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AIMS AND SCOPE

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A Bibliometric Analysis of Circular Economy: Policy Implications for Sustainability in Sub-Saharan Africa

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Abstract

This study aims to identify and map out circular economy in scientific literature in the global and Africa context. The circular economy has been adopted mostly in industrial production systems in the developed economies, its application in Africa is limited mostly to environment sector. A paucity of scholarly research and scientific publications on CE instigated the need to map out circular economy for sustainable development Africa. This article provides an overview of scientific publications on circular economy built in Africa through the Scopus database. The study used bibliometric analysis based on data obtained from Scopus database highlighting scientific literature. The analysis obtained 414 publications from 2005 to 2024. It provides descriptive and analytical graphs and bibliographic maps generated in R-Studio software. Findings shows main scientific and scholars are in European and Chinese universities with scanty publications in Africa. These findings signal the inadequacy of scientific research to inform policies on circular economy in Africa. It calls for future demand for more research and scientific publication on circular economy linked to sustainability in Africa.

Keywords: Circular, Economy, Social Life Cycle Assessment, Sustainability, Africa, Policy



1. Introduction

The genesis of the circular economy (CE) can be traced in 1976 with the Batelle Institute Geneva scholars who produced a report titled “The Potential for Substituting Manpower for Energy” for the Directorate-General for Labour and Social Affairs of the European Union. The essence of CE as a development framework for long-term sustainability and for supporting of growing economies (Dominko et al., 2023; Schaubroeck et al., 2021; Yu et al., 2022). The CE is widely discussed using three basic elements of an economic system; resource suppliers, waste assimilators and sources of utility that advocate for cyclical use of resources for the creation, supply and use of products generated for companies (Luis & Celma, 2020; Schaubroeck et al., 2021). Built on CE principle of reducing waste, use of waste and recycling materials (Ogunmakinde et al., 2022; Ogutu et al., 2023; Schaubroeck et al., 2021), the CE is gaining keen interest among researchers, government policy makers, and organizations as an alternative to the linear economy for promoting sustainability because it provides solutions to ecological and socio-economic challenges resulting from increasing consumption of non-renewable resources, waste generation, pollution and resource scarcity (Goyal et al., 2021).

The Circular Economy as an emerging production development model is important for developing economic because it promises sustainable jobs and rational use of resources with environmental, and economic benefits. CE focuses on circularity, reusing and replacing the resources (Luthin et al., 2024). The CE is about decoupling economic activities based on the intake of limited resources and scheming waste out from the system (Gedam et al., 2021; Morales & Belmonte-Urena, 2021). The Circular Economy explores new productive and economic systems that allow for the creation of production systems while saving resources. It has attracted scholarly work and businesses because it operationizes the implementation of sustainable development (Kirchherr et al., 2017; Ogunmakinde et al., 2022). However, there is inadequate evidence in scholarly literature of circular economy for sustainability in the Sub-Saharan Africa.

2. Theoretical background

The concept of circular (CE) economy as a strategy for moving towards sustainability in the European Union is well articulated in the European Circular Economy Action Plan as a blueprint policy for boosting green jobs, growth, and investment for promoting the transition to a carbon-neutral, resource efficiency. In the context of Africa, the African Union (AU) agenda 2063 is the Africa’s development framework for transforming the continent encompasses inclusive and sustainable development. The AU launched the African Circular Economy Alliance in 2016 as development strategy (Ogunmakinde et al., 2022). By 2022, CE has expanded to more than 20 African countries because recycling is a solution to the growing environmental pollution caused by plastics, metals and glass to mitigate the environmental effects.

While linear economy production system takes end-of-life products as waste, circular economy perceives end-of-life products as resources (Gedam et al., 2021), CE has elevated important development strategy that considers sustainability. For this need, circular economy inspired by the World Trade Center calling for public and private industries to adopt it with the potential to support green job creation as an approach to economic growth that is in line with sustainable environmental and economic development (Dunmade, 2021). Circular economy promotes efficient use of resource materials and energy while also



decreasing environmental pollution (Andersen et al., 2022; Furness et al., 2021; Yu et al., 2022). Due to its socio-economic and environmental importance CE is gaining high acceptance of novel strategy of sustainable development. Understanding the life cycle of CE is crucial to achieving the SDG 12 that calls on achieving economic growth and sustainable development requires reducing ecological footprint by changing the way we produce and consume goods and resources. LCA has been used for decision making applications in circular economy perspectives as a standardized tool by the International Organization of Standardization with the guidelines 'ISO 14040–44: 2006 Life Cycle Assessment' and 'ISO 14045: 2012 Eco-efficiency', where "Eco-efficiency" considers some economic aspects for calculating impacts of products (Furness et al., 2021). It is a fact that CE has also become an important field of sustainability, policy makers and academic research with increasing number of publications in scientific journals covering environmental and economic aspects (Geissdoerfer et al., 2017), with less emphasis on social benefits of CE.

It is urged in the academic research that CE focuses on technological solutions to economic problems. It is these premises that CE boost economy while protecting the environment. Circular economy is therefore a promising sustainable development strategy to overcome greenhouse gas emissions in African economies where emissions are projected to increase by more than 2.5 times by 2050 driven by large transformations in urbanization, industrialization, mineral extraction and electrification (Racki et al., 2014). Much research has been done and scholarly articles written on CE with potential environmental and economic impact; whereby the environmental benefits include waste diversion and emission reduction, reduced raw material use, reduced carbon and glasshouse gas emissions, and provides product regeneration (Ogunmakinde et al., 2022). The operational benefits include product quality improvements, efficiency. However, the sustainability social dimensions in the CE are marginalized. The social impact dimensions include job creation, social equity, workers' occupational health and safety, workers' rights of association, which are the major pillars of Social Life Cycle Assessment (S-LCA) studies (Luthin et al., 2024). Certainly the omission is due to methodological challenge for studying social assessment and its particularities and adaptations (Reinales et al., 2020).

The application of CE in Africa is relevant for sustainable development of many sectors such as manufacturing industries, construction, agriculture, and extractive. For example, the extractive industry in Africa is one of the major economic resources and production accounting between 4.6 – 86 percent contribution to GDP (Nhabinde & Heshmati, 2021). On the other hand, it accounts for about 50 percent of global GHG emissions a biodiversity loss owing to land use. Promoting circular economy in the extractive industry contribute to environmental protection through recycling of water use in the minerals processing and protection of biodiversity. CE is linked to sustainable development because it focuses on industrial applications with both product-oriented, natural resources and services, practice to better understand the limitations that countries focus on strategic investments of the circular economy with different outcomes such as re-use applications and waste management. The circular economy takes into consideration of trade-offs between economic development and environmental protection, industrialization sustainability and environmental management. It also preserves the environment by reducing the consumption of natural resources and prevent depletion of resources by recycling (Mhlanga et al., 2022; Razmjooei et al., 2023).



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It is argued that circular economy as a new paradigm for economic development offers significant environmental and economic benefits. It replaces the notion of end-of-life in production and consumption practices through reusing and recycling products and materials in production, distribution and consumption value chain (Berg et al., 2018). By so doing, CE complements the attainment of the 17 Sustainable Development Goals (SDGs) and in particular the SDG-12 which aim to “ensure sustainable consumption and production patterns” with indicators on the number of national policy instrument to promote sustainable production systems and consumption patterns. As such, CE implement SDG 12 by promoting recycling of production materials for sustainable environmental protection. This article examines the scientific publications on CE that promote a balanced environment, economic and social dimensions for sustainable development approaches.

Scholars (Andersen et al., 2022; Dominko et al., 2023; Gedam et al., 2021; Valdivia et al., 2021) around the globe look at the CE production systems, economic structures, environment and sustainability. Production systems could have significant impact on environment due to significant amount of energy and natural gas needed in production processes (Gaidajis & Kakanis, 2021). More often production and productivity as well as economic and environmental benefits are given more prominence to the expense of social sustainability.

Countries in the Sub-Saharan Africa face challenges of keeping and managing sustainable economic productivity, be it in the manufacturing, extractive industry or agriculture. The concept of circular economy provides potential solutions for addressing socio-environmental-economic challenge (Buda, 2022). Whereas Life cycle assessment (LCA) analytical tools are used for identification and evaluation of potential environmental impacts related to products, production processes, and environmental impacts that derive from emissions, wastes, resource use, and energy consumption (Finkbeiner et al., 2010); the impacts are categorized in the context of global warming potential (GWP), eutrophication, resource use, and others (Gaidajis & Kakanis, 2021), LCA does not cover the social impact. By so doing, pillars of sustainable development, environment, economic (Sala et al., 2016; Sharma, 2017) which has less focus on the social dimensions. Social Life Cycle Assessment (S-LCA) is a methodology to assess the social impacts of products and services across their life cycle (UNEP, 2009). It has become a useful framework for sustainability assessment of products and services (Kalvani et al., 2021). S-LCA include the social dimension to examine the subcategories related to impact on labor conditions, local community conditions, consumers’ well-being (Manik et al., 2013; UNEP, 2009). Social life cycle assessment therefore guides social impact evaluation on stakeholders throughout the life cycle of production and consumption. S-LCA method contributes to the assessment of social externalities of products (Tsalidis, 2022). It is argued that policymakers need to know where the social externalities of products occur in order to make informed decisions and therefore S-LCA is a necessary method in supporting African policy makers and governments in transforming their economies into circular economy (Tsalidis, 2022). The fundamental methodological boundaries of this study covers the relational processes on Circular Economy articles in scientific journals that considers Social Life Cycle Assessment (S-LCA) in Africa. While CE and S-LCA are well studied globally, there seems to be less published in Africa. However, there is insufficient publications and academic research to substantively provide evidence to inform policy decisions on the social benefits of CE. A bibliometric analysis is one of the credible methods to give a valuable reference focusing scientific publications (Singh et al., 2021).



3. Methodology

The study employs desk-top review as a technique of collecting data from secondary sources. The main objective of this paper is to highlight the intellectual structure of S-LCA in Circular economy (CE) in the context of Sub-Saharan Africa continent following research questions.

RQ1: What is the intellectual structure of S-LCA in Circular Economy in Africa?

RQ2: What research strands are dominant in Circular Economy?

RQ3: What are dominant institutions on Circular Economy and S-LCA in Africa?

3.1 Bibliometric analysis

A bibliometric analysis is a research method that utilizes quantitative analysis and statistics to describe patterns of publications within a given topic, field, institute, or country in the Social Science Citation Index (SSCI), Science Citation Index (SCI), World of Science or Scopus databases (Chiu, 2005). A bibliometric analysis of CE Social-Life Cycle Assessment (S-LCA) was therefore adopted as a methodology to identify, examine and shape the intellectual structure of circular economy in scientific literature in context of Africa. The bibliometric is an adopted but different methodology from the traditional systematic literature review (De Bakker, 2005). It is a developed method for investigating research from the subject of library and science knowledge. It grants the elaboration of network analysis, giving a clear image of the different links between various scientific studies, countries, authors, and keywords. Additionally, it figures out the co-occurrence of keywords and an overview of the different themes' evolution (Van Eck *et al.*, 2014; Sarkodie *et al.*, 2020). A bibliometric is a set of statistical methods used to measure and analyze the quality and quantity of articles, books, and other publications on a specified area of study from scientific documentations obtained from databases. This method aims to contribute to a better understanding of the scientific research in bibliometric research which synthesizes past and current research findings (Büyükkidik, 2022). This research method makes an objective assessment of the scientific literature using a quantitative approach in systematic and reproducible literature review. This method provides light for future research in the relevant literature as it gives a retrospective view of the published literature that evaluates academic contributions in a focal field (Guleria & Kaur, 2021). Although bibliometric analysis is used in many disciplines, there is little evidence on circular economy and social life cycle assessment

3.2 Database

Bibliometric studies use appropriate databases for retrieving published scientific documents (Ekundayo & Okoh, 2018; Furness *et al.*, 2021). This study adopted bibliometric analysis after searching for data in Scopus database as the appropriate database. This database has more than 23, 000 indexed journals in all scientific fields (Rojas-Sánchez *et al.*, 2023). In addition, Scopus database was preferred because it enables export of data to other programs more friendly as well as allowing search key terms in titles or titles/abstracts or name of the journal or name of the author or affiliation (Furness *et al.*, 2021).

3.3 Searching criteria.

A Boolean search technique was using search query that retrieved relevant published documents. The search query comprised of keywords: "circular" AND "economy" AND social AND life AND cycle AND Africa which brought 8 hits. Whereas the search query of key words “circular” AND “economy” AND “social” AND “life” AND “cycle” AND “assessment” brought on results of 414 hits. The search query inclusion criteria was publications in English language between 2005 -2024.

3.4 Bibliometric data

Data collection for this study was done through Scopus database retrieving information using a bibliometric technique from scientific publications over a specific period from 2015-2024. About 411 data were retrieved from Scopus database from 2015 -2024 which were exported to Microsoft Excel. The exported data included annual growth of publications, types of documents, languages, countries, authors, institutions, journals, citations, and funding agencies. The retrieved were analyzed data for bibliometric indicators using Rstudio v.4.3.3 software (2024-04-07) with bibliometrix R-package. Data were then imported into Rstudio and converted to a bibliographic data frame to create tables, figures and visualization maps as indicated in results and discussion section. The bibliometric method was useful for obtaining data on circular economy and social life cycle analysis or sustainability studies. The underlying theoretical frameworks include authorship, affiliation, country scientific production, citation, and co-citation.

4. Results and Discussion

The performed data analysis show titles of articles and journals, authors and their affiliations, and publications that have a greater relevance on Social Life Cycle Assessment on Circular Economy literature. The results were studied using bibliometric graphics and maps and using Rstudio software. A total of 414 from global datasets compared to 8 datasets obtained from Africa on circular economy and social life cycle assessment. Table 1. displays characteristics of the extracted information on the scientific studies based on the key research words.

Table 1: Main information

Description	Results
MAIN INFORMATION	
Timespan	2005 – 2024
Sources (Journal, Books, etc)	169
Documents	414
Annual Growth rate %	20,76
Document Average Age	2,76
Average citation per doc	28,86
References	29.776

DOCUMENT CONTENTS	
Keywords plus (ID)	2.891
Author's Keywords (DE)	1.197
AUTHORS	
Authors	1.537
Authors of single-authored docs	30
AUTHORS COLLABORATION	
Single-authored docs	30
Co-Authors per doc	4,31
International co-authorships %	37,2
DOCUMENT TYPES	
Article	250
Book	3
Book chapter	28
Conference paper	40
Conference review	2
Editorial	3
Letter	1
Note	1
Review	82
Short survey	4

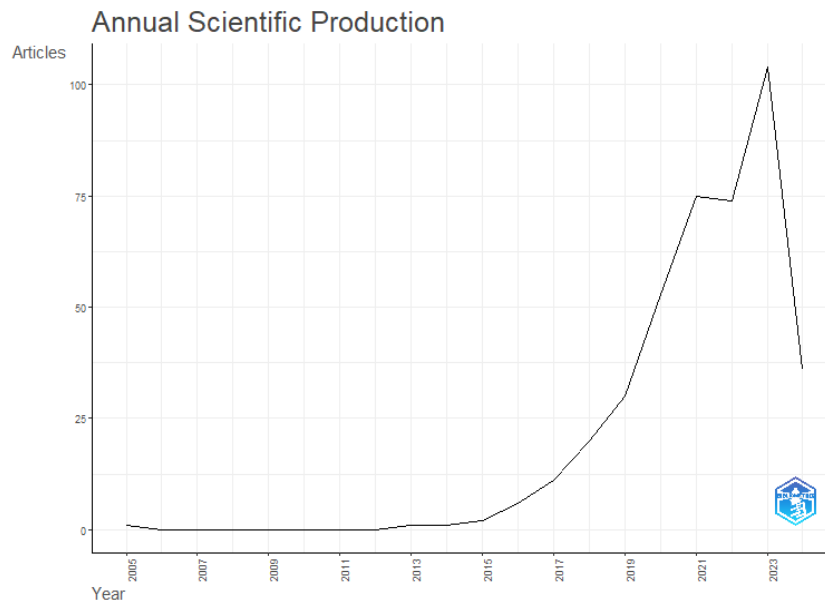
Source: Author's elaboration

Fig. 1 shows annual scientific production of articles on CE began slowly in 2015 and gained momentum from 2016 to 2023. This is probably because there was more emphasis on the global Sustainable Development Goal 8-9 that promote sustainable industrialization and economic growth, thus global and regional economic policies are geared towards sustainability.

Since circular economy is an emerging area, scholarly publications in the global literature started with low pace in 2005 and it reached the highest peak in 2023. The increase in scientific studies between 2015 to 2023 can be associated with the global emphasis on sustainability in production.

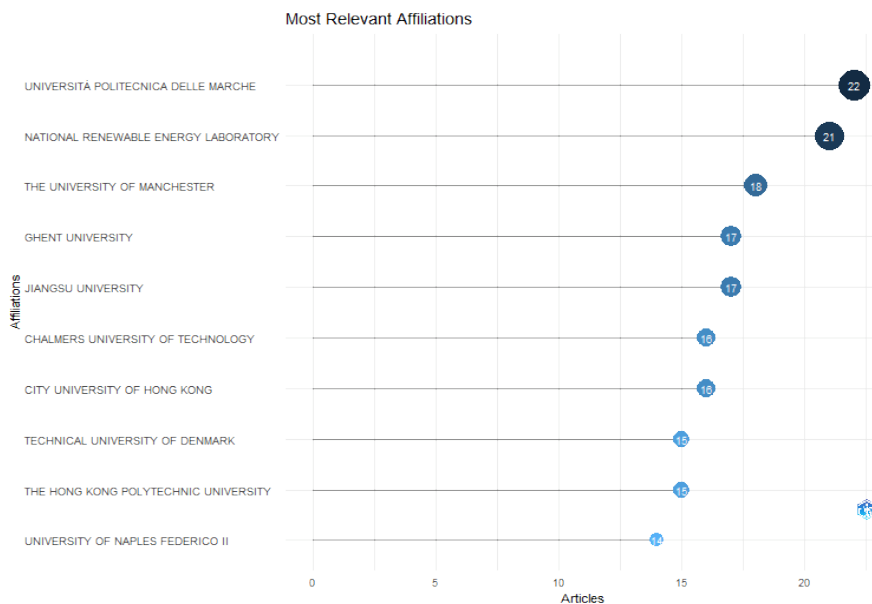
Our analysis shows that for a period between 2015- 2023, most CE and S-LCA publications were affiliated within European universities and China (Fig. 2). This implies there is sufficient capacity for CE knowledge generation in the European and Chinese universities.

Figure 1: Annual Scientific Production



Source: Author's elaboration

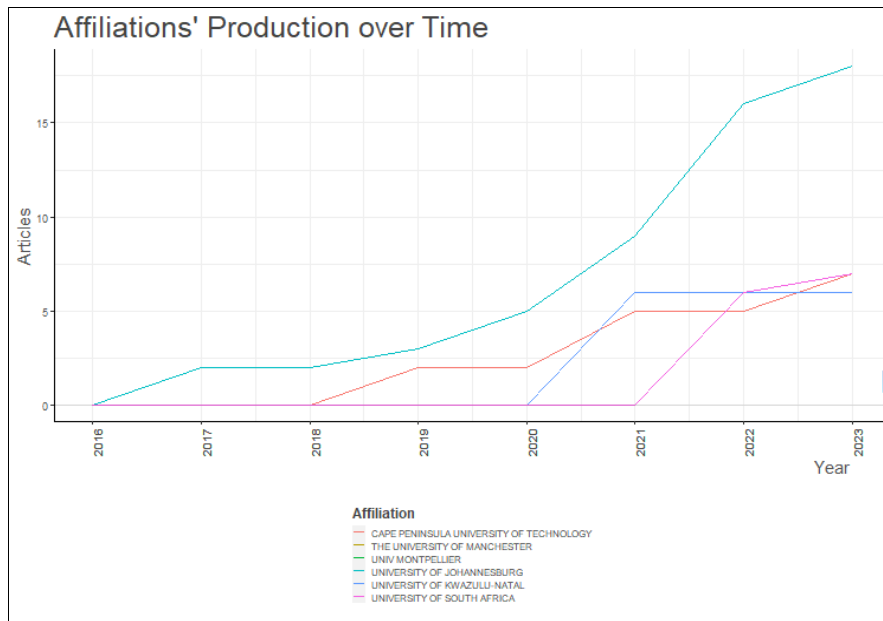
Figure 2: Most Relevant Institution Affiliations



Source: Author's elaboration

However, it was observed other than European and Chinese universities, very few publications are based on African CE and Social life cycle assessment. This is because low research and scientific publications on S-LCA on Circular Economy come from African universities Fig. 3.

Figure 3: Affiliations' Production Over Time

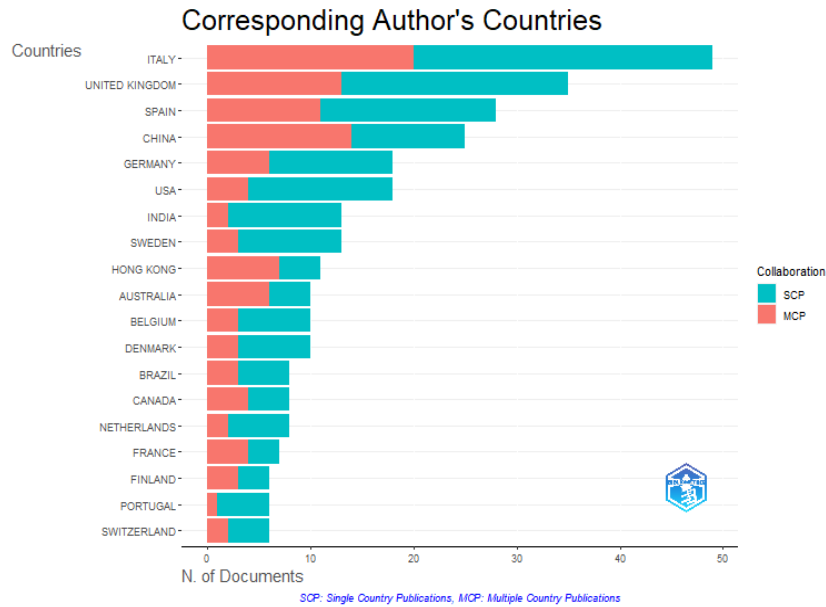


Source: Author's elaboration

This implies that as more African countries adopts CE, more research funding and capacity will be required in the African universities for scientific publication on CE and life cycle assessment. It is important only a few of African countries have made publications on CE and social life cycle assessment area. The most affiliated African universities with scientific knowledge production over time on CE and S-LCA in order of ranking are South Africa, Ghana, Nigeria Kenya, Rwanda, Tunisia, Malawi, Morocco, Senegal, Tanzania, Algeria, Zimbabwe and Mali which have not network with scholars in the North

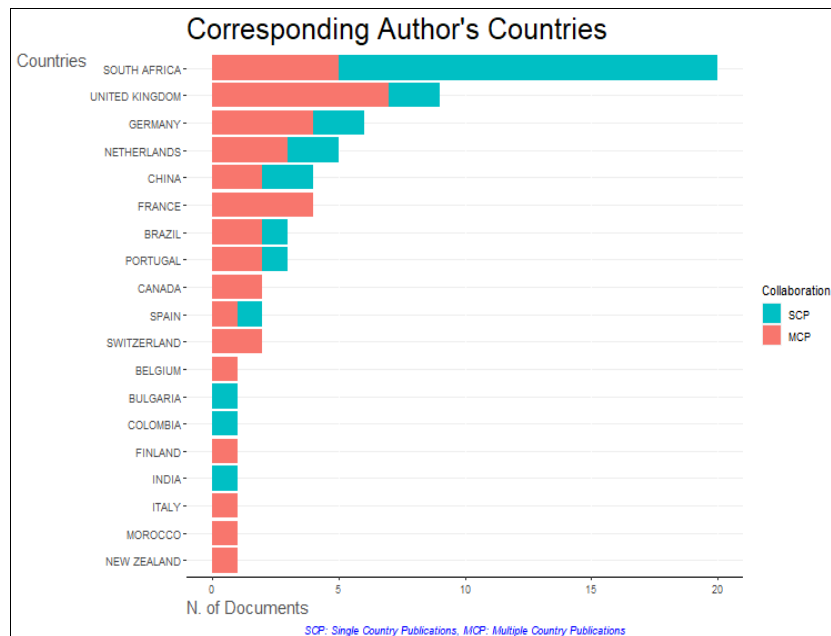
Figure 4 displays global corresponding author's countries on CE and life cycle assessment (LCA) with Italy, the United Kingdom, Spain, China, Germany and the US having more publications in scientific evidence on S-LCA in Circular Economy. It is also important to note that, Africa does not feature well in the CE global bibliometric analysis. However, South Africa (Fig.5) was observed with more multiple country publications on circular economy knowledge due to its importance for sustainability.

Figure 4: Corresponding Global Author's Countries



Source: Author's elaboration

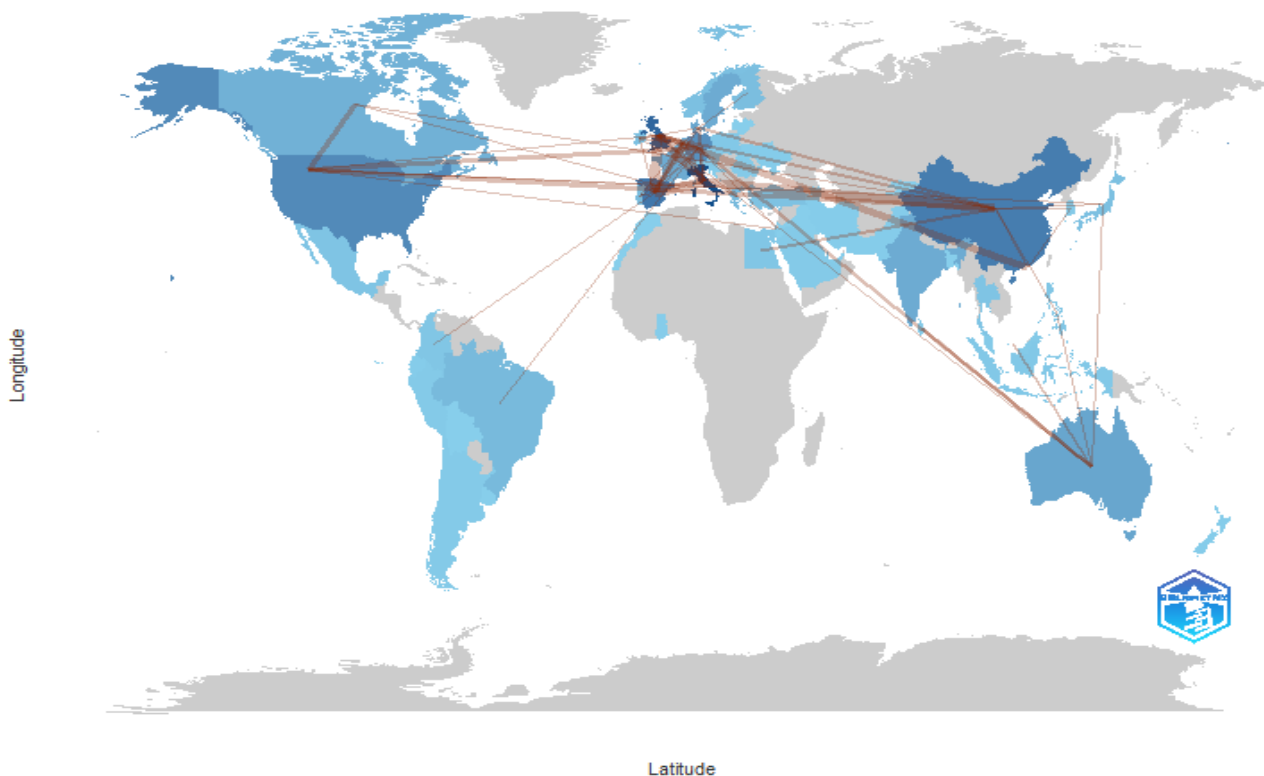
Figure 5: Corresponding African Author's Countries



Source: Author's elaboration

This paper shows an absence of North-South co-knowledge creation between African countries and the North (Fig.6). This throws a challenge and a waking call for African scholars to take interest and initiatives to network with the North publishers on this area for the African universities in particular to increase number of publications.

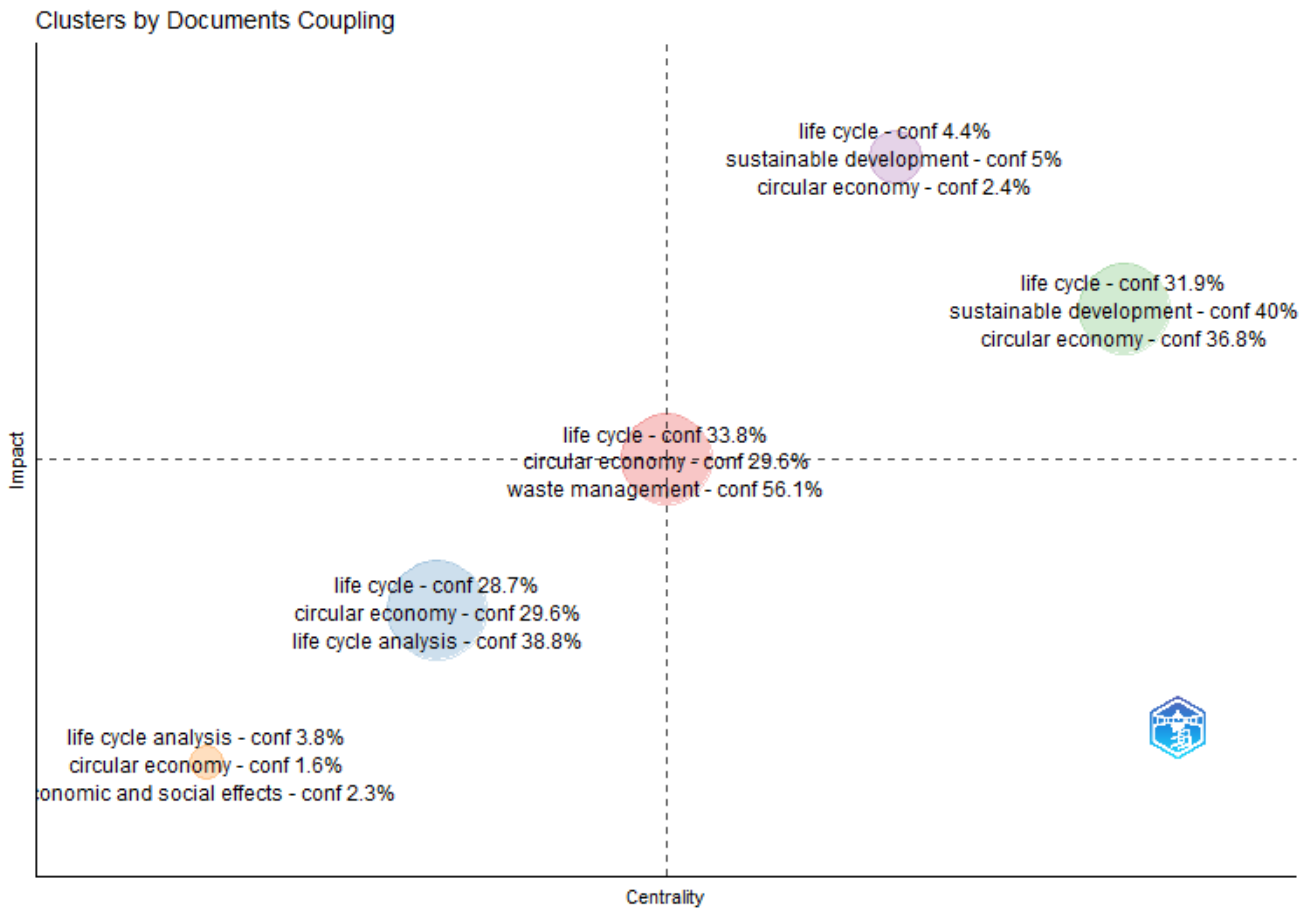
Figure 6: North-North vs North-south Co-Creation



Source: Author's elaboration

While bibliometric maps shows European countries with most authors who have identified S-LCA in circular economy publications over time from 2005 to 2024. Clusters by document coupling establishes relationship between documents with common work in bibliometric analysis (Martinho & Mourão, 2020). This is an indication of co-existence between CE and S-LCA for sustainability assessment.

Figure 7: CE Clusters by Document Coupling

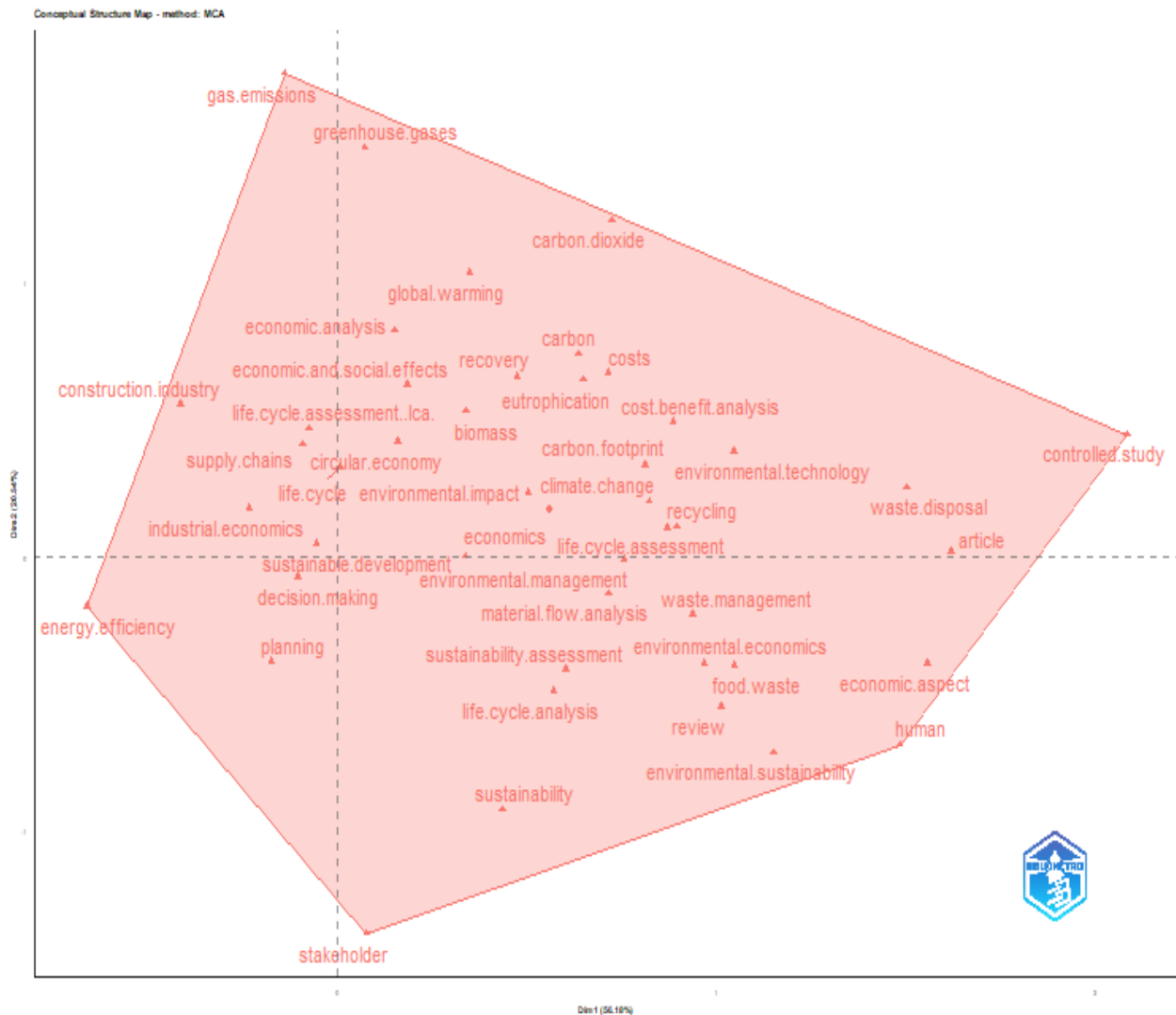


Source: Author's elaboration

Figure 7 indicates waste management (56.1%), life cycle (33.8%) and circular economy (29.6%) intersects with higher centrality. Whereas publications on life cycle (31.9%), sustainable development (40%) and circular economy (36.8%) are given high impact and centrality, thus it is important for the global, regional as well as national policies to develop and implement circular economies that considers the three sustainability pillars at hand.

The paper illustrates the dendrogram research strands including life cycle assessment, global warming, sustainable development, sustainability assessment, energy efficiency which all have positive or negative impact on stakeholders. Fig. 8 displays the dominant research strands for sustainability assessment including environmental, economic and social aspects for sustainability of major sectors such as construction industry, energy, industries, etc.

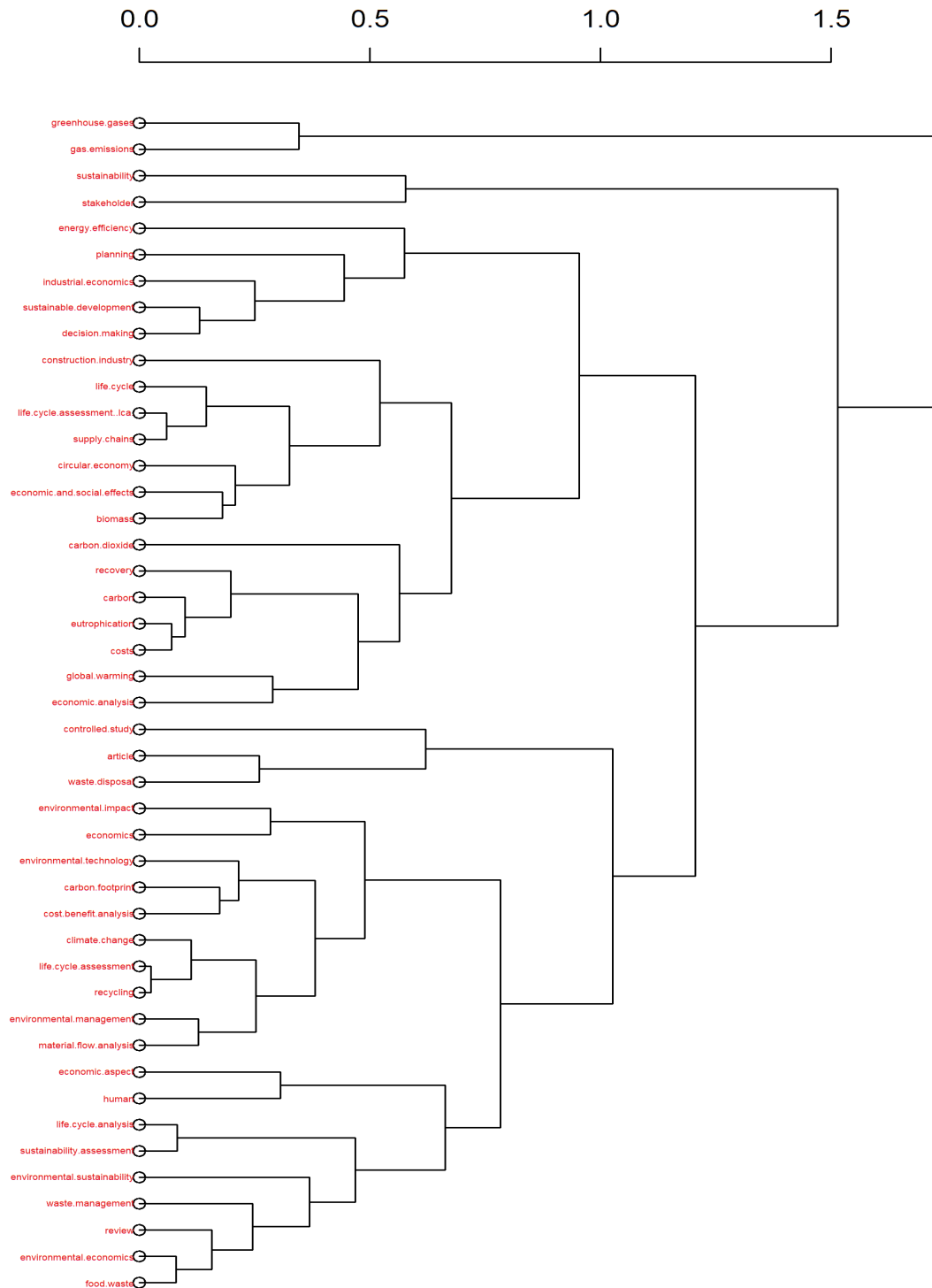
Figure 8: Dendrogram research strands



Source: Author's elaboration

It is equally important to note that bibliometric analysis is a useful research methodology for studying relational and co-existence of knowledge such as circular economy and social life cycle analysis, which have not taken the attention of African scholars and researchers. This finding has relevance for increasing co-knowledge creation and collaborations between south and north and or south-south scholars. On the other hand, it is worth noting the high concentration of publications in the European Union as Chinese universities. The bibliometric analysis has also shown implication that circular economy and S-LCA are relatively new in African perspectives as they are still emerging areas. Universities and research and development institutions ought to engage to publish on these researchable topics in the established research strands.

Figure 9: Dendrogram research strands



Source: Author's elaboration



Furthermore, the bibliometric analysis in this article shows that circular economy and social life cycle analysis have not taken the attention of African scholars and researchers. This finding has relevance for increasing co-knowledge creation and collaborations between south and north and or south-south scholars. This study implies that circular economy and S-LCA are relatively new in African perspectives as they are still emerging areas. Universities and research and development institutions ought to engage to publish on these researchable topics.

5. Conclusion and Policy Implications

The study results illustrate that CE assures not only the environment and economic sustainability but also social well-fare of actors in the value chain. This study observed paucity of S-LCA literature on Circular Economy in scientific journals. Following the limited publication, this study recommends for increasing articles of S-LCA on Circular Economy in the Sub-Saharan Africa (SSA), where industrialization is taking pace, environmental and economic concerns are of priority of academic and policy makers. Countries in the SSA face challenges of keeping and managing sustainable economic productivity, be it in the manufacturing, extractive industry or agriculture. The concept of circular economy provides potential solutions for addressing the multidimensional socio-environmental-economic challenge. The article contributes to both academic research and policy actions for undertaking the circular economy for the sustainable development in the Sub-Saharan Africa.

The increasing environmental and production ecosystems challenges call for policies that are promoting sustainable economic development, where production systems do not compromise with the current and economic growth of future generations. Scientists find new ways of production systems that make our ecological footprint compatible with global sustainability. The concept of the circular economy has brought relevant contributions to global sustainable development. The African researchers and scholars need to co-create knowledge and publications within the south-north as well as south-south collaborations.

This paper contributes to knowledge in many ways. First, by providing a bibliometric map of the CE publications and research in Africa, where we found none despite of the growing CE compared to European countries, Asia and Latin America. This is a challenge to African scientists and scholars to increase research and publication on CE, sustainability and social life cycle assessment. Our findings suggest that despite the increasing importance of Circular economy in Africa and the theoretical progress in scientific literature of sustainability and Social life cycle assessment, African scholars have not penetrated into the literature. As CE scholars accept the role of sustainability, governments and companies dealing with CE must uphold the pillars of sustainability.

While collaborative publications between south-south scholars and researchers is encouraged for the promoting implementation of CE practices, African scholars ought to take lead to inform policy decision making on CE and sustainability. The role of researchers is to generate scientific evidence to policy makers. This include the social life cycle assessment of CE long-term policies as well as the development of circular economy development framework. Since there is paucity of scientific research

and publication of CE and S-LCA in Africa, it is recommended for having co-knowledge creation between governments and academia whereby, the role of academia is to identify policies linked to a specific CE projects and conduct analysis for understanding and realizing providing informed solutions and recommendations to policy makers and implementation of sustainability policies tackling environmental challenges.

Conflict of Interest

I declare of not having any potential conflict of interest in the process from manuscript to publishing of this article.

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References

- Andersen, S. C., Birgisdottir, H., & Birkved, M. (2022). Life Cycle Assessments of Circular Economy in the Built Environment—A Scoping Review. *Sustainability (Switzerland)*, *14*(11). <https://doi.org/10.3390/su14116887>
- Berg, A., Antikainen, R., Hartikainen, E., Kauppi, S., Kautto, P., Lazarevic, D., Piesik, S., & Saikku, L. (2018). Reports of the Finnish Environment Institute -Circular Economy for Sustainable Development. *Reports of the Finnish Environment Institute*, *26*, 24. <https://helda.helsinki.fi/handle/10138/251516%0Ahttp://hdl.handle.net/10138/251516>
- Buda, G. (2022). Seven Businesses Using Principles of Circular Economy in Sub-Saharan Africa: Results of Field Research in Uganda. *Afrika Tanulmányok / Hungarian Journal of African Studies*, *16*(1), 5–20. <https://doi.org/10.15170/at.2022.16.1.1>
- Büyükkidik, S. (2022). A Bibliometric Analysis: A Tutorial for the Bibliometrix Package in R Using IRT Literature. *Journal of Measurement and Evaluation in Education and Psychology*, *13*(3), 164–193. <https://doi.org/10.21031/EPOD.1069307>
- Chiu, W.-T. (2005). *Bibliometric analysis of homeopathy research during the period of 1991 to 2003*. *63*(1), 3–23.
- Dominko, M., Primc, K., Slabe-Erker, R., & Kalar, B. (2023). A bibliometric analysis of circular economy in the fields of business and economics: towards more action-oriented research. In *Environment, Development and Sustainability* (Vol. 25, Issue 7). Springer Netherlands. <https://doi.org/10.1007/s10668-022-02347-x>
- Dunmade, I. (2021). *Journal of Popular Education in Africa : ISSN 2523-2800 (online)* *Journal of Popular Education in Africa : ISSN 2523-2800 (online)*. *5*(10), 53–60.
- Ekundayo, T. C., & Okoh, A. I. (2018). A global bibliometric analysis of Plesiomonas-related research (1990 – 2017). *PLoS ONE*, *13*(11), 1–17. <https://doi.org/10.1371/journal.pone.0207655>

- Finkbeiner, M., Schau, E. M., Lehmann, A., & Traverso, M. (2010). *Towards Life Cycle Sustainability Assessment*. 3309–3322. <https://doi.org/10.3390/su2103309>
- Furness, M., Bello-Mendoza, R., Dassonvalle, J., & Chamy-Maggi, R. (2021). Building the ‘Bio-factory’: A bibliometric analysis of circular economies and Life Cycle Sustainability Assessment in wastewater treatment. *Journal of Cleaner Production*, 323(September), 129127. <https://doi.org/10.1016/j.jclepro.2021.129127>
- Gaidajis, G., & Kakanis, I. (2021). *Life Cycle Assessment of Nitrate and Compound Fertilizers Production — A Case Study*.
- Gedam, V. V., Raut, R. D., Lopes de Sousa Jabbour, A. B., Tanksale, A. N., & Narkhede, B. E. (2021). Circular economy practices in a developing economy: Barriers to be defeated. *Journal of Cleaner Production*, 311(April), 127670. <https://doi.org/10.1016/j.jclepro.2021.127670>
- Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143(0), 757–768. <https://doi.org/10.1016/j.jclepro.2016.12.048>
- Goyal, S., Chauhan, S., & Mishra, P. (2021). Circular economy research: A bibliometric analysis (2000–2019) and future research insights. *Journal of Cleaner Production*, 287, 125011. <https://doi.org/10.1016/j.jclepro.2020.125011>
- Guleria, D., & Kaur, G. (2021). Bibliometric analysis of ecopreneurship using VOSviewer and RStudio Bibliometrix, 1989–2019. *Library Hi Tech*, 39(4), 1001–1024. <https://doi.org/10.1108/LHT-09-2020-0218>
- Kalvani, S. R., Sharaai, A. H., & Abdullahi, I. K. (2021). Social consideration in product life cycle for product social sustainability. *Sustainability (Switzerland)*, 13(20). <https://doi.org/10.3390/su132011292>
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127(April), 221–232. <https://doi.org/10.1016/j.resconrec.2017.09.005>
- Luis, E. C., & Celma, D. (2020). Circular economy. A review and bibliometric analysis. *Sustainability (Switzerland)*, 12(16). <https://doi.org/10.3390/SU12166381>
- Luthin, A., Traverso, M., & Crawford, R. H. (2024). Circular life cycle sustainability assessment: An integrated framework. *Journal of Industrial Ecology*, 28(1), 41–58. <https://doi.org/10.1111/jiec.13446>
- Manik, Y., Leahy, J., & Halog, A. (2013). Social life cycle assessment of palm oil biodiesel: A case study in Jambi Province of Indonesia. *International Journal of Life Cycle Assessment*, 18(7), 1386–1392. <https://doi.org/10.1007/s11367-013-0581-5>
- Martinho, V. D., & Mourão, P. R. (2020). Circular economy and economic development in the European Union: A review and bibliometric analysis. *Sustainability (Switzerland)*, 12(18). <https://doi.org/10.3390/SU12187767>
- Mhlanga, J., Haupt, T. C., & Loggia, C. (2022). Shaping circular economy in the built environment in Africa. A bibliometric analysis. *Journal of Engineering, Design and Technology*. <https://doi.org/10.1108/JEDT-03-2022-0175>
- Morales, M. E., & Belmonte-Urena, L. J. (2021). Theoretical research on circular economy and sustainability trade-offs and synergies: A bibliometric analysis. *2021 IEEE International Conference on Technology and Entrepreneurship, ICTE 2021*. <https://doi.org/10.1109/ICTE51655.2021.9584537>
- Nhabinde, S., & Heshmati, A. (2021). The Extractive Industry’s Impact on Economic Growth in SADC Countries. *SSRN*

Electronic Journal, 13586. <https://doi.org/10.2139/ssrn.3674307>

- Ogunmakinde, O. E., Egbelakin, T., & Sher, W. (2022). Circular Economy in Africa's Built Environment: A Conceptual Bibliometric Analysis. *IOP Conference Series: Earth and Environmental Science*, 1101(6). <https://doi.org/10.1088/1755-1315/1101/6/062016>
- Ogotu, M. O., Akor, J., Mulindwa, M. S., Heshima, O., & Nsengimana, C. (2023). Implementing circular economy and sustainability policies in Rwanda: Experiences of Rwandan manufacturers with the plastic ban policy. *Frontiers in Sustainability*, 4. <https://doi.org/10.3389/frsus.2023.1092107>
- Racki, J., Patel, P., & DeGroot, D. (2014). Africa 2050: Urbanization. *Global Journal of Emerging Market Economies*, 6(1), 15–34. <https://doi.org/10.1177/0974910113511191>
- Razmjooei, D., Alimohammadlou, M., Ranaei Kordshouli, H. A., & Askarifar, K. (2023). A bibliometric analysis of the literature on circular economy and sustainability in maritime studies. *Environment, Development and Sustainability*, 0123456789. <https://doi.org/10.1007/s10668-023-02942-6>
- Reinales, D., Zambrana-Vasquez, D., & Saez-De-Guinoa, A. (2020). Social life cycle assessment of product value chains under a circular economy approach: A case study in the plastic packaging sector. *Sustainability (Switzerland)*, 12(16). <https://doi.org/10.3390/su12166671>
- Rojas-Sánchez, M. A., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2023). Systematic literature review and bibliometric analysis on virtual reality and education. In *Education and Information Technologies* (Vol. 28, Issue 1). Springer US. <https://doi.org/10.1007/s10639-022-11167-5>
- Sala, S., Reale, F., Cristóbal-García, J., Marelli, L., & Rana, P. (2016). Life cycle assessment for the impact assessment of policies. Life thinking and assessment in the European policies and for evaluating policy options. In *Joint Research Centre* (Vol. 28380). <https://doi.org/10.2788/318544>
- Schaubroeck, T., Gibon, T., Igos, E., & Benetto, E. (2021). Sustainability assessment of circular economy over time: Modelling of finite and variable loops & impact distribution among related products. *Resources, Conservation and Recycling*, 168(November 2020), 105319. <https://doi.org/10.1016/j.resconrec.2020.105319>
- Sharma, P. (2017). A study on Life Cycle Assessment. *International Journal of Engineering and Advanced Technology (IJEAT)*, January 2019, 0–5.
- Singh, S., Trivedi, B., Dasgupta, M. S., & Routroy, S. (2021). A bibliometric analysis of circular economy concept in E-waste research during the period 2008-2020. *Materials Today: Proceedings*, 46, 8519–8524. <https://doi.org/10.1016/j.matpr.2021.03.525>
- Tsalidis, G. A. (2022). Type I Social Life Cycle Assessments: Methodological Challenges in the Study of a Plant in the Context of Circular Economy. *Sustainability (Switzerland)*, 14(22). <https://doi.org/10.3390/su142215031>
- UNEP. (2009). Guidelines for Social Life Cycle Assessment of Products. *Management*, 15(2), 104. http://www.unep.fr/shared/publications/pdf/DTIx1164xPA-guidelines_sLCA.pdf
- Valdivia, S., Backes, J. G., Traverso, M., Sonnemann, G., Cucurachi, S., Guinée, J. B., Schaubroeck, T., Finkbeiner, M.,



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<https://doi.org/10.1007/s11367-021-01958-2>

Yu, Z., Khan, S. A. R., & Umar, M. (2022). Circular economy practices and industry 4.0 technologies: A strategic move of automobile industry. *Business Strategy and the Environment*, 31(3), 796–809. <https://doi.org/10.1002/bse.2918>


Examining the dimensionality of Circular Economy metrics using Hierarchical Clustering on Principal Components

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Abstract

The Circular Economy (CE) indices have become a valuable tool for supporting the development of policies that provide information that reduces environmental pressures and impacts. However, highly dimensional data identifying many CE indicators is impractical in application. This paper aims to create a composite index of the CE indicators using the Hierarchical Clustering on Principal Components (HCPC) to extract the meaning of the CE indicators, as reducing dimensionality can improve understanding of indicators and metrics. The advantage of the HCPC methodology over principal components analysis (PCA) alone involves applying objective clustering techniques to the PCA results, which results in a better cluster solution. This study analysed a dataset of 61 indicators obtained from De Pascale, Arbolino, Szopik-Dezczyńska, Limosani, and Ioppolo (2021). The composite indices revealed the dimensions of industrial symbiosis (IS), CE strategies, and spatial applications of the CE and IS concepts. The bottom-up and top-down approaches for CE and IS strategies have been the main implementation approaches in different governments and regions.

Keywords: Circular Economy, Circular Economy indicators, industrial symbiosis, Hierarchical Clustering on Principal Components



1. Introduction

The circular economy (CE) is being touted as a promising solution to mitigate human activities' growing environmental and resource pressures (Bocken, De Pauw, Bakker, & Van Der Grinten, 2016). Several countries have adopted CE principles to achieve zero waste, a crucial goal for most economies as it reduces greenhouse emissions and environmental impacts from current linear waste production systems, making CE a crucial part of future strategies. A CE promotes system innovations to improve waste management resource efficiency and balance the economy, environment, and society (Kristensen & Mosgaard, 2020). The CE paradigm promotes autonomous production processes that reuse materials, generating increased interest in research and developing metrics for a circular shift. The interest in circularity indicators has led to extensive literature on CE. Currently, there are three levels of indicators for measuring the CE, i.e., micro (companies, product), meso (industrial symbiosis (IS), eco-industrial parks (EIPs)), and macro (governments, global, national, regional, city) (de Oliveira, Dantas, & Soares, 2021; De Pascale et al., 2021; Kristensen & Mosgaard, 2020; Moraga et al., 2019).

The rise of EIPs is a significant trend in the new industrial reality, aiming to promote environmental benefits and economic development through collaboration between companies (Felicio, Amaral, Esposto, & Durany, 2016). IS promotes a collective approach to competitive advantage across industries by integrating the physical exchange of materials, energy, water, and by-products into their business processes (Felicio et al., 2016; Geng, Fu, Sarkis, & Xue, 2012; Geng, Zhang, Ulgiati, & Sarkis, 2010; Jacobsen, 2006). Moreover, as such, EIPs must be able to promote IS.

The IS and CE are intricate subjects that require meticulous coordination due to the potential differences in preferences among various stakeholders. Therefore, policymakers must take a direct lead in pushing and driving IS and the CE. Through legislation, governments have managed to work towards putting CE plans into action. The Chinese government has played a significant role in the implementation of IS. They can define policy, and everyone within the country follows. CE, adopted in China to promote economic growth despite material and energy limitations, has garnered significant global interest from governments, international bodies, industrial associations, and corporations (Franklin-Johnson, Figge, & Canning, 2016). China leads the ranking of countries that have contributed most to the increasing growth rate in research, implementation, and extensive development of CE concepts in academia and politics (De Pascale et al., 2021; Geng et al., 2012). In 2008, China was the first country to adopt legislation to deploy CE strategies by enacting a specific law, confirming China's prominence (De Pascale et al., 2021; Geng et al., 2012; Moraga et al., 2019). Unlike China, the European Commission and its member countries use self-regulatory, bottom-up strategies for implementing CE strategies, which primarily rely on external factors (Cayzer, Griffiths, & Beghetto, 2017; Linder, Sarasini, & van Loon, 2017). The European Commission and member countries employ self-regulatory, bottom-up approaches to implement CE strategies, unlike China, which primarily relies on external factors.

CE is extensively researched, yet its practical application in economic initiatives remains a significant challenge. The extensive literature on CE necessitates rigorous analysis to ensure its relevance for functional purposes due to its disconnection. Several studies have come to the fore and have identified CE indicators (Argüelles, Benavides, & Fernández, 2014; de Oliveira et al., 2021; De Pascale et al., 2021; Parchomenko, Nelen, Gillabel, & Rechberger, 2019; Stanković, Janković-Milić, Marjanović, &

Janjić, 2021). The current set of circularity metrics is criticised for failing to fully capture the multidisciplinary and systemic nature of the CE (Stanković et al., 2021). These studies critically examine the dimensionality of CE indicators used in studies, highlighting their high dimensionality and potential limitations for practitioners. It suggests that reducing dimensionality can improve understanding of indicators and metrics. The research highlights the need for further knowledge of current research work. Therefore, this paper aims to create a composite index of the CE indicators using the Hierarchical Clustering on Principal Components (HCPC) to extract the meaning of the CE indicators. A dataset of 61 indicators developed in a previous paper identified by De Pascale et al. (2021) will be analysed using the HCPC to achieve the stated aim. This approach reduces data dimensionality and enables further understanding of the already-identified CE issues—IS, spatial applications of the CE concept, and CE strategies. Based on this dataset, the exercise attempts to cluster and classify indicators and papers to provide a structure for the problem.

The rest of the document is structured as follows: Section 2 offers an extensive review of Circular Economy (CE) indicators found in previous studies, providing an understanding of the many metrics and approaches used to evaluate CE performance. In Section 3, the data sources and methodology of this study are explored. The analytical frameworks used for CE indicator analysis and classification, such as principal component analysis (PCA) and hierarchical clustering, are explained. Part 4 presents the PCA analysis and hierarchical clustering findings, thoroughly studying the principal components and clusters found, thereby illuminating the underlying patterns and trends in the CE environment. Ultimately, Section 5 summarises the results derived from the research, emphasising the critical takeaways and implications for furthering CE initiatives.

2. Review of CE indicators in research

The growing resource demand and environmental issues drive a shift towards sustainable production and consumption (Gallego-Schmid, Chen, Sharmina, & Mendoza, 2020). Contemporary sustainability literature focuses on the potential of the CE to disrupt the unsustainable production and consumption linear economy (Kristensen & Mosgaard, 2020). However, considerable effort is required to transition toward a more CE (Parchomenko et al., 2019). In transitioning to this CE economy, indices are fast becoming a valuable tool to support the development of policies in providing information and reducing environmental pressures and impacts (De Pascale et al., 2021).

There three main levels of indicators for measuring CE in the literature so far are macro (global, national, regional, city, governments), meso (IS, EIPs), and micro (single firm, product) (de Oliveira et al., 2021; De Pascale et al., 2021; Geng et al., 2012; Kayal et al., 2019; Kristensen & Mosgaard, 2020; Linder et al., 2017; Mazur-Wierzbicka, 2021; McCarthy, Kapetanaki, & Wang, 2019; Moraga et al., 2019). de Oliveira et al. (2021) present a fourth dimension, nano (products). The lack of detailed measurement and documentation of the CE's progress can hinder understanding of the subject matter, creating barriers for actors at the specific CE level. Governments, policymakers, and business practitioners need more information on CE typologies to promote their business environment towards IS.

Transitioning to a CE requires significant effort, but a widely accepted framework for monitoring progress is lacking due to the vast and diverse areas covered by different assessment methodologies (Parchomenko et al., 2019). Despite the concept's lack

of clarity, CE focuses on defining action plans supported by specific indicators (Moraga et al., 2019). Transitioning to circular systems may not always lead to favourable alternatives, as potential environmental, economic, or social trade-offs may arise (de Oliveira et al., 2021).

Past CE research methodologies include reviews and empirical papers, with CE indicators classification, categorising and assessing existing work, with some articles developing a measurement method (de Oliveira et al., 2021; Kristensen & Mosgaard, 2020). Some of the approaches used in developing the metric for measuring CE indicators have included the (a) Principal Component Analysis and PROMETHEE (de Oliveira et al., 2021), (b) The Multiple Correspondence Analysis (MCA) (Parchomenko et al., 2019), and (c) indicators grouped by using a double classification: first according to the three spatial dimensions of sustainability –macro, micro and meso – then based on the 3R Core CE principles (De Pascale et al., 2021).

3. Data and methods

3.1 Data collection

The data for this research was obtained from De Pascale et al. (2021) through a systematic literature review, and a final list of indicators was extracted and grouped into three clusters: micro, meso, and macro. The review process involved selecting academic databases, search terms, and screening for practical purposes. Definitions and key concepts were determined, and the gathered material was summarised for future insights. The first step involved a systematic search for published CE indicator implementation studies.

The study used a methodological approach to define and select a sampling framework to review Circular Economy (CE) indicators. The framework was based on a time scale of 2000-2019 and a preliminary search of existing literature in Scopus and Web of Science databases. The results were refined using advanced search terms and keywords to identify the level of implementation of CE indicators at micro, meso, and macro spatial levels. A combination of selected keywords was chosen and compared with other CE reviews to ensure high-level significance. The keyword "Circular Economy" was selected to ensure coherence with the main topic. The academic databases were searched for spatial levels (micro, meso, and macro) and identified keywords for each level.

The classification system includes micro-level (company), meso-level (circular economy), and macro-level (city, country, region) terms, combining them to create a comprehensive understanding of the circular economy. The categories of indicator, index, assessment, evaluation, and measuring were incorporated into the literature as they are frequently used in CE studies. The study enumerated 61 articles that were used for the analysis.

3.2 Description of the Explanatory Variables

Table 1 shows the CE indicators identified by De Pascale et al. (2021). The study quantified these as categorical variables by creating lists of indicators to capture the various attributes of CE indicators. The multivariate approach implemented the Hierarchical Clustering on Principal Components (HCPC). This multivariate approach uses Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) on these attributes.

Table 1: Description of the dimensions of circular economy indicators

Attributes	Description
Approach:	It includes five subdivisions: Quantitative, qualitative, VBI, analytical tool, and theoretical results.
Application-level:	Refers to Product, Materials, (embodied) Energy, Components, Resource Waste (/waste streams), Product families, IS districts and networks, National, Regional, Provincial, the European Union (EU), and World Regions.
Core CE principles:	This category concerns the following Core CE principles: Reduce, Reuse, Recycle, Recover, Remanufacture, and Redesign
Sustainable Development Dimensions:	The dimensions are Environmental, Economic, and Social.
Level of CE indicators:	The spatial level applications of the circularity vary between macro - as a city, region, or nation, meso – as EIPs (eco-EIPs) and IS, and micro levels – as a single company or products using different methods and techniques.
Regions:	The study considered the following regions: the United States of America (USA), Europe, EU, Belgium, Netherlands, Italy, England/ United Kingdom (UK), India, Spain, Denmark, China, South Korea, Australia, Jordan, Japan, Switzerland, and World Regions.

Source: De Pascale et al. (2021)

3.3 Analytical techniques

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3.3.1 Multivariate Approach for Classification

- Principal Components Analysis

The study utilised Principal Component Analysis (PCA) to create typologies of CE indicators, a statistical method that reduces variables into smaller dimensions with minimal information loss (Jolliffe, 2002). PCA is a feature extraction technique that transforms an initial dataset of variables into a new uncorrelated dataset of orthogonal linear combinations (PCs). It aims to reduce the dimensionality of the data by obtaining the largest variance original variables, accounting for as much variation as possible (Jolliffe, 2002; Manly, 2005); this means that the first PC is the linear combination with the largest variance, while the second one is the linear combination with the second-largest variance, orthogonal to the first PC, etc. According to Costello and Osborne (2005), Varimax rotation simplifies the data's factor structure and makes its interpretation more straightforward and reliable. The authors argue that Varimax rotation, which produces uncorrelated factors, is superior to other rotation orthogonal methods like quartimax and equamax, as it cannot improve fundamental aspects of analysis like variance extraction. De Pascale et al. (2021) grouped the indicators using a double classification: first, according to the three spatial dimensions of sustainability – macro, micro, and meso– and then based on the 3R Core CE principles. The study mapped out dummy variables for indicators' attributes, such as level, country, analytical approach, application level, core CE principles, and sustainable development dimensions, but this approach failed to provide a clear group structure and dimensionality of the CE indicators in

the research. Jolliffe (2002) posits that the approach to using cluster analysis is vital in cases where such a group structure is lacking. Following Vyas and Kumaranayake (2006) and Achia, Wangombe, and Khadioli (2010), PCA was applied to the dummy variables to reduce the dimensionality of the data and categorise the CE indicators into distinct dimensions (Jolliffe, 2002). The PCA scores of CE indicators initially extracted and retained were followed by Varimax rotation for the above reasons. The study used the Kaiser-Maier-Olkin (KMO) and Bartlett's sphericity tests to assess the suitability of the variables for PCA. Hair, Black, Babin, Anderson, and Tatham (2006) suggest that researchers should consider variables suitable if their KMO values exceed 0.5, and Bartlett's sphericity test yields statistical significance at $p < 0.05$. PCs with Eigenvalues equal to or greater than 0.7 were retained, following Jolliffe (2002).

- Hierarchical cluster analysis

The study used Hierarchical Clustering (HCA) to classify CE indicators based on their similarity or dissimilarity. The technique uses Euclidean distance as the dissimilarity metric. The research used PCA on CE indicators' characteristics data, a hierarchical clustering method called Hierarchical Clustering on Principal Components (HCPC), to analyse the classification limits of CE indicators.

Hierarchical cluster analysis estimates the number of clusters in a dataset using Principal Component Analysis (PCA). The study uses Ward's criterion to perform hierarchical clustering on all principal components derived from PCA on the initial dataset of variables. Ward's method estimates hierarchical clusters that create equal and evenly sized clusters, with solutions estimated based on cases and variables.

Several studies, including Argüelles et al. (2014), have used HCPC and K-means clustering as candidate multivariate approaches. HCPC offers two main advantages: it applies objective clustering techniques to PCA results, resulting in a better cluster solution than factorial analysis alone, and Ward's classification enhances the robustness of the final clustering results. Garson (2009), cited in Yobe, Mudhara, and Mafongoya (2019), suggests that hierarchical clustering is the most suitable technique for data sets with less than 250 observations, indicating that datasets below this threshold are unsuitable. According to Kaur and Kaur (2013), the K-means algorithm outperforms the hierarchical algorithm on data sets with over 250 observations. However, preliminary analyses with a smaller sample size confirmed this, as the K-means clustering technique failed to adequately classify cases, leading to using the HCPC technique for multivariate classification.

4. Results

4.1 Descriptive Statistics of the Circular Economy Indicators

The dummy variables were created to measure the variation of the CE indicators accurately, enabling a quantitative analysis of their performance. Table 2 shows the descriptive statistics that measure the mean, standard deviation, minimum, and maximum. On average, the Quantitative Approach was extensively used, with a mean of 0.7458. The dominant application level is for product, and the mean value is 0.4068. The dummy variables were created to accurately measure the variation of the CE indicators, enabling a quantitative analysis of their performance.

Table 2: Descriptive statistics of the circular economy indicators

Variable	Mean	Std. Dev.	Min	Max
Approach:				
Quantitative	0.7458	0.4392	0	1
Qualitative	0.0847	0.2809	0	1
VBI	0.0678	0.2536	0	1
Analytical tool	0.0170	0.1302	0	1
Theoretical results	0.0169	0.1302	0	1
Application-level:				
Product	0.4068	0.4954	0	1
Materials	0.1695	0.3784	0	1
(embodied) Energy	0.0678	0.2536	0	1
Components	0.0678	0.2536	0	1
Resource Waste (/ waste streams)	0.0508	0.2216	0	1
Product families	0.0169	0.1302	0	1
Industrial symbiosis districts and networks	0.1017	0.3048	0	1
National	0.0508	0.2216	0	1
Regional	0.0847	0.2809	0	1
Provincial	0.0339	0.1825	0	1
EU	0.0678	0.2536	0	1
World Regions	0.0170	0.1302	0	1
Core CE principles:				
Reduce	0.5593	0.5007	0	1
Reuse	0.6610	0.4774	0	1
Recycle	0.8136	0.3928	0	1
Recover	0.1356	0.3456	0	1
Remanufacture	0.1864	0.3928	0	1
Redesign	0.1017	0.3048	0	1
Sustainable Development Dimensions:				
Environmental	0.8983	0.3048	0	1
Economic	0.9153	0.2803	0	1
Social	0.4746	0.5036	0	1
Level of CE indicators:				
Micro-level	0.5085	0.5042	0	1
Macro-level	0.2373	0.4291	0	1
Regions:				
USA	0.0508	0.2216	0	1
Europe	0.0169	0.1302	0	1
EU	0.1017	0.3048	0	1
Belgium	0.0508	0.2216	0	1
Netherlands	0.0339	0.1825	0	1
Italy	0.0169	0.1302	0	1
England/UK	0.0339	0.1825	0	1

Variable	Mean	Std. Dev.	Min	Max
Approach:				
India	0.0169	0.1302	0	1
Spain	0.0169	0.1302	0	1
Denmark	0.0169	0.1302	0	1
China	0.0169	0.1302	0	1
South Korea	0.0169	0.1302	0	1
Australia	0.0169	0.1302	0	1
Jordan	0.0169	0.1302	0	1
Japan	0.0169	0.1302	0	1
Switzerland	0.0169	0.1302	0	1
World Regions	0.0169	0.1302	0	1

Source: De Pascale et al. (2021)

Observations = 58. VBI is a Value-based indicator/Evaluation indicator system.

4.2 Multivariate analysis results

The results of the multivariate analysis, which employed the PCA, are presented below. Table 3 shows the level of the scree plot of the estimated PCs of CE indicators.

Table 3: Estimated PCs of circular economy indicators

Component	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
Initial eigenvalues:															
% of Variance	13.014	7.314	5.636	5.438	5.388	4.722	4.252	3.760	3.540	3.471	3.267	3.034	2.859	2.643	2.582
Cumulative %	13.014	20.328	25.964	31.402	36.790	41.512	45.764	49.524	53.064	56.535	59.801	62.835	65.694	68.337	70.980
Approach:															
Quantitative						-0.464			-0.426						
Qualitative						0.887									
Value-based indicator/Evaluation indicator system									0.824						
Analytical tool															
Theoretical results												0.910			
Core CE principles:															
Reduce	0.694													0.316	
Reuse													0.480		
Recycle								0.706							
Recover			0.731												
Remanufacture	-0.350					0.530		-0.499							
Redesign						0.604	-0.320				0.568				
Sustain. Develop. Dimensions:															
Environmental	0.448										0.356			0.358	
Economic							0.791								
Social	0.632														
Level of CE indicators:															
Micro-level	-0.857														
Macro-level	0.637														
Application-level:															
Product	-0.811														
Materials	-0.445	0.351						0.446							
Components					0.538			-0.601							
Resource Waste (/ waste streams)					0.836										
Product families					0.843										
Industrial symbiosis districts and networks													-0.524		0.453



Component	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
National				0.547						0.734					
Regional	0.549								-0.375						
Provincial									0.671						
(embodied) Energy			0.868												
Regions:															
USA		0.513		0.743											
Europe			0.769												
EU		0.342		0.441								0.636			
Belgium	-0.377													-0.309	
Netherlands														0.826	
Italy											0.847				
England/UK		0.889													
India		0.888													
Spain							-0.808								
Denmark															
China	0.694								0.315						
South Korea															
Australia													-0.846		
Jordan															0.858
Japan				0.897											
World Regions										0.911					

Source: De Pascale et al. (2021)

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization.

The coefficients with a value of 0.3 and less were suppressed and not displayed in the estimated PC scores results.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.291; Bartlett's Test of Sphericity Approx. Chi-Square = 1301.698; df = 903; Sig. = 0.000.

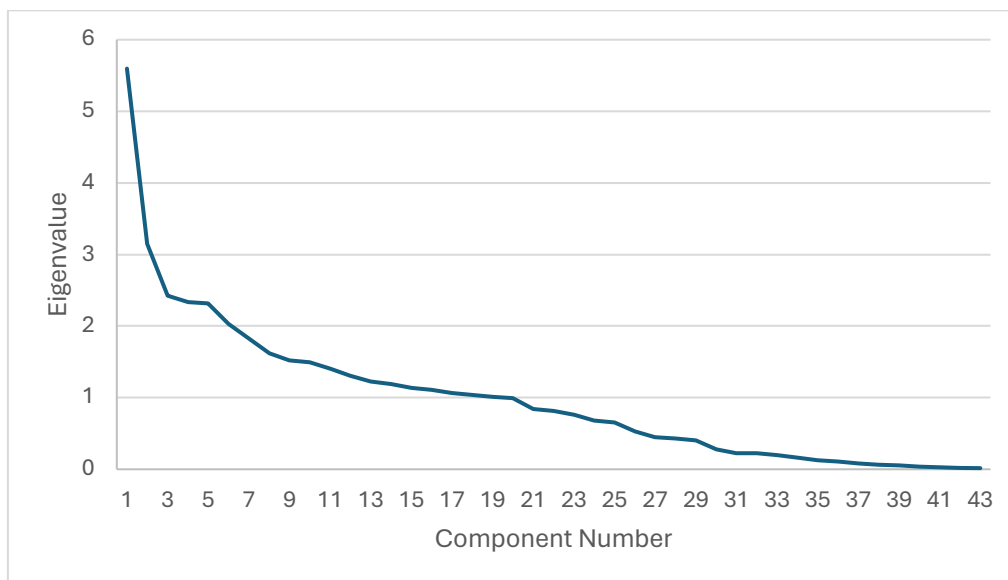
PC 14, which explained 2.77% of the variance, was dropped from the analysis because the variation explained by the factor loadings did not make economic sense.

The application of PCA on the attributes of the CE indicators produced initial Eigenvalues 1.015, 19 PCs that explained a cumulative 80.941% of the variance in the dummy variables but only retained 15 PCs for the analysis Table 4. This study dropped PC 14 – which accounts for 2.77% – from the analysis because the variation it explained did not make economic sense. Therefore, the total variance explained by the PCs used in this analysis was 70.92%. The study dropped two variables – the meso-level of CE indicators and EIPs – because the rotation failed to converge in estimating the PCA's rotated component matrix.

The study utilised KMO and Bartlett's sphericity measures to assess the feasibility of incorporating 58 cases of indicators into a dataset. The KMO measure showed a 0.291 value, indicating a significant relationship between variables. Bartlett's test showed a $p < 0.001$ correlation, indicating variables could be factored in. Varimax with the Kaiser normalisation rotation method improved PC interpretation.

The scree plot below shows the estimated PCs (Figure 1). The study plots Eigenvalue against PCs, with PC1 having the highest score loadings and a high Eigenvalue. PC-2 explains less variation and has a lesser Eigenvalue. The study estimates diminishing declines of Eigenvalue with other PCs, using a cut-off of PCs with an Eigenvalue of 1 and considering PCs that met this criterion.

Figure 1: Scree plot of the estimated PCs of CE indicators



Source: Author's elaboration

The first principal component (PC-1) explains 13.01% of the variance in the indicators of CE, with the estimated component loadings expressed in the following equation:

$$\begin{aligned}
 PC-1 = & 0.694 \text{ Reduce CE principles} - 0.350 \text{ Remanufacture CE principles} \\
 & + 0.448 \text{ Environmental Sustainable Development Dimensions} \\
 & + 0.632 \text{ Social Sustainable Development Dimensions} - 0.857 \text{ Micro - level of CE indicators} \\
 & + 0.637 \text{ Macro - level of CE indicators} - 0.811 \text{ Product Application - level} \\
 & - 0.445 \text{ Materials Application - level} + 0.549 \text{ Regional Application - level} - 0.377 \text{ Belgium} \\
 & + 0.694 \text{ China.}
 \end{aligned}$$

In PC-1, Reduce CE principles, Social Sustainable Development Dimensions, and Macro-level CE indicators were the most dominant loadings variables. Therefore, this PC was named *Reduce CE principles*. PC-2 explains 7.314% of the variance, and the most dominant loadings were on the Materials Application-level and in the USA, EU, England/UK and India regions; this PC was thus called *Materials Application-level*. PC-3 accounts for 5.64% of the variance with dominant loadings on Recover CE principles, Energy (embodied) Application-level and the EU region and was intuitively named Energy (embodied) Application level. PC-4 was called *National Application-level* because the most significant loading for this component was the National Application Level; the other loading for this coefficient was the USA and EU regions.

The fifth component, PC-5, which accounted for 5.34% of the variation in the PC estimation, was called *Diverse Application-level* because it had loading for Application-Level variables, namely Components, Resource Waste and Product families. The sixth component, PC-6, *Recover and Redesign CE principles Qualitative Approach*, accounted for 4.72% of the variation and had significant loadings on qualitative – and negatively so on quantitative – approach, as well as Recover and Redesign CE principles. The seventh component, PC-7, was named *Sustainable Development Economic Dimension* because this PC had dominant positive loadings on the Sustainable Development Economic. The study revealed that Redesign CE principles, specifically PC-8, accounted for 3.76% of the study's variation. PC-8 had positive coefficients for Recycle and Remanufacture CE principles, positive coefficients for Materials and Components Application-level, and negative coefficients for the research approach. PC-9 had significant coefficient loadings on regional and provincial variables and China region. Hence PC-9 was called *Approach Value-based indicator/ Evaluation indicator system* and accounted for 3.54% of the variance.

PC-10, named *Application Level National and World Regions*, had dominant coefficient loadings of 0.734 Application Level National and 0.911 for the World regions, accounting for 3.47% of the variation. The next component, PC-11, accounted for 3.26% of the variation. The variables Redesign CE principles and Environmental Sustainable Development Dimensions had positive coefficient loadings of 0.568 and 0.356, respectively; this PC was called *Redesign CE principles Environmental Sustainable Development Dimensions*. PC-12 is accounted for by 3.034% of the variation and represents the dimension of the CE indicators with significant coefficient loadings on the variables for the Theoretical results approach and the EU region; this PC was thus identified as the *Theoretical results approach*. PC-13, accounting for 2.86%, showed positive coefficient loadings on Reuse CE principles, while negative coefficient loadings were observed on IS districts, networks Application-level, and Australia.

The next component, *Reduce CE principle and Environmental Sustainability Development Dimensions*, accounted for 2.64% of the variation. The component loadings of the coefficients on the variables are as follows:

$$\begin{aligned}
 PC-14 = & 0.316 \text{ Reduce CE principles} \\
 & + 0.358 \text{ Environmental Sustainability Development Dimensions} - 0.309 \text{ Belgium} \\
 & + 0.826 \text{ Netherlands.}
 \end{aligned}$$

The PC-16, the Application-level PC, represents coefficient loadings on IS districts and networks in the Jordan region, exhibiting minimal variation in CE indicator scores.

4.2.1 Hierarchical clustering

The HCPC analysis uses the HCA to analyse the PCA outcome. Figure 2 displays a dendrogram representing the HCA result, with the vertical axis representing observations and clusters and the horizontal axis representing the distance between them. Similar observations are grouped based on their dissimilarity, allowing for better understanding and classification.

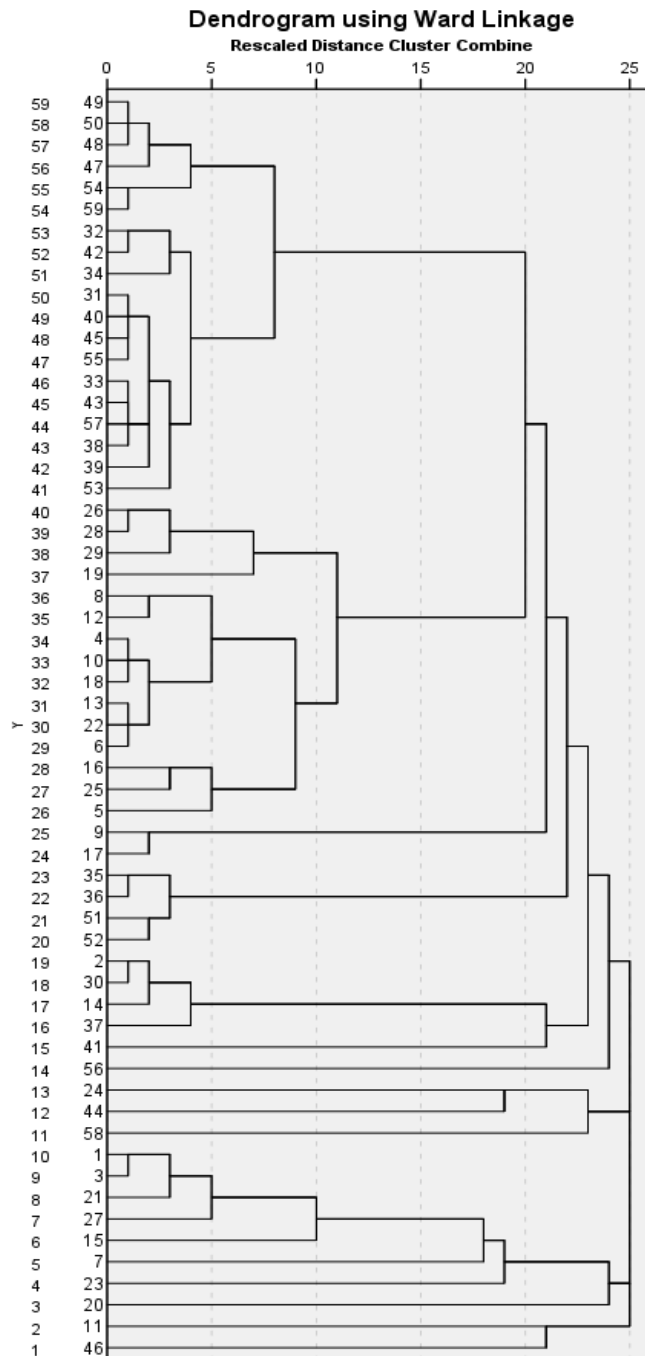
Figure 2 shows a hierarchical dendrogram, where PCs are extracted and arranged into new clusters along the y-axis. Each branch represents connections, and the closer they are to each other, the more related they are. For instance, PC-6 and 15 are members of one cluster from a branch that splits into two, similar to the next group comprising PCs 13, 16, 9, and 8. However, the group composed of PC-2 and PC-4 is far apart in the chart.

An imaginary cut-off point in a dendrogram creates a cluster, which becomes larger and more heterogeneous as the branching diagram moves up. This results in more variation within the cluster. For example, two variables next to each other, like PC-6 and PC-15, will be similar. Expanding the group, like one large group with PCs 6, 15, 13, 16, 9, 8, 5, 7, and 1, will result in more similar observations than grouped observations in another branch. However, there is still much variation in each group, necessitating a trade-off decision on where to make the cut-off.

The study identifies two clusters in a dendrogram, with each observation in the clusters being similar. Large clusters, with more observations, are more heterogeneous. The choice of meaningful clusters depends on the degree of change in grouping due to slight deviations. The study suggests a two-cluster solution on the dendrogram, while Figure 3 has a four-cluster solution. The ideal variation is minimally affecting solutions. The study's findings align with this rationale.

Clustering solutions by variables

Figure 2: Hierarchical clustering and initial partition solutions by variables



Source: Author's elaboration on Linkage method—Ward's method. Euclidean distance of all elements

Table 4 shows references with their title and country for each cluster that result from the dendrogram in Figure 2. The PC-16, also known as the Application-level PC, represents coefficient loadings on IS districts and networks in the Jordan region, exhibiting minimal variation in CE indicator score (Guo-gang, 2011; Li & Su, 2012; Xiong, Dang, & Qian, 2011). Other studies in this set of results focus on industrial parks (Felicio et al., 2016; Geng, Zhang, Côté, & Fujita, 2009; Geng et al., 2010; Tiejun, 2010; Wenbo, 2011; Zhao, Guo, & Zhao, 2018), while the case studies included (Adibi, Lafhaj, Yehya, & Payet, 2017; Bovea & Pérez-Belis, 2018; Huysman, De Schaepe-meester, Ragaert, Dewulf, & De Meester, 2017; Huysman et al., 2015; Sałabun, Palczewski, & Wątróbski, 2019). The countries that dominated the studies included China, EU members, Belgium, and the USA.

Table 4: List of clusters by references, article and countries

Cluster	Reference	Country
1	Das, Yedlarajiah, and Narendra (2000)	
	Lee, Lu, and Song (2014)	
	MacArthur (2015)	Europe
	Huysman et al. (2017)	Belgium; England
	Mohamed Sultan, Lou, and Mativenga (2017)	UK; EU; USA; India
	Azevedo, Godina, and Matias (2017)	
	Mesa, Esparragoza, and Maury (2018)	
	Vanegas et al. (2018)	Belgium
2		
	Nelen et al. (2014)	
	J. Y. Park and Chertow (2014)	USA
		EU
	Huysman et al. (2015)	Belgium
	Scheepens, Vogtländer, and Brezet (2016)	Netherlands
	Cayzer et al. (2017)	
	Figge, Thorpe, Givry, Canning, and Franklin-Johnson (2018); Franklin-Johnson et al. (2016)	
	van Schaik and Reuter (2016)	
	Linder et al. (2017)	
	Di Maio, Rem, Baldé, and Polder (2017)	Netherlands
	Favi, Germani, Luzi, Mandolini, and Marconi (2017)	
	Adibi et al. (2017)	
	Figge et al. (2018)	
	Marconi, Germani, Mandolini, and Favi (2019)	
Mandolini, Favi, Germani, and Marconi (2018)		

Cluster	Reference	Country
	Cong, Zhao, and Sutherland (2019)	
	Zwolinski, Lopez-Ontiveros, and Brissaud (2006)	
	Jacobsen (2006)	Denmark
	Karlsson and Wolf (2008)	
	Geng et al. (2010)	China
	Sařabun et al. (2019)	
	Wen and Li (2010)	China
	Geng et al. (2009)	China
	Su, Heshmati, Geng, and Yu (2013)	China
	Geng et al. (2012)	China
	Wenbo (2011)	China
	Li and Su (2012)	Beijing - China
	Wen and Li (2010)	China
	H.-S. Park and Behera (2014)	South Korea
	Pagotto and Halog (2016)	Australia
	Felicio et al. (2016)	
	Zhao et al. (2018)	China
	Tiejun (2010)	China
	Geng, Liu, Liu, Zhao, and Xue (2011)	China
	Guo-gang (2011)	China
	Faizi, Rashid, Sařabun, Zafar, and Wątróbski (2018)	China
	Chun-rong and Jun (2011)	
	Qing, Qiongqiong, and Mingyue (2011)	China
	Xiong et al. (2011)	China
	Wu, Shi, Xia, and Zhu (2014)	China
	Haas, Krausmann, Wiedenhofer, and Heinz (2015)	EU Members
	Haupt, Vadenbo, and Hellweg (2017)	Switzerland
	Tisserant et al. (2017)	World Regions
	Moraga et al. (2019)	
	Mayer et al. (2019)	EU Members
	Fregonara, Giordano, Ferrando, and Pattono (2017)	Italy
	Moriguchi (2007)	EU; USA; Japan
3	Bovea and Pérez-Belis (2018)	Spain
	Kayal et al. (2019)	Jordan
4	Smol, Kulczycka, and Avdiushchenko (2017)	EU Members

Source: Author's elaboration

5. Discussion

Firms, governments, and regional authorities have started recognising environmental benefits and economic growth through collaboration between companies that flow directly from IS—generating better collective benefits than could have been achieved from the sum of all individual benefits combined (Bocken et al., 2016; Felicio et al., 2016; Jacobsen, 2006; Karlsson & Wolf, 2008). IS offers several benefits, including reducing waste disposal costs by converting waste into by-products for other industries, enabling innovation and process development, leading to increased profitability, and benefiting from the geographical proximity of businesses (Bocken et al., 2016; Karlsson & Wolf, 2008).

Creating a composite index can help better understand the CE indicators and measure the development of the CE guides. Applying PCA based on the above data reduced the dimensionality of the 58 – previously 61 – CE indicators in De Pascale et al. (2021) to 15 PCs, which could be classified. Table 4 shows the list of the HCPC composite indices based on the title of the articles and the regions where these studies took place. This technique provides a structural approach to navigating the multifaceted realm of circular economy indicators.

The HCPC reduced estimated PCs, resulting in terminal elements of the dendrogram from hierarchical classification. The dendrogram yielded four clusters of CE indicators, determining the group's CE performance based on specific characteristics, like countries with similar features (Stanković et al., 2021). The understanding of regional and global trends is improved by this hierarchical classification, which provides a systematic framework for identifying distinctive groupings within the CE landscape.

The areas in this first cluster include European countries (Huysman et al., 2017; McCarthy et al., 2019; Mohamed Sultan et al., 2017; Vanegas et al., 2018), the USA (Mohamed Sultan et al., 2017) and India (Mohamed Sultan et al., 2017). This first cluster displays a variation of approaches within different national contexts, spotlighting geographical concentrations of CE initiatives. Due to the need to respond to the impacts of unsustainable linear production methods, CE approaches will likely provide a compelling driver across many different governments, countries and regions. Das et al. (2000), Lee et al. (2014), and Mesa et al. (2018) in the first cluster did not focus on a particular region in their research. The first two of these studies focused on estimating the end-of-life product disassembly effort and cost and assessing product End-Of-Life performance. The last of the two studies focused on developing a sustainable circular index. The diverse research focus within this cluster illustrates the breadth of CE initiatives, spanning multiple geographical contexts and ranging from index development to product lifecycle analysis.

The following aggregation obtained after applying the HCPC, i.e. Cluster 2, shows studies in Europe (Di Maio et al., 2017; Haas et al., 2015; Huysman et al., 2015; Jacobsen, 2006; Mayer et al., 2019; Scheepens et al., 2016), the USA (J. Y. Park & Chertow, 2014), South Korea (H.-S. Park & Behera, 2014), China (Faizi et al., 2018; Geng et al., 2012; Geng et al., 2011; Geng et al., 2009; Geng et al., 2010; Guo-gang, 2011; Li & Su, 2012; Su et al., 2013; Tiejun, 2010; Wen & Li, 2010; Wenbo, 2011; Wu et al., 2014; Xiong et al., 2011; Zhao et al., 2018), Australia (Pagotto & Halog, 2016) and the World Regions (Tisserant et al., 2017). This second cluster has a broad geographical scope and implicates the variable approaches adopted by different countries and regions and the global reach of CE initiatives. Most of these primarily focused on industrial parks (Felicio et al.,

2016; Geng et al., 2009; Geng et al., 2010; Tiejun, 2010; Wenbo, 2011; Zhao et al., 2018). Industrial parks in China are for environmental and economic growth benefits, and collaboration between companies is critical in realising this achievement; thus, it is crucial to promoting IS. According to Felicio et al. (2016), the IS in EIPs requires the implementation of intense broker involvement. Impediments to the level of symbiosis during operations usually are market changes and technological advancement. Wenbo (2011) further posits that developing CE is the only way to realise the new industrialisation, and building EIPs is an essential means of promoting CE performance. The next area of focus in this cluster that received attention from researchers is that of IS, which includes research done in China (Geng et al., 2009), Denmark (Jacobsen, 2006), South Korea (H.-S. Park & Behera, 2014) and Australia (Pagotto & Halog, 2016). The importance of collaborative efforts in promoting circular economy performance—particularly in industrialised nations—is highlighted by the focus on industrial parks as hubs for sustainability initiatives.

The cluster solution suggests a lack of coverage of CE approaches, leading to a lack of studies. These approaches may have been developed to address a specific CE problem but were never expanded to other areas. They may also be challenging to set up in regions with similar CE issues, becoming unsupported and ineffective; this could be the case with two clusters. Nonetheless, the research gaps identified in CE indicate potential areas for further research and strategic intervention to advance more comprehensive and successful circular economy initiatives.

Cluster 3 comprises two studies (Fregonara et al., 2017; Moriguchi, 2007) of the HCPC aggregates. Studies conducted in Italy, the EU, the USA, and Japan examined resource productivity indicators and environmental impact. The need to address environmental issues, such as waste reduction and pollution, is a common response to widely accepted action plans. This third cluster explores resource productivity and environmental impacts, highlighting the ongoing need to address pressing environmental issues across geographic boundaries through sustained research and policy interventions.

Cluster 4 classifies the studies focusing on circular design guidelines in Spain (Bovea & Pérez-Belis, 2018), measuring a firm's circularity in the water industry in Jordan (Kayal et al., 2019), and CE indicators concerning eco-innovation in the EU member countries (Smol et al., 2017). This final cluster focuses on particular CE initiatives, such as industrial circularity, design guidelines, and eco-innovation, and illustrates the various strategic approaches used in multiple industries and regions. Our journal adheres to the APA 7th edition style for citations and references. Please ensure that all citations in the text and the reference list comply with this format.

6. Conclusions

The study used HCPC to identify clusters in a dataset with 61 CE indicators, retaining 58 after data cleaning, utilising complementarities between clustering and principal components methods. The first stage estimation of PCA only allowed for 15 of the 16 PCs to be meaningfully interpreted. The HCPC clustering technique from four clusters provided a better cluster solution than the principal components method, identifying research dimensions such as IS, CE strategies, and spatial arrangement.

Policy recommendations for IS and CE subjects require coordination among stakeholders with diverse agendas. Policymakers must lead the implementation of policies related to these subjects. Despite different approaches, governments and regions are adopting actions that drive the agenda forward. China has successfully used a top-down approach to policy implementation, allowing the government to prescribe policies and have everyone adopt them. This top-down approach could be a crucial lead for other countries seeking similar practices to follow. China's top-down approach could serve as a model for other countries.

The bottom-up approach to policy implementation has been successful in European countries, with governments, regions, and businesses realising the benefits of adopting such policies. These systems receive support and spread quickly, often guided by an overarching goal. The central role of government is critical in implementing regulations that fit the purpose, ensuring that well-established and beneficial systems receive support and spread quickly.

The specific impacts of top-down and bottom-up policy approaches on IS and CE projects in many geographic and cultural situations may be the subject of future research. Furthermore, examining how well various stakeholder coordination mechanisms work to implement policies will shed light on how to improve cooperation and alignment in IS and CE to achieve shared objectives. Furthermore, looking into possible synergies between top-down and bottom-up techniques may provide insightful information about optimising policy frameworks for scalability and maximum efficacy.

Understanding how to successfully negotiate the complicated terrain of corporate environmentalism can be improved by looking into these areas further, which will ultimately lead to better-informed decision-making and sustainable worldwide practices.

7. Conflict of Interest

The author has no conflict of interest to declare.

6. References

- Achia, T. N., Wangombe, A., & Khadioli, N. (2010). A logistic regression model to identify key determinants of poverty using demographic and health survey data. *European Journal of Social Sciences*, 13(1), 38-45.
- Adibi, N., Lafhaj, Z., Yehya, M., & Payet, J. (2017). Global Resource Indicator for life cycle impact assessment: Applied in wind turbine case study. *Journal of Cleaner Production*, 165, 1517-1528.
- Argüelles, M., Benavides, C., & Fernández, I. (2014). A new approach to the identification of regional clusters: hierarchical clustering on principal components. *Applied Economics*, 46(21), 2511-2519.
- Azevedo, S. G., Godina, R., & Matias, J. C. d. O. (2017). Proposal of a sustainable circular index for manufacturing companies. *Resources*, 6(4), 63.
- Bocken, N. M., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of industrial and production engineering*, 33(5), 308-320.

- Bovea, M. D., & Pérez-Belis, V. (2018). Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. *Journal of Environmental Management*, 228, 483-494. doi:<https://doi.org/10.1016/j.jenvman.2018.08.014>
- Cayzer, S., Griffiths, P., & Beghetto, V. (2017). Design of indicators for measuring product performance in the circular economy. *International Journal of Sustainable Engineering*, 10(4-5), 289-298.
- Chun-rong, J., & Jun, Z. (2011). Evaluation of regional circular economy based on matter element analysis. *Procedia Environmental Sciences*, 11, 637-642.
- Cong, L., Zhao, F., & Sutherland, J. W. (2019). A design method to improve end-of-use product value recovery for circular economy. *Journal of Mechanical Design*, 141(4).
- Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical assessment, research & evaluation*, 10(7), 1-9.
- Das, S. K., Yedlarajiah, P., & Narendra, R. (2000). An approach for estimating the end-of-life product disassembly effort and cost. *International Journal of Production Research*, 38(3), 657-673. doi:10.1080/002075400189356
- de Oliveira, C. T., Dantas, T. E. T., & Soares, S. R. (2021). Nano and micro level circular economy indicators: Assisting decision-makers in circularity assessments. *Sustainable Production and Consumption*, 26, 455-468. doi:<https://doi.org/10.1016/j.spc.2020.11.024>
- De Pascale, A., Arbolino, R., Szopik-Depczyńska, K., Limosani, M., & Ioppolo, G. (2021). A systematic review for measuring circular economy: The 61 indicators. *Journal of Cleaner Production*, 281, 124942. doi:<https://doi.org/10.1016/j.jclepro.2020.124942>
- Di Maio, F., Rem, P. C., Baldé, K., & Polder, M. (2017). Measuring resource efficiency and circular economy: A market value approach. *Resources, Conservation and Recycling*, 122, 163-171.
- Faizi, S., Rashid, T., Sałabun, W., Zafar, S., & Wątróbski, J. (2018). Decision making with uncertainty using hesitant fuzzy sets. *International Journal of Fuzzy Systems*, 20(1), 93-103.
- Favi, C., Germani, M., Luzi, A., Mandolini, M., & Marconi, M. (2017). A design for EoL approach and metrics to favour closed-loop scenarios for products. *International Journal of Sustainable Engineering*, 10(3), 136-146.
- Felicio, M., Amaral, D., Esposto, K., & Durany, X. G. (2016). Industrial symbiosis indicators to manage eco-industrial parks as dynamic systems. *Journal of Cleaner Production*, 118, 54-64.
- Figge, F., Thorpe, A. S., Givry, P., Canning, L., & Franklin-Johnson, E. (2018). Longevity and circularity as indicators of eco-efficient resource use in the circular economy. *Ecological Economics*, 150, 297-306.
- Franklin-Johnson, E., Figge, F., & Canning, L. (2016). Resource duration as a managerial indicator for Circular Economy performance. *Journal of Cleaner Production*, 133, 589-598.
- Fregonara, E., Giordano, R., Ferrando, D. G., & Pattono, S. (2017). Economic-environmental indicators to support investment decisions: A focus on the buildings' end-of-life stage. *Buildings*, 7(3), 65.

Gallego-Schmid, A., Chen, H.-M., Sharmina, M., & Mendoza, J. M. F. (2020). Links between circular economy and climate change mitigation in the built environment. *Journal of Cleaner Production*, 260, 121115. doi:<https://doi.org/10.1016/j.jclepro.2020.121115>

Garson, D. (2009). Reliability analysis. [Online]. Available at: <http://faculty.chass.ncsu.edu/garson/PA765/reliab.htm>. In: Accessed 15 Sep 2017.

Geng, Y., Fu, J., Sarkis, J., & Xue, B. (2012). Towards a national circular economy indicator system in China: an evaluation and critical analysis. *Journal of Cleaner Production*, 23(1), 216-224. doi:<https://doi.org/10.1016/j.jclepro.2011.07.005>

Geng, Y., Liu, Y., Liu, D., Zhao, H., & Xue, B. (2011). Regional societal and ecosystem metabolism analysis in China: A multi-scale integrated analysis of societal metabolism (MSIASM) approach. *Energy*, 36(8), 4799-4808.

Geng, Y., Zhang, P., Côté, R. P., & Fujita, T. (2009). Assessment of the national eco-industrial park standard for promoting industrial symbiosis in China. *Journal of Industrial Ecology*, 13(1), 15-26.

Geng, Y., Zhang, P., Ulgiati, S., & Sarkis, J. (2010). Emergy analysis of an industrial park: The case of Dalian, China. *Science of The Total Environment*, 408(22), 5273-5283. doi:<https://doi.org/10.1016/j.scitotenv.2010.07.081>

Guo-gang, J. (2011). Empirical analysis of regional circular economy development--study based on Jiangsu, Heilongjiang, Qinghai Province. *Energy Procedia*, 5, 125-129.

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. *Journal of Industrial Ecology*, 19(5), 765-777.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2006). *Multivariate data analysis* (Vol. 6). Pearson Prentice Hall Upper Saddle River.

Haupt, M., Vadenbo, C., & Hellweg, S. (2017). Do we have the right performance indicators for the circular economy?: insight into the Swiss waste management system. *Journal of Industrial Ecology*, 21(3), 615-627.

Huysman, S., De Schaepmeester, J., Ragaert, K., Dewulf, J., & De Meester, S. (2017). Performance indicators for a circular economy: A case study on post-industrial plastic waste. *Resources, Conservation and Recycling*, 120, 46-54. doi:<https://doi.org/10.1016/j.resconrec.2017.01.013>

Huysman, S., Debaveye, S., Schaubroeck, T., De Meester, S., Ardente, F., Mathieux, F., & Dewulf, J. (2015). The recyclability benefit rate of closed-loop and open-loop systems: A case study on plastic recycling in Flanders. *Resources, Conservation and Recycling*, 101, 53-60.

Jacobsen, N. B. (2006). Industrial symbiosis in Kalundborg, Denmark: a quantitative assessment of economic and environmental aspects. *Journal of Industrial Ecology*, 10(1-2), 239-255.

Jolliffe, I. T. (2002). Principal component analysis and factor analysis. In *Principal component analysis* (pp. 150-166).

Karlsson, M., & Wolf, A. (2008). Using an optimisation model to evaluate the economic benefits of industrial symbiosis in the forest industry. *Journal of Cleaner Production*, 16(14), 1536-1544.

- Kaur, M., & Kaur, U. (2013). Comparison Between K-means and Hierarchical Algorithm Using Query Redirection. *International Journal of Advanced Research in Computer Science and Software Engineering*, 3(7), 1454-1459.
- Kayal, B., Abu-Ghunmi, D., Abu-Ghunmi, L., Archenti, A., Nicolescu, M., Larkin, C., & Corbet, S. (2019). An economic index for measuring firm's circularity: The case of water industry. *Journal of Behavioral and Experimental Finance*, 21, 123-129. doi:<https://doi.org/10.1016/j.jbef.2018.11.007>
- Kristensen, H. S., & Mosgaard, M. A. (2020). A review of micro level indicators for a circular economy—moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, 243, 118531.
- Lee, H. M., Lu, W. F., & Song, B. (2014). A framework for assessing product End-Of-Life performance: reviewing the state of the art and proposing an innovative approach using an End-of-Life Index. *Journal of Cleaner Production*, 66, 355-371.
- Li, R., & Su, C. (2012). Evaluation of the circular economy development level of Chinese chemical enterprises. *Procedia Environmental Sciences*, 13, 1595-1601.
- Linder, M., Sarasini, S., & van Loon, P. (2017). A metric for quantifying product-level circularity. *Journal of Industrial Ecology*, 21(3), 545-558.
- MacArthur, E. (2015). Circularity indicators: An approach to measuring circularity. *Methodology*, 23.
- Mandolini, M., Favi, C., Germani, M., & Marconi, M. (2018). Time-based disassembly method: how to assess the best disassembly sequence and time of target components in complex products. *The International Journal of Advanced Manufacturing Technology*, 95(1), 409-430.
- Manly, B. F. (2005). Tests of significance with multivariate data. In *Multivariate statistical methods: a primer*, (3rd ed.) (pp. 105-124). Boca Raton, FL: Chapman & Hall.
- Marconi, M., Germani, M., Mandolini, M., & Favi, C. (2019). Applying data mining technique to disassembly sequence planning: a method to assess effective disassembly time of industrial products. *International Journal of Production Research*, 57(2), 599-623.
- Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., & Blengini, G. A. (2019). Measuring progress towards a circular economy: a monitoring framework for economy-wide material loop closing in the EU28. *Journal of Industrial Ecology*, 23(1), 62-76.
- Mazur-Wierzbicka, E. (2021). Circular economy: advancement of European Union countries. *Environmental Sciences Europe*, 33(1), 1-15.
- McCarthy, B., Kapetanaki, A. B., & Wang, P. (2019). Circular agri-food approaches: will consumers buy novel products made from vegetable waste? *Rural Society*, 28(2), 91-107.
- Mesa, J., Esparragoza, I., & Maury, H. (2018). Developing a set of sustainability indicators for product families based on the circular economy model. *Journal of Cleaner Production*, 196, 1429-1442.
- Mohamed Sultan, A. A., Lou, E., & Mativenga, P. T. (2017). What should be recycled: An integrated model for product recycling desirability. *Journal of Cleaner Production*, 154, 51-60. doi:<https://doi.org/10.1016/j.jclepro.2017.03.201>

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., Dewulf, J. (2019). Circular economy indicators: What do they measure? *Resources, Conservation and Recycling*, 146, 452-461. doi:<https://doi.org/10.1016/j.resconrec.2019.03.045>

Moriguchi, Y. (2007). Material flow indicators to measure progress toward a sound material-cycle society. *Journal of Material Cycles and Waste Management*, 9(2), 112-120. doi:10.1007/s10163-007-0182-0

Nelen, D., Manshoven, S., Peeters, J. R., Vanegas, P., D'Haese, N., & Vrancken, K. (2014). A multidimensional indicator set to assess the benefits of WEEE material recycling. *Journal of Cleaner Production*, 83, 305-316.

Pagotto, M., & Halog, A. (2016). Towards a circular economy in Australian agri-food industry: an application of input-output oriented approaches for analysing resource efficiency and competitiveness potential. *Journal of Industrial Ecology*, 20(5), 1176-1186.

Parchomenko, A., Nelen, D., Gillabel, J., & Rechberger, H. (2019). Measuring the circular economy - A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production*, 210, 200-216. doi:<https://doi.org/10.1016/j.jclepro.2018.10.357>

Park, H.-S., & Behera, S. K. (2014). Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks. *Journal of Cleaner Production*, 64, 478-485.

Park, J. Y., & Chertow, M. R. (2014). Establishing and testing the "reuse potential" indicator for managing wastes as resources. *Journal of Environmental Management*, 137, 45-53.

Qing, Y., Qiongqiong, G., & Mingyue, C. (2011). Study and integrative evaluation on the development of circular economy of Shaanxi province. *Energy Procedia*, 5, 1568-1578.

Sałałun, W., Palczewski, K., & Wątróbski, J. (2019). Multicriteria approach to sustainable transport evaluation under incomplete knowledge: Electric bikes case study. *Sustainability*, 11(12), 3314.

Scheepens, A. E., Vogtländer, J. G., & Brezet, J. C. (2016). Two life cycle assessment (LCA) based methods to analyse and design complex (regional) circular economy systems. Case: making water tourism more sustainable. *Journal of Cleaner Production*, 114, 257-268. doi:<https://doi.org/10.1016/j.jclepro.2015.05.075>

Smol, M., Kulczycka, J., & Avdiushchenko, A. (2017). Circular economy indicators in relation to eco-innovation in European regions. *Clean Technologies and Environmental Policy*, 19(3), 669-678. doi:10.1007/s10098-016-1323-8

Stanković, J. J., Janković-Milić, V., Marjanović, I., & Janjić, J. (2021). An integrated approach of PCA and PROMETHEE in spatial assessment of circular economy indicators. *Waste Management*, 128, 154-166. doi:<https://doi.org/10.1016/j.wasman.2021.04.057>

Su, B., Heshmati, A., Geng, Y., & Yu, X. (2013). A review of the circular economy in China: moving from rhetoric to implementation. *Journal of Cleaner Production*, 42, 215-227. doi:<https://doi.org/10.1016/j.jclepro.2012.11.020>

Tiejun, D. (2010). Two quantitative indices for the planning and evaluation of eco-industrial parks. *Resources, Conservation and Recycling*, 54(7), 442-448.

- Tisserant, A., Pauliuk, S., Merciai, S., Schmidt, J., Fry, J., Wood, R., & Tukker, A. (2017). Solid waste and the circular economy: a global analysis of waste treatment and waste footprints. *Journal of Industrial Ecology*, 21(3), 628-640.
- van Schaik, A., & Reuter, M. A. (2016). Recycling indices visualising the performance of the circular economy. *World Met Erzmetall*, 69, 5-20.
- Vanegas, P., Peeters, J. R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., . . . Duflo, J. R. (2018). Ease of disassembly of products to support circular economy strategies. *Resources, Conservation and Recycling*, 135, 323-334.
- Vyas, S., & Kumaranayake, L. (2006). Constructing socio-economic status indices: how to use principal components analysis. *Health policy and planning*, 21(6), 459-468.
- Wen, Z., & Li, R. (2010). Materials metabolism analysis of China's highway traffic system (HTS) for promoting circular economy. *Journal of Industrial Ecology*, 14(4), 641-649.
- Wenbo, L. (2011). Comprehensive evaluation research on circular economic performance of eco-industrial parks. *Energy Procedia*, 5, 1682-1688.
- Wu, H.-q., Shi, Y., Xia, Q., & Zhu, W.-d. (2014). Effectiveness of the policy of circular economy in China: A DEA-based analysis for the period of 11th five-year-plan. *Resources, Conservation and Recycling*, 83, 163-175.
- Xiong, P., Dang, Y., & Qian, W. (2011). The empirical analysis of circular economy development efficiency in Jiangsu Province. *Energy Procedia*, 5, 1732-1736.
- Yobe, C. L., Mudhara, M., & Mafongoya, P. (2019). Livelihood strategies and their determinants among smallholder farming households in KwaZulu-Natal province, South Africa. *Agrekon*, 1-14.
- Zhao, H., Guo, S., & Zhao, H. (2018). Comprehensive benefit evaluation of eco-industrial parks by employing the best-worst method based on circular economy and sustainability. *Environment, development and sustainability*, 20(3), 1229-1253.
- Zwolinski, P., Lopez-Ontiveros, M.-A., & Brissaud, D. (2006). Integrated design of remanufacturable products based on product profiles. *Journal of Cleaner Production*, 14(15-16), 1333-1345.