THE ROLE OF DIGITALIZATION AND WAYS TO ACCELERATE THE IMPLEMENTATION OF THE CIRCULAR ECONOMY

Senior Researcher, PhD, Gabriela-Cornelia PICIU
Centre for Financial and Monetary Research "Victor Slăvescu", Romania
E-mail: gabriela_piciu@yahoo.com

Abstract: *The study analyzes the impact of implementing digitalization in the circular economy, its ability to integrate and capitalize on digital technologies, and through these tools the circular model is refined and innovated. The fact that the circular economy brings so many benefits: reducing the consumption of natural resources by regenerating and reusing materials, reducing pollution by reducing waste, and extending product use cycles. The integration of emerging digital technologies into the circular economy can improve the efficiency and sustainability of the circular model. By using advanced technologies, such as the Internet of Things (IoT), big data, artificial intelligence, and blockchain, the state of materials and products can be tracked in real time, which allows it to reduce pollution risks and improve recycling and reuse processes. Digitalization also facilitates collaboration between different entities of the economic ecosystem, thus promoting an exchange of information essential for the implementation of a circular model. The study examines digital transformation within the circular economy, which can significantly reduce costs, improve operational efficiency and support innovations that contribute to the development of greener and more economical solutions. Thus, we can say that the integration of these two areas ,the circular economy and digitalization, is essential to support the transition to a more sustainable and resource-efficient future.*

Keywords: *digitalization, circular economy, inclusive economic growth,* digital technologies, benefits
JEL Classification: *O32,O33.*

1. Introduction

The circular economy (CE) is an economic model that aims to optimize resource consumption, reduce waste and promote a continuous cycle of reuse, repair, reuse and recycling of products and materials (Kirchherr et al., 2017). The circular economy is a regenerative economy, its operation is based on keeping materials in use for as long as possible, thus increasing the lifespan of products and on the other hand reducing waste and pollution (Ellen MacArthur Foundation, 2013). The circular economy has ten 10 R principles also called strategies, which include: reject, rethink, reduce, repair, remanufacture, reuse, reorient, recycle and end-of-life recovery, which are seen as operationalization principles of CE (Reike et al., 2018).

Currently, digital technologies are seen as accelerators of the circular economy, becoming essential factors in social development. These technologies, through the combination of cyber systems, Big Data, artificial intelligence (AI), blockchain and the Internet of Things (IoT) can support circular models in multiple ways: from the use of a large number of data that lead to knowledge of the natural and economic environment, to improving the use of materials and materials used, logistics and the manufacture of smart products, to the sharing of services or, through rental, of products.

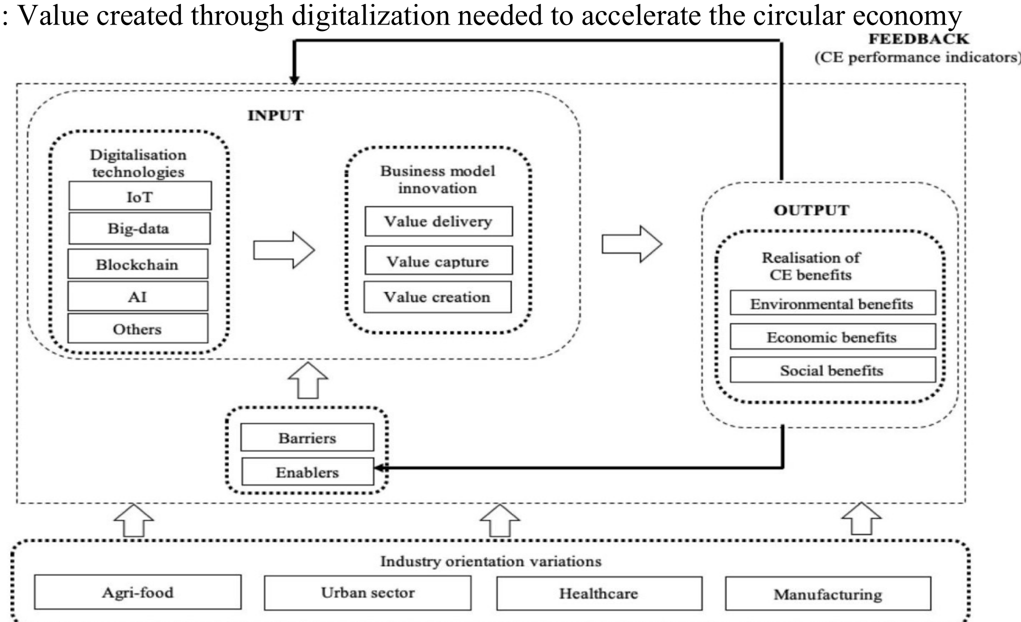
The collective and responsible use of circular models facilitated by digital technologies can support environmental protection by optimizing resource use and reducing waste (Radu, 2023).

Implementing circular models facilitated by digital technologies can contribute to achieving the United Nations Sustainable Development Goal No. 8, which aims to promote inclusive and sustainable economic growth, full and productive employment and decent work for all. The use of digital technologies also promotes social inclusion by creating economic opportunities for diverse groups, including through the development of digital skills and access to new forms of work.

Literature review

In the literature, studies on the connection between digital technologies and EC (Chauhan et al., 2019), (Bag et al., 2021) and (Ma et al., 2020), highlight its benefits, due to the possibility of using a very large number of data, at a fast pace and safely (Kristoffersen et al., 2020). Mobile applications dedicated to collaborative consumption, such as Vinted and Too Good To Go, contribute to promoting sustainability, supporting EC strategies by maintaining resources in a closed system (Del Mar Alonso-Almeida et al., 2020). Thus, the integration of advanced digital technologies into organizational processes can also create a competitive advantage (Ellen MacArthur Foundation, 2012), and innovations in business models and circular economies can create not only economic value, but also social and environmental value, by creating, providing and capturing value, significantly contributing to the sustainable development of the company and society (Boons et al., 2013), (Mentink B. 2014) (Figure 1).

Figure 1: Value created through digitalization needed to accelerate the circular economy



Sursa: Chetna et all, 2022)

Thus, we can say that these digital technologies can transform theoretical CE principles into feasible and practical activities (Antikainen et al., 2018; Garcia-Muina et al., 2018a; Kintscher et al., 2020). The application of these technologies can complement the skills and capabilities of those working with circular models and facilitate circularity-based decision-making (Mboli et al., 2020). To support the transition to a more efficient and sustainable circular economy model, it is necessary to focus on reducing carbon emissions and using resources in a responsible way. This not only contributes to a cleaner environment, but also promotes a fairer and more resilient economy.

2. The link between circular economy strategies and digital technologies

Circular economy actions facilitate more efficient use of raw materials and materials used in production, including the following types of C.E. strategies: rejection, rethinking and reduction, and refer to Rejection of redundant product by abandoning its function or offering the same function with a different product, More intensive use of products (for example, by sharing products or by marketing multifunctional products), Increasing efficiency in the manufacture or use of products by reducing consumption of natural and material resources.

Another CE action includes the strategies of reuse, repair, remanufacture, re-use, including the reuse by another consumer of an end-of-life product that is still in good condition and fulfills its original function, the repair and maintenance of the defective product so that it can be used with its original function, the restoration of an old product and its updating, the use of parts of a defective product in a new product with the same function, the use of an end-of-life product or its component parts and their use in a new product with a different function (Table 1).

Table 1: Circular economy strategies

Categories of circular activities	Circular economy strategies	Name of the circular economy strategy	Circular economy activities
Category 1: Efficient use of raw materials and materials used in production	R1	Refuse	Rejection refers to making a product redundant by giving up the function it provides
	R2	Rethink	Repurposing refers to increasing the use of a product, for example, by sharing the product
Category 2: Extending the life of the product and its components	R3	Reduce	Reduction refers to increasing the efficiency in the production or use of the product, consuming fewer natural resources
	R4	Reuse	Reuse by another consumer of a discarded product that is still in good condition and fulfills its original function
	R5	Repair	Repairing and maintaining a defective product so that it can be used with its original function
	R6	Refurbishment	Refurbishing an old product and upgrading it
	R7	Remanufacturing	Using parts of a defective product in a new product with the same function

	R8	Reuse	Using a discontinued product or its component parts and using them in a new product with a different function
Categoria 3: Utilizarea optimă a materialelor considerate deșeuri	R9	Recycling	Processing of materials to obtain the same (high quality) or lower (low quality) quality.
	R10	Recovery	Incineration of material with energy recovery

Source: author's conception

As we have shown above, in practice, the implementation of the circular model is based on 10 strategies (10R), which can be classified according to different categories of circularity actions and objectives. On the vertical axis, there are different actions for a product or system, and on the horizontal axis are the different objectives of implementing the circular economy through its strategies (Figure 2).

Figure 2: Classification of R principles

Product-system	Resell/Reuse Repair Remanufacture	Refurbish Remanufacture	Repurpose Remanufacture
Component	Repair Remanufacture Reuse	Remanufacture	Repurpose
Raw materials	Recycle	Recycle	Recycle Recover
	Original function	Upgraded, original function	Different function

Source: post-processing (Potting et al., 2017)

Digital technologies such as Big Data, Artificial Intelligence (AI), Blockchain and the Internet of Things (IoT) can support the circular economy in several ways.

Big Data or data analytics can help track the flow of materials, identify consumption patterns and detect opportunities to recycle or reuse resources. This can contribute to creating more efficient and sustainable business models. Big data and CE Big data plays an important role in facilitating the acquisition of the desired information for decision-making. Thus, companies take an active role in creating new databases that include them and new ones. Previously overlooked data sets, such as weather conditions, changing economic conditions, are accessed by third-party providers and used to create company-specific decision-making models. Integrating big data and large-scale group decision-making can promote circularity by addressing various problems of the linear economy, as it integrates different aspects of CE through interactions with stakeholders. For example, Big Data facilitates the application of techniques such as cluster analysis and reduces the weight of the decision-making process.

Artificial Intelligence (AI) can optimize production and recycling processes, providing intelligent solutions for resource management and waste reduction. It can also facilitate the design of products that are easier to repair, reuse or recycle.

Blockchain technology can create a transparent and secure system for tracking materials and products throughout their entire life cycle. Blockchain can help verify the provenance of resources, ensure the integrity of supply chains and facilitate the exchange of recycled products.

Internet of Things (IoT): IoT can connect physical objects to the internet and monitor their conditions in real time. This can support waste management, energy efficiency and resource reuse by collecting and analyzing data on energy consumption, product maintenance conditions, etc.

Blockchain is an information storage and transmission technology that is based on the principle of distribution and security.

The impact of digital technologies on CBM elements can be found in (Table 2).

Table 2: Impact of digital technologies on CBM elements

Adoption of digital technologies	CBM – Value Creation
Adoption of IoT	Sustainable Products
Distributed manufacturing	Satisfying Green Customer Demand
Knowledge generation from Information technology and communication technology	Robust Products and Services
Digital technologies combined with each other	Slowing, Narrowing and Closing Resource Flows
Eco-design tools enabled digitalization	Sustainable and Efficient Products
Blockchain adoption	Improved Product Design
Fintech innovations	Preventive and Predictive Maintenance

Source: adapted from Chauhan, C., Parida, V., & Dhir, A. (2022)

Combined, these technologies can revolutionize circular economy processes, improving their efficiency, transparency and sustainability. Furthermore, they can support the development of new business models that promote innovation in resource management and reduce environmental impact.

3. Barriers to the adoption of digital technologies to accelerate the implementation of the Circular Economy (CE)

The digitalization of the European Union (EU) faces multiple challenges that hinder the uniform progress of the Member States. The barriers identified to date are: Organizational and technological barriers, Strategic and psychological barriers, Political and regulatory barriers, Cultural and educational barriers. There are various barriers to the implementation of the digitalization of the circular economy, the most significant of which are:

1. Organizational and technological barriers

Lack of structured data management processes and difficulties in developing IoT-compatible products. Among the main barriers identified is the lack of an efficient IT architecture in the public sector. It has been found that many public institutions do not have adequate IT systems to provide efficient electronic public services, which affects the quality and accessibility and performance of digital solutions, such as predictive models for waste management. There is also an insufficient number of qualified personnel in the field of information technologies in the public sector, which makes it difficult to develop and maintain digital services and very high costs associated with the adoption of technologies such as big data.

2. Strategic and psychological barriers

Technological and strategic barriers are considered the most important in terms of adopting a data-driven supply chain in the circular economy.

The lack of predictability that characterizes the impact that emerging technologies, especially those implemented in the circular economy, can create uncertainties for investors and organizations that want to implement digital solutions.

Also, changing the behavior of consumers and those involved in economic processes can be a challenge, especially in the context in which the adoption of new technologies sometimes requires a considerable effort on their part.

Information vulnerability is another barrier in a digitalized system. There are security and privacy risks, and protecting sensitive information is a particularly important aspect.

3. Political and regulatory barriers

Political and regulatory barriers refer to legislative changes and regulations can delay the adoption of innovative technologies. The lack of government impetus blocks the implementation of advanced digital applications, and the absence of a clear and stable legislative framework can be an obstacle to the implementation of new technologies. In addition, the existence of shortcomings in the collection of data related to material flows and other operational phases prevents decision-makers from creating effective policies. For example, Japan has difficulty differentiating between the traditional "3Rs" and modern CE, due to the lack of clarity in public policies. Regulatory complexity and excessive bureaucracy can also be barriers to the implementation of digital technologies in the EC. Complicated regulations and bureaucratic procedures can discourage investment in technology and slow down the digitalization process. To address these challenges, the European Commission launched the "Roadmap to the Digital Decade", setting clear objectives for 2030 in the areas of digital skills, infrastructure, enterprise digitization and online public services. This program aims to harmonize digital policies at EU and Member State level, reducing market fragmentation and stimulating investment in technology.

As for the European digital market, it is characterised by high barriers to entry and a low number of vertically integrated players, which limits competition and innovation.

4. Cultural and educational barriers

The lack of environmental education and the absence of a strong culture of resource conservation are major barriers to the adoption and implementation of circular economy (CE) principles. These shortcomings, together with low market pressure — whether from consumers or other economic actors — hinder progress towards the digital transition towards a sustainable economic model. These structural obstacles hold back the transformations needed to integrate digital technologies in support of circularity, underlining the need for a systemic approach that includes education, public awareness and policies to stimulate demand for sustainable solutions.

4. Results of implementing digitalisation in the CE

Circular models have a beneficial and important role in transforming technology, the economy and the environment. From the specialized literature, we can say that the impact of digitalization on CE is found in the way it enables and emphasizes the introduction of circular business models (CBM), as well as in the transformation into product service systems (PSS) (Table 3).

Table 3: Value capture due to the impact of digital technologies on CBM elements

CBM- Value Capture
Easy Tracking and Monitoring Reducing Costs
Reduced Transportation Reuse and Recycle Attract Additional Customers
Robust Decision Making in the Design Phase
Increased Efficiency Attract Target Customers
Increased Competitiveness
Increased Control over Products and Systems through End of Life
Decision Support Avoid Barriers to CBM Adoption Cost and Cash Flow Savings

Source: adapted from Chauhan, C., Parida, V., & Dhir, A. (2022)

Thus, according to scientific studies, the Internet of Things (IoT) and artificial intelligence (AI) are considered to be key factors in the implementation and acceleration of the circular economy. The article proposes a framework that integrates these emerging technologies and highlights the interconnections between research streams and proposed solutions for achieving a circular economy. This framework provides a unified vision on how digitalization can transform the circular economy, proposing new perspectives on the advantages and implementation of this model.

5. Conclusions

Digitalization plays a key role in driving inclusive economic growth by harnessing technological advances to bridge gaps in accessibility, participation and long-term value creation.

Digital technologies, such as IoT, enable real-time monitoring and management of products, facilitating the tracking of material flows and the optimization of recycling processes. For example, through connected sensors, IoT can help identify exactly when a product reaches the end of its life cycle, thus allowing it to be recycled or reused efficiently.

AI can improve decision-making in resource management and the optimization of waste streams, through data-driven predictions and recommendations. AI can also support the design of products that are easier to recycle, repair or reuse, creating a more sustainable cycle.

In this regard, the article not only highlights the barriers and challenges, but also provides a clear framework for the digitalization of the circular economy. This can become a guide for future research and practical implementations, bringing benefits not only in terms of sustainability, but also in economic efficiency and business model innovation. Going forward, it will be essential for research to address the political and social challenges related to digitalization and explore new ways to integrate emerging technologies within a circular framework.

References:

1. Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P., 2018. Digitalisation as an enabler of circular economy. *Procedia Cirp*, *73*, pp.45-49.
2. Bencsik, B., Palmié, M., Parida, V., Wincent, J., & Gassmann, O., 2023. Business models for digital sustainability: Framework, microfoundations of value capture, and empirical evidence from 130 smart city services. *Journal of Business Research*, 160, 113757.
3. Canesi, R., & Marella, G., 2022. Towards European Transitions: Indicators for the Development of Marginal Urban Regions. *Land*, *12*(1), 27.
4. Chauhan, C., Parida, V., & Dhir, A., 2022. Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises.
5. Chauhan, C., Parida, V., & Dhir, A., 2022. Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises. *Technological Forecasting and Social Change*, *177*, 121508.
6. Ellen MacArthur Foundation, 2012. Towards the Circular Economy: Economic and business rationale for an accelerated transition.
7. Ellen MacArthur Foundation, 2013. Towards the Circular Economy.
8. Ferrari, R., & Salazar, C., 2022. Digitalization, Sustainability, and Economic Inclusion: A Systematic Review of the Literature. *Sustainability*, 14(12), 7220.
9. Floridi, L., 2020. *The Ethics of Artificial Intelligence and Digital Technologies*. Oxford University Press.
10. Garcia-Muiña, F. E., González-Sánchez, R., Ferrari, A. M., & Settembre-Blundo, D., 2018. The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company. *Social Sciences*, *7*(12), 255.
11. Gervasi, O., Perri, D., Simonetti, M., & Tasso, S., 2022. Strategies for the digitalization of cultural heritage. In *International Conference on Computational Science and Its Applications* (pp. 486-502). Cham: Springer International Publishing.
12. Goggin, G., 2021. Disability, Internet, and digital inequality: The research agenda. In *Handbook of digital inequality* (pp. 255-273). Edward Elgar Publishing.

13. Kintscher, L., Lawrenz, S., Poschmann, H., & Sharma, P., 2020. Recycling 4.0-Digitalization as a Key for the Advanced Circular Economy. *J. Commun.*, *15*(9), pp.652-660.
14. Kruk, S.R., Kloppenburg, S., Toonen, H.M., & Bush, S.R., 2021. Digitalizing environmental governance for smallholder participation in food systems. *Earth system governance*, 10, 100125.
15. Kruk, S.R., Toonen, H.M., & Bush, S.R., 2024. Digital sustainability assurance governing global value chains: The case of aquaculture. *Regulation & Governance*, *18*(4), pp.1153-1170.
16. Lutz, C., 2019. Digital inequalities in the age of artificial intelligence and big data. *Human Behavior and Emerging Technologies*, *1*(2), pp.141-148.
17. Mboli, J.S., Thakker, D., & Mishra, J.L., 2022. An Internet of Things-enabled decision support system for circular economy business model. *Software: Practice and Experience*, *52*(3), pp.772-787.
18. McBride, C.M., Morrissey, E.C., & Molloy, G.J., 2020. Patients' experiences of using smartphone apps to support self-management and improve medication adherence in hypertension: qualitative study. *JMIR mHealth and uHealth*, *8*(10), 17470.
19. OECD, 2023. *Digital Transformation and Economic Inclusion: Policy Considerations*. OECD Publishing.
20. Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A., 2017. Circular economy: measuring innovation in the product chain. *Planbureau voor de Leefomgeving*, (2544).
21. Reike, D., Vermeulen, W.J., & Witjes, S., 2018. The circular economy: new or refurbished as CE 3.0?—exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. *Resources, conservation and recycling*, *135*, pp.246-264.
22. Zhang, D., Pee, L.G., Pan, S.L., & Cui, L., 2022. Big data analytics, resource orchestration, and digital sustainability: A case study of smart city development. *Government information quarterly*, *39*(1), 101626.