

DOI: <https://doi.org/10.34069/AI/2024.73.01.25>

How to Cite:

Gorokhova, T., Kravchenko, M., Muterko, H., Korostova, I., & Lukash, M. (2024). Exploring the integration of circular economy and digitalization: current research progress and trends. *Amazonia Investiga*, 13(73), 297-306. <https://doi.org/10.34069/AI/2024.73.01.25>

Exploring the integration of circular economy and digitalization: current research progress and trends

Explorando la integración de la economía circular y la digitalización: avances y tendencias actuales de la investigación

Received: December 21, 2023

Accepted: January 27, 2024

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Abstract

The European Union robustly advocates the circular economy model as a foundation for sustainable business growth. However, the adoption rate by businesses remains tepid. Simultaneously, the Fourth Industrial Revolution underscores digitalization's potential for transformation. Many studies point to the role of digital tools in accelerating the circular economy. However, the nexus between digital technology and circular economy principles is a budding and rapidly evolving academic area. While ample research addresses digitalization and the circular economy independently, holistic studies merging the two are limited. This article aims to dissect the current trajectory and future directions of research that integrates both domains, offering deep insights for subsequent scholarly explorations. We employed a bibliometric approach, extracting literature chiefly from the

Анотація

Європейський Союз рішуче підтримує модель циркулярної економіки як основу для сталого зростання бізнесу. Однак рівень впровадження бізнесом залишається низьким. Водночас Четверта промислова революція підкреслює потенціал цифровізації для трансформації. Багато досліджень вказують на роль цифрових інструментів у прискоренні циркулярної економіки. Проте взаємозв'язок між цифровими технологіями та принципами циркулярної економіки є новою академічною сферою, яка швидко розвивається. У той час як велика кількість досліджень стосується цифровізації та циркулярної економіки окремо, цілісні дослідження, які об'єднують ці два аспекти, обмежені. Ця стаття має на меті розібрати поточну траєкторію та майбутні напрямки досліджень, які об'єднують обидві сфери, пропонуючи глибоке розуміння для

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Web of Science database and applying VOSviewer software for keyword association visualizations. Our analysis encompasses varied aspects, from publication trends to interdisciplinary intersections and practical implementations.

Keywords: innovations, technology integration, collaborative methodologies, digitalization, circular economy, economic paradigms, emerging information technology, strategic blueprints, progress, trends, advanced data analytics.

Introduction

The traditional economic paradigm is increasingly viewed as ill-equipped to craft a forward-thinking society. Overconsumption of vast natural resources has led to unforeseen and largely irreversible harm to both local ecosystems and the wider environment. Instead of elevating living standards, an expanding portion of the world's populace is fraught with uncertainties about the future. Given this context, the global discourse has pivoted towards sustainable development, perceived as the new road map to foster societal advancement. The circular economy is gaining traction as a potent strategy to embody the tenets of sustainable development, presenting an alternative to the conventional economic system by emphasizing resource renewal and prudent utilization (Murray et al., 2017).

The genesis of the phrase "circular economy" remains a topic of discussion. The circular economy is a production model that emphasizes the reuse of materials and the efficient consumption of natural resources (Greyson, 2007; Boulding, 1996). Thanks to this approach, a cyclical production process is achieved, maximizing the use of materials, and extending the product lifecycle (Liu et al., 2009; Yuan & Moriguchi, 2008). While the term "circular economy" is subject to varying interpretations, it's commonly perceived as a broad concept depicting a cyclical, self-sustaining system (Murray et al., 2017; Pearce & Turner, 1990).

In the modern era, the idea of a circular economy garners support from a lot of countries such as the European Union (EU), the United States of America (USA), the United Kingdom (UK), Asia countries, and numerous global businesses. The shared belief is that mutual efficacy is instrumental in guiding sustainable growth for enterprises (Hammer & Pivo, 2017). Such progression is attainable through integrating

наступних наукових досліджень. Ми застосували бібліометричний підхід, витягуючи літературу переважно з бази даних Web of Science і застосовуючи програмне забезпечення VOSviewer для візуалізації асоціацій ключових слів. Наш аналіз охоплює різноманітні аспекти, від тенденцій публікацій до міждисциплінарних перетинів і практичних реалізацій.

Ключові слова: інновації, технологічна інтеграція, спільні методології, цифровізація, циркулярна економіка, економічні парадигми, нові інформаційні технології, стратегічні плани, прогрес, тенденції, передова аналітика даних.

innovative business approaches and cultivating a sense of ecological responsibility.

Embracing the tenets of the circular economy comes with its set of hurdles. One prominent issue is the shifting of operational risks squarely onto the companies (Neely, 2008). When products are retained by businesses instead of consumers, there's a surge in upkeep expenses which may deter some customers (Rizos et al., 2016). Additionally, products designed for longevity in the circular economy, having elongated update cycles, may not align with fast-evolving technologies, potentially stalling advancements. As noted by Nobre (2017), the cyclic or closed-loop approach is gradually reshaping the dominant linear economic mindset. The traditional linear approach follows a pattern of produce, use, and discard. However, the circular framework upholds the 3-R ethos: 1) minimizing resource usage with a focus on renewables; 2) repurposing items to ensure optimal use; and 3) recycling, channelling waste, and residuals back into the economic stream (Millar et al., 2018).

The rapid strides in digital technology are widely acknowledged for their game-changing potential, often being hailed as the bedrock of the fourth industrial revolution (Bressanelli et al., 2018). Concurrently, the affordability and ubiquity of digital information and communication technologies (ICTs) have popularized the use of mobile computers, communication gadgets, global positioning systems, and the Internet. Notably, the Internet stands out as the linchpin of digitalization (Sturgeon, 2021). The foundational technologies and platforms propelling digitalization offer immense opportunities to boost productivity and enhance the global

interconnectivity of consumers, workers, companies, and related sectors. Furthermore, they present robust instruments to foster innovation even in the most remote areas (Sturgeon, 2021). Thus, digital evolution is characterized by a fusion of advanced ICTs, digitalized knowledge, and web-based data, casting its influence over a vast spectrum of industrial and societal facets within the global landscape.

Furthermore, digital technology plays a pivotal role in bolstering the incorporation of the circular economy in enterprises (Bocken et al., 2016). Consider the Internet of Things (IoT) as an example. It equips businesses with the capability to remotely monitor live data related to their products' usage, condition, and location (Baines & Lightfoot, 2014), track materials throughout their life cycle using IoT tools, and facilitate the refurbishment of outmoded items. These innovations set the stage for a transition to a circular economy (Lewandowski, 2016).

In the realm of digital transformation, integrating process analysis with thorough data evaluation results in significant improvements in the management of storage, sales, and the performance of economic actions across varied sectors, technologies, machinery, products, and services (Liu et al., 2021). However, it's crucial to recognize that the intersection of the circular economy and digital technology is a nascent and rapidly evolving research area. While abundant studies focus on the circular economy and digital economy separately, there's a noticeable gap in research that interlinks these domains. Consequently, the purpose of this paper is to delve into the progress and trends in the confluence of the circular and digital economies, providing a foundation for future investigative pursuits in this specialized domain.

The objective of this research is to offer a detailed overview of scholarly works pertaining to Circular Economy (CE). Utilizing the Web of Science database, the researcher meticulously selected relevant publications, discarding those unrelated to the subject. The process involved sorting, organizing, and graphically displaying the information, culminating in a clear and structured narrative. The study poses several research questions, including:

1. What are the publication trends in CE over the past ten years?
2. What is the nature of author collaboration in CE research during this period?

3. What are the trends in CE titles over these ten years?

Literature review

Naudé (2011) expressed skepticism about the practicality of implementing Circular Economy (CE), considering it a challenging and unattained goal. The corporate sector often struggles with this implementation, facing hurdles such as:

- Physical resources like data, technology, and fundamental materials;
- Non-physical elements including a culture geared towards data, circular innovation, transparency, and collaborative creation;
- Skillsets related to systems thinking and data analytics (Kristoffersen et al., 2021; Aksoy & Hacioglu, 2021).

Despite these challenges, industry professionals persist in their efforts to incrementally apply CE principles. Kirchherr et al. (2017) identified CE as an amalgamation of reducing, reusing, and recycling practices. Potting et al. (2017) categorized the transition from a linear to a circular economy using a scale from R0 (refuse) to R9 (recover).

Carvalho et al. (2020) and Hislop & Hill (2011) highlighted CE's role in enhancing circularity, reducing energy and resource usage, and supporting sustainable resource management. Kirchherr et al. (2017) further noted that CE aims for long-term economic growth, environmental conservation, and social equity, benefiting future generations. CE encourages sustainable lifestyles and should influence strategies and policies grounded in sustainability (Unal et al., 2018). Akkalatham et al. (2021) discovered a link between recycling willingness, lean manufacturing, and CE efficacy. Environmentally responsible practices enhance productivity and necessitate continuous innovation, including efficient use of tools like pre-shredders and power plants, to conserve mineral resources.

Ghisellini et al. (2016) posited that successful CE implementation would significantly boost sustainable business and societal outcomes. This involves resource optimization during production, distribution, and consumption (Kirchherr et al., 2017). Kristoffersen et al. (2021) suggested that managers need to strategically manage industrial life cycles, focusing on innovation, reduction, and resource recirculation. Li & Yu (2018), among others, argued that eco-friendly behaviors within organizations can positively affect sustainability across economic, environmental, and social dimensions.

Materials and methods

In our research, we utilize a bibliometric analysis method. This involves extracting relevant articles from the Web of Science (WoS) database and then importing them into VOSviewer, a tool tailored for bibliometric evaluation and keyword depiction. Bibliometric charts act as a quantitative instrument, enabling the visualization of bibliometric characteristics across various scientific papers through different network structures. This graphical representation offers insights into the structure and evolution of multiple research fields (Suryantini et al., 2021). For this investigation, we source data from the WoS core collection, centering our research on the phrases "circular economy" and "digitalization". We employ the VOSviewer software, a freely available tool introduced in 2009 by Van Eck & Waltman (2010) at Leiden

University's Centre for Science and Technology Studies (CSTS) in the Netherlands, to perform a keyword co-occurrence assessment of the selected literature. This approach, focusing on keyword overlap, has been applied in diverse areas from healthcare (Yeung et al., 2021) to elderly community engagement and crisis response (Fu et al., 2020). Keywords act as prisms, honing in on central themes and topics within a field's body of literature. They can highlight dominant research areas and unfolding patterns (Huang et al., 2020). As such, we use VOSviewer in our research to conduct a keyword co-occurrence evaluation, aiming to explore the relationship between the circular economy and digitalization.

The methodology applied in this research is laid out systematically, as delineated in Table 1.

Table 1.
The structure of the research methodology.

Stages of research	Content
Data sorting from WoS using search subject "circular economy" and "digitalization"	Categorising 1855 relevant scientific articles from 2015 to the first quarter of 2023 including key words, author, year, research methods, content.
Analysing the publication of circular economy and digitalization sphere	To examine the trends in published articles focused on the circular economy and digitalization over different years, a bar chart analysis was conducted.
VOSviewer analysis on "circular economy" and "digitalization"	VOSviewer was employed to conduct a comprehensive analysis of keyword co-occurrence using articles sourced from the Web of Science (WoS). This analysis aimed to reveal the status and future directions within the field. The first aspect of the analysis involved keyword analysis, where the frequency and relationships of keywords were examined. Additionally, overlay visualization analysis was performed to identify the connections and overlaps between different sets of keywords.
Multidisciplinary research	To further analyse the status and future directions of the subject areas related to the research, a classification and selection process was conducted using keyword co-occurrence analysis in VOSviewer.

The research approach is articulated through four clear stages:

1. Identifying the core research focus and gathering articles related to the circular economy and digitalization. This involves organizing and systematically compiling all relevant information.
2. Utilizing bar graphs and pie charts to document and showcase the sources of publications that touch on the circular economy and digitalization, providing a comprehensive perspective on the origins of these works.
3. Undertaking keyword co-occurrence analysis using VOSviewer. This involves crafting visual mappings of keyword links, highlighting the most prevalent keywords, creating visualization overlays, and identifying emerging research terms.

4. Pursuing interdisciplinary explorations by investigating various thematic areas within the WoS database. This entails selecting specific thematic sectors and executing keyword co-occurrence analyses specific to each selected area.

These stages form the foundational structure of our research approach, equipping us with the means to deeply analyze and grasp the nexus between the circular economy and digitalization.

Results and discussions

The information used in this research was derived from the Web of Science (WoS) core collection. By centering the search on "circular economy" and "digitalization", we obtained a total of 1855 articles spanning from 2015 to the first quarter of 2023. Figure 1 visually represents the upward trend in the

Within the identified clusters, chief keywords central to discussions about the circular economy and digitalization include terms like circular economy, digitalization, industry, waste management, artificial intelligence, and technology. These keywords encapsulate the primary themes emerging from the keyword co-occurrence assessment using VOSviewer.

Table 2 provides a breakdown of the most frequently referenced keywords from the analysis. These terms make at least ten appearances and come with attributes such as their colour designation, related cluster, frequency of mention, and overall link strength. This table serves as a snapshot of the core terms intertwined in the cross-disciplinary exploration of the circular economy

and digitalization, emphasizing their significance and consistent reference in scholarly literature.

By deploying the overlay visualization technique, we can extract pivotal insights about the primary research themes over different periods, paving the way for understanding potential future research directions. Figure 3 presents a visual depiction of keywords from all the literature examined in this study, covering from 2015 to the early part of 2023. The array of colours in the graphic denotes the chronological order, initiating with shades of purple and green, ultimately reaching yellow. This colour transition reflects the journey from the initial stages of research to the most up-to-date findings.

Table 2. High-frequency keywords “circular economy” and “digitalization” from year 2015 to the first quarter of 2023 via network visualisation of VOSviewer.

Colour	Cluster	Keyword	Occurrence	Total Link Strength
Red	1	Digitalisation	6	26
Green	2	Circular economy	41	110
Blue	3	Industry	11	54
Yellow	4	Waste management	11	49
Purple	5	Artificial intelligence	5	31
Brown	6	Technology	11	44

By examining the overlay visualization, researchers can gain a comprehensive understanding of the temporal distribution and development of research topics within the field

of interest. This visualization aids in identifying emerging trends, shifting focuses, and potential areas for further exploration in future research endeavours.

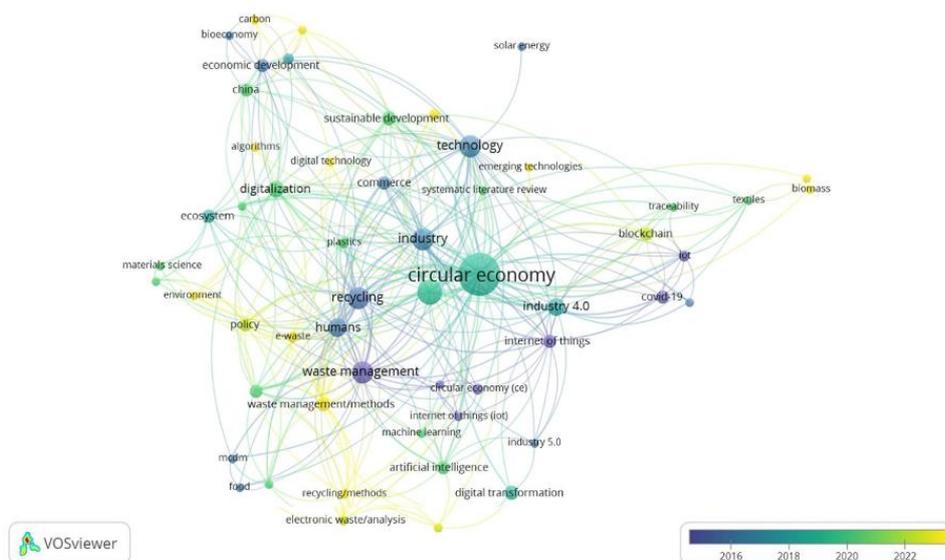


Figure 3. High-frequency keywords “circular economy” and “digitalization” from year 2015 to the first quarter of 2023 via network visualization of VOSviewer.

The following are the summarized hot research keywords within the field of circular economy from the years 2015 to the first quarter of 2023:

1. **Business-related keywords:** This scheme encompasses keywords such as business models, servitization, value co-creation, and consumer behaviour. These keywords highlight the growing interest in developing innovative business models that promote circular economy principles, emphasize value creation, and involve active participation from consumers.
2. **Keywords centered on technology:** This category encompasses terms such as digital technologies, internet of things (IoT), and smart producing. These keywords indicate the significance of technological advancements in driving circular economy initiatives, particularly in areas such as digitalization, automation, and efficient resource management.
3. **Sustainability-related keywords:** Keywords within this scheme revolve around sustainability strategies, supply chain management, and sustainable business practices. These keywords underscore the importance of incorporating sustainable practices into circular economy frameworks, ensuring responsible resource management and minimizing environmental impact.
4. **Circular waste management keywords:** This scheme comprises keywords like waste management, recycling, and waste-to-energy. It highlights the growing emphasis on effective waste management practices, including recycling and the conversion of waste materials into valuable resources, as crucial components of circular economy strategies.
5. **Emerging technology keywords:** This scheme includes keywords such as AI and blockchain, indicating the rising interest in leveraging advanced technologies to enhance circular economy practices. AI and blockchain have the potential to optimize resource utilization, trace product lifecycles, and enable transparent and efficient supply chains.

In the current research hotspots of the first quarter of 2023, the keywords “big data” and “supply chain management” have emerged with higher frequency, suggesting their prominent presence and potential strong connections within the research field. This indicates that these topics have attracted significant attention and have been extensively studied. Additionally, keywords such as “barriers”, “impact”, and “performance” are

also frequently mentioned, further emphasizing their relevance and significance within the current research landscape.

On the other hand, certain keywords like “artificial intelligence”, “demolition waste”, “consumer behaviour”, “life cycle assessment”, “climate change”, and “BIM” appear less frequently, suggesting that they may have untapped research potential. These topics hold promise for future research endeavours as they offer opportunities for new insights and advancements in the field of circular economy and digitalization.

The topic of circular economy and digitalization is characterized by its multidisciplinary nature, encompassing various subject areas. The main fields that contribute to this topic are digital technology and environmental science.

The integration of these disciplines is crucial for advancing circular economy practices and achieving sustainable implementation strategies. By integrating knowledge from both digital technology and environmental studies, scholars can craft pioneering business strategies, devise impactful policies, and accelerate the shift towards a circular economy.

It enables the exploration of synergies between technological advancements and environmental considerations, fostering a holistic approach towards sustainable development. By bringing together expertise from different disciplines, researchers can develop comprehensive solutions that promote circularity, resource efficiency, and choosing effective business model and economic system.

Conclusions

The aim of this study is to revolve around probing the contemporary research milestones and trajectories in the nexus of the circular economy and digitalization. As a part of our approach, relevant articles were retrieved from the core compilation of the WoS database and subsequently underwent VOSviewer analysis for keyword visualization. This assessment aimed to discern the intertwined relationship between the circular economy and digitalization. From this inquiry, three salient revelations emerged:

1. The leveraging of the VOSviewer bibliometric method enabled a comprehensive keyword co-occurrence investigation, shedding light on co-occurrence clusters, primary research

themes, and keyword evolution trends linked to "circular economy" and "digitalization."

2. An encompassing scrutiny of articles across diverse academic fields and publications highlighted the interdisciplinary nature of this research topic.
3. The identification of existing research gaps and burgeoning trends, offering a roadmap for future scholarly pursuits, stands to benefit a wide audience, ranging from the general populace and policy shapers to academic researchers.

Moreover, the intertwined network of terms closely associated with the circular economy and digitalization includes keywords such as sustainability, Industry 4.0, design, management, and framework. These terms illuminate potential avenues for future research. Key research terms identified through overlay visualization from 2015 to the first quarter of 2023 can be distilled into five main themes: collaborative methodologies, economic paradigms, emerging information technology, strategic blueprints, and advanced data analytics. These themes provide a roadmap for upcoming scholarly pursuits.

A limitation of this study is its singular focus on the WoS database. There's a likelihood that other significant publications may be indexed in other databases like Scopus or Google Scholar. To achieve a more encompassing view, subsequent investigations should consider sourcing from multiple databases and juxtaposing the outcomes with the present study. However, amalgamating, and visualizing data from diverse databases using VOSviewer could pose challenges, warranting careful consideration in future research efforts.

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