar & Fahham Hasan Qaiser	2020	Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance	Resources, Conservation and Recycling DOI:10.1016/j.resconrec.2019.104583	7,23
#6	Tonni Agustiono Kurniawan, Mohd Hafiz Dzarfan Othman, Goh Hui Hwang & Petros Gikas	2022	Unlocking digital technologies for waste recycling in Industry 4.0 era: A transformation towards a digitalization-based circular economy in Indonesia	Journal of Cleaner Production DOI:10.1016/j.jclepro.2022.131911	7,16
#7	Shashank Kumar, Rakesh D. Raut, Kirti Nayal, Sascha Kraus, Vinay Surendra Yadav & Balkrishna E. Narkhede	2021	To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP	Journal of Cleaner Production DOI:10.1016/j.jclepro.2021.126023	7,15
#8	Jayani Ishara Sudusinghe & Stefan Seuring	2022	Supply chain collaboration and sustainability performance in circular economy: A systematic literature review	International Journal of Production Economics DOI:10.1016/j.ijpe.2021.108402	6,85
#9	Serena Giorgi, Monica Lavagna, Ke Wang, Mohamed Osmani, Gang Liu & Andrea Campioli	2022	Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices	Journal of Cleaner Production DOI:10.1016/j.jclepro.2022.130395	6,74
#10	Melanie R.N. King, Paul D. Timms & Sara Mountney	2023	A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns	Journal of Cleaner Production DOI:10.1016/j.jclepro.2022.135538	6,6

Data availability

Data will be made available on request.

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