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ARTIFICIAL INTELLIGENCE, BIG DATA AND IOT IN CIRCULAR ECONOMY: RESEARCH TRENDS AND PERSPECTIVES

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Abstract. *The transition to a sustainable and regenerative model of the economy the circular economy advocates relies on digitization and innovation that should help and support long-term sustainability. AI is a key technology that can support a smooth transition to a circular economy. At the same time, the Internet of Things is the main driver of process integration with other technologies, while Big Data plays an important role in the process of effective decision-making. Therefore, it is not surprising that research on the contemporary technologies in the circular economy attracts enormous attention of both the academic and professional community and that the number of publications in this field is increasing rapidly. In this paper, VOSviewer is used to discover research trends and provide a comprehensive and integrated approach to research on the role of artificial intelligence, big data and IoT as drivers of the circular economy.*

Key words: *Circular economy, Artificial intelligence, Big data, Internet of things, IoT, AI.*

JEL Classification: C890, O31, O33

1. INTRODUCTION

The circular economy is a new concept that aims to enable the transition from a linear economy in which products and resources are thrown away after use to a regenerative model that enables their reuse through regular product and raw materials servicing and maintenance. This extends the lifetime of products and raw materials, and their recycling ultimately reduces waste. Hence, the circular economy relies on three principles: reduce-reuse-recycle (3R) and, as such, contributes to the achievement of the sustainable development

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goals set by the UN. The rational use of resources and waste reduction show not only economic and social implications of the new model, but also emphasize responsibility towards the environment and limited natural resources.

Given that modern business environment has connected sustainability of organizations with digital innovations, it is not surprising that more and more organizations, as well as professional and academic community are interested in considering the role of digital innovations in the transition to a circular economy. In this context, digital innovations ensure the maximum use of limited resources using digital platforms, smart devices and artificial intelligence. Noman et al. (2022) highlight the contribution of AI to the transition to a circular economy, underlining numerous areas of its application: production, waste management, reverse logistics, supply chain management and customer relationship management. In this context, AI facilitates product design with a longer lifespan, timely indicates possible machine breakdowns or the need to switch to renewable sources, while preventing overproduction by predicting product demand.Moreover, in communication with customers, it helps them choose products that support the principles of the circular economy. Particular focus is on the importance of applying AI in assessing the environmental impact of products throughout their entire life cycle.

On the other hand, Big data plays an important role in the process of effective decision-making. According to Chauhan et al. (2022), big data integration can promote circularity by solving various problems of the linear economy by integrating various aspects of the circular economy through physical, cyber and stakeholder interactions. The Internet of Things as the main driver of process integration with other technologies supports circularity by enabling data-driven optimization solutions. Also, the IoT CE approach enables longer product use, while the IoT architecture allows the integration of smart objects into the business ecosystem (Chauhan et al., 2022).

Science mapping aims to reveal the structure and dynamics of scientific fields. The qualitative and quantitative analysis of the available data reveals the structure of the scientific field and the dynamics of research trends. In order to gain a broader insight into the use of artificial intelligence, big data technology and the Internet of Things in the circular economy, this paper analyzes study literature available in the SCOPUS database. VOSviewer and biblioshiny studio R library (Aria and Cuccurullo, 2017), the leading publicly available knowledge mapping and text mining tools, are used to analyze the application of the mentioned technologies in the circular economy.

The paper is organized in the following way: the first part of the paper presents the basics of the used science mapping methodology. The second part focuses on the use of modern information technologies in the context of the circular economy and includes three subsections. The first one analyzes the development continuum of the field; the second one gives the contextual analysis, while the third section analyzes research trends and perspectives. The concluding part of the paper reviews the presented research and points to directions for future research.

2. Research Methodology

This part of the paper presents the basic concepts of the scientometrics approach, which is used in this paper as an analytical method. More details about the approach used can be found in Van Eck and Waltman (2010), Leydesdorff and Milojević, (2012), McAllister et al. (2022) and Haghani (2023).

In the first step of the scientometrics analysis, a static image of the analyzed area at a given moment is obtained. In this step, the number of publications per year is used as a basis for the analysis of research trends in a specific research area. Aggregated data shows the growth of research activities over a time period and gives insight into expectations for the future (Zupic & Čater, 2015).

In the next step, the aggregated data gives us an overview of trends in the observed area. VOSviewer uses text mining to recognize published terms, and then uses a mapping technique called Visualization of Similarity (VoS), which is based on co-word analysis, to create science landscapes. Specifically, this paper observes two different aspects of the analysis, the time frame to analyze the evolution of research topics, and cluster to identify research categories and topics.

Co-word analysis is a content analysis technique that uses words in documents to establish relationships and build the conceptual structure of a domain (Chen and Song, 2019). The basic idea behind this concept is that there are underlying close-related concepts behind words that often appear together in a document. Unlike other sciencometric methods that indirectly link documents through citations and co-authorships, co-words analysis is the only sciencometric method that uses document content to construct a similarity measure. Co-words analysis gives a semantic map of topics and their relationships, which represent the concept of the scientific field and serve to understand its cognitive structure. A series of semantic maps help monitor the conceptual development of the field or changes in research trends. Co-word analysis can be applied to different parts of a document, to titles, keywords or to the entire text (Zupic and Čater (2015)).

According to Kokol et al. (2018), authors' keywords most succinctly represent the content that authors would like to communicate to the research community. Based on that, in this paper content analysis relies on cluster analysis of authors' keywords. In this type of content analysis using VOSviewer, author-defined keywords that are closely related to each other are located within one cluster and are marked with the same color, the color of the cluster. Within the thematic analysis, the terms/labels that appear within the cluster are used as codes to define and name the topics for each cluster, and then as keywords in the process of determining the appropriate corpus publication that serves to more closely define the topic (Kokol et al. (2022)).

In order to create an adequate corpus of publications, according to practices presented in Cagno et al. (2021), Nobre et al. (2017) and Završnik et al. (2024), we created the following search query: TITLE-ABS-KEY(("BIG DATA" OR "bigdata" OR iot OR "Internet of Things" OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "intelligent system" OR "support vector machine" OR ("decision tree" AND (induction OR heuristic)) OR "random forest" OR "Markov decision process" OR "hidden Markov model" OR "fuzzy logic" OR "k-nearest neighbour" OR "naive Bayes" OR "Bayesian learning" OR "artificial neural network" OR "convolutional neural network" OR "recurrent neural network" OR "generative adversarial network" OR "deep belief network" OR "perceptron" OR "natural language processing" OR "natural language understanding" OR "general language model") AND ("circular economy" OR "circular econom*")) AND (LIMIT-TO (LANGUAGE, "English")) AND (EXCLUDE (DOCTYPE ,"tb") OR EXCLUDE (DOCTYPE ,"er") OR EXCLUDE (DOCTYPE ,"no") OR EXCLUDE (DOCTYPE, "dp") OR EXCLUDE(DOCTYPE, "bk")) AND (LIMIT-TO(SUBJAREA, "ENGI") OR LIMIT-TO(SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO(SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-

TO(SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA, "AGRI") OR LIMIT-TO(SUBJAREA,"MULT")). The search was performed in the Scopus database on the 12 July 2024.

3. Results and Discussion

This part of the paper gives the results of the analysis of the corpus of available publications based on the previously defined instructions. The initial search of the SCOPUS index database produced 1097 documents that meet the search criteria. The documents were published in a total of 506 sources, while the number of authors is 3424. The available corpus includes 99 book chapters, 265 conference papers, 64 conference reviews, 8 editorials, 114 reviews and 2 short surveys.

First, the analysis of the volume and dynamics of research publications shows that the first papers on the use of contemporary technologies in the circular economy were published in 2009. The observed dynamics is shown in Figure 1, created using the biblioshiny() studio R. Data show that the field of using artificial intelligence, Big data and IoT in the circular economy is relatively new and that the incubation period in publishing that, according to Noman (2022), is reflected in the small number of publications per year, where the number of publications is less than 4, with variations in 2011 (7), 2014 (9), lasts until the beginning of 2016. After that, the period of scientific creativity initialization begins, marked by the number of 20 to 44 publications per year and a linear increase in the number of publications. The initialization period ends in 2019. The year 2021 records a significant increase in interest and number of publications, when the annual volume of publications ranges from 60 to 180. As of 2022, a further sharp jump in the number of publications can be observed, with the highest number of publications in 2023. Based on the period when this research was carried out, mid-July 2024, and the number of publications already published, it can be expected that the number of publications in 2024 will exceed the previous numbers. The average annual growth of the number of publications in the observed time range from 2009 to July 2024 is 33.35%. Given the evident cumulative increase in the number of publications in previous years, it is clear that researchers around the world are interested in this scientific field.

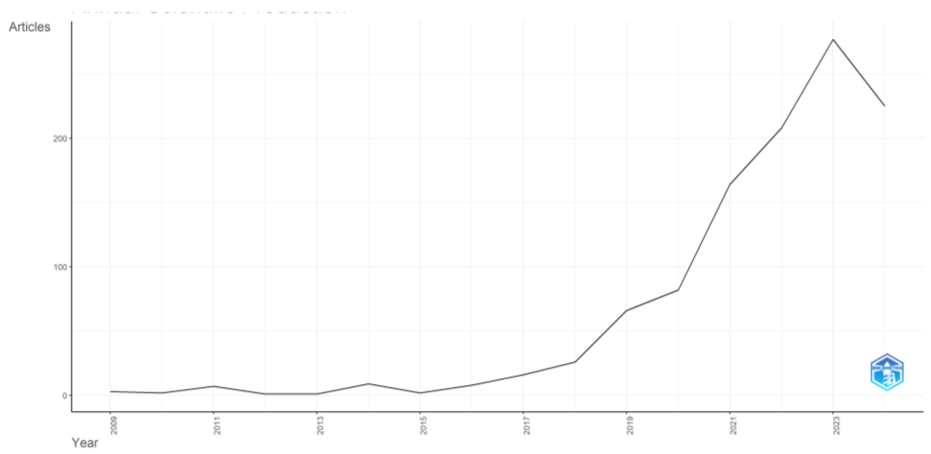

Fig. 1 Presentation of the dynamics of AI, Big data and IoT publications in CE

3.1. Trend analysis

The analysis in Figure 2 shows three time periods in the development of the area, the period before 2021, the period between 2021 and 2023, and the period after 2023.

In the first period before 2021, research focused on big data-based applications used to support decision-making systems. In this period, the Internet of things gets its place in the circular economy model. Sustainable manufacturing, recycling, supply chain management, innovations in the circular economy in general stand out as significant areas of application.

In the period between 2021 and 2022, applications include Blockchain technology and artificial neural networks for the classification of urban waste and support in accepting the green deal initiative and the transition to Industry 4.0 and smart cities. This period was marked by the increased application of digitization and digital technologies in the field of achieving sustainable development goals.

The period after the first quarter of 2022 focuses on the application of machine learning, deep learning and artificial intelligence and the emphasis shifts to classification issues. Areas of interest are optimization, energy efficiency and Industry 5.0. This period is also marked by computer-vision systems in the circular economy. The previous analysis confirmed the phased but full application of digital innovations in all areas of the circular economy, contributing to sustainable development and environmental protection.

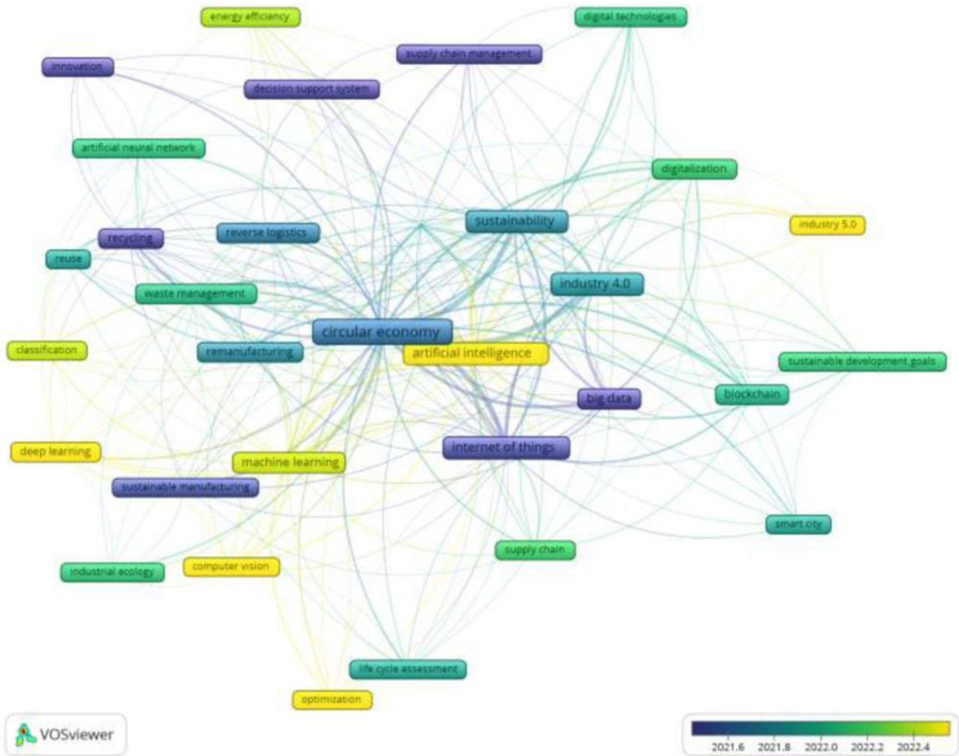

Fig. 2 The timeline of research literature production

3.2. Content analysis

The total number of authors' keywords in all publications is 2855. In this paper, the minimum number of occurrences of keywords is set to 10. This means that only keywords that appear in pairs in 10 or more publications are shown on the keyword map. The total number of keywords that meet the set criteria is 35. In the next step, although they meet the set criteria, the words systematic literature review, bibliometric analysis and literature review are excluded from further analysis in order to keep the focus of the analysis on the application of modern ICT technologies in business. Nevertheless, it is important to point out that such an incidence of keywords occurrence speaks in favor of the relevance of bibliometric and review approaches in knowledge systematization in the field of circular economy.Moreover, this also confirms the topicality of the research presented in this paper. After the selections made in further steps, a total of 32 keywords are selected for further analysis. It is important to note that when performing co-word analysis, it is necessary to eliminate different representations and contexts of the same form. For that reason, thesaurus files are used and adapted in this paper.

Based on the VOSviewer algorithm, six significant clusters of key concepts are created. Each of the created clusters basically groups research activities. The performed cluster analysis indicates research frontiers, important research topics and trends in the development of the research area. Table 1 shows the results of the performed inductive content analysis in the available corpus of publications based on clusters in Figure 3.

Table 1 Content Analysis

Cluster	Colour	Labels / Representative Author Keywords	Categories
1	Red (8)	artificial neural network (14), classification (10), energy efficiency (11), innovation (10), recycling (35), remanufacturing (29), reuse (12), waste management (38)	artificial neural networks for classification and inovations for waste management, recycling and remanufacturing
2	Green (8)	circular economy (555), computer vision (14), deep learning (28), industrial ecology (11), life cycle assessment (15), machine learning (96), optimization (10), sustainable manufacturing (11)	deep learning and machine learning for circular economy, sustainable manufacturing and life cycle assessment,
3	Dark blue (5)	artificial intelligence (130), big data (61), digital technologies (17), digitalization (39), sustainable development (37)	artificial intelligence and big data for sustainable development
4	Yellow (5)	industry 4.0 (133), industry 5.0 (11), smart city (14), sustainability (149), sustainable development goals (12)	sustainability in smart city, industry 4.0 and industry 5.0
5	Purple (3)	decision support system (14), reverse logistics (22), supply chain management (13)	decision support system in reverse logistics and supply chain management
6	Orange (3)	Blockchain (34), internet of things (141), supply chain (15)	internet of things and blockchain (34) in supply chain

Source: Authors

In Table 1, the number of occurrences of keywords is presented in parentheses and serves to define the label. In the process of inductive content analysis, the authors' suggestions for further categorization within the examined area are given in the category column.

Further thematic analysis of the content of the areas presented in Figure 3 identifies six scientific research directions according to the order of clusters in Table 1: 1) ANN and innovations for waste management and remanufacturing, 2) Analyzing complex data using deep learning and machine learning to support the transition to CE, 3) AI and big data applications for sustainable manufacturing, 4) Sustainability in smart city, industry 4.0 and industry 5.0 and sustainable development, 5) Role of data-driven insight in reverse logistics and supply chain management and 6) IoT and blockchain in sustainable supply chain management.

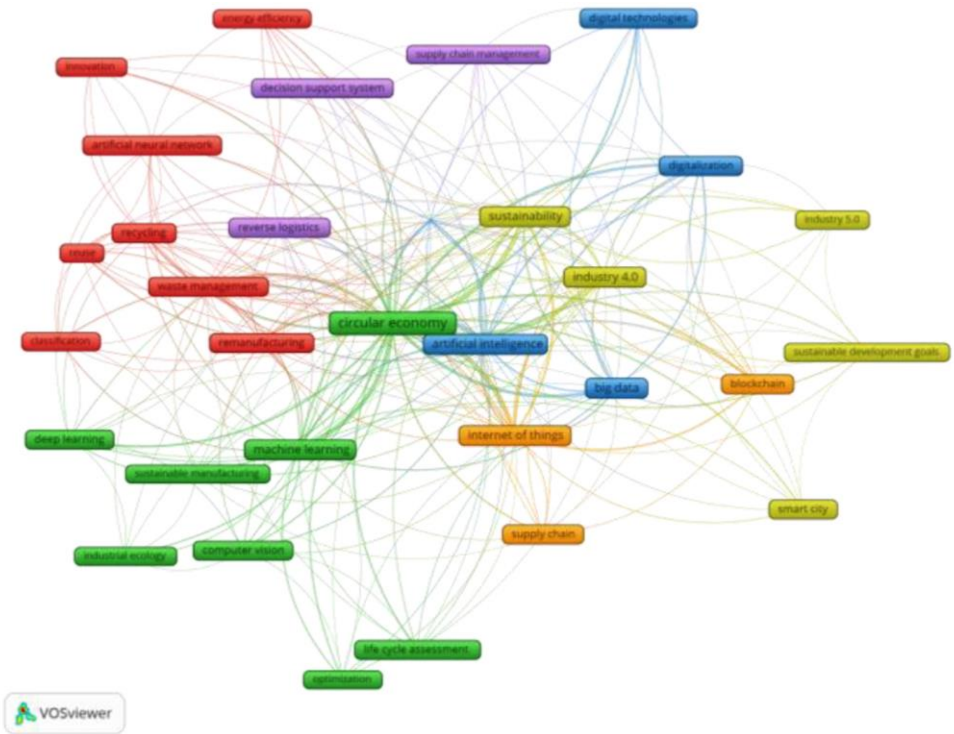

Fig. 3 Themes regarding AI, Big data and IoT use in CE

Figure 3 clearly indicates that the central areas that have attracted the attention of a huge number of scholars are circular economy and sustainable development. At the same time, in the context of the application of modern technology in the domain of circular economy, deep learning and machine learning techniques (red and green cluster) made a significant contribution. The growing application of AI, on the other hand, has found its most significant application in the domain of sustainable development goals (blue cluster). Internet of things and decision support system have confirmed their application in the domain of supply chain management (orange and purple cluster). However, the latest application of digital technology refers to both sustainable development and circular economy, and as such leads to the creation of industry 5.0 (yellow cluster), which will put modern technology in the service of sustainability, care for people and the environment.

Finally, it should be emphasized that, like most similar studies, the presented research has certain limitations. The main limitation is that the presented analyses referred only to publications in the SCOPUS index database. However, it should also be noted that the SCOPUS index database is considered the largest available database of scientific publications (Kokol et al., 2018) and that many similar papers do not see using only the SCOPUS database for research as a limitation.

4. Conclusion

The transition from a linear economy to a circular economy has the effect of reducing material extraction, waste disposal and, consequently, environmental pressures to a level that our environment can tolerate without effort. It is widely accepted that digital technologies enable the transition to a circular economy. Recent years have also brought a trend to combine artificial intelligence with all aspects of the circular economy. Scientific mapping aims to reveal the structure and dynamics of scientific fields. This study includes a qualitative and quantitative analysis of a corpus of scientific publication data available in the SCOPUS index database.

The presented analysis showed that the use of artificial intelligence in the circular economy is expanding, but that it is still not fully utilized. In addition to artificial intelligence, Big data and the Internet of things were another subject of analysis. The performed analyses show the trend of increasing interest of the scientific community in the further use of the mentioned technologies to further support sustainable development.

The derived thematic areas indicate that digital technologies are most often viewed as a single whole. Authors further intend to focus on the analysis of specific information technologies in the context of the circular economy, but also on the analysis of certain circularity areas and its further application, especially in the domain of waste management, packaging design and customer relationships in the process of their servicing, in order to contribute to this specific domain and see further research directions.

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VEŠTAČKA INTELIGENCIJA, TEHNOLOGIJA VELIKIH PODATAKA I ITERNET INTELIGENTNIH UREĐAJA U CIRKULARNOJ EKONOMIJI: ISTRAŽIVAČKI TRENDOVI I PERSPEKTIVE

Prelazak na održivi i regenerativni model ekonomije kakav zagovara cirkularna ekonomija oslanja se na digitalizaciju i inovacije koje treba da pomognu i podrže održivost na duže staze. AI se sematra ključnom tehnologijom koja može podržati nesmetan prelazak na cirkularnu ekonomiju. Sa druge strane, poznato je da je Internet stvari glavni pokretač integracije procesa sa drugim tehnologijama, a da Big data igraju važnu ulogu u procesu efikasnog donošenja odluka. Stoga ne čudi da istraživanja o najsavremenijim tehnologijama u cirkularnoj ekonomiji privlače ogromnu pažnju kako akademske tako i stručne javnosti i da se broj publikacija iz ove oblasti rapidno povećava. U ovom radu, VOSviewer se koristi za otkrivanje trendova u istraživačkim temama kako bi se obezbedio sveobuhvatan i integrisan pristup istraživanju uloge veštačke inteligencije, velikih podataka i IoT-a kao pokretača cirkularne ekonomije.

Ključne reči: *cirkularna ekonomija, veštačka inteligencija, Big data, Internet inteligentnih uređaja, IoT, AI*