ReGeo
ISSN: 2177-3246

CIRCULAR ECONOMY IN THE PHARMACEUTICAL INDUSTRY: MANAGEMENT PERSPECTIVES AND STRATEGIC IMPLEMENTATION

ECONOMIA CIRCULAR NA INDÚSTRIA FARMACÊUTICA: PERSPECTIVAS DE GESTÃO E IMPLEMENTAÇÃO ESTRATÉGICA

ECONOMÍA CIRCULAR EN LA INDUSTRIA FARMACÉUTICA: PERSPECTIVAS DE GESTIÓN E IMPLEMENTACIÓN ESTRATÉGICA

10.56238/revgeov16n5-324

Bruno de Moura Pires[1], Glaucia Cristina de Souza Oliveira[2], Laís Stephany do Carmo Vieira Feitosa[3], Belmiro do Nascimento João[4]

ABSTRACT

This study analyzes the implementation of CE in the pharmaceutical industry from a managerial perspective, identifying the main challenges, enablers, and strategies for transitioning from linear to circular models, through a systematic review of literature indexed in the Web of Science between 2017 and 2025. The research examines the technological, organizational, and environmental dimensions that influence the adoption of circular practices in the pharmaceutical sector. The results show that pressures from external stakeholders, green information technology systems, and internal environmental management are the primary enablers of circularity. However, significant barriers include regulatory complexity, technological limitations, and challenges in the reverse logistics of toxic products. The analysis reveals that the pharmaceutical industry prioritizes remanufacturing and reuse practices, while recycling remains undersized. The study contributes to the theoretical development of CE in the pharmaceutical context and offers practical insights for managers and policymakers.

Keywords: Circular Economy. Pharmaceutical Industry. Sustainability. Bibliometric Analysis. Scientific Trends.

RESUMO

Este estudo analisa a implementação da Economia Circular (EC) na indústria farmacêutica sob uma perspectiva gerencial, identificando os principais desafios, fatores facilitadores e estratégias para a transição de modelos lineares para modelos circulares, por meio de uma revisão sistemática da literatura indexada na Web of Science entre 2017 e 2025. A pesquisa examina as dimensões tecnológicas, organizacionais e ambientais que influenciam a adoção

[1] Master's student in Administration. Pontifícia Universidade Católica de São Paulo (PUC-SP). São Paulo, Brazil. E-mail: bruno.pires@pacontabil.com.br
[2] Master's student in Administration. Pontifícia Universidade Católica de São Paulo (PUC-SP). São Paulo, Brazil. E-mail: glaucia.oliveira@pacontabil.com.br
[3] Master's student in Administration. Pontifícia Universidade Católica de São Paulo (PUC-SP). São Paulo, Brazil. E-mail: laistephany@yahoo.com.br
[4] Dr. in Communication and Semiotics. Pontifícia Universidade Católica de São Paulo (PUC-SP). São Paulo, Brazil. E-mail: bjoao@pucsp.br

de práticas circulares no setor farmacêutico. Os resultados mostram que as pressões de stakeholders externos, os sistemas de tecnologia da informação verde e a gestão ambiental interna são os principais facilitadores da circularidade. No entanto, barreiras significativas incluem a complexidade regulatória, limitações tecnológicas e desafios na logística reversa de produtos tóxicos. A análise revela que a indústria farmacêutica prioriza práticas de remanufatura e reutilização, enquanto a reciclagem permanece subdimensionada. O estudo contribui para o desenvolvimento teórico da EC no contexto farmacêutico e oferece insights práticos para gestores e formuladores de políticas públicas.

Palavras-chave: Economia Circular. Indústria Farmacêutica. Sustentabilidade. Análise Bibliométrica. Tendências Científicas.

RESUMEN

Este estudio analiza la implementación de la Economía Circular (EC) en la industria farmacéutica desde una perspectiva gerencial, identificando los principales desafíos, factores habilitadores y estrategias para la transición de modelos lineales a modelos circulares, mediante una revisión sistemática de la literatura indexada en Web of Science entre 2017 y 2025. La investigación examina las dimensiones tecnológicas, organizacionales y ambientales que influyen en la adopción de prácticas circulares en el sector farmacéutico. Los resultados muestran que las presiones de los grupos de interés externos, los sistemas de tecnologías de la información verde y la gestión ambiental interna son los principales facilitadores de la circularidad. Sin embargo, existen barreras significativas, como la complejidad regulatoria, las limitaciones tecnológicas y los desafíos en la logística inversa de productos tóxicos. El análisis revela que la industria farmacéutica prioriza las prácticas de remanufactura y reutilización, mientras que el reciclaje permanece subdimensionado. El estudio contribuye al desarrollo teórico de la EC en el contexto farmacéutico y ofrece aportes prácticos para gestores y responsables de políticas públicas.

Palabras clave: Economía Circular. Industria Farmacéutica. Sostenibilidad. Análisis Bibliométrico. Tendencias Científicas.

1 INTRODUCTION

The transition from linear to circular models represents one of the most promising approaches to mitigate environmental impacts and promote industrial sustainability (Sheldon, 2017; D'Amato, Veijonaho & Toppinen, 2020). In the pharmaceutical sector, this transition is particularly relevant due to the complexity of production processes, high waste generation, and the stringent regulatory requirements that characterize the industry (Ranjbari et al., 2022).

While the application of Circular Economy (CE) principles has been widely documented in sectors such as manufacturing, agriculture, and the chemical industry (Fisher et al., 2018; Chamorro et al., 2022), their integration into the pharmaceutical industry remains less explored, especially from the point of view of organizational management. This gap is particularly significant, given that CE implementation in the pharmaceutical sector faces specific barriers at the operational, strategic, and tactical levels, including technological, financial, political, stakeholder management, and reverse logistics challenges.

This study aims to analyze the managerial dimensions of CE implementation in the pharmaceutical industry, identifying the leading enablers, barriers, and strategies for the circular transition. The research contributes to the theoretical development of CE in the pharmaceutical context and offers *practical insights* for managers and policymakers.

2 LITERATURE REVIEW

2.1 CIRCULAR ECONOMY IMPLEMENTATION: THEORETICAL FOUNDATIONS AND EMPIRICAL EVIDENCE

The pharmaceutical industry faces escalating environmental sustainability issues, including gaseous emissions, waste generation, and excessive energy and non-renewable material consumption (Farrukh & Sajjad, 2025). Nevertheless, the adoption of sustainable business models, such as the circular economy (CE), is still in its infancy in this sector due to complex manufacturing and supply chain operations (Farrukh & Sajjad, 2025; Khan & Ali, 2022). This complexity is further compounded by the stringent regulatory requirements and the high-risk nature of pharmaceutical products, which necessitate careful consideration in any sustainability initiative.

Drawing on the Natural Resource-Based View (NRBV), Farrukh and Sajjad (2025) identified five significant CE practices in pharmaceutical supply chain management: green procurement, sustainable production, reverse logistics, sustainable distribution, and digitalization. Their multiple-case study approach, involving 18 semi-structured interviews with senior executives and corporate managers from four large pharmaceutical companies in

Pakistan, revealed that these practices are essential for reducing hazardous waste, improving environmental protection, conserving resources, and ensuring the responsible and safe disposal of medicines. This finding resonates with Chandra and Subashini's (2025) bibliometric analysis, which identified a significant shift in industry priorities toward green manufacturing, circular economy models, life cycle assessments, and the adoption of digital innovations such as IoT and blockchain to enhance supply chain sustainability.

The integration of CE principles into pharmaceutical operations represents more than an environmental imperative; it constitutes a strategic reconfiguration of value creation mechanisms. Chuang, Lee, and Liu (2022) examined pharmaceutical companies in the context of business model innovation (BMI), developing a sustainable business model (SBM) that conceptualizes BMI through three dimensions: technological, social, and organizational. Their research, conducted through purposive sampling across 12 companies, emphasized the evolution of innovations in SBM based on balanced scorecard principles, suggesting that successful CE implementation requires holistic organizational transformation rather than isolated operational adjustments.

2.2 SOCIO-POLITICAL DRIVERS AND ENABLERS OF CIRCULARITY

Understanding the drivers and enablers of CE adoption is critical for effective implementation. Sabat, Bhattacharyya, and Krishnamoorthy (2022) applied the stimulus-organism-response (SOR) theory to explore socio-political drivers and enablers of CE in the pharmaceutical industry. Their two-step research approach, interviewing eight industry practitioners followed by surveying 166 chiefs of production and operations functions from 124 pharmaceutical companies, revealed that pressure from suppliers and other public stakeholders was driving regenerative CE practices. The results further demonstrated that CE enablers, such as green information technology systems and internal environmental management, were critical to making pharmaceutical manufacturing operations circular.

This finding aligns with Khan and Ali's (2022) identification of enablers using fuzzy quality function deployment (FQFD), which ranked "industrial symbiosis," "reverse logistic infrastructure," and "blockchain technology" as the top-three enablers for circular supply chain management (CSCM) adoption in the pharmaceutical industry. The convergence of these findings across different methodological approaches strengthens the evidence base for prioritizing technological and collaborative enablers in CE implementation strategies.

Interestingly, Sabat et al. (2022) observed an overemphasis on remanufacture and reuse principles in the pharmaceutical industry, while the focus on recycling principles remained subdued. This imbalance suggests a strategic gap in CE implementation that

managers and regulators must address for more effective circularity. The emphasis on remanufacturing and reuse may reflect the industry's comfort with these practices within existing regulatory frameworks, whereas recycling pharmaceutical products poses greater technical and regulatory challenges.

2.3 BARRIERS TO CIRCULAR ECONOMY ADOPTION

Despite the identified enablers, the pharmaceutical industry faces substantial barriers to CE adoption. Khan and Ali (2022) identified ten barriers impeding CSCM adoption and used the fuzzy full consistency method (F-FUCOM) to prioritize them. Their results indicated that "lack of financial resources and funding," "market challenges," and "lack of coordination and collaboration among the entire supply chain network" constitute the top-most barriers. These findings are particularly significant as they highlight systemic challenges that extend beyond individual organizational capabilities.

Mahdiraji, Govindan, and Hajiagha (2023) provided complementary insights through their case study of the pharmaceutical industry in Iran's emerging economy, employing a systematic literature review followed by the Fuzzy-Delphi method to screen for challenges in CE- and eco-innovation (EI)-focused supply chain management. Their research represents one of the first papers to provide in-depth insights into the interactions between coordination contracts and the challenges of CE- and EI (eco-innovation)-focused pharmaceutical SCM for sustainability and resilience. Using the fuzzy version of SECA (Simultaneous Evaluation of Criteria and Alternatives), they concluded that cost-tariff, profit-sharing, cost-sharing, and revenue-sharing-commission mechanisms would be appropriate for addressing the inefficiencies in the main supply chain functions.

The regulatory complexity identified by Chandra and Subashini (2025) as a persistent challenge corroborates these findings. Their bibliometric analysis from 2015 to 2025 revealed that despite advances in sustainability research, the pharmaceutical sector continues to face challenges, including regulatory barriers, complex waste management, and inconsistent adoption of sustainable practices across regions. This suggests that barriers to CE adoption are not merely operational or financial but are deeply embedded in the institutional and regulatory context of pharmaceutical operations.

2.4 CLOSED-LOOP SUPPLY CHAINS AND INVENTORY MANAGEMENT

The operationalization of CE principles in pharmaceutical supply chains necessitates innovative approaches to inventory management and product flow. Suhandi and Chen (2023) developed a closed-loop supply chain inventory model for the pharmaceutical industry that

simultaneously addresses environmental, social, and economic sustainability. Their model focuses on recycling drugs to reduce the economic burden on patients (social sustainability) and prevent the waste of unused medications (environmental sustainability), while optimizing pharmacies' inventory decisions and government subsidies to achieve economic sustainability.

The closed-loop supply chain inventory model represents a practical application of CE principles that addresses multiple stakeholder concerns. Suhandi and Chen (2023) demonstrated the feasibility of drug recycling programs by examining the impact of government incentives on patient demand for recycled and new drugs and patients' willingness to use recycled drugs. Their non-linear programming model, solved using the generalized reduced gradient method, has theoretical implications for patient behavior and practical implications by examining the role of non-profit pharmacies in achieving maximum environmental and social benefits.

This work complements Farrukh and Sajjad's (2025) emphasis on reverse logistics as a critical CE practice. The integration of closed-loop systems requires not only technological infrastructure but also careful management of stakeholder perceptions, particularly regarding the safety and efficacy of recycled pharmaceutical products. The success of such initiatives depends on building trust among patients, healthcare providers, and regulatory authorities.

2.5 BIODIVERSITY AND ENVIRONMENTAL SUSTAINABILITY IN PHARMACEUTICAL SUPPLY CHAINS

An often-overlooked dimension of pharmaceutical supply chain sustainability is biodiversity risk management. Butt and Arshi (2025) addressed this gap through 48 semi-structured interviews with managers from triadic firms (six manufacturing, five supplying, and five distributing) in the pharmaceutical industry. Their research, grounded in Socioecological Systems (SES) theory, revealed specific practices that firms deploy to mitigate biodiversity risks: sustainable sourcing practices, robust monitoring and risk assessment, ecosystem restoration, development of new policies and frameworks, accountability through reporting, streamlining circular economy practices, and capacity building.

This extension of sustainability considerations to biodiversity represents a more comprehensive understanding of pharmaceutical supply chain impacts. Butt and Arshi (2025) demonstrated that biodiversity stewardship is essential to sustainable supply chain ecosystems and contributes to progress toward UN SDGs, particularly SDG 13 on climate action and SDG 15 on life on land. Their findings suggest that CE implementation in the

pharmaceutical industry must consider not only material flows and waste management but also the broader ecological impacts of sourcing and production activities.

The integration of biodiversity considerations with CE principles creates a more holistic framework for pharmaceutical sustainability. While Farrukh and Sajjad (2025) emphasized green procurement as a CE practice, Butt and Arshi (2025) deepened this understanding by specifying how procurement decisions affect biodiversity and how firms can mitigate these risks. This connection between circular economy practices and biodiversity protection represents an important frontier for pharmaceutical supply chain management research and practice.

2.6 STRATEGIC COORDINATION AND RESILIENCE IN CIRCULAR PHARMACEUTICAL SUPPLY CHAINS

The successful implementation of CE in pharmaceutical supply chains requires effective coordination mechanisms. Mahdiraji et al. (2023) innovatively employed game-theoretic coordination contracts (GTCCs) to address challenges in CE- and EI-focused pharmaceutical SCM. Their research identified that the "diamond category" of coordination mechanisms—including cost-tariff, profit-sharing, cost-sharing, and revenue-sharing commission—would be most appropriate for addressing supply chain inefficiency.

This focus on coordination mechanisms addresses the barrier identified by Khan and Ali (2022) regarding "lack of coordination and collaboration among the entire supply chain network." The use of game theory provides a rigorous analytical framework for understanding how different supply chain actors can align their incentives to support circular economy objectives. Mahdiraji et al.'s (2023) work suggests that moving beyond traditional transactional relationships toward more sophisticated coordination contracts is essential for achieving both sustainability and resilience in pharmaceutical supply chains.

The emphasis on resilience is particularly relevant in the pharmaceutical context, where supply chain disruptions can have severe public health consequences. The integration of CE principles with resilience objectives represents a strategic evolution from viewing sustainability as primarily an environmental concern to recognizing it as a core element of supply chain robustness and reliability.

2.7 DIGITAL INNOVATION AND BUSINESS MODEL TRANSFORMATION

The role of digital technologies in enabling CE implementation emerges as a consistent theme across multiple studies. Chandra and Subashini (2025) highlighted the adoption of digital innovations such as IoT and blockchain to enhance supply chain sustainability, while

Sabat et al. (2022) identified green information technology systems as critical enablers. Farrukh and Sajjad (2025) explicitly listed digitalization as one of the five significant CE practices in pharmaceutical supply chain management.

These technological enablers facilitate transparency, traceability, and real-time monitoring, which are necessary for effective circular supply chains. Blockchain technology, in particular, addresses trust and verification challenges in pharmaceutical supply chains, enabling secure tracking of products through multiple lifecycle stages. IoT sensors can monitor product conditions, track inventory levels, and provide data for optimizing reverse logistics operations.

However, integrating digital technologies requires corresponding business model innovation. Chuang et al. (2022) emphasized that sustainable business model innovation (SBMI) in the pharmaceutical industry must integrate technological, social, and organizational dimensions. Their framework suggests that digital technologies are most effective when embedded within comprehensive business model transformations that reshape value propositions, value creation processes, and value capture mechanisms.

2.8 SYNTHESIS: TOWARD AN INTEGRATED FRAMEWORK

The reviewed literature reveals a multifaceted landscape of CE implementation in the pharmaceutical industry, characterized by significant opportunities alongside substantial challenges. Table 1 synthesizes the key enablers and barriers identified across the reviewed studies, providing a comprehensive overview of factors affecting CE adoption.

Table 1

Synthesis of Enablers and Barriers for CE Implementation in the Pharmaceutical Industry

CE Practice Category. Lists the main Circular Economy practices identified in the pharmaceutical industry.	**Studies Identifying Practice. Indicates which authors mentioned/studied each specific practice, creating the "dialogue between authors."**	**Implementation Level. Evaluates the current level of implementation of each practice in the pharmaceutical industry. ---------- Low-Moderate (Little practical implementation) Moderate: (Medium implementation)**	**Research Gap. It identifies practice-specific research gaps – i.e., what still needs to be studied/developed.**

		Moderate-High: (Good implementation) High: (High implementation).	
Green Procurement	Farrukh & Sajjad (2025), Butt & Arshi (2025). Butt & Arshi brought the dimension of biodiversity that Farrukh & Sajjad did not explore deeply.	Moderate-High	Biodiversity integration. While green procurement is practiced, there is a lack of systematic integration of biodiversity considerations into purchasing decisions.
Sustainable Production	Farrukh & Sajjad (2025), Chuang et al. (2022). Chuang et al. developed the business model innovation framework that complements the practices identified by Farrukh & Sajjad	High	Process optimization metrics. There is a lack of standardized metrics to measure the optimization of sustainable processes.
Remanufacturing	Sabat et al. (2022). Sabat et al. identified overemphasis on remanufacturing; that is, the industry focuses heavily on it.	High	Quality assurance protocols. Lack of Consolidated Quality Assurance Protocols for Remanufactured Products
Reuse	Sabat et al. (2022), Suhandi & Chen (2023). Suhandi & Chen developed a mathematical model for reuse systems, but identified that patient acceptance is crucial.	Moderate-High	Patient acceptance barriers. There is a need better to understand the barriers to patient acceptance of reused medicines.
Recycling	Sabat et al. (2022), Suhandi & Chen (2023). This is the biggest problem identified: Sabat et al. explicitly state that the	Low-Moderate	Regulatory frameworks. There is a lack of regulatory frameworks that allow for the safe recycling of

	focus on recycling is "mostly subdued".		pharmaceutical products.
Reverse Logistics	Farrukh & Sajjad (2025), Khan & Ali (2022). Khan & Ali identified "RL infrastructure" as the 2nd most important enabler, complementing Farrukh & Sajjad	Moderate	Infrastructure development. Lack of physical and operational infrastructure
Digitalization	Farrukh & Sajjad (2025), Chandra & Subashini (2025). Chandra & Subashini did a bibliometric analysis showing the growth of IoT and blockchain, which Farrukh & Sajjad identified as a key practice.	Moderate	Integration challengers. Difficulties of integrating different digital systems
Sustainable Distribution	Farrukh & Sajjad (2025)	Moderate	Last-mile delivery optimization

The evidence suggests that successful CE implementation in pharmaceuticals requires: (1) technological enablers, including digital infrastructure and reverse logistics systems; (2) organizational capabilities in environmental management and cross-functional coordination; (3) external support through stakeholder pressure, government incentives, and collaborative networks; and (4) strategic coordination mechanisms that align incentives across supply chain partners.

Conversely, the barriers span multiple levels: (1) operational challenges, including financial constraints and technical complexity; (2) strategic issues such as business model transformation requirements; and (3) institutional factors, including regulatory complexity and market acceptance. The preponderance of evidence indicates that overcoming these barriers requires systemic interventions rather than isolated initiatives, emphasizing the need for policy support, industry collaboration, and continued innovation in both technology and management practices.

3 METHODOLOGY

This study adopts a bibliometric approach to systematically assess scientific output on the Circular Economy in the pharmaceutical industry. The Web of Science (WoS) Core Collection database was selected as the data source due to its academic rigor and extensive coverage of high-quality peer-reviewed journals across the fields of sustainability, engineering, management, and pharmaceutical sciences. The search strategy combined CE-related terms such as "circular economy," "circularity," "cradle to cradle," and "industrial symbiosis" with pharmaceutical-related terms including "pharmaceutical industr," "pharma," "drug production," and "API manufactur." Only peer-reviewed journal articles were included, and no temporal restrictions were applied. The final search was conducted on 19 August 2025.

After obtaining the dataset, bibliometric analyses were conducted using the Bibliometrix package and its Biblioshiny web interface. These tools enabled the identification of term frequencies, co-occurrence networks, keyword clusters, thematic evolution, and citation patterns. The bibliometric mapping identified dominant research streams and underexplored areas relevant to managerial CE implementation. Articles were screened to ensure relevance to organizational, managerial, technological, or supply chain perspectives related to CE. Studies focused mainly on chemical extraction, analytical chemistry, or biotechnological processes without explicit links to CE management or strategic circular practices were excluded to maintain the analytical focus on organizational transformation.

Although bibliometric methods offer an effective way to synthesize large bodies of literature, they have limitations. Relying exclusively on the WoS database may exclude relevant studies published in regional journals or indexed in other databases such as Scopus or PubMed. Moreover, bibliometric analysis cannot capture the full qualitative nuance of managerial practices or contextual differences across countries. Despite these limitations, the method provides a robust, systematic foundation for identifying research patterns and strategic themes, which are further elaborated in the narrative synthesis presented in the following sections.

The data for the present research were obtained from the Web of Science (WoS) bibliographic database. The search considered, for topic, ("circular economy" OR circularity OR "cradle to cradle" OR "industrial symbiosis") AND ("pharmaceutical industr*" OR pharma* OR "drug production" OR "API manufactur*"), only "articles", without a time limit. The search was conducted on 19 August, 2025.

The data were analyzed using bibliometric techniques in the Bibliometrix software via the Biblioshiny interface, allowing the identification of frequent terms, co-occurrence patterns,

and thematic groupings. The content analysis was quantitative, being conducted from the structure of the keyword network to identify patterns and trends in searches on CE in the pharmaceutical sector.

5 RESULTS AND DISCUSSION

5.1 BIBLIOMETRIC MAPPING AND EMERGING TRENDS

The bibliometric analysis of scientific production between 2017 and 2025 reveals the predominance of the terms *extraction* (72) and *antioxidant activity* (70), signaling the recurrent focus on obtaining and characterizing bioactive *compounds*. In the background, the terms *phenolic compounds* (53), *optimization* (51), and circular economy (51) stand out, indicating a growing integration of process efficiency, the functionality of natural ingredients, and sustainability principles. There was significant growth in these themes between 2021 and 2022, with their incidence practically doubling in the *corpus* analyzed (Table 2).

Table 2

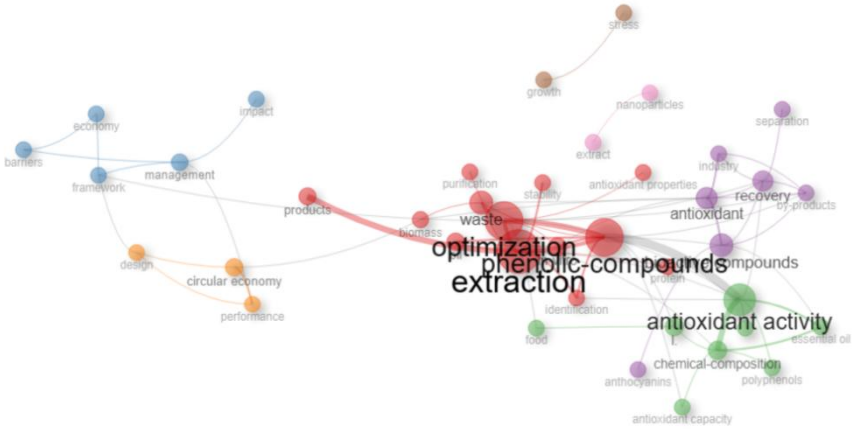
Frequency of the Main Terms in the Literature (2017-2025)

Term	Frequency	Percentage
Extraction	72	18,5%
Antioxidant activity	70	18,0%
Phenolic compounds	53	13,6%
Optimization	51	13,1%
Circular economy	51	13.1%
Waste	45	11,5%
Management	38	9,8%
Framework	35	9,0%

The analysis of the network of co-occurrence of scientific terms shows the main thematic axes structured in distinct *clusters*: *Red Cluster*: Concentrates terms related to technical and laboratory processes (*waste*, *purification*, *biomass*). Green *Cluster: Brings together concepts related to chemical composition and bioactivity (*chemical composition, antioxidant activity, polyphenols*).Blue and Orange Clusters*: Organize managerial themes (*management*, *circular economy*, *framework*). Pink and Purple *Clusters*: Point to specific research branches (nanoparticles, recovery) (Figure 1).

Figure 1

Keyword co-occurrence network

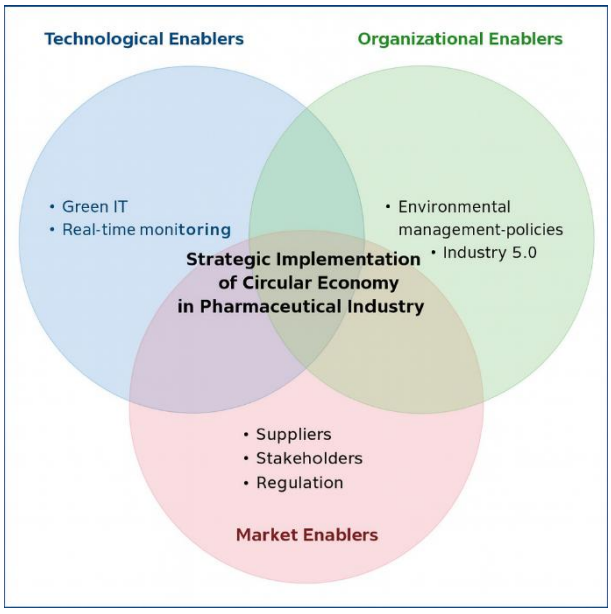


Source: Prepared by the authors based on the Bibliometrix software (2025).

The implementation of CE practices in the pharmaceutical industry is driven by several organizational and technological enablers (Sabat, Bhattacharyya & Krishnamoorthy, 2022). The analysis reveals that pressures from suppliers and public stakeholders constitute the main socio-political drivers for the adoption of regenerative CE practices (Figure 2).

Figure 2

CE Enabler Framework in the Pharmaceutical Industry



Source: Prepared by the authors

The study by Sabat, Bhattacharyya, and Krishnamoorthy (2022) identifies barriers to CE transition in pharmaceutical companies, categorized into operational, strategic, and tactical levels, with the main barriers related to technology, finance, policies, *stakeholder* management, and reverse logistics, particularly for toxic products.

Implementing circular pharmaceutical supply chains (CPSC) requires integrated strategies that cover everything from product design to waste management. The sustainability of the pharmaceutical industry is a topic of growing interest, with reducing waste in the supply chain a central aspect.

Strategies identified may include the redistribution of unused but still valid medicines; the sharing of real-time data through the implementation of technologies to monitor expiration dates and demand; and integrated reverse logistics, with the development of efficient systems for the collection and processing of pharmaceutical waste.

Industry 5.0 presents opportunities to optimize processes, reduce waste, improve resource utilization, and enable real-time monitoring and decision-making in the supply chain. The convergence between Industry 5.0 (Agrawal, Sharma & Sarkar, 2025) and CE strategies offers significant potential for transformation of the pharmaceutical sector, including smart monitoring, i.e. IoT systems for product tracking and identification of circularity opportunities; predictive analysis with the use of *big data* to optimize demand and reduce waste and, finally, process automation, with the implementation of automated systems for classification and redistribution of products.

The findings suggest that the successful implementation of CE in the pharmaceutical industry requires a holistic managerial approach that integrates technological, organizational, and regulatory considerations. Managers should therefore prioritize inter-organizational development through strategic partnerships along the supply chain; the development of core competencies, specifically in environmental management systems and in sustainability and innovation; and the adoption of emerging technologies to enable circularity practices.

Another key issue is the need for supportive government policies as a critical enabler for the circular transition. This can be done through tax incentives for adopting CE practices, the development of robust digital infrastructure, the simplification of regulatory processes for circular products, and the establishment of standards and metrics for the circular economy.

For the issue of circular supply chains (Tsolakis & Srai, 2018), these require a fundamental reconfiguration of traditional operating models, such as implementing end-to-end tracking systems, developing capacities for multiple material flows, and strengthening partnerships with suppliers and *stakeholders*.

This study has limitations related to the temporal scope of the analysis and the concentration on publications in English. Future research can explore: longitudinal studies on CE implementation in the pharmaceutical sector; comparative analyses across different geographic regions; the development of specific metrics for pharmaceutical circularity assessment; and, finally, research on emerging circular business models in the pharmaceutical sector.

6 CONCLUSIONS

This study reveals that CE implementation in the pharmaceutical industry is at an emerging stage, with accelerated growth in academic interest, particularly between 2021 and 2022. The bibliometric analysis shows convergence between technical-scientific approaches and sustainability strategies, demonstrating alignment with the Sustainable Development Goals (UN, 2023), particularly SDGs 9 and 12.

Key enablers identified include stakeholder pressures, green information technology systems, and internal environmental management, while barriers focus on technological, financial, and regulatory aspects. The industry emphasizes remanufacturing and reuse practices, with significant opportunities to develop recycling strategies.

The integration of Industry 5.0 and CE strategies offers transformative potential for the sector, enabling real-time monitoring, process optimization, and substantial waste reduction. For managers and policymakers, the findings indicate the need for integrated approaches that account for the regulatory and operational specifics of the pharmaceutical sector.

The theoretical contribution of this work lies in the systematization of the managerial dimensions of the pharmaceutical CS, offering *a conceptual framework* for future investigations. From a practical perspective, the study provides actionable insights for implementing circular strategies, thereby contributing to the construction of a more sustainable and efficient pharmaceutical ecosystem.

The pharmaceutical industry stands at a critical juncture in its sustainability journey. The evidence synthesized in this review demonstrates both the necessity and feasibility of circular economy transformation, while acknowledging substantial challenges that remain. Success requires coordinated action across multiple fronts: technological innovation, organizational capability development, supply chain collaboration, regulatory reform, and financial resource mobilization.

The convergence of findings across diverse studies, methodologies, and geographical contexts provides a robust evidence base for action. Pharmaceutical companies that proactively embrace CE principles, invest in enabling technologies and capabilities, and

engage constructively with stakeholders and regulators will be well-positioned for competitive advantage in an increasingly sustainability-conscious global marketplace.

For researchers, the field offers rich opportunities for theoretical development, methodological innovation, and practical contribution. The research gaps identified in this review provide a roadmap for future investigation that can advance both academic understanding and practical implementation.

Ultimately, pharmaceutical CE represents more than an environmental imperative or regulatory compliance requirement—it constitutes a strategic opportunity to create value through innovation, differentiation, and leadership in sustainable healthcare. The transition from linear to circular models in this essential industry carries implications for environmental protection, resource conservation, public health, and sustainable development more broadly. The evidence reviewed here suggests that while challenges are substantial, the path forward is increasingly clear, and the time for decisive action is now.

REFERENCES

Agrawal, A., Sharma, A., & Sarkar, B. (2025). Business strategies for sustainable development: Leveraging Industry 5.0 and circular pharmaceutical supply chains to overcome medicine waste. Business Strategy and the Environment, 34(4), 4291–4311. https://doi.org/10.1002/bse.4202

Butt, A., & Arshi, T. (2025). Mitigating biodiversity risks to achieve sustainable development in supply chains: A socioecological systems theory perspective. Sustainable Development. https://doi.org/10.1002/sd.70510

Chamorro, M., Pérez, J. F., Hernández, M., & Barrera, M. (2022). Circular economy in the chemical industry: Progress and future perspectives. Journal of Cleaner Production, 351, 131532. https://doi.org/10.1016/j.jclepro.2022.131532

Chandra, N., & Subashini, R. (2025). Mapping the landscape of sustainable development in the pharmaceutical industry: A bibliometric analysis. Discover Sustainability, 6(1). https://doi.org/10.1007/s43621-025-02010-1

Chuang, L., Lee, Y., & Liu, T. (2022). Towards sustainable business model innovation for the pharmaceutical industry. Sustainability, 14(18). https://doi.org/10.3390/su141811760

D'Amato, D., Veijonaho, S., & Toppinen, A. (2020). Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs. Forest Policy and Economics, 110. https://doi.org/10.1016/j.forpol.2018.12.004

Farrukh, A., & Sajjad, M. (2025). A natural resource-based view of circular economy practices in the pharmaceutical industry. Business Strategy and the Environment. https://doi.org/10.1002/bse.70413

Fisher, R., Charnley, F., & Pope, R. (2018). Mapping the design space of circular economy business models. Journal of Cleaner Production, 197, 1441–1453. https://doi.org/10.1016/j.jclepro.2018.06.297

Khan, F., & Ali, Y. (2022). Implementation of the circular supply chain management in the

pharmaceutical industry. Environment, Development and Sustainability, 24(12), 13705–13731. https://doi.org/10.1007/s10668-021-02007-6

Mahdiraji, H., Govindan, K., Yaftiyan, F., Garza-Reyes, J., & Hajiagha, S. (2023). Unveiling coordination contracts' roles considering circular economy and eco-innovation toward pharmaceutical supply chain resiliency: Evidence of an emerging economy. Journal of Cleaner Production, 382. https://doi.org/10.1016/j.jclepro.2022.135135

United Nations. (2023). Transforming our world: the 2023 Agenda for Sustainable Development. https://sdgs.un.org/2030agenda

Ranjbari, M., Esfandabadi, Z. S., Jafari, S., & Rashidi, M. (2022). Three decades of research on waste management in the pharmaceutical industry: A bibliometric and thematic analysis. Journal of Environmental Management, 302, 113988. https://doi.org/10.1016/j.jenvman.2021.113988

Sabat, K., Bhattacharyya, S., & Krishnamoorthy, B. (2022). Circular economy in pharmaceutical industry through the lens of stimulus organism response theory. European Business Review, 34(6), 936–964. https://doi.org/10.1108/EBR-02-2022-0037

Sheldon, R. A. (2017). The E factor 25 years on: The rise of green chemistry and sustainability. Green Chemistry, 19(1), 18–43. https://doi.org/10.1039/C6GC02157C

Suhandi, V., & Chen, P. (2023). Closed-loop supply chain inventory model in the pharmaceutical industry toward a circular economy. Journal of Cleaner Production, 383. https://doi.org/10.1016/j.jclepro.2022.135474

Tsolakis, N., & Srai, J. (2018). Mapping supply dynamics in renewable feedstock-enabled industries: A systems theory perspective on "green" pharmaceuticals. Operations Management Research, 11(3–4), 83–104. https://doi.org/10.1007/s12063-018-0134-y