FAIMA Business & Management Journal is indexed in international databases: ProQuest, ERIH PLUS, Index Copernicus and Google Scholar.

PUBLISHER
POLITEHNICA Press – National University of Science and Technology POLITEHNICA Bucharest, Romania

POLITEHNICA Press
ISSN 2344-4088 Address: 313 Splaiul Independentei, 060042, Bucharest, Romania
ISSN-L 2344-4088 Tel: (+40) 21 402 9074 e-mail: politehnicapress@upb.ro

CONTENTS

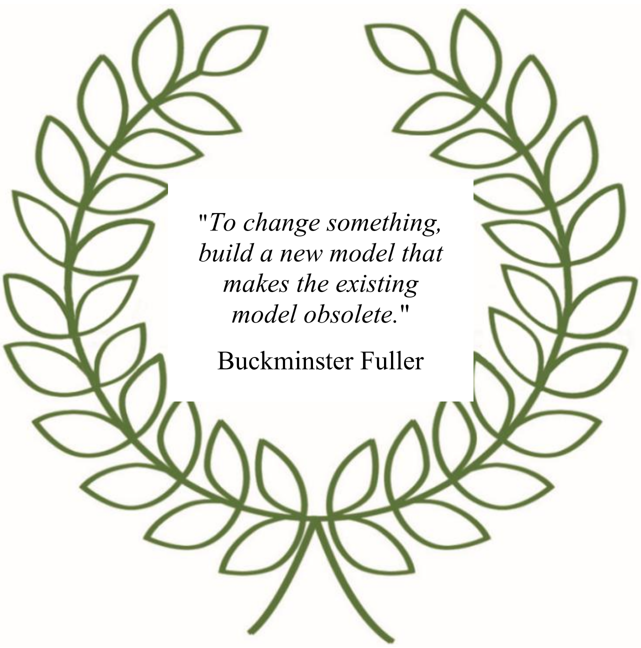
EDITORIAL

A New Framework for Creating Value

The traditional linear model of "take, make, use, and dispose" has long been the default logic of industrial economies. For most of the twentieth century, it worked - or at least, its costs were diffuse enough to remain invisible. Today, that is no longer the case. Resource scarcity, supply chain fragility, and accelerating environmental degradation have made the structural limits of linearity impossible to ignore. Organizations that continue to treat these pressures as external variables - to be managed through incremental efficiency gains — are underestimating the depth of the challenge.

Sustainability, for much of its corporate history, occupied an uncomfortable position: acknowledged in annual reports, rarely integrated into strategy. That separation is becoming harder to maintain. Across sectors, circularity is increasingly understood not as a constraint, but as a different framework for creating and sustaining value — one built around designing out waste, extending the productive life of materials and products, and regenerating rather than depleting natural systems. The shift in framing matters: what was once treated as an environmental obligation is being reconsidered as a source of long-term competitive advantage.

The operational transition, however, is anything but straightforward. Circularity requires changes at multiple levels simultaneously - in product design, supply chain architecture, business models, and customer relationships. Emerging technologies such as AI, IoT-based asset tracking, and advanced material science are making closed-loop systems increasingly viable, but they are enabling conditions, not solutions in themselves. The organizations that struggle most with circular transitions tend to do so not because of technical limitations, but because the organizational and cultural dimensions of change are underestimated. Moving toward "product-as-a-service" models, for instance, is not merely a commercial adjustment - it reconfigures incentive structures, performance metrics, and the very logic of how value is exchanged with customers.



This is where leadership becomes a decisive variable. Circular transformation demands a capacity for cross-functional alignment, tolerance for ambiguity, and a genuinely long-term orientation - qualities that are difficult to cultivate in organizations still rewarded primarily for short-cycle returns. Regulatory developments, including the European Green Deal, are compressing the timeline for many of these decisions, but compliance alone is a weak foundation for transformation. The more durable motivation is strategic coherence: building organizations that are structurally less exposed to resource volatility and better positioned to adapt as both markets and ecosystems continue to shift.

Ultimately, the circular economy represents something more than a set of operational practices. It is a different way of thinking about what economic activity is for — and what it costs, not only financially, but systemically. For organizations willing to engage with that question seriously, it remains one of the more consequential strategic conversations of the decade.

Olga BUCOVETCHI
Guest Editor

"*If you don't like change, you're going to like irrelevance.*"

Eric Shinseki

The Circular Approach of Strategic Resource Management

Alin-Iulian FRINCU[1*], Cristina-Maria BATUSARU[2], Dorel BADEA[2]

[1] Bucharest University of Economic Studies, 6 Piata Romana, Bucharest, Romania

[2] Nicolae Balcescu Land Forces Academy, 3 Revolutiei, Sibiu, Romania

Abstract

The intersection of military operations and circular economy principles has become a strategically significant research domain, particularly in the context of resource security and defense sustainability. This study presents a bibliometric analysis of 410 documents published between 2015 and 2025, retrieved from the Scopus and Web of Science databases and merged after removing duplicates. The analysis was conducted using the Bibliometrix R package through the Biblioshiny interface and examines publication trends, geographic contributions, thematic clusters and conceptual evolution. Through a thematic analysis of the subject area, economic development, military and renewable energy were identified as the core motor themes. The findings can provide evidence to support the development of strategies for military resource resilience for defense policymakers and sustainability research.

Keywords: circular economy, military sustainability, security resources

Introduction

The scope of global security issues has now moved beyond conventional military threats to include issues of resource scarcity, energy dependence and climate change. The circular economy emerged in this new arena as a strategic framework applicable to not just civilian industries, but also Armed Forces and Defence Agencies worldwide. The Ellen MacArthur Foundation (2013) has defined the circular economy as *an industrial model designed to maintain products, components, and materials at*

"Buy less, choose well."
Vivienne Westwood

*Correspondence to Alin-Iulian FRINCU: frincualiniulian@gmail.com

their maximum utility and value as long as possible. There are numerous opportunities for improving military operational resilience, and long-term sustainability, while making use of the circular economy.

The world's largest consumers of energy, materials and water include military establishments. The logistics involved in providing fuel, food, construction materials and other items to support operations in active operational environments creates tactical vulnerabilities to adversaries (Marqusee et al., 2017). Many countries have examined circular economy approaches to reduce supply chain reliance and operational footprint as well as increase the life cycle of military assets (NATO, 2021; U.S. Department of Defense, 2022).

Though there is a pressing need for applying circular economy principles to military operations, existing academic literature on this topic remains insufficiently mapped and appeared as a fragmented body of work. The current research pertaining to this subject is spread throughout a variety of disciplines (defense studies, environmental science, operations research and sustainability science) with no systematic overview of the intellectual structure, thematic focus, or evolutionary path of the field. In this study, a bibliometric analysis of 410 documents from the Scopus and the Web of Science Core Collection, published between 2015-2025, will be is conducted to provide the necessary information.

The research is guided by four objectives: (1) to assess the temporal evolution of scientific production; (2) to identify the most relevant sources and contributing countries; (3) to map the conceptual and thematic structure of the literature; and (4) to trace the evolution of key themes over time. By providing a structured overview of existing scholarship, the study contributes to academic debates and highlights underexplored topics that need further investigation.

Previous notable studies have examined aspects of this intersection. Geissdoerfer et al. (2017) provide a fundamental explanation of circular economy concepts that are relevant to all industries. According to Walker et al. (2020), a strategic weakness in defence operations is energy reliance. Despite the lack of a cohesive bibliometric synthesis, these contributions collectively demonstrate that the subject is continually evolving.

Methodology of research

This study employs a bibliometric research design, combining performance analysis with science mapping techniques. Bibliometric methods are appropriate for mapping large, interdisciplinary research fields and enable systematic identification of publication trends, influential contributors and conceptual clusters (Donthu et al., 2021; Aria and Cuccurullo, 2017).

Data Collection and Processing. The Web of Science (WoS) Core Collection and Scopus (Elsevier), two complementary bibliographic databases, provided the dataset. To provide a thorough capture of the research field a tailored Boolean query organised around three main subject pillars was used to explore both databases.

The search string combined sustainability and circularity concepts ("circular economy" OR "sustainability" OR "resource efficiency") with the military institutional context ("military" OR "armed forces" OR "defence sector" OR "defense industry"), further refined by operational and resource-specific keywords ("supply chain" OR "logistics" OR "materials" OR "waste" OR "energy"). The search was applied to the title, abstract, and author keyword fields, restricted to English-language documents published between 2015 and 2025.

Records from both sources were exported in BibTeX format and merged into a single dataset using the Bibliometrix R package. Duplicate records, identified by matching DOIs were systematically removed. The final cleaned dataset comprises 410 unique documents. All analyses were performed using the Biblioshiny graphical interface, which facilitated the generation of performance indicators, co-occurrence networks, thematic maps, and growth projections.

Dataset Descriptive Overview. The primary bibliometric indicators of the examined corpus are shown in Figure 1. The dataset comprises contributions from 1,732 writers spread across 259 different publication sources over a ten-year period (2015–2025). A strong collaborative focus in this field of study is confirmed by the comparatively modest percentage of single-authored documents (33 out of 410). This pattern is further supported by the average of 4.68 co-authors per document and the worldwide co-authorship rate of 29.76%. Thematic breadth is attested to by the 1,769 unique author keywords, and increasing academic importance is indicated by the average citation rate of 18.85 per item. The field is growing quickly, as seen by its 29.61% annual growth rate.

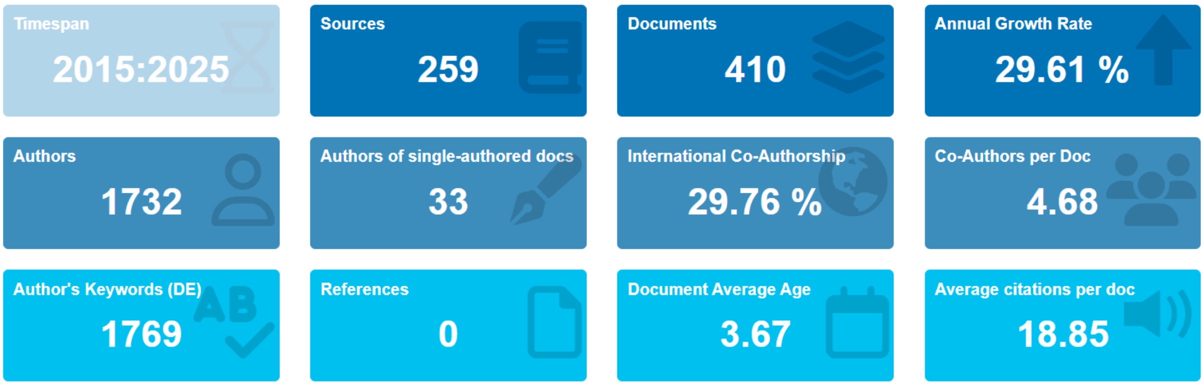


Figure 1 – *Overview of Bibliometric Dataset*

Analytical Techniques. The study integrates the following bibliometric techniques:

- Annual Scientific Production – to assess temporal growth and identify acceleration phases.
- Life Cycle Analysis – to model logistic growth and project peak publication volume and saturation.
- Most Relevant Sources – to identify journals with the highest contribution to the field.
- Corresponding Authors' Countries – to analyze geographic distribution including Single Country Publications (SCP) and Multiple Country Publications (MCP).
- Most Cited Countries – to assess citation-based geographic impact.
- Word Cloud and Co-occurrence Network – to explore keyword frequency and semantic relationships.
- Thematic Mapping – to classify research themes into four quadrants: motor themes, niche themes, basic themes and emerging or declining themes.

Results and Discussion

Publication Dynamics. A consistent increase in the number of articles published is evident when analyzing the temporal distribution of the publication during this period. As illustrated in Figure 2, the number of annual publications increased from 8 in 2015 to 107 by 2025, representing more than a 13-fold increase in output over this 11-year period.

The period 2015–2019 saw very limited growth with fewer than 20 articles published annually. However, since 2020, there has been a dramatic increase or acceleration in the rate of publication. This inflection point in publication output occurred around the same time that several related policy developments became evident, including: an increasing recognition among the NATO member countries about the importance of sustainability in their defence postures; a growing global focus on creating sustainable energy systems as part of achieving their post-Paris Agreement climate goals, and continued efforts to enhance the use of renewable energy for powering military bases. Also, the interest in circular and closed-loop resource strategies has grown as a result of the disruption created by the COVID-19 pandemic. The COVID-19 pandemic created structural catalysts for resource security issues, thereby prioritising them on both policy and scholarly agendas (Amankwah-Amoah et al., 2021).

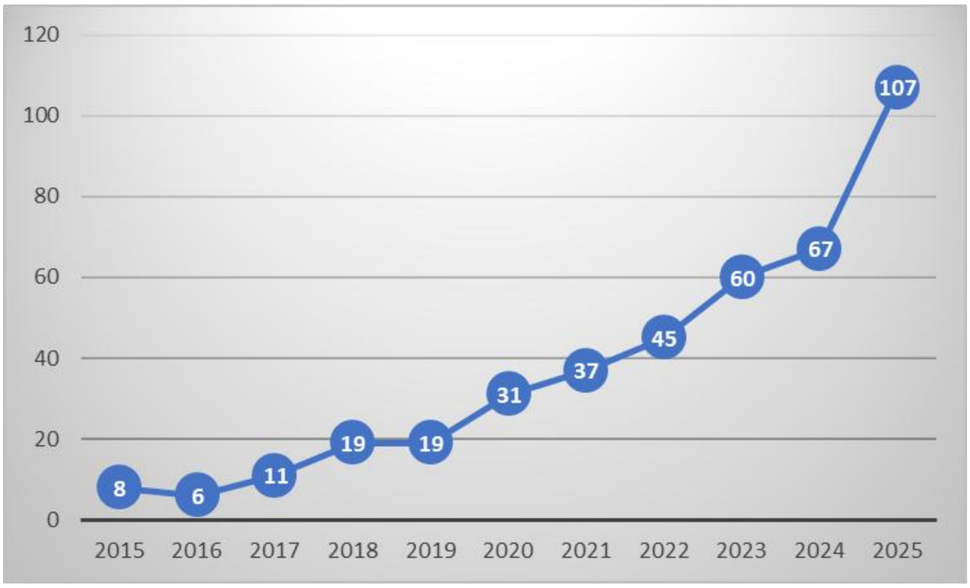


Figure 2 – *Annual Scientific Production (2015–2025)*

Life Cycle of Domain. Figure 3 presents a projected research life cycle for Circular Economy applications within military and security contexts, modelled using a logistic growth curve. The observed data indicate a rapid acceleration in scholarly output over recent years, reflecting heightened academic and institutional interest.

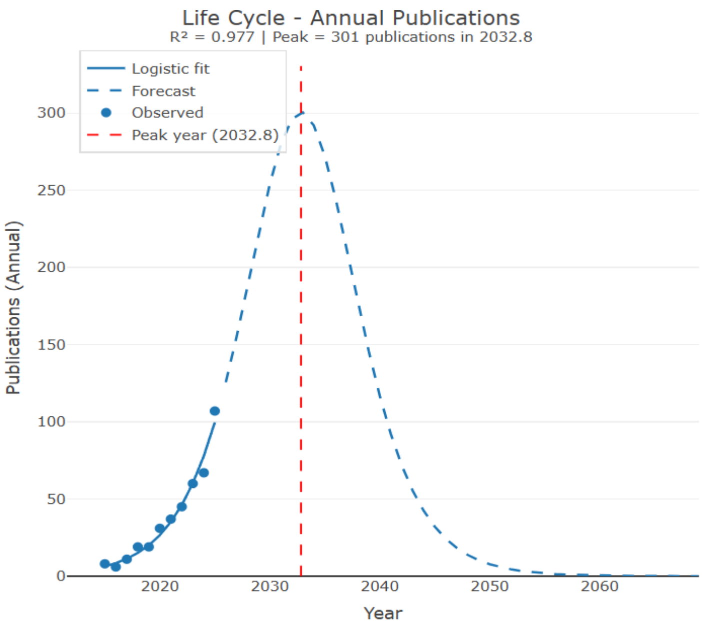


Figure 3 – *Research life cycle projection for Circular Economy in military and security contexts*

By utilizing the logistic growth model to analyze the dataset, it was determined that there is an exceptionally good fit with the data ($R^2 = 0.977$) indicating that this field follows the traditional S curve trajectory. This analysis also predicts that publication rates each year will reach a maximum of about 301 documents during the years 2032-2033 and the expected total saturation level (K) for this field will be close to 4,100 publications. Based on current levels of production in this area, 50% saturation will occur late in the 2020's which means that future research in this field will continue to produce higher levels of research output at greater levels of sophistication. Understanding this life cycle is of great importance for researchers, policymakers and defense organizations. It provides insights into the maturity of the field, helps identify optimal timing for investment and collaboration, and supports strategic planning for sustainable transformation within military and security operations.

Most Relevant Sources. The analysis of publication sources reveals a strong concentration around sustainability-oriented journals. The journal Sustainability is popular with 70 things published which is about 17 percent of everything we looked at. This reflects that is probably as most people doing research in this area are thinking about how to make organizations like the work better with the resources they have.

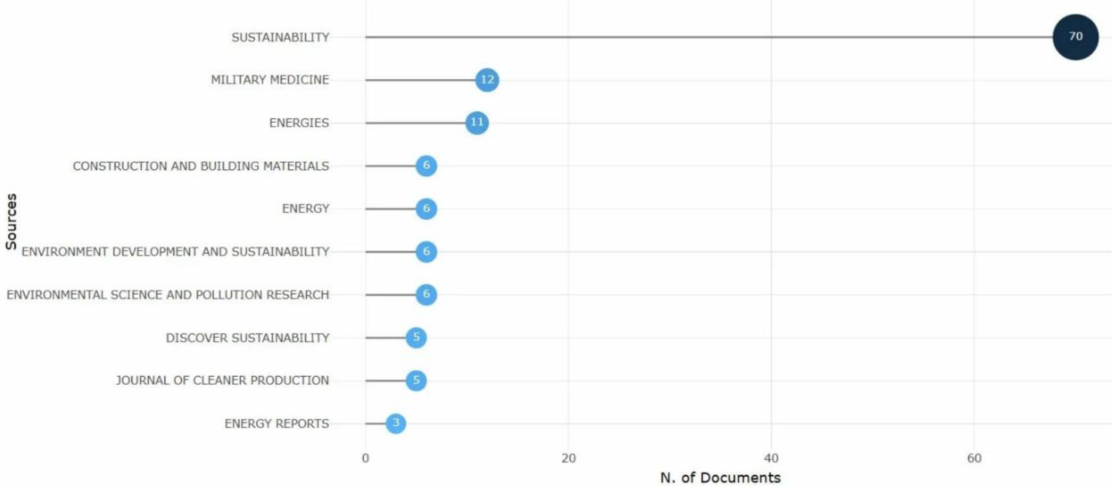


Figure 4 – *Ranking of most relevant sources by document volume*

The next popular place is Military Medicine with 12 things published and then Energies with 11 things published. The presence of Military Medicine indicates that circular economy themes have been explored in health and medical supply chain contexts within defence. Energies reflect significant attention to energy transition and renewable energy in military settings. Construction and Building Materials, Energy, Environment Development and Sustainability and Environmental Science and Pollution Research each contribute 6 documents. The breadth of these venues confirms the interdisciplinary character of the field, while also pointing to a degree of fragmentation across disciplinary communities.

Geographic Distribution of Research. The geographic analysis reveals a clear concentration of research activity in major global powers. Table 1 presents the top countries by publication count, together with Single Country Publications (SCP), Multiple Country Publications (MCP) and corresponding collaboration rates.

The United States leads with 61 documents (14.9% of the total) and a relatively low MCP rate (13.1%), consistent with the sensitive or strategically proprietary nature of some defense-related research. China follows with 56 documents (13.7%) and a notably higher MCP rate (30.4%), indicating greater integration into international research networks. Poland (23 documents) and Korea (19 documents) emerge as significant contributors from outside the traditional anglophone centers. Poland's presence likely reflects its strategic position within NATO and sustained investment in military modernization and energy security, while Korea's contribution corresponds to its advanced defense industry and leadership in renewable energy technology.

Tabel 1 – *Top 12 countries by Scientific Production and Collaboration Indicators*

Country	Articles	Articles %	SCP	MCP	MCP %
USA	61	14.9	53	8	13.1
China	56	13.7	39	17	30.4
Poland	23	5.6	19	4	17.4
Korea	19	4.6	16	3	15.8
India	18	4.4	15	3	16.7
Turkey	15	3.7	15	0	0.0
Ukraine	14	3.4	7	7	50.0
United Kingdom	11	2.7	6	5	45.5
Bangladesh	9	2.2	6	3	33.3
Canada	9	2.2	3	6	66.7
Italy	9	2.2	4	5	55.6
Saudi Arabia	7	1.7	2	5	71.4

Ukraine (14 documents, MCP 50%) displays intensive international collaboration, particularly relevant given recent geopolitical developments that have placed military resource resilience at the center of national and allied policy. Canada (MCP 66.7%), Italy (MCP 55.6%) and Saudi Arabia (MCP 71.4%) contribute primarily through internationally co-authored publications, suggesting that these countries participate in the field chiefly via joint research programs.

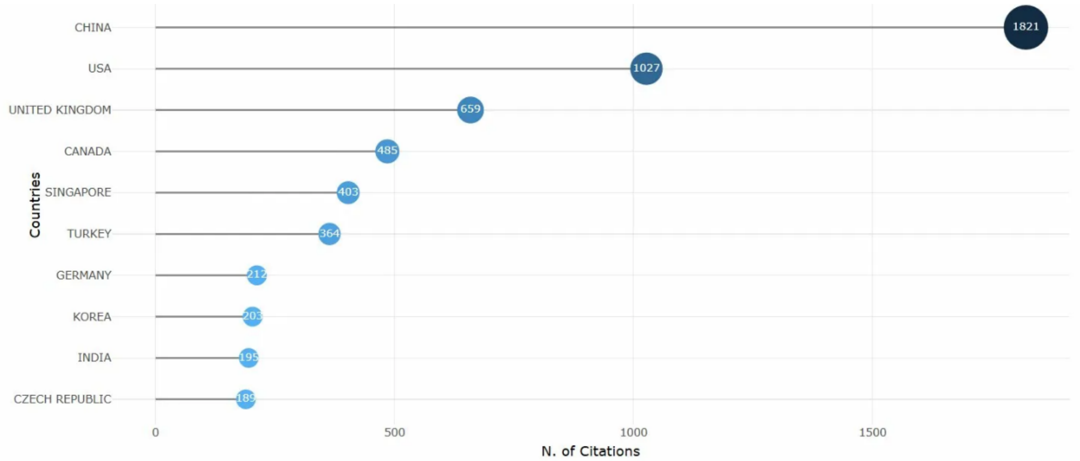


Figure 5 – *Most cited countries*

The citation impact analysis (Figure 5) reveals a partially different ordering. China leads with 1,821 total citations, followed by the United States (1,027), the United Kingdom (659) and Canada (485). Notably, Singapore (403 citations) and the Czech Republic (189 citations) achieve disproportionately high citation impact relative to their publication volumes, suggesting that focused, high-quality contributions can accumulate significant influence independent of overall output scale.

Conceptual Structure: Keywords and Co-occurrence Analysis. The word cloud constructed from author keywords (Figure 6) provides a first-order cartography of the conceptual landscape of the field, with the visual weight of each term proportional to its frequency of occurrence across the corpus. The term sustainability dominates the visual field by a considerable margin, appearing in a large, bold typeface that distinguishes it unambiguously from all other concepts. This dominance reflects the overarching theoretical lens through which research at the intersection of military operations and circular economy is consistently framed. Military circular economy is primarily understood in literature as a dimension of organizational and systemic sustainability rather than as an isolated engineering or logistical challenge.

The second tier of prominence belongs to performance, rendered in a similarly large typeface. The juxtaposition of sustainability and performance in the word cloud is analytically significant and captures a central tension in the literature: the question of whether circular economy strategies are compatible with, or even supportive of, operational effectiveness. Studies in this strand examine whether resource efficiency measures reduce, maintain or enhance military readiness, and several contributions argue that circular approaches, particularly in energy management and equipment lifecycle extension, can simultaneously reduce costs and improve mission capability (Marqusee et al., 2017; Walker et al., 2020).

Figure 6 – *Word Cloud Analysis*

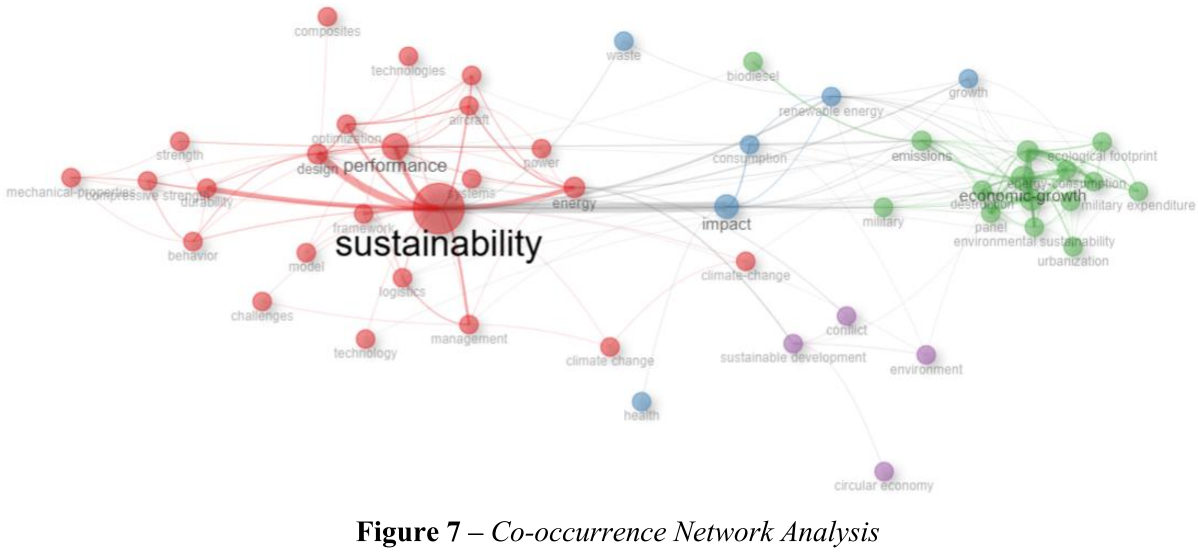


Figure 7 – *Co-occurrence Network Analysis*

The co-occurrence network (Figure 7) moves beyond frequency to reveal the relational architecture of the field. The network confirms the word cloud's prominence hierarchy while adding critical structural information about the organization of the field. The network is organized around four distinct clusters, identified by colour, each representing a coherent thematic subdomain with a characteristic set of internal linkages.

The red cluster is by far the largest and most densely connected in the network. Sustainability occupies the position of central hub with thick red edges radiating outward to performance, design, optimization, framework, systems, technologies, aircraft, logistics, management, model, behaviour, challenges, technology, mechanical-properties, composites, compressive strength, durability and strength, among others. The density of internal linkages in this cluster indicates that these terms co-occur with very high frequency within the same documents. The link between sustainability and energy, which serves as the primary bridge to the blue cluster confirms that the transition between circular design thinking and energy security concerns is a well-trafficked intellectual pathway in the corpus.

The blue cluster is anchored by the terms: energy, consumption, renewable energy, waste, biodiesel and health, with a secondary node representing climate-change. This cluster captures an energy and environmental management strand of the literature, focused on the flows of energy and materials within and around military operations. Health, positioned at the lower boundary of this cluster, likely represents research on the health implications of military energy use, pollution from defence activities, or the health dimensions of green base management. This structural centrality confirms the argument, advanced by multiple authors in the corpus, that energy security is the single most important driver of military circular economy adoption, linking material sustainability practices on one side to macroeconomic and geopolitical considerations on the other.

The green cluster organizes itself around economic-growth as its dominant node. The cluster includes emissions, military, military expenditure, ecological footprint, energy-consumption, environmental sustainability, urbanization, panel, destruction and growth. The presence of panel together with economic-growth and military expenditure strongly signals that this cluster is defined by panel data econometric studies that examine the relationship between defence spending, carbon emissions and economic performance at the country level, a well-established research tradition in military environmental economics. The co-occurrence of ecological footprint with military and military expenditure reflects the growing literature quantifying the ecological cost of armed forces at national and global scales.

The purple cluster, smaller and more peripheral, groups conflict, environment, sustainable development and circular economy. The positioning of this cluster at the lower periphery of the network, with relatively thin connecting edges to the other three clusters, indicates that it represents an emerging or specialized strand that is gaining visibility but has not yet achieved deep integration with the dominant research communities.

Taken together, the word cloud and the co-occurrence network tell a coherent story about the conceptual architecture of the field. The field is anchored by a large, internally diverse but well-integrated red cluster centred on sustainability, performance and design; connected through energy as a structural bridge to an energy and materials management community; linked through emissions and economic growth to a macroeconomic and policy analysis community; and tangentially connected to an emerging conflict-ecology community that brings circular economy principles into direct contact with geopolitical and security dynamics.

Thematic Map: Research Maturity and Positioning. The thematic map (Figure 8) classifies research themes according to their relevance degree (centrality) on the horizontal axis and development degree (density) on the vertical axis, organizing them into four quadrants.

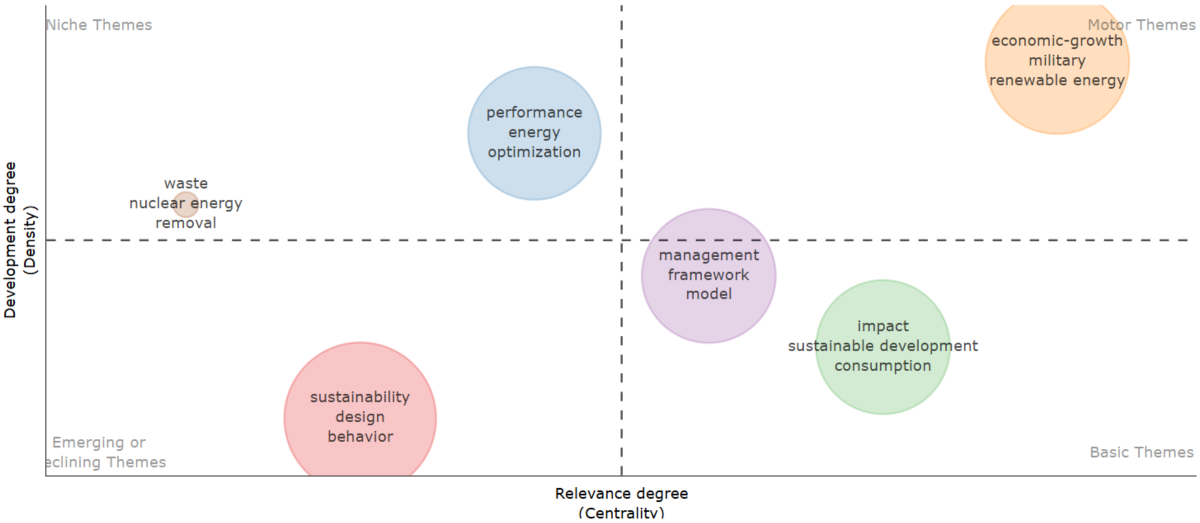


Figure 8 – *Thematic Map of article subject*

In the Motor Themes quadrant (high centrality, high density), we find economic growth, military and renewable energy. These themes are both highly connected to other research topics and internally well-developed, constituting the intellectual engines of the field. The positioning of military as a motor theme confirms that defence applications of circular economy principles occupy a central rather than peripheral role. Renewable energy appears here as an established bridge between defence sustainability and energy security.

The Niche Themes quadrant (high density, low centrality) contains performance, energy and optimization. These themes are internally coherent and well-developed but maintain fewer connections to the broader research community, likely representing specialized subfields such as operational performance optimization or energy system engineering for military contexts.

The Basic Themes quadrant (high centrality, low density) includes impact, sustainable development and consumption. These concepts serve as widely referenced foundational anchors across the literature but are not internally clustered into dense research programs. Their presence here suggests the field draws extensively on general sustainability and development science frameworks.

The Emerging or Declining Themes quadrant (low centrality, low density) contains waste, nuclear energy and removal. The positioning of nuclear energy may indicate either a declining strand on nuclear power as a military energy source, or an emerging interest in long-term defence energy independence. Waste and material removal represent underexplored but practically important areas connecting military logistics to circular material flows.

A central cluster containing management, framework and model, alongside sustainability, design and behaviour, sits near the quadrant boundaries. This positioning indicates that theoretical and methodological research on management frameworks for military sustainability is a well-developed yet still-evolving area bridging motor and basic themes. Its central location suggests it will play an increasingly important integrative role as the field matures.

Benchmarks of reality in the field of Circular Economy. The integration of circular economy principles into the field of security and defense reflects a structural transformation driven by converging pressures: the growing demand for critical resources, the need to reduce the carbon footprint, and the requirement for strategic resilience. The specialized literature highlights that the circular economy, defined as a model oriented toward reuse, recycling, and extending product life cycles, contributes to reducing dependence on finite resources and optimizing their use.

In the defense context, this paradigm acquires strategic significance. According to the analysis published by Circle Economy, the tension between increasing defense budgets and decarbonization objectives can be mitigated through the adoption of circular principles, which reduce the demand for raw materials and strengthen economic and societal resilience (Circle Economy, 2024).Thus, the circular economy is not only a sustainability tool but also a security multiplier by reducing vulnerabilities associated with global supply chains. Recent strategic documents confirm this direction. The British concept on circular economy in defense emphasizes that its implementation leads to increased resilience of logistical supply chains, extended equipment life cycles, and improved operational efficiency (UK Ministry of Defence, 2023). Moreover, the proposed approach does not imply reducing military capabilities (“do without”), but rather a paradigm shift toward “do differently,” making more efficient use of existing resources and fostering innovation in military support processes. At the European level, initiatives such as the Incubation Forum for Circular Economy in European Defence demonstrate the institutionalization of this concept, aiming to integrate circular principles into defense industries to reduce emissions, increase strategic autonomy, and minimize supply chain vulnerabilities. At the same time, academic research highlights that adopting the circular economy in the military sector requires systemic innovations and new business models adapted to the complexity of security ecosystems (Soufani et al., 2018).

On the other hand, the literature also points out current limitations. The integration of circular principles into defense industrial processes remains fragmented and challenging, particularly due to technological specificity and security requirements, which hinder the achievement of decarbonization objectives (Fiott, 2025). These constraints indicate the need for coherent policies and enhanced cooperation among the public sector, industry, and academia.

Relatively recent contributions from scientific and professional literature (Batusaru et al., 2023), as well as expert analyses (for example, reflections on the relationship between NATO and the circular economy or the recognition of the research conducted by Wagemans, L. (2024)), support the idea that the circular economy is becoming an emerging vector of modern security. In the same vein, synthesis works such as Sustainability Trends and Dynamics: An Integrative Approach to Economic, Social, and Environmental Perspectives highlight the interdependence between economic, social, and environmental dimensions (Gorski et al., 2024), emphasizing the integrative role of the circular economy in contemporary public policies.

Conclusions

This bibliometric study provides a preliminary and systematic examination of a relatively underexplored niche, mapping the scientific literature situated at the intersection of military perspectives and the circular economy, conceptualized within the framework of security-related resource management. Analysing 410 merged and deduplicated documents from Scopus and the Web of Science Core Collection (2015–2025), the study reveals a rapidly growing field with an annual growth rate of 29.61%, projected to peak around 2032–2033.

The analysis highlighted four principal findings. First, the number of papers being published is going up fast and this is because the military is trying to be more sustainable and there are concerns about supply chains after the pandemic and we need to make sure we have enough energy. Second, if we look at how the number of papers growing, we can see that it will keep growing until we get to around 4,100 papers, which means there is still a lot of work to be done in this area. Third, The United States and China are publishing the papers but China, the United Kingdom and Canada are getting the most attention for their papers and smaller countries like Singapore and the Czech Republic are showing that even if you are small, you can still make important contributions. Fourth, conceptual clusters: circular design, macroeconomic resource analysis, energy transition and environmental conflict constitute the primary intellectual building blocks of the field.

The circular economy and military perspectives are connected in this study. The military perspectives and circular economy are important for security resources. The study of perspectives and circular economy is growing fast. The military perspectives and circular economy will keep growing until, around 2032 or 2033.

Several research gaps warrant future attention. The limited treatment of material circularity in military supply chains, the underexplored relationship between circular economy and military resilience in conflict settings, and the absence of standardized metrics for assessing circular resource performance in defence contexts all represent promising directions. Methodologically, the predominance of cross-sectional studies calls for longitudinal designs that track implementation outcomes over time.

The circular economy offers a powerful yet underutilized framework for enhancing military resource security. By reducing dependence on vulnerable supply chains, extending the lifecycle of critical assets and integrating renewable energy sources, military organizations can build more resilient and sustainable operational capabilities. As resource scarcity and environmental change increasingly intersect with global security challenges, the integration of circular economy principles into defence strategy will evolve from an aspirational sustainability goal to a strategic operational necessity.

REFERENCES

1. Amankwah-Amoah, J., Khan, Z., Wood, G. & Knight, G. (2021) COVID-19 and digitalization: The great acceleration. *Journal of Business Research*. 136. pp.602–611.
2. Aria, M. & Cuccurullo, C. (2017) bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*. 11(4). pp.959–975.
3. Bătusaru, C. M. & Sbarcea, I. R. (2023). Security in the Context of Sustainability: The Implications on Defence Expenditures. *Studies in Business and Economics*. 18(2). pp.48-66.
4. Bocken, N.M.P., de Pauw, I., Bakker, C. & van der Grinten, B. (2016) Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*. 33(5). pp.308–320.
5. Circle Economy. (2024) *Defence or decarbonisation. NATO's 5% spending plan sparks a battle for resources.* Available from: https://legacy.circle-economy.com/blog/defence-or-decarbonisation-natos-5-spending-plan-sparks-a-battle-for-resources.
6. Donthu, N., Kumar, S., Mukherjee, D., Pandey, N. & Lim, W.M. (2021) How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*. 133. pp.285–296.
7. EDA – European Defence Agency (2020) *Defence & Climate Change: Trends and Key Issues for the European Defence Community.* Brussels: EDA Publication.
8. Ellen MacArthur Foundation (2013) *Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition.* Cowes: Ellen MacArthur Foundation.
9. Fiott, D. (2025, November 12). *Decarbonising defence: Reconciling the green agenda with the reindustrialisation of Europe's defence sector*. Institut de relations internationales et stratégiques (IRIS).
10. Geissdoerfer, M., Savaget, P., Bocken, N.M.P. & Hultink, E.J. (2017) The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*. 143. pp.757–768.
11. Gherasim, A. (2023) Indicators of sustainability in military organizations. *Annals–Series on Military Sciences.* 15.1. pp. 124-128.
12. Gorski, A. T. & Ranf, E. D. (2024) Sustainability Trends and Dynamics: An Integrative Approach to Economic, Social, and Environmental Perspectives. *Scientific Bulletin*. *29*(1). pp 46-60.
13. Marqusee, J., Schultz, C. & Robyn, D. (2017) *Power Begins at Home: Assured Energy for U.S. Military Bases*. Philadelphia: Pew Charitable Trusts.
14. Morales-Fusco, P., Saurí, S., Ruiz-Boada, A. & Lekue-Sagarna, L. (2020) Evaluating renewable energy options for military installations: A multi-criteria approach. *Energies*. 13(18). p.4749.

15. NATO. (2021) *Climate Change and Security Action Plan*. Brussels: North Atlantic Treaty Organization.

16. Porancea-Răulea, A. & Batusaru, C. (2024) Embracing Sustainability in Military Management: Challenges and Opportunities. *In: International Conference Knowledge-Based Organization*. Nicolae Balcescu Land Forces Academy. pp. 269-275.

17. Sandin, G., Roos, S. & Johansson, M. (2019) Environmental impact of textile fibers – what we know and what we don't know. Gothenburg: RISE Research Institutes of Sweden.

18. Soufani, K., Tse, T., Esposito, M., Dimitrou, G. & Kikiras, P. (2018) A roadmap to circular economy in EU defence inspired by the case of the Dutch Ministry of Defence. *The European Financial Review*. doi:10.17863/CAM.27365.

19. Tao, R., Glont, O.R., Li, Z.-Z., Lobont, O.R. & Guzun, A.A. (2020) New evidence for Romania regarding dynamic causality between military expenditure and sustainable economic growth. *Sustainability*. 12(12). p.5053.

20. UK Ministry of Defence. (2023) *Sustainable circular economics for defence: Concept note.* [Online] Available from: https://www.gov.uk/government/publications/sustainable-circular-economics-for-defence-concept-note/sustainable-circular-economics-for-defence-concept-note--2.

21. U.S. Department of Defense (2022) *Department of Defense Climate Risk Analysis*. Washington D.C.: Department of Defense.

22. Wagemans, L, (2024) *Exploring circular economy strategies to reduce dependency on Critical Raw Materials in the defence sector*. Master Thesis. [Online] Available from: https://repository.tudelft.nl/record/uuid:3ae4470e-deab-468a-a5a5-02d170016a77.

23. Walker, R.V., Beck, M.B., Hall, J.W., Dawson, R.J. & Heidrich, O. (2020) The energy-water-food nexus: Strategic analysis of technologies for transforming the urban metabolism. *Journal of Industrial Ecology*. 18(5). pp.686–698.

"A circular economy is a step in the right direction towards a permaculture economy."

Hendrith Vanlon Smith Jr.

Solutions for Energy Efficiency in Service Buildings

Laura DOBRE-DOROFTEI*, Petronela-Cristina SIMION

National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independentei, Bucharest, Romania

Abstract

Both during construction and in operation, buildings consume significant amounts of resources. In this context, energy efficiency can be considered a circular economy solution by reducing energy consumption. Thus, this article presents an analysis of solutions for increasing energy efficiency in buildings using photovoltaic panels. The EDGE platform was used to assess the building's current energy efficiency and the installed capacity requirements for the PV system. Research was conducted to identify an optimal solution in terms of space, installed capacity, and costs. Using data available on the ENF Solar platform, optimal solutions were identified for panel tilt angles of 30°, 25°, 20°, 15°, and 10°, and their benefits were highlighted. Finally, it was determined that the maximum output that can be accommodated on the roof surface is 201.6 kW at a cost of €21,974, covering 41.36% of the building's electricity consumption.

Keywords: photovoltaic panels, EDGE platform, office building

"At its core, the issue of a clean environment is a matter of public health."
Gina McCarthy

Introduction

Globally, buildings account for approximately 40% of energy and process-related CO_2 emissions, as well as contributing to resource depletion, environmental pollution, and biodiversity loss (World Green Building Council, 2026). Circular economy principles aim to restore, renew, or revitalize the energy and material sources and minimize waste as much as possible (EC, 2022). Circular economy strategies contribute to achieving global climate goals, while increasing energy efficiency and energy security and supporting economic restructuring toward more sustainable, resilient, and low-emission development (Fragkos, 2022). Adopting circular economy principles in the construction sector can reduce resource consumption and waste generation. Circular

*Correspondence to Laura DOBRE-DOROFTEI: lauradorofteil0@gmail.com

building design should aim for low energy and water consumption and optimize use of these resources during the operational phase. Energy efficiency practices and local and renewable energy sources are essential approaches, alongside circular economy principles, for reducing the negative environmental impact of buildings (Rahla et al., 2021). Strong performance in the renewable energy sector can act as a buffer against setbacks in circular economy activities, potentially through institutional strengthening or behavioral changes that promote sustainability (Bergougui & Ben-Salha, 2025).

To reduce energy consumption, renewables together with an improvement of both insulation and systems in buildings is a sustainable solution (D'Agostino et al., 2017). Regardless of the measures adopted, they have a significant impact on increasing energy efficiency if they are powered by clean energy from photovoltaic panels (Galatioto et al., 2019).

The main aim of this paper is to provide a model to analyse the possibilities of increasing the energy efficiency of a building by optimally sizing a photovoltaic power plant to ensure maximum output for the available space, with high efficiency and at a feasible cost. An office building was used as a case study. Increasing efficiency in office buildings is a topic of interest both because of the increased energy consumption and because of the possibility of integrating various systems to reduce it. Moreover, from an economic point of view, reducing energy consumption helps to reduce energy bills, making the building more attractive to tenants. From a technical point of view, according to Georgios Chantzis, several researchers are considering the possibility of using office buildings for balancing the energy system, both through flexibility in the consumption of the equipment used and by installing renewable energy sources or storage (Chantzis et al., 2023).

Methodological approach

The research conducted in this paper is a qualitative secondary study aimed at optimizing a photovoltaic system installed on the roof of an office building selected as a case study, in order to improve its energy efficiency. To achieve this objective, the research involved several stages.

First, the building's energy efficiency and energy consumption were assessed. This was done using the EDGE (Excellence in Design for Greater Efficiencies) platform, into which the building's data was entered. The only surface available for installing a photovoltaic system is the building's roof, which, however, does not allow for the installation of the full photovoltaic capacity required. Consequently, an analysis was conducted to optimize a photovoltaic system that would make the most efficient use of the available space, ensuring the highest possible installed capacity at a competitive price.

Using the ENF Solar platform dedicated to photovoltaic products, 58 photovoltaic panels were selected from 15 manufacturers. The criteria for selecting the panels were:

- the use of three technologies: HJT, TOPCon, and Back Contact
- panel efficiency above 20%
- competitive prices
- the availability of the panels in Europe

Using the panels selected in the previous analysis, further research was conducted to optimize a photovoltaic system on the roof surface. For this research, the maximum capacity of the photovoltaic system that can be installed on the roof surface was calculated for each individual panel for tilt angles of 30°, 25°, 20°, 15°, and 10°. Based on the calculation results, aiming for an above-average installed capacity and a purchase price below the average, the most optimal solution in terms of installed capacity-to-price ratio was identified for each tilt angle.

Subsequently, using these results and the PVWatts Calculator software, the energy production was estimated for each optimal solution identified. The production data was entered into the EDGE platform to analyse the benefits (the percentage of the building's energy consumption covered by the photovoltaic system, building efficiency, and annual net carbon emissions).

Finally, using the price comparison tool available on the ANRE website, an average purchase price of €0.2985/kWh for energy from the energy market was selected. Using this price, the economic benefits of the energy savings resulting from the solutions identified for each individual tilt angle were calculated, and conclusions were drawn.

The methodology presented above is schematically represented in Figure 1.

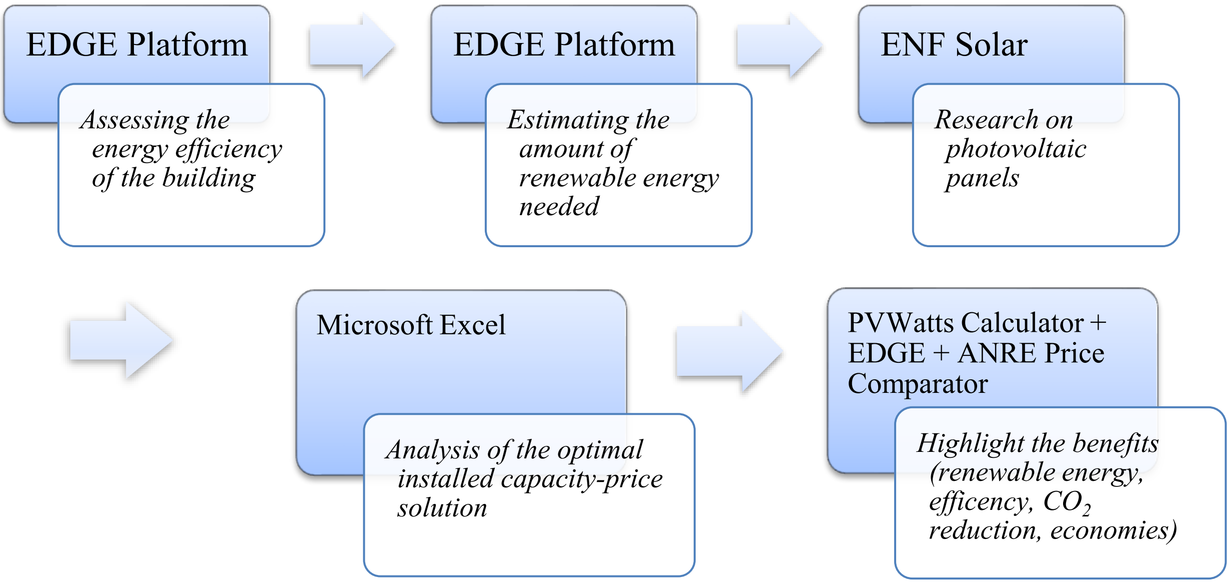


Figure 1 – *Methodology diagram*

Results and discussion

To create the building simulation on the EDGE platform, data on the building characteristics must be entered. The case study analysed an office building with a total area of 12750 m^2, six upper floors and one lower floor. The building exterior is made of 62.52% insulated glazed area and a reinforced concrete structure. The heat transfer coefficients for roof, floor and external walls are 0.20, 0.15 and 0.23 W/(m^2*K), respectively. The building is cooled by a chiller with a cooling capacity of 839 kW for the office part and a 96-kW chiller for the IT areas, with an average coefficient of performance of 3.2 (W/W). The heating and domestic hot water of the building is provided by a natural gas condensing thermal power plant with a capacity of 800 kW, and an efficiency of 91%. The average indoor lighting efficiency is 113 (lm/W). Water consumption of the bathroom and kitchen sinks is 6 l/min and 5 l/min respectively.

According to the results extracted from the EDGE platform (Figure 2), compared to the reference model, the analysed office building is 31.93% more energy efficient, 21.28% more water efficient and uses 4.35% more sustainable materials. The total annual energy consumption of the building is about 1,2778 MWh/year and net carbon emissions are 374.1 t CO2e/Year (t CO2e/Year – t CO2 equivalent = standard unit used to measure carbon footprints and express the impact of different greenhouse gases) according to the platform's calculations.

It can be seen from Figure 2 that the inefficiency of the building is mainly due to the high consumption of the equipment used (laptops, monitors, printers), the lighting system and the cooling system. Thus, an important solution to be considered is the purchase and installation of photovoltaic panels.

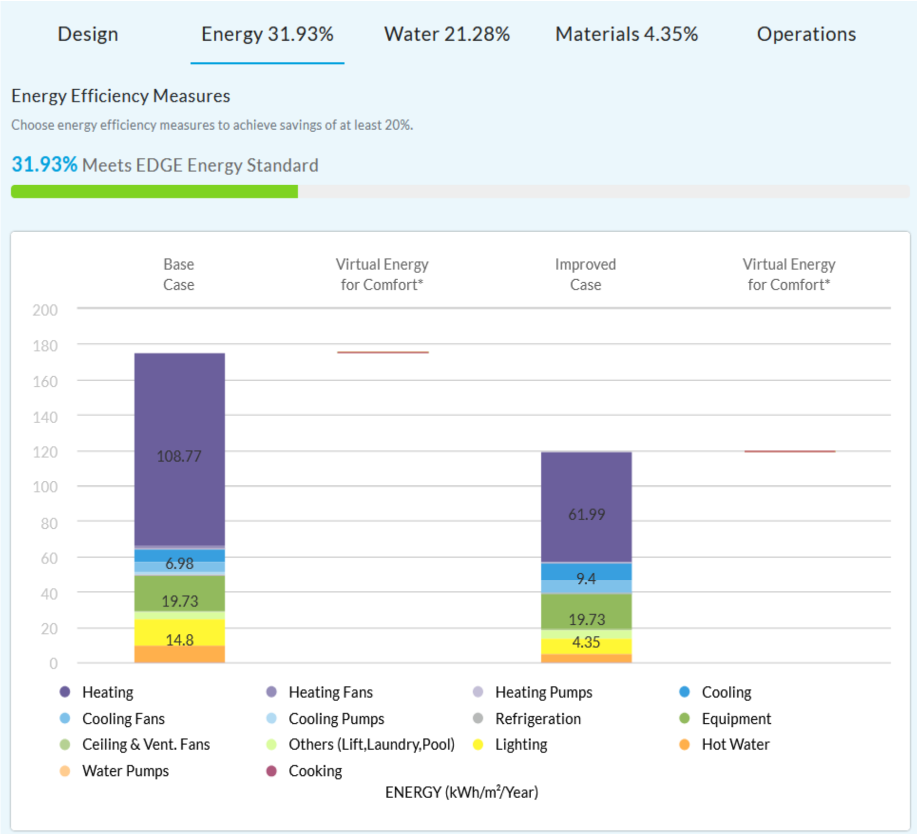


Figure 2 – *Print Screen of the EDGE platform with office building simulation*

Based on the input data entered, the EDGE platform calculates approximate the building's total energy consumption of about 1,2778 MWh/year, of which 56.33% is natural gas consumption and 43.67% is electricity consumption. Thus, the electricity consumption is approximately 558093 kWh and the installed capacity requirement of a photovoltaic power plant to support the entire electricity consumption of the building is 449.36 kW (Lat/Lng: 44.48°, 26.10°, 33° tilt angle) (PVwatt Calculator).

Use of photovoltaic panels to improve the energy efficiency of an office building

The EDGE platform does not allow the selection of the energy efficiency, size, technology used, etc., of the PV plant, but only the percentage of the building's energy consumption that it can sustain. According to the "EDGE User Guide" (International Finance Corporation, 2021), it is considered that commercially available photovoltaic panels can achieve efficiency levels up to 22.5%.

Taking this into account, the following is an analysis of several types of PV panels from different manufacturers (November 2024). Among the most efficient and widely used PV cell technologies are HJT, TOPCon and Back Contact (Dibyendu Kumar Ghosh, 2022). It is also found that the maximum efficiency of the chosen technologies is between 22.18% and 24%. The most efficient technology included in the analysis is Back Contact. As the transportation of the panels from the supplier can significantly increase the costs, it was considered in the choice of examples that the panels should be available in Europe. Table 1 shows the information on technology, power, efficiency, dimensions, and price for several types of panels from different manufacturers.

Table 1 – *Specifications and costs of panels from different manufacturers*

Manufacturer	Technology	Power [W]	Efficiency [%]	Dimensions [mm]	Price [€/W]
Q cells	HJT	395	20.60	1722x1134x30	0.123
Suneng Solar	Bifacial, HJT	400	21.96	1755x1038x30	0.231
Q cells	HJT	415	21.30	1722x1134x30	0.134
Jolywood	TOPCon	420	21.43	1728x1134x30	0.148
Jinko Solar	TOPCon	420	21.51	1722x1134x30	0.137
LONGi Solar	Back Contact	425	21.80	1722x1134x30	0.109
Sonnex Energie	Back Contact	430	21.80	1885x1039x35	0.300
LONGi Solar	Back Contact	430	22.00	1722x1134x30	0.115
Canadian Solar	TOPCon	430	22.00	1722x1134x30	0.110
Sunket Energy	TOPCon	430	22.00	1722x1134x30	0.128
Astronergy	TOPCon	430	22.00	1722x1134x30	0.100
Trina Solar	TOPCon	435	21.80	1762x1134x30	0.128
Sonnex Energie	Bifacial, TOPCon	435	22.28	1722x1134x30	0.250
Ja Solar	Bifacial, TOPCon	435	22.30	1722x1134x30	0.100
LONGi Solar	Back Contact	435	22.30	1722x1134x30	0.100
Trina Solar	Bifacial TOPCon	440	22.00	1762x1134x30	0.145
Jinko Solar	Bifacial, TOPCon	440	22.02	1762x1134x30	0.105
AIKO	Bifacial, Back Contact	440	22.10	1757x1134x30	0.110
Canadian Solar	TOPCon	440	22.50	1722x1134x30	0.108
Sonnex Energie	TOPCon	440	22.50	1722x1134x30	0.350
LONGi Solar	Back Contact	440	22.50	1722x1134x30	0.138
REGITEC	Bifacial, TOPCon	440	22.53	1722x1134x30	0.106
Jinko Solar	TOPCon	445	22.27	1762x1134x30	0.101
Trina Solar	TOPCon	445	22.30	1762x1134x30	0.120
AIKO	Bifacial, Back Contact	445	22.80	1722x1134x30	0.174
Trina Solar	TOPCon	450	22.50	1762x1134x30	0.129
Jinko Solar	Bifacial, TOPCon	450	22.52	1762x1134x30	0.125
Canadian Solar	TOPCon	450	23.00	1722x1134x30	0.109
RECOM	Back Contact	450	23.00	1722x1134x35	0.128
Suneng Solar	Bifacial, HJT	450	23.04	1722x1134x30	0.153
AIKO	Bifacial, Back Contact	455	23.30	1722x1134x30	0.170
Canadian Solar	Bifacial, TOPCon	470	23.00	1800x1134x30	0.123
Sonnex Energie	HJT	475	21.85	2126x1042x5	0.250
Jinko Solar	TOPCon	480	22.24	1906x1134x30	0.100
Q cells	HJT	485	20.80	2054x1134x32	0.155
Suneng Solar	Bifacial, HJT	520	23.40	1960x1134x30	0.153
LONGi Solar	Back Contact	550	21.30	2278x1134x35	0.120
Risen energy	HJT	580	22.20	2384x1096x30	0.125
Jinko Solar	TOPCon	580	22.45	2278x1134x35	0.114
Canadian Solar	TOPCon	580	22.50	2278x1134x30	0.109
LONGi Solar	Back Contact	580	22.60	2278x1134x35	0.146
Canadian Solar	Bifacial, TOPCon	585	22.60	2278x1134x30	0.120
Jinko Solar	TOPCon	585	22.65	2278x1134x35	0.109
Jinko Solar	Bifacial, TOPCon	585	22.65	2278x1134x30	0.118
Risen energy	HJT	595	22.80	2384x1096x30	0.140
Trina Solar	Bifacial, TOPCon	605	22.40	2384x1134x30	0.103
Risen Energy	TOPCon, Bifacial	610	21.80	2465x1134x30	0.125

Manufacturer	Technology	Power [W]	Efficiency [%]	Dimensions [mm]	Price [€/W]
RECOM	Back Contact	610	23.60	2278x1134x35	0.118
AIKO	Back Contact	620	24.00	2278x1134x35	0.123
AIKO	Back Contact	625	23.70	2323x1134x35	0.160
Risen energy	HJT	690	22.20	2384x1303x35	0.125
Canadian Solar	Bifacial, TOPCon	695	22.40	2384x1303x33	0.119
Trina Solar	Bifacial, TOPCon	700	22.50	2384x1303x33	0.112
REGITEC	Bifacial, HJT	700	22.50	2384x1303x35	0.107
REGITEC	Bifacial, TOPCon	705	22.70	2384x1303x35	0.100
Canadian Solar	Bifacial, TOPCon	715	23.00	2384x1303x33	0.112
Sunerg Solar	Bifacial, HJT	720	23.18	2384x1303x35	0.151
Risen energy	HJT	725	23.30	2384x1303x35	0.140

Electrical efficiency refers to a PV panel's ability to convert incoming solar energy into useable electrical power. It is a critical metric that indicates how effectively a PV panel transforms sunlight into electricity. The electrical efficiency of a PV panel can be calculated using (1)

$$\text{Electrical efficiency of PV panel} = \frac{P_{out}}{I r \times n \times L \times w} \quad (1)$$

where:
P_{out} = Output electric power of the PV panel (W)
I = Solar insulation (W/ m^2)
n = PV cells number
L = effective length of the cell (m)
W = effective width of the cell (m) (Hassan Raad, 2025)

Given that solar irradiance is constant, the efficiency of the panels is determined by the panel's electrical power relative to its effective surface area. In other words, the panel's efficiency increases as its power increases while maintaining the same effective area. Figure 3 illustrates the costs and efficiency of the photovoltaic panels analysed.

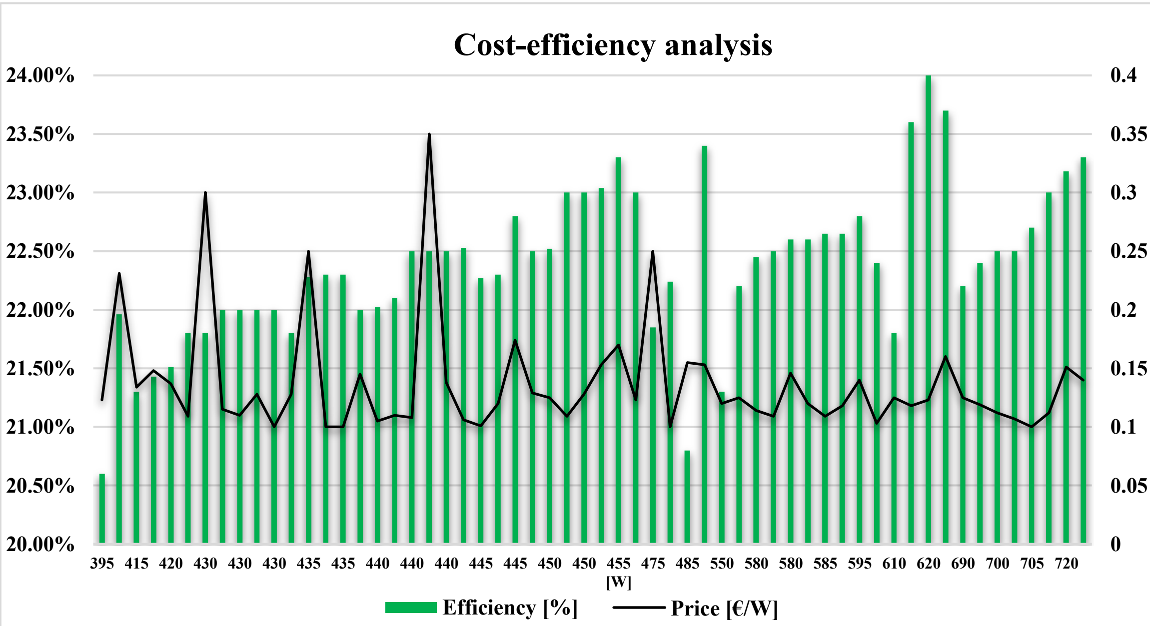


Figure 3 – *Relationship between efficiency and cost of the photovoltaic panels*

Using the data from Table 1, a power-to-cost ratio analysis was further carried out, in which the aim was to obtain the highest possible power at the lowest possible cost. To be able to perform this analysis it is necessary to know the number of PV panels that fit on the roof surface. The roof area is approximately 1,500 m^2. If a 1.2 m clearance is left from the edge on each side, the available installation area becomes approximately 1,304 m^2 (55.8 m x 23.37 m).

The total power for each type of panel was calculated by multiplying the number of panels by its power, and the total cost was calculated with eq. (1).

$$\textit{Total cost} = \textit{Power panel} \,[\mathrm{W}] \times \textit{no. panels} \times \textit{price}\,[€/\mathrm{W}] \quad (1)$$

For the installation of a photovoltaic system, the energy production and costs for each type of panel at tilt angles of 30°, 25°, 20°, 15°, and 10° are presented in Table 2. The calculation considered the latitude of the location (44.48°) and the Sun's declination angle of -23.45° on December 21 (Stanciu & Stanciu, 2014).

Table 2 – *Installed capacity and price of the photovoltaic system installed at panel tilt angles of 30°, 25°, 20°, 15°, and 10°*

Technology	30°		25°		20°		15°		10°	
	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]
HJT	139.2	13920	153.1	15312	167	16704	181	18096	194.9	19488
Bifacial, HJT	140.8	49280	154.9	54208	169	59136	183	64064	197.1	68992
HJT	139.2	34800	153.1	38280	167	41760	181	45240	194.9	48720
TOPCon	134.4	18413	147.8	20254	161.3	22095	174.7	23937	188.2	25778
TOPCon	136.4	14322	150.0	15754	163.7	17186	177.3	18619	191	20051
Back Contact	138	13933	151.7	15326	165.5	16720	179.3	18113	193.1	19506
Back Contact	139.5	17438	153.5	19181	167.4	20925	181.4	22669	195.3	24413
Back Contact	139.2	13920	153.1	15312	167	16704	181	18096	194.9	19488
TOPCon	139.2	15869	153.1	17456	167	19043	181	20629	194.9	22216
TOPCon	140.4	15304	154.4	16834	168.5	18364	182.5	19895	196.6	21425
TOPCon	140.4	16567	154.4	18224	168.5	19881	182.5	21537	196.6	23194
TOPCon	137.6	15136	151.4	16650	165.1	18163	178.9	19677	192.6	21190
Bifacial, TOPCon	140.8	15206	154.9	16727	169	18248	183	19768	197.1	21289
Bifacial, TOPCon	144	15696	158.4	17266	172.8	18835	187.2	20405	201.6	21974
Back Contact	145.7	17921	160.3	19713	174.8	21505	189.4	23297	204	25090
Bifacial TOPCon	139.2	15173	153.1	16690	167	18207	181	19725	194.9	21242
Bifacial, TOPCon	140.4	16848	154.4	18533	168.5	20218	182.5	21902	196.6	23587
Bifacial, Back Contact	143.9	17120	143.9	17120	159.9	19022	175.8	20924	191.8	22827
TOPCon	148	16577	148.0	16577	164.5	18418	180.9	20260	197.3	22102
TOPCon	134.9	17261	148.3	18987	161.8	20713	175.3	22439	188.8	24165
Back Contact	136.4	19778	150.0	21756	163.7	23734	177.3	25711	191	27689
Bifacial, TOPCon	138	16554	151.7	18209	165.5	19865	179.3	21520	193.1	23176
TOPCon	139.5	17996	153.5	19795	167.4	21595	181.4	23394	195.3	25194
TOPCon	139.2	14332	153.1	15766	167	17199	180.9	18632	194.8	20065
Bifacial, Back Contact	144.9	16229	144.9	16229	161	18032	177.1	19835	193.2	21638
TOPCon	140.8	14925	154.9	16417	169	17910	183	19402	197.1	20895
Bifacial, TOPCon	145.9	14594	145.9	14594	162.2	16215	178.4	17837	194.6	19458
TOPCon	137.6	17613	151.4	19374	165.1	21135	178.9	22897	192.6	24658

Technology	30°		25°		20°		15°		10°	
	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]	Power [kW]	Price [€/W]
Back Contact	137.6	13760	151.4	15136	165.1	16512	178.9	17888	192.6	19264
Bifacial, HJT	134.4	19891	147.8	21880	161.3	23869	174.7	25859	188.2	27848
Bifacial, Back Contact	134.2	16775	147.6	18453	161	20130	174.5	21808	187.9	23485
Bifacial, TOPCon	136	14824	149.6	16306	163.2	17789	176.8	19271	190.4	20754
HJT	137.6	15824	151.4	17406	165.1	18989	178.9	20571	192.6	22154
TOPCon	139.2	13920	153.1	15312	167	16704	181	18096	194.9	19488
HJT	140.8	19430	154.9	21373	169	23316	183	25260	197.1	27203
Bifacial, HJT	137.2	41151	149.6	44892	162.1	48633	174.6	52374	199.5	59856
Back Contact	132	15840	145.2	17424	158.4	19008	171.6	20592	184.8	22176
HJT	139.2	20323	153.1	22356	167.0	24388	181	26420	194.9	28452
TOPCon	136.4	15004	150.0	16504	163.7	18005	177.3	19505	191	21006
TOPCon	142.4	24778	156.6	27255	170.9	29733	185.1	32211	199.4	34689
Back Contact	145.6	24752	160.2	27227	174.7	29702	189.3	32178	203.8	34653
Bifacial, TOPCon	148.8	18302	163.7	20133	178.6	21963	193.4	23793	208.3	25623
TOPCon	150	24000	165.0	26400	180	28800	195	31200	210	33600
Bifacial, TOPCon	144	18432	158.4	20275	172.8	22118	187.2	23962	201.6	25805
HJT	146.4	17275	161.0	19003	175.7	20730	190.3	22458	205	24185
Bifacial, TOPCon	136.4	31508	148.8	34373	161.2	37237	173.6	40102	198.4	45830
TOPCon, Bifacial	144	22032	158.4	24235	172.8	26438	187.2	28642	201.6	30845
Back Contact	145.6	22277	160.2	24504	174.7	26732	189.3	28960	203.8	31188
Back Contact	149	22505	149.0	22505	165.6	25006	182.2	27506	198.7	30007
Back Contact	126.4	15547	139.0	17102	151.7	18657	164.3	20211	177	21766
HJT	132.8	17795	146.1	19575	159.4	21354	172.6	23134	185.9	24913
Bifacial, TOPCon	131	20297	144.0	22327	157.1	24357	170.2	26386	183.3	28416
Bifacial, TOPCon	135.9	33963	148.2	37050	160.6	40138	172.9	43225	197.6	49400
Bifacial, HJT	133.4	16675	146.7	18343	160.1	20010	173.4	21678	200.1	25013
Bifacial, TOPCon	136.9	19159	150.5	21075	164.2	22991	177.9	24907	205.3	28739
Bifacial, TOPCon	142.8	17854	142.8	17854	158.7	19838	174.6	21821	190.4	23805
Bifacial, HJT	150.1	21011	150.1	21011	166.8	23345	183.4	25680	200.1	28014
HJT	144.9	15504	144.9	15504	161	17227	177.1	18950	193.2	20672

As can be seen in Table 2, for the 30° tilt angle power is between 126.4 kW and 150.075 kW at prices between €13,760 and €49,280. It was found that, in this case, the most advantageous solution is the purchase of a 145.935 kW Bifacial, TOPCon plant at a cost of €14593.5.

In the case of panels installed at a 25° tilt angle, the power is between 165 kW and 139.04 kW at prices between €54208 and € 14593.5. The most advantageous in this case is a TOPCon photovoltaic system with a power of 158.4 kW at a cost of €17265.6.

In the case of panels installed at a 20° tilt angle, the power is between 180 kW and 151.68 kW at prices between €59136 and € 16215. The most advantageous in this case is a TOPCon photovoltaic power plant with a power of 172.8 kW at a cost of €18835.2.

In the case of panels installed at a 15° tilt angle, the power is between 195 kW and 164.32 kW at prices between € 64064 and € 17836.5. The most advantageous in this case is a TOPCon photovoltaic power plant with a power of 187.2 kW at a cost of €20404.8.

In the case of installed at a 10° tilt angle, the power is between 210 kW and 176.96 kW at prices between €68992 and €19264. The most advantageous in this case is a TOPCon photovoltaic power plant with a power of 201.6 kW at a cost of €21974.

Table 3 shows the power output and benefits (percentage of the building's electricity consumption supplied by the photovoltaic system, building efficiency and net carbon emissions) following the implementation of the identified solutions. As can be seen, reducing the tilt angle of the panels increases the installed capacity by approximately 14 kW for every 5°. On the other hand, the rate of increase in the output of photovoltaic systems decreases as the tilt angle decreases. However, it can be seen that the greatest reductions in electricity consumption, CO_2 net emissions, and increases in efficiency occur when the system is installed at a 10° angle.

Table 3 – *The advantages of photovoltaic systems identified as solutions*

Power [kW]	**PV**	**Tilt**	**Annual energy production [kWh/year]**	**PV Annual building electricity supply [%]**	**Building efficiency [%]**	**Net Carbon Emissions [t CO_2e/ Year]**
145.935	REGITEC 705	30	180,682	32.37	36.95	347.3
158.4	Can solar 450	25	194,171	34.79	37.26	345.7
172.8	Can solar 450	20	208,431	37.35	37.59	344
187.2	Can solar 450	15	220,754	39.56	37.87	342.5
201.6	Can solar 450	10	230,818	41.36	38.10	341.2

Assuming that electricity is purchased on the electricity market, at an average price of €0.2985/kWh, reducing energy consumption leads to lower electricity bills and thus to savings of between €54,000 and €69,000 per year, as shown in Table 4. The estimated savings are approximately three times greater than the cost of purchasing the solar panels.

Table 4 – *Economic benefits*

	30	**25**	**20**	**15**	**10**
Price [€]	14593.5	17265.6	18835.2	20404.8	21974
Save on bills [€]	53,936.51	57,963.19	62,220.03	65,898.65	68,902.92

Thus, the analysis revealed that, although buildings do not always have sufficient surface area to install a photovoltaic system capable of covering the entire energy demand, a viable solution in such cases is to install the panels at the shallowest possible angles. The analysis highlights that, from the perspective of energy production, cost-effectiveness, and emissions reduction, installing the panels at a 10-degree angle is the most advantageous.

Conclusion

In conclusion, this paper examines ways to improve energy efficiency in buildings using renewable energy resources as part of the circular economy. Local energy production, particularly of renewable energy, reduces pressure on the transmission system and has beneficial effects in reducing emissions caused by the use of fossil fuels.

The research conducted in this paper highlights the fact that, when space for installing a photovoltaic system is limited, the most advantageous installation angle is 10°. This is the case even if the tilt angles of the panels are below the optimal angle for collecting solar radiation, as it allows for the installation of a greater number of photovoltaic panels and thus a higher installed capacity. Furthermore, the research revealed that for the available space in the analysed case study, the most advantageous solution is the installation of 450 kW Canadian Solar panels, totalling an installed capacity of 201.6 kW. The benefits of this solution include an approximate annual production of 230,818 kWh, representing approximately 41.36% of the building's total electricity consumption, a 6.17% increase in energy efficiency, a reduction in net carbon emissions of 32.9 t CO_2e/year and annual savings of approximately €68,900.

This paper makes a practical contribution by expanding the body of research on the efficient use of available local space for installing a photovoltaic system to increase energy efficiency. The paper also provides an overview of the photovoltaic panel market, including an analysis of the main types, efficiency levels, sizes, and prices. It further offers a practical contribution by providing a model for the efficient selection and sizing of a photovoltaic system when available space is limited.

REFERENCES

1. World Green Building Council. (2026) *What is a Sustainable Built Environment?* [Online] Available from: https://worldgbc.org/what-is-a-sustainable-built-environment/#:~:text=The%20built%20environment%20has%20a%20significant%20impact,water%2C%20and%20land%20pollution%2C%20and%20biodiversity%20loss. [Accessed: 15th April 2026].
2. EC (2022) European Commission. *Circular economy strategy*. [Online] Available from: https://research-and-innovation.ec.europa.eu/research-area/environment/circular-economy/circular-economy-strategy_en. [Accessed: 15th April 2026].
3. Panagiotis, F. (2022) Analysing the systemic implications of energy efficiency and circular economy strategies in the decarbonisation context. *AIMS Energy*. 10(2). pp. 191–218. https://doi.org/10.3934/energy.2022011.
4. Rahla, K.M., Mateus, R. & Bragança, L. (2021) Implementing Circular Economy Strategies in Buildings—From Theory to Practice. *Applied System Innovation*. 4(2):26. https://doi.org/10.3390/asi4020026.
5. Bergougui, B. & Ben-Salha, O. (2025) How Does the Circular Economy Asymmetrically Affect Clean Energy Adoption in EU Economies? *Sustainability*. 17. 9523. https://doi.org/10.3390/su17219523.
6. D'Agostino, D., Cuniberti, B. & Bertoldi, P. (2017) Energy consumption and efficiency technology measures in European non-residential buildings. *Energy and Buildings*. 153. pp. 72-86. https://doi.org/10.1016/j.enbuild.2017.07.062.
7. Galatioto, A., Ricciu, R., Salem, T. & Kinab, E. (2019) Energy and economic analysis on retrofit actions for Italian public historic buildings. *Energy*. 176:58–66, https://doi.org/10.1016/j.energy.2019.03.167.
8. Chantzis, G., Giama, E. & Papadopoulos, A. (2023) Building Energy Flexibility Assessment in Mediterranean Climatic Conditions: The Case of a Greek Office Building, *Applied Sciences.* 13. no. 12: 7246. https://doi.org/10.3390/app13127246.
9. International Finance Corporation. *EDGE platform*. [Online] Available from: https://app.edgebuildings.com/project/allBuildings. [Accessed: 5th November 2024].
10. ENF Solar. *Solar Panels*. [Online] Available from: https://www.enfsolar. com/pv/panel?page=1. [Accessed: 10th November 2024].
11. Alliance for Energy Innovation. PVWatts Calculator. [Online] Available from: https://pvwatts.nlr.gov/index.php. [Accessed: 16th April 2026].
12. ANRE. *Comparator oferte-tip de furnizare a energiei electrice*. (in English: Electricity veneer type offer comparator) [Online] Available from: https://posf.ro/ comparator? comparatorType=electric. [Accessed: 16th April 2026].

13. International Finance Corporation. (2021) *EDGE User Guide - Version 3.0.a.* [Online] Available from: https://edgebuildings.com/wp-content/uploads/2022/04/211026-EDGE-User-Guide-for-All-Building-Types-Version-3.0.A.pdf. [Accessed: 5th November 2024].
14. Ghosh, D.K., Bose, S., Das, G., Acharyya, S., Nandi, A., Mukhopadhyay, S. & Sengupta, A. (2022) Fundamentals, present status and future perspective of TOPCon solar cells: A comprehensive review. *Surfaces and Interfaces*. 30. 101917. https://doi.org/10.1016/j.surfin.2022.101917.
15. Raad, H., Ali, S., Faraj, J., Castelain, C., Chahine, K. & Khaled, M. (2025) Enhancing photovoltaic panel efficiency through Water-Cooling: A parametric comparative evaluation of energetic, economic, and environmental benefits. *Unconventional Resources*. 7. 100208. ISSN 2666-5190. https://doi.org/10.1016/j.uncres.2025.100208.
16. Stanciu, C. & Stanciu., D. (2014) Optimum tilt angle for flat plate collectors all over the World – A declination dependence formula and comparisons of three solar radiation models. *Energy Conversion and Management*. 81. pp. 133-143. https://doi.org/10.1016/j.enconman.2014.02.016

"Consumption isn't just about taking, it's also about honoring the life cycle of the things we use."
Ken Breniman

Corporate Performance in Central and Eastern Europe

Ileana BOTEZ

Bucharest University of Economic Studies, 6 Piata Romana, Bucharest, Romania

Abstract

This study examines how board competence and board diversity affect firm performance in Central and Eastern European (CEE) capital markets during 2015–2024. Using a hand-collected panel of 44 listed firms from Austria, Poland, Hungary, the Czech Republic, and Romania, the analysis evaluates whether variation in board-level human capital translates into accounting-based and market-based performance outcomes. Fixed-effects panel regressions reveal a strong and economically meaningful relationship between board competence and firm performance. Board diversity is positively associated with performance, but its effects depend on the underlying level of board competence. By contrast, formal board independence shows no significant unconditional relationship with performance once competence and diversity are controlled for. The findings suggest that governance effectiveness in CEE markets is driven primarily by board-level human capital rather than formal compliance mechanisms.

Keywords: corporate governance; board competence; firm performance

Introduction

Corporate boards play a central role in shaping firm performance through their monitoring, advisory, and strategic functions. In modern corporations, characterized by the separation of ownership and control, boards are expected to ensure effective oversight while contributing to strategic decision-making and risk management (Fama and Jensen, 1983). These functions become particularly important in emerging and transition economies, where institutional frameworks are less stable and external governance mechanisms are weaker (La Porta et al., 1999).

Recent research has increasingly focused on board composition as a determinant of firm outcomes, with particular attention to board

"Often when you think you're at the end of something, you're at the beginning of something else."
Fred Rogers

*Correspondence to Ileana BOTEZ: ileana.botez@bvb.ro

competence and board diversity. Diversity can be conceptualized as the degree of heterogeneity within a group, which influences interaction patterns and decision-making processes (Blau, 1977). Board competence reflects the collective human capital of directors - such as financial, legal, and industry expertise - which enhances the board's ability to process complex information and support strategic decisions (Hillman and Dalziel, 2003; DeFond et al., 2005). Board diversity, typically captured through gender, nationality, and independence, has been associated with improved decision-making and monitoring, although empirical findings remain mixed and context-dependent (Adams and Ferreira, 2009; Carter et al., 2010; Hassan et al., 2020). Early empirical evidence suggests that board diversity is positively associated with firm value, particularly through enhanced monitoring and broader strategic perspectives (Carter et al., 2003). Importantly, the contribution of women on boards extends beyond observable characteristics, influencing board processes such as conflict resolution, communication, and decision quality (Nielsen and Huse, 2010).

Despite this growing body of literature, existing studies often analyse competence and diversity separately, providing limited evidence on their joint effects. Moreover, the effectiveness of board independence remains inconclusive, particularly in environments characterized by concentrated ownership (Rashid, 2018). These limitations are especially relevant in Central and Eastern Europe (CEE), where governance practices operate under heterogeneous institutional conditions despite formal convergence to European Union standards (Aguilera and Jackson, 2003).

This study addresses these gaps by examining the joint effects of board competence and board diversity on firm performance in CEE capital markets over the period 2015–2024. Using a hand-collected panel dataset of 44 listed companies from Austria, Poland, Hungary, the Czech Republic, and Romania, the analysis integrates accounting-based and market-based performance measures with detailed board-level characteristics.

This study contributes to corporate governance literature in three important ways. First, it provides new empirical evidence on the role of board competence in shaping firm performance in emerging European markets. Second, it examines the interaction between competence and diversity, highlighting their complementary effects. Third, it offers a comparative perspective across five CEE countries, contributing to the limited evidence from this region.

The remainder of the paper is organized as follows. Section 2 presents the literature review and hypotheses development, Section 3 outlines the research methodology, Section 4 reports and discusses the results, and Section 5 concludes.

Literature Review and Hypotheses Development

Corporate governance literature emphasizes the role of boards as a key internal mechanism for aligning managerial actions with shareholder interests. Board effectiveness depends not only on formal structures, but also on directors' characteristics, particularly their competence and diversity. These dimensions are especially relevant in CEE, where ownership concentration and institutional heterogeneity shape governance outcomes (La Porta et al., 1999; Lakatos, 2023).

From an agency theory perspective, boards are responsible for monitoring management and mitigating conflicts of interest arising from the separation of ownership and control (Fama and Jensen, 1983). While early research highlights board independence as a key determinant of monitoring effectiveness, subsequent studies show that independence alone is insufficient when directors lack the expertise required to evaluate complex financial and strategic decisions (DeFond et al., 2005; Xie et al., 2003). In CEE markets, where agency conflicts often involve controlling shareholders, the monitoring role of boards becomes more demanding, increasing the importance of board competence.

Resource dependence theory complements this view by emphasizing the advisory role of boards. Directors provide valuable resources, including expertise, experience, and access to external networks, which enhance firms' ability to respond to environmental uncertainty (Pfeffer and Salancik, 1978; Hillman and Dalziel, 2003). Empirical evidence shows that financial, legal, and industry expertise improves decision-making quality and firm performance (Gantenbein et al., 2014). These insights support the use of a composite board competence index capturing multiple dimensions of directors' human capital.

Upper echelons theory further suggests that board diversity enhances decision-making by expanding cognitive perspectives and reducing groupthink (Hambrick and Mason, 1984). However, empirical findings on board diversity remain mixed. While gender diversity has been associated with improved performance in some studies (Adams and Ferreira, 2009; Carter et al., 2010), its effects are often context dependent (Hassan et al., 2020). In CEE markets, where governance practices vary and ownership is concentrated, diversity may influence internal processes more than market outcomes.

Board independence, although widely promoted in governance codes, does not consistently translate into improved firm performance. In environments characterized by concentrated ownership, formally independent directors may lack effective autonomy, limiting their monitoring capacity (Rashid, 2018). These considerations suggest that independence may play a secondary or conditional role relative to competence and diversity.

Overall, the literature indicates that both board competence and board diversity influence firm performance, but their effects are neither uniform nor independent. Existing studies frequently analyse these attributes separately and provide limited evidence from CEE markets. Moreover, insufficient attention has been given to the interaction between competence and diversity, despite theoretical arguments suggesting complementarity (Hillman and Dalziel, 2003). This study addresses these gaps by examining their joint effects in a dynamic panel framework.

The empirical analysis is conducted within the institutional framework of Central and Eastern European (CEE) capital markets, where corporate governance practices are shaped by national governance codes operating under a comply-or-explain regime. These frameworks are broadly aligned with international standards promoting transparency, accountability, and effective board oversight (OECD, 2015). Although all sample countries are subject to EU-level regulation, governance implementation remains heterogeneous due to differences in ownership structures, enforcement mechanisms, and disclosure practices.

Across the five countries examined - Austria, Poland, the Czech Republic, Hungary, and Romania - listed firms are required to disclose compliance with national governance codes or provide explanations for deviations. This framework promotes transparency and market discipline, enabling investors to assess governance quality in a flexible and context-sensitive manner.

Despite this shared regulatory architecture, governance practices differ substantially across countries. Austria exhibits high levels of compliance and standardized reporting, supported by stronger enforcement. In contrast, Poland and Hungary display more volatile compliance patterns, often influenced by state ownership and political factors. The Czech Republic reflects a more principles-based approach shaped by parent–subsidiary structures, while Romania shows gradual improvements in governance practices over time.

These institutional differences have direct implications for empirical analysis. They introduce heterogeneity in governance measurement and disclosure quality and suggest that governance mechanism - particularly board independence and diversity - may operate differently depending on ownership structures and institutional constraints. Accordingly, governance variables are interpreted within their institutional context rather than as universally comparable indicators, reinforcing the need for a context-aware empirical approach.

Based on this framework, the following hypotheses are formulated:

H1: Board competence is positively associated with firm performance (DeFond et al., 2005; Huang, 2013).

H2: Board gender diversity is positively associated with firm performance (Safiullah et al., 2022; Carter et al., 2010).

H3: Multidimensional board diversity is positively associated with firm performance (Adams and Ferreira, 2009; Giannetti and Zhao, 2016).

H4: Board independence has no statistically significant unconditional effect on firm performance once board competence and diversity are controlled for (DeFond et al., 2005; Rashid, 2018).

H5: Board competence and board diversity interact positively in their association with firm performance (Adams and Ferreira, 2009).

To synthesize the theoretical framework and hypotheses development, Figure 1 illustrates the conceptual model underlying the empirical analysis. The model highlights the direct effects of board competence and board diversity on firm performance, as well as their interaction effect.

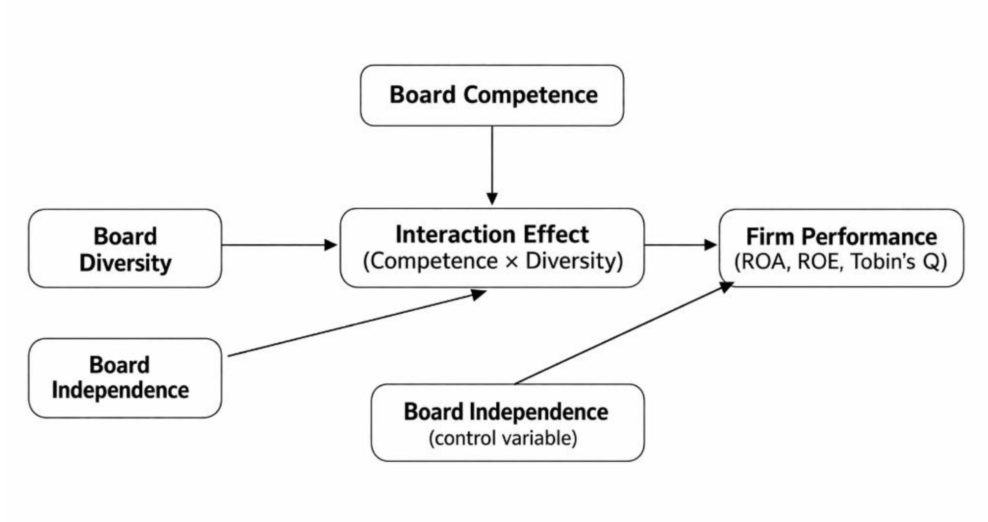


Figure 1 - *Conceptual model*

Board competence and board diversity are expected to influence firm performance both directly and through their interaction. Competence captures the board's human capital and its capacity to process complex information, while diversity contributes to decision-making quality by expanding cognitive perspectives. The interaction term (competence × diversity) reflects the hypothesis that diversity becomes value-enhancing only when supported by sufficient expertise. Board independence is treated as a control variable, capturing formal governance structure rather than substantive effectiveness.

Research Methodology

Sample and data sources. The empirical analysis is based on a hand-collected panel dataset of 44 listed financial and non-financial companies from the main regulated markets of Austria, Poland, Hungary, the Czech Republic, and Romania. The observation period covers ten years, from 2015 to 2024, resulting in a maximum of 440 firm-year observations, subject to data availability. The selection of firms reflects the main stock exchanges in the region and ensures a balanced representation of developed and emerging CEE markets.

Board-level information was manually collected and cross-validated using annual reports, corporate governance statements, and stock exchange disclosures. Financial and market variables were obtained from issuers' annual financial statements and publicly available market disclosures. This approach ensures consistency in variable construction while preserving cross-country comparability across different governance systems.

Variables. Firm performance is measured using both accounting-based and market-based indicators, consistent with prior literature (DeFond et al., 2005; Adams and Ferreira, 2009). The accounting-based measures include Return on Assets (ROA), as a proxy for operational performance, and Return on Equity (ROE), capturing shareholder profitability. Stock return volatility (VOL) is used as a proxy for firm risk and market perception. The market-based indicator is Tobin's Q, reflecting firm valuation. Together, these measures capture complementary dimensions of firm performance.

The main explanatory variables capture board-level characteristics. Board competence (COMP) is operationalized through a composite index aggregating directors' financial, legal, and industry-specific expertise, as well as tenure-related attributes. The index is normalized to ensure comparability across firms and years.

Board diversity (DIV) is measured along three dimensions: gender diversity (proportion of female directors), international diversity (share of non-national directors), and formal board independence (proportion of independent directors). In selected specifications, a composite diversity index is also employed to capture the multidimensional nature of diversity. To account for the joint effects of board characteristics, interaction terms between board competence and diversity measures are included in the empirical models.

The analysis further includes standard control variables commonly used in corporate governance research, namely board size, firm size (log of total assets), financial leverage (total debt to total assets), growth opportunities (market-to-book ratio), and industry effects. These variables help isolate the effect of board characteristics on firm performance.

Empirical Model. To examine the relationship between board characteristics and firm performance, the study uses fixed-effects panel regressions. Firm fixed effects control for time-invariant unobserved heterogeneity across companies, while year fixed effects capture common macroeconomic and market-wide shocks affecting all firms each year. This approach controls for unobserved heterogeneity across firms and time-specific effects (Wooldridge, 2010). The baseline specification can be expressed as follows:

$$Performance_{i,t} = \alpha + \beta_1\, COMP_{i,t} + \beta_2\, DIV_{i,t} + \beta_3\left(COMP_{i,t} x\, DIV_{i,t}\right) + \gamma Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}$$

where:

- $Performance_{i,t}$ represents firm performance (ROA, ROE, or VOL);
- $COMP_{i,t}$ denotes board competence;
- $DIV_{i,t}$ captures board diversity;
- $Controls_{i,t}$ represents firm-level control variables;
- μ_i are firm fixed effects;
- λ_t are year fixed effects;
- $\varepsilon_{i,t}$ is the error term.

While potential endogeneity concerns cannot be fully ruled out, firm and year fixed effects are included to control for unobserved heterogeneity and common shocks. Additionally, robustness checks using alternative specifications support the stability of the results.

To test the complementarity between board competence and board diversity, interaction terms are introduced in additional model specifications. Robustness checks based on alternative variable constructions and model specifications confirm the stability of the main results. Robust standard errors are used to account for potential heteroscedasticity. The inclusion of interaction terms allows for testing whether the effect of board diversity depends on the level of board competence.

Table 1 reports the baseline regression results for the relationship between board characteristics and firm performance. The specifications examine the effects of board competence, gender diversity, the diversity index, and the interaction between competence and diversity across accounting-based and market-based performance measures.

Table 1 - *Regression results*

Variables	ROA (1)	ROA (2)	Tobin's Q (3)
Board competence	0.042***	0.038***	0.017**
	(0.011)	(0.010)	(0.007)
Board diversity (gender)		0.011*	0.009
		(0.006)	(0.005)
Diversity index			0.012*
			(0.007)
Competence × Diversity			0.028**
			(0.013)
Board independence	0.006	0.005	0.004
	(0.005)	(0.004)	(0.003)
Board size	0.004	0.003	0.002
	(0.003)	(0.003)	(0.002)
Firm size (log assets)	Yes	Yes	Yes
Leverage	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Observations	440	440	440
Adjusted R^2	0.31	0.34	0.27

*Notes: Robust standard errors are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All models include firm and year fixed effects. Firm size is measured as the natural logarithm of total assets. The results indicate that board competence has the strongest and most consistent association with firm performance, while diversity effects are weaker and more context dependent.*

To assess the robustness of the baseline findings, Table 2 reports results from alternative model specifications.

Table 2 - *Robustness checks: alternative specifications of the baseline model*

Variables	(1) Lagged	(2) ROE	(3) No Interaction	(4) Full Model
Board competence	0.039***	0.045***	0.041***	0.038***
	(0.012)	(0.013)	(0.011)	(0.010)
Board diversity	0.010*	0.013*	0.012*	0.011*
	(0.006)	(0.007)	(0.006)	(0.006)
Competence × Diversity	0.026**	0.031**		0.028**
	(0.014)	(0.015)		(0.013)
Board independence	0.005	0.006	0.006	0.005
	(0.004)	(0.005)	(0.004)	(0.004)

Variables	(1) Lagged	(2) ROE	(3) No Interaction	(4) Full Model
Board size	0.003	0.004	0.004	0.003
	(0.003)	(0.003)	(0.003)	(0.003)
Firm size (log assets)	Yes	Yes	Yes	Yes
Leverage	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	396	440	440	440
Adjusted R^2	0.29	0.32	0.30	0.34

*Notes: Robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, *p<0.1. Column (1) uses lagged variables to mitigate reverse causality. Column (2) replaces ROA with ROE as an alternative performance measure. Column (3) excludes the interaction term as a benchmark specification. Column (4) is the full baseline model.*

The robustness checks confirm the stability of the main results. Board competence remains positive and statistically significant across all specifications, indicating a consistent association with firm performance. The interaction term between competence and diversity retains its significance in models where it is included, supporting the complementarity hypothesis. The use of lagged variables mitigates concerns related to reverse causality, while alternative performance measures yield qualitatively similar results. Overall, the findings are robust to changes in model specification and variable definition.

Results and Discussion

Descriptive overview. The descriptive analysis reveals substantial variation in board characteristics across firms, countries, and years, supporting the use of multivariate panel econometric techniques. Board competence and board diversity exhibit pronounced cross-sectional and temporal variation, indicating that board composition evolves meaningfully across both firms and institutional contexts.

The competence index shows significant dispersion across firms and countries, reflecting differences in directors' expertise and board-level human capital. Similarly, diversity indicators -such as gender representation, international composition, and formal independence - vary considerably across jurisdictions, consistent with differences in ownership structures and governance frameworks in CEE capital markets.

By contrast, board size remains relatively stable throughout the sample period. This stability suggests that governance adjustments occur primarily through changes in board composition rather than structural redesign, reinforcing the relevance of focusing on qualitative board attributes.

Pairwise correlations among the main governance variables remain moderate, indicating that competence, diversity, and independence capture distinct dimensions of board structure and that multicollinearity is not a major concern. Overall, the descriptive evidence provides preliminary support for the empirical analysis by confirming both sufficient variation in the data and the conceptual distinction between key governance variables. Taken together, these perspectives suggest that board effectiveness is a multidimensional construct shaped by both structural and cognitive factors.

Board competence and firm performance (H1). The regression results provide consistent support for H1, indicating that board competence is positively associated with firm performance. The estimated coefficients for the competence index are positive and statistically significant across both accounting-based measures (ROA, ROE) and the market-based indicator (Tobin's Q).

This finding suggests that boards with higher levels of financial, legal, and industry expertise are more effective in monitoring management and supporting strategic decision-making. The results are consistent with agency theory, which emphasizes the role of informed monitoring (Fama and Jensen, 1983), as well as with resource dependence theory, which highlights the importance of board human capital (Hillman and Dalziel, 2003).

In the context of CEE capital markets, where firms operate in environments characterized by institutional volatility and concentrated ownership, the importance of board competence appears particularly pronounced. Competent boards are better equipped to interpret complex regulatory changes and respond to macroeconomic shocks, thereby improving firm-level outcomes. The economic magnitude of the competence effect is also meaningful, confirming its role as a value-creating governance mechanism.

Board diversity and firm performance (H2–H3). The results provide partial support for H2 and H3, indicating that board diversity has a positive but context-dependent association with firm performance. Gender diversity is positively associated with accounting-based performance measures, although the magnitude of the effect is moderate. This suggests that increased female representation contributes to improved internal governance processes, such as monitoring quality and deliberation, rather than directly affecting market valuation.

The results for multidimensional diversity are less uniform. International diversity may enhance firm performance by bringing access to global knowledge and networks, although its effectiveness depends on firms' strategic and institutional context (Kim et al., 2021). While the composite diversity index shows a positive association with performance in some specifications, the effects are weaker and not consistently statistically significant across all models. This finding reflects the heterogeneous nature of diversity and its dependence on institutional context.

In CEE markets, where ownership concentration and state influence remain important, diversity effects may be mediated by governance structures and may not translate directly into improved firm performance. These results are consistent with prior literature emphasizing that diversity outcomes are contingent on firm-specific and institutional factors (Adams and Ferreira, 2009; Hassan et al., 2020).

Board independence as a control mechanism (H4). The empirical evidence does not support a significant unconditional effect of board independence on firm performance, providing support for H4. Once board competence and diversity are included in the regression models, the coefficient associated with independence becomes statistically insignificant. This finding suggests that formal independence, as defined by governance codes, does not necessarily translate into effective monitoring. In CEE markets, where ownership structures are often concentrated, independent directors may lack the incentives or the authority to challenge controlling shareholders.

The result aligns with prior empirical evidence indicating that independence alone is insufficient to ensure board effectiveness (Rashid, 2018). Instead, the findings highlight the importance of substantive governance characteristics, such as expertise and diversity, over formal compliance indicators.

Complementarity between competence and diversity (H5). The effectiveness of diverse boards depends on leadership and the ability to integrate different perspectives, suggesting that diversity alone may not translate into improved outcomes without adequate coordination and expertise (Kanadlı et al., 2018).

To test H5, interaction terms between board competence and diversity measures are introduced in the regression models. The results indicate a positive and statistically significant interaction effect, suggesting that the performance benefits of board diversity are conditional on the level of board competence. The interaction effect is particularly relevant in the context of CEE markets, where firms face complex and evolving institutional environments. Competence acts as an enabling factor that allows diverse boards to translate heterogeneous perspectives into improved strategic and operational decisions. To examine the complementarity between board competence and diversity, Table 3 reports the interaction effects across alternative performance measures.

Table 3 - *Interaction effects between board competence and diversity*

Variables	ROA	Tobin's Q
Board competence	0.034*** (3.21)	0.015** (2.18)
Board diversity	0.011 (1.45)	0.004 (0.88)
Competence × Diversity	0.045*** (3.67)	0.018** (2.54)
Controls + Fixed Effects	Yes	Yes
Adjusted R^2	0.39	0.31

*Notes: t-statistics are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All models include firm and year fixed effects. Control variables include firm size, leverage, and board size.*

The results indicate that the interaction between board competence and diversity is positive and statistically significant across both performance measures. While diversity alone does not exhibit a significant effect, its interaction with competence suggests that heterogeneous boards become value-enhancing only when supported by sufficient expertise. These findings provide strong empirical support for the complementarity hypothesis and highlight the importance of considering joint governance effects rather than isolated board attributes.

Figure 2 provides a visual summary of the estimated effects of board characteristics on firm performance across model specifications. The figure highlights that board competence exhibits the strongest and most consistent positive effect, followed by the interaction between competence and diversity. In contrast, diversity measures show smaller and less robust effects, while board independence remains statistically insignificant. Overall, the results emphasize the central role of board competence and the complementary nature of diversity.

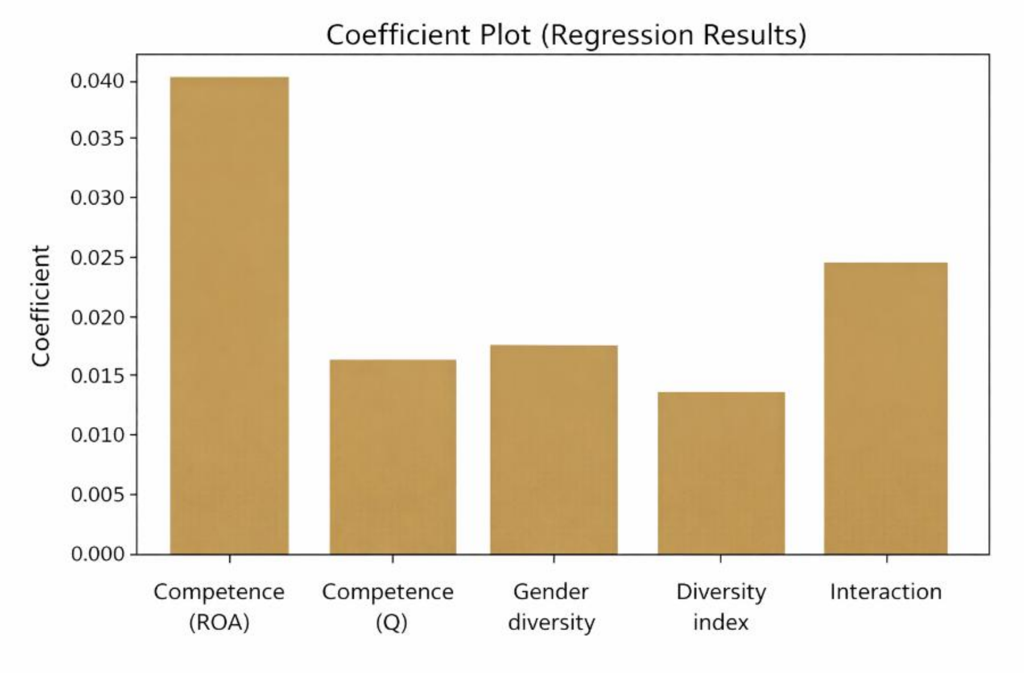


Figure 2 - *Estimated effects of board characteristics on firm performance*

The graphical representation reinforces the econometric findings by highlighting the relative magnitude of coefficients and the central role of board competence as the primary driver of firm performance. From an economic perspective, board competence emerges as a key driver of value creation in CEE firms, while diversity effects remain conditional on expertise. These findings are consistent with prior literature emphasizing the informational and advisory roles of boards (Adams and Ferreira, 2009; Hillman and Dalziel, 2003), while extending this perspective to emerging European markets. The results also suggest that governance quality in CEE is shaped less by formal compliance and more by substantive board capabilities.

Discussion. Overall, the results highlight the central role of board competence as the primary driver of firm performance, while board diversity plays a complementary and context-dependent role. Formal board independence, by contrast, appears to have limited explanatory power once substantive board characteristics are considered.

These findings contribute to the corporate governance literature by providing evidence from CEE capital markets, a region that remains underrepresented in empirical research. The results also suggest that governance effectiveness depends less on formal compliance with governance codes and more on the actual capabilities and composition of boards.

From a policy perspective, the findings indicate that governance reforms should focus not only on increasing board independence or diversity, but also on enhancing the competence and expertise of directors. In emerging and transitional markets, strengthening board human capital may represent a more effective mechanism for improving firm performance than relying solely on formal governance structures.

Conclusions

This study examines the relationship between board characteristics and firm performance in Central and Eastern European (CEE) capital markets, focusing on board competence, board diversity, and board independence. Using a hand-collected panel dataset of 44 listed firms over the period 2015–2024 and fixed-effects regression models, the analysis provides evidence on how board composition influences firm outcomes in institutionally heterogeneous environments. The results indicate that board competence represents the most robust and consistent determinant of firm performance. Higher levels of board expertise, captured through financial, legal, and industry-specific knowledge, are associated with improved accounting-based and market-based performance, highlighting the central role of board human capital in complex and volatile environments.

Board diversity exhibits a positive but context-dependent relationship with performance. Gender diversity is associated with improved accounting-based outcomes, while multidimensional diversity shows weaker and less consistent effects. By contrast, board independence does not exert a statistically significant unconditional effect once competence and diversity are controlled for, suggesting that formal governance mechanisms alone may not ensure effective monitoring in contexts characterized by concentrated ownership.

Importantly, the analysis identifies a positive interaction between board competence and board diversity, indicating that the benefits of diversity are conditional on the level of expertise within the board. This finding supports the view that diversity enhances performance only when supported by sufficient cognitive and professional capacity.

The study contributes to the corporate governance literature by providing new empirical evidence from CEE capital markets and by jointly examining competence and diversity within a unified framework. The findings highlight the distinction between formal governance structures and substantive board effectiveness, emphasizing the importance of board capabilities over formal compliance.

From a practical perspective, the results suggest that policymakers and regulators should complement existing governance frameworks with measures aimed at improving board competence. While diversity and independence remain important governance objectives, their effectiveness depends on the underlying expertise of board members. For firms, the findings underline the importance of strategic board composition in terms of skills and experience.

This study is subject to several limitations. The sample is limited to listed firms in five CEE markets, which may affect generalizability. In addition, the measurement of board characteristics relies on publicly available data, and although fixed-effects models mitigate endogeneity concerns, causality cannot be fully established.

Future research may extend this analysis by incorporating broader cross-country samples, alternative governance measures, and institutional variables such as investor protection and legal enforcement. Further work could also explore the role of board characteristics in shaping firm resilience during periods of economic stress. Overall, the findings suggest that governance effectiveness in CEE markets is driven less by formal compliance mechanisms and more by the substantive configuration of board human capital. Board effectiveness emerges from the interaction of multiple dimensions, with competence acting as the enabling factor that allows diversity to translate into improved outcomes in emerging capital markets.

References

1. Adams, R.B. & Ferreira, D. (2009) Women in the boardroom and their impact on governance and performance. *Journal of Financial Economics*. 94(2). pp. 291–309.
2. Blau, P.M. (1977) *Inequality and Heterogeneity: A Primitive Theory of Social Structure*. New York: Free Press.
3. Carter, D.A., Simkins, B.J. & Simpson, W.G. (2003) Corporate governance, board diversity, and firm value. *The Financial Review*. 38(1). pp. 33–53.
4. Carter, D.A., D'Souza, F., Simkins, B.J. & Simpson, W.G. (2010) The gender and ethnic diversity of US boards and board committees and firm financial performance. *Corporate Governance: An International Review*. 18(5). pp. 396–414.
5. DeFond, M.L., Hann, R.N. & Hu, X. (2005) Does the market value financial expertise on audit committees of boards of directors? *Journal of Accounting Research*. 43(2). pp. 153–193.
6. Fama, E.F. & Jensen, M.C. (1983) Separation of ownership and control. *Journal of Law and Economics*. 26(2). pp. 301–325.
7. Gantenbein, P., Volonté, C. & Zaby, S. (2014) The strategic role of board composition. *Journal of Banking & Finance*. 48. pp. 65–77.
8. Hambrick, D.C. & Mason, P.A. (1984) Upper echelons: The organization as a reflection of its top managers. *Academy of Management Review*. 9(2). pp. 193–206.
9. Hassan, R., Marimuthu, M. & Johl, S.K. (2020) Diversity, corporate governance and firm performance. *Corporate Governance: The International Journal of Business in Society*. 20(3). pp. 483–502.
10. Hillman, A.J. & Dalziel, T. (2003) Boards of directors and firm performance: Integrating agency and resource dependence perspectives. *Academy of Management Review*. 28(3). pp. 383–396.
11. Huang, W. (2013) Board tenure and firm performance. *Journal of Corporate Finance*. 22. pp. 1–16.
12. Kanadlı, S.B., Torchia, M. & Gabaldon, P. (2018) Increasing women's contribution on boards: The importance of chairperson leadership effectiveness. *Corporate Governance: An International Review*. 26(2). pp. 91–105.
13. Kim, D., Pathak, S. & Werner, S. (2021) When do international directors contribute to firm performance? *Journal of Business Research*. 122. pp. 292–304.
14. La Porta, R., Lopez-de-Silanes, F., Shleifer, A. & Vishny, R.W. (1999) Corporate ownership around the world. *Journal of Finance*. 54(2). pp. 471–517.
15. Lakatos, E.S. (2023) Corporate governance and board diversity in Central and Eastern Europe. *Journal of Risk and Financial Management*. 16(4). pp. 1–18.

16. Nielsen, S. & Huse, M. (2010) The contribution of women on boards of directors: Going beyond the surface. *Corporate Governance: An International Review*. 18(2). pp. 136–148.
17. OECD (2015) *G20/OECD Principles of Corporate Governance*. Paris: OECD Publishing.
18. Pfeffer, J. & Salancik, G.R. (1978) *The External Control of Organizations: A Resource Dependence Perspective*. New York: Harper & Row.
19. Rashid, A. (2018) Board independence and firm performance: Evidence from emerging economies. *Journal of Corporate Finance*. 50. pp. 121–139.
20. Xie, B., Davidson, W.N. & DaDalt, P.J. (2003) Earnings management and corporate governance: The role of the board and audit committee. *Journal of Corporate Finance*. 9(3). pp. 295–316.

"One of the key elements of circular economy thinking is designing-out waste."
Ines Garcia

Methodological Guide for Implementation Circular Economy

Roxana-Mariana NECHITA[1,2*], Dana-Corina DESELNICU[2], Víctor Caro FUENTES[3], Cozmin CRISTOIU[4]

[1]National Institute of Research and Development in Mechatronics and Measurement Technique, 6-8, Pantelimon Road, Bucharest, Romania

[2]National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independentei, Bucharest, Romania

[3]Escuela Técnica Superior de Ingenieros Informáticos, Universidad Politécnica de Madrid, Boadilla del Monte, Madrid, Spain

[4]Robodictive SRL, bl. Sc Gheorghe Doja St., Pitesti, Romania

Abstract

This paper provides a structured guide to implement sustainable changes in manufacturing. The research uses 16 academic articles to identify best practices for circular economy adoption. The study focuses on how businesses can connect economic models with technology to improve material recovery. The analysis organizes the transition into four specific phases. The first phase focuses on strategic realignment and collaborative governance. It emphasizes service-based business models and supply chain alignment. The second phase covers design for longevity and material purity. The third phase highlights technological integration and data transparency. The final phase involves operational optimization and systemic scaling. This section addresses reverse logistics networks and the use of performance metrics. This study offers a clear roadmap for organizations to separate economic growth from environmental damage.

Keywords: circular economy, industrial innovation, sustainability, resource management

Introduction

The current global production model operates on a linear trajectory that has reached its ecological and physical limits (Lafforgue and Lorang, 2022). For decades, industrial systems followed a pattern of extracting raw materials, transforming them into short-lived products, and discarding them as waste (Michelini et al., 2017). This approach assumes that natural resources are infinite and that the environment can absorb an unlimited amount of byproduct. However, the rapid depletion of primary

*Correspondence to Roxana-Mariana NECHITA: roxana.nechita2000@gmail.com

materials and the accumulation of pollutants in ecosystems demonstrate that this logic is no longer sustainable (Mitake er al. 2025). Under the aforementioned circumstances, the transition toward a circular framework represents a fundamental shift in how value is created and maintained within the global economy and could be a possible solution or a way to mitigate the problems inherent to the actual model.

The core problem lies in the structural inefficiency of resource use. Even with modern improvements in manufacturing, a large percentage of materials lose their economic value after a single use cycle (Adelekan and Sharmina, 2025; Laurentia et al., 2019). This systemic waste results in significant financial losses for industries and puts immense pressure on supply chains (Figge et al.; Grecu et al., 2025). When biological or technical components are not recovered, the energy and labor invested in their creation are permanently lost. This situation creates a dependency on volatile commodity markets and increases the carbon footprint of every product manufactured (Nechita et al., 2024).

This issue manifests most clearly in energy-intensive industries and sectors that rely on complex global supply chains (Zhao and You, 2024). Manufacturing hubs in both developed and emerging economies face the same challenge: they are producing more goods than the planet can replenish. The problem is evident in the rising costs of waste management and the increasing scarcity of rare earth elements necessary for modern electronics (Bajenaru er al., 2025; Hachaichi and Talandier, 2023). In urban environments, the concentration of waste creates immediate logistical and environmental burdens, while in industrial zones, the lack of integrated systems prevents one company's waste from becoming another's resource (Germain, 2020).

The timing of this crisis is immediate. Over the last two decades, the pace of consumption has accelerated, leading to a situation where the Earth's annual biocapacity is exhausted earlier each year. We are currently in a period where the climate goals set by international agreements cannot be met without a drastic change in industrial output (Neves and Marques, 2022; Pomoni et al., 2024). As populations grow and more people enter the global middle class, the demand for goods will continue to rise. If the transition to circularity does not happen within the current decade, the resulting environmental degradation may become irreversible.

This problem affects a wide range of stakeholders, from corporate leaders and policymakers to the general public. Businesses suffer from unpredictable material costs and regulatory pressure. Governments struggle to meet sustainability targets while maintaining economic growth. On an individual level, communities face the health consequences of pollution and the economic strain of rising prices. Future generations are perhaps the most affected group, as they will inherit a world with fewer resources and more environmental debt (Mukherjee et al., 2023).

Despite the growing volume of literature on sustainability, there is a clear gap in research regarding the practical integration of specific technological innovations within circular frameworks. Many studies focus on the theoretical benefits of the circular economy or analyze isolated case studies. There is a lack of a systematic synthesis that connects "closed-loop" systems and "cradle-to-cradle" principles with the latest advancements in bio-based materials and remanufacturing technologies. Researchers often overlook the precise intersections where innovation turns a theoretical circular concept into a viable industrial standard.

The central research question of this study is: How can technological and innovative practices be systematically organized into a methodological guide to facilitate the transition toward a circular and bio-based economy? By addressing this question, the research seeks to move beyond abstract concepts and provide a structured approach for implementing sustainable industrial changes.

The primary objective of this research is to develop a methodological guide for circular economy practices based on a systematic review of highly cited academic literature. This involves identifying the most effective technological interventions and innovation strategies that support remanufacturing and the use of bio-based resources. The study aims to categorize these practices to provide a clear roadmap for organizations looking to adopt circular models. By filtering the most influential research in the field, this guide ensures that the recommendations are grounded in proven academic evidence.

Expected results include the identification of key success factors for "closed-loop" systems and a detailed classification of innovations that enable "cradle-to-cradle" production. The study will produce a set of evidence-based guidelines that bridge the gap between high-level theory and industrial application. These findings will provide a foundation for future policies and corporate strategies, offering a clear path toward reducing waste and maximizing resource efficiency. Ultimately, this work will contribute to a more resilient economic structure where growth is decoupled from environmental destruction.

Materials and methods

The development of this methodological guide relies on a structured and transparent selection of academic evidence. To ensure that the findings are based on a verifiable process, the research adopts the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) workflow. This framework allows for a clear explanation of how the data was gathered, filtered, and finalized. By following a standard protocol, the methodology avoids subjective bias and focuses on the most influential contributions to the field of circular and bio-based economies.

The Web of Science (WoS) Core Collection served as the primary source for this research. This database is widely recognized for its high standards of indexing and its focus on peer-reviewed journals with significant impact factors. Using a single, high-quality database ensures that the metadata remains consistent throughout the analysis. The search strategy was designed to identify the specific intersection between economic models, technological tools, and practical circularity mechanisms.

The search query was constructed using three distinct sequences, each serving a specific logical purpose within the research framework. The first sequence, *TI = (circular NEAR/1 (econom* OR bioeconom*))*, targets the core subject. By searching within the title (*TI*), the process ensures that the circular economy or bioeconomy is the central theme of the article. This is a fundamental step because it prevents the inclusion of studies where circularity is only a secondary or peripheral topic.

The second sequence, *TS = (technolog* OR innovat*)*, addresses the tools required for change. In academic literature, the term "Enabling Technologies" is a standard phrase used to describe the technical advancements that make a new economic model possible. Without innovation, the transition from a linear to a circular system remains a theoretical goal. This segment captures the technical essence of the study.

The third sequence, *TS = ("closed-loop" OR "cradle-to-cradle" OR remanufactur* OR "bio-based")*, focuses on "Circularity Mechanisms." These terms represent the practical actions that turn a concept into a reality. Whether it is the restoration of products through remanufacturing or the use of biological materials that return safely to the environment, these mechanisms provide the finality for the first two groups of terms. Table 1 summarizes these components and their justifications.

Table 1 – *Search query concepts explanation*

Search segment	Role / Position	Technical role
$TI =$ $NEAR/1$ $bioeconom*$	Circular economy core	Defines the central subject and ensures the study is rooted in the correct economic context.
$TS = (technolog \vee innovat)$	Enabling technologies	Identifies the innovations that permit the existence of new, sustainable industrial models.
$TS =$ cradle-to-cradle $remanufactur$ bio-based	Circularity mechanisms	Focuses on the specific practical actions such as recovery, reuse, and biological cycles.

The selection process followed a logical progression to narrow down the vast amount of available data to a focused set of high-impact articles. As seen in the PRISMA diagram (Figure 1), the initial application of the query formula across different focus areas resulted in three distinct sets of data. The core search for circular economy themes yielded 210 results. The search for enabling technologies was much broader, returning 20,149 records, while the search for specific circularity mechanisms produced 946 results.

The intersection of these three formulas was the first major filtering point. This step removed all records that did not simultaneously address the core theme, the technological aspect, and the specific mechanism of circularity. After this intersection, 555 results remained, while 19,985 records were excluded for failing to meet the combined criteria. This sharp reduction demonstrates the specificity of the research objective.

The next phase of the methodology involved refining the results based on the type of document. The study excluded conference papers, book chapters, and editorial reviews, focusing only on "Articles." This decision ensures that the methodological guide is built on original research that has undergone a full peer-review process and presents primary data. This filter resulted in 343 eligible articles, with 212 records excluded during this stage.

A significant quality control step was the application of an impact filter. The search was refined to include only "Highly Cited Papers" – a data-driven classification within the WoS ecosystem that identifies articles based on their citation volume compared to peer publications in the same field and year, serving as an objective filter distinct from an author-led selection process. In the context of a systematic review, using highly cited work is a strategic choice. It ensures that the guide is based on findings that have already been validated and utilized by a large number of other researchers in the scientific community. This refinement left 17 results, excluding 326 articles that did not meet the high-citation threshold.

The final stage of the PRISMA workflow involved a manual check of the remaining 16 articles. The titles and abstracts were analyzed to confirm their compliance with the study's objective of creating a methodological guide. During this phase, it was determined that all 16 articles perfectly matched the required criteria. There were zero records excluded at this final step. Therefore, the final sample for the systematic review consists of these 16 high-impact studies.

Once the final 16 articles were identified, the methodology moved toward data extraction and synthesis. Each article was analyzed to identify best practices in the circular economy. The analysis focused on how these studies describe the implementation of "closed-loop" and "cradle-to-cradle" systems. By looking at the technical details provided in these highly cited works, the research could extract common patterns and successful strategies.

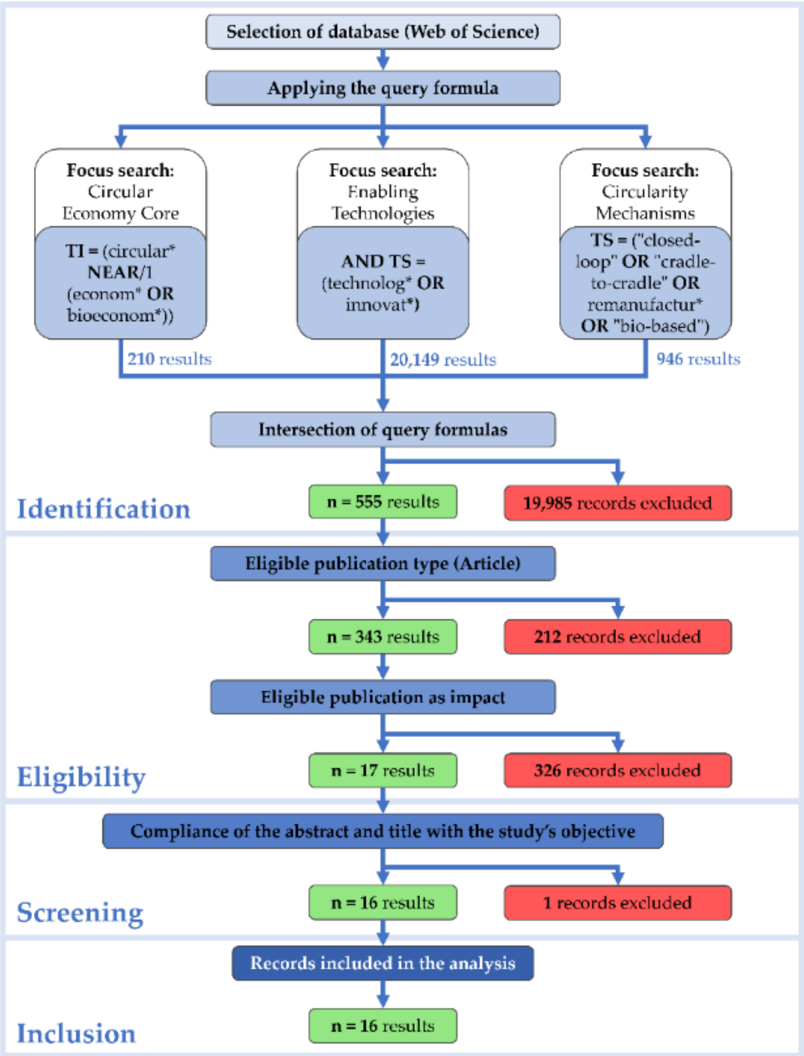


Figure 1 – *PRISMA workflow*

The analysis also prioritized the "bio-based" and "remanufacturing" aspects mentioned in the search query. These elements are necessary for understanding how different industries handle material lifecycles. The goal was to see how innovation acts as a bridge between a traditional manufacturing setup and a circular one. Each of the selected papers provided evidence of how specific technologies lead to better resource efficiency.

This systematic approach provides a solid foundation for the subsequent guide. By using a transparent and repeatable method, the research ensures that the recommendations are not based on random selection but on a filtered hierarchy of academic excellence. The use of the PRISMA workflow guarantees that every step, from the initial database selection to the final manual review, is documented and logical. This clarity is essential for a methodological guide that aims to be used by professionals and researchers alike in the field of sustainable innovation.

Results of research

This chapter presents the findings of the systematic review and organizes them into a coherent body of knowledge. The first part examines the 16 selected studies in detail, discussing their methodologies, specific findings, and the logic they provide for circular transitions. The second part synthesizes these results into a methodological guide, offering a practical framework for implementing circular economy and bioeconomy principles.

Discussion of the selected literature. The academic landscape of the circular economy is built on a variety of industrial perspectives, ranging from heavy manufacturing and construction to biotechnology and textile production. A central finding across several studies is that the circular economy is not a fixed destination but a process of continuous adaptation. Prieto-Sandoval et al. (2018) provide a foundational consensus on this topic, arguing that eco-innovation is the primary driver of circularity. Their research maps the knowledge field and concludes that a paradigm shift in how we perceive resources is necessary. They suggest that companies must move beyond the simple goal of waste reduction and instead focus on creating regenerative systems. This shift implies that every byproduct of an industrial process should be viewed as a potential feedstock for another, effectively erasing the concept of "waste" from the corporate vocabulary.

The practical application of these ideas is explored by Ghisellini and Ulgiati (2020) through an extensive study of 292 organizations in Italy. Their data shows that while many firms adopt basic recycling practices, very few reach the level of full remanufacturing or product-service systems. The constraints they identify include high transition costs and a lack of integrated supply chain cooperation. The authors suggest that many organizations still view circularity through a linear lens, attempting to "fix" the end of the pipe rather than redesigning the entire system. This theme of cooperation is further developed by De Angelis et al. (2018), who propose the concept of the "Circular Supply Chain" (CSC). They argue that traditional supply chain management must be replaced by a model where material flows are both open and closed. Their work emphasizes a shift from product ownership to leasing models, which ensures that the manufacturer stays connected to the product throughout its life. This connection is not just logistical; it is a fundamental change in the business relationship, where the producer becomes a service provider responsible for maintenance and recovery.

In the building and construction sector, the challenges of circularity are particularly visible due to the large scale of materials used. Leising et al. (2018) provide an analysis of three pilot projects in the Dutch building sector. They conclude that the early involvement of all partners in the design phase is the most critical factor for success. They introduce a collaboration tool designed to help project teams align their goals. Without this early alignment, the physical recovery of building components at the end of their useful life becomes nearly impossible. Complementing this, Ogunmakinde et al. (2022) examine how circular construction contributes to the United Nations Sustainable Development Goals (SDGs). Their review links circular practices to specific targets like goal 12 (responsible consumption) and goal 11 (sustainable cities), proving that industrial changes have broad social benefits. Schroeder et al. (2019) expand this analysis by matching circular economy practices with a wide range of SDG targets. They find that circularity is a prerequisite for achieving global sustainability, especially in areas related to water management and clean energy. Their findings suggest that the circular economy is not an isolated environmental strategy but a core component of the global development agenda.

The technological aspect of the transition is another major area of debate. Jensen et al. (2023) investigate the data needs for "Digital Product Passports" (DPP). This technology is seen as a key policy instrument because it allows for the tracking of materials across different users. Their study identifies seven data clusters that are essential for decision-making during the product life cycle, such as material composition and dismantling instructions. By providing transparency, the DPP removes the informational barriers that currently hinder recycling and remanufacturing. Similarly, Despeisse et al. (2017) explore how 3D printing can unlock value by enabling on-demand production. This technology reduces material waste and allows for the local repair of products, which shortens the loop of the circular economy. The ability to manufacture a spare part on-site can extend the life of industrial equipment by years, preventing the premature disposal of complex machinery.

The textile industry faces its own unique set of struggles, as documented by Franco (2017). Through multiple case studies of companies using "Cradle to Cradle" (C2C) certification, Franco explores the tension between established business models and the need for systemic change. The study shows that circularity requires a redesign of the entire product architecture, not just a change in raw materials. It is a process that touches upon dye selection, fiber blends, and even the type of thread used in seams. This need for chemical and material redesign is supported by Sheldon and Norton (2020) in their perspective on green chemistry. They argue that the plastic pollution crisis can only be solved by moving toward bio-based alternatives that are designed for easy recycling or biodegradation. Their research highlights the role of biocatalytic technologies in breaking down plastics into their original components, allowing for a "true" circularity where quality is never lost during the recycling process.

The bioeconomy branch of circularity is represented by studies focused on waste valorization. Wagh et al. (2024) describe the conversion of agro-industrial waste into high-value products as a "sustainable symphony." They focus on biorefineries that extract energy and chemicals from agricultural residues. This model transforms the agricultural sector from a source of raw food products into a hub for green chemical manufacturing. Velvizhi et al. (2022) provide technical evidence on how lignocellulosic biomass can be processed into value-added materials, paving a path toward a circular bioeconomy. Their work emphasizes the importance of integrated processes that maximize the utility of every fraction of the biomass. Ariyanti et al. (2025) offer a specific case study on the production of furfural from corn cob waste using hydrothermal processes. This research proves that agricultural byproducts, which are usually burned or discarded, can become valuable feedstocks for the chemical industry, providing a renewable alternative to petroleum-based chemicals.

In the forestry sector, D'Amato et al. (2020) analyze how Finnish small and medium-sized enterprises (SMEs) adopt circular business models. They find that these firms use wood-based resources to create innovative products that replace fossil-based materials. The study notes that circularity helps these companies improve their competitiveness in the global market by offering low-carbon solutions to a demanding consumer base. Furthermore, the concept of "Urban Mining" is examined by Xavier et al. (2021) as a solution for electronic waste (e-waste). They argue that the recovery of materials from post-consumer waste is a form of closed-loop supply chain management that reduces the environmental impact of traditional mining. By treating the city as a mine, organizations can secure critical raw materials while solving the growing problem of toxic waste. Finally, Urbinati et al. (2017) propose a taxonomy of business models, categorizing companies based on their degree of circularity. Their work shows that the most advanced firms are those that integrate circularity into both their internal operations and their customer-facing value propositions. They move beyond efficient production to create a circular relationship with the market.

Based on the comprehensive literature review provided, the following table (Table 2) synthesizes the core concepts of the circular economy and identifies the specific authors and studies that support each development.

Table 2 – *Cross-referenced synthesis of circular economy concepts*

Core concept	Mechanism and industrial application	Supporting literature
Eco-innovation as the driver	Moving from simple waste reduction to regenerative systems; paradigm shift in resource perception.	(Prieto-Sandoval, Jaca and Ormazabal, 2018); (Ghisellini and Ulgiati, 2020); (De Angelis, Howard and Miemczyk, 2018)
Supply chain collaboration	Transitioning from product ownership to leasing/service models; integrated industrial symbiosis.	(De Angelis, Howard and Miemczyk, 2018); (Leising, Quist and Bocken, 2018); (Franco, 2017); (Urbinati, Chiaroni and Chiesa, 2017)
Circular design	Designing for disassembly and longevity; modularity and elimination of non-recyclable "monsters."	(Franco, 2017); (Sheldon and Norton, 2020); (Leising, Quist and Bocken, 2018); (Jensen et al., 2023)
Digital transparency	Use of DPP to track material composition and maintenance history across the life cycle.	(Jensen et al., 2023); (Despeisse et al., 2017); (De Angelis, Howard and Miemczyk, 2018)
Bio-based waste valorization	Converting agri-forest residues into high-value chemicals/energy via integrated biorefinery processes.	(Wagh et al., 2024); (Velvizhi et al., 2022); (Ariyanti et al., 2025); (D'Amato, Veijonaho and Toppinen, 2020); (Sheldon and Norton, 2020)
Strategic SDG alignment	Mapping industrial practices to UN goals for water, energy, and sustainable cities.	(Schroeder, Anggraeni and Weber, 2019); (Ogunmakinde, Egbelakin and Sher, 2022); (D'Amato, Veijonaho and Toppinen, 2020)
Secondary sourcing (urban mining)	Recovery of critical metals from e-waste to reduce environmental footprints of traditional mining.	(Xavier et al., 2021); (Ghisellini and Ulgiati, 2020) (Urbinati, Chiaroni and Chiesa, 2017)

Together, these 16 articles demonstrate that the circular economy is supported by a combination of technological innovation, strategic collaboration, and material science. The literature shifts from general theory to specific industrial applications, providing a solid foundation for the methodological guide developed in the following section.

Methodological guide and implementation

This section introduces the original methodological guide developed from the synthesis of the reviewed literature. This framework (Figure 2) serves as a practical roadmap for organizations seeking to transition from linear to circular models. It is structured into four sequential phases, each supported by the empirical findings discussed in the previous section.

Figure 2 – *The proposed workflow as a methodological guide*

Phase 1: Strategic Realignment and Collaborative Governance

The transformation from a linear to a circular model begins with a fundamental change in how a company defines its purpose. Linear systems rely on the extraction of raw materials, the production of goods, and the eventual disposal of those goods as waste. This traditional approach assumes that resources are abundant and that the environment can handle an endless stream of discarded products. The shift to circularity requires an organizational movement toward the retention of value. Firms must stop viewing their output as a simple product sold to a customer. Instead, they must view their output as a value provider that remains under their responsibility for its entire life cycle.

The first step in this strategy is the completion of a Circular Business Audit. This audit identifies specific areas where resources leak from the organization. It tracks the flow of materials through the factory floor and into the market. Managers must calculate the volume of waste generated at every stage of production and analyze the causes of this waste. This data provides the baseline for the transition. Without this clear picture of current material flows, any change will lack a firm foundation. The audit identifies where companies lose potential revenue by treating byproducts as trash rather than as inputs for other processes.

Following the findings of Prieto-Sandoval et al. (2018) and Urbinati et al. (2017), organizations must align their business models with service-based approaches. This means moving away from selling products and moving toward selling the utility or the service that a product provides. For example, a lighting company might sell light hours rather than light bulbs. This change aligns the company's profit motive with product longevity. The company now has a financial incentive to make the product last longer and to ensure its easy repair.

As Leising et al. (2018) and De Angelis et al. (2018) emphasize, circularity is a team effort that extends beyond the internal boundaries of a single firm. This committee must include representatives from the entire supply chain. It requires participation from product designers, procurement specialists, waste management partners, and logistics experts. The goal is to align the incentives of all these parties. In a linear model, a supplier often benefits from selling more raw material. In a circular model, the committee works to change this incentive.

For example, a supplier might be paid for the performance of a material rather than for the volume sold. This shifts the focus from quantity to efficiency. The committee also works to map these strategic goals against the SDGs. As Schroeder et al. (2019) note, this mapping ensures that the business strategy remains in line with global policy trends. It helps the company communicate its commitment to sustainability in a way that investors and regulators understand. The committee manages the conflicts that arise when different departments prioritize different outcomes. By formalizing this governance structure, the organization ensures that the transition receives the necessary attention and resources to succeed.

Phase 2: Design for Longevity and Material Purity

The second phase moves from strategy to product engineering. Design choices made at the start of the production process determine the entire life cycle of a product. A product that is difficult to disassemble at the end of its life will almost always end up in a landfill. Based on the C2C principles discussed by Franco (2017) and the green chemistry protocols outlined by Sheldon and Norton (2020), organizations must prioritize design for disassembly. Designers should select robust and resistant materials, especially for machines placed in environments that could cause degradation. This approach avoids the use of complex material blends that defy separation. When manufacturers glue or weld together different materials, they create a product that cannot be recycled in any cost-effective way.

Engineers must adopt a Modular Product Architecture. This design style ensures that individual components can be easily swapped for repair or upgrade. A modular design allows the company to replace a single faulty part rather than discarding the entire unit. This saves the customer money and reduces the demand for new raw materials. It also enables the company to keep its own products in use for longer periods. The focus shifts to making components that are robust and easy to replace. Companies should also apply an open source model for discontinued products. When firms stop offering repair services for old products, they can release technical specifications for specific parts. This allows other companies to create these parts, provided there are monetary incentives. This strategy increases the capacity to repair old items.

Material selection is another key element of this phase. Organizations must prioritize renewable and bio-based sources. Following the evidence from Wagh et al. (2024) and Velvizhi et al. (2022), firms should explore the use of agro-industrial byproducts as raw materials. These materials often represent waste from other industries, such as agriculture or food processing. By turning these byproducts into production inputs, companies reduce their dependence on virgin materials and lower their environmental impact.

The guide suggests the implementation of a Material Purity Protocol. This protocol requires that every substance entering the production process must be categorized. The design team must ensure that every material can return to either a biological or a technical loop at the end of the product life. A biological loop allows organic materials to return to the earth as nutrients. A technical loop allows synthetic materials, such as metals or polymers, to return to the manufacturing process without losing quality.

This phase eliminates the creation of products that are neither recyclable nor biodegradable. Design teams must test materials for their recyclability before the product goes into production. They must also consider the chemicals used in manufacturing. Green chemistry protocols advocate for the reduction of hazardous substances in the production process. This makes the recycling process safer and cheaper. By investing time and effort into the design stage, companies avoid the downstream costs of waste management and material loss. This approach ensures that the product is designed for its next life from the very beginning.

Phase 3: Technological Integration and Data Transparency

In the third phase, technology enables the management of circular flows. The transition requires a level of data transparency that linear models do not support. The central tool for this task is the DPP, as investigated by Jensen et al. (2023). This passport provides a clear record of the product life. It should contain a full bill of materials and specific instructions for the end of the product life. This transparency allows recyclers to recover materials at their highest value. Without this data, recyclers often treat products as mixed waste, which results in downcycling instead of true recovery.

The passport acts as a communication link between the manufacturer, the user, and the recycler. It tells the recycler what materials exist in the product and how to safely disassemble it. It also provides the user with information about how to repair the product or where to return it. This data reduces the uncertainty that currently plagues the recycling industry. When recyclers know exactly what they are receiving, they can develop more efficient processes to recover valuable components.

Furthermore, the guide recommends the adoption of Additive Manufacturing for localized repair hubs. As Despeisse et al. (2017) suggest, 3D printing allows a company to support products in the field without maintaining large inventories of spare parts. This technology enables the production of components on demand. When a customer needs a repair part, a local hub can print it and ship it immediately. This reduces the carbon footprint of transport and the costs associated with warehousing. It also extends the life of products that would otherwise be discarded due to the lack of available spare parts.

For industries with significant electronic or metal components, Urban Mining protocols should be integrated into the sourcing strategy. As explored by Xavier et al. (2021), this concept involves treating the company own returned products as a mine for secondary materials. This transforms the waste management department into a procurement unit. Instead of buying raw materials from traditional mining sources, the company recovers metals and rare materials from its own old products.

This strategy requires a shift in how the company views waste. Waste is no longer a liability to be disposed of. It is an asset to be recovered. The company designs its processes to extract the maximum value from these returned items. This reduces the need for new material extraction and protects the company from price volatility in the commodities market. By integrating digital passports, additive manufacturing, and urban mining, companies create a technology-based infrastructure that supports the circular model. This infrastructure makes circularity operationally and economically viable.

Phase 4: Operational Optimization and Systemic Scaling

The final phase focuses on the reverse logistics network and the scaling of circular practices. Organizations must build the physical infrastructure to take products back from the market. A linear supply chain is designed to move goods from the factory to the consumer. A circular supply chain must be able to move goods from the consumer back to the factory or to a recycling facility. This requires an efficient network for the collection, transport, and processing of used goods.

Organizations must optimize their transport routes to use empty return trips for the collection of used items. In many industries, trucks deliver goods to retailers or customers and then return empty. This is a massive waste of transport capacity. By using these return trips to pick up used products, companies reduce both their costs and their environmental impact. As Ghisellini and Ulgiati (2020) note, this practice improves the efficiency of the entire logistics network. It also strengthens the relationship with the customer, who gains a convenient way to return used products.

Continuous monitoring is necessary for success. The guide proposes the use of Circularity Metrics. These metrics provide a clear picture of whether the transition is delivering the expected results. One important metric is the Material Reutilization Score. This score measures the percentage of recycled or renewable materials used in the production process. Another metric is the Product Lifetime Extension Index. This index tracks how long a product stays in use before it is discarded or recycled. These metrics allow managers to set targets and track progress over time. They turn abstract sustainability goals into measurable business outcomes.

Once a circular loop is successful for one product line, the model must be scaled across the entire organization. This is often the most difficult part of the process. It requires overcoming the resistance to change and updating the internal processes of the whole company. This phase includes Customer Engagement programs to educate users on their role in the loop. To further promote recycling, organizations should offer financial incentives for returned byproducts. Mobile device manufacturers and network providers already use this approach by offering payments or discounts to customers who return old devices. This encourages product take-back and helps recover value within the circular economy.

D'Amato et al. (2020) and Ogunmakinde et al. (2022) find that scaling circularity involves changing the organizational culture. Every department, from marketing to finance, must understand how the circular model supports the long-term success of the business. The company must promote the benefits of its circular products to the market. It must also work with regulators to advocate for policies that support circularity. By following this four-phase methodological guide, organizations systematically dismantle their linear structures and replace them with a resilient framework. This approach ensures that the transition is grounded in verified industrial practices and supported by the latest advancements in technology and material science.

Conclusion

The implementation of a circular economy model shifts the focus of a business from volume to value retention. By following the four phases of strategic realignment, product design, technological integration, and operational scaling, organizations replace linear waste generation with managed resource cycles. Each phase addresses a specific barrier, from the lack of collaboration in the supply chain to the difficulty of reclaiming secondary materials. Success depends on the ability of firms to treat returned products as assets and to use data to guide every decision. While this transition requires effort and investment in new infrastructure, the resulting model offers a path to economic stability and resource efficiency. Organizations that adopt these strategies strengthen their position in the market and contribute to a more sustainable industrial future. The adoption of these practices transforms the way companies relate to their products, their partners, and their customers, ensuring that resources remain in the economy for as long as possible.

Acknowledgments. This work has been supported by: (1) Research Program Nucleu within the National Research Development and Innovation Plan 2022–2027, carried out with the support of MCID, project no. PN 23 43 04 01; (2) Support Center for International RDI Projects in Mechatronics and Cyber-Mix-Mechatronics, Contract no. 323/22.09.2020, project co-financed by the European Regional Development Fund through the Competitiveness Operational Program (POC) and the national budget; (3) the CERMISO Center (Project Contract No. 159/2017, Program POC-A.1-A.1.1.1.1-F), and (4) ERASMUS-EDU-2023-EUR-UNIV, Project 101124676 — EELISA, funded by the European Union, https://eelisa.eu/. The authors also acknowledge the use of DeepL version: Translate and DeepL version: Write AI-powered edits for the translation of the manuscript from Romanian to English, last accessed on April 20, 2026. Figures 1 and 2 were created using PowerPoint, part of the Microsoft Office Professional 2013 suite, version 15.0.5603.1000. Additionally, Figure 2 incorporates elements from Flaticon, accessed on April 5, 2026.

Views and opinions expressed are those of the authors only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

REFERENCES

1. Adelekan, A. & Sharmina, M. (2025) A review of circular business models for zero carbon, zero waste and zero material extraction in the building sector’. *Procedia CIRP*. 135. pp. 14–20.
2. Ariyanti, D., Rimantho, D., Leonardus, M., Ardyani, T., Lisnawati, Fiviyanti, S., Sarwana, W., Hanifah, Y., Agustian, E., Meliana, Y., Susparini, N.T., Fansuri, M.H., Putra, O.A. & Simanungkalit, S. (2025) Valorization of corn cob waste for furfural production: A circular economy approach. *Biomass and Bioenergy*. 194. p. 107665.
3. Bajenaru, V.-D., Nechita, R.-M. & Istriteanu, S.-E. (2025) Intelligent Eco-Technologies for End-of-Life Photovoltaic Modules: A Systematic Review. *Technologies*. 13(10). Multidisciplinary Digital Publishing Institute. p.476.

4. D'Amato, D., Veijonaho, S. & Toppinen, A. (2020) Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs. *Forest Policy and Economics*. 110. p. 101848.
5. De Angelis, R., Howard, M. & Miemczyk, J. (2018) Supply chain management and the circular economy: towards the circular supply chain. *Production Planning & Control*. 29(6). Taylor & Francis. pp. 425–437.
6. Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S.J., Garmulewicz, A., Knowles, S., Minshall, T.H.W., Mortara, L., Reed-Tsochas, F.P. & Rowley, J. (2017) Unlocking value for a circular economy through 3D printing: A research agenda. *Technological Forecasting and Social Change*. 115. pp. 75–84.
7. Figge, F., Thorpe, A.S. & Good, J. (2021) Us before me: A group level approach to the circular economy. *Ecological Economics*. 179. p. 106838.
8. Franco, M.A. (2017) Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry. *Journal of Cleaner Production*. 168. pp. 833–845.
9. Germain, M. (2020) Limits to growth and structural change. *Structural Change and Economic Dynamics*. 55. pp. 204–221.
10. Ghisellini, P. & Ulgiati, S. (2020) Circular economy transition in Italy. Achievements, perspectives and constraints. *Journal of Cleaner Production*. 243. p. 118360.
11. Grecu, I., Nechita, R.-M., Stochioiu, F.-P.-G., Ulerich, O., Dumitrescu, C.-I. & Cristoiu, C. (2025) A Decision-Oriented Framework for Sustainable Supply Chain Redesign: A DEMATEL-Based Approach. *Logistics*. 9(3). Multidisciplinary Digital Publishing Institute. p. 90.
12. Hachaichi, M. & Talandier, M. (2023) Assessing the ecological performance of French territories using a spatially-nested approach. *Ecological Indicators*. 155. p. 110947.
13. Jensen, S.F., Kristensen, J.H., Adamsen, S., Christensen, A. & Waehrens, B.V. (2023) Digital product passports for a circular economy: Data needs for product life cycle decision-making. *Sustainable Production and Consumption*. 37. pp. 242–255.
14. Lafforgue, G. & Lorang, E. (2022) Recycling under environmental, climate and resource constraints. *Resource and Energy Economics*. 67. p. 101278.
15. Laurentia, A., Viorica, D., Maria, S., Mihai, G., Mihaela, N., Corina, D.D. & Xioyan, P. (2019) Biodegradable Polymer Composite based on Recycled Polyurethane and Finished Leather Waste. *IOP Conference Series: Earth and Environmental Science*. 401(1). IOP Publishing. p. 012006.
16. Leising, E., Quist, J. & Bocken, N. (2018) Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner Production*. 176. pp. 976–989.
17. Michelini, G., Moraes, R.N., Cunha, R.N., Costa, J.M.H. & Ometto, A.R. (2017) From Linear to Circular Economy: PSS Conducting the Transition. *Procedia CIRP*. 64. pp. 2–6.
18. Mitake, Y., Kishita, Y. & Umeda, Y. (2025) Exploring Smart Circular Systems: Intersection of Servitization, Digitalization, and Circularity. *Procedia CIRP*. 135. pp. 738–743.
19. Mukherjee, P.K., Das, B., Bhardwaj, P.K., Tampha, S., Singh, H.K., Chanu, L.D., Sharma, N. & Devi, S.I. (2023) Socio-economic sustainability with circular economy — An alternative approach. *Science of The Total Environment*. 904. p. 166630.
20. Nechita, R.-M., Ulerich, O., Nechita, M.-M. & Cristoiu, C. (2024) Topology Optimization in the Automotive Industry. *FAIMA Business & Management Journal*. 12(4). pp.62-70.
21. Neves, S.A. & Marques, A.C. (2022) Drivers and barriers in the transition from a linear economy to a circular economy. *Journal of Cleaner Production*. 341. p. 130865.
22. Ogunmakinde, O.E., Egbelakin, T. & Sher, W. (2022) Contributions of the circular economy to the UN sustainable development goals through sustainable construction. *Resources. Conservation and Recycling*. 178. p. 106023.
23. Pomoni, D.I., Koukou, M.K., Vrachopoulos, M.Gr. & Vasiliadis, L. (2024) Circular economy: A multilevel approach for natural resources and wastes under an agri-food perspective. *Water-Energy Nexus*. 7. pp. 103–123.
24. Prieto-Sandoval, V., Jaca, C. & Ormazabal, M. (2018) Towards a consensus on the circular economy. *Journal of Cleaner Production*. 179. pp. 605–615.

25. Schroeder, P., Anggraeni, K. & Weber, U. (2019) The Relevance of Circular Economy Practices to the Sustainable Development Goals. *Journal of Industrial Ecology*. 23(1). John Wiley & Sons. Ltd. pp. 77–95.

26. Sheldon, R.A. & Norton, M. (2020) Green chemistry and the plastic pollution challenge: towards a circular economy. *Green Chemistry*. 22(19.) pp. 6310–6322.

27. Urbinati, A., Chiaroni, D. & Chiesa, V. (2017) Towards a new taxonomy of circular economy business models. *Journal of Cleaner Production*. 168. pp. 487–498.

28. Velvizhi, G., Balakumar, K., Shetti, N.P., Ahmad, E., Kishore Pant, K. & Aminabhavi, T.M. (2022) Integrated biorefinery processes for conversion of lignocellulosic biomass to value added materials: Paving a path towards circular economy. *Bioresource Technology*. 343, p. 126151.

29. Wagh, M.S., S, S., Nath, P.C., Chakraborty, A., Amrit, R., Mishra, B., Mishra, A.K. & Mohanta, Y.K. (2024) Valorisation of agro-industrial wastes: Circular bioeconomy and biorefinery process – A sustainable symphony. *Process Safety and Environmental Protection*. 183. pp. 708–725.

30. Xavier, L.H., Giese, E.C., Ribeiro-Duthie, A.C. & Lins, F.A.F. (2021) Sustainability and the circular economy: A theoretical approach focused on e-waste urban mining. *Resources Policy*. 74. p. 101467.

31. Zhao, X. & You, F. (2024) From sustainable macro debris chemical recycling to microplastic reclamation: Overview, research challenges, and outlook. *Journal of Cleaner Production*. 454. p. 142281.

"*When we throw anything away it must go somewhere.*"
Annie Leonard

Governance Transparency Index

Ileana BOTEZ*[1], Alina-Mioara COBUZ-BAGNARU[2]

[1]Bucharest University of Economic Studies, 6 Piata Romana, Bucharest, Romania

[2] George Emil Palade University of Medicine, Pharmacy, Science and Technology, 38 Gh. Marinescu blvd, Targu Mures, Romania

Abstract

This study examines how corporate governance transparency influences price formation and market discipline in European capital markets, with implications for sustainable capital allocation in the context of the circular economy transition. We develop an integrated framework in which governance transparency affects market outcomes through informational, structural, and institutional channels. Using a hand-collected panel of 44 listed firms from five Central and Eastern European markets over 2015–2024, we construct a Governance Transparency Index (GTI) and examine its relationship with stock return volatility and market depth. The results show that higher governance transparency is associated with lower volatility and improved market depth. Overall, the findings indicate that the market impact of corporate governance depends jointly on transparency, tradability, and institutional credibility, with implications for EU capital market integration and sustainable capital allocation.

Keywords: governance transparency, governance disclosure, free float, market liquidity

Introduction

Capital markets rely on timely, credible, and tradable information to efficiently incorporate firm-specific fundamentals into prices. While corporate governance has traditionally been analysed as an internal monitoring mechanism aimed at mitigating agency conflicts, its role as an informational infrastructure for capital markets has received comparatively less systematic attention. Governance arrangements determine not only how firms are controlled, but also what information is disclosed, how consistently it is communicated, and how effectively investors can assess managerial accountability.

" Solution to pollution – dilution – is an outdated and ineffective response, that does not examine the design that caused the pollution."
Michael Braungart

The theoretical foundation for the informational role of governance lies in the disclosure literature. Prior research shows that increased disclosure reduces information asymmetry and improves

*Correspondence to Ileana BOTEZ: ileana.botez@bvb.ro

market liquidity (Diamond and Verrecchia, 1991), while higher disclosure quality is associated with lower bid–ask spreads and increased trading activity (Leuz and Verrecchia, 2000). Governance-related disclosure - covering board structure, oversight mechanisms, remuneration policies, and shareholder rights - enhances the transparency of managerial incentives and control structures. Corporate governance can therefore be understood as a mechanism through which providers of capital secure returns on their investment (Shleifer and Vishny, 1997), an effect that becomes relevant for markets only when governance arrangements are observable and interpretable.

Despite this theoretical linkage, empirical evidence on the market impact of corporate governance remains mixed. A key limitation of prior research is the frequent conflation of governance quality with governance transparency. Many studies rely on composite governance indicators without distinguishing whether governance affects market outcomes through improved internal control or through enhanced public disclosure. This distinction is particularly relevant in European capital markets, where governance reforms are increasingly embedded in transparency requirements under the EU Listing Act and the broader Capital Markets Union (CMU) agenda.

This paper focuses explicitly on corporate governance transparency - the extent to which governance structures, processes, and responsibilities are clearly and publicly disclosed - and examines whether such transparency improves price formation by reducing information asymmetry. We argue that governance affects market outcomes not merely because it exists, but because it is observable, tradable, and credible.

To capture this mechanism, the paper develops an integrated framework based on three complementary channels. First, transparency expands the public information set and reduces uncertainty regarding managerial incentives, contributing to price discovery (Bushman and Smith, 2001). Second, tradability determines whether disclosed information can be incorporated into prices. When free float is limited, trading activity is constrained and disclosure effects remain muted; by contrast, higher tradable share supply enables investors to act on available information, facilitating price formation. Third, institutional credibility influences how governance disclosures are interpreted. Alignment with internationally recognized standards, such as the G20/OECD Principles of Corporate Governance (2023), enhances the comparability and reliability of disclosed information, strengthening its pricing relevance.

Empirically, the analysis is conducted on a hand-collected panel of 44 listed firms from Austria, Poland, Hungary, the Czech Republic, and Romania over the period 2015–2024. We construct a Governance Transparency Index (GTI) capturing periodic reporting, governance disclosure, ongoing regulated information, and shareholder-related transparency, and combine it with firm-level free float and OECD alignment indicators to examine how transparency, tradability, and credibility jointly affect market quality. From a financial reporting perspective, governance disclosure should be viewed not only as a compliance requirement, but as a value-relevant information channel that directly affects market outcomes.

The findings indicate that governance transparency contributes to improved price formation by reducing information asymmetry and enhancing market liquidity, but that these effects are conditional on tradability and institutional credibility. Beyond traditional market outcomes, the results suggest that improved transparency supports more efficient capital allocation by enabling investors to identify firms characterized by stronger accountability and long-term orientation, including those aligned with resource-efficient and circular economic models (Geissdoerfer et al., 2017; Friede et al., 2015).

By integrating informational, structural, and institutional dimensions, this study contributes to the literature by repositioning corporate governance as a market-facing informational mechanism, identifying tradability as a key transmission channel, and demonstrating the role of institutional credibility in amplifying the market relevance of governance disclosure.

Literature review and hypotheses

Capital markets play a central role in supporting the transition toward more sustainable and resource-efficient economic systems. In particular, the circular economy - defined as a model aimed at reducing resource use and waste through reuse, recycling, and efficiency - relies on the ability of financial markets to allocate capital toward firms adopting such business models (Geissdoerfer et al., 2017; Kirchherr et al., 2017). In this context, corporate governance contributes to sustainability objectives by enhancing transparency, accountability, and long-term strategic orientation (OECD, 2023), while improved disclosure reduces informational frictions and facilitates the incorporation of sustainability considerations into investment decisions (Dhaliwal et al., 2011; Friede et al., 2015).

Against this background, this study develops an integrated framework in which corporate governance transparency affects market discipline through three complementary mechanisms: information availability, tradability, and credibility. These mechanisms are grounded in the disclosure, market microstructure, and institutional governance literatures and provide a unified explanation for the heterogeneous empirical findings in prior research.

Governance Transparency and Information Asymmetry. The relationship between disclosure and market quality represents a central theme in financial economics. Information asymmetry between insiders and outside investors generates adverse selection, wider spreads, and lower liquidity. Prior research shows that enhanced disclosure reduces information asymmetry and improves market liquidity (Diamond and Verrecchia, 1991), while higher disclosure quality is associated with lower trading costs and greater market depth (Leuz and Verrecchia, 2000). Disclosure also facilitates external monitoring and mitigates agency conflicts (Healy and Palepu, 2001).

While much of this literature focuses on financial reporting, governance-related disclosure plays a similar role. Governance transparency provides information about board structure, oversight mechanisms, and shareholder rights, thereby improving investors' ability to assess managerial behavior. Corporate reporting systems are therefore central not only to financial transparency but also to governance effectiveness and capital allocation (Bushman and Smith, 2001).

Importantly, governance transparency is conceptually distinct from governance quality. Markets can process only observable information. Even well-designed governance structures cannot influence prices if they are not clearly disclosed. Governance transparency can thus be interpreted as the observable component of governance that enters the public information environment and affects price formation. Enhanced disclosure also facilitates the integration of sustainability considerations into investment decisions (Dhaliwal et al., 2011).

Tradability, Ownership Structure, and Market Microstructure. The incorporation of information into prices depends not only on disclosure but also on trading conditions. Market microstructure theory predicts that improved public information enhances price efficiency, but these effects require sufficient trading activity.

Ownership structure plays a critical role in this process. Concentrated ownership limits trading volume and reduces the scope for market-based discipline, whereas dispersed ownership enhances participation and price discovery (La Porta et al., 1999). Free float captures the effective supply of tradable shares and therefore represents the market-facing dimension of ownership structure.

From a microstructure perspective, limited free float constrains market depth and amplifies price impact, slowing the incorporation of information into prices. By contrast, higher free float enables investors to act on publicly available information, facilitating arbitrage and strengthening price discovery. Improved corporate transparency enables investors to better assess sustainability performance and long-term value creation, thereby supporting more efficient capital allocation (Friede et al., 2015). Consequently, governance transparency is expected to have stronger effects in firms with higher tradability.

Nonlinear and Conditional Effects. The relationship between governance transparency and market outcomes is unlikely to be linear. When tradable share supply is limited, additional transparency may generate only marginal effects because trading remains constrained. Once a sufficient level of free float is reached, however, governance information can be more efficiently incorporated into prices. Such nonlinearities are consistent with microstructure models in which liquidity externalities amplify the impact of public information (Kyle, 1985; Diamond and Verrecchia, 1991). They also help explain mixed empirical findings in the governance literature, where average effects may mask important structural heterogeneity across firms.

Institutional Credibility and OECD Alignment. In addition to information availability and tradability, the effectiveness of governance disclosure depends on credibility. Corporate governance operates through both formal regulation and soft-law mechanisms, including principles, codes, and best practices (Coffee, 2007). The impact of such frameworks depends on investor perception and confidence. The G20/OECD Principles of Corporate Governance (2023) represent a key international benchmark for governance transparency, board accountability, and shareholder rights. Alignment with these principles enhances the comparability and reliability of governance disclosures, particularly in cross-border investment contexts (Aguilera and Cuervo-Cazurra, 2009). Corporate governance also plays a key role in aligning firms with sustainability objectives by enhancing transparency, accountability, and long-term strategic orientation (OECD, 2023). From a market perspective, OECD alignment can be interpreted as a credibility-enhancing mechanism that strengthens the pricing relevance of governance transparency.

Integrated Framework and Link to Sustainable Capital Allocation. Bringing these strands together, this study proposes an integrated transparency–tradability–credibility framework. Governance transparency expands the public information set, free float enables the incorporation of information into prices, and institutional alignment enhances credibility. This framework has implications beyond traditional market quality outcomes. By reducing informational frictions and improving price discovery, governance transparency facilitates more efficient capital allocation. In this sense, financial markets can support the transition toward circular economy models by directing capital toward firms characterized by higher transparency, accountability, and resource efficiency (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Friede et al., 2015).

Corporate governance transparency therefore acts as an enabling mechanism rather than a direct driver of sustainability outcomes. To synthesize these mechanisms, Figure 1 presents the integrated conceptual framework underlying the empirical analysis.

Corporate governance is conceptualized as an informational infrastructure through which transparency, tradability, and institutional credibility jointly influence market discipline and price formation. The framework captures three complementary mechanisms. First, governance transparency expands the public information set and reduces information asymmetry. Second, tradability, proxied by free float, determines whether disclosed information can be incorporated into prices through trading. Third, institutional credibility, proxied by OECD alignment, enhances the reliability and comparability of governance disclosures.

Together, these mechanisms imply that the market impact of governance transparency is conditional on both trading capacity and institutional anchoring, motivating the interaction and nonlinear specifications tested in the empirical analysis.

Hypotheses Development. Based on the integrated framework, the following hypotheses are formulated:

H1. Corporate governance transparency is positively associated with market quality, reflected in lower return volatility, improved liquidity, and reduced-price impact (Diamond and Verrecchia, 1991; Leuz and Verrecchia, 2000; Bushman and Smith, 2001).

H2. Free float positively moderates the relationship between corporate governance transparency and market quality, such that the effects of transparency are stronger in firms with higher tradable share supply (La Porta et al., 1999).

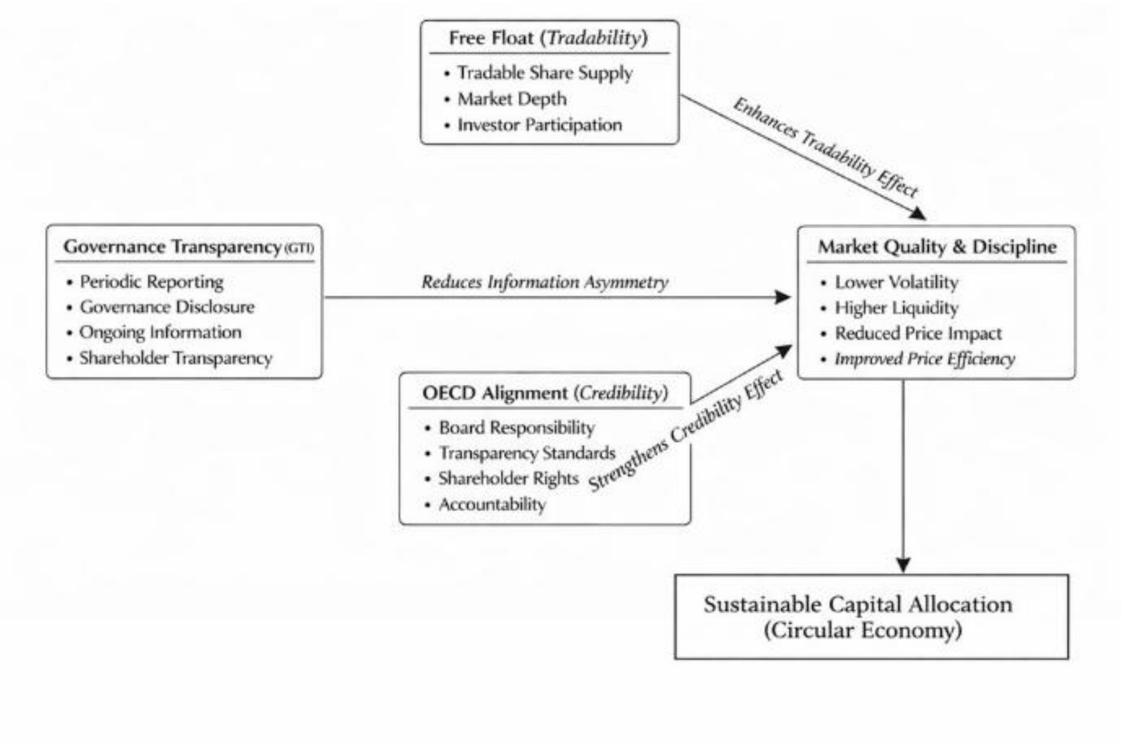


Figure 1 - *Conceptual framework*

H3. The effect of corporate governance transparency on market quality becomes economically significant only above a threshold level of free float (Kyle, 1985; Diamond and Verrecchia, 1991).

H4. Alignment with OECD corporate governance principles strengthens the relationship between corporate governance transparency and market quality by enhancing the credibility of disclosures (Coffee, 2007; Aguilera and Cuervo-Cazurra, 2009; OECD, 2023).

H5. The impact of corporate governance transparency on market quality is strongest when transparency, tradability, and institutional credibility are jointly present (Bushman and Smith, 2001; Leuz and Wysocki, 2016; Dhaliwal et al., 2011; Friede et al., 2015).

Methodology of research

Sample and Data. The empirical analysis is based on a panel of 44 listed firms from five Central and Eastern European (CEE) markets - Austria, Poland, Hungary, the Czech Republic, and Romania - observed annually over the period 2015–2024, resulting in 440 firm–year observations.

The CEE setting provides substantial variation in ownership structures, liquidity regimes, and disclosure practices, allowing the identification of conditional effects linking governance transparency to market outcomes. During the sample period, governance frameworks evolved and disclosure requirements were progressively harmonized at the EU level.

Governance data are hand-collected from publicly available sources, including annual reports, corporate governance statements, investor relations websites, and regulated disclosure platforms. Market data are obtained from exchange-level and commercial financial databases, while ownership data, including free float, are derived from firm-level shareholding disclosures.

Variables and Measurement

Governance Transparency (GTI). Corporate governance transparency is measured using a rule-based Governance Transparency Index (GTI), capturing four dimensions aligned with EU disclosure architecture: periodic reporting, governance disclosure, ongoing regulated information, and shareholder-related transparency. Each component is coded using observable binary criteria, ensuring cross-country comparability. The aggregate index is computed as the average of component indicators.

Tradability (Free Float). Free float is measured as the percentage of shares available for public trading. It captures effective tradable share supply and market depth. To assess nonlinear effects, threshold indicators are constructed based on sample or market-year medians.

Credibility (OECD Alignment). OECD alignment is proxied through binary indicators reflecting compliance with key governance pillars, including board responsibility, transparency standards, shareholder rights, and accountability. An aggregate indicator captures institutional credibility.

Market Outcomes. Market discipline is evaluated using microstructure-based measures: return volatility, liquidity proxies, and price impact. These variables capture informational uncertainty, trading frictions, and the efficiency of price formation.

Control Variables. Standard firm-level controls include firm size (log market capitalization), leverage (debt-to-equity ratio), and profitability (return on assets).

Empirical Specification. To test the hypotheses, we estimate firm- and year-fixed-effects panel regressions of the form:

$$Y_{i,t} = \alpha + \beta_1 GTI_{i,t} + \beta_2 X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}$$

Where: $Y_{i,t}$ represents market quality measures (volatility, liquidity, or price impact), $X_{i,t}$ is a vector of control variables, $GTI_{i,t}$ denotes governance transparency, μ_i firm fixed effects and λ_t are year fixed effects.

To examine moderating effects, interaction models are estimated:

$$\begin{aligned} Y_{i,t} = \alpha + \beta_1 GTI_{i,t} + \beta_2 FreeFloat_{i,t} \\ + \beta_3 (GTI \times FreeFloat)_{i,t} + \mu_i \\ + \lambda_t + \varepsilon_{i,t} \end{aligned}$$

where: $FreeFloat_{i,t}$ captures tradability

To capture credibility effects, triple-interaction specifications are employed:

$$\begin{aligned} Y_{i,t} = \alpha + \beta_1 GTI_{i,t} + \beta_2 FreeFloat_{i,t} \\ + \beta_3 OECD_{i,t} \\ + \beta_4 (GTI \times FreeFloat \\ \times OECD)_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \end{aligned}$$

where $OECD_{i,t}$ reflects institutional credibility

All models include firm and year fixed effects, with standard errors clustered at the firm level. Threshold specifications are additionally estimated to test nonlinear effects of tradability.

Descriptive Statistics. To provide an initial overview of the empirical setting, Table 1 presents descriptive statistics for the main variables used in the analysis. This step is essential to assess the distributional properties of governance transparency, tradability, and market outcome variables, and to evaluate the extent of cross-sectional heterogeneity within the sample.

The sample consists of 44 listed firms from five Central and Eastern European markets observed annually over 2015–2024 (440 firm–year observations). GTI is the aggregate Governance Transparency Index. Free Float is the percentage of shares available for public trading. OECD aligned is a binary indicator equal to one if the firm is aligned with the OECD Corporate Governance Principles (2023). Volatility250D denotes 250-day stock return volatility. Market Cap is end-of-year market capitalization. ROA is return on assets, and Debt to Equity measures financial leverage.

Table 1 - *Descriptive statistics (firm–year level)*

Variable	Mean	Std. Dev.	Min	25%	Median	75%	Max
GTI_total	0.932	0.070	0.812	0.875	0.938	1.000	1.000
Free float	0.520	0.230	0.060	0.308	0.440	0.686	1.000
OECD aligned	0.500	0.501	0.000	0.000	0.500	1.000	1.000
Volatility (250D)	29.490	7.718	12.514	22.719	27.644	35.949	48.618
Market capitalization	6,174	5,304	0,052	2,520	5,014	8,115	34,359
ROA	4.436	6.811	-2.900	1.100	2.420	4.893	74.245
Debt-to-equity	67.442	156.867	0.000	26.453	43.437	77.520	2,563.740

Notes: This table reports descriptive statistics for the main variables used in the analysis. Volatility (250D) represents 250-day stock return volatility. Market capitalization is expressed in EUR billions. Free float is measured as the proportion of tradable shares

The descriptive statistics reveal several important features of the sample. First, governance transparency (GTI) exhibits relatively high average values, reflecting the progressive convergence of disclosure practices across CEE markets, but still retains meaningful cross-sectional variation. Second, free float shows substantial dispersion, indicating heterogeneous ownership structures and varying levels of tradability, which is central to the paper's identification strategy. Third, volatility displays considerable variation, suggesting differences in market quality across firms and over time.

Overall, these patterns provide preliminary support for the relevance of conditional effects, particularly the interaction between transparency and tradability, which is formally tested in the multivariate analysis.

Correlation patterns (Table 2) suggest a negative association between governance transparency and volatility, as well as a positive association with firm size. These patterns provide preliminary support for hypothesized relationships and motivate multivariate analysis. Table 2 reports pairwise correlations among the main variables and provides a preliminary assessment of the relationships underlying the empirical analysis. GTI denotes the Governance Transparency Index, Free Float is the tradable share ratio, OECD aligned is a binary OECD alignment indicator, Vol250 is 250-day volatility, LogMktCap is the logarithm of market capitalization, ROA is return on assets, and Leverage DE is the debt-to-equity ratio.

Table 2 - *Correlation matrix (key variables)*

	GTI_ total	Free Float	OECD_ aligned	Vol250	LogMkt Cap	ROA	Leverage_ DE
GTI_total	1.000	0.005	0.970	-0.052	0.107	0.093	0.083
FreeFloat	0.005	1.000	-0.004	0.134	0.227	-0.005	-0.035
OECD_aligned	0.970	-0.004	1.000	-0.031	0.042	0.119	0.077
Vol250	-0.052	0.134	-0.031	1.000	-0.038	-0.114	0.181
LogMktCap	0.107	0.227	0.042	-0.038	1.000	-0.078	-0.185
ROA	0.093	-0.005	0.119	-0.114	-0.078	1.000	-0.128
Leverage_DE	0.083	-0.035	0.077	0.181	-0.185	-0.128	1.000

The correlation matrix provides initial evidence consistent with the theoretical framework. Governance transparency is negatively associated with stock return volatility, suggesting that improved disclosure may reduce informational uncertainty.

At the same time, the high correlation between GTI and OECD alignment reflects the close link between transparency and institutional governance standards, highlighting the importance of carefully disentangling their individual effects in the regression analysis. Importantly, correlation coefficients remain below conventional multicollinearity thresholds, supporting the inclusion of interaction terms in subsequent models.

To illustrate the dynamic evolution of governance transparency across the sample period, Figure 2 plots the time-series trajectory of the Governance Transparency Index (GTI). The upward trend reflects increasing convergence in governance disclosure practices across CEE markets.

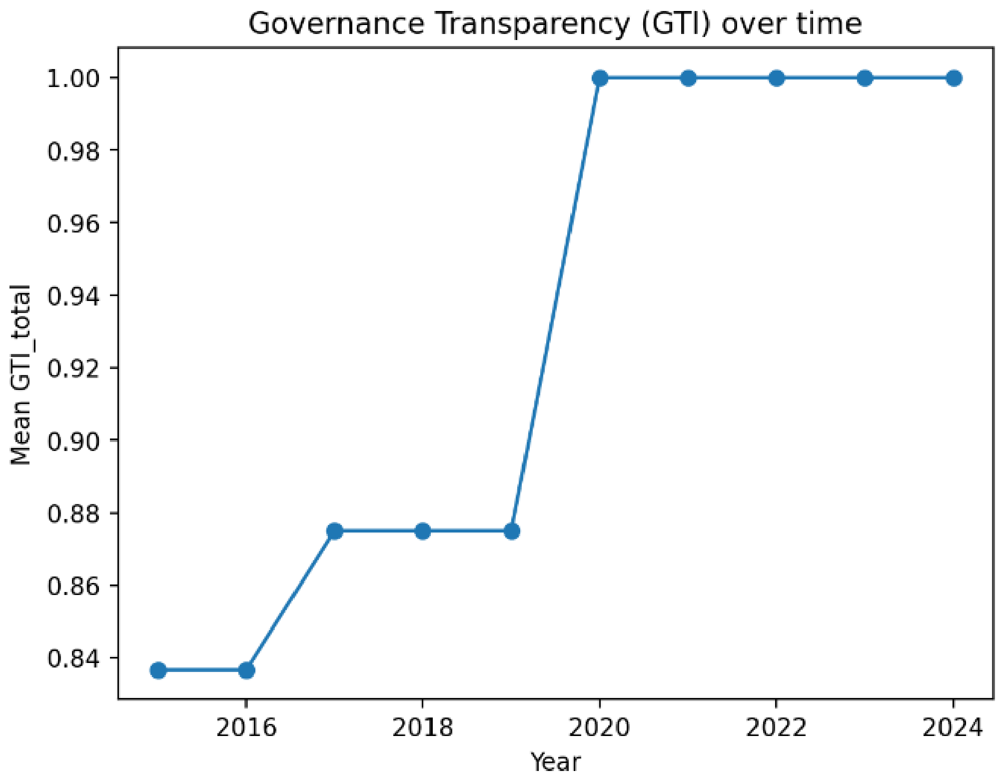


Figure 2 - *Governance Transparency (GTI total) over time*

The figure highlights a clear upward trend in governance transparency, consistent with ongoing regulatory harmonization and increased disclosure requirements at the EU level. This temporal pattern supports the relevance of time fixed effects in the empirical specification and suggests that part of the variation in governance transparency is driven by institutional developments rather than purely firm-level characteristics.

Empirical Results and Discussion

This section presents the empirical evidence corresponding to Hypotheses H1–H5.

Governance Transparency and Market Quality (H1). Consistent with H1, the coefficient on GTI is negative in the volatility specification, indicating that higher governance transparency is associated with lower return volatility. This result supports the informational role of transparency in reducing estimation risk and information asymmetry (Diamond and Verrecchia, 1991; Leuz and Verrecchia, 2000). In the market-depth specification, GTI is positively associated with log free-float market capitalization, suggesting that transparency improves liquidity conditions and trading capacity. Overall, the results provide evidence that governance transparency enhances market quality, consistent with H1.

Tradability as a moderating and threshold condition (H2-H3-H4). Consistent with H2, the interaction term (GTI × Free Float) indicates that the marginal effect of governance transparency increases with tradable share supply. This suggests that transparency becomes more informative and economically relevant in firms with higher free float, where trading activity facilitates the incorporation of disclosed information into prices (La Porta et al., 1999). Beyond the moderating effect, the results also support H3. Threshold analyses indicate that the impact of governance transparency becomes economically meaningful only above the median level of free float. Below this threshold, limited trading activity constrains the pricing of governance-related information. These findings identify tradability as a critical structural condition for the effectiveness of governance transparency in capital markets.

Credibility and Institutional Amplification (H4-H5). Consistent with H4, the interaction term (GTI × OECD) suggests that governance transparency has stronger pricing relevance when disclosures are anchored in internationally recognized governance standards. This finding supports the view that credibility enhances the interpretability and comparability of governance-related information (Coffee, 2007; Aguilera and Cuervo-Cazurra, 2009). The standalone OECD alignment variable is not consistently significant, indicating that credibility alone does not directly improve market outcomes.

Most importantly, the triple interaction (GTI × Free Float × OECD) is statistically significant in the volatility specification, supporting H5. This result indicates that governance transparency has the strongest impact on market quality when transparency, tradability, and institutional credibility are jointly present. These findings confirm that market discipline emerges from the interaction of informational availability, trading capacity, and institutional anchoring (Bushman and Smith, 2001; Leuz and Wysocki, 2016).

Table 3 presents the main regression results testing the conditional effects of governance transparency on market quality. The specifications are designed to capture not only the direct impact of transparency, but also its interaction with tradability (free float) and institutional credibility (OECD alignment), in line with the integrated theoretical framework.

Table 3 - *Conditional Effects: Transparency, Tradability, and Credibility*

	Volatility (250D)	**Log Free-float MktCap**
GTI	-0.0000 (0.0000)	-0.0902 (0.4016)
Free float	-0.0000 (0.0000)	0.0313*** (0.0052)
OECD aligned	0.0000 (0.0000)	0.0088 (0.0771)
GTI × Free float	-0.0000 (0.0000)	-0.0084 (0.0054)
GTI × OECD	-0.0000 (0.0000)	0.1095* (0.0628)
Free float × OECD	-0.0000*** (0.0000)	-0.0022 (0.0014)
GTI × Free float × OECD	0.0000*** (0.0000)	-0.0022 (0.0014)

	Volatility (250D)	Log Free-float MktCap
Log(Market cap)	-0.0000 (0.0000)	1.0126*** (0.0174)
ROA	-0.0000 (0.0000)	0.0018* (0.0009)
Debt-to-equity	-0.0000 (0.0000)	0.0001** (0.0000)
Observations	290	290
Adjusted R^2	1.000	0.997
Firm FE / Year FE	Yes / Yes	Yes / Yes

*Notes: Coefficients rounded for presentation are reported with clustered standard errors (firm level) in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels. Volatility is 250-day return volatility. Log Free-float MktCap is the logarithm of market capitalization multiplied by free float (%), used as a market-depth proxy. The high R^2 values reported in the regressions reflect the inclusion of firm and year fixed effects, which absorb a substantial portion of cross-sectional and time-series variation. This is consistent with prior empirical studies employing similar panel specifications in corporate governance and disclosure research.*

The results provide strong support for the conditional nature of governance transparency effects. While the standalone coefficient of GTI is generally weak, its interaction with free float is economically meaningful, indicating that transparency becomes relevant only when sufficient trading capacity exists.

The triple interaction term (GTI × Free Float × OECD) further confirms that governance transparency exerts its strongest impact in environments characterized by both high tradability and strong institutional anchoring. This finding supports the proposed transparency–tradability–credibility nexus and helps explain why prior empirical evidence on governance effects has been mixed. Overall, the results suggest that governance transparency is not a standalone determinant of market quality, but rather part of a broader ecosystem in which informational, structural, and institutional factors jointly shape price formation.

Economic Significance and Implications. In economic terms, a one-standard-deviation increase in GTI is associated with a reduction in return volatility of approximately 0.9% relative to the sample mean. Although modest in magnitude, this effect is economically meaningful given the persistence of governance structures and disclosure practices.

The results highlight that transparency alone is not sufficient. Its market impact depends on complementary structural and institutional conditions. Tradability determines whether disclosed information can be incorporated into prices, while OECD alignment enhances the credibility and interpretability of governance disclosures.

From a broader perspective, governance transparency contributes to more efficient capital allocation by reducing informational frictions and improving investor decision-making. In this sense, transparency acts as an enabling mechanism through which capital markets can support firms adopting sustainable and resource-efficient business models consistent with circular economy principles (Geissdoerfer et al., 2017; Friede et al., 2015).

The findings are also consistent with EU regulatory developments, including the Non-Financial Reporting Directive and Shareholder Rights Directive II, suggesting that improvements in transparency are partly policy driven. However, the results should be interpreted with caution. Although firm fixed effects mitigate unobserved heterogeneity, residual endogeneity concerns remain. These findings highlight that empirical models which omit structural (tradability) and institutional (credibility) dimensions may underestimate the true market relevance of corporate governance transparency.

Overall, the empirical findings provide consistent support for the integrated framework developed in this study, in which governance transparency affects market outcomes through the joint interaction of informational, structural, and institutional channels.

Conclusions

This paper examines how corporate governance influences market discipline by conceptualizing governance not only as an internal monitoring mechanism, but as an information-generating and market-facing institution. Using a hand-collected panel of 44 listed firms across five Central and Eastern European markets over the period 2015–2024, the analysis demonstrates that governance affects capital market outcomes through three interdependent channels: transparency, tradability, and institutional credibility. These findings have direct implications for practitioners, regulators, and market operators, highlighting that improvements in disclosure practices alone are insufficient without adequate tradability and credible institutional anchoring.

From a financial reporting perspective, governance disclosure should be understood not merely as a compliance requirement, but as a value-relevant information channel with direct implications for market efficiency. The empirical results show that corporate governance transparency improves market quality by reducing return volatility and enhancing market depth, supporting its role in mitigating information asymmetry and facilitating price discovery. However, these effects are inherently conditional. Tradability, proxied by free float, determines whether disclosed information can be effectively incorporated into prices. In firms with limited tradable share supply, the pricing relevance of governance disclosure is attenuated, whereas in firms with higher free float, transparency translates into economically meaningful improvements in market outcomes.

Institutional credibility further reinforces this mechanism. Alignment with the OECD Corporate Governance Principles (2023) enhances the interpretability and comparability of governance disclosures, strengthening their pricing relevance. Most importantly, the results indicate that governance transparency exerts its strongest impact when transparency, tradability, and credibility are jointly present, supporting a conditional and multi-dimensional model of market discipline.

The study contributes to the literature by developing a rule-based Governance Transparency Index (GTI), linking governance transparency to market microstructure outcomes, and identifying tradability and institutional credibility as key conditioning mechanisms.

From a broader perspective, the findings suggest that governance transparency contributes to more efficient capital allocation by reducing informational frictions and improving investor decision-making. In this context, transparency emerges as an enabling mechanism through which capital markets can support long-term investment strategies and facilitate the transition toward sustainable and resource-efficient business models consistent with circular economy principles (Geissdoerfer et al., 2017; Friede et al., 2015).

It is important to note that while this study establishes corporate governance transparency as a critical informational infrastructure for sustainable finance, it focuses on the market-facing mechanisms of price formation and discipline rather than direct firm-level circularity metrics. Consequently, the framework demonstrates how transparency acts as an enabling condition for capital allocation but does not provide a direct empirical measurement of specific circular economy outcomes, such as resource recovery rates or waste reduction. Future research could bridge this gap by integrating the Governance Transparency Index (GTI) with granular environmental performance data to further validate the link between governance disclosure and the physical transition to a circular economic model.

The results should be interpreted with caution. Although firm fixed effects mitigate unobserved heterogeneity, residual endogeneity concerns remain. Future research may further explore causal identification strategies and alternative measures of governance quality, tradability, and market liquidity.

REFERENCES

1. Aguilera, R. V. & Cuervo-Cazurra, A. (2009) Codes of good governance. *Corporate Governance: An International Review.* 17(3). pp.376–387. DOI 10.1111/j.1467-8683.2009.00737.x.
2. Bushman, R. M. & Smith, A. J. (2001) Financial accounting information and corporate governance. *Journal of Accounting and Economics.* 32(1–3). pp.237–333. DOI 10.1016/S0165-4101(01)00027-1.
3. Bushman, R. M., Piotroski, J. D. & Smith, A. J. (2004) What determines corporate transparency? *Journal of Accounting Research.* 42(2). pp.207–252. DOI 10.1111/j.1475-679X.2004.00136.x.
4. Coffee, J. C. (2007) Law and the market: The impact of enforcement. *University of Pennsylvania Law Review.* 156(2). pp.229–311. DOI 10.2307/40041380.
5. Diamond, D. W., & Verrecchia, R. E. (1991) Disclosure, liquidity, and the cost of capital. *Journal of Finance.* 46(4). pp.1325–1359. DOI 10.1111/j.1540-6261.1991.tb04620.x.
6. Dhaliwal, D., Li, O. Z., Tsang, A. & Yang, Y. G. (2011) Voluntary nonfinancial disclosure and the cost of equity capital. *The Accounting Review*. pp. 86(1). 59–100. DOI 10.2308/accr.00000005.
7. Friede, G., Busch, T. & Bassen, A**.** (2015) ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment.* 5(4). pp.210–233. DOI 10.1080/20430795.2015.1118107.
8. Geissdoerfer, M., Savaget, P., Bocken, N. M. P. & Hultink, E. J. (2017) The Circular Economy: A new sustainability paradigm? *Journal of Cleaner Production.* 143. pp. 757–768. DOI 10.1016/j.jclepro.2016.12.048.
9. Healy, P. M., & Palepu, K. G. (2001) Information asymmetry, corporate disclosure, and the capital markets. *Journal of Accounting and Economics.* 31(1–3). 4pp05–440. DOI 10.1016/S0165-4101(01)00018-0.
10. Holmström, B., & Tirole, J. (1993) Market liquidity and performance monitoring. *Journal of Political Economy.* 101(4). pp.678–709. DOI 10.1086/261893.
11. Kirchherr, J., Reike, D. & Hekkert, M. (2017) Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling.* 127. pp. 221–232. DOI 10.1016/j.resconrec.2017.09.005.
12. La Porta, R., Lopez-de-Silanes, F., Shleifer, A. & Vishny, R. (1999) Corporate ownership around the world. *Journal of Finance.* 54(2). pp.471–517. DOI 10.1111/0022-1082.00115.
13. Leuz, C. & Verrecchia, R. E. (2000) The economic consequences of increased disclosure. *Journal of Accounting Research. 38*(Supplement). pp. 91–124. DOI 10.2307/2672909.
14. Leuz, C., & Wysocki, P. (2016) The economics of disclosure and financial reporting regulation. *Journal of Accounting Research. 54*(2). pp.525–622. DOI 10.1111/1475-679X.12115.
15. OECD. (2023) *G20/OECD Principles of Corporate Governance*. Paris: OECD Publishing. DOI 10.1787/ed750b30-en.
16. Shleifer, A. & Vishny, R. W. (1997) A survey of corporate governance. *Journal of Finance.* 52(2). pp.737–783. DOI 10.1111/j.1540-6261.1997.tb04820.x.

"*We are living on this planet as if we had another one to go to.*"
Terry Swearingen

Digital Platforms and Circular Economy Practices

Irina AMARIEI, Bogdan FLEACA

National University of Science and Technology POLITEHNICA Bucharest,
313 Splaiul Independentei, Bucharest, Romania

Abstract

This study examines the development of research related to the circular economy and digital platforms. Using a bibliometric analysis, keyword patterns and publication trends are analysed to illustrate the field's evolution. A structured overview of the main themes within the scientific literature in this field is provided, with results emphasising the increasing importance of digitalisation in discussions of circular practices. The bibliometric analysis reveals growing academic interest in the link between the circular economy and digital technologies, as keyword analysis indicates that the circular economy remains the dominant research theme, followed by concepts such as sustainability, digital platforms, information systems, and digitalisation. These patterns demonstrate a rising interest in the area and a recent shift towards digitalisation and digital platforms in discussions related to the circular economy.

Keywords: circular economy, circular business model, digital platform

"We cannot solve our problems with the same thinking we used when we created them."

Albert Einstein

Introduction

In the context of increasing pressures on the responsible use of natural resources and the need to reduce the environmental impact, the circular economy has become an increasingly mentioned framework for the transition to more sustainable production and consumption models. The circular economy aims to maintain resources, materials and products in the economy for as long as possible, unlike the traditional linear economic model that is based on extraction, production and disposal.

Due to this change, data and digital platforms are gaining an increasingly important role, allowing the collection and transmission of information necessary for the coordination of circular activities. Digital platforms can function as coordination infrastructures that facilitate the exchange of

Correspondence to Irina Amariei: amar.irina57@gmail.com

information, supporting accessibility and collaboration between different entities involved. This bibliometric study proposes to map scientific literature on the relationship between digital platforms and the circular economy, highlighting the main research directions and their evolution.

Literature Review

As circular economy strategies require interaction and communication between many actors, digital technologies and digital platforms can make these interactions possible as they collect, organise and transmit information about products, services, users, and resources. Digital platforms play an important role in circular business models where networking, communication, and collaboration with stakeholders involved are necessary (Antikainen et al., 2018). Digital platforms can provide traceability, transparency, and operational efficiency for circular business models.

Han et al (2023) present a framework highlighting how digital technologies such as the Internet, IoT, big data and Artificial Intelligence can enhance a circular economy model and argue that such digital technologies could improve resource efficiency and prolong product lifespan as long as the environmental and economic costs are weighed against the benefits of using the digital technologies (Han et al., 2023). Bellini et al (2024) also state that digital technologies can facilitate data management, which can lead to an increase in the successful implementation of circular economy strategies (Bellini et al., 2024).

Digital platform technology supports circular business models by promoting resource reduction, reuse, and recycling among various ecosystem parts. A study based on analysing ten European digital platforms and investigating orchestration mechanisms found that digital platforms could unlock new circular business models and offered insights for managers (Blackburn et al., 2023).

Liam et al (2025) examined how digital platforms affect the integration of circular economy practices, emphasising their potential to maximise resource utilisation, reduce waste, and foster sustainable growth. The study uses qualitative interviews and quantitative surveys and concludes that digital platforms can improve resource efficiency while making recycling and reuse possible. This, however, comes with expenses, legal restrictions, a possible lack of digital literacy in small and medium sized companies, and data privacy problems (Liam et al., 2025).

Digital platforms can enable collaboration among multiple stakeholders involved in circular value chains. Soldatos et al (2021) propose a platform architecture designed to facilitate data exchange and coordination across sectors to improve resource efficiency and sustainability. The study highlights how digital platforms can be used as coordination mechanisms and shows how effective data sharing is essential for implementing circular business models (Soldatos et al, 2021).

A simulation conducted by Charnley et al (2019) in which developments in digital technologies were taken into consideration within the context of the circular economy shows that digital technologies can aid in implementing circular strategies in the UK automotive manufacturing industry (Charnley et al, 2019). Digital platforms can be a support for coordinating complex networks and thus can sustain circular innovation, circular strategies, and facilitate the transition to a circular economy (Prisco, 2026).

While analysing digital platforms through a value creation point of view, a study using data from 243 companies shows that digital platforms act as intermediaries that facilitate collaboration and resource coordination among actors involved and argue that platforms support circular economy adoption by enabling business model innovation (Wu et al, 2024).

In Romania, a study focused on 149 organisations from a variety of industries and of various sizes examined how these entities incorporate digital technologies into circular economy practices. The study found that many companies acknowledge the advantages of digital technology for enhancing sustainability and resource efficiency, but implementation is hindered by a lack of digital expertise, resistance to change, and a lack of infrastructure. However, organisations plan to increase their investments into digitisation to improve sustainability and innovation (Lakatos et al, 2026).

Although there is a growing number of studies linking digital technologies and platforms to the circular economy, the literature remains fragmented across various disciplines. Therefore, a bibliometric analysis to map the evolution, main themes, and research trends is useful in providing a structured understanding of how platforms and digital technologies support the transition toward more sustainable economic models.

Research Methodology

A bibliometric analysis was conducted using the Web of Science (WoS) database to map the evolution and research trends regarding the relationship between platforms and digital technologies and the circular economy. The databases considered for the analysis are presented in Table 1. These databases provide structured and standardised citation data while also being compatible with VOSviewer.

Table 1 – *Databases considered for the analysis*

Database	**Advantages**	**Limitations**
Web of Science (WoS)	Widely used in bibliometric studies (Zhu and Liu, 2020); extensive historical data, enhanced search tool.	Possible bias against non-English language research or research that comes from non-Western countries (Tennant, 2020); selective coverage depending on the field of research.
Scopus	Large database with extensive content; frequently used in bibliometric studies (Zhu and Liu, 2020).	Also has a possible bias against non-English language research or research that comes from non-Western countries (Tennant, 2020); harder to use interface.
Dimensions	Broad coverage of publications; free access version.	Complex search tool; subscription based for full access.

The Web of Science (WoS) database was selected for this study for the following reasons: access to the database is provided through the university, the database is recognised for its quality indexing standards and is widely used in bibliometric analyses for its easy and structured bibliographic data.

A preliminary analysis of the literature was conducted to identify the most relevant concepts related to the research topic, as it helped determine the most relevant terms used by researchers. As the circular economy becomes increasingly important when talking about sustainability and sustainable practices, there is an interest in the growing role of digital technologies, such as digital platforms in supporting circular systems that reduce waste and improve resource efficiency.

Understanding the development and the main themes of this emerging research field by analysing the existing scientific literature helps clarify the importance of this field and shows support for future research. Based on the preliminary analysis, several frequently used keywords and main themes were identified, and representative terms were selected to use in a formula to capture the relevant publications addressing the research field. The formula used to perform the analysis was:

TS = ("circular econom" OR "circular business model*" OR "circular system*") AND TS = ("digital platform*" OR "online platform*" OR "data technolog*" OR "information system*").*

Where:

- TS (Topic Search) – searches in the title of the article, in the abstract, in the authors' keywords and in the keywords plus.
- *"circular econom*" OR "circular business model*" OR "circular system*"* – was used to search for articles connected to circular economy.
- *"digital platform*" OR "online platform*" OR "data technolog*" OR "information system*"* – was used to search for articles connected to digital platforms or digital technologies.

The formula used was designed to identify studies in the literature that approach both concepts, circular economy research as well as digital platforms or technologies. The bibliometric analysis was conducted at the beginning of March 2026, and 416 results were obtained. VOSviewer and Microsoft Excel were used to organise and analyse the data extracted from the database. Both software were selected due to their good handling of large data sets, easy-to-use interface and frequency of use in bibliometric studies.

Results and Discussion

In Figure 1, the authors will show the total number of publications between 2008 and 2026.

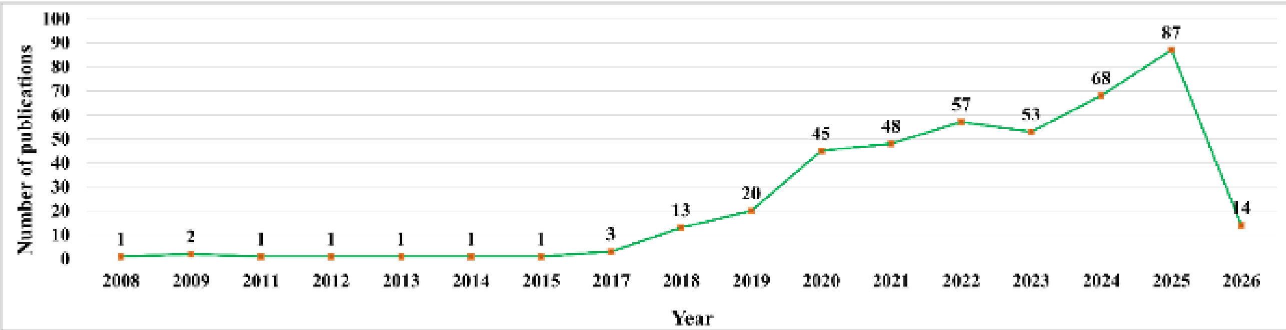


Figure 1 - *Publications per year*

According to Figure 1, the number of publications on the circular economy and digital platforms has increased since 2018. This may be due to the emergence of various sustainability initiatives and policies, the increasing discussion related to the scarcity of natural resources and the need for business models with a focus on sustainability, product longevity and improved supply chains, among others. The lower number of articles in 2026 is because the analysis is carried out this year, and more publications will certainly appear by the end of the year. Table 2 presents the scholars who have at least 5 articles published in the analysed field.

Table 2 - *Scholars with at least 5 articles published in the analysed field*

Scholar	Papers	Scholar's affiliation	Country
Valenti Francesca	8	University of Bologna	Italy
Umeda Yasushi	6	University of Tokyo	Japan
Fraccascia Luca	5	Sapienza University of Rome and University of Twente	Italy/The Netherlands
Kishita Yusuke	5	University of Tokyo	Japan

As can be seen in Table 2, there are 4 scholars who have published at least 5 articles in the analysed field, the largest number of works being by Valenti Francesca. To better visualise the collaboration networks between the scholars of the publications, an analysis was performed with VOSviewer, taking into account the scholars who have published at least 3 works in the analysed field. Figure 2 shows the 27 scholars who have published at least 3 articles in the analysed field in 15 clusters with 18 links. There are various small cooperation networks between the scholars.

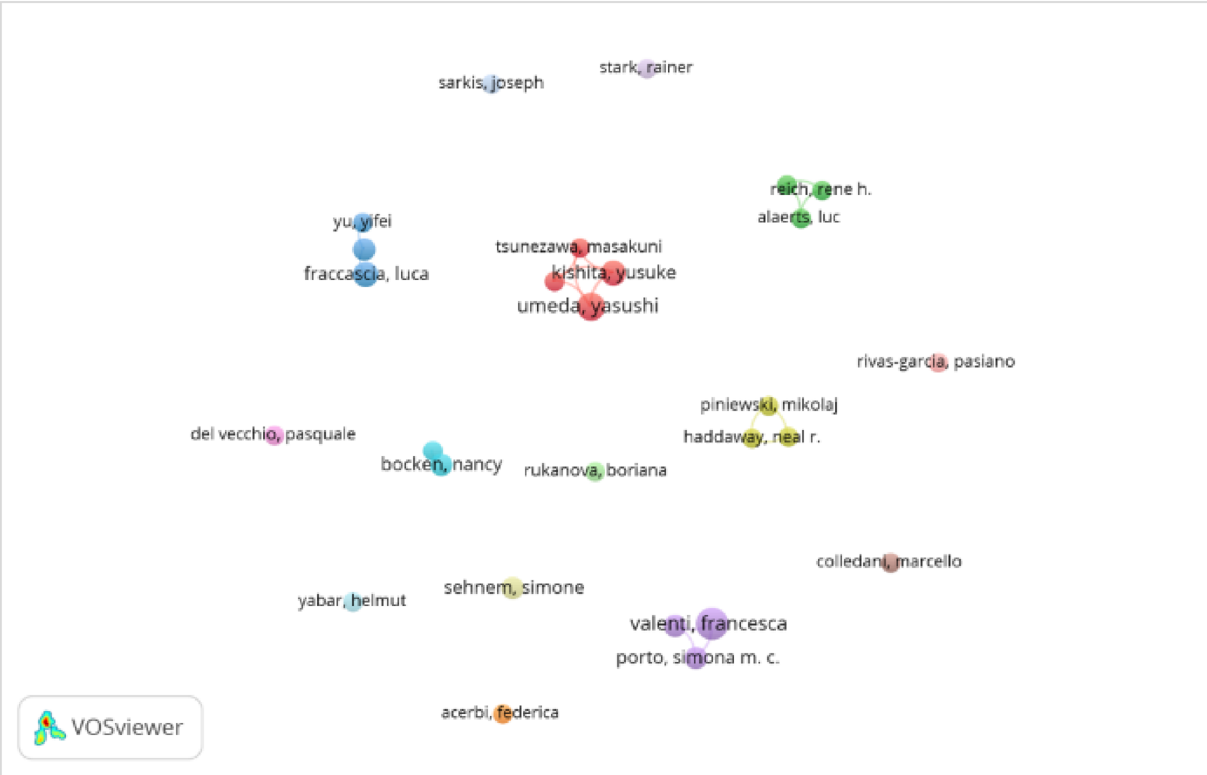


Figure 2 - *Scholars who have published at least 3 articles in the analysed field*

Table 3 presents the scholars' affiliations. Of the 756 organisations, 10 of them met the threshold of having at least 5 papers related to the analysed field published. The first three organisations are the University of Twente, with 12 papers and 474 citations, Delft University of Technology, with 10 papers and 746 citations, and Polytechnic University of Milan, with 9 papers and 83 citations. To better understand the networks between the affiliations of the scholars, organisations with at least 3 papers were taken into consideration.

Table 3 - *Affiliated organisations with at least 3 papers published*

Organisation	**Documents**	**Citations**
University of Twente	12	474
Delft University of Technology	10	746
Polytechnic University of Milan	9	83
University of Catania	8	103
RWTH Aachen University	7	132
Sapienza University of Rome	6	73
University of Tokyo	6	34
Chinese Academy of Sciences	5	190
Technical University Berlin	5	80
Swiss Federal Institute of Technology	5	303
Maastricht University	4	249

Organisation	Documents	Citations
University of Johannesburg	4	47
LUT University	4	119
Autonomous University of Nuevo León	4	41
University of Salento	4	98
KU Leuven	4	17
University of Naples Federico II	4	52
Stockholm University	3	35
Warsaw University of Life Sciences	3	35
University of the Chinese Academy of Sciences	3	163
IMDEA Water	3	56
KDDI Research	3	11
Lund University	3	372
NTNU	3	83
RISE Research Institutes of Sweden	3	26
RMIT University	3	110
University of Girona	3	56
Universidad Politécnica de Apodaca	3	16
VITO	3	55
Copenhagen Business School	3	44
University of Lincoln	3	327
University of Trento	3	103
Polytechnic University of Turin	3	10
Tampere University	3	66
Utrecht University	3	81
Asia University	3	141
KTH Royal Institute of Technology	3	66
Luxembourg Institute of Science and Technology	3	232
Nanjing University of Science and Technology	3	6
Norwegian University of Science and Technology	3	714
University of Beira Interior	3	41
University of West Santa Catarina	3	18
University Sains Malaysia	3	115
University of South Australia	3	1
University of Tehran	3	20
University of Zagreb	3	92
Worcester Polytechnic Institute	3	682

Figure 3 presents the scholars’ affiliations and shows the 47 organisations with at least 3 articles published in the analysed field in 24 clusters. There are various small cooperation networks between the organisations.

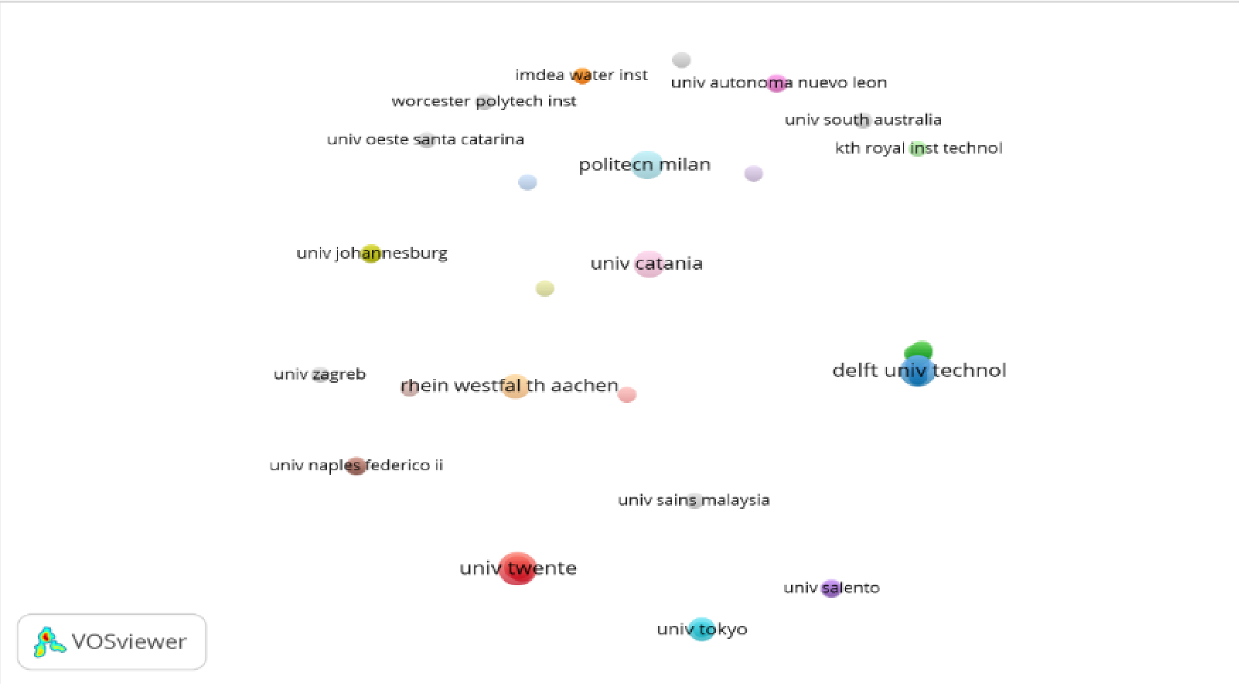


Figure 3 - *Affiliated organisations with at least 3 papers published*

Table 4 presents the countries with at least 5 documents published in the analysed field. Of the 84 countries, 35 met the threshold.

Table 4 - *Countries with at least 5 papers published in the analysed field*

Countries	Documents	Citations
Italy	59	690
People's Republic of China	48	1048
The Netherlands	38	1855
Germany	36	1593
England	32	1319
United States of America	29	1454
Brazil	25	917
Australia	22	612
Sweden	21	645
France	19	1312
Spain	18	395
Finland	17	743
India	16	229
Japan	13	118
Portugal	12	58
Switzerland	11	433
Canada	11	235
Greece	11	288
Poland	10	50
South Africa	10	106
Belgium	10	123

Countries	Documents	Citations
Austria	8	390
Norway	8	845
Iran	8	123
Scotland	7	290
Mexico	7	92
Taiwan	7	227
Russia	7	282
Türkiye	7	30
Malaysia	6	161
Denmark	5	262
Hungary	5	145
Saudi Arabia	5	49
Vietnam	5	165
Romania	5	37

Figure 4 presents the countries with at least 5 documents published in the analysed field.

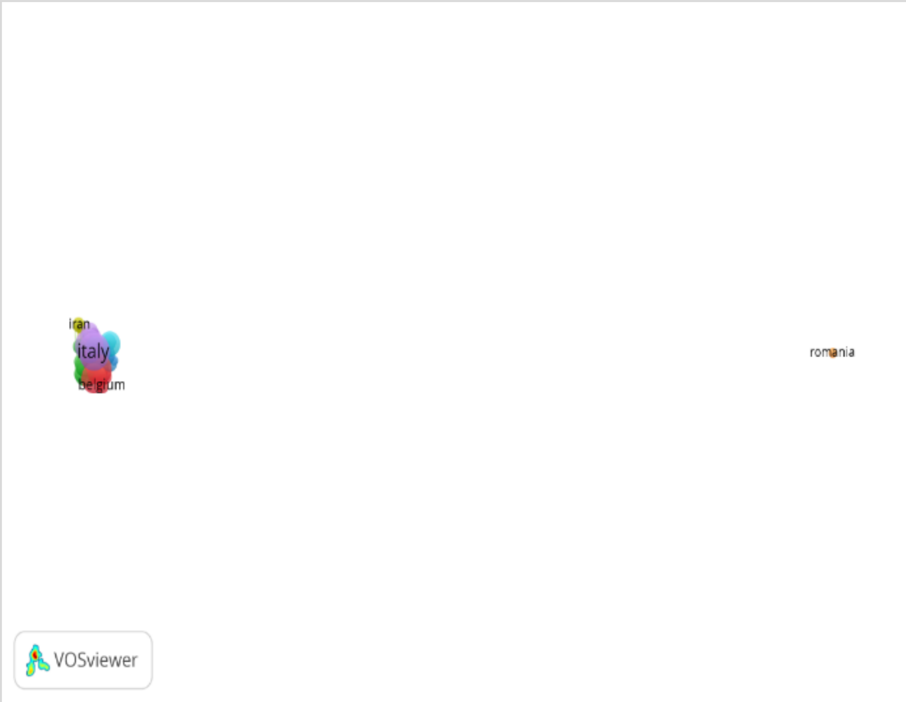


Figure 4 - *Countries with at least 5 papers published in the analysed field*

The first three countries are Italy with 59 documents and 690 citations, the People's Republic of China with 48 documents and 1048 citations, and the Netherlands with 38 documents and 1855 citations. Figure 4 shows the 35 countries with at least 5 articles published in the analysed field in 7 clusters.

To have a better understanding of the networks, Figure 5 shows six of the clusters. There are various networks between the countries, suggesting that there are multiple collaboration networks among them. The 7th cluster that is not shown in Figure 5 is represented by only one country, Romania, which suggests that the country doesn't have any co-authorship or citation links for the threshold used.

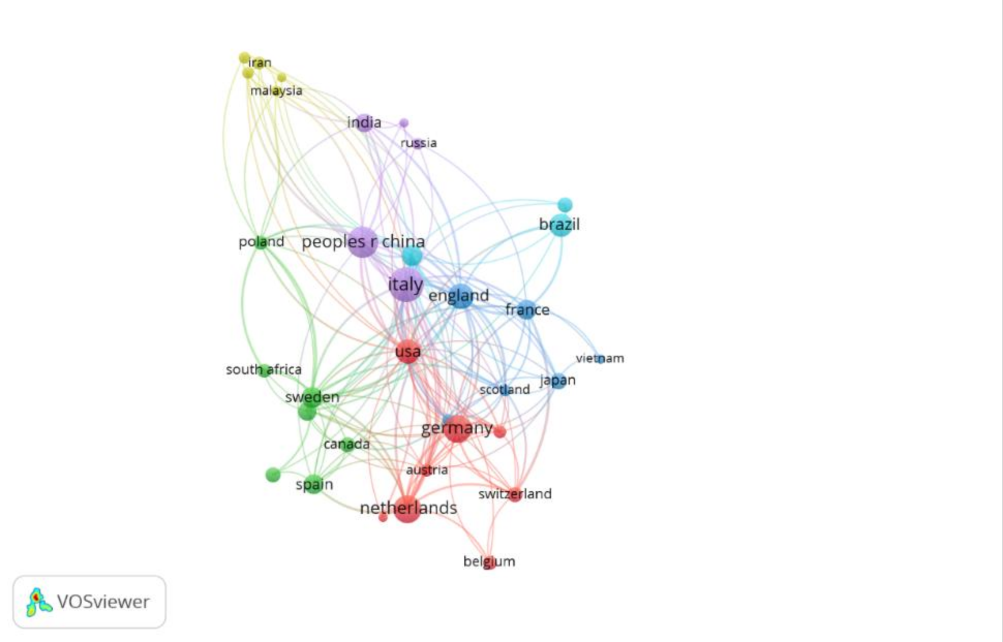


Figure 5 - *Countries with at least 5 papers published in the analysed field (partial view)*

Table 5 presents the first 10 publication titles based on the record count, confirming a focus on circular economy and resource efficiency, as well as technology and strategic management.

Table 5 - *Publication titles based on record count*

Publication titles	Record count
Sustainability	44
Journal of Cleaner Production	23
Procedia CIRP	11
IFIP Advances in Information and Communication Technology	9
Business Strategy and the Environment	7
Resources, Conservation and Recycling	7
Applied Sciences	5
Energies	5
Environmental Science and Pollution Research	5
Journal of Business Research	5

Table 6 presents the first 10 Web of Science Categories based on the record count.

Table 6 - *Web of Science Categories based on the record count*

Web of Science Categories	Record count
Environmental Sciences	152
Green Sustainable Science Technology	136
Environmental Studies	81
Engineering Environmental	62
Management	54

Web of Science Categories	Record count
Business	39
Computer Science Interdisciplinary Applications	31
Engineering Manufacturing	30
Energy Fuels	26
Engineering Industrial	24

According to Table 6, an interdisciplinary research landscape exists, from environmental focus and sustainability to engineering, management, and business. Table 7 shows the top 20 author keywords and their number of occurrences. Of 1333 keywords identified, 47 of them had several occurrences in at least 5 papers. Analysing the keywords reveals a strong connection between circular economy research and digital transformation.

Table 7 - *First 20 author keywords based on the number of occurrences*

Author Keyword	Occurrences
circular economy	239
sustainability	62
GIS	26
digital platforms	23
information systems	17
digital platform	17
digitalization	16
waste management	15
digital transformation	15
industrial symbiosis	15
artificial intelligence	14
digital technologies	13
blockchain	12
life cycle assessment	12
reverse logistics	11
sustainable development	11
geographic information system	11
industry 4.0	10
recycling	9
circular business models	8

As seen in Table 7, while traditional concepts such as sustainability, waste management, and recycling remain central in research, there is also an increase in concepts like digital platforms, digital transformation, artificial intelligence, and blockchain. This suggests an evolution of the traditional fields of research and an enabling of digital infrastructures as drivers of circular value creation. The appearance of keywords such as GIS and life cycle assessment highlights an emphasis on data driven decision making and performance measurement. Figure 6 presents the 47 author keywords, which are grouped in 7 clusters.

The main keyword for each cluster is:

- Cluster 1 – geographic information system (red colour)
- Cluster 2 – sustainability (green colour)
- Cluster 3 – waste management (dark blue colour)

- Cluster 4 – digital platforms (yellow colour)
- Cluster 5 – digitalisation (purple colour)
- Cluster 6–information systems (light blue colour)
- Cluster 7 – circular economy (orange colour)

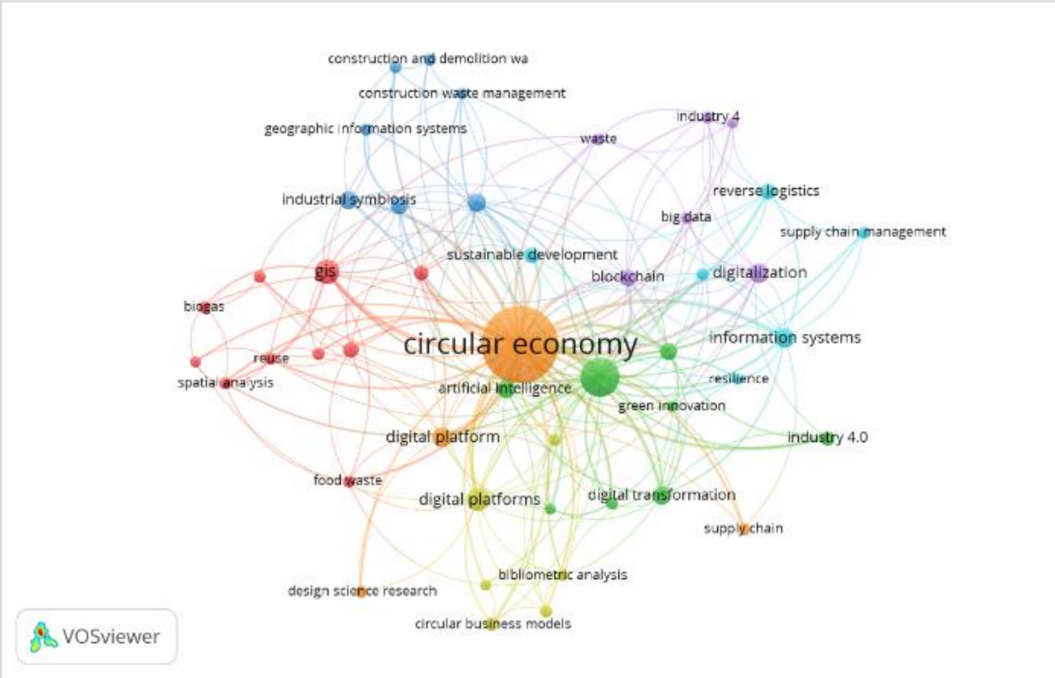


Figure 6 - *Author keywords*

Figure 7 illustrates the overlay visualisation of the keywords, which further reveals the temporal evolution of the research in the analysed field, highlighting a transition to digitalisation of the circular economy.

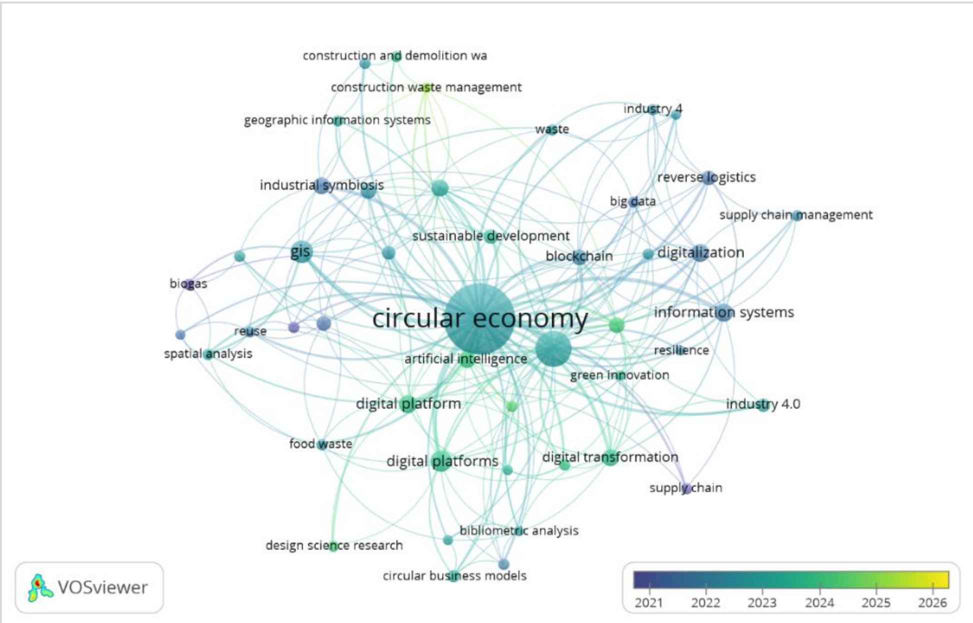


Figure 7 - *Author keywords – overlay visualisation*

The findings of this bibliometric study show that circular economy research is evolving and indicates that digital technologies are becoming central to how circular systems are designed and managed. The analysis also shows that circular economy research is becoming more interconnected and interdisciplinary. The results show that the field is rapidly entering a new phase where digital innovation is becoming a core mechanism to create long term benefits for society and the environment in relation to circular business models.

Conclusions

This bibliographic study examined the current state of scientific literature on the relationship between the circular economy and digital platforms. Following the analysis, it can be observed that while traditional concepts such as waste management, recycling, and sustainability have a central role in research, new concepts such as digital platforms, artificial intelligence, and digital transformation are becoming more prevalent. The keyword analysis, as shown in Table 7 and Figure 6, highlights the structure of the analysed field. The higher mentioned keyword is circular economy, followed by sustainability, while keywords such as GIS, digital platform, and information systems indicate that there is a strong connection between circular economy and digital infrastructures.

Table 4 and Figure 4 indicate a strong international interest in the analysed field, with Italy leading with 59 documents, followed by the People's Republic of China with 48 documents, the Netherlands with 38 documents, and Germany with 36 documents. The results show that while European countries play a significant role in shaping the field, there is also a diverse and global research community, as the topic is gaining interest in various regions of the world. Table 6 shows the interdisciplinarity of the field, as it combines environmental science, engineering, management, and computer science to address the challenges of implementing circular business models.

Circular economy research is evolving and is entering a new phase where digital transformation is becoming central to providing long term benefits for society and the environment. Limitations regarding the search strategy should be mentioned, namely the fact that the search was performed with the Web of Science database, other documents from other databases or the Internet were not taken into account, and the fact that the search was based on a set of words used in the formula, and different variations of those used could have included other studies.

REFERENCES

1. Antikainen, M., Uusitalo, T. & Kivikyto-Reponen, P. (2018) Digitalization as an Enabler of Circular Economy. *Procedia CIRP*. 73. pp. 45-49. https://doi.org/10.1016/j. procir. 2018.04.027.
2. Bellini, A., Tadayon, A., Andersen, B. & Klungseth, N.J. (2024) The role of data when implementing circular strategies in the built environment: A literature review. *Cleaner Environmental Systems*. 13. 100183. https://doi.org/10.1016/j.cesys.2024.100183.
3. Blackburn, O., Ritala, P. & Keranen, J. (2023) Digital Platforms for the Circular Economy: Exploring Meta-Organizational Orchestration Mechanisms. *Organization & Environment*. 36(2). pp. 253-281. https://doi.org/10.1177/10860266221130717.
4. Charnley. F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O. & Tiwari, A. (2019) Simulation to enable a data-driven circular economy. *Sustainability*. 11(12). p 3379. https://doi.org/10.3390/su11123379.
5. Han, Y., Shevchenko, T., Yannou, B., Ranjbari, M., Esfandabadi, Z.S., Saidani, M., Bouillass, G., Bliumska-Danko, K. & Li, G. (2023) Exploring How Digital Technologies Enable a Circular Economy of Products. *Sustainability*. 15(3). p.2067. https://doi. org/ 10.3390/su15032067.
6. Liam, N., Simanjuntak, A., Newell, H. & Xiang Tan, W. (2025) Opportunities and Challenges in Implementing Circular Economy within Digital Platforms. *International Transactions on Education Technology*. 3(2). pp. 125-133. https://doi.org/10.33050/itee.v3i2.765.

7. Lakatos, E.S., Rhazzali, A.L., Pernice, U., Panait, O.B., Arion, F. & Cioca, L.I. (2026) Integrating Emerging Digital Technologies into Circular Economy Practices. *Processes*. 14(3). p.556. https://doi.org/10.3390/pr14030556.
8. Prisco, A., Rey, A., Sciarelli, M. & Tuccillo, D. (2026) Linking Loops: How Digital Platforms Orchestrate Circular Economy Networks. *Sustainable Development*. 1-13. https://doi.org/10.1002/sd.70641.
9. Soldatos, J., Kefalakis, N., Despotopoulou, A.M., Bodin, U., Musumeci, A., Scandura, A., Aliprandi, C., Arabsolgar, D. & Colledani, M. (2021) A digital platform for cross-sector collaborative value networks in the circular economy. *Procedia Manufacturing*. 54. pp. 64-69. https://doi.org/10.1016/j.promfg.2021.07.011
10. Tennant, J. (2020) Web of Science and Scopus are not global databases of knowledge. *European Science Editing*. 46. DOI:10.3897/ese.2020.e51987
11. Wu, H., Li, S., Hou, W. & Zhang, X. (2024) Leveraging Digital Platforms for Circular Economy: A Value Creation View. *Sustainability*. 16(24). 11180. https://doi.org/ 10.3390/su162411180
12. Zhu, J.& Liu, W. (2020) A tale of two databases: the use of Web of Science and Scopus in academic papers. *Scientometrics*. 123(2). https://doi.org/10.1007/s11192-020-03387-8.

"*We never know the worth of water till the well is dry*."

Thomas Fuller

Circular Economy Strategies and Resource Optimization in Investment Processes

Elena ALEXE, Nicola Georgiana BUCUR, Bianca Stefania NITU, Ionut Marius CROITORU*

National University of Science and Technology POLITEHNICA Bucharest
313 Splaiul Independentei, Bucharest, Romania

Abstract

This article examines the relationship between circular economy strategies and resource optimization in investment processes through a structured literature review of recent studies indexed to the Web of Science Core Collection. Based on a Topic Search (TS) limited to the period 2021–2025 and to the document types Article and Review, 466 records were identified. After title screening, abstract screening, and an additional verification of ambiguous cases through Author Keywords and Keywords Plus, the final sample included 183 studies. The retained literature was classified into three circular economy categories and three investment-related categories. The results show a clear dominance of Resource efficiency and Resource optimization. The thematic matrix further indicates that the literature primarily connects circular economy with operational optimization and project evaluation rather than with deeper strategic transformation and financing mechanisms.

Keywords: circular economy; resource optimization; investment processes

"*When you put the whole picture together, recycling is the right thing to do.*"
Pam Shoemaker

Introduction

The circular economy is increasingly recognized as an innovative production model aimed at maintaining the value of products, materials, and resources for as long as possible while minimizing waste generation (Deselnicu et al., 2018). In a broader strategic sense, this transition is also consistent with the growing emphasis placed on aligning organizational strategy with wider sustainability objectives and development frameworks (Fleacă et al., 2018). Beyond its role in

Correspondence to Ionut Marius CROITORU: ionut.croitoru0208@upb.ro

policy frameworks, recent research approaches the circular economy as a concept that fundamentally changes how resources are used, how production and consumption interact, and how organizations generate, maintain, and recover value. In this context, resource efficiency is often highlighted as a core element of the transition, while the debate has gradually expanded to include aspects such as innovation, new business models, digitalization, and governance mechanisms. Empirical studies indicate that investment and innovation play an important role in improving circular performance, particularly within European economies, and that public policies and institutional frameworks have a direct impact on the speed of this transition (Lehmann et al., 2022; Hartley et al., 2023; Yen and Ha, 2025).

Sustainable development has gained increasing global attention, being defined as a balanced integration of economic, environmental, and social dimensions, as reflected in the United Nations Sustainable Development Goals (Fleacă et al., 2018; Todorova et al., 2025; Nica et al., 2026).

At the same time, the investment dimension of the circular economy has gained increasing attention. The implementation of circular strategies involves not only technological and organizational changes, but also complex decisions related to project selection, capital allocation, feasibility evaluation, and risk management. Some studies explicitly emphasize the role of investment and innovation in advancing the circular economy (Lehmann et al., 2022), while others focus on the contribution of digitalization and business innovation to circular performance and the development of circular business models (Kalogiannidis et al., 2022; Neligan et al., 2023). In parallel, a growing body of research highlights the importance of public expenditure, financial policies, and polycentric governance structures in supporting resource productivity and facilitating the circular transition (Mango and Vincent, 2025; Yen and Ha, 2025). At the same time, the literature also draws attention to a number of challenges and limitations. These include inherent tensions between the economic, social and environmental objectives of the circular economy, as well as the risks related to leakage effects, high initial investment costs, and the partial or inconsistent implementation of circular strategies (Safarzynska et al., 2023; Ferrer-Serrano and Salesa, 2025).

More recently, several studies have drawn attention to the role of financial mechanisms, management accounting, and financial innovation in supporting the transition toward a circular economy. These contributions indicate that the successful implementation of circular practices depends not only on technical efficiency, but also on organizations' capacity to integrate appropriate evaluation methods, financing tools, and decision-support systems (Aureli et al., 2025; Kumar et al., 2025). However, these perspectives remain relatively marginal compared to the dominant focus of the literature, which continues to prioritize efficiency and optimization.

Despite the recent growth of circular economy research, the literature remains fragmented across several perspectives, including resource efficiency, technological and process innovation, and business model transformation. Earlier conceptual contributions have also emphasized that circular economy principles are interpreted and implemented differently across national and regional settings, including Romania and the wider European context (Ivascu and Ardelean, 2017; Leuştean, 2014). However, there is still limited integration of these approaches with investment-related dimensions such as resource optimization, project evaluation and decision-making, as well as capital allocation and implementation. For the post-2020 period, there is a lack of structured review that systematically connects circular economy strategies with investment processes.

Accordingly, this article aims to identify, structure and interpret the main thematic connections between circular economy strategies and resource optimization within investment processes, based on a structured review of recent literature. To achieve this objective, the study addresses the following research questions:

- **RQ1**. How is the recent literature on circular economy strategies within investment processes thematically structured?
- **RQ2**. Which investment-related dimensions are most closely associated with circular economy strategies in the reviewed literature?
- **RQ3**. What implications do the identified thematic patterns have for future research and for investment-oriented managerial practice in circular economy contexts?

The main contribution of this study lies in structuring a fragmented body of literature into a coherent thematic framework, built around three circular economy categories and three investment-related categories. This approach enables the identification of both well-developed areas and less explored intersections, in a manner that is analytically clear and practically relevant.

The remainder of the article is organized as follows. Section 2 outlines the methodology and the screening process. Section 3 presents the thematic results. Section 4 discusses the implications of the findings for both research and managerial practice. Finally, Section 5 provides the conclusions.

Methodology of research

This study was designed as a structured literature review examining the relationship between circular economy strategies and resource optimization within investment processes. The literature was retrieved from the Web of Science Core Collection, *chosen for its high-quality indexing standards* and relevance for interdisciplinary research in sustainability and economics (Figure 1).

The search strategy was based on a Topic Search (TS) query combining three thematic dimensions: circular economy, resource efficiency/optimization, and investment processes. The query was constructed using Boolean operators and truncation to ensure both coverage and precision:

TS= (("circular econom*" OR "circular strateg*" OR circularity OR "circular business model*" OR "closed-loop" OR "closed loop") AND ("resource optim*" OR "resource efficien*" OR "material efficien*" OR "resource allocation" OR "resource productivity" OR "efficient resource use") AND (invest* OR "investment process*" OR "investment decision*" OR "investment project*" OR "project evaluation" OR "project selection" OR "capital budgeting" OR "technology choice" OR "economic evaluation")).

The Topic Search (TS) field in the Web of Science Core Collection was selected, as it simultaneously covers the Title, Abstract, Author Keywords, and Keywords Plus. This approach allowed for the identification of recent interdisciplinary literature while maintaining a clear focus on the intersection between circular strategies, efficient resource use, and investment-related aspects. The use of Boolean operators and truncation was intended to ensure an appropriate balance between sensitivity and specificity of the search.

The dataset was finalized on March 23, 2026, at 18:00 EET (Bucharest). The initial search returned 663 records. After applying filters for publication years (2021-2025) and document types (Article and Review), the dataset was reduced to 466 records.

The study selection process followed a structured multi-stage approach inspired by PRISMA guidelines. First, a title screening was conducted to eliminate clearly irrelevant studies. Second, the remaining records were assessed through abstract screening. Third, articles with unclear relevance were further evaluated based on Author Keywords and Keywords Plus. This process resulted in a final sample of 183 articles, as illustrated in Figure 1.

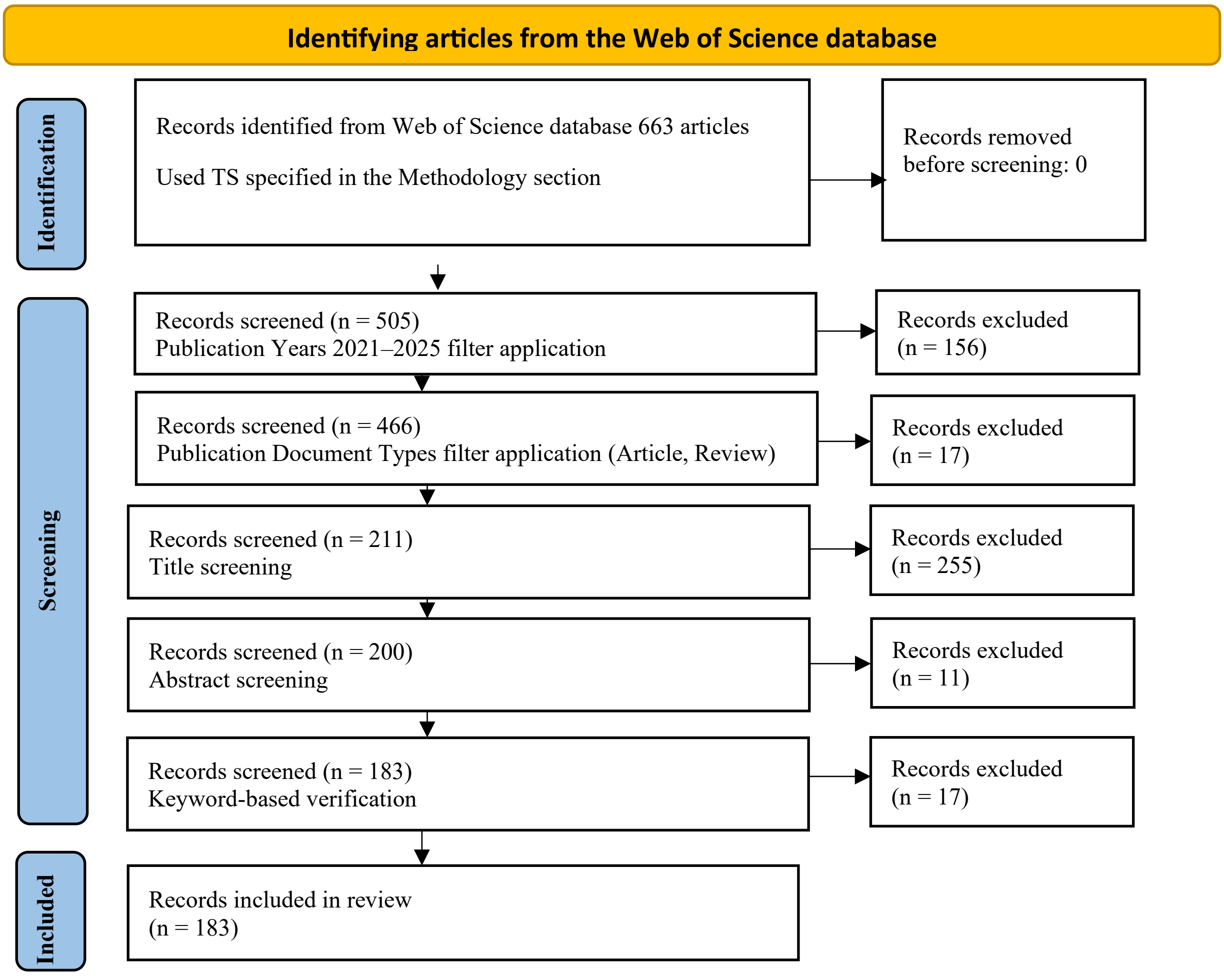


Figure 1 - PRISMA-style flow diagram of study

For the thematic interpretation, the selected studies were classified into three circular economy categories and three investment-related categories. The circular economy categories included: Resource efficiency (CE1), Circular technology/process innovation (CE2), and Circular business models/transition (CE3), as presented in Table 1. The investment-related categories comprised: Resource optimization (INV1), Project evaluation, risk and decision-making (INV2), and Capital allocation and implementation (INV3), presented in Table 2.

Table 1 - *Distribution of 183 articles by CE group*

CE group	Article number	Percentage
CE1 = Resource efficiency	134	73.2%
CE2 = Circular technology/process innovation	32	17.5%
CE3 = Circular business models/transition	17	9.3%

Table 2 - *Distribution of 183 articles by INV group*

INV group	Article number	Percentage
INV1 = Resource optimization	91	49.7%
INV2 = Project evaluation, risk and decision-making	66	36.1%
INV3 = Capital allocation and implementation	26	14.2%

In addition to the thematic screening, the profile of the 466 identified records provides a useful validation of the review context. The temporal distribution indicates a strong concentration in the most recent years of the selected period: 2025 alone accounts for 50.2% of the filtered records, followed by 2024 with 21.7%, 2023 with 12.0%, 2022 with 9.4%, and 2021 with 6.7%. This distribution confirms the recent and rapidly expanding nature of the topic.

Table 3 - *Distribution of the 466 articles from the Web of Science query*

Publication Year	Article number	Percentage of 466
2025	234	50.215%
2024	101	21.674%
2023	56	12.017%
2022	44	9.442%
2021	31	6.652%

The disciplinary profile of the identified records further supports the relevance of the review. In terms of Research Areas (Table 4), literature is primarily concentrated in Environmental Sciences Ecology (43.8%), Science Technology Other Topics (32.6%), and Engineering (28.8%), while Business Economics (11.2%) and Operations Research Management Science (3.6%) are less represented. A similar pattern is observed in the Web of Science Categories (table 5), where Environmental Sciences (36.7%) and Green Sustainable Science Technology (30.5%) dominate, whereas Management (6.0%) and Business (4.7%), account for smaller shares. This distribution suggests that the relationship between the circular economy and investment is still predominantly examined from technical and environmental perspectives, thereby reinforcing the need for a review focused on managerial and investment-related dimensions.

Table 4 - *Distribution of the 466 articles by Research Area*

Research Area	Article number	Percentage of 466
Environmental Sciences Ecology	204	43.777%
Science Technology Other Topics	152	32.618%
Engineering	134	28.755%
Business Economics	52	11.159%
Energy Fuels	36	7.725%
Materials Science	34	7.296%
Construction Building Technology	29	6.223%
Chemistry	24	5.150%
Operations Research Management Science	17	3.648%
Computer Science	14	3.004%

Table 5 - *Distribution of the 466 articles by Web of Science Category*

Web of Science Category	Article number	Percentage of 466
Environmental Sciences	171	36.695%
Green Sustainable Science Technology	142	30.472%
Environmental Studies	92	19.742%
Engineering Environmental	63	13.519%
Energy Fuels	36	7.725%
Construction Building Technology	29	6.223%
Management	28	6.009%
Engineering Civil	26	5.579%
Materials Science Multidisciplinary	26	5.579%
Business	22	4.721%

Results of research

Overview of the reviewed literature. The final sample includes 183 articles (Table 6), distributed across three circular economy categories and three investment-related categories. The overall distribution reveals a strong concentration on operational and efficiency-oriented dimensions, suggesting that recent literature tends to associate the circular economy primarily with resource use optimization and process performance, rather than with more profound business model transformation or financial implementation mechanisms.

From the perspective of CE groups, the largest share of the literature falls within CE1 = Resource efficiency, comprising 134 articles, which represents approximately 73.2% of the final sample. CE2 = Circular technology/process innovation includes 32 articles (17.5%), while CE3 = Circular business models/transition accounts for only 17 articles (9.3%).

This distribution indicates that recent research is predominantly oriented toward understanding the circular economy through the lens of efficient resource use, waste reduction, productivity, and material performance. Evidence from the reviewed studies supports this trend, either by emphasizing the relationship between investment, innovation, and resource efficiency (Lehmann et al., 2022), or by highlighting the link between public expenditure and resource productivity (Mango and Vincent, 2025).

From the perspective of INV groups, the largest category is INV1 = Resource optimization, with 91 articles (49.7%), followed by INV2 = Project evaluation, risk and decision-making, with 66 articles (36.1%), and INV3 = Capital allocation and implementation, with 26 articles (14.2%). This distribution suggests that literature more frequently approaches the investment dimension in terms of resource use efficiency and project evaluation, while comparatively less attention is given to concrete aspects related to capital allocation and financial implementation mechanisms.

Table 6 - *Distribution of the 183 article CE group/ INV group*

CE group / INV group	INV1	INV2	INV3	Total
CE1	73	42	19	134
CE2	13	15	4	32
CE3	5	9	3	17
Total	91	66	26	183

Interpretation of CE groups. The category CE1 = Resource efficiency clearly dominates the literature and represents the main conceptual core linking the circular economy to investment. Within this category, circular strategies are typically interpreted in terms of reduced resource consumption, extended material value, increased resource productivity, and lower production losses. Consequently, the associated investment logic is largely oriented toward efficiency, performance evaluation, and economic justification. Several studies in the sample explicitly address aspects such as investment, innovation, resource productivity, and the economic impact of circular practices (Lehmann et al., 2022; Grdic and Spoljaric, 2022; Liu et al., 2025).

The category CE2 = Circular technology/process innovation is comparatively smaller, yet remains significant as it captures literature that links the circular economy with digitalization, circular technologies, process innovation, monitoring tools, and new technical configurations of implementation. This group mainly includes studies that conceptualize the circular transition as a process driven by technological change and by organizations' capacity to integrate digital, data-driven, and innovation management solutions. In this context, research on digitalization and circular performance, the role of disruptive digital technologies in resource optimization, and the development of data typologies for the circular economy is particularly relevant (Kalogiannidis et al., 2022; Agrawal et al., 2023; Araujo et al., 2025; Popescu et al., 2020).

The category CE3 = Circular business models/transition is the smallest in numerical terms. However, this underrepresentation represents one of the most significant findings of the analysis. Literature addresses the circular transition less frequently in terms of business model transformation, strategic reinvestment, organizational reconfiguration, or broader systemic changes in value creation. At the same time, some studies indicate that digitalization can act as an enabling factor in the development of circular business models, while others highlight the role of management accounting systems and organizational dialogue in supporting the adoption of circular solutions (Neligan et al., 2023; Aureli et al., 2025). In addition, a limited number of recent contributions emphasize the need to move beyond a narrow focus on technical optimization and cost reduction, advocating instead for a broader perspective that incorporates organizational transformation and reinvestment with social and strategic implications (Diprose et al., 2025; Ferrer-Serrano and Salesa, 2025).

Interpretation of INV groups. The category INV1 = Resource optimization accounts for nearly half of the sample and confirms that recent literature approaches investment in the context of the circular economy primarily through the lens of efficiency and improved resource use. This category includes studies focused on productivity, resource management, material performance, and cost reduction, indicating that the dominant investment rationale is largely operational and functional.

The category INV2 = Project evaluation, risk and decision-making ranks second, reflecting a relatively consistent body of literature that examines the circular transition in terms of project selection, economic appraisal, risk assessment, and decision-support mechanisms. This dimension is particularly important, as it connects circular economy objectives with traditional investment analysis frameworks (Georgescu et al., 2025). It includes studies that address not only performance outcomes, but also challenges such as trade-offs, high initial costs, paradoxes, and limitations in implementation (Safarzynska et al., 2023; Ferrer-Serrano and Salesa, 2025).

The category INV3 = Capital allocation and implementation is the least represented, suggesting that the existing literature places considerably less emphasis on aspects such as financing structures, actual capital allocation, budget prioritization, and the practical implementation of circular investments. Although some studies discuss the role of public expenditure, investment flows, reinvestment of surplus, and financial mechanisms, this dimension remains comparatively underdeveloped in relation to the other two categories (Mango and Vincent, 2025; Diprose et al., 2025; Kumar et al., 2025).

Interpretation of the 3×3 matrix. The matrix combining CE and INV groups provides the clearest representation of the thematic structure of literature. The strongest intersection is CE1–INV1, with 73 articles, representing approximately 39.9% of the total sample. This indicates that the literature predominantly links Resource efficiency with Resource optimization, treating the circular economy primarily as an issue of efficient resource use within investment-related decisions and processes.

The second most prominent intersection is CE1–INV2, with 42 articles (23.0%), showing that Resource efficiency is also frequently associated with Project evaluation, risk and decision-making. Together, these two intersections account for nearly two-thirds of the sample, confirming that recent literature approaches the circular economy mainly through the combined lens of operational efficiency and investment appraisal.

The intersections involving CE2 are considerably smaller yet reveal a distinct pattern. The CE2–INV2 intersection (15 articles) is slightly more prominent than CE2–INV1 (13 articles), suggesting that research on technological and process innovation is more often associated with project evaluation, risk, and decision-making than with simple resource optimization. This is consistent with the nature of technological change, which typically involves uncertainty, upfront investment, and the need for more advanced evaluation mechanisms.

The intersections associated with CE3 are the least represented. Among them, CE3–INV2 is the most visible (9 articles), followed by CE3–INV1 (5 articles) and CE3–INV3 (3 articles). This distribution indicates that when the literature addresses circular business models/transition, it tends to do so primarily in terms of decision-making, risk, and evaluation rather than capital allocation. At the same time, the very limited presence of the CE3–INV3 intersection suggests that the relationship between business model transformation and the concrete financing and implementation mechanisms remains underdeveloped in recent research.

Discussion

The results indicate that recent literature on circular economy strategies and investment processes is strongly dominated by an operational logic centered on resource efficiency and resource optimization. This finding is important because it suggests that, during the 2021–2025 period, the circular economy has been primarily approached as a framework for improving resource performance, reducing waste, and enhancing process efficiency, rather than as a driver of deeper strategic transformation. In addition, recent research shows that climate-related financial policies can directly support circularity performance, reinforcing the argument that the financial dimension of the circular transition deserves more explicit attention in investment-oriented literature (Yen and Ha, 2025). The prominence of the CE1–INV1 intersection further confirms that the literature mainly associates circular transition with more efficient resource use in projects, processes, and organizational systems.

This orientation can be explained by the fact that resource efficiency provides the most direct and easily measurable economic rationale for adopting circular practices. Cost reduction, increased resource productivity, and the economic justification of investments are generally easier to assess than systemic business model transformation or the long-term benefits of a fully circular transition (Grigore et al., 2024). In this respect, the findings are consistent with studies showing that investment and innovation can enhance circular performance, as well as with research emphasizing the role of economic evaluation and institutional incentives in supporting the adoption of circular economy practices (Lehmann et al., 2022; Mango and Vincent, 2025).

At the same time, the distribution of the results indicates that the literature assigns a significant, though secondary, role to the relationship between the circular economy and project evaluation, risk and decision-making. This dimension is particularly visible in the CE1–INV2 and CE2–INV2 intersections, suggesting that the circular transition is increasingly approached as a matter of investment choice, feasibility assessment, and uncertainty management. This perspective is especially relevant for managerial practice, as the implementation of circular strategies often involves high upfront costs, reliance on infrastructure, exposure to market risk, and the need for multi-criteria decision-making. Studies addressing circular economy paradoxes, initial costs, leakage effects, and financial implications support this interpretation

(Safarzynska et al., 2023; Ferrer-Serrano and Salesa, 2025; Bertelli et al., 2025).

One of the most important findings of this study is the underrepresentation of CE3 = Circular business models/transition, particularly the weak intersection with INV3 = Capital allocation and implementation. This result suggests that the current literature pays limited attention to the strategic transformation of organizations through circular business models supported by concrete financing and implementation mechanisms. In other words, while the literature explains relatively well why the circular economy can improve efficiency and how it can be evaluated, it provides far less insight into how it is financed, implemented, and scaled in practice. This gap is particularly significant given that recent studies highlight the role of financial innovation, climate-related financial policies, managerial evaluation tools, and the relationship between circular economy performance and firms' financial outcomes in accelerating or constraining circular transition (Kumar et al., 2025; Yen and Ha, 2025; Aureli et al., 2025; Sarfraz et al., 2023). This area therefore represents one of the most promising directions for future research.

A second important direction emerging from the analysis concerns the role of technology/process innovation as a bridge between operational efficiency and strategic transformation. Although the CE2 category is significantly smaller than CE1, the literature indicates that digitalization, disruptive digital technologies, and data infrastructures can support both circular performance and the development of more advanced circular business models (Kalogiannidis et al., 2022; Agrawal et al., 2023; Neligan et al., 2023; Simion et al., 2013). This suggests that future research should more explicitly examine how technological investments can facilitate the transition from basic resource efficiency practices to more complex circular organizational models.

These findings also have important implications for decision-makers. If the literature continues to focus primarily on efficiency and optimization, there is a risk that the circular economy will be reduced to an incremental approach centered on improving resource use, without being accompanied by deeper organizational, financial, and strategic transformation. Recent studies addressing transformative re-investments, public policy frameworks, and data infrastructures for the circular economy highlight the need for a more integrated perspective, in which the circular transition is supported simultaneously by technology, governance, measurement systems, and financing mechanisms (Hartley et al., 2023; Diprose et al., 2025; Araujo et al., 2025).

Organizations operate in environments characterized by uncertainty, where effective decision-making depends on the identification, analysis, and evaluation of risks that may affect the achievement of objectives (Tiganoaia et al., 2019).

Accordingly, the findings point to a research agenda structured around three main directions. First, there is a need to extend the literature beyond resource efficiency toward business model transformation and the development of organizational capabilities. Second, greater attention should be given to the dimension of capital allocation and implementation, particularly through studies that explicitly address the financing of the circular transition, budgeting mechanisms, and implementation stages. Third, future research should more clearly integrate technology/process innovation with investment appraisal and long-term managerial outcomes. In this sense, the article answers RQ3 by demonstrating that future research should focus not only on measuring circular efficiency, but also on understanding how it can be translated into viable, financed, and coherently implemented projects.

The analysis provides a direct response to the three research questions. First, RQ1 is addressed by identifying the thematic structure of the literature through three circular economy categories, highlighting a strong concentration around Resource efficiency. Second, RQ2 is addressed through the examination of the investment-related dimensions and the CE × INV matrix, which shows that Resource optimization and Project evaluation, risk and decision-making are the dominant investment-related associations in the reviewed literature. Third, RQ3 is addressed by interpreting these distributions as evidence of an imbalanced research field, one that has progressed significantly in operational and evaluative terms, but remains comparatively underdeveloped in relation to capital allocation, implementation, and circular business model transformation.

Sustainable organizational performance depends on the balanced integration of economic, environmental, and social dimensions, requiring coherent strategies and coordinated actions across organizational processes (Fleacă et al., 2018).

Conclusions

This article examined the relationship between circular economy strategies and resource optimization in investment processes through a structured literature review of 183 articles published between 2021 and 2025. The findings indicate that recent literature is predominantly concentrated within the Resource efficiency category, followed, at a considerable distance, by Circular technology/process innovation and, to a much lesser extent, by Circular business models/transition. From an investment perspective, Resource optimization represents the most prominent dimension, followed by Project evaluation, risk and decision-making, while Capital allocation and implementation remain comparatively underrepresented.

The main contribution of the study lies in organizing a fragmented body of literature into a simplified thematic framework that highlights both dominant areas and underdeveloped intersections. In particular, the 3×3 matrix shows that the literature primarily links the circular economy with efficient resource use and with investment appraisal logic, while placing significantly less emphasis on business model transformation and on concrete financing and implementation mechanisms.

From a practical standpoint, these findings suggest that organizations and decision-makers aiming to implement the circular economy principles require more than efficiency-driven arguments. There is a need for more comprehensive frameworks that address project selection, risk management, capital allocation, and the strategic implementation of circular initiatives. From an academic perspective, the study highlights the need for future research that explores the connection between business model transition, financing, and implementation, as well as the more explicit integration of technology/process innovation into investment analysis.

A limitation of the study relates to the use of a single database and a defined time frame, as well as to the adoption of a simplified thematic framework aligned with the concise format of the manuscript. Nevertheless, this approach enabled the development of a clear and comparable overview of how recent literature connects circular economy strategies with investment processes. In conclusion, although the literature has made significant progress, the transition from resource efficiency toward fully financed and effectively implemented circular transformation remains insufficiently addressed.

REFERENCES

1. Agrawal, R., Yadav, V.S., Majumdar, A., Kumar, A., Luthra, S. & and Garza-Reyes, J.A. (2023) Opportunities for disruptive digital technologies to ensure circularity in supply chain: A critical review of drivers, barriers and challenges. *Computers & Industrial Engineering*. 178. doi: 10.1016/j.cie.2023.109140.
2. Araujo, J.B., Nolte, A., Berg, H., Dittrich, M., Greiff, K., Plociennik, C., Pomp, A. & and Viere, T. (2025) A Typology for Circular Economy Data. *Journal of Circular Economy*. 3 (1). doi: 10.55845/UXBM6358.
3. Aureli, S., Foschi, E. & Paletta, A. (2025) Management accounting for a circular economy: current limits and avenue for a dialogic approach. *Accounting, Auditing & Accountability Journal*. 38 (9). pp.291-319**.**
4. Deselnicu, V., Zainescu, G., Albu, L., Deselnicu, D.C., Militaru, G. & Pang, X. (2018) Circular Economy – an Innovative and Creative Production Model. *Proceedings: ICAMS 2018 – International Conference on Advanced Materials and Systems*. doi: 10.24264/icams-2018.XI.5.

5. Diprose, G., Dombroski, K., Stronge, D. & Greenaway, A. (2025) Expanding circular economies through transformative re-investments. *Local Environment*. Article; Early Access. doi: 10.1080/13549839.2025.2533143.
6. Ferrer-Serrano, M. & Salesa, A. (2025) Revisiting the Circular Economy Paradox: A Triple Bottom Line Perspectve. *Sustainable Development.* 33(5). doi:10.1002/sd.3539
7. Fleacă, E., Fleacă, B. & Maiduc, S. (2018) Aligning Strategy with Sustainable Development Goals (SDGs): Process Scoping Diagram for Entrepreneurial Higher Education Institut
8. Georgescu, A., Gurau, M.M., Bucovetchi, O. & Dinu, A. (2025) The European Cybersecurity Framework for Critical Energy Infrastructures. In: *The Palgrave Handbook of Cybersecurity, Technologies and Energy Transitions*. Cham: Springer Nature Switzerland. pp.1-39.
9. Grdic, Z.S. & Spoljaric, T. (2022) Possibilities of Sustainable Economical Development in Framework of Circular Economy. *Ekonomski Pregled*. 73 (1). doi: 10.32910/ep.73.1.2.
10. Grigore, G.E., Nicolae, S. & Vladut, O. (2024) A Multivariate Analysis of the Interplay between Energy Resources, Economic Growth, and Financial Stability: Evidence from Azerbaijan. *Proceedings of the International Conference on Business Excellence*. 18 (1). pp.3185-3211. doi: 10.2478/picbe-2024-0260.
11. Hartley, K., Schulzchen, S., Bakker, C.A. & Kirchherr, J. (2023) A policy framework for the circular economy: Lessons from the EU. *Journal of Cleaner Production*. 412. doi: 10.1016/j.jclepro.2023.137176.
12. Ivascu, L. & Ardelean, B.-O. (2017) Principles of Circular Economy in Romania, Europe and China. *DEStech Transactions on Social Science, Education and Human Science*. doi: 10.12783/dtssehs/seme2017/18037.
13. Kalogiannidis, S., Kalfas, D., Chatzitheodoridis, F. & Kontsas, S. (2022) The Impact of Digitalization in Supporting the Performance of Circular Economy: A Case Study of Greece. *Journal of Risk and Financial Management*. 15 (8). doi: 10.3390/jrfm15080349.
14. Kumar, B., Kumar, A., Sassanelli, C. & Kumar, L. (2025) Exploring the role of finance in driving circular economy and sustainable business practices. *Journal of Cleaner Production*. 486. 144480. doi: 10.1016/j.jclepro.2024.144480.
15. Nica, I., Delcea, C., Bigioi, A.D. & Bigioi, C.E. (2026) Assessing the Impact of Environmental Sustainability and Energy Efficiency on Economic Growth: A Multivariate Analysis Aligned with the EU's Sustainable Development Goals. *Sustainability*. 18 (5). 2335. doi: 10.3390/en16073090.
16. Lehmann, C., Cruz-Jesus, F., Oliveira, T. & Damasio, B. (2022) Leveraging the circular economy: Investment and innovation as drivers. *Journal of Cleaner Production*. 360. doi: 10.1016/j.jclepro.2022.132146.
17. Leuştean, B. (2014) Knowledge and the European Behavior. *Review of General Management*. 20 (2). p.83
18. Liu, Y., Usman, M., Akbar, A. & Hedvicakova, M. (2025) From Linear to Circular: Assessing the Influence of Circular Economy Practices on Business and Environmental Dynamics. *Polish Journal of Environmental Studies*. 34 (1). doi: 10.15244/pjoes/186581.
19. Mango, F. & Vincent, R.C. (2025) Does polycentric climate governance drive the circular economy? Evidence from subnational spending and dematerialization of production in the EU. *Ecological Economics*. 231. doi: 10.1016/j.ecolecon.2025.108533.
20. Neligan, A., Baumgartner, R.J., Geissdoerfer, M. & Schöggl, J.-P. (2023) Circular disruption: Digitalisation as a driver of circular economy business models. *Business Strategy and the Environment*. 32 (3). pp.1175-1188. doi: 10.1002/bse.3100
21. Popescu, C., Simion, C. & Popescu, M. (2020) Digital Economy and E-Marketing Advices for Small Businesses. *FAIMA Business & Management Journal*. 8 (2). pp.59-69.

22. Safarzynska, K., Di Domenico, L. & Raberto, M. (2023) The leakage effect may undermine the circular economy efforts. *Scientific Reports*. 13 (1). doi: 10.1038/s41598-023-44004-x.

23. Sarfraz, M., Ivascu, L., Artene, A.E., Bobitan, N., Dumitrescu, D., Bogdan, O. & Burca, V. (2023) The relationship between firms' financial performance and performance measures of circular economy sustainability: an investigation of the G7 countries. *Economic Research-Ekonomska Istraživanja*. 36 (1). doi: 10.1080/1331677X.2022.2101019.

24. Simion, C.P., Bucovtchi, O.M. & Popescu, C.A. (2013) Critical infrastructures protection through threat analysis framework. *Annals of the Oradea University*. 1. pp.351-354.

25. Tiganoaia, B., Niculescu, A., Negoita, O. & Popescu, M. (2019) A new sustainable model for risk management—RIMM. *Sustainability*. 11 (4). 1178. doi: 10.3390/su11041178.

26. Todorova, A., Kostadinova, I., Doltu, T.M. & Kaya, T. (2025) Green Jobs, Energy Efficiency and Sustainable Development: A Theoretical Overview of the Potential for Transformation and Synergistic Effects. *Proceedings: 2025 10th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE)*. pp.1-7.

27. Yen, N.H. & Ha, L.T. (2025) Climate-related financial policies as an enabler of circularity: a new insight from selected countries of the European Union. *International Journal of Climate Change Strategies and Management*. 17 (1). pp.610-630.

"*Additive manufacturing has a major role to play in the circular economy*."

Hendrith Vanlon Smith Jr.

Social Media Promotions and the Life Cycle of Online Purchases

Diana-Alexandra NITA[1], Georgiana MOICEANU[1], Catalin-Florin ICHIMOV[2]

[1] National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independentei, Bucharest, Romania

[2]Anritsu Solution SRL, 201 Barbu Vacarescu Blvd, Bucharest, Romania

Abstract

This research examines the effect of social media ads and promotions on Romanian consumers' online purchasing behaviour and the usefulness and life cycle of the products purchased after exposure to such promotional content. The study is based on an online survey distributed between March and May 2026, with a final sample of 77 respondents. The study tests two hypotheses. The first is that social media ads and promotions influence consumers' online purchase decisions. The second is that products purchased after being exposed to such ads or promotions tend to be short-lived or underutilised. The results show that most respondents have purchased products after seeing them advertised on social media. From a circular economy perspective, the results demonstrate that many products are used for only a limited period, stored but not used. The study thus highlights the need for more responsible digital advertising and greater consumer awareness on product use and circular consumption.

Keywords: social media ads, online buying, product underuse, circular economy

Introduction

Social media platforms have become central infrastructures for product discovery, online persuasion, and consumer conversion. A substantial body of research shows that Instagram- and influencer-based communication can affect purchase decisions because users perceive non-traditional online personalities as credible, relatable, and easier to identify with than traditional celebrities (Djafarova & Rushworth, 2017). On visual platforms, follower counts,

"Innovation is the act that endows resources with a new capacity to create wealth."
Peter Drucker

*Correspondence to Georgiana MOICEANU: georgiana.moiceanu@upb.ro

message value, and branded-content credibility also shape brand attitudes and trust, while parasocial interaction and homophily further strengthen purchase intentions (De Veirman et al., 2017). This effect appears especially strong in fashion and beauty categories, where attitudes toward influencers are positively associated with brand attitude and consumers' willingness to buy promoted items (Chetioui et al., 2020). More recent evidence from TikTok also shows that short-video environments, recommendation systems, social influence, and perceived usefulness foster purchase intentions, highlighting the growing commercial power of algorithmic visual platforms in Europe as well (Grabowska et al., 2025).

At the same time, the implications of this promotional environment extend beyond the purchase moment itself. Research on impulse buying shows that social media can act as an inspiration trigger for unplanned purchases, particularly in the fashion sector (Aragoncillo & Orus, 2018). A smaller but highly relevant sustainability-oriented literature goes further by showing that social media positively affects fast-fashion purchase intention, while sustainability advocacy can reduce this tendency by increasing awareness of environmental consequences (Cayaban et al., 2023). Systematic review evidence also suggests that most social-media fashion research still focuses on brand-led influence rather than on sustainable consumption practices, activism, reduced consumption, reuse, or repair (Vladimirova et al., 2024). This gap matters because fast fashion is structurally associated with frequent consumption, short-lived garment use, and large waste flows, all of which create tensions with circular-economy goals (Niinimäki et al., 2020).

From a circular-economy perspective, the key issue is not only whether social media promotions generate purchases, but also what happens to those products afterwards. Literature on garment longevity shows that extending product lifetimes is essential for reducing environmental impacts, while collaborative models such as resale, renting, swapping, and reuse can help keep products in circulation for longer (Laitala & Klepp, 2020) At the policy level, the European Environment Agency now explicitly notes that digital technologies and social media can contribute to rising textile consumption, even while Europe is trying to shift toward longer use, reuse, repair, and recycling (EEA, 2025). Parallel EEA work on electronics shows that shorter lifetimes and marketing-induced obsolescence create similar circularity pressures in technology markets (EEA, 2020). Against this background, the present study examines Romanian consumers in order to test two hypotheses:

H1: Social media ads and promotions affect consumers' online buying choices.

H2: Items bought after exposure to ads/promotions on social media platforms tend to be ephemeral or underutilised.

Research methodology

The goal of the research is to study the influence of social network advertisements and promotions on the online purchasing behaviour of consumers in Romania. The study seeks to understand the extent to which consumers are exposed to online product promotions, the factors that influence their decision to purchase, the usefulness of the products purchased and the length of time these products are used after purchase. Data were collected through an online questionnaire addressed to the users of social media in Romania, in the period March-May 2026. The final sample was of 77 respondents, 46 female and 31 male. The questionnaire was designed to investigate the effect of social media ads and promotions on online purchase behaviour and the subsequent use of items purchased in response to such stimuli.

The questionnaire was structured in three main sections. The first part was about the profile of the respondents such as age, gender and habits of social media usage. This section was included to understand the frequency with which respondents are faced with digital content and advertising online. The second part of the thesis studied the relationship of social media promotions and online purchasing behaviour. The questions asked to the respondents were: Have you ever bought a product after seeing it on social media? On which social media platforms have you seen these products? Which brands or online stores were the most common in your advertisements? How often did you buy products after seeing them online? What kind of products did you buy? What was the main reason for your decision to buy?

The last part was about the usefulness and life cycle of the bought products after been exposed to the social media ads/promotions. Respondents were asked to rate the usefulness of these products, how long they normally used the products and what they did with products that they no longer used. This section is directly related to circular economy principles, as it tells us whether the purchased products are being used for a long time, underused, not used, returned, resold, donated, recycled or thrown away.

A limitation of this study is that the data were collected through an online questionnaire distributed to a convenience sample of respondents from Romania, so the results cannot be generalised to the entire population. Furthermore, as the answers are self-reported, the respondents could have over- or underrated the influence of social media ads on their buying behaviour or the actual use of the products they bought. The study is also limited to stated perceptions and behaviours versus confirmed purchase data.

Research results

The demographic structure of the sample was analyzed in order to provide a clearer profile of the respondents and to observe how age groups are distributed by gender. As shown in Table 1, the sample is mainly composed of young adults, especially respondents aged 18-34, which is relevant for a study focused on social media exposure and online purchasing behavior.

Table 1 – *Demographic structure of respondents by age group and gender*

Age group	Female	Male	Total	Total percentage
Under 18	2	2	4	5.2%
18-24	15	6	21	27.3%
25-34	17	14	31	40.3%
35-44	6	7	13	16.9%
45-54	4	2	6	7.8%
55+	2	0	2	2.6%

Among the total respondents, the predominant time spent on social media is more than 3 hours per day, reported by 44 respondents (57.1%). Another 23 respondents (29.9%) use social media between 1 and 3 hours per day, which shows that most participants are highly exposed to digital content, ads, and online promotions (Figure 1).

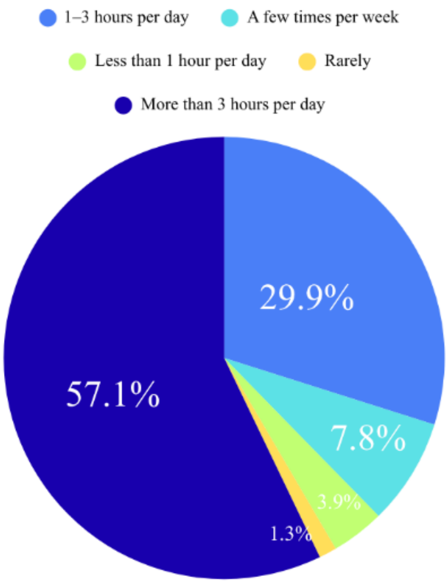


Figure 1 – *Distribution of respondents by daily social media usagel*

The second part of the questionnaire focused on the relationship between social media promotions and online purchasing behaviour. The results show that social media plays an important role in product discovery, especially through platforms such as Instagram (37.7%) and TikTok (20.8%). Instagram appears as the main platform where respondents discovered products later purchased online, followed by TikTok and Facebook. This suggests that visually oriented platforms have a stronger influence on online buying behaviour, especially when products are promoted through attractive images, short videos, trends, or repeated ads.

A significant majority of respondents, 88.3%, stated that they had bought an online product after seeing it in a social media ad or promotion. This result supports the first hypothesis of the study, according to which social media ads and promotions influence consumers' online purchasing decisions (Figure 2).

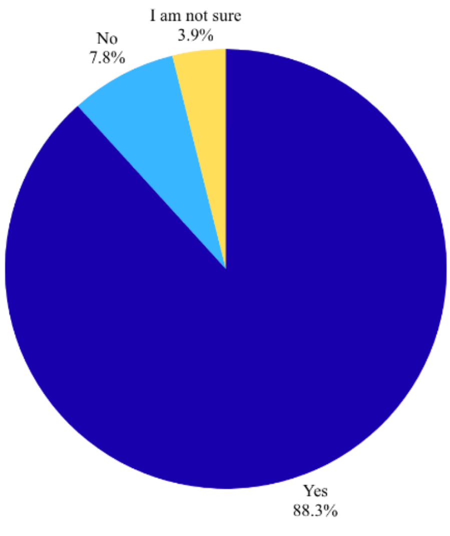


Figure 2 – *Purchase after exposure to social media ads or promotions*

Among the brands and online stores most frequently seen in social media ads by the respondents, Trendyol and Fashion Days were mentioned most often, each with 11 mentions. They were followed by Sephora with 10 mentions, Notino with 9 mentions, and Zalando and Amazon, each with 8 mentions. This indicates that the respondents are mainly exposed to advertising from fashion, beauty, and online marketplace retailers.

Most respondents do not buy promoted products weekly, but they still make such purchases occasionally. The largest share, 36.4%, buys products seen on social media once every few months, while 29.9% do so a few times per year. This shows that social media promotions have a recurring influence on online shopping behaviour, even if the purchase is not always frequent. Clothes represent the most frequently purchased product category, with 36.4% of respondents choosing this option. This is relevant for the circular economy perspective, as fashion-related purchases are often connected to fast-changing trends, short product life cycles, and the risk of underuse.

The most important factor influencing the purchase decision was discount / low price, selected by 29.9% of respondents. Other relevant triggers were product trendiness and visual appearance, each selected by 11.7% of respondents. These results indicate that both economic incentives and emotional or visual stimuli contribute to online purchasing behaviour (Figure 3).

The last part of the questionnaire focused on the usefulness and life cycle of the products purchased after exposure to social media ads or promotions. This section is directly connected to circular economy principles, as it shows whether these products are used long-term, underused, kept unused, returned, resold, donated, recycled, or thrown away.

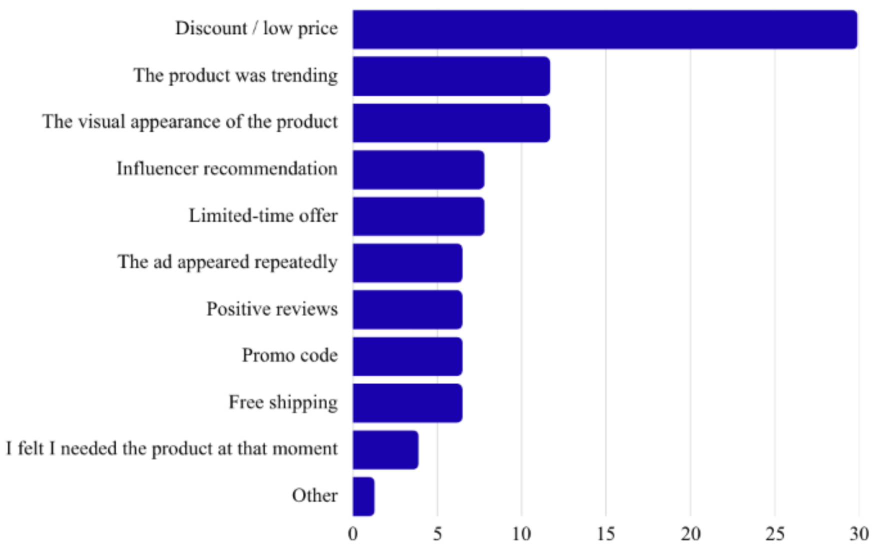


Figure 3 – *Main factor triggering the purchase decision*

The last part of the questionnaire focused on the usefulness and life cycle of the products purchased after exposure to social media ads or promotions. This section is directly connected to circular economy principles, as it shows whether these products are used long-term, underused, kept unused, returned, resold, donated, recycled, or thrown away.

The results show that only 16.9% of respondents considered these products very useful and used them frequently. At the same time, 52% of respondents stated that they used the products only a few times, once, or not at all, which suggests a high level of underuse. This suggests that many purchases influenced by social media promotions do not necessarily lead to long-term product use (Figure 4).

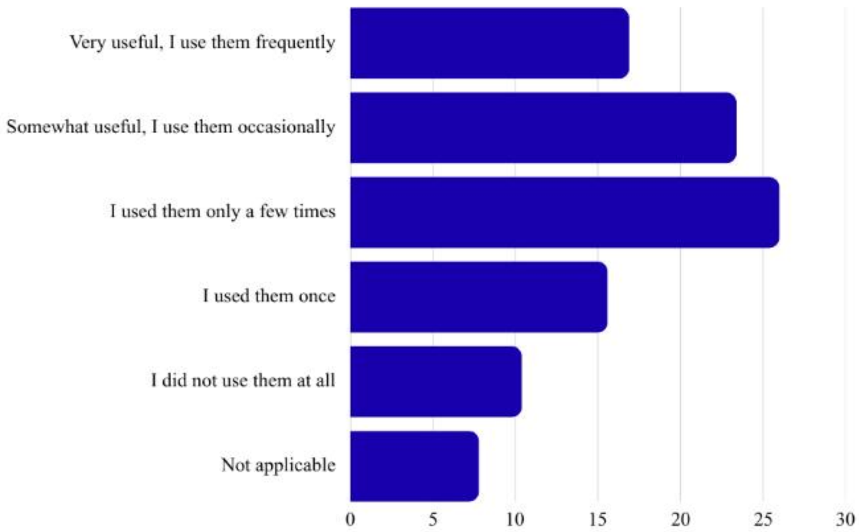


Figure 4 – *Usefulness of products bought after seeing them promoted on social media*

The data on product duration also corroborate this. Many respondents reported short periods of use: 19.5% of products were used only once; 23.4% of products were used for a few weeks; 6.5% of products were not used at all. Taken together these categories represent 49.4% of the sample and suggest that almost half of the respondents had a short or very limited product life cycle after purchasing items promoted on social media. By comparison, only 16.9% said they typically used these products for over a year. This is an important finding from a circular economy perspective, as the extended use of products is key to reduce overconsumption and extend the life of resources.

Adding to the circularity challenge is the post-use behaviour of respondents. The most common response was "I keep them but do not use them," reported 35.1% of respondents. This means a lot of products are stored and inactive and are not re-used, re-sold, donated, recycled or reintroduced into a circular flow. However, these products do not immediately end up in the trash can, but they are also not participating in a circular economy, because their value is not being used.

At the same time, some respondents reported more circular behaviour. 14.3% said that they sell products that they no longer use, 9.1% donate them, 7.8% give them to someone else and 3.9% recycle them. Such actions are closer to circular economy principles, as they prolong the life cycle of the product and decrease waste. However, the low percentage of recycling and the high percentage of unused stored products suggest that circular practices are not yet dominant among the respondents.

These findings generally support the second hypothesis of the study that products purchased after being exposed to social media ads or promotions are often used for a short period of time or become underused. The results suggest that social media promotions can affect not only online purchasing decisions but also consumption forms where products have limited usefulness and short life cycles. This underscores the need for more responsible digital advertising, consumer education and post-purchase practices that encourage reuse, resale, donation, recycling and extending the use of products, from a circular economy perspective.

Conclusion

This research aimed to analyse the impact of ads and promotions on social media on the online buying behaviour of Romanian consumers, especially the usefulness and the life cycle of the products purchased after seeing such promotional content. The findings indicate that the social media platforms play a crucial role in the discovery and purchase decisions of the products. Instagram and TikTok were the main sources where respondents discovered products they purchased online, confirming the significance of visual and algorithmic-oriented platforms in shaping consumer behaviour.

The results verified the first hypothesis of the research that social media advertisements and promotions influence online purchase decisions of consumers. An overwhelming majority of respondents (88.3%) said they had bought a product online after seeing it advertised or promoted on social media. In addition, the results indicate that the most important factors that trigger purchase decisions are discount, low price, product trendiness and visual appearance.

This reflects that both emotional/visual incentives and rational incentives such as price discounts influence online buying behaviour. The research also supports the second hypothesis, that products bought after seeing social media ads or promotions are often short-lived or underused. Findings show that more than half of the respondents used these products only a few times, once, or never. Almost half the sample also claimed to be using such products just once or for a few weeks or not using them at all in general. The findings indicate that many purchases that result from social media promotions do not translate into long-term use of the product. This is especially relevant from a circular economy perspective. The most frequently reported post-use behaviour by respondents was to keep products unused. These products are not disposed of immediately, but they are also not in an active circular flow, as they are not reused, resold, donated, recycled or otherwise reintegrated into productive use. At the same time, some respondents reported more circular behaviours such as selling, donating, giving products to someone else or recycling them, but these practices are still less dominant.

The findings imply that social media marketing can have an effect not only on the point of sale but also on the consumption patterns in general. Social media-driven consumption can result in overconsumption and resource inefficiency when products are bought because of discounts, trends, repeated exposure or visual attractiveness, but subsequently only used for a short time or stored unused. As such, the results suggest a need for more responsible digital advertising, increased consumer awareness, and post-purchase practices that promote longer product use, resale, donation, repair and recycling. In this context, social media should not be understood as only a tool for accelerating consumption, but also as a possible channel to promote more sustainable and circular consumption behaviours.

REFERENCES

1. Aragoncillo, L. & Orus, C. (2018) Impulse buying behaviour: an online-offline comparative and the impact of social media. *Spanish Journal of Marketing – ESIC*. 22(1). pp. 42-62. DOI: 10.1108/SJME-03-2018-007.
2. Cayaban, C. J. G., Prasetyo, Y. T., Persada, S. F., Borres, R. D., Gumasing, M. J. J. & Nadlifatin, R. (2023) The influence of social media and sustainability advocacy on the purchase intention of Filipino consumers in fast fashion. *Sustainability*. 15(11). 8502. DOI: 10.3390/su15118502.
3. Chetioui, Y., Benlafqih, H. & Lebdaoui, H. (2020) How fashion influencers contribute to consumers' purchase intention'. *Journal of Fashion Marketing and Management*. 24(3). pp. 361-380. DOI: 10.1108/JFMM-08-2019-0157.
4. De Veirman, M., Cauberghe, V. & Hudders, L. (2017) Marketing through Instagram influencers: the impact of number of followers and product divergence on brand attitude. *International Journal of Advertising*. 36(5). pp. 798-828. DOI: 10.1080/02650487.2017.1348035.

5. Djafarova, E. & Rushworth, C. (2017) Exploring the credibility of online celebrities Instagram profiles in influencing the purchase decisions of young female users. *Computers in Human Behavior*. 68. pp. 1-7. DOI: 10.1016/j.chb.2016.11.009.

6. European Environment Agency. (2020) *Europe's consumption in a circular economy: the benefits of longer-lasting electronics*. [Online] Available from: https://www.eea.europa.eu/en/analysis/publications/europes-consumption-in-a-circular-economy-the-benefits-of-longer-lasting-electronics. [Accessed: 1st May 2026].

7. European Environment Agency. (2025) *Circularity of the EU textiles value chain in numbers*. [Online] Available from: https://www.eea.europa.eu/en/analysis/publications/circularity-of-the-eu -textiles-value-chain-in-numbers. [Accessed: 14th April 2026].

8. Grabowska, J., Jaciow, M. & Strzelecki, A. (2025) The impact of TikTok on consumers' purchase intentions. *Journal of Economics and Management*. [Online] Available from:https://www.researchgate.net/publication/394193133_The_impact_of_TikTok_on_consumers'_purchase_intentions. [Accessed: 14th April 2026].

9. Laitala, K. & Klepp, I. G. (2020) What affects garment lifespans? International clothing practices based on a wardrobe survey in China, Germany, Japan, the UK, and the USA. *Sustainability*. 12(21). 9151. DOI: 10.3390/su12219151.

10. Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T. & Gwilt, A. (2020) The environmental price of fast fashion. *Nature Reviews Earth & Environment*. 1(4). pp. 189-200. DOI: 10.1038/s43017-020-0039-9.

11. Vladimirova, K., Henninger, C. E., Alosaimi, S. I., Brydges, T., Choopani, H., Hanlon, M., Iran, S., McCormick, H. & Zhou, S. (2024) Exploring the influence of social media on sustainable fashion consumption: a systematic literature review and future research agenda. *Journal of Global Fashion Marketing*. 15(2). pp. 181-202. DOI: 10.1080/20932685.2023.2237978.

"We are using resources as if we had two planets, not one."

Ban Ki-moon

Digitalization for Circular Economy in Transport Governance

Constantin-Sebastian LAZAR*

National Communications Authority, 2 Delea Noua St. Bucharest, Romania

Abstract

This paper examines what contribution can circular economy principles bring to the Romanian public institutions from the transport sector. This paper underlines the important role of digitalization in supporting sustainable infrastructure development and resource optimization. The study uses a conceptual and analytical framework to explore how digital technologies, including data-driven platforms, infrastructure monitoring systems, and digital asset management tools, help the shift from linear to circular models. The paper also suggests a management-focused framework that incorporates digitalization as a strategic tool for implementing a circular economy in transport governance. The results aim to bring value to the understanding of how digital transformation can support circular economy objectives within the public sector organizations with attribution in the transport field.

Keywords: circular economy, digitalization, transport governance

Introduction

Linear Economy represented the solution organizations adopted for decades and was based on a system in which natural resources are extracted, transformed into products and discarded as waste after use. As a result of world development and the continues production of goods, both waste generation and resource loss increased. As global demand for materials continues to rise, the limitations of the linear model have become evident, highlighting the need for more sustainable and resource-efficient approaches (EMF, 2019).

In response to these challenges, the idea of a circular economy has emerged as a sustainable alternative. It aims to reduce waste and improve resource efficiency by closing material loops. The circular economy encourages strategies like reuse, repair, remanufacturing, and recycling. It also

"Pollution is nothing but the resources we are not harvesting."
R. Buckminster Fuller

*Correspondence to Constantin-Sebastian LAZAR: acojocaru1112@upb.ro

highlights the need to extend product lifecycles and regenerate natural systems. This shift seeks to separate economic growth from resource use and environmental impact, providing a more sustainable model for long-term development (Geissdoerfer et al., 2017).

A key enabler of circular economy implementation that provides tools for data collection and integrated resource management is digitalization. Digital transformation improves transparency in software application, this fact being a necessity for circular strategies implementation in sectors with extensive infrastructure networks (Mergel et al., 2019). Regarding Romanian authorities with attributions in transport sector, digital transformation will play an essential role. According to the EC (2020), achieving sustainable and smart mobility requires both systemic changes in infrastructure management and technological innovation.

The purpose of this paper is to examine how digitalization can act as a facilitator for circular economy implementation within public institutions from Romania with attributions in the transport sector. In addition to offering a conceptual and analytical view, the study suggests a digital inventory application structure to support circular resource management in transport infrastructure systems. This approach shows how digital tools can improve material traceability, lifecycle monitoring, and the efficient use of resources in Romanian public administration. The paper seeks to provide useful insights and practical guidance for policymakers, managers, and technical specialists involved in transport governance in Romania.

Theoretical framework

This section provides the definitions of the most important concepts relevant for understanding this paper and also researchers approaches for the paper theme.

Circular Economy in Public Infrastructure. Circular economy is generally defined as an economic system that aims to minimize resource input and waste generation by maintaining the value of products, materials and resources for as long as possible (Kirchherr et al., 2017). Figure 1 depicts the main differences between the linear and the circular economy models. Unlike the linear model, circular economy promotes a regenerative approach, focusing on reuse, recycling, and lifecycle optimization..

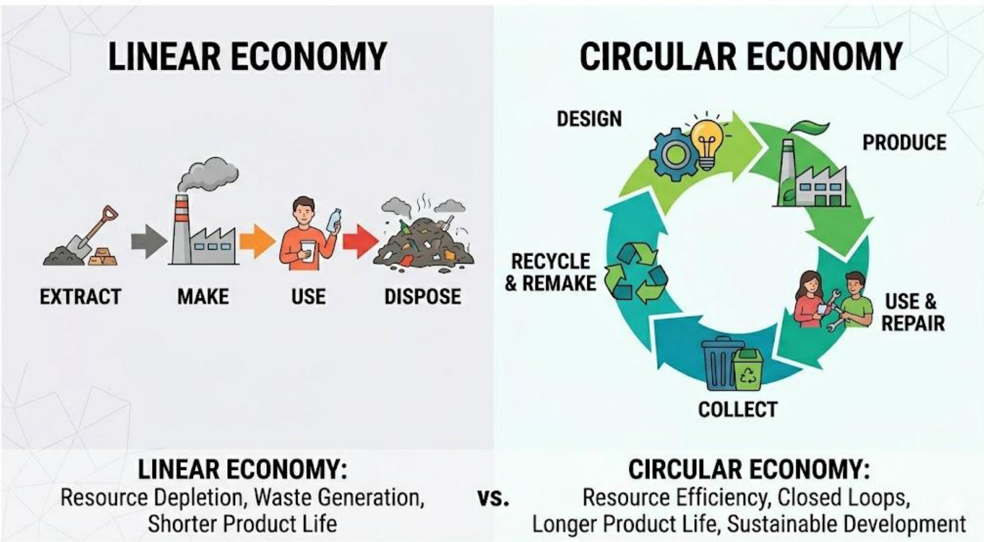


Figure 1 – *Differences between Linear and Circular Economy Models*

In the context of public infrastructure, a report of European Environment Agency (2022) suggests that the transition to circular models in infrastructure systems is essential for reducing environmental impact and improving resource efficiency across European economies. The relevance for the transport sector consists in the fact that infrastructure projects require significant material consumption and long operational lifecycles.

Implementing circular economy in infrastructure can face some challenges. Pomponi and Moncaster (2017) suggests that circular approaches must integrate lifecycle thinking from the design phase to the end of use of the product. Adams et all (2022) considered that public institutions play a crucial role for circular transitions. The main responsibility of the authorities is to adopt sustainable procurement practices and to integrate circular principles into infrastructure planning and management. Regarding the probability of succes in implementing circular economy, Valenturf and Purnell (2021) underline that successful implementation depends on aligning policy frameworks, economic incentives and operational practices.

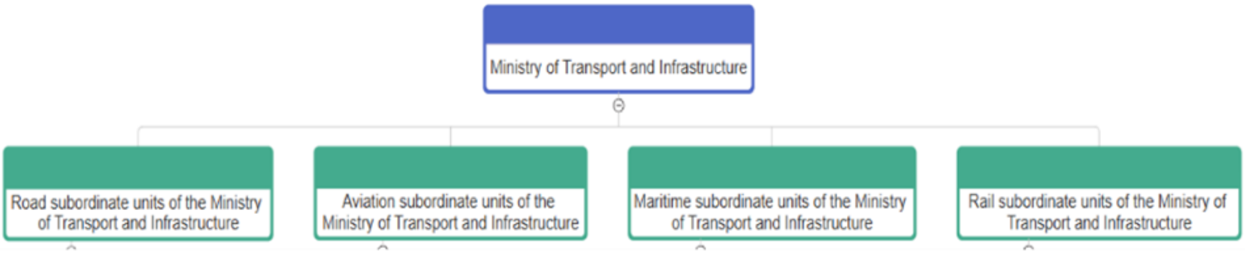
Digitalization as an Enabler of Circular Economy. Digitalization plays a key role in the shift from linear to circular economic models by providing the technology needed to monitor, manage, and optimize resource flows. Digital technologies help collect, process, and integrate large amounts of data. This improves transparency, traceability, and lifecycle management of assets. These abilities are crucial for implementing circular economy strategies, especially in complex systems like transport infrastructure, where resources and assets are spread out and always changing (Pagoropoulos et al., 2017).

Recent research shows that digital technologies significantly help put circular economy principles into practice. Solutions like the Internet of Things (IoT), cloud computing, and advanced data platforms allow for real-time monitoring of infrastructure assets. They also support better management of materials and resources. According to Kristoffersen et al. (2022), digitalization enables the creation of integrated systems that improve visibility across value chains and encourage circular practices such as reuse, maintenance optimization, and lifecycle extension.

Another important fact is that digital platforms improve coordination between the entities involved in infrastructure management and development. Digital platforms enable data sharing and interoperability. The Organization for Economic Co-operation and Development (2023) represents a mean for enhancing interoperability, transparency and supports better management of public resources and infrastructure systems. Regarding product lifecycle, digital tools allow institutions to track the use and condition of resources. This fact facilitates the decision related to reuse or recycling. Nobre and Tavares (2017) sustained that such capabilities are essential for circular models existence, as they enable more efficient allocation of resources and reduce unnecessary waste generation. Moreover, The World Economic Forum (2024) highlights that digital transformation is a key driver for accelerating circular economy adoption, particularly in sectors with high infrastructure complexity, such as mobility systems and transport.

The Romanian Transport Sector Context. In Romania, digitalization is becoming a key focus for updating public institutions. However, issues like disconnected IT systems, limited compatibility, and a lack of digital skills still slow down progress. It is important to tackle these challenges so that digital technologies can effectively support the circular economy. Thus, digitalization should be viewed not just as a technical upgrade, but also as a shift in management and organization that improves coordination, efficiency, and sustainable resource use.

The Romanian transport sector is coordinated by the Ministry of Transport and Infrastructure of Romania, which oversees a complex network of public institutions responsible for the development, management, and regulation of national transport infrastructure. These institutions operate across multiple domains, including road, rail, air, and maritime transport, each with distinct operational responsibilities and organizational structures. The Ministry of Transport and Infrastructure's organizational structure can be seen at a high level in Figure 2:



(Source: Lazar, 2025)

Figure 2 – *Organizational Structure of the Ministry of Transport and Infrastructure of Romania*

Some of the most important entities that are under the Ministry of Transport and Infrastructure of Romania are: National Company for Road Infrastructure Administration (CNAIR), the National Railway Company (CFR SA), the Romanian Auto Registry (RAR) and the Romanian Air Traffic Services Administration (ROMATSA). The official report published by Ministry of Transport and Infrastructure of Romania (2024), the sector is institutional fragmented. This thing creates challenges related coordination and decision taking. In Romania, there are initiatives supported by National Recovery and Resilience Plan (PNRR) that promotes digitalization and alignment to European Union Objectives (EC 2023). However, the problem is not only technological but institutional also.

Regarding digital skills and infrastructure, according to the European Commission (2024), Romania's levels are below average. A comparative overview between Romania and European Union is illustrated in Lazar (2025). In this scenario, every proposal of new application architectures can improve the operations specific for Romanian transport institutions. Regarding circular economy, a digital inventory system specific for all the institutions subordinated to the Ministry of Transport and Infrastructure would be a necessity and represents one of the key ideas this paper presents.

Methodological approach

This study uses a conceptual and analytical research design to explore the role that digitalization can play in enabling circular economy practices among public institutions in transport sector. A qualitative approach was deemed suitable for the initial stage of identifying fundamental patterns, challenges and opportunities. The methodology contains three main components: literature review, comparative analysis and analytical framework.

Literature Review. For the literature review this paper analyzes existing studies on the circular economy, digitalization and their intersection in public infrastructure systems. This involved a review of academic articles, policy reports and institutional publications to identify the key concepts, enablers, and facilitators or challenges of CES adoption.

Very important for this section were the most recent contributions (2020-2025) that studied how digital technologies can support circular practices, and those who studied infrastructure-intensive sectors like transport, and construction. Moreover, frameworks from international organization and other resources informing on sustainability and digitalization elements relevant for public governance were taken into consideration.

Comparative Analysis. The research requires a comparative analysis to find proven international practices which can serve as strategic solutions for Romania. The research analyzes particular instances from European Union member states and developed nations to study their methods for implementing digital transformation and circular economy principles in transportation, and infrastructure networks. The research examines three main aspects which consist of digital system implementation levels, technology application for resource control, and institutional adoption of circular economy principles. The comparative analysis enables researchers to find elements which can be moved between

Analytical Framework. Based on the findings from the literature review and comparative analysis, the study develops an analytical framework that integrates digitalization and circular economy principles within a managerial perspective. The framework focuses on the interaction between digital tools, organizational processes, and resource management practices in public institutions.

In addition, the framework supports the conceptual design of a digital inventory application architecture aimed at improving material traceability, lifecycle monitoring, and resource optimization in transport infrastructure systems. This approach allows the study to move beyond theoretical analysis and provide a practical model that can support the implementation of circular economy principles within the Romanian transport sector.

Results and Discussion

Digital Applications for Circular Economy. This paper already highlighted the importance of digital transformation in the other subsection. There are several digital applications for circular economy that can be implemented in Romania.

A key international application model is represented by Digital Twin technology, which allows the replication of different assets in virtual reality. Digital Twins contribute to sustainability because it optimizes the maintenance cycles and it extends asset lifespan in transport networks (OECD, 2024; Kristoffersen et al. 2021).

On the other hand, Romania is below average in EU regarding the ability of technology adoption and implementation. In this scenario, implementing Digital Twin technology can be a very difficult task. An easier approach that it is doable in a shorter period of time can be a digital inventory application. This is a digital application of circular economy and can improve certain institution operation and can save certain amounts of ministry founds by reusing some specific products. The main reality that this application observes is that some goods of institution subordinated to the Ministry of Transport and Infrastructure of Romania, that are not used by the institution can be relocated to other subordinated entities in need. For example, some computers that no longer meet the performance requirements of ROMATSA operations, can be redirected as standard office workstation within local branches of Romanian Auro Registry (RAR) or CFR SA.

Regarding the architecture of the application, Figure 3 depicts the main layers of the application.

For the digital inventory application, this paper propose a classification of assets. Low-value assets (below 3000 euros) will be assigned in the application to the employees and high-value assets (over 3000 euros) will be assigned at institutions such as regional directorates or units subordinated to the ministries. This classification ensures that strategic assets remain under institutional control. The threshold of 3000 euros can be changed depending on specific laws.

A key principle of the system is that redistribution decisions are prioritized at the institutional level. Before making any asset for disposal, institutions must evaluate internal redistribution options. This promotes reuse and extends the lifespan of assets. This approach supports the goals of a circular economy by reducing unnecessary purchases and minimizing waste.

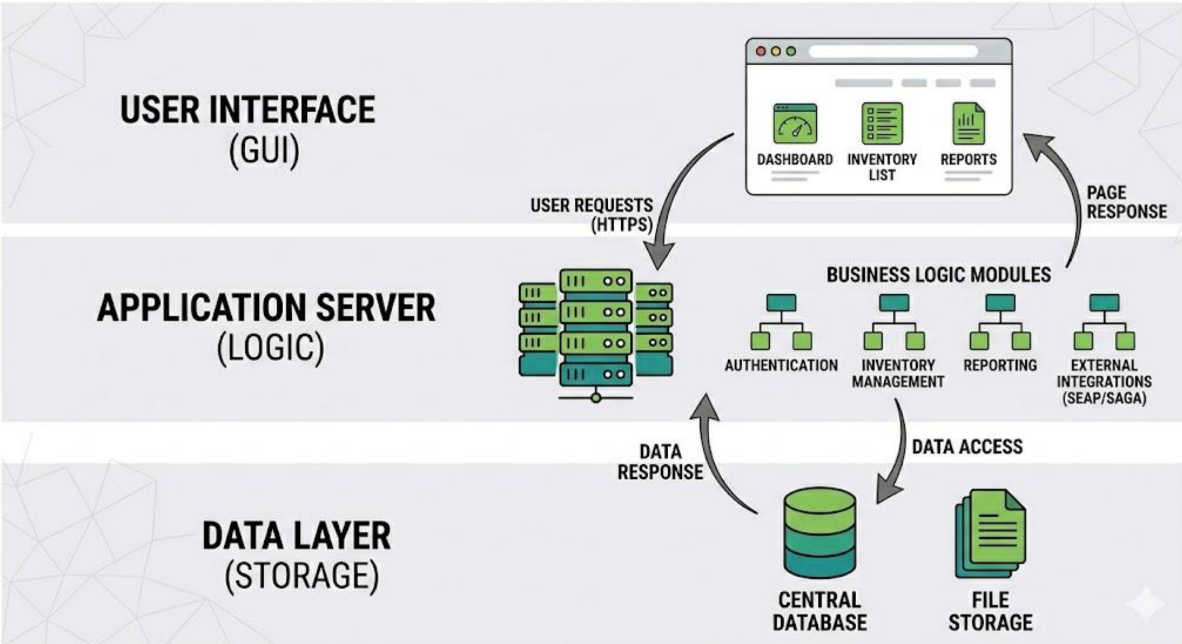


Figure 3 – *Architectural framework of the proposed application*

From a governance perspective, the Ministry of Transport operates at a macro-level monitoring layer. It provides insight into all subordinate institutions and their combined asset structures. At the same time, each institution has micro-level visibility, enabling them to track assets assigned to individual employees. This two-layer structure ensures centralized oversight and decentralized operational control. It improves transparency, efficiency, and resource use across the entire system. All the possible users and their capabilities can be observed in Table1.

Table 1 – *User Roles and System Capabilities*

User Type	Capabilities in the System
Standard User (Employee)	view assigned personal assets (< 3000 euros); confirm handover/receipt of assets; report asset condition; submit requests for allocation of new assets
Institutional Manager	manage institutional assets (≥ 3000 euros); allocate assets to employees; transfer assets between institutions; approve requests from subordinate users
Institution Administrator	create requests for new resources; initiate asset disposal proposals; manage approval workflows for acquisition requests; trigger redistribution of assets within the institution or to the Ministry level
System Administrator	manage users and roles; configure institutional structures; import external data; monitor system audit logs and security events

Key Challenges and Comparative Insights. Although there is a significant potential for digitalization to enable circular economy transitions in Romania, there still exist some institutional barriers in the transport sector. Institutional fragmentation represents one of the most important challenge. The effects of this challenge were studied and highlighted in the OECD report (2024).

A second major limitation is the digital skills of the public administration people and the openness for new system integration. Helander et al. (2023) emphasize that public sector innovation depends heavily on the ability of institutions to adapt organizational structures and promote digital competencies across all administrative levels.

From a comparative perspective, several EU member states such as the Netherlands, Germany, and Denmark have already implemented advanced digital infrastructure management systems. These countries use integrated digital platforms and AI-based predictive maintenance systems to optimize infrastructure performance and reduce material waste. According to OECD (2024), such systems are key enablers of circular economy implementation in transport networks, as they support lifecycle optimization and resource efficiency at scale.

Conclusion

This paper investigated the role of digitalization as an enabling factor for circular economy implementation within Romanian public institutions operating in the transport sector. The result of the analysis is that circular economy principles can be implemented in an organization especially when there is an infrastructure for data availability. Digital transformation is not only a technological update but a structural change in how public resources are managed.

A key contribution of this study is the development of a conceptual digital inventory system for the Romanian transport governance context. The proposed model introduces a two-level asset classification system that separates low-value assets assigned to employees from high-value assets managed at the institutional level. This structure supports operational flexibility and strategic control, while also ensuring compliance with public sector accountability requirements.

The proposed system also introduces a circular redistribution mechanism, where assets are first evaluated for internal reuse before being considered for disposal. This mechanism directly contributes to extending asset lifecycles, reducing unnecessary procurement, and improving resource efficiency across institutions such as CNAIR, CFR SA, ROMATSA, and RAR. In this sense, the system operationalizes circular economy principles in a practical and implementable digital governance tool.

From a governance perspective, the model allows for a dual-layer monitoring structure. The Ministry of Transport has oversight over all subordinate institutions, while each institution keeps control over internal asset allocation. This balance between central oversight and decentralized management improves transparency, decision-making efficiency, and coordination in a fragmented institutional environment. The study also points out that successfully implementing this system relies not just on technological readiness but also on institutional capacity, interoperability, and the development of digital skills within public administration. These findings support existing research that highlights the need for organizational change in public sector digitalization (Helander et al., 2023; OECD, 2024).

Overall, the paper makes both theoretical and practical contributions to the literature on circular economy and digital governance by suggesting a scalable and realistic digital inventory framework for the Romanian transport sector. Future research could build on this model through technical prototyping, simulation-based validation, or pilot implementation in selected public institutions.

Acknowledgments. This work has been supported by: ERASMUS-EDU-2023-EUR-UNIV, Project 101124676 - EELISA, funded by the European Union, https://eelisa.eu/.

REFERENCES

1. Adams, K.T., Osmani, M., Thorpe, T. & Thornback, J. (2022) *Circular economy in construction: current awareness, challenges and enablers.* Proceedings of the Institution of Civil Engineers – Waste and Resource Management. 175(1). pp. 1–13. [Online] Available from: https://doi.org/10.1680/jwarm.16.00011. [Accessed: 5th April 2026].
2. EMF, Ellen MacArthur Foundation. (2019) *Completing the Picture: How the Circular Economy Tackles Climate Change.* [Online] Available from: https:// ellenmacarthurfoundation.org/completing-the-picture. [Accessed: 5th April 2026].
3. EC, European Commission. (2020) *Shaping Europe's Digital Future*. Brussels: European Commission. [Online] Available from: https://commission.europa.eu/publications/ communication-shaping-europes-digital-future_en. [Accessed: 7th April 2026].
4. EC, European Commission. (2023) *Romania's Recovery and Resilience Plan.* Brussels: European Commission. [Online] Available from: https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility/country pages/romanias-recovery-and-resilience-plan_en [Accessed: 7th April 2026].
5. EC, European Commission. (2024) *Digital Economy and Society Index (DESI) 2024 – Romania.* Brussels: European Commission. [Online] Available from: https://digital-strategy.ec.europa.eu/en/policies/desi-romania. [Accessed: 10th April 2026].
6. EEA, European Environment Agency. (2022) *Circular economy in Europe — Developing the knowledge base.* Copenhagen: EEA. [Online] Available from: https://www.eea.europa.eu/publications/circular-economy-in-europe. [Accessed: 10th April 2026].
7. Geissdoerfer, M., Savaget, P., Bocken, N.M.P. & Hultink, E.J. (2017) The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*. 143. pp. 757–768. [Online] Available from: https://doi.org/10.1016/j.jclepro.2016.12.048. [Accessed: 10th April 2026].
8. Helander, N. & Makkonen, M. (2023) *Public Innovation and Digital Transformation.* London: Routledge. [Online] Available from: https://doi.org/10.4324/9781003230854. [Accessed: 10th April 2026].
9. Kirchherr, J., Reike, D. & Hekkert, M. (2017) Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*. 127. pp. 221–232. [Online] Available from: https://doi.org/10.1016/j.resconrec.2017.09.005. [Accessed: 13th April 2026].
10. Kristoffersen, E., Blomsma, F., Mikalef, P. & Li, J. (2021) The smart circular economy: A digital-enabled framework for sustainable value creation. *Journal of Business Research*. 120. pp. 241–261. [Online] Available from: https://doi.org/10.1016/j. jbusres.2020.07.044. [Accessed: 13th April 2026].
11. Lazăr, C.S. (2025) The Effect of Digitalization on the Resilience of Public Transport Organizations. *FAIMA Journal*. 13(4). [Online] Available from: https://faimajournal. upb.ro/archive/Revista_FAIMA_13(4). [Accessed: 13th April 2026].
12. Mergel, I., Edelmann, N. & Haug, N. (2019) Defining digital transformation: Results from expert interviews. *Government Information Quarterly*. 36(4). 101385. [Online] Available from: https://doi.org/10.1016/j.giq.2019.06.002. [Accessed: 13th April 2026].
13. MTI, Ministry of Transport and Infrastructure (Romania). (2024) *Annual Performance Report of Public Institutions in Transport Sector.* [Online] Available from: https://www.mt.ro. [Accessed: 13th April 2026].
14. Nobre, G.C. & Tavares, E. (2017) Scientific literature analysis on big data and Internet of Things applications on circular economy: A bibliometric study. *Journal of Cleaner Production.* 377. [Online] Available from: https://ideas.repec.org/a/spr/scient /v111y2017i1d10.1007_s11192-017-2281-6.html. [Accessed: 13th April 2026].

15. OECD. (2023) *Digital Government Review of Romania*. Paris: OECD Publishing. [Online] Available from: https://doi.org/10.1787/68361e0d-en. [Accessed: 13th April 2026].
16. OECD. (2024) *OECD Digital Government and Infrastructure Outlook.* Paris: OECD Publishing. [Online] Available from: https://www.oecd.org/digital/. [Accessed: 13th April 2026].
17. Pagoropoulos, A., Pigosso, D.C.A. & McAloone, T.C. (2017) The emergent role of digital technologies in the circular economy. *Procedia CIRP*. 64. pp. 19–24. [Online] Available from: https://doi.org/10.1016/j.procir.2017.02.047. [Accessed: 13th April 2026].
18. Pomponi, F. & Moncaster, A. (2017) Circular economy for the built environment: A research framework. *Journal of Cleaner Production*. 143. pp. 710–718. [Online] Available from: https://doi.org/10.1016/j.jclepro.2016.12.055. [Accessed: 13th April 2026].
19. Valenturf, A.P.M. & Purnell, P. (2021) Principles for successful circular economy implementation. *Sustainable Production and Consumption*. 27. pp. 1437–1457. Available at: https://doi.org/10.1016/j.spc.2021.02.018. [Accessed: 13th April 2026].
20. WEF. (2024) World Economic Forum. *Driving the Circular Economy through Digital Transformation.* [Online] Available from: https://www.weforum.org/reports. [Accessed: 13th April 2026].

" Conservation means the wise use of the earth and its resources for the lasting good of men."
Gifford Pinchot

Organizational Communication and Circular Economy in Digital Services

Alexandra PUTANU*

National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independentei, Bucharest, Romania

Abstract

This paper was conducted to examine how organizational communication can support circular economy implementation in the digitalized service sector. The study adopts a conceptual and exploratory approach based on a structured literature review focusing on organizational communication, circular economy, digitalization and service organizations. The findings show that communication plays a strategic role in aligning employees with circular objectives, facilitating the understanding of organizational change and reducing resistance to transformation. Digital tools further strengthen these processes by improving information flows, traceability and coordination across stakeholders. At the same time, barriers such as organizational silos, weak sustainability cultures and uneven digital competences may hinder progress. The importance of the study lies in its integrated perspective, which connects communication, circularity and digitalization.

Keywords: organizational communication; circular economy; service sector

Introduction

"Who can exhaust a man? Who knows a man's resources?"
Jean-Paul Sartre

The shift from the linear "take, make, use and dispose" model to a circular economy has become a key priority in business and policy. Circular economy aims to reduce resource use, waste and emissions through reuse, repair, remanufacturing and recycling, but its implementation requires substantial organisational change (Liao, 2022). At the same time, digitalisation is transforming service-sector business models, coordination and customer relations (Neligan et al., 2023). In this context, organizational communication becomes a strategic enabler, helping employees and

*Correspondence to Alexandra PUTANU: alexandra_putanu@yahoo.com

stakeholders understand change, align with circular goals and support the transition to sustainable, digitally enabled service models.

Although research on the circular economy, digitalisation and organizational communication has expanded, these fields are often examined separately. Circular economy studies focus on sustainability models and innovation, digitalisation research on technologies and organizational change, and communication studies on reporting and change management. This gap is particularly evident in the service sector, where few studies directly link circular transformation, communication processes and digital environments. This paper addresses that underexplored intersection and highlights the need for a more integrated perspective.

Against this background, this paper examines how organizational communication can act as a strategic enabler of circular economy implementation in the digitalized service sector. It starts from the assumption that circular strategies in service organisations depend not only on technology adoption, but also on how actors interpret goals, exchange information, coordinate practices and communicate circular value to stakeholders.

The central objective of the paper is to analyse the relationship between organizational communication and circular economy strategies. Communication is important because circular transformation requires strategic coherence, managerial legitimacy, employee engagement and stakeholder coordination. In digitalised service environments, communication is further reshaped by digital tools, faster information flows and more immediate feedback.

More specifically, the paper pursues three objectives: to analyse the relationship between organizational communication and circular economy strategies; to explore how digitalization reshapes communication processes in service organizations; and to identify communication practices that support circular transformation, including internal communication, stakeholder dialogue, transparency and coordinated sustainability messaging.

The remainder of the paper is organised as follows. The next section presents the methodology and explains the literature-based approach. This is followed by the results and discussion section, which analyses the thematic links between organizational communication, circular economy strategies and digitalisation in the service sector. The final section presents the conclusions, theoretical contributions, practical implications, limitations and directions for future research.

Research methodology

This paper adopts a conceptual and exploratory design based on a structured literature review. This approach is suitable because the topic lies at the intersection of organizational communication, circular economy strategies, digitalization and service sector transformation. A literature-based method helps organise fragmented knowledge, identify recurring themes and develop a coherent conceptual framework. The study is exploratory because it does not test a causal model through primary data, but clarifies conceptual relationships. The review follows predefined criteria for search, screening and synthesis, ensuring a clear, systematic and concise methodological approach.

The literature search was conducted using three major academic sources: Scopus, Web of Science and Google Scholar. Scopus and Web of Science were selected because they index high-quality peer-reviewed publications and allow structured searches across business, management, sustainability and communication research. Google Scholar was used as a complementary source in order to identify influential and recent studies that might not be fully covered by the other databases.

The search strategy relied on combinations of the following keywords: “organizational communication”, “circular economy”, “digitalization”, “service sector” and “sustainability communication”. Additional related terms, such as “digital transformation”, “circular business model”, “service organizations”, “stakeholder communication” and “internal communication”, were also included in order to capture the diversity of concepts used in the literature. The search focused mainly on studies published between 2015 and 2025, while earlier foundational works were retained where necessary to support conceptual definitions and theoretical framing. The purpose of the data collection process was not only to gather studies on each topic separately, but also to identify literature that could illuminate the relationships between communication, circularity and digitalized service environments.

The sources were selected using four criteria: only English-language publications were included; priority was given to peer-reviewed journal articles, with limited use of reputable institutional reports; the review focused mainly on literature from the last five to ten years, while retaining key classical studies; and manufacturing-only studies were excluded unless relevant to services. After the initial search, titles, abstracts and keywords were screened, and the remaining studies were evaluated for relevance and credibility.

The literature was analysed through thematic analysis and comparative synthesis to identify recurring patterns, compare arguments and organise findings coherently. Studies were coded by focus, including internal communication, stakeholder engagement, digital infrastructures, data use, coordination mechanisms and barriers to change, then grouped into broader themes. Particular emphasis was placed on digital communication tools and data-driven coordination, while also considering employee alignment, stakeholder value creation and communication barriers in circular transformation.

Results and discussion

Organizational communication as a strategic enabler of circularity. Organizational communication should be regarded as a strategic enabler of circularity rather than a secondary support function (Sinha, 2022). Circular economy strategies require organisations to redefine routines, responsibilities and value propositions, which means that employees must understand why change is necessary and how it affects their work. Research on internal sustainability communication shows that communication is essential for embedding sustainability practices in organisational processes (Temel et al., 2025), while studies on employee engagement indicate that meaningful communication between managers and employees improves strategic alignment (Gede, 2025). In the context of circular transformation, internal communication helps translate broad circular principles into clear operational expectations (Weder & Stranzl, 2025).

This role is especially important because circular transformation is also a process of organisational sensemaking (de Metz et al., 2024). Employees are more likely to support circular initiatives when these are framed not merely as compliance requirements (Al-Najjar et al., 2025), but as coherent strategic directions linked to long-term value creation, service innovation and stakeholder expectations. The literature suggests that communication facilitates this process by clarifying objectives, connecting sustainability with organisational purpose and reducing uncertainty during change (Lashitew, 2021). Communication therefore does more than transmit information. It shapes how change is interpreted and whether it is perceived as legitimate, relevant and achievable (Aririguzoh, 2022).

The review also shows that communication can reduce resistance to circular transformation (Klein, 2022). Moving from familiar linear routines to circular approaches may appear uncertain, costly or difficult to coordinate. In such contexts, supportive communication becomes critical. When managers communicate consistently, explain expected benefits and encourage dialogue, employees are more likely to engage with change rather than resist it (Blackman et al., 2022). Internal communication thus contributes to organisational readiness, legitimacy and commitment. Overall, the literature indicates that circular strategies are more likely to succeed when communication is treated as a core mechanism for alignment, understanding and participation throughout the transition process (Vikstedt & Rajala, 2023).

The role of digitalization in circular communication processes. Digitalization strengthens the strategic role of communication in circular transformation by improving how organizations exchange information, coordinate activities and support decision-making (Nijhum, 2025). The literature shows that technologies such as the Internet of Things, big data analytics, artificial intelligence and blockchain can enable circular economy implementation (Marković & Jemović, 2024), while digital communication tools reshape internal collaboration and organizational coordination (Marion & Fixson, 2021). In practice, this includes the use of intranets, dashboards, collaboration platforms, AI-supported systems and enterprise tools such as ERP and CRM infrastructures.

A key finding is that digitalization increases the speed, visibility and integration of communication processes (van Zoonen et al., 2026). Digital tools support faster information exchange, remote and cross-functional collaboration, and more continuous feedback than traditional hierarchical communication structures (Ahmad et al., 2023). This is especially important for circular strategies, which depend on coordinated information about service use, maintenance, recovery, reuse and stakeholder interaction. Digitalization therefore helps organizations communicate not only more quickly, but also more systematically. The review also indicates that digital communication enhances traceability and real-time responsiveness (Balaska et al., 2024).

By making resource flows, service interactions and stakeholder responses more visible, digital tools improve monitoring and support better-informed decisions. However, digitalization does not automatically ensure successful circular implementation. Many digital technologies remain unevenly adopted, and their effectiveness depends on how well they are embedded in organizational routines and learning processes. Importantly, digitalization does not replace relational communication. Even in highly digital service ecosystems, trust, managerial interpretation, stakeholder listening and relationship-building remain essential. Digital infrastructures are therefore most effective when they complement, rather than substitute for, human communication and coordination in the implementation of circular strategies.

Communication across stakeholders in the service ecosystem. Circular transformation in the service sector depends on effective communication across a wide stakeholder ecosystem. In service contexts, value is often co-created through interactions among customers, service providers, suppliers, digital intermediaries, regulators and communities. Because circular services frequently involve shared use, maintenance, recovery and ongoing interaction, communication becomes essential for coordination and value creation (Karpen et al., 2023). It helps manage expectations, align operational activities and integrate knowledge distributed across different actors.

Customers need to understand the benefits of circular offerings, while partners and suppliers require clear information to support collaboration. Public authorities and communities also expect transparency, accountability and credible sustainability commitments. The review further shows that transparency strengthens trust and organisational legitimacy (Fehrer et al., 2024). Clear communication about circular practices, data use, service outcomes and stakeholder responsibilities can reduce uncertainty and improve cooperation. This is especially important in digitalised service ecosystems, where platform-based interactions and data-driven coordination make trust a critical condition for successful and credible circular service implementation.

Barriers to effective communication in circular transition. The literature identifies several barriers to effective communication during circular transition. First, organisational silos can fragment information and hinder coordination across departments such as operations, sustainability, marketing, IT and service design, leading to inconsistent implementation of circular objectives (Jeleel-Ojuade, 2024). Second, a weak sustainability-oriented culture may reduce the credibility of circular communication, especially when sustainability is promoted externally but not embedded internally in values and practices (Alemu, 2025). Third, uneven digital capabilities and limited employee readiness can restrict the effective use of communication platforms, data systems and coordination tools. Finally, inconsistency between strategic discourse and actual organisational practice can undermine trust and legitimacy (Aggerholm & Thomsen, 2024). When circularity is presented as a priority but is not supported by structures, resources or routines, employees and stakeholders may perceive communication as symbolic rather than genuine. Therefore, successful circular communication requires cross-functional alignment, a strong sustainability culture, digital preparedness and visible managerial commitment.

Discussion

Taken together, the findings confirm that the circular economy should be understood not only as an operational model, but also as a communicational one. The literature reviewed consistently suggests that circular strategies require internal alignment, stakeholder dialogue, legitimacy-building, and trust-based coordination (Aggerholm & Thomsen, 2024; Klein et al., 2022; Temel et al., 2025; Vikstedt & Rajala, 2023). This interpretation extends dominant circular economy discussions, which often prioritise processes, technologies, and business models, by showing that communication is one of the organisational mechanisms through which circularity becomes actionable (Bocken et al., 2021; Fehrer et al., 2024; Karpen et al., 2023; Neligan et al., 2023).

In the service sector in particular, where value is co-created and relationships are continuous, communication is not an accessory to circularity; it is part of its implementation logic (Fehrer et al., 2024; Karpen et al., 2023). The findings also show that digitalization strengthens the reach and impact of communication, but does not replace it. Digital platforms, collaboration tools, and data-driven systems improve visibility, traceability, and coordination, thereby making circular strategies more manageable across complex service networks (Ahmad et al., 2023; Balaska et al., 2024; Marković & Jemović, 2024; Neligan et al., 2023). Yet the same literature indicates that digital tools do not automatically generate trust, legitimacy, or employee commitment. These outcomes still depend on listening, explanation, participation, and relationship management (Aggerholm & Thomsen, 2024; Blackman et al., 2022; de Metz et al., 2024; Weder & Stranzl, 2025).

The implication is that digitalization should be treated as an amplifier of communication capacity rather than as a substitute for strategic communication itself (Marion & Fixson, 2021; Nijhum, 2025; van Zoonen et al., 2026). Finally, the review underlines the specific relevance of these issues for the digitalized service sector. Services are characterised by intangibility, high relational intensity, and frequent stakeholder interaction, which means that circularity in services depends heavily on communication, co-creation, and coordinated interpretation of value (Fehrer et al., 2024; Karpen et al., 2023; Vikstedt & Rajala, 2023). The service literature reviewed suggests that circular service management remains underdeveloped as a field, yet the available evidence already shows that circular services rely on multistakeholder engagement and communication-rich ecosystems (Fehrer et al., 2024; Karpen et al., 2023). Therefore, for service organisations pursuing circular transformation, communication should be managed as a strategic capability that connects digital tools, stakeholder relationships, and organisational change (Alemu, 2025; Gede, 2025; Temel et al., 2025).

To better illustrate the relationships discussed in this paper, Figure 1 presents a conceptual framework of the role of organizational communication in supporting circular economy strategies in the digitalized service sector. The diagram highlights the central position of organizational communication in connecting digital tools and data-driven processes with circular service strategies and their organizational outcomes. It also reflects the idea that communication is not a peripheral activity, but a strategic mechanism through which circular transformation becomes understandable, coordinated and operationally viable.

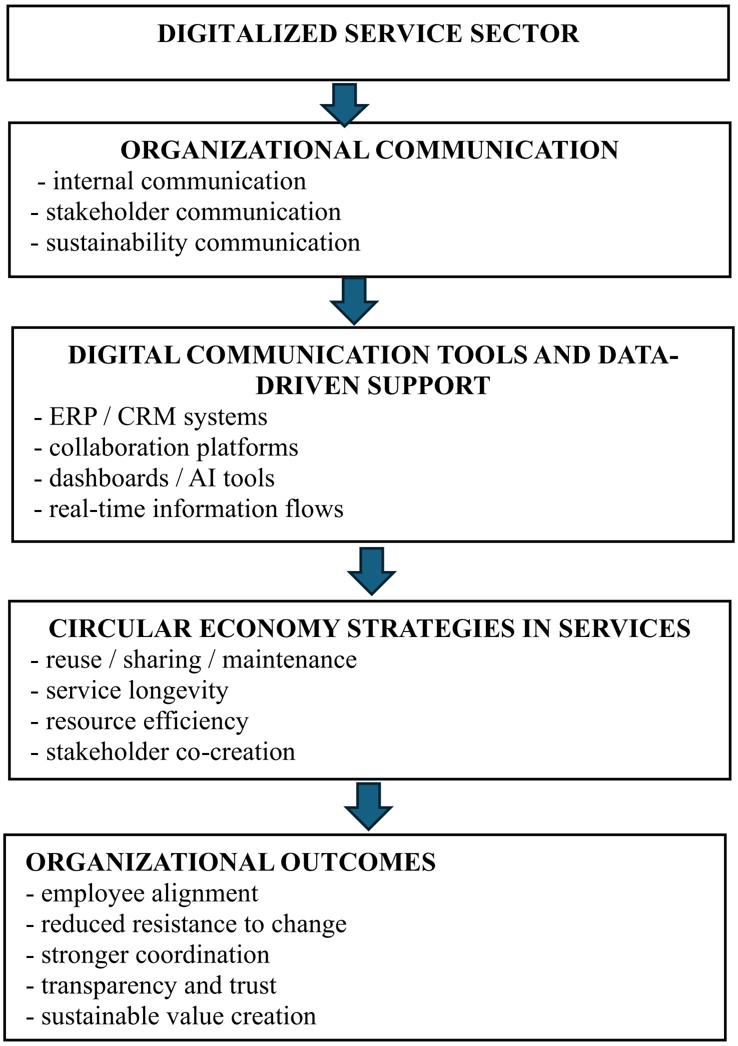


Figure 1 - *Conceptual framework of organizational communication as a driver of circular economy strategies in the digitalized service sector*

Figure 1 shows that the digitalized service sector provides the broader context in which circular transformation takes place. Within this environment, organizational communication occupies a central role by linking internal communication, stakeholder communication and sustainability communication with the practical implementation of circular economy strategies. The framework further suggests that digital communication tools, such as ERP and CRM systems, collaboration platforms, dashboards and AI-based instruments, strengthen this process by enabling faster information flows, improved coordination and real-time feedback. These communication and digitalization mechanisms support circular strategies in services, including reuse, sharing, maintenance, service longevity and resource efficiency. As a result, organizations may achieve important outcomes such as employee alignment, reduced resistance to change, stronger coordination, greater transparency and trust, and sustainable value creation. Overall, the diagram supports the argument that organizational communication acts as a strategic driver of circularity in digitally enabled service organizations.

Conclusions

This paper shows that organizational communication is a strategic driver of circular economy implementation in the digitalized service sector. It helps explain circularity, align employees and support legitimate change. The study also concludes that digitalization accelerates circular strategies by improving information flows, traceability and coordination, although technology cannot replace trust or managerial coherence. In service organizations, successful circular transformation depends on strong alignment between communication, organizational culture and sustainability objectives, especially in stakeholder-intensive and value co-creation contexts.

The main theoretical contribution of this paper is that it connects three fields often studied separately: organizational communication, circular economy and the digitalized service sector. By linking these domains, the study shows that circularity should be understood not only as an operational or technological model, but also as a communicational one. In this way, the paper broadens the understanding of circular economy implementation and highlights the importance of communication in digitally mediated service environments.

The study offers several practical implications. First, managers should develop clear communication strategies to support circular transformation and ensure that circular goals are understandable and actionable for employees and stakeholders. Second, digital tools should be integrated into change processes rather than treated as isolated technical solutions. Third, employee training is essential, as circular transformation depends on both digital competences and a shared understanding of sustainability objectives. This study is based on a literature review, so its conclusions depend on the scope and quality of existing sources. In addition, it lacks direct empirical validation, since it does not test the proposed relationships through primary data such as interviews, surveys or case studies. Future research could examine this topic through quantitative or qualitative studies in service companies, comparisons between industries, and investigations into the impact of artificial intelligence on communication for circularity, especially in relation to trust, transparency, decision-making and organizational alignment.

REFERENCES

1. Aggerholm, H.K. & Thomsen, C. (2024) Strategic communication in contexts of high sustainability pressure: balancing purposefulness, transparency and participation in pursuit of organizational legitimacy. *Journal of Communication Management.* 28(1). pp.58-73. [Online] Available from: https://doi.org/10.1108/JCOM-12-2022-0131. [Accessed: 26th March 2026].
2. Ahmad, T., Boit, J. & Aakula, A. (2023) The role of cross-functional collaboration in digital transformation. *Journal of Computational Intelligence and Robotics.* 3(1). pp.205-242.
3. Alemu, B.A. (2025) Cultivating a culture of sustainability: the role of organizational values and leadership in driving sustainable practices. *Business Ethics and Leadership.* 9(1). pp.79-94. [Online] Available from: https://doi.org/10.61093/bel.9(1).79-94.2025. [Accessed: 24th March 2026].
4. Al-Najjar, B., Salama, A. & Abed, A. (2025) From compliance to commitment: examining the influence of corporate governance and social performance on firms' circular economy initiatives. *Journal of Business Ethics.* pp.1-24. [Online] Available from: https://doi.org/10.1007/s10551-025-06111-9. [Accessed: 25th March 2026].
5. Aririguzoh, S. (2022) Communication competencies, culture and SDGs: effective processes to cross-cultural communication. *Humanities and Social Sciences Communications.* 9(1). pp.1-11. [Online] Available from: https://doi.org/10.1057/s41599-022-01109-4. [Accessed: 25th March 2026].

6. Balaska, V., Symeonidis, S., Antoniou, S., Fotiadis, T., Chatzoglou, P. & Gasteratos, A. (2024) Digitalising the supply chain for enhanced efficiency and customer satisfaction. In: *Olympus International Conference on Supply Chains.* Cham: Springer Nature Switzerland. pp.321-334. [Online] Available from: https://doi.org/10.1007/978-3-031-69351-9_26. [Accessed: 26th March 2026].
7. Blackman, D.A., Buick, F., O'Donnell, M.E. & Ilahee, N. (2022) Changing the conversation to create organizational change. *Journal of Change Management.* 22(3). pp.252-272. [Online] Available from: https://doi.org/10.1080/14697017.2022.2040570. [Accessed: 26th March 2026].
8. Bocken, N.M., Weissbrod, I. & Antikainen, M. (2021) Business model experimentation for the circular economy: definition and approaches. *Circular Economy and Sustainability.* 1(1). pp.49-81. [Online] Available from: https://doi.org/10.1007/s43615-021-00026-z. [Accessed: 28th March 2026].
9. de Metz, N., Jansen van Rensburg, M. & Davis, A. (2024) Shared sensemaking during a strategic change process: a non-managerial perspective. *Journal of Strategy and Management.* 17(4). pp.763-780. [Online] Available from: https://doi.org/10.1108/JSMA-10-2023-0264. [Accessed: 28th March 2026].
10. Fehrer, J.A., Kemper, J.A. & Baker, J.J. (2024) Shaping circular service ecosystems. *Journal of Service Research.* 27(1). pp.49-68. [Online] Available from: https://doi.org/10.1177/10946705231188670. [Accessed: 25th March 2026].
11. Gede, D.U. (2025) Strategic alignment and its effects on employee engagement: empirical evidences from Ethiopian education sector. *International Review of Public Administration.* 30(2). pp.113-135. [Online] Available from: https://doi.org/10.1080/12294659.2025.2454058. [Accessed: 24th March 2026].
12. Jeleel-Ojuade, A. (2024) The role of information silos: An analysis of how the categorization of information creates silos within financial institutions, hindering effective communication and collaboration. *SSRN Electronic Journal.* SSRN 4881342. [Online] Available from: https://dx.doi.org/10.2139/ssrn.4881342. [Accessed: 24th March 2026].
13. Karpen, I.O., Edvardsson, B., Tronvoll, B., Jaakkola, E. & Conduit, J. (2023) Circular service management: toward conceptual understanding and service research priorities for a more sustainable future. *Journal of Service Management.* 34(6). pp.50-69. [Online] Available from: https://doi.org/10.1108/JOSM-06-2023-0269. [Accessed: 24th March 2026].
14. Klein, N., Ramos, T.B. & Deutz, P. (2022) Factors and strategies for circularity implementation in the public sector: An organisational change management approach for sustainability. *Corporate Social Responsibility and Environmental Management.* 29(3). pp.509-523. [Online] Available from: https://doi.org/10.1002/csr.2215. [Accessed: 24th March 2026].
15. Lashitew, A.A. (2021) Corporate uptake of the Sustainable Development Goals: Mere greenwashing or an advent of institutional change? *Journal of International Business Policy.* 4(1). pp.184-200. [Online] Available from: https://doi.org/10.1057/s42214-020-00092-4. [Accessed: 28th March 2026].
16. Liao, A. (2022) Circular economy. In: *Warranty chain management: Digitalization and sustainability.* Singapore: Springer Nature Singapore. pp.375-399. [Online] Available from: https://doi.org/10.1057/s42214-020-00092-4. [Accessed: 28th March 2026].
17. Marion, T.J. & Fixson, S.K. (2021) The transformation of the innovation process: How digital tools are changing work, collaboration, and organizations in new product development. *Journal of Product Innovation Management.* 38(1). pp.192-215. [Online] Available from: https://doi.org/10.1111/jpim.12547. [Accessed: 27th March 2026].
18. Marković, I. & Jemović, M. (2024) Artificial intelligence, big data and IoT in circular economy: research trends and perspectives. *Facta Universitatis, Series: Economics and Organization.* pp.285-293. [Online] Available from: https://doi.org/10.22190/FUEO241104019M. [Accessed: 27th March 2026].
19. Neligan, A., Baumgartner, R.J., Geissdoerfer, M. & Schöggl, J.P. (2023) Circular disruption: Digitalisation as a driver of circular economy business models. *Business Strategy and the Environment.* 32(3). pp.1175-1188. [Online] Available from: https://doi.org/10.1002/bse.3100. [Accessed: 24th March 2026].

20. Nijhum, A.M. (2025) Artificial intelligence-driven digital transformation models for enhancing organizational communication and decision-making efficiency. *American Journal of Scholarly Research and Innovation.* 4(01). pp.536-577. [Online] Available from: https://doi.org/10.63125/8qqmrm26. [Accessed: 29th March 2026].
21. Sinha, E. (2022) Identifying enablers and outcomes of circular economy for sustainable development: A systematic literature review. *Business Strategy & Development.* 5(3). pp.232-244. [Online] Available from: https://doi.org/10.1002/bsd2.195. [Accessed: 29th March 2026].
22. Temel, M., von Haartman, R. & Hilletofth, P. (2025) Exploring communication dynamics for organisational sustainability: interconnections and impact on performance. *Corporate Communications: An International Journal.* 30(7). pp. 95-120. [Online] Available from: https://doi.org/10.1108/CCIJ-01-2025-0004. [Accessed: 28th March 2026].
23. van Zoonen, W., Sivunen, A.E. & Treem, J.W. (2026) Connectivity and surveillance: The role of communication visibility in the era of digitalization and remote work. *Management Communication Quarterly.* 40(2). pp.250-279. [Online] Available from: https://doi.org/10.1177/08933189251364527. [Accessed: 25th March 2026].
24. Vikstedt, E. & Rajala, T. (2023) Alignment through value consolidation mechanisms—focusing on multi-stakeholder collaboration for circular economy. In: *Stakeholder Engagement in a Sustainable Circular Economy: Theoretical and Practical Perspectives.* Cham: Springer International Publishing. pp.273-310. [Online] Available from: https://doi.org/10.1007/978-3-031-31937-2_9. [Accessed: 27th March 2026].
25. Weder, F. & Stranzl, J.M. (2025) Internal communication for sustainability. Expanding corporate sustainability communication with the inner development goals (IDGs). *Corporate Communications: An International Journal.* 30(7). pp.121-137. [Online] Available from: https://doi.org/10.1108/CCIJ-02-2025-0049. [Accessed: 26th March 2026].

"Courage enlarges, cowardice diminishes resources."

Christian Nestell Bovee

Global Organizational Approached Through Hofstede's Theory

Marius-Dan PECULEA*

National University of Political Studies and Public Administration, 30A Expozitiei Blvd., Bucharest, Romania

Abstract

The present paper, as part of a broader research project, undertakes a literature-based analysis to examine the influence of structural changes on organizational culture and the relevance of national cultural models in the current global context. The paper offers a novel synthesis of current organizational practices, emerging cultural dynamics, and persistent critiques of Hofstede's framework, particularly its static and reductionist treatment of national cultures. By integrating recent empirical findings and theoretical perspectives, this review aims to contribute to a more contextually relevant and empirically grounded understanding of how culture operates within and across organizations in an increasingly globalized, post-pandemic, and AI driven era. The results of this paper will be used directly for the strategic definition that offer broader research regarding the relationship between technology and organizational culture in the context of emerging artificial intelligence.

Keywords: Hofstede's theory, organizational culture, globalization

Introduction

Hofstede's model, first introduced in 1980, remains of the first comprehensive frameworks explaining cultural similarities and differences across organizations. While previous attempts were made, Geert Hofstede was the first to introduce a wholesome system to classify organizational behavior according to a coherent set of criteria: power distance, uncertainty avoidance, individualism/collectivism and masculinity/collectivity (Stedhan and Yamamura, 2004; Courtright et al., 2011). Later, two more cultural dimensions were added, namely long-term

"The greatest achievement of the human spirit is to use one's resources."
Luc de Clapiers

*Correspondence to Marius-Dan PECULEA: mpeculea@gmail.com

orientation and indulgence versus restraint (Wenchang et al., 2024; Khlif and Chaieb, 2025).

Hofstede's cultural dimensions are a fundamental tool to understand cultural differences. Nonetheless, due to the important structural changes which have affected human society since the emergence of this theory – mainly globalization and the political and technological dissolvement of borders – have brought forward criticism to its applicability. Critics argue that the model's underlying assumption of cultural stability may no longer reflect the dynamic realities of today's globalized work environments. This leads to the first research question guiding this paper:

RQ1: To what extent does Hofstede's theory of cultural dimensions remain valid in the context of globalization?

In addition to questioning the general applicability of the model, resent research has pointed to another critical aspect of organizational culture: the role of subcultures with large, multinational organizations. The theory of Hofstede's cultural dimensions gives valuable insights into the way in which cultural differences impact on organizational environments. However, organizations that are growing supra-national (even global) have led according to Lee and Kramer (2016) and Nelson and Gopalan (2003) to the appearance of very strong organizational cultures, which supersede national traits of the employees. However, research shows this is not a general trend (Fischer et al., 2022). The emergence of strong organizational cultures in supra- and multi-national organizations may have as a side effect the appearance of subcultures which show national traits. Subcultures in organizations can emerge according to Chandler et al (2018) due to several factors such as age, gender, department and function, or nationality and is to a certain degree a naturally occurring phenomenon. This observation gives rise to the second research question:

RQ2: What is the influence of subcultures emerging within strong surpa-national or global organizations on organizational behavior?

This paper is part of the PhD research, called "Human to Machine Interaction in Organizations in the Era of Artificial Intelligence: Key Success and Failure Factors of Organizational Cultures". The findings of this paper regarding the two research questions will strategically define the experimental part of the research by shaping the extent of the data collection process, and the subsequent analysis of the collected information, by defining both limitations of research and constraining the interpretation.

Methodological approach

Due to the exponential growth of academic publications in recent decades, bibliometric analysis has become an increasingly valuable quantitative research method for systematically examining scientific literature. Bibliometrics, a subfield of scientometrics, allows for the objective and systematic analysis of large datasets using mathematical and statistical approaches. In this study, bibliometric analysis is employed to explore the relevance of national cultural models - particularly Hofstede's theory - in the context of globalization and recent structural transformations affecting organizational behavior. The analysis was designed to support the investigation of two central research questions regarding the continued validity of Hofstede's model and the role of emerging subcultures in global organizations.

The analysis was designed to support the investigation of two central research questions regarding the continued validity of Hofstede's model and the role of emerging subcultures in global organizations. As outlined in the introduction, this study aims to address the following research questions:

(1) To what extent does Hofstede's framework of cultural dimensions remain valid in the context of increasing globalization?

(2) How do emerging subcultures within dominant transnational or ideologically driven organizations influence traditional models of national culture?

The paper assesses these two questions by studying existing literature on the topics. The research focuses on papers published after the year 2000. As the primary source of documentation, the Scopus database has been chosen. The undertaken bibliometric analysis is an indicator for the general interest in the topic, revealing efforts made in later years to study this issue. Thus, the conclusion can be drawn, that the academic community has responded to recent structural changes in society, by trying to determine their influence on organizational behavior.

The list of relevant literature has been compiled with the aid of Scopus' artificial intelligence tool. The results of the compilation have later been analyzed and filtered by deductive processes, to ensure coherence and cohesion of the analyzed information.

The analysis involved a multi-stage filtering process based on publication date, subject area, and keyword relevance to ensure the inclusion of literature directly aligned with the scope of the research questions. The final dataset was examined to determine the extent of academic engagement with Hofstede's model in the 21st century, as well as to identify publications addressing the role of organizational subcultures in shaping or challenging national cultural frameworks. This bibliometric approach enables a quantitative exploration of the field, providing an empirical basis for evaluating the current relevance and limitations of Hofstede's cultural dimensions in light of structural global changes.

Results and discussion

Bibliometric Analysis. There is a growing interest in studying Geert Hofstede's theory. The search of the Scopus database using only the keyword "Hofstede's cultural dimensions" has produced a total of 2.585 documents which tackle this subject. Further refinement of the search parameters has been performed, by limiting the period of publishing to papers after the year 2000, reducing the number of relevant papers to 2.498.

A subsequent limitation of the subject area to only four has resulted in a deeper filtering of the search results, now showing 1.949 published materials. The subjects that were allowed after filtering were Business, Management and Accounting; Social Sciences; Economics, Econometrics and Finance; and Decision Sciences.

The last filtering was made for keywords. A total of ten keywords were allowed, out of which seven revolved around the researched topic – Hofstede's Cultural Dimensions. Other topics were: Cultural Difference; Innovation and Globalization. After applying this last filter, a total of 1.108 relevant papers remained. Topics revolving around the individual cultural dimensions of Hofstede's model, as well as topics pointing to exact sciences such as mathematics or computer science have been eliminated from the search.

From the yearly distribution of paper occurrence, a growing interest for the topic can be derived, with the number of published materials constantly going over 60 after 2017. This is shown in Figure 1.

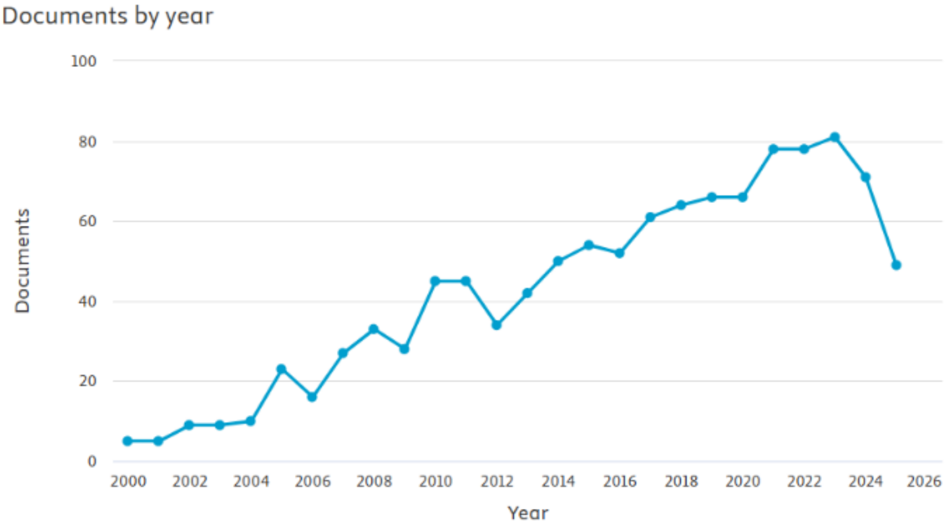


Figure 1 – *The yearly distribution of published papers on the topic of Hofstede's Cultural Dimensions*.

Also, in Figure 1 the peak of scientific interest to the topic Can be measured in the period between 2021 and 2023, most likely caused by the societal structural changes which were the result of the COVID-19 crisis.

In Figure 2 the topic's rate of occurrence per country is shown. More than 1/3 of all papers Approaching the subject of Hofstede's cultural dimensions come from the US. This stems from the fact that many globally active organizations are in the United States. The scientific interest for this topic is naturally located in the same area. The United Kingdom China and Australia also contribute together with another quarter of all published papers.

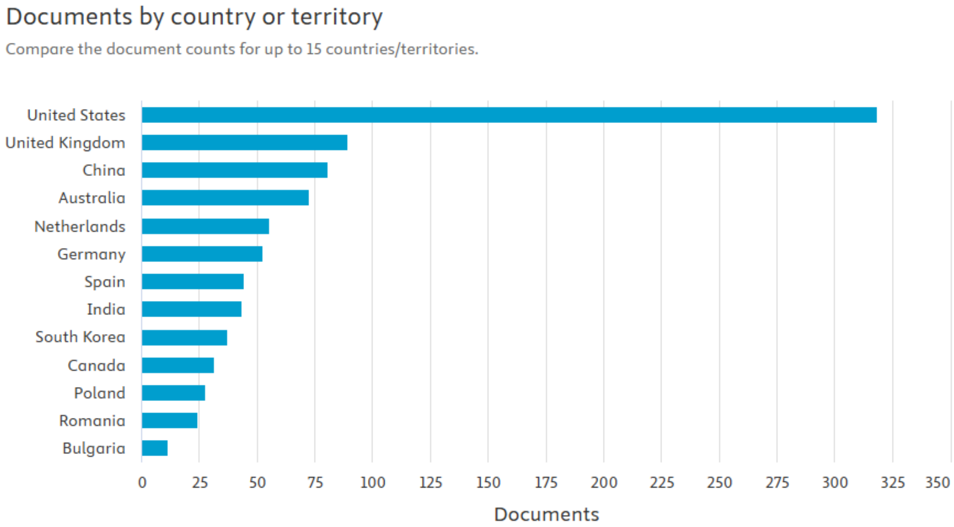


Figure 2 – *Published papers per country on the topic of Hofstede's Cultural Dimensions*.

Most of the papers were published in the fields of business and management, social sciences, economics and decision sciences, amounting to three quarters of all papers on this subject, as is shown in Figure 3.

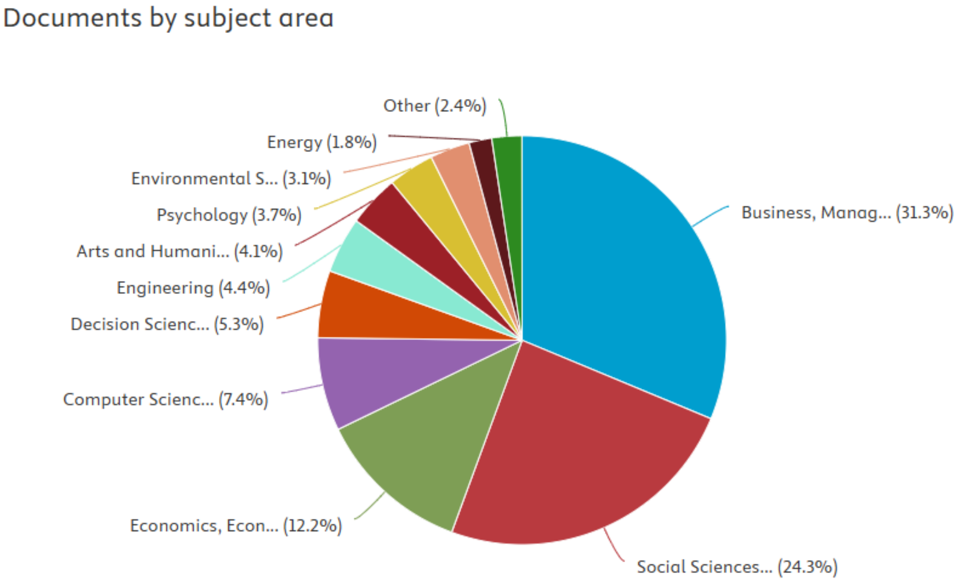


Figure 3 – *Documents by subject area on the topic of Hofstede's Cultural Dimensions.*

Based on this information, the decision to limit search results to the four fields mentioned above was made, to limit the number of stray findings and to limit the number of exceptions to the general rules and trends regarding the topic, which might influence the intended general character of the research.

Key Literature Insights to Hofstede's Theory. There has been always criticism to Hofstede's theory of cultural dimensions, ranging from ecological fallacy – projecting national level culture characteristics onto individuals or organizations is a form of misunderstanding, leading to stereotypes – (Brewer & Venaik, 2014), to missing subcultural and regional differences within the same country due to an assumed cultural homogeneity issue (Louhabi et al., 2020; Evan & Holy, 2023). Other criticisms by Beugelsdijk et al. (2015) refer to the actuality of the data, some of which was collected in the late 1960s and early 1970s. That is why according to Lei & Jin (2024), Especially due to the rise of remote working as a direct consequence of the COVID-19 pandemic, he reexamination of Hofstede's dimensions is necessary. Results suggest that these dimensions might need an adaptation for remote work contexts.

Studies show that the application of Hofstede's cultural dimensions must be adapted to the modern context such as remote working, updated information and dynamic intercultural interactions, requiring continuous refinement and validation to maintain relevance and effectiveness in today's organizational environment. Expatriate managers might face communication challenges due to cultural differences (Rey & Caro 2017). These challenges manifest themselves particularly in relationship to uncertainty avoidance and power distance, affecting international business expansion processes. On the other hand, Hofstede's dimensions are still applicable in international advertising strategies, aiding in understanding original characteristics such as language lifestyle and norms (Nair & Ramakrishnan, 2016). Also, the European textile and clothing industry applies hosted this dimension which provides insights into issues like organizational responsibility, job satisfaction and leadership styles (Angelova, 2017).

Criticism of Hofstede's Cultural Dimensions. Theory has led to the emergence of newer theories such as the cultural intelligence framework, the GLOBE (Global Leadership and Organizational Behavior Effectiveness) cultural dimensions which integrated the dynamic of cultural values (Shoham & Alon, 2010) or Minkov's revision which reduces Hofstede's model to just two dimensions, which function as Reliable predictors of various cultural differences (Minkov, 2024). These new frameworks offer more dynamic and representative approaches to understanding cultural values (Gerlach & Eriksson, 2021) and are also based on newer data.

Regarding the changes which have been brought by the current technological development, it has been established that the applicability of Hofstede's cultural dimensions has been affected in various ways. First, according to Minkov (2024) and Macfadyen (2011) there is criticism that the model is too simplistic and does not account for the dynamic and complex nature of modern cultures. Second, the influence of national culture on digital maturity and the adoption of digital technologies is not conclusive, since some of Hofstede's dimensions foster digital maturity while others hinder it (Festing & Proff, 2025). That is why the design and usability of global applications depends on the consideration of cultural dimensions; however, the intensity of this dependence can vary significantly (Ford & Kotze, 2005; Lodge, 2007).

While strong organizational cultures or high-performance cultures may or may not supersede national traits, the emergence of subcultures is a naturally occurring phenomenon. According to Chandler et al. (2018) subcultures within organization emerge based on various demographic and organizational factors. Also, the presence of multiple subcultures within an organization can lead to various interpretations and strategies for addressing issues which are influenced by the relative values of these subcultures (Mello & Schloemer, 2022). The interaction between global and national cultures can lead in the vision of Kaplan (2012) To the development of unique organizational subcultures that blend global models with local meanings.

Conclusions

Blending national and corporate cultures has enhanced employee identification with the organization especially in globalized environments and improved the overall corporate image of those organizations which have embraced cultural diversity and have drawn synergies from it. Taking into consideration the trend of creating multicultural teams in such organizations, this integration becomes particularly important according to Dartey-Baak (2011). In this regard, understanding Hofstede's dimensions has helped managers develop cross cultural competences, which were crucial for effective communication, leadership and conflict resolution (Angelova, 2017), remaining relevant for understanding organizational behavior and management practices across different cultural contexts.

Research, however, indicates cultural values to be dynamic. In contemporary societies individualism and indulgence tend to have a higher importance than in the past. Also, distance to power seems to be decreasing in organizations, although not uniformly and being a highly complex and context-dependent phenomenon (Mattos et al., 2024). Hofstede's paradigm is increasingly criticized for not capturing the dynamism of modern cross- and multicultural environments (Fang, 2010). This dynamic character has been further influenced by advancements in technology. These advancements have had influences both on societal and economic development and have affected individual country's scores of Hofstede's dimensions. However, despite these changes, cultural differences between countries show a certain stability, indicating that the framework is still valid (Angelova, 2017).

Modern technological development has both challenged and reshaped the validity of Hofstede's cultural dimensions, since increased interconnectedness and exposure to different cultures through technology leads to a blending of cultural traits, challenging according Bouymaj and Pereira (2022) to the distinct cultural profiles proposed by Hofstede. Soloviov (2022) concludes that alternative sets of cultural indicators may provide a better model fit compared to Hofstede's dimensions. However, there is no direct evidence addressing the specific influence of modern technological development on the validity of Hofstede's theory.

The interaction between organizational and national cultures is a very complex process, and while strong organizational cultures can significantly influence the success of organizations and sometimes supersede national traits, scientific evidence suggests that both play crucial roles and that their relative influence can vary depending on the specific context and cultural tightness of the national environment (Jayasuriya, 2024; Banto, 2014). Subcultures continuously adapt and change highlighting the lack of cultural predictability and stability within organizations, further increasing the critical pressure on Hofstede's theory (Chandler, 2019). The emergence of subcultures with national traits in global organizational cultures is a natural phenomenon driven by the influence of national culture and the dynamic nature of subcultures in which global and local contexts interplay.

Hofstede's cultural dimensions theory remains valid in the current global context. While the criticism remains also valid, due to the rather static character of the theory, new theories such as the GLOBE study, come to support and complete Hofstede's model, allowing for deeper insight into the intricate structures and inner workings of multicultural organizations. Also, the cultural dimensions theory gains validity when studying subcultures that are naturally formed in multicultural organizations. Even when global organizational cultures are very strong, forming perfectly uniform teams is not possible. Subcultures will form at national, regional and even department level, leading to clustering of values experiences and expectations.

The primary limitation of this research lies in the inherent complexity of the topicrelative to the defined scope of the paper. The multitude of cultures, the geographical distributions of organizations, organizational culture and management styles make a comprehensive study of the topic a long-term project. However, it is exactly this complexity which opens various opportunities for further study, especially in the context of the changes that are being brought upon by AI advancements.

A second limitation is linked to the narrowly focused objective of the present paper: to address two specific research questions using bibliometric analysis as a preparatory step for more in-depth empirical inquiry. While this method effectively highlights the state of academic discourse on the subject, it serves primarily as a strategic foundation for the design of subsequent research. The insights gained through this study will inform the development of more targeted tools and methodologies for collecting primary data—particularly in exploring the interplay between organizational culture and AI implementation processes.

REFERENCES

1. Angelova, R.A. (2017) Cross-cultural management of the European textile and clothing industries: Application of Hofstede's cultural dimensions. *Handbook of Research on Organizational Culture and Diversity in the Modern Workforce*. pp. 239 – 260. DOI: 10.4018/978-1-5225-2250-8.ch011.
2. Banto, A. (2014) Organizational culture and organizational effectiveness in a global context. *Cross-Cultural Interaction: Concepts, Methodologies, Tools and Applications*. 3. pp. 1210 – 1225. DOI: 10.4018/978-1-4666-4979-8.ch069.
3. Beugelsdijk, S., Maseland, R. & van Hoorn, A. (2015) Are Scores on Hofstede's Dimensions of National Culture Stable over Time? A Cohort Analysis. *Global Strategy Journal*. 5(3). pp. 223-240. https://doi.org/10.1002/gsj.1098.
4. Bouymaj, I. & Pereira, R.T.F.B. (2022) Homogenization or diversification? The impact of globalization on cultural identity of the first and second-generation immigrants. *Journal of Globalization Studies*. 13 (1). pp. 73 – 89. DOI: 10.30884/jogs/2022.01.06.
5. Brewer, P. & Venaik, S. (2014) The Ecological Fallacy in National Culture Research. *Organization Studies*. 35 (7). pp. 1063 – 1086. DOI: 10.1177/0170840613517602.
6. Chandler, N. (2019) Neo-Tribes or subcultures? The nature of subcultures in large complex organizations. Recent advances in the roles of cultural and personal values in organizational behavior. pp. 18 – 35. DOI: 10.4018/978-1-7998-1013-1.ch002.
7. Chandler, N., Csepregi, A. & Heidrich B. (2018) The World I Know: Knowledge Sharing and Subcultures in Large Complex Organizations. *Knowledge Management and Organizational Learning*. 6. pp. 117 – 143. DOI: 10.1007/978-3-319-66890-1_7.
8. Courtright, J., Wolfe, R., Baldwin, J. (2011) *Public Relations in Global Cultural Contexts: Multi-paradigmatic Perspectives.* In Nilanjana Bardhan, N. & Weaver, C.K. (eds). pp. 108 – 139. New York: Taylor & Francis Group. DOI: 10.4324/9780203866153-11.
9. Dartey-Baah, K. (2011) The impact of national cultures on corporate cultures in organizations. *Academic Leadership*. 9(1).
10. Evan, T. & Holý, V. (2023) Cultural diversity and its impact on governance. *Socio-Economic Planning Sciences*. 89. https://doi.org/10.1016/j.seps.2023.101681.
11. Fang, T. (2010) Asian management research needs more self-confidence: Reflection on Hofstede (2007) and beyond. *Asia Pacific Journal of Management*. 27(1). pp. 155 – 170. DOI: 10.1007/s10490-009-9134-7.
12. Festing, C. & Proff, H. (2025) Assessing the impact of national culture on digital maturity. *Digital Business*. 5 (2). DOI: 10.1016/j.digbus.2025.100121.
13. Fischer, R., Karl J., Van Rensburg, G.J. & Ferreira, M.C. (2022) Multilevel issues in organizations and culture: A review of theoretical and methodological innovations for the study of national and organizational culture. *Handbook of Research Methods for Organizational Culture*. pp. 52 – 67.

14. Ford, G. & Kotzé, P. (2005) Designing usable interfaces with cultural dimensions. *Lecture Notes in Computer Science* (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 3585 (LNCS). pp. 713 – 726. DOI: 10.1007/11555261_57.
15. Gerlach, P. & Eriksson, K. (2021) Measuring Cultural Dimensions: External Validity and Internal Consistency of Hofstede's VSM 2013 Scales. *Frontiers in Psychology*. 12. DOI: 10.3389/fpsyg.2021.662604.
16. Jayasuriya, N. (2024) Global cultural differences in performance management: Performance management worldwide. *Employee Performance Management for Improved Workplace Motivation*. pp. 215 - 228. DOI: 10.4018/979-8-3693-4387-6.ch009.
17. Kaplan, D. (2012) Institutionalized erasures: How global structures acquire national meanings in Israeli popular music. *Poetics*. 40(3). pp. 217 - 236. DOI: 10.1016/j.poetic.2012.03.001.
18. Khlif, H., Chaieb, S. (2025) The influence of Hofstede's cultural dimensions on digitalization: a cross-country investigation. *International Journal of Accounting and Information Management*. DOI: 10.1108/IJAIM-07-2024-0236.
19. Lee, Y., Kramer, A. (2016) The role of purposeful diversity and inclusion strategy (PDIS) and cultural tightness/looseness in the relationship between national culture and organizational culture. *Human Resource Management Review*. 26(3). pp. 198 – 208. DOI: 10.1016/j.hrmr.2016.01.001.
20. Lei, Z., Jin, H. (2024) Developing a Hyper-Personal Team Building Curriculum for Multicultural Remote Working: Theorization and Tentative Application in Progress, Lecture Notes in *Networks and Systems*. 1150 (LNNS). pp. 312 – 329. DOI: 10.1007/978-3-031-72430-5_27.
21. Lodge, C. (2007) The impact of culture on usability: Designing usable products for the international user. *Lecture Notes in Computer Science* (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 4559 LNCS (PART 1). pp. 365 – 368. DOI: 10.1007/978-3-540-73287-7_44.
22. Louahabi, Y., Moustaghfir, K., Cseh, M. (2020) Testing Hofstede's 6-D model in the North and Northwest regions of Morocco: Implications for human resource development. *Human Systems Management.* 39(1). pp. 51 - 68. DOI: 10.3233/HSM-190615.
23. Macfadyen, L.P. (2011) Perils of parsimony: The problematic paradigm of 'national culture'. *Information Communication and Society*. 14(2). pp. 280 – 293. DOI: 10.1080/1369118X.2010.486839.
24. Mattos, C.S., Dutra, E., Santos, G. (2024) An Instrument for Assessing Power Distance in Agile Organizations - Preliminary Results. *ACM International Conference Proceeding Series*. pp. 136 – 146. DOI: 10.1145/3701625.3701653.
25. Mello, J.E., Schloemer, H. (2022) Do organizational subcultures matter? A case study of logistics and supply chain management. *International Journal of Logistics Management.* 33(1). pp. 141 - 164. DOI: 10.1108/IJLM-04-2021-0230.
26. Minkov, M. (2024) The evolution of Hofstede's model, Elgar Encyclopedia of Cross-Cultural Management. pp. 14 - 22. DOI: 10.4337/9781803928180.ch04.
27. Nair, P.S., Ramakrishnan, C. (2016) Effect of Hofstede's dimensions on skin care advertising at the micro level: A content analysis of Olay's Indian and US digital ads. 2016 *International Conference on Advances in Computing, Communications and Informatics.* DOI: 10.1109/ICACCI.2016.7732259.
28. Nelson, R.E., Gopalan, S. (2003) Do Organizational Cultures Replicate National Cultures? Isomorphism, Rejection and Reciprocal Opposition in the *Corporate Values of Three Countries. Organization Studies*. 24(7). pp. 1115 - 1151. DOI: 10.1177/01708406030247006.
29. Rey, J., Caro, F.J. (2017) The challenges of intercultural communication in the age of globalization: The case of Spanish companies based in Morocco. *Prisma Social.* (17). pp. 415 – 437.
30. Shoham, A., Alon, I. (2010) Changing cultural clusters: a research note. *International Journal of Business and Globalization.* 5(3). pp. 328 – 342. DOI: 10.1504/IJBG.2010.035026.

31. Stedham, Y.E., Yamamura, J.H. (2004) Measuring national culture: does gender matter?. *Women in Management Review.* 19(5). pp. 233 – 243. DOI: 10.1108/09649420410545953.
32. Wenchang C., Vasudevan A., Arumugam V., Zhang J., Balakrishnan R., Rusuli M.S.C. (2024) A Case Study with Hofstede's Culture: Working Performance of Chinese Expatriates in Dubai. *Journal of Ecohumanism*. 3(4). pp. 1674 – 1690. DOI: 10.62754/joe.v3i4.3697.

" *I believe the best economic system is one that uses markets to allocate scarce resources.*"
Gary Hamel

Digital Transformation of Romanian Banking Toward Sustainable Consumer Lending

Catalin George TESLEANU*

International Credit and Commercial Analysis Platform CRIF Romania
10 Bucuresti Nord Road, Bucharest, Romania

Abstract

The digitization of consumer lending represents one of the most consequential structural transformations in retail financial services over the past decade. This paper examines the digital transformation of consumer credit in Romania. Drawing on updated empirical data, alongside a detailed case-study analysis of a digital consumer financing implementation at a leading Romanian non-bank financial institution, the paper maps the structural evolution from paper-based, courier-dependent credit origination to fully digital, real-time approval workflows. In the context of eIDAS 2.0 (effective May 2024) and Law 214/2024, the paper argues that digital consumer lending is no longer a strategic option but a structural imperative. Implementation of digital consumer lending process contributes significantly with the integration in ESG ratings that serve as a strategic imperative for the Romanian Financial instutions.

Keywords: photovoltaic panels, energy efficiency, EDGE platform

Introduction

The convergence of digital technology, changing consumer demographics, and a rapidly expanding e-commerce ecosystem has fundamentally altered the architecture of retail financial services across Central and Eastern Europe (CEE). Romania, as one of the region's largest economies and fastest-growing digital markets, sits at the intersection of these transformative forces. Yet its banking sector - historically characterized by high physical-branch density, paper-intensive processes, and conservative credit eligibility criteria - has been slow to adapt to the pace of digital change demanded by its increasingly connected population.

"I think that our abuse of the planet and our resources is an anxiety."
Carol Ann Duffy

*Correspondence to Catalin George TESLEANU: ctesleanu@icapcrif.com

The tension between institutional inertia and digital disruption is particularly acute in the consumer credit segment. Traditional consumer lending in Romania required borrowers to submit physical documentation, undergo courier-dependent contract processes lasting up to 14 days, and interface with branch-based or telephone sales teams. Meanwhile, a new cohort of digitally-native consumers - Millennials and Generation Z, now constituting the majority of the economically active population - expects instantaneous, mobile-first credit decisions integrated seamlessly into their e-commerce purchasing journeys.

The paper makes four contributions. First, it provides an updated empirical characterization of Romania's digital financial services ecosystem for 2020–2025. Second, it develops a process-level analysis of e-signature implementation in the Romanian regulatory context, with particular attention to eIDAS 2.0 and Law 214/2024. Third, it analyses the financial performance of digital consumer lending under base, best, and worst-case scenarios. Fourth, it situates Romanian digital consumer lending within the global shift toward Buy Now Pay Later (BNPL) and embedded finance models.

The literature on digital transformation in banking draws on multiple theoretical traditions. Christensen's (1997) theory of disruptive innovation provides the foundational framework: digital-first financial entrants (FinTechs, neobanks) enter the market by targeting overserved or underserved segments with simplified, lower-cost products, progressively moving upmarket to challenge incumbents on their core offerings. The application of this framework to banking is well-established (King, 2019; Skinner, 2020)

Complementary to the disruption thesis is the literature on platform economics in financial services. Rochet and Tirole (2003) characterize financial intermediaries as two-sided platforms connecting borrowers and lenders; digital technologies fundamentally alter the economics of such platforms by reducing matching costs, information asymmetry, and transaction friction. E-commerce-embedded consumer lending is a direct instantiation of platform economics in consumer credit. Alt and Puschmann (2012) characterize digital lending as the 'datafication' of credit, arguing that competitive advantage derives from information architecture rather than capital.

Methodological approach

This paper employs a mixed-methods design combining macro-level market analysis with a micro-level process and financial case study. The macro-level analysis draws on secondary data from Eurostat's Digital Economy and Society Survey (DESI) for 2024; the BNR interactive statistical database for consumer credit aggregates through 2025; GPeC e-commerce industry reports; McKinsey's Digital Challengers series for CEE; and Statista / DataReportal digital indicators for Romania.

The case study component draws on primary documentation from a digital consumer financing implementation at a Romanian non-bank financial institutions (IFN) subsidiary of a major European financial group, covering the period 2013–2020. The case provides process-level data on as-is and to-be credit origination flows, pre-scoring scorecard design, stakeholder architecture, CAPEX/OPEX investment parameters, and financial performance under three scenarios. Where internal data is referenced, it is treated as representative of market-level practice, consistent with case study research ethics. The financial scenario analysis updates key parameters (cost of funds, digital origination share, average issued value) to reflect the 2024/2025 market environment.

Romania's digital banking adoption has lagged relative to its internet penetration level. The share of individuals using the internet for banking reached 30.97% in 2025 (Eurostat/TradingEconomics, 2025), placing Romania in the lower tier of EU member states and significantly below the EU average of approximately 58%. This adoption gap has been narrowing rapidly: Revolut has built a Romanian user base exceeding 3 million as of 2023, with Bucharest recording the highest per-capita concentration of Revolut users of any EU city (The Recursive, 2024), demonstrating the latent demand for digital-first financial services that traditional institutions have been slow to capture. Romania's FinTech sector comprised approximately 23 significant companies generating aggregate revenues of €59.5 million in 2023 - a 21% year-on-year increase - with Bucharest accounting for 77% of total industry turnover (€45.6 million). The top five players generate 83% of sector revenues, reflecting a winner-takes-most dynamic consistent with platform economics (The Recursive, 2024). In the consumer lending space, the critical FinTech capabilities are real-time credit scoring integrating bureau, fiscal, and behavioural data; digital KYC; and e-signature infrastructure.

Generational Shifts and Consumer Behaviour. Romania's digital banking adoption has lagged relative to its internet penetration level. The share of individuals using the internet for banking reached 30.97% in 2025 (Eurostat/TradingEconomics, 2025), placing Romania in the lower tier of EU member states and significantly below the EU average of approximately 58%. This adoption gap has been narrowing rapidly: Revolut has built a Romanian user base exceeding 3 million as of 2023, with Bucharest recording the highest per-capita concentration of Revolut users of any EU city (The Recursive, 2024), demonstrating the latent demand for digital-first financial services that traditional institutions have been slow to capture. Romania's FinTech sector comprised approximately 23 significant companies generating aggregate revenues of €59.5 million in 2023 - a 21% year-on-year increase - with Bucharest accounting for 77% of total industry turnover (€45.6 million). The top five players generate 83% of sector revenues, reflecting a winner-takes-most dynamic consistent with platform economics (The Recursive, 2024). In the consumer lending space, the critical FinTech capabilities are real-time credit scoring integrating bureau, fiscal, and behavioural data; digital KYC; and e-signature infrastructure.

Digital consumer credit implementation

The case study draws from the experience of a Romanian IFN subsidiary of a major European financial group, specialising in consumer credit products distributed through retail partnerships, direct telephone, and online channels. The institution had issued over 457,000 credit cards in the Romanian market, maintained a total credit outstanding of approximately 1.2 billion RON, and employed over 500 people directly. The parent group - present in over 60 countries with approximately 183,000 employees and 2024 revenues of approximately USD 79.8 billion (BNP Paribas, 2025) - provided a strategic framework within which the Romanian digital implementation was contextualised.

Online credit partnerships were first established in Romania in 2013. Over the subsequent period, the online channel registered average annual growth exceeding 50%. However, the process remained partially analogue: despite digital application front-ends, contract execution required physical documentation and courier delivery, elevating time-to-finance to 8–14 days and generating approximately 30% abandonment rates at the documentation submission stage. The existing process comprised four sequential stages across direct telephone, direct online, and e-commerce partner channels.

Stage 1 - Application: automated eligibility check (Expert System call) generating a Green/Orange/Red preliminary score; accepted applications generated a PDF documentation package.

Stage 2 - Documentation: the package was dispatched via courier, adding 3–10 business days regardless of scoring outcome.

Stage 3 - Manual Granting: physical documentation reviewed by the granting team with manual ANAF telephone income verification, credit bureau cross-check, and document completeness validation.

Stage 4 - Financing: approval and disbursement only after complete validated physical documentation was received. Total time-to-finance: 8–14 days.

The redesigned digital process eliminated the physical documentation requirement through three technological components: (i) Automated Database Interrogation — real-time integration with ANAF (income verification), Credit Bureau and RECOM (company register), completing three-database eligibility verification in seconds; (ii) Electronic Signature (eSign) — a dedicated Subscription Zone presenting the credit documentation package for electronic signature via three options (SMS-OTP simple signature, advanced AdES signature, or qualified QES), with mandatory consents including ANAF consent captured within the workflow; and (iii) Digital Archiving - secure, auditable electronic document storage enabling instant retrieval (Table 1).

Table 1 - *Description of data transfer from connected parties in the process flow*

Process Stage	As-Is (Physical)	To-Be (Digital)	Impact
Income verification	Manual ANAF phone call (1–3 days)	Real-time ANAF API query (<10 sec)	TTF -3 days
Credit bureau	Manual bureau check (same day)	Automated API (<5 sec)	Capacity freed
Contract signature	Courier dispatch + return (3–10 days)	e-Sign in Subscription Zone (minutes)	TTF -8 days
Document archiving	Physical file storage	Encrypted digital archive	Instant retrieval
Total time-to-finance	8–14 days	<24 hours (target)	~90% reduction
Abandonment rate	~30%	~10% (target)	-20pp

The financial model is built on three KPIs: Average Issued Value (AIV), number of daily credits, and total credit volume. The baseline AIV for online credit credits was 1,800 RON, expected to increase to approximately 2,250 RON post-implementation through reduced abandonment and pre-scoring expansion. CAPEX consisted primarily of IT infrastructure upgrades (core banking system, application front-ends, Subscription Zone, ANAF integration). OPEX increases were driven by four additional FTE for the transition granting team. Consumer credit revenues are generated through the spread between funding cost and effective portfolio yield (interest plus fees, net of cancellations. Overview on product characteristic for creid card consumer are represente in Table 2.

Table 2 - *Romanian Banking Sector vs. EU Average, 2024*

Revenue Component	Value(RON)
Average Issued Value (AIV)	2,250
Total interest and fees (credit life)	~742
Impairment provision (IFRS 9 Stage 1)	~135
Net revenue per credit	~607
Funding cost (annualised % of AIV)	~90
Net interest margin per credit	~517

Three financial scenarios were modelled for the second version of the application (incorporating facial identification KYC and full e-signature automation). The base case assumes 15% per annum organic volume growth, generating a projected ROA of 9% from Year 3 and NIBT exceeding 600,000 RON — the most probable outcome given historical digital channel growth data. The best case assumes 50% volume growth from combined pre-scoring, AIV increase, and abandonment reduction, generating 16.5 million RON net income and 8.7 million RON NIBT over the four-year lifecycle, reaching the corporate ROA target of 13.5%+. The worst case assumes organic-only growth with delayed KYC deployment, with ROA at or slightly below the 13.5% corporate target. All three scenarios confirm commercial viability - confirming the asymmetric risk profile that makes digital investment straightforward to justify. Revenues for case study are represented in Table 3.

Table 3 - *Revenues for case study*

Scenario	Revenue (4yr, MRON)	NIBT (4yr, MRON)	ROA (Year 3)	Key Driver
Base Case	~12.0	~0.6	~9%	15% organic volume growth
Best Case	~16.5	~8.7	~13.5%+	50% growth + pre-scoring
Worst Case	~9.5	~0.3	~9%□	Organic only, delayed KYC

Results and discussion

Environmental, Social, and Governance (ESG) considerations have evolved from voluntary disclosure practices to a structural regulatory requirement across the European Union, fundamentally reshaping the strategic and operational landscape of banking institutions. For Romanian financial institutions - long characterized by conservative risk postures, high collateral requirements, and limited sustainability integration - this transition represents a profound and time-constrained transformation that intersects directly with the digital lending paradigm examined in this paper.

The theoretical foundation for ESG integration in banking rests on three convergent arguments. First, the material risk argument: climate and environmental risks constitute financially material risks to bank portfolios through physical asset impairment, counterparty creditworthiness deterioration, and regulatory transition costs (Dikau & Volz, 2021). Second, the long-term value argument: firms with superior ESG performance demonstrate lower cost of capital, reduced volatility, and higher operational resilience (Friede, Busch & Bassen, 2015). Third, the license-to-operate argument: stakeholder expectations — from regulators, institutional investors, and digitally-informed consumers — increasingly price ESG risk into bank valuations, funding costs, and customer acquisition dynamics (EBA, 2025).

For Romania specifically, ESG integration occurs at the intersection of two structural pressures: the European Union's mandatory sustainability reporting architecture, which imposes binding disclosure obligations on large Romanian banks; and the competitive digital transformation imperative analyzed throughout this paper, which positions sustainability-linked digital products as a differentiating growth lever in the e-commerce-embedded consumer credit market.

The Global Reporting Initiative (GRI) provides the most widely adopted international framework for sustainability disclosure, with its standards applied by organizations across more than 100 countries. The GRI Standards operate on a modular architecture comprising three series. The Universal Standards - GRI 1 (Foundation 2021), GRI 2 (General Disclosures 2021), and GRI 3 (Material Topics 2021) - establish the conceptual and procedural foundation applicable to all organizations. Topic Standards address specific environmental, social, and governance dimensions, including GRI 201 (Economic Performance), GRI 205 (Anti-corruption), GRI 302 (Energy), GRI 305 (Emissions), GRI 401 (Employment), and GRI 405 (Diversity and Equal Opportunity). Sector Standards provide industry-specific guidance on material topics and disclosure priorities.

For the financial services sector, the GRI Financial Services Sector Supplement (FS1–FS11) historically provided supplementary disclosure guidance on themes including social and environmental policies applied to business lines (FS1–FS3), active ownership and engagement (FS10–FS11), and portfolio-level environmental performance assessment (FS8). A dedicated GRI Sector Standard for Financial Services - encompassing banking, insurance, and capital markets - is under development by GRI's Sector Standards Technical Committee, with publication expected in 2025–2026. This standard will represent a material advancement in the specificity and comparability of ESG disclosure for institutions such as Romanian commercial banks and non-bank financial institutions (IFNs) (GRI, 2024).

Environmental Dimension: Digital Transformation as a Sustainability Enabler. The environmental dimension of ESG in banking encompasses two analytically distinct categories: operational environmental performance (own emissions, energy consumption, resource use) and financed environmental impact (the climate footprint of the loan portfolio and investment assets). The latter constitutes the dominant source of environmental impact for financial institutions: data from the seven Romanian banks that published inaugural CSRD-compliant sustainability reports for the 2024 financial year indicate that Scope 3 financed emissions account for 99.8% of total reported greenhouse gas emissions, consistent with global banking sector patterns (EY Romania, 2025; PCAF, 2024).

Banca Transilvania - Romania's largest domestically owned bank by assets - provides the most granular publicly available ESG environmental data for the Romanian banking sector. Its 2024 Sustainability Report discloses total carbon emissions of approximately 55,315 tCO_2e, disaggregated as: Scope 1 (direct emissions: mobile and stationary combustion) approximately 7,644 tCO2e; Scope 2 (purchased electricity) approximately 4,555 tCO2e; and Scope 3 (primarily purchased goods and services, business travel, and financed emissions) approximately 45,896 tCO2e. Notably, 73% of the bank's total electricity consumption was sourced from renewable energy, demonstrating early progress against the operational sustainability dimension (Banca Transilvania, 2024).

The digital transformation of consumer lending - the central subject of this paper - has a direct and measurable positive relationship with the environmental dimension of bank ESG performance. The elimination of physical document couriering (previously adding 3–10 business days to credit origination, as documented in Section 6) reduces transport-related Scope 3 emissions. The transition to digital archiving eliminates paper consumption and physical storage requirements. More structurally, the shift from branch-intensive to digital-first service delivery reduces the energy footprint of bank operations: branch network rationalization driven by digital adoption directly decreases real estate energy consumption, a material component of Scope 1 and 2 emissions for traditional banks. EY Romania's (2025) analysis of the first-wave CSRD reports confirms that climate change and operational environmental performance are material topics for 100% of reporting Romanian banks, establishing environmental performance as a board-level priority rather than a discretionary disclosure.

Green Asset Ratio (GAR) data - the EU Taxonomy-aligned metric quantifying the share of bank exposures financing environmentally sustainable economic activities - reveals a significant performance gap between Romanian and EU average institutions. The average turnover-based GAR for Romanian reporting banks stands at 0.41%, and the CapEx-based GAR at 1.11%, compared to an EU/EEA average loan GAR of approximately 6% as of mid-2024 (CRIF, 2024; EBA, 2024). Green loans represent only 1.6% of total Romanian bank loan portfolios - significantly below EU peers - while green assets constitute approximately 3% of Romanian bank portfolios, less than half the euro area average (World Bank, 2024). This gap reflects structural challenges including the dominance of brown-sector lending (approximately 50% of total corporate loans) and the nascent state of EU Taxonomy-aligned product design in the Romanian market. The Table 4 analysis Romania's ESG ratings in comparation with EU average based on GRI Standards.

Table 4- *Environmental ESG Indicators — Romanian Banking Sector, 2024.*

Indicator	**Romania (2024)**	**EU/EEA Average**	**GRI Standard**
Green Asset Ratio — turnover-based (avg.)	0.41%	~6%	GRI 203 / GRI 305
Green Asset Ratio — CapEx-based (avg.)	1.11%	n/a	GRI 203
Green loans / total bank loans	1.6%	~5–8%	GRI FS8
Green assets / total bank portfolios	~3%	~7%+	GRI FS8
Brown sector lending / corporate loans	~50%	n/a	GRI 305
GHG: Scope 3 share of total emissions	99.8%	~95–99%	GRI 305
Renewable electricity (Banca Transilvania)	73%	variable	GRI 302
Green financing originated (Banca Transilvania, 2024)	RON 1.8 bn	n/a	GRI FS8
Annual green financing investment gap	7% of GDP	4% of GDP	GRI 201

Social Dimension: Financial Inclusion, Consumer Rights, and Workforce. The social dimension of ESG in Romanian banking encompasses three analytically distinct subdimensions: workforce characteristics and diversity, financial inclusion and consumer protection, and community impact. GRI Standards GRI 401 (Employment), GRI 405 (Diversity and Equal Opportunity), and GRI FS7 (monetary value of products and services designed to deliver a specific social benefit) provide the primary disclosure framework for this dimension.

Aggregate workforce data from the seven first-wave CSRD-reporting Romanian banks reveals notable characteristics. Female employees represent 74.8% of the banking sector workforce — significantly above the EU banking average — reflecting the historical gender composition of Romanian financial services employment. Female representation at Supervisory Board level averages 40%, consistent with emerging EU diversity targets. However, a structural gender pay gap of 27.8% persists — materially above the EU banking sector average — reflecting vertical segregation patterns in which female employees are concentrated in lower-seniority operational roles while leadership positions remain male-dominated. Board independence averages 54% across reporting institutions, and 71% of board members hold sustainability-linked remuneration provisions, signaling the progressive integration of ESG performance into executive incentive structures. Annual training investment averages 46.4 hours per employee, with anti-corruption and compliance training reaching 95.3% of at-risk functions (EY Romania, 2025).

Financial inclusion represents perhaps the most structurally significant social ESG dimension for

Romanian banking. Romania's financial inclusion metrics remain the weakest in the EU across multiple dimensions: only 6 in 10 Romanians hold a bank account; bank assets as a percentage of GDP stand at 49.8% as of Q3 2024 - the lowest ratio among all EU member states; and the total loans-to-GDP ratio of 28% places Romania at the bottom of EU rankings (BNR, 2025; World Bank, 2024). Collateral requirements for MSME borrowers reach 240% of loan value - the highest among regional peers - further constraining credit access. These structural deficits have direct ESG implications: financial exclusion is a material social impact indicator under GRI FS7 and ESRS S4 (Consumers and End-users), and institutions demonstrating leadership in financial inclusion score materially higher on social pillar assessments.

The digital transformation of consumer lending documented throughout this paper addresses financial inclusion through the channel-architecture dimension: e-commerce-embedded credit and BNPL products reach consumer segments — particularly rural, mobile-first, and credit-thin populations — that the physical branch network systematically under-serves. The 3.4 million new digital users acquired during the COVID-19 period (Section 9) represent a direct expansion of the financially included population facilitated by digital channel investment. McKinsey's (2022) analysis of Romanian banking identifies access to credit as the primary unmet financial service need among underbanked Romanians, positioning digital consumer lending as a social-value-generating activity with direct GRI materiality under the financial services sector framework. Consumer rights — transparent pricing, clear contractual terms, fair collections practices, and accessible dispute resolution — constitute an additional material social topic for Romanian IFNs, reinforced by Law 243/2024's consumer credit interest rate caps and EBA's Consumer Protection Guidelines.

Governance Dimension: ESG Risk Management and Board Accountability. The governance dimension of ESG - encompassing board structure, risk management frameworks, anti-corruption controls, tax transparency, and executive accountability mechanisms - is addressed in GRI Standards GRI 2 (General Disclosures), GRI 205 (Anti-corruption), and GRI 207 (Tax), and forms the foundational pillar upon which credible environmental and social performance is constructed. For Romanian banks, the governance ESG dimension has been materially strengthened by two regulatory developments: the transposition of CRD VI (Capital Requirements Directive VI) requiring national implementation by January 2026, which mandates structured ESG risk management frameworks, climate risk stress testing, and board-level ESG accountability; and CSRD's mandatory double materiality assessment, which requires governance processes for identifying, assessing, and managing sustainability impacts, risks, and opportunities (EBA, 2025; EC, 2023).

The National Bank of Romania has established a dedicated institutional architecture for green finance governance. The BNR participates in the Network of Central Banks and Financial Supervisors for Greening the Financial System (NGFS) and maintains a dedicated Climate Risk Monitoring Dashboard for the Romanian banking sector. The National Committee for Macroprudential Oversight (NCMO) issued Recommendation R/6/2021 on green finance and established six specialist sub-working groups addressing taxonomy application, transparency requirements, and green finance product development. Green lending data collection was initiated by the BNR in May 2022 using the EU Taxonomy framework as a classification reference. The BNR's Financial Stability Report (June 2025) identifies climate change as a structural vulnerability to Romanian financial stability, noting that non-financial companies generating 40% of gross added value face material climate-related risks that will transmit through credit portfolios to bank balance sheets (BNR, 2025).

ESG risk integration at the institutional level is advancing across the major Romanian banking groups. UniCredit Romania operates under a group-level ESG framework with verified external ratings — MSCI rating A, Refinitiv ESG score 87/100, Bloomberg ESG score in the 96th percentile — and has committed to 2025–2027 targets of 15% ESG lending, 15% sustainable bond issuance, and 50% of investment products with ESG characteristics. The alignment of digital infrastructure — automated scoring, real-time data integration, digital documentation — with ESG risk management creates operational synergies: the same data architecture enabling rapid consumer credit decisions can be extended to incorporate ESG risk scoring at the point of origination, enabling portfolio-level ESG steering through product and pricing design.

CSRD Implementation and Romanian Banking Regulatory Obligations. The Corporate Sustainability Reporting Directive (CSRD, Directive 2022/2464/EU) represents the most consequential ESG regulatory development for Romanian financial institutions, establishing binding sustainability reporting obligations that supersede the prior Non-Financial Reporting Directive (NFRD) in scope, specificity, and assurance requirements. Under the CSRD implementation timeline, large public-interest entities - including listed Romanian banks and those exceeding the large-entity thresholds - were required to publish their first CSRD/ESRS-aligned sustainability statements for the 2024 financial year, with publication in early 2025.

Seven Romanian banks published inaugural CSRD-compliant sustainability reports in the first wave (2025), marking a structural inflection point in the ESG maturity of the Romanian banking sector. EY Romania's analysis of these first-wave reports identifies climate change and own workforce as universally material topics (100% of reporting institutions), with consumer rights, business conduct, and anti-corruption as the next tier of priority material topics (EY Romania, 2025). The double materiality assessment - mandatory under CSRD - requires banks to evaluate both the financial materiality of sustainability risks to their business model and the impact materiality of their activities on society and the environment across their value chain.

The European Sustainability Reporting Standards (ESRS) - the disclosure standards mandated under CSRD - require reporting across twelve topical standards spanning environmental (ESRS E1: Climate Change through E5: Circular Economy), social (ESRS S1: Own Workforce through S4: Consumers and End-users), and governance (ESRS G1: Business Conduct) dimensions. For Romanian banks, ESRS E1 (Climate Change) and ESRS S1 (Own Workforce) impose the most immediately demanding disclosure requirements, including transition plan disclosure, Scope 1, 2, and 3 GHG emission quantification, physical and transition risk assessment, and detailed workforce disaggregation data. ESRS S4 (Consumers and End-users) is of particular significance for consumer credit institutions, requiring disclosure of material impacts on customers - including financial inclusion, responsible lending practices, and consumer protection mechanisms - that directly intersect with the digital consumer lending architecture documented in this paper.

The GRI–ESRS interoperability framework enables Romanian banks adopting GRI Standards voluntarily to satisfy a significant proportion of CSRD/ESRS mandatory data points simultaneously, reducing aggregate compliance costs. The BNR's Climate Risk Monitoring Dashboard provides sector-level benchmarking against which individual institution disclosures can be contextualized. The CRR III/CRD VI banking regulatory package - with CRR III applicable since 1 January 2025 and CRD VI requiring national transposition by 10 January 2026 - introduces parallel Pillar 1 and Pillar 2 ESG risk integration requirements, mandating climate risk scenario analysis, ESG risk assessment in credit underwriting, and dedicated ESG risk management frameworks at institutional governance level (EBA, 2025). The convergence of CSRD/ESRS and CRR III/CRD VI obligations creates a regulatory architecture in which ESG is simultaneously a disclosure requirement, a risk management imperative, and a prudential supervisory concern for Romanian banks.

ESG Performance Benchmarks: Romanian Banking Sector, 2024–2025. Synthesizing the available ESG performance data for the Romanian banking sector across the environmental, social, and governance dimensions reveals a sector in structural transition: material progress on governance integration and first-wave CSRD compliance, measurable but nascent progress on green finance volumes, and persistent structural deficits in financial inclusion and green asset ratios relative to EU peers (Table 6).

Table 6 - *ESG Performance*

ESG Dimension / Indicator	Romanian Banking Sector	EU Benchmark	GRI Standard
ENVIRONMENTAL			
Green Asset Ratio (turnover-based)	0.41%	~6%	GRI 302/305
GHG Scope 3 share of total emissions	99.8%	~95–99%	GRI 305
Green loans / total loans	1.6%	n/a	GRI FS8
Renewable electricity (leading institution)	73%	variable	GRI 302
SOCIAL			
Bank account penetration	~60%	~90%+	GRI FS7
Bank assets / GDP	49.8%	>100%	GRI 201
Loans / GDP	28%	>50%	GRI 201
Female employees (sector avg.)	74.8%	~55%	GRI 405
Gender pay gap (sector avg.)	27.8%	~15–20%	GRI 405
Female Supervisory Board (avg.)	40%	EU target: 40%	GRI 405
Annual training hours / employee	46.4 hrs	n/a	GRI 404
GOVERNANCE			
Board members w/ ESG remuneration	71%	n/a	GRI 2
Independent board members	54%	n/a	GRI 2
Anti-corruption training coverage	95.3%	n/a	GRI 205
CSRD first-wave reporters (2025)	7 banks	variable	ESRS/GRI 2

Romania adopted Law 214/2024 on electronic signature and trust services on 8 July 2024 (entering into force 8 October 2024), establishing a clear legal hierarchy for signature types and implementing eIDAS provisions. For consumer lending, the law resolves ambiguities that previously constrained digital origination, explicitly addressing electronic signatures in financial services contracts. The ANAF digital consent integration - enabling real-time fiscal income verification - materially improves income verification accuracy relative to telephone methods, reducing first-generation NPL risk on digitally originated portfolios.

The ESG-digital banking nexus in Romania thus operates at two levels: the operational level, where digital banking reduces the bank's own environmental footprint through branch network rationalization, paperless workflows, and digital document management (directly relevant to GRI 302 and GRI 305 disclosures); and the portfolio level, where digital infrastructure enables the deployment of green and socially-oriented financial products at scale, improving both GAR metrics (environmental) and financial inclusion metrics (social). Research conducted on Romanian banking confirms a positive empirical correlation between banking digitalization, financial performance, and renewable energy investment (Strategica, 2022), supporting the argument that digital transformation and ESG integration are mutually reinforcing rather than competing strategic imperatives for Romanian financial institutions.

Conclusion

This paper has examined the digital transformation of consumer lending in Romania, integrating updated market data for 2020–2025 with a detailed process and financial case study of a digital consumer credit implementation at a leading Romanian IFN. The central argument - that digital consumer lending is a structural imperative, not a strategic option — is supported by the convergence of generational behavioural change, e-commerce market growth, regulatory enablement, and FinTech competitive pressure.

Key empirical findings include: Romania's e-commerce market reaching approximately €7 billion in 2023 with a 7.81% projected CAGR through 2030; internet banking penetration reaching 30.97% in 2025; COVID-19 generating 3.4 million new digital users in Romania in the first five months of 2020; e-signature and ANAF-integrated workflows reducing time-to-finance from 14 days to under 24 hours; and projected ROA of 9–13.5% across financial scenarios confirming commercial viability.

The regulatory landscape has been transformed by eIDAS 2.0 (May 2024) and Romania's Law 214/2024, creating a clear legal framework for digital origination and establishing the EUDI Wallet as the next-generation KYC infrastructure. The BNPL model, growing at 11.5% CAGR in Europe, represents the product frontier toward which e-commerce-embedded consumer credit is evolving.

Future research should examine three open areas. First, the empirical measurement of NPL differentials between digitally-originated and traditionally-originated consumer credit portfolios in Romania. Second, the competitive dynamics between traditional IFN digital platforms and BNPL-native entrants in the Romanian e-commerce embedded finance market post-2024. Third, the implications of EUDI Wallet deployment for KYC economics and borrower onboarding costs across the Romanian financial services sector.

References

1. Alt, R. & Puschmann, T. (2012) The rise of customer-oriented banking: Electronic markets are paving the way for change in the financial industry. *Electronic Markets*. 22(4). pp. 203–215.
2. AEI (2024) Alliance for Energy Innovation. PVWatts Calculator. [Online] Available from: https://pvwatts.nlr.gov/index.php. [Accessed: 16th April 2026].
3. ANRE. (2020) *Comparator oferte-tip de furnizare a energiei electrice*.(in English: :Electricity supply type offer comparator) [Online] Available from: https://posf. ro/ comparator?comparatorType=electric. [Accessed: 16th April 2026].
4. Bergougui, B. & Ben-Salha, O. (2025) How Does the Circular Economy Asymmetrically Affect Clean Energy Adoption in EU Economies? *Sustainability*. 17. 9523. https://doi.org/10.3390/su17219523.
5. BNR (2025) National Bank of Romania, Bank Lending Survey. February 2025. [Online] Available from: https://www.bnr.ro/ [Accessed: 15th April 2026].

6. Barbesino, P., Camerani, R. & Gaudino, A. (2022) Embedded Finance: *When Payments Become An Experience*. Wiley.
7. BNP Paribas Group. (2025) Results as at 31 December 2024. *Press Release, 4 February 2025*. [Online] Available from: https://group.bnpparibas/en/press-release/bnp-paribas-group-results-as-at-31-december-2024 [Accessed: 15th April 2026].
8. BNP Paribas Personal Finance. (2024) *Annual Report 2024*. [Online] Available from: https://personal-finance.bnpparibas/en/reports/ [Accessed: 15th April 2026]
9. Christensen, C. M. (1997) The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. *Harvard Business School Press*.
10. CoinLaw. (2026) *Millennial vs. Gen Z Banking Preferences Statistics 2026*. [Online] Available from: https://coinlaw.io/millennial-vs-gen-z-banking-preferences-statistics/ [Accessed: 15th April 2026].
11. Chantzis, G., Giama, E. & Papadopoulos, A. (2023) Building Energy Flexibility Assessment in Mediterranean Climatic Conditions: The Case of a Greek Office Building, *Applied Sciences.* 13 (12): 7246. https://doi.org/10.3390/app13127246.
12. Deloitte. (2024) Gen Z and Millennials Alike: What Banks Must Know. *Deloitte Insights*. [Online] Available from: https://www.deloitte.com/us/en/insights/industry /financial-services/gen-z-millennial-digital-banking.html [Accessed: 15th April 2026].
13. D'Agostino, D., Cuniberti, B. & Bertoldi, P. (2017) Energy consumption and efficiency technology measures in European non-residential buildings. *Energy and Buildings*. 153. pp. 72-86. https://doi.org/10.1016/j.enbuild.2017.07.062.
14. ElevatePay. (2024) *Understanding Buy Now Pay Later in Romania*. [Online] Available from: https://www.elevatepay.co/blog/bnpl-in-romania [Accessed: 15th April 2026].
15. EBA (2022), European Banking Authority. *Guidelines on the Use of Remote Customer Onboarding Solutions* (EBA/GL/2022/15).
16. EC (2024a), European Commission Digitalisation in Europe — 2024 Edition. *Eurostat Interactive Publications.* [Online] Available from: https://ec.europa.eu/eurostat/web/ interactive-publications/digitalisation-2024 [Accessed: 15th April 2026].
17. EC (2024b), European Commission, Regulation (EU) 2024/1183 amending Regulation (EU) 910/2014 (eIDAS 2.0). *Official Journal of the European Union*.
18. EC (2022), European Commission. *Circular economy strategy*. [Online] Available from: https://research-and-innovation.ec.europa.eu/research-area/environment/circular-economy/circular-economy-strategy_en. [Accessed: 15th April 2026].
19. ENF (2022) Solar. *Solar Panels*. [Online] Available from: https://www.enfsolar. com/pv/panel?page=1. [Accessed: 10th November 2024].
20. GPeC (2023) The Current State of the E-Commerce Market: *Challenges and Opportunities for 2025*. [Online] Available from: https://www.gpec.ro/en/ [Accessed: 15th April 2026].
21. Galatioto, A., Ricciu, R., Salem, T. & Kinab, E. (2019) Energy and economic analysis on retrofit actions for Italian public historic buildings. *Energy*. 176:58–66, https://doi.org/10.1016/j.energy.2019.03.167.
22. Ghosh, D.K., Bose, S., Das, G., Acharyya, S., Nandi, A., Mukhopadhyay, S. & Sengupta, A. (2022) Fundamentals, present status and future perspective of TOPCon solar cells: A comprehensive review. *Surfaces and Interfaces*. 30. 101917. https://doi.org/10.1016/j.surfin.2022.101917.
23. ICLG. (2024) *Fintech Laws and Regulations Report 2024–2025: Romania*. [Online] Available from: https://iclg.com/practice-areas/fintech-laws-and-regulations/romania [Accessed: 15th April 2026].
24. IFC (2022) International Finance Corporation. *EDGE platform*. [Online] Available from: https://app.edgebuildings.com/project/allBuildings. [Accessed: 5th November 2024].
25. IFC (2021) International Finance Corporation. (2021) *EDGE User Guide - Version 3.0.a.* [Online] Available from: https://edgebuildings.com/wp-content/uploads /2022/04/211026-EDGE-User-Guide-for-All-Building-Types-Version-3.0.A.pdf [Accessed: 5th November 2024].

26. Juniper Research. (2024) *Buy Now Pay Later Market Report*. [Online] Available from: https://www.juniperresearch.com/research/fintech-payments/ecommerce/buy-now-pay-later-research-report/ [Accessed: 15th April 2026].
27. King, B. (2019) Bank 4.0: Banking Everywhere, Never at a Bank. *Marshall Cavendish Business*.
28. Lironi, E. (2021) Digital Identity and Trust Services in the European Union. *European Parliamentary Research Service*.
29. MarkWide Research. (2025) *Romania E-Commerce Market — Size, Share, Trends, Analysis & Forecast 2026–2035*. [Online] Available from: https://markwideresearch.com/romania-e-commerce-market/ [Accessed: 15th April 2026].
30. McKinsey & Company. (2021a) *Digital Challengers in the Next Normal: Romania in the CEE Context*. [Online] Available from: https://www.mckinsey.com/featured-insights/europe/digital-challengers-in-the-next-normal-romania-in-the-cee-context [Accessed: 15th April 2026].
31. McKinsey & Company. (2021b) *Thoughtful Digitization Can Help Romanian Companies Retain Digital Customers Acquired During COVID-19*. [Online] Available from: https://www.mckinsey.com/featured-insights/europe/thoughtful-digitization [Accessed: 15th April 2026].
32. McKinsey & Company. (2022) *A Time for Reinvention: Challenges and Solutions for the Romanian Banking System*. [Online] Available from: https://www.mckinsey. com/industries/financial-services/our-insights/a-time-for-reinvention-challenges-and-solutions-for-the-romanian-banking-system. [Accessed: 15th April 2026]
33. Panagiotis, F. (2022) Analysing the systemic implications of energy efficiency and circular economy strategies in the decarbonisation context. *AIMS Energy*. 10(2). pp. 191–218. https://doi.org/10.3934/energy.2022011.
34. Rahla, K.M., Mateus, R. & Bragança, L. (2021) Implementing Circular Economy Strategies in Buildings-From Theory to Practice. *Applied System Innovation*. 4(2):26. https://doi.org/10.3390/asi4020026.
35. Raad, H., Ali, S., Faraj, J., Castelain, C., Chahine, K. & Khaled, M. (2025) Enhancing photovoltaic panel efficiency through Water-Cooling: A parametric comparative evaluation of energetic, economic, and environmental benefits. *Unconventional Resources*. 7. 100208. ISSN 2666-5190. https://doi.org/10.1016/j.uncres.2025.100208.
36. Stanciu, C. & Stanciu., D. (2014) Optimum tilt angle for flat plate collectors all over the World – A declination dependence formula and comparisons of three solar radiation models. *Energy Conversion and Management*. 81. pp. 133-143. https://doi.org/10.1016/j.enconman.2014.02.016.
37. WGBC (2026) World Green Building Council. *What is a Sustainable Built Environment?* [Online] Available from: https://worldgbc.org/what-is-a-sustainable-built-environment/#:~:text=The%20built%20environment%20has%20a%20significant%20impact,water%2C%20and%20land%20pollution%2C%20and%20biodiversity%20loss. [Accessed: 15th April 2026].

"We try to generate more waste in order to generate the inputs for the power plants that we've made such large investments in."
Ian Boyd

A Key Role of Disruptive Technologies in the Circular Economy

Alexandru-Adrian BLAGAU*, Cezar SCARLAT

National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independentei, Bucharest, Romania

Abstract

In the context of digital transformation, the integration of disruptive technologies into operational processes has generated significant changes in the way resources are managed, facilitating the transition of industries to sustainable models specific to the circular economy. In this paper, the authors analyze the role of disruptive technologies such as artificial intelligence, machine learning, IoT, Big Data and blockchain in the transition from a linear to a circular economy. At the same time, in order to identify the main trends, research directions and relationships between these technologies and the circular economy, the authors perform a bibliometric analysis of the specialized literature, indexed in international databases. The authors analyze relevant applications of disruptive technologies at the industrial sector, highlighting how they can increase the efficiency of operational processes, but also the challenges they can generate.

Keywords: disruptive technologies, circular economy, artificial intelligence

Introduction

The global environmental crisis highlights the urgent need for effective management of natural resources. Climate change has far-reaching consequences that extend beyond environmental degradation (Keles et al., 2025). Driven by globalization and consumerism, the depletion of natural resources and environmental degradation have increased global interest in the Circular Economy (CE) concept. The CE seeks to replace the traditional end-of-life approach with restoration and closed-loop product lifecycles. Its main objectives are to eliminate waste, preserve the value embedded in products and materials, promote the use of renewable energy, and phase out toxic substances (Sassanelli et al., 2019).

In this paper, the authors analyze the integration of disruptive technologies in the CE, using a bibliometric analysis to identify trends, innovations, applications and challenges generated. In this context, disruptive technologies such as artificial intelligence, the Internet of Things (IoT), blockchain and additive manufacturing play a key role in accelerating the transition from the

"Entrepreneurship is a medley of everything old to create something new."
Richie Norton

traditional linear model to a circular one. The bibliometric analysis allows for the rigorous mapping of the specialized literature, highlighting the volume and dynamics of publications, collaboration networks and emerging themes in the field.

The circular economy is a model of production and consumption that aims to extend the lifespan of materials and products. The primary goal of this system is to minimize waste. The circular economy proposes keeping materials in the economic cycle through recycling and recovery processes, facilitating their repeated reuse and the continuous generation of value. This principle shifts away from the traditional linear economic model, characterized by the take-make-waste approach, which relies on the intensive consumption of readily available and inexpensive material and energy resources (European Parliament, 2023). The "R" strategies of the circular economy (Figure 1) facilitate waste reduction and resource efficiency, supporting environmental protection and sustainable development. The strategies include Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover. Their application reduces raw material consumption, extends the life of products and reduces waste, contributing to lower emissions and stimulating innovation (Circularise, 2023).

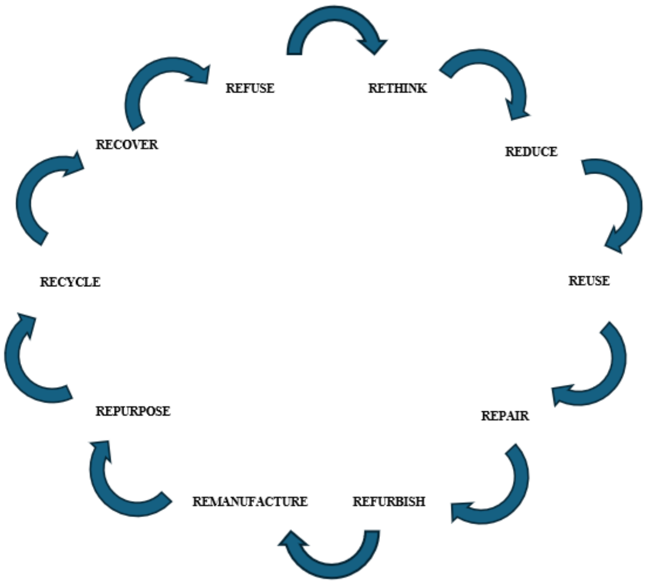


Figure 1 – *The "R" strategies of the circular economy*

Disruptive technologies play a key role in the adoption of the circular economy model, supporting the optimization of recycling flows, material flow management, life cycle monitoring. These represent major scientific innovations that significantly influence the way organizations operate. The Internet of Things, Big Data Analytics, AI, Blockchain, 3D printing are disruptive technologies that influence the circular economy (Bongomin et al., 2020).

The Internet of Things (IoT) is a disruptive technology that has the potential to radically transform entire markets and established ways of operating. IoT is a network of physical devices equipped with sensors, software, and network connectivity that allows for the efficient collection and transfer of data in real time. This technology generates huge amounts of data, also known as Big Data. To be able to analyze this data, organizations must integrate advanced data processing technologies (IBM, 2024).

The capabilities of Big Data Analytics (BDA) are increasingly recognised as essential for comprehensive decision-making within the Circular Economy (CE), and they are attracting considerable interest from both academic and industry professionals. BDA encompasses data sets and analytical methodologies that are sufficiently large and complex to necessitate advanced storage, management, analysis, and visualisation technologies (Awan et al., 2021).

Artificial intelligence (AI) represents a disruptive technology that enables computers to perform human-like tasks, including perception, speech, decision-making, and translation. As AI advances rapidly, organisations are using it to improve products, services, operations, and customer experiences (Machucho and Ortiz, 2025).

Blockchain technology, first introduced by Satoshi Nakamoto as an open distributed ledger for cryptocurrencies, faced initial skepticism due to its complexity. However, awareness of its benefits has driven extensive research into its applications, with blockchain regarded as both foundational and disruptive. Blockchain technology offers several notable advantages, including its function as a distributed ledger, decentralised governance, enhanced transparency, immutable transactions, resistance to tampering or manipulation, and broad accessibility (Upadhyay et al., 2021).

Additive manufacturing, also referred to as 3D printing, is an disruptive technology that produces three-dimensional objects by systematically building structures layer upon layer. Additive manufacturing has applications across various industries, including aerospace, automotive, healthcare, and consumer goods, offering unique advantages such as reduced material waste and rapid prototyping (Kassab et al., 2023).

The transition to a circular economy is a fundamental step in achieving sustainability goals, by reducing waste, making resource use more efficient and extending the lifespan of products. In a global context marked by pressures on natural resources, adopting a circular model is no longer an option, but a necessity. Disruptive technologies are essential factors in facilitating this process, contributing to the automation of operations, the implementation of data-based decisions and supporting continuous improvement in the context of the circular economy (Rodriguez Romo et al., 2025).

IoT offers real-time remote monitoring, enables rapid prototyping, and drives continuous improvement through cyclic learning. It provides robust solutions for tracking products and tools, monitoring logistics and conditions, predictive maintenance, and overseeing the entire lifecycle. Big Data empowers effective utilization of machine-generated information across product development and supply chain management. It supports waste reduction initiatives and fosters intelligent, collaborative industrial environments by facilitating data-driven decision-making through integrated analytics from multiple sources. Blockchain delivers enhanced visibility, transparency, and smart contract functionality throughout the value chain A.I. facilitates comprehensive data analytics and resource optimization in product design, as well as business model enhancement. It enables remote monitoring during manufacturing, accelerates prototyping, and supports iterative learning through repeated cycles.

Additionally, A.I. assists with waste sorting and material reprocessing and enhances business models via tracking of products and tools, monitoring conditions and logistics, predictive maintenance, and lifecycle management. AI-driven applications enable real-time product monitoring and improve recycling by analyzing data across the value chain, helping recover materials and minimize resource loss (Popescu et al., 2025). Machine Learning contributes to process and system optimization by analyzing and managing industrial workflows, which improves performance and reduces inefficiencies. It allows for the processing and utilization of large volumes of data, thereby promoting operational flexibility and continuity (Voulgaridis et al., 2022). Additive manufacturing, when combined with plastic recycling, creates distributed recycling by additive manufacturing (DRAM). This approach decentralizes recycling, making it more accessible by allowing local recycling near the point of use. DRAM eliminates centralized systems, reduces inventory and transportation costs, and streamlines supply chains and logistics (Upadhyay et al., 2021).

Methodological approach

This study is based on bibliometric analysis, a method that systematically and quantitatively evaluates bibliographic data from the Web of Science database. It provides a structured approach to organizing and interpreting the body of knowledge identified through the use of specific search terms and filtering criteria.

The search and filtering strategy targeted recent research (2020–2025) on the intersection of circular economy and disruptive technologies, applying specific filters to match current trends. To identify the most relevant data for the study, we applied the following filters:

- we set the range to 2020-2025;
- we selected only papers written in English;
- we selected only original research articles and review articles.

To identify bibliometric data from the Web of Science Core Collection, we used the following query on 01.04.2026:

"*circular economy" AND ("Internet of Things" OR "IoT" OR "Industrial IoT" OR "IIoT" OR "artificial intelligence" OR "AI" OR "machine learning" OR "deep learning" OR "blockchain" OR "distributed ledger technology" OR "DLT" OR "smart contracts" OR "big data" OR "digital twin" OR "cyber-physical systems" OR "CPS" OR "cloud computing" OR "edge computing" OR "fog computing" OR "3D printing" OR "robotics" OR "autonomous systems" OR "computer vision" OR "image recognition" OR "object detection" OR "augmented reality" OR "AR" OR "virtual reality" OR "VR" OR "mixed reality" OR "3D printing")*

Following the first query, we identified 3,597 articles, and after applying the filters, we identified 2,544 relevant articles.

To analyze the obtained data, we used the following software programs:

- RStudio / biblimetrix library – biblioshiny;
- VOSViewer V1.6.20.

Results and Discussion

The first query of the Web of Science Core Collection identified 3,597 results. After applying the filters, we reached a total of 2,544 results relevant to our analysis.

Following the analysis of the temporal evolution (Figure 2) we identified that in 2025 a number of 947 articles were registered, signaling an increase of 80% compared to the previous year, where 526 articles were identified. This significant increase represents an increased interest in research on the links between disruptive technologies and how they can influence the circulation economy.

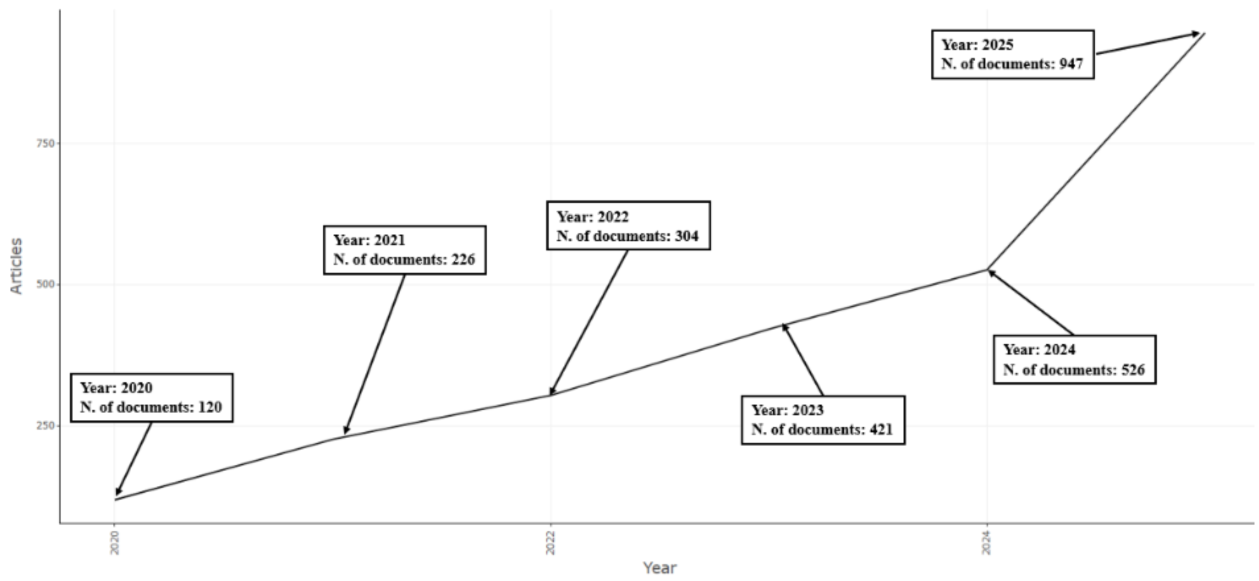


Figure 2 – *Temporal evolution of articles*

A statistical analysis (Figure 3) of the source journals revealed that Sustainability accounted for the highest volume of articles satisfying the study's selection criteria, comprising 256 published articles.

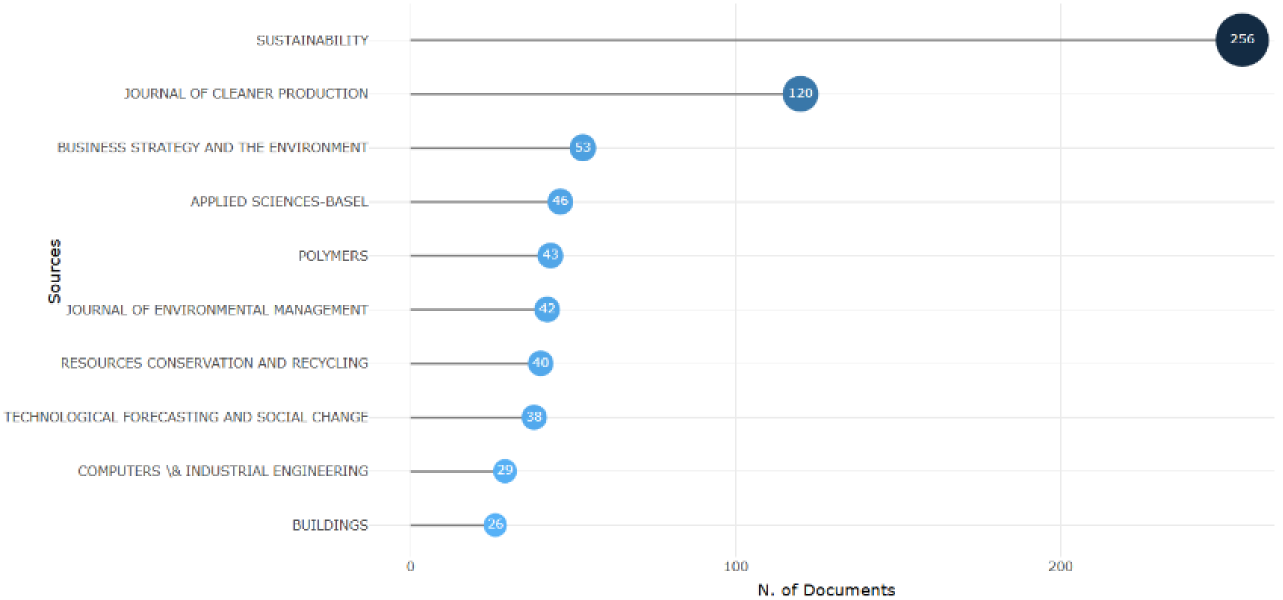


Figure 3 – *Journals analysis*

Figure 4 presents the word cloud map of authors' keywords, revealing that "circular economy", "sustainability" and "management" are core topics, illustrating the main research concerns but also the strong relationship between them.

Figure 4 – *Word cloud map*

Figure 5 shows the most frequent words, thus highlighting that the most studied disruptive technologies in the circular economy are: big data (217 uses), blockchain (216 uses), machine learning (205 uses), and artificial intelligence (203)

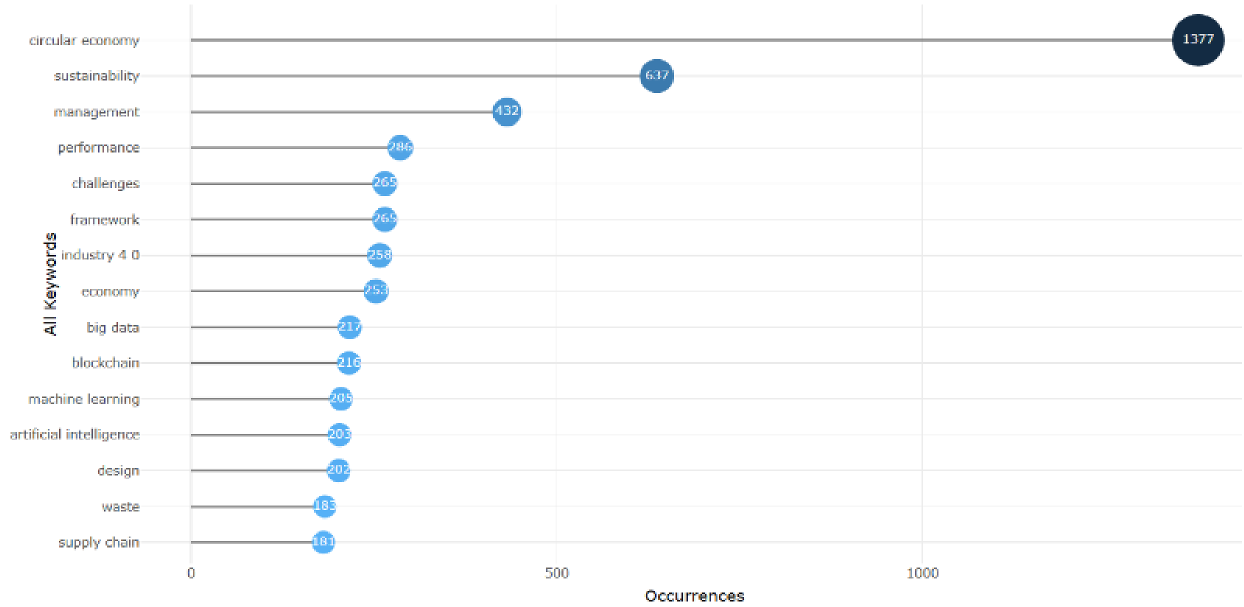


Figure 5 – *Most frequent words*

Bibliometric analysis of the keyword co-occurrence network (Figure 6) reveals three separate thematic clusters within the literature.

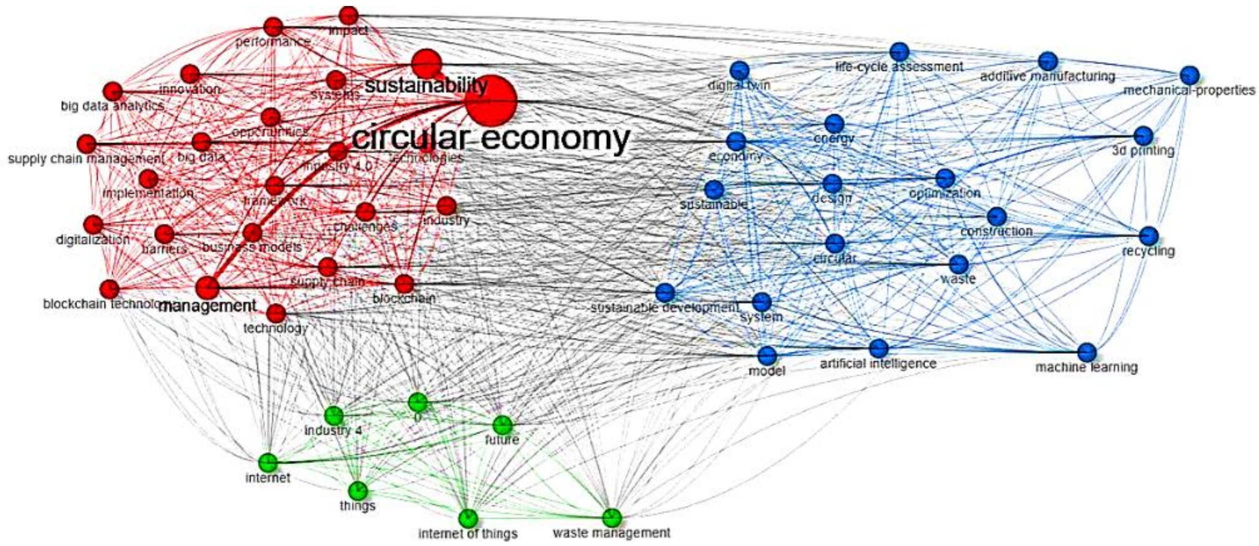


Figure 6 – *Keyword co-occurrence network*

The first cluster (red) is centered around the concept of "circular economy" and includes keywords such as "sustanability" and "management". The simultaneous presence of the disruptive keywords blockchain and big data, along with barriers, opportunities and challenges within the circular economy, indicates the authors' interest in their potential and the impact they can generate.

The second cluster (blue) includes keywords such as „internet", „future" and the disruptive technology „internet of things" close to „waste management". This cluster indicates the authors' interest in connectivity and material flows, especially waste management as a practice of circularity, IoT for product and material monitoring, and the Internet for connectivity.

The third cluster (green) includes keywords such as “optimization”, „sustainable development”, „recycling”, „life-cycle assessment” and disruptive technologies: “artificial intelligence”, “machine learning”, “digital twin” and “3d printing” words specific to a level of production and optimization. "3d printing" and "recycling" indicate a complementary relationship within the circular economy, while AI and ML indicate an increased interest of the authors in data-driven decisions and optimization.

In total, 114 countries have contributed to the existing research on circular economy and distruptive technologies. Countries with fewer than 5 publications were excluded from the analysis. To avoid distortion from large multi-country consortiums, documents with more than 25 country affiliations were excluded. Of the 114 countries identified in the dataset, 82 met the inclusion criteria and were incorporated into the final co-authorship network (Figure 7)

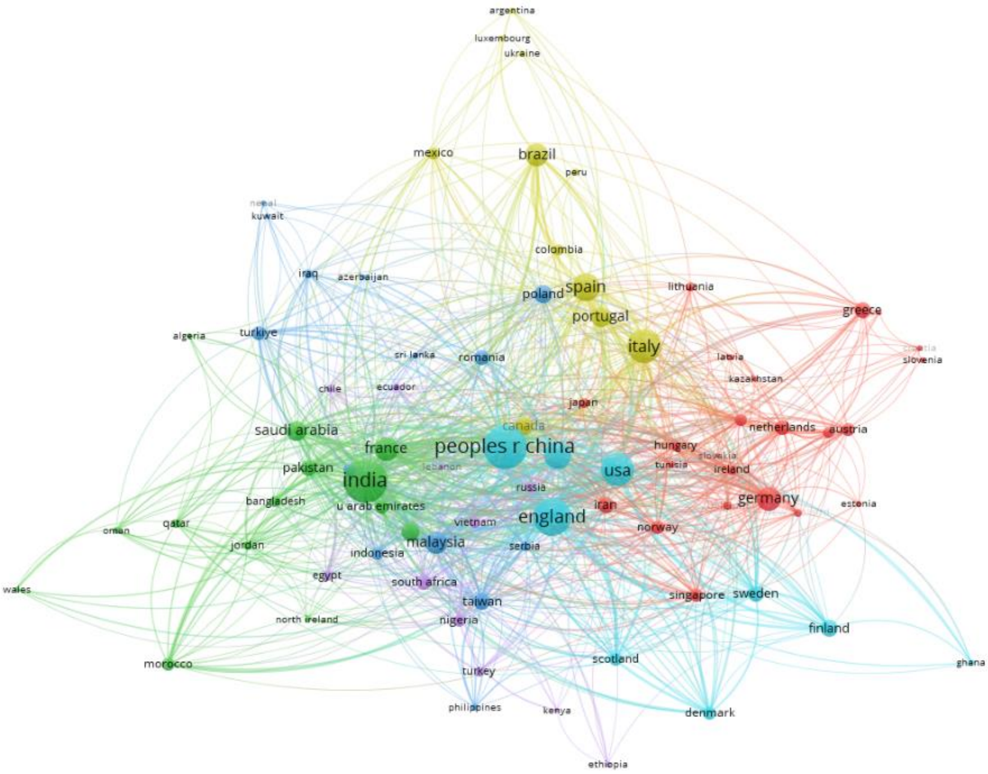


Figure 7 – *Co-autorship Countries*

Based on the results, the most cited countries are: India with 13,159 citations and 405 papers, England with 12,772 citations and 300 papers, People's Republic of China with 12,583 citations and 413 papers and the USA with 10,114 citations and 225 papers. In Romania, 48 relevant works were identified in the field of circular economy and disruptive technologies, accumulating a total of 738 citations.

Conclusions

The authors conducted a bibliometric analysis aimed at assessing the connections between the circular economy and disruptive technologies, such as big data, artificial intelligence, machine learning, blockchain and 3D printing, as well as the level of interest of the scientific community in these emerging directions. At the same time, the main ways in which these technologies can support the circular economy were identified, contributing to optimizing the use of resources, increasing process efficiency and developing sustainable production and consumption models.

The analysis of the evolution of the number of articles published in the period 2020 - 2025 highlights a significant increase in interest in this topic, with a pronounced peak in 2025. This trend may indicate a growing awareness of the importance of the circular economy, as well as of the essential role that disruptive technologies play in facilitating the transition to sustainable production and consumption models.

The bibliometric analysis identifies the main disruptive technologies in the circular economy, highlighting the directions of innovation and transformation. The results reflect current trends and provide a basis for future research.

REFERENCES

1. Awan, U., Shamim, S., Khan, Z., Zia, N. U., Shariq, S. M. & Khan, M. N. (2021) Big Data Analytics Capability and Decision-Making: The Role of Data-Driven Insight on Circular Economy Performance. *Technological Forecasting and Social Change*. 168. pp.120-766.
2. Bongomin, O., Ocen, G., Nganyi, E., Musinguzi, A. & Omara, T. (2020) Exponential Disruptive Technologies and the Required Skills of Industry 4.0. *Journal of Engineering*. 2020. p.1-17. Available from: https://doi.org/10.1155/2020/4280156.
3. CIRCULARISE. (2023) *R-Strategies for a Circular Economy*. [Online] Available from: https://www.circularise.com/blogs/r-strategies-for-a-circular-economy. [Accessed: 1st April 2026].
4. European Parliament. (2023) *Circular Economy: Definition, Importance and Benefits*. [Online] Available from: https://www.europarl.europa.eu/topics/en/article/ 20151201STO05603/circular-economy-definition-importance-and-benefits. [Accessed: 1st April 2026].
5. IBM. (2024) *Internet of Things*. [Online] Available from: https://www.ibm.com/think/topics/internet-of-things. [Accessed: 1st April 2026].
6. Kassab, A., Al Nabhani, D., Mohanty, P., Pannier, C. & Ayoub, G. Y. (2023) Advancing Plastic Recycling: Challenges and Opportunities in the Integration of 3D Printing and Distributed Recycling for a Circular Economy. *Polymers*. 15(19). p.3881. Available from: https://doi.org/10.3390/polym15193881.
7. Keles, C., Cruz Rios, F. and Hoque, S. (2025) Digital Technologies and Circular Economy in the Construction Sector: A Review of Lifecycle Applications, Integrations, Potential, and Limitations. *Buildings*. 15(4). p.553. Available from: https://doi.org/10.3390/buildings15040553.
8. Machucho, R. & Ortiz, D. (2025) The Impacts of Artificial Intelligence on Business Innovation: A Comprehensive Review of Applications, Organizational Challenges, and Ethical Considerations. *Systems*. 13(4). p.264. Available from: https://doi.org/10.3390/systems13040264.
9. Popescu, F., Blagau, A. A., Ichimescu, C., Ioniţescu, S. & Radu, I. A. (2025) From Linear to Circular Defense Industry Using Disruptive Technology and AI. Proceedings: *International Conference of Management and Industrial Engineering*. 12. pp.520-528.
10. Rodriguez Romo, M. F., Siva, V., Papakostas, N., Ghadimi, P. & Hargaden, V. (2025) Circular Economy and Digital Technologies: A Research Agenda for Intelligent Circular Systems. *Resources, Conservation & Recycling Advances*. 28. pp.200-292. Available from: https://doi.org/10.1016/j.rcradv.2025.200292 .

11. Sassanelli, C., Rosa, P., Rocca, R. & Terzi, S. (2019) Circular Economy Performance Assessment Methods: A Systematic Literature Review. *Journal of Cleaner Production*. 229. pp.440-453.
12. Upadhyay, A., Mukhuty, S., Kumar, V. and Kazancoglu, Y. (2021) Blockchain Technology and the Circular Economy: Implications for Sustainability and Social Responsibility. *Journal of Cleaner Production*. 293. pp.126-130.
13. Voulgaridis, K., Lagkas, T., Angelopoulos, C. M. & Nikoletseas, S. E. (2022) IoT and Digital Circular Economy: Principles, Applications, and Challenges. *Computer Networks*. 219. pp.109-456.

"*The barrier to disruptive innovation often isn't knowing enough.*"
Tom Goodwin

Topics in future issues of FAIMA Business & Management Journal 2026

Green Business Models

Volume 14, Issue 3 – September 2026

Intelligent Systems in Marketing

Volume 14, Issue 4 – December 2026