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Article

Networks associative with circular economy research as a model of sustainability

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Abstract: Research networks organized around a particular topic are built as knowledge is produced and socialized. These are parts of a seminal or initial production, to which new authors and subtopics are added until research and knowledge networks are formed around a particular area. The purpose of the research was to find this type of relationship or network between authors, institutions, and countries that have contributed to the issue of the circular economy and specifically its relationship with sustainability. This allows those interested in the said object of study to know the research advances of the network, enter their research lines, or create new networks according to their interests or needs. The study used a bibliometric-type descriptive quantitative approach using the Scopus scientific database, the R Studio data analytics application, and the Bibliometrix library. The results were found to determine a relationship building from 2006, which makes it an emerging topic. However, the growth it has achieved in recent years of more than 31% shows a strong interest in the subject. Of the subtopics that have been addressed, sustainability, recycling, solid waste, wastewater, and renewable energy. Similarly, sectors such as construction, the automotive industry, tourism, cities, the agricultural sector, the chemical industry, and the implementation of technologies 4.0 and 5.0 in their processes stood out. The most prominent country in the scientific approach to this area is Italy. The most prominent author for his citations is Molina-Moreno, the source of knowledge that stands out for his contributions is the University of Granada and different networks have been built around their knowledge.

Keywords: environment; bibliometrics; scientific community; sustainable development

1. Introduction

Knowledge and innovation are drivers of development. In today's rapidly evolving landscape, the significance of knowledge and innovation cannot be overstated. They are the backbone of economic growth, social progress, and technological advancement. By fostering a culture of inquiry and creativity, societies can harness these elements to address complex challenges and improve quality of life. Today, with information technologies, it is possible to collaborate in real time between different countries, institutions, and researchers to manage knowledge, innovate products, and processes, and socialize contributions (Jurado Zambrano et al., 2023). This real-time collaboration transcends geographical barriers, enabling diverse teams to work seamlessly. The ability to share insights and expertise instantaneously enhances the creative process, leading to more robust solutions and innovations. Likewise, these collaborations are recorded in scientific databases, and with the support of specialized software, it is possible to perform analytics to understand the progress achieved (Cancino Escalante et al., 2020). Such analytics provide insights into the current state of research but also highlight trends, gaps, and opportunities for

future exploration.

A scientific database is a collection of data in each space that allows studies to be carried out on a specific topic (Lemus-Delgado and Pérez Navarro, 2020). These databases serve as invaluable resources for researchers, providing access to a wealth of information that can inform their work. They aggregate findings from various studies, offering a comprehensive view of a particular field. The data that are part of these databases come from different sources of scientific knowledge because of the research that has been carried out and socialized over the years (Vega, 2012). As a result, they reflect the cumulative knowledge generated by scholars and practitioners, making it easier to trace the evolution of concepts and practices over time. Thus, a database on the circular economy contains the socialization in articles, books, book chapters, magazines, editorials, and working documents that have been carried out by researchers dedicated to this topic. This extensive collection of materials allows for a multidimensional understanding of the circular economy, encompassing theoretical frameworks, practical applications, and case studies.

A scientific database analytics program is known as one that can process data and transform it into information either through tables or graphs based on the use of statistics (Chaparro-Martínez et al., 2016). These programs play a crucial role in distilling complex datasets into actionable insights. By visualizing data trends and patterns, researchers can quickly identify key findings and make informed decisions. In this sense, a data analytics program on the circular economy makes it easier to find research advances in this area of knowledge. Such programs can also facilitate meta-analyses, enabling researchers to synthesize findings across multiple studies and draw broader conclusions.

The circular economy is an area of knowledge that cannot be alien to any business or social sector; its advantages have been strengthened by considering it a relevant strategy for sustainable development (Acosta-Pérez et al., 2020). As global challenges such as climate change and resource depletion become increasingly pressing, the circular economy offers a viable pathway for sustainable practices. By promoting resource efficiency and waste reduction, businesses can not only enhance their competitiveness but also contribute to environmental preservation. In this sense, in the scientific field and for those who research the topic of circular economy, understanding the form of collaboration existing between researchers, research sources, and countries according to scientific progress is of great relevance. To understand the level of knowledge and innovation achieved and the processes carried out to achieve it. Such understanding can lead to the identification of best practices, foster international partnerships, and drive further innovation in the circular economy. Moreover, it can inform policymakers about the effectiveness of various strategies, guiding the development of supportive frameworks that encourage sustainable practices across sectors.

For this reason, bibliometric research was carried out using specialized and high-impact databases as well as data analysis tools to find the scientific networks created around the knowledge area of the circular economy. The results demonstrate the existence of consolidated relationships at an international level by a scientific community that works around the area of study. In Colombia, important steps have been taken to be part of this community. But in the same way, its participation can be

strengthened with contributions from different researchers dedicated to this topic as well as with the support of research and university institutions.

2. Materials and methods

The non-experimental quantitative approach of a descriptive nature was used, based on data analytics from scientific sources. The database used was Scopus and the analytics applications used were R Studio and the Bibliometrix library (see **Figure 1**), with the following work scheme.

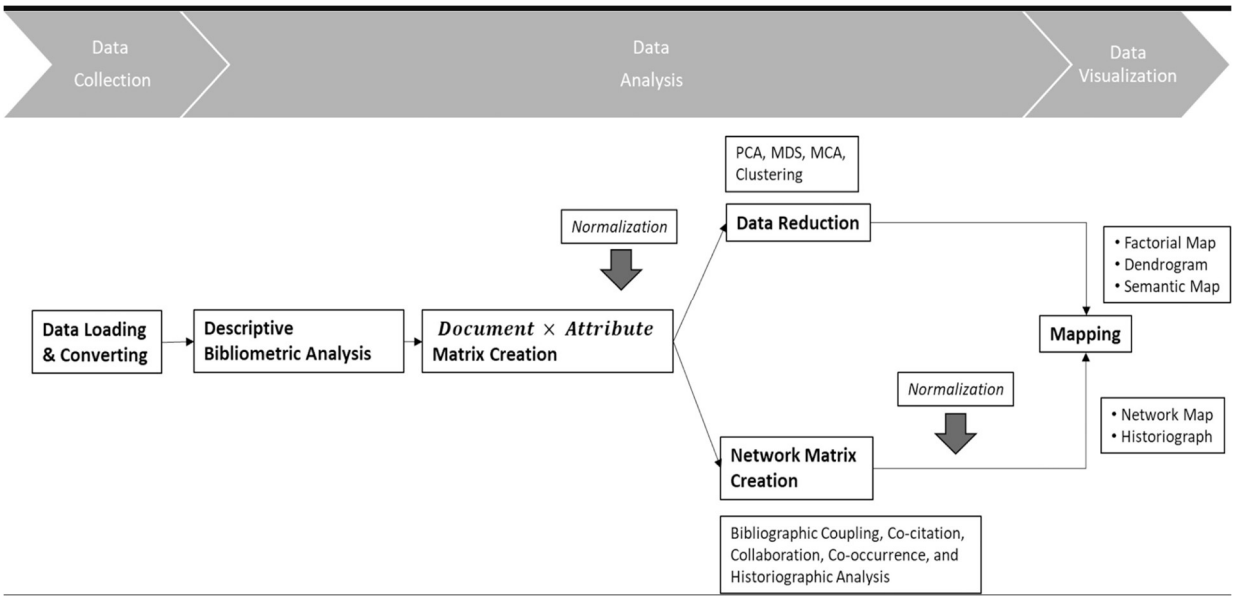


Figure 1. Workflow of the Bibliometrix library of R Studio.
Source: Bibliometrix.

Figure 2. General information.
Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: The graph shows general information on the study database.

More than 1000 documents were reviewed and 638 documents from 356 sources and 2339 authors were selected for the study in Chinese, Croatian, English, French, Italian, Lithuanian, Polish, Portuguese, Russian, and Spanish. The revision spans from 2006 to 2023, represented in articles, books, book chapters, conferences, editorials, working papers, and short surveys (see **Figure 2**), in search of the existence of networks around the circular economy as a sustainability model. Graphical analyses

such as word clouds, three-dimensional graphs, and graph analysis were applied to the study. Fields Plot, relationship maps, trend maps, and co-occurrence graphs.

The exclusion criteria used to select the 638 documents were the following: The year of publication, selecting the most up-to-date ones. Documents that did not centrally address the topic of circular economy and sustainability and Documents with keywords that were not related to the central topic.

Among the limitations of the study are geographical biases because although the documents are published in several languages, most of those who publish do so in English, which presents a more global than local approach. Likewise, the methodology of bibliometric studies seeks to quantitatively analyze the state of science, limiting the depth of the area of study due to the large amount of literature.

3. Results and discussion

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results and their interpretation, as well as the experimental conclusions that can be drawn.

3.1. Network of semantic and conceptual affinities

A semantic and conceptual affinity is understood as the relationships between different actors, whether they are researchers, sources of knowledge, or institutions with an area of knowledge or textual word that is used in the development of their research (see **Figure 3**). To do this, using data analysis tools, the texts are broken down into words, through lexical-semantic similarity values. In this way, lexical marks and relationships specific to a particular scientific community are found (Ortega Ramírez and Sánchez Rodríguez, 2021).

Figure 3. Semantic and conceptual affinities.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: A visualized word cloud of frequently used keywords in the field of study. The larger the word, the greater its use in the study documents.

To understand how these semantic networks are used by different authors in different countries and journals or knowledge sources, two three-field diagrams, known as Sankey diagrams, were constructed. In the first one, 20 countries, 20 authors, and 20 keywords (top 20) were related. **Figure 4** shows the formation of a great relationship between the research interests of the authors and the countries, that make up the semantic network for the area of circular economy as a sustainability model.

This includes countries such as Italy, Spain, the United States, Germany, Colombia, Chile, China, Malaysia, the United Kingdom, India, Romania, and Poland. Authors such as Molina-Moreno, Leyva-Diaz, D'adamo, Nocca, Girard, Bosone, Angrisa, Gravagnulo, Petrillo, Cortés-García, Failla, Ferella, Tseng, Kowalski, Forcina, Makara, Busu, Cerreta, Esparragoza and Hidalgo y Crespo. All of them are related in different ways to the circular economy themes already mentioned. Italy, has the largest network of collaboration and interests in circular economy, recycling, sustainability, and waste management, with 206 points, followed by Spain with 65 points. Colombia appears in this network with 11 points in collaboration with two authors and related to issues of wastewater, circular economy, and sustainability.

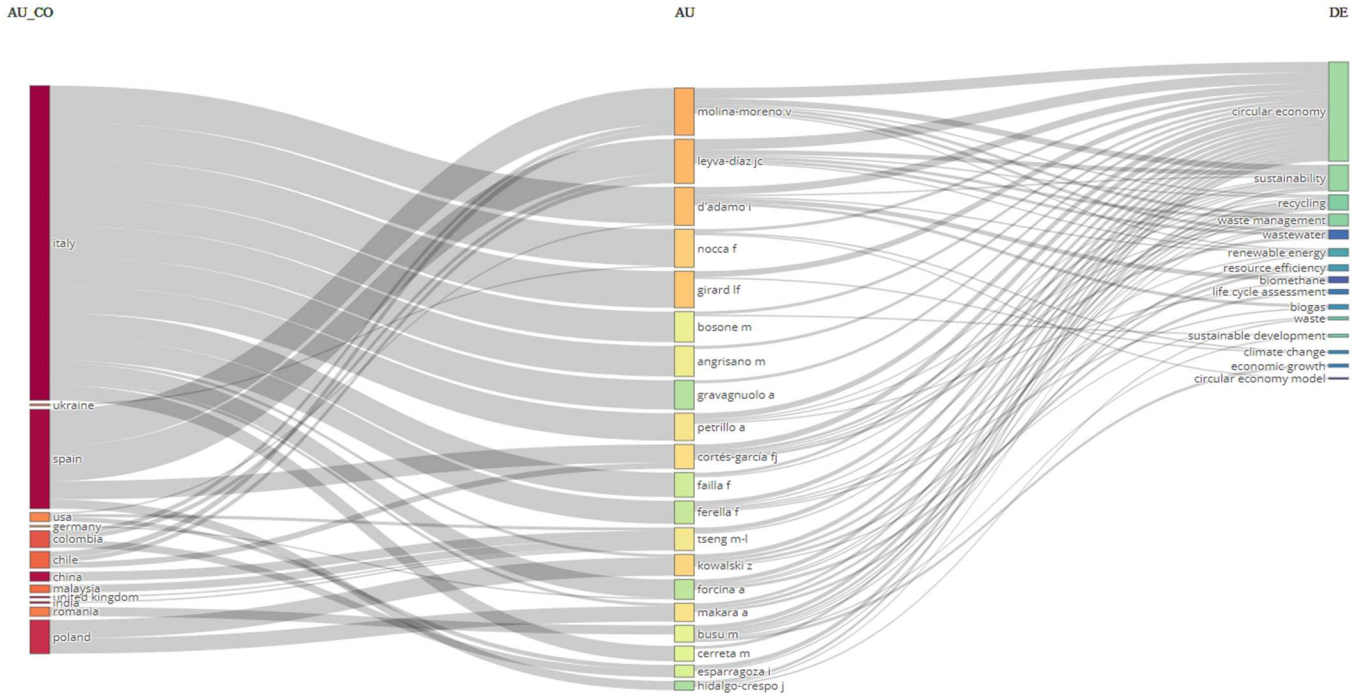


Figure 4. Network of semantic and conceptual affinities between countries, authors, and keywords.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: A three-field plot of countries, authors, and keywords; emphasis is placed on the height of each box and the thickness of the connecting lines; the taller the box, the more significant; and the thicker the correlation of the lines, the more information or volume of work was produced.

For the elaboration of the second diagram, authors, keywords, and sources were selected. The results identify the Journal of Cleaner Production and Energies Molecules showing greater interest in sustainable development issues. While Science of the Total Environment and Journal of Environmental Management focus their greatest interest on waste management and of course sustainability in the areas of sustainability and resources, conservation, and recycling. It also conducts environmental science and pollution research on recycling topics. Similarly, the network of authors distributes their productivity in these sources according to their research topics (see **Figure 5**).

Furthermore, the network collaboration between authors and countries on issues of circular economy, recycling, sustainability, and waste management indicates that science and the productive sector see an opportunity for the generation of new business models and benefits for the environment. Hence the creation of public policies such as

the National Strategy for the Circular Economy, of Colombia, in 2018 and the Roadmap towards a Circular Economy in the Industrial Sector of Peru and Chile in 2019 and 2021 respectively. Or the Pact for the Circular Economy of Ecuador in 2018. 2019. As well as the General Law of Circular Economy of Mexico or integral management of solid waste approved in 2021 in the Dominican Republic. All of them care for the environment and give added value to waste (Gutiérrez León, 2022). This relationship is observed in detail below.

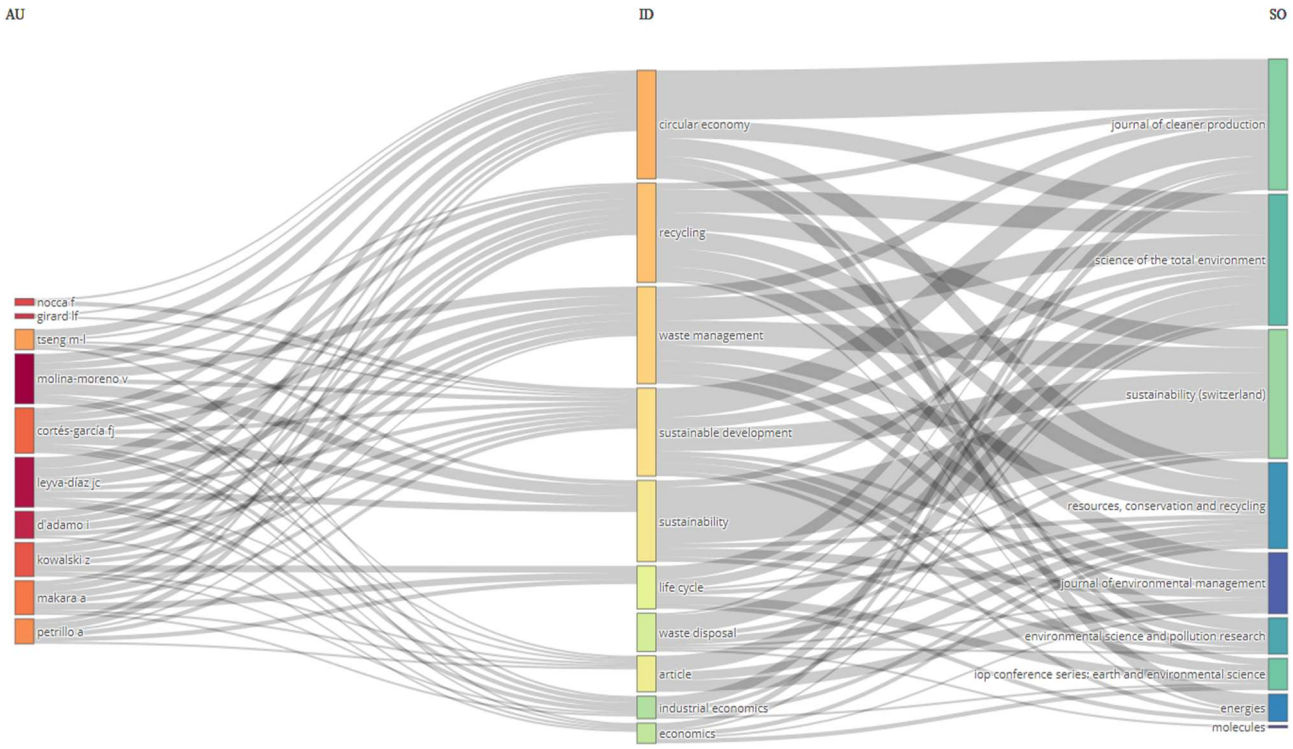


Figure 5. Interests in knowledge sources.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: A three-field grid of authors, keywords, and sources; emphasis is placed on the height of each box and the thickness of the connecting lines; the taller the box, the more significant; and the thicker the correlating lines, the more information or volume of work was produced.

3.2. Network of relationships between authors and countries

The network of solidarity economy relationships for sustainable development is part of SDG (Sustainable Development Goals) 17, which seeks to improve the effectiveness and impact of organizations and the social sector. Research and its actors play a key role in its fulfillment.

To understand the relationship between authors and countries with the object of study, it was necessary to perform a frequency analysis. In green, the publications from a single country are shown, and in pink, the publications made with other countries. The most productive countries are Italy, Spain and China. Italy has 102 documents, of which 82 are from the same country and 20 are in collaboration with other countries, followed by Spain, which, although it has less productivity (63), has greater collaboration with other countries (24). Then China with 41 documents of which 33 are with the same country and 8 in collaboration with other countries (see **Figure 6**). In the list, it can be observed that Colombia has 8 publications of which 5 are from the

same country and 3 are in collaboration with other countries (37.5%). This represents a good percentage of collaboration, the same occurs with the United Kingdom, which reaches 38% of productivity with other countries, as does Spain.

Country	Articles	SCP	MCP	Freq	MCP_Rati
	128	99	29	0,20062696	0,2265625
ITALY	102	82	20	0,15987461	0,19607843
SPAIN	63	39	24	0,09874608	0,38095238
CHINA	41	33	8	0,06426332	0,19512195
UNITED KINGDOM	31	19	12	0,04858934	0,38709677
POLAND	23	19	4	0,03605016	0,17391304
INDIA	22	16	6	0,03448276	0,27272727
BRAZIL	21	16	5	0,03291536	0,23809524
AUSTRALIA	12	8	4	0,01880878	0,33333333
GREECE	12	11	1	0,01880878	0,08333333
PORTUGAL	12	11	1	0,01880878	0,08333333
MEXICO	10	6	4	0,01567398	0,4
ROMANIA	10	9	1	0,01567398	0,1
CANADA	8	5	3	0,01253918	0,375
COLOMBIA	8	5	3	0,01253918	0,375
NETHERLANDS	8	3	5	0,01253918	0,625
USA	8	7	1	0,01253918	0,125
CHILE	7	2	5	0,01097179	0,71428571
MALAYSIA	6	4	2	0,00940439	0,33333333
SWEDEN	6	4	2	0,00940439	0,33333333
FRANCE	5	3	2	0,00783699	0,4
GERMANY	5	3	2	0,00783699	0,4
TURKEY	5	4	1	0,00783699	0,2
UKRAINE	5	4	1	0,00783699	0,2
BELGIUM	4	3	1	0,00626959	0,25
CZECH REPUBLIC	4	4	0	0,00626959	0
FINLAND	4	1	3	0,00626959	0,75
NIGERIA	4	3	1	0,00626959	0,25
PAKISTAN	4	3	1	0,00626959	0,25
SERBIA	4	3	1	0,00626959	0,25
SINGAPORE	4	1	3	0,00626959	0,75
ECUADOR	3	0	3	0,00470219	1
EGYPT	3	0	3	0,00470219	1
INDONESIA	3	3	0	0,00470219	0

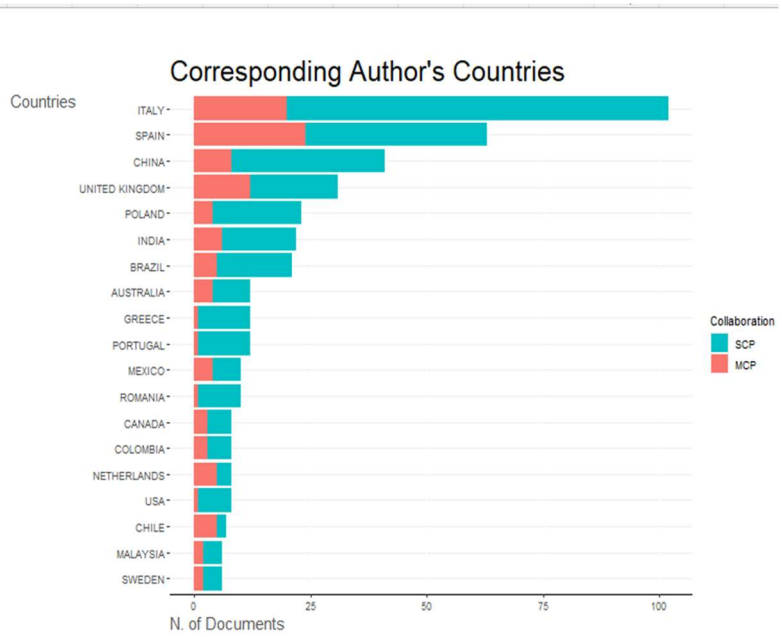


Figure 6. Network of relationships between authors and countries.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: The top 19 countries and their productivity ratio with others are presented. The larger the box, the greater the cooperation. The productivity of the country itself appears in green and the productivity of the country in collaboration with others appears in pink.

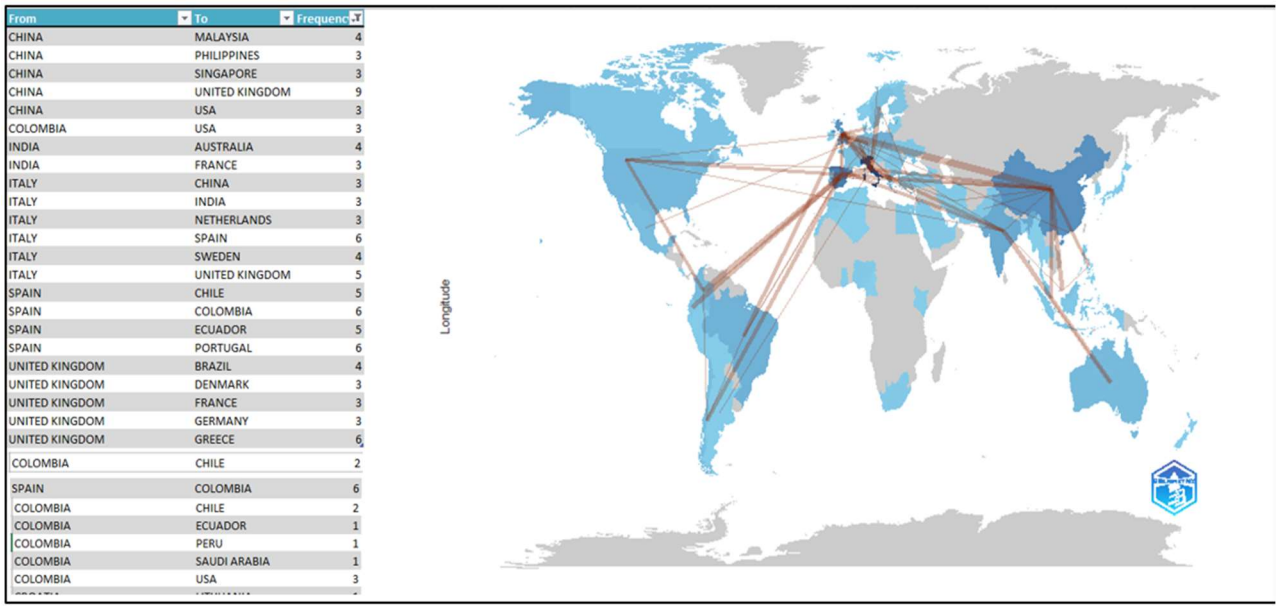
In the European continent, the proliferation of strategies on the circular economy has been evident, with countries such as Italy, Spain, and England standing out (Raudales-García et al., 2024). These strategies have been accompanied by laws, promotion and impact actions. In Italy and Spain, for example, since 2020, investment funds and research training have been allocated to topics such as eco-innovation and sustainable consumption. And the application of models in the fashion, food, and electronic waste industries and the promotion of reusable products and services. Companies dedicated to the collaborative economy have also been created to find new ways to give utility to products (Mejía-Ochoa et al., 2023).

3.3. Network of contributions between countries

Understanding that there is collaboration between countries and that this contribution is broad in terms of research on the subject of study, it is important to review how one country relates to another. In this sense, researchers from Italy relate mainly to Spain, followed by the United Kingdom, Sweden, France, China, India, and the Netherlands. From Spain to Colombia there are 6 contributions, as well as from the United Kingdom to Greece, from Italy to Spain, and from Spain to Portugal. Likewise, from Colombia, there are contributions to Chile, Ecuador, Peru, Saudi Arabia, and the United States (see **Figure 7**).

The 2030 sustainable development agenda, and SDG 17 in particular, guides the alliances that must exist between countries to ensure that none are left behind in the

standards and procedures necessary for sustainability.



From	To	Frequency
CHINA	MALAYSIA	4
CHINA	PHILIPPINES	3
CHINA	SINGAPORE	3
CHINA	UNITED KINGDOM	9
CHINA	USA	3
COLOMBIA	USA	3
INDIA	AUSTRALIA	4
INDIA	FRANCE	3
ITALY	CHINA	3
ITALY	INDIA	3
ITALY	NETHERLANDS	3
ITALY	SPAIN	6
ITALY	SWEDEN	4
ITALY	UNITED KINGDOM	5
SPAIN	CHILE	5
SPAIN	COLOMBIA	6
SPAIN	ECUADOR	5
SPAIN	PORTUGAL	6
UNITED KINGDOM	BRAZIL	4
UNITED KINGDOM	DENMARK	3
UNITED KINGDOM	FRANCE	3
UNITED KINGDOM	GERMANY	3
UNITED KINGDOM	GREECE	6
COLOMBIA	CHILE	2
SPAIN	COLOMBIA	6
COLOMBIA	CHILE	2
COLOMBIA	ECUADOR	1
COLOMBIA	PERU	1
COLOMBIA	SAUDI ARABIA	1
COLOMBIA	USA	3

Figure 7. Contribution network between countries.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: Countries in blue show productivity in the area. The stronger the blue color, the higher the productivity. The red lines represent a collaboration between countries.

3.4. Network of relationships between different authors

A scientific collaboration network is understood as one where the nodes are the authors and the union or links between them are the co-authorships. The analysis carried out using the normalization of associations presents twelve groups of authors according to the selected research topics. Cluster 1 is represented by the authors Kowalski Z and Makara, by uniting their approaches, they have achieved a more comprehensive vision, which not only advocates the adoption of circular models from a business point of view but also from the need for public policies that support this transition.

Cluster 2 is made up of D'damo and Ferella, their joint work has facilitated the transformation of business models towards circularity, promoting the reconfiguration of value chains, the efficient use of resources, and open innovation to collaborate on circular solutions. The third cluster is Petrillo, Forcina, and Travaglioni, who have joined forces to investigate the sustainable reuse of coffee waste, analyzing processes such as composting, biodiesel production, and brick manufacturing.

Cluster 4 Levi and Romani have investigated additive manufacturing as a promising method to improve circular economy models through the use of recycled composites. Cluster 5 is made up of Abu-ghunmi D. and Abu-ghunmi L. who investigate how the water industry is transitioning from a linear to a circular economic model. Cluster 6 Aguayo and Aznar highlight that the circular economy offers systemic solutions to challenges such as climate change, biodiversity loss and pollution.

Cluster 7 Molina-Moreno, Leyva-Diaz, Cortéz-García, and Sánchez-Molina, focused on sustainability and efficiency in the treatment of industrial wastewater,

addressing the design of circular economy indicators to assess sustainability. Cluster 8 Hidalgo-Crespo, Soto and Amaya, their work covers areas such as the recycling of expanded polystyrene and the energy recovery of used domestic cooking oil. Cluster 9 Girard, Nocca, Angrisano, Bosone and Gravagnuolo, whose research highlights the synergistic relationship between sustainable urban development and the preservation of cultural landscapes.

In cluster 10, Alexopouylos, Angelis-Dimakis, Angelis V, and Atampatzis, their work has focused on the development of digital platforms for the reuse of solid waste and on the implementation of circular economy strategies in collaboration with Greece, Albania, and Bulgaria. Cluster 11: Tseng and Sarkis have contributed to coordinating industrial and commercial policies to conserve resources and energy and finally, cluster 12 with Failla and Matarazzo who research electronic waste in treatment plants for reuse. The contribution made by cluster 7, chaired by Molina-Moreno, is highlighted by the number of contributions and citations (see **Figure 8**).

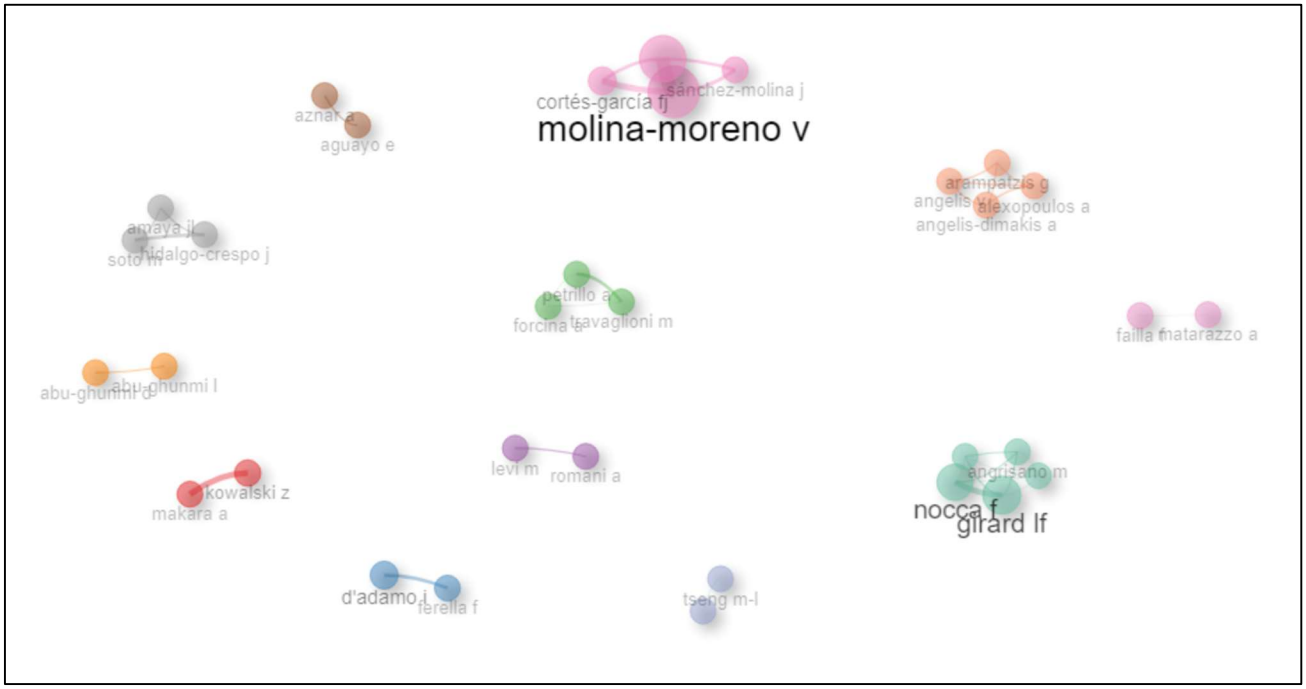


Figure 8. Author network.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: Mapping of the authors' collaboration network; the larger the author's name, the wider the collaboration network.

To establish the causes of the leadership that some authors exercise over others, it is necessary to review the permanence and consistency of the authors with publications over the years in the area of study. In that order of ideas, in **Figure 9**, it can be seen how Molina-Moreno continued to publish since 2016, as well as Leyva-Diaz, Girard LF and Nocca F. The highest number of publications of the first was reached in 2018. Some authors emerged in 2018, such as Tseng; others in 2019, such as Dádamo with great impact, Kowalski and Makara, and another in 2020 with good productivity, such as Petrillo. The graph allows us to see the consolidation of the network that permanently strengthens the object of study.

This relationship is linked to seminal documents that gave rise to the interest of researchers in different topics of circular economy (see **Figure 10**). The document by

Bocken in 2016 presents sustainable strategies for corporate business models, which reached 1497 citations in 2023 and were followed by Ezpeleta in 2019 on the same topic of study. A second group was started by Casiano in 2018 in the area of wastewater treatment, which has reached 43 citations and is followed by Alvizuri in 2021. A third group was started by Moschovi in 2018 on topics of preservation in the automotive sector, reaching 3 citations, and continued on the same topic by Yakoumis in 2021. And a fourth group was created by Gravagnuolo on topics of circular cities in 2019, with 103 citations, and followed on that topic by the author Angrisano in 2023.

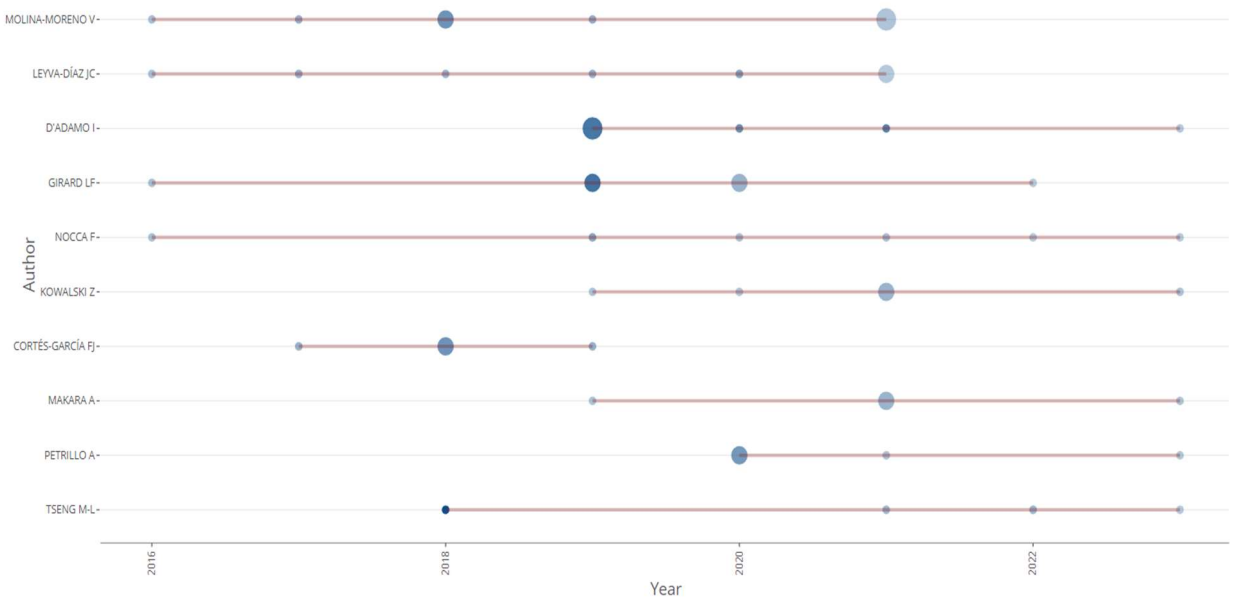


Figure 9. Behavior of the author network productivity over time.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: The line represents the timeline of the authors; the size of the bubbles is proportional to the number of papers produced by an author per year; the intensity of the bubble color is proportional to the total number of citations per year; the first bubble on the line indicates when the author started publishing in the field; the larger the bubble, the greater the number of papers published per author per year; bubbles with deeper color intensity indicate a greater number of citations.

Figure 10. History of the circular economy as a sustainability model.

Source: Scopus database, Data analytics with R Studio, and the Bibliometrix library. Note: The bibliometric history chart shows the beginnings of the networks that are formed by authors in subtopics into which the circular economy is divided. The size of the circle is determined by the number of citations that the author receives in his document, and the lines between one author and another represent affinity with the researched topic.

However, the authors do not work in isolation, nor are they alien to the institutional interests of which they are a part. In this sense, it is also relevant to carry out a study of the relationship between institutions.

3.5. Network between institutions

There are 5 clusters of collaboration between universities. The first cluster includes the National University of Singapore, the Politecnico di Milano, and the Univesitá of studi di milano. In the second cluster are the University of Milan of Padua, the University of Guelph, and the University of Bologna. The third cluster includes the University of Bologna. of Cagliari and Imperial College London. In the fourth cluster the University of Granada and the University of Jaén and in the last cluster the Rmit University and the Polytechnic University of Madrid. The largest contributions are delivered by the fourth cluster, which is the star node of the network (see **Figure 11**). The greater the number of contacts of a node, the larger its network and the resources, information or knowledge to which it has access (García Hernández, 2013)

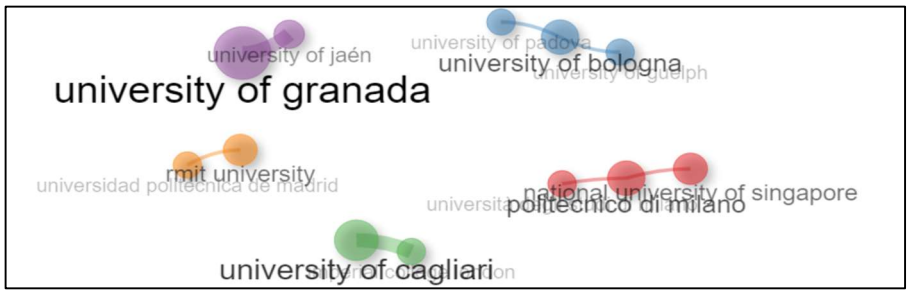


Figure 11. Network between institutions.

Source: Scopus database, Data analytics with R Studio and the Bibliometrix library. Note: Mapping of the collaboration network of institutions; the larger the name of the institution, the broader the collaboration network.

3.6. Contribution of networks to knowledge

The most relevant articles with a high number of citations share concepts with other researchers, around the circular economy model. In this sense, the documentary analysis allowed us to highlight the following:

A circular economy model allows organizations to create regenerative manufacturing systems and achieve economic and social sustainability, turning the application of the circular economy model into a competitive advantage. To apply the model, it is necessary to overcome technological, economic, regulatory, and psychological barriers. As well as the development of environmental awareness in citizens and environmental education (Raudales-García et al., 2024; Solís-Muñoz and Cogollo-Flórez, 2021).

The use of circular economy models extracts the maximum value from resources, regenerates them and gives them a better useful life (García Hernández, 2013; Solís-Muñoz and Cogollo-Flórez, 2021). Many sectors have benefited from the circular economy, such as construction, with road rehabilitation and renewable materials; automotive manufacturing and metal recycling, oil refining; industrial applications; tourism, agricultural and agri-food systems; among others (Martín-Portugués et al., 2019). Likewise, wastewater treatment is a challenge that must be addressed.

The characteristics of sustainable development are related to long-term system change, access to information on technological development sustainable consumption, equity, and equality (Gómez Romero and Garduño Román, 2020; López-Pacheco et al., 2021). It is necessary to move from a consumerist model to a regenerative model and this must begin with a cultural change. Sustainability is both an environmental and social change that will impact future generations. In this sense, it must start by recognizing environmental and socioemotional problems and building new business models that respond to a favorable future environment and are replicable in various organizations (Bocken et al., 2016; Bocken et al., 2018). It can be applied at the micro, macro and intermediate levels and in all sectors. It is about enhancing the value and productivity of resources and reducing slack and losses (Cabrales Salazar et al., 2022).

The circular economy suggests the implementation of eco-technical and intelligent solutions capable of responding to the current situation of global warming and waste of materials (Mula et al., 2010). It also seeks to transform the linear production model into new production cycles based on waste to reduce gas emissions, regenerate resources or convert them for new cycles, as well as innovate towards new models.

Technologies, smart systems, and data-driven models enable deeper monitoring and analysis such as material flow analysis, life cycle assessment, and impact projections. Institutionalization of open data participatory consultative processes and increased trust in science are required (Lopes de Sousa Jabbour et al., 2023). Technological collaboration in line with a circular strategy, skills development of the digital workforce, technology sharing to achieve circular co-benefit, and stakeholder engagement for technology transfer are important aspects (Satyro et al., 2021; Vera-Acevedo and Raufllet, 2022). Thanks to the development of new experiential strategies and tools, research and academic practice can be linked to foster new opportunities to implement circular economy models (Vence and Pereira, 2018). The Circular Economy (CE) has progressed towards a sustainable digital approach, capable of being implemented in different scenarios.

Industry 5.0 has evolved from a fully automated field of application to a balanced technological combination with the participation of the human factor. As a result, an increasing number of digital models are being introduced (Vence and Pereira, 2018). This is why the digital circular economy and Industry 5.0 have been two significant research attractions in recent years, due to the evolution of their predecessors towards advanced technologies (Gutiérrez-Ascón et al., 2022). Regarding the future of research, the authors consider that they should focus on the integration of different stages of the supply chain with circular economy models and tools to create a closed-loop agri-food system (Rivera Acosta and Martínez Torres, 2021).

Political efforts to embrace such models are crucial to building shared knowledge and understanding (Hernández-Leal et al., 2017). Greater public trust and political credibility are also required in the circular economy model. There is a major difference in the approach to recycling leading to new products that create transport and production, new jobs, and potential GDP (Gross Domestic Product) growth (González and Pomar Fernández, 2021). The new closed-loop package is a key instrument for territories, environmental protection, the competitiveness of the economy, and the promotion of sustainable reindustrialization (Ortega Ramírez and Sánchez Rodríguez,

2021).

4. Discussion

Co-creation research allows for competitive advantages (Wilches Velásquez, 2020). According to García Hernández (2013), strategic alliances between researchers in co-authorship strengthen scientific productivity, innovation, and knowledge management, and the socialization of impactful results broadens the fields of action in localities, regions and business sectors. Research in scientific areas of knowledge presents better opportunities for socialization and weighting as interpersonal, inter-institutional, and interdisciplinary links are strengthened in socialization and discussion around results and adequate circulation of information (Aguado-López et al., 2009).

The circular economy is considered a means to achieve social, economic, and environmental objectives considered in the Sustainable Development Goals (SDG) to which the current world is committed. This is why its model summarized in processes of reducing, recycling, rehabilitating, repairing, redistributing, restoring, redesigning, rethinking, remanufacturing, reusing, and recovering must be incorporated into organizational practices. To promote collaboration among the agents that influence so that the challenges that this represents are jointly achieved (Almeida-Guzmán and Díaz-Guevara, 2020).

Collaboration and alliances with actors in research, academia, the productive sector, international organizations, and public institutions are necessary to shape and transform the way of production and achieve a common vision (EU-LAC Foundation, 2018). Another relevant aspect is the transfer of knowledge by educational entities as a result of joint research work that allows the discovery of efficient and innovative designs. Investing efforts in the implementation of courses and training activities in sustainability from circular economy models (Molinillo, 2022).

The circular economy is a cyclical work of creation and use to prolong the life of products and connect environmental frameworks with development (Senthil and Saravanan, 2019). With economic growth, it is not possible to improve the quality of the environment; however, by reducing pollution, it is possible to make an environmental renovation, which is possible through the circular economy model (George et al., 2015).

However, the use of the circular economy leads to lower consumption of natural resources and an increase in employment. It is necessary to dismantle barriers that prevent its impact from being greater, such as the permanent increase in consumption patterns. The collaborative economy, the extension of the life of products (Nieves Mendoza and Morales Cely, 2022), and a true integration between sustainability and business development (Ritzén and Sandström, 2017). Aspects on which the network of collaborators and scholars of the circular economy must focus their efforts.

In the existing literature, innovations for the circular economy were found, such as emerging technologies that use solar energy to convert waste into sustainable fuels and chemicals (Bhattacharjee et al., 2024), microplastic extraction and subsequent reuse through the use of iron oxide nanoparticles, and innovative approaches in electronic waste management to mitigate the environmental impact derived from the

development of generative artificial intelligence (AI) that significantly increased energy consumption and the generation of electronic waste (Wang et al., 2024). On the other hand, computer simulations are used to predict the long-term effects of the implementation of the circular economy in different industrial sectors (Liu et al., 2024).

Likewise, the emergence of Industry 5.0 has the potential to transform circular economy research by integrating advanced technologies such as artificial intelligence, robotics, 3D printing, and the Internet of Things (IoT). In addition, intelligent monitoring of material flows and optimization of reverse logistics will improve waste and resource management.

Scientific collaborative networks address common themes throughout the value chain of specific sectors where circular economy processes can be carried out. However, it is necessary that the results of these studies can be shared with government entities in such a way that they contribute to the creation of public policies, guide processes through the leadership of experts and key actors, and direct tasks according to the potential of collaborators. Likewise, new research is relevant that integrates relationships between the circular economy and artificial intelligence, public policies, new circular business models, emerging technologies and their impact on different sectors to find solutions to those barriers that prevent their application in some scenarios.

5. Conclusion

The analysis carried out in this work is based on a scientific basis and the application of data science allowed the establishment of a wide network of relationships between scientific actors involved in the topic of circular economy as a sustainability model. Thus, in a period between 2006 and 2023, 638 documents have been indexed in Scopus, prepared by 2339 authors.

The networks involved that have been created allow the strengthening of knowledge between authors, countries, and institutions. Colombia is beginning to have a good representation in these relationships that can encourage new authors and strengthen the topics that have been handled so far. The results found can provide evidence of a permanent approach in the area of study with an increase in productivity of more than 31% in the study period, especially from 2016 onwards. This broadens the perspectives of researchers working on the topic.

There is also a wide range of research journals that maintain their interest in the area of the collaborations that are presented. Italy is the most representative country, as are the collaboration networks it has with other countries and it can be an opportunity for an alliance. There is a good coupling between authors and a wide network of collaborative topics that can be addressed. It is worth highlighting the great scope that the circular economy has for sustainability in organizational sectors and the impact it can have on the environment and society.

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writing—original draft preparation, JASA; writing—review and editing, YGC; visualization, OMD; supervision, JASA; project administration, YGC; funding acquisition, OMD. All authors have read and agreed to the published version of the manuscript.

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