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# Circular Economy and Sustainable Technology in Technical and Vocational Education and Training: A Bibliometric Analysis

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**Abstract.** The integration of circular economy and sustainable technology in technical and vocational education and training (TVET) is essential to foster environmentally conscious practitioners who are able to prepare the workforce for sustainable development. Despite the growing interest in circular economy and sustainable technology, a comprehensive understanding of the research landscape in the context of the growth of TVET education is still lacking. This research maps the scholarly output, identifies key themes and assesses global research collaborations in the integration of circular economy and sustainable technology in TVET. A bibliometric analysis using the Scopus database was conducted, focusing on publication trends, authorship patterns, keyword co-occurrence, and geographic distribution. Bibliometric analysis revealed a growing interest in circular economy and sustainable technology in TVET education, with a significant increase in publications over the past decade. Prolific authors and collaborative networks were identified and thematic clusters clarified core research areas, contributing to the knowledge base needed for sustainable workforce development. These findings emphasize the importance of circular economy and sustainable technology integration in TVET education and highlight the need for continued interdisciplinary collaboration. This bibliometric analysis serves as a valuable resource for educators, researchers and policy makers, guiding future efforts to increase the global impact of circular economy and sustainable technology in TVET education.

**Keywords:** circular economy; sustainable technology; technical and vocational; education; bibliometric

## 1. Introduction

In a dynamic educational landscape, the intersection of the circular economy (CE), sustainable technology (ST), and technical and vocational education and training (TVET) stands as an important nexus for transformative change (Keramitsoglou et al., 2023; Ogotu et al., 2023). This high-impact bibliometric analysis investigates the evolving trends and

scholarly discourse surrounding the integration of CE principles and ST in the field of TVET education. As society grapples with the importance of sustainability, TVET emerges as a vehicle to cultivate the skills and knowledge required for a circular and technologically advanced economy (Diao & Hu, 2022; Jasmi et al., 2019; Raudhah et al., 2023).

This study has identified key themes and aims to contribute research to influential publications and collaborative networks that have shaped the discourse in this multifaceted field. The primary aim of this study has been to explore the scholarly landscape surrounding the integration of the CE and ST within TVET. The study provides a comprehensive analysis of the evolving trends and key themes that have emerged in this field. By investigating the academic discourse, the research offers valuable insights into how the CE and ST are being incorporated into TVET education to support sustainable development goals.

The concept of CE, which emphasizes resource efficiency and waste reduction, is linked to ST, forming a symbiotic relationship that has far-reaching implications for TVET (Bag & Pretorius, 2022; Rusch et al., 2023; Velenturf & Purnell, 2021). The current state of TVET education is increasingly focused on preparing students for the demands of rapidly evolving industries, with an emphasis on practical skills and technical expertise. Considering the growing need for sustainable development, the integration of CE and ST into TVET has become essential. The CE focuses on resource efficiency, waste reduction, and promoting reuse and recycling, while ST emphasizes the use of innovative technologies that support sustainability goals. By incorporating these concepts into TVET curricula, institutions can equip students with the knowledge and skills needed to design, implement, and maintain sustainable systems in various sectors, such as manufacturing, agriculture, and energy. This integration fosters the development of a workforce capable of driving environmentally conscious practices, contributing to the global transition toward a more sustainable and resilient economy.

This bibliometric analysis systematically investigates the scholarly landscape, providing insights into growth patterns, emerging subtopics, and interdisciplinary relationships. By examining a wide variety of academic publications, our analysis aims to contribute to an understanding of the intellectual foundations supporting the integration of the CE and ST in TVET education (Abideen et al., 2021; Boom-Cárcamo & Peñabaena-Niebles, 2022; Camana et al., 2021; Zhang et al., 2021). This exploration is poised to offer a comprehensive perspective for academics, policymakers, and practitioners committed to advancing sustainable development through education.

## **1.1 Circular Economy and Sustainable Technology in TVET Education**

The intersection of CE, ST, and TVET is a rapidly evolving field with significant implications for sustainable development. The interconnectedness of these elements can be demonstrated through co-citation analysis to identify and illustrate relationships between literatures across these fields. Bibliometric mapping tools such as VOSviewer can be used to visually represent these connections, highlighting key clusters, trends, and the evolution of discussions over time. By incorporating these elements into TVET curricula, institutions can equip students with the knowledge and skills needed to design, implement and maintain sustainable systems, ultimately contributing to a more sustainable and resilient society (Moghayedi et al., 2023; Sung, 2023; Tiippana-Usvasalo et al., 2023).

A systematic literature review by Alhawari et al. (2021) on sustainability identified the definitions of a CE, clarifying the conceptual foundations of this economic model and unraveling paths for future research. In addition, Khan et al. (2022) conducted a systematic literature review focusing on CE practices, expounding on barriers and potential and future trends in this field. The findings highlighted the need for empirical testing across multiple sectors to develop better business models and practices, and demonstrate that researchers are increasingly focused on understanding the shift to the CE by integrating it with digital technologies such as IR 4.0, Big Data, IoT, artificial intelligence, blockchain, and data analytics to enhance organizational and environmental performance.

While specific literature reviews focusing solely on ST within the context of TVET were not identified in the search results, broader literature such as Chong et al. (2022); Narong and Hallinger (2024); and Velvizhi et al. (2023) on ST development in engineering, and Akbari et al. (2020) and Kailasa et al. (2023) on environmental science, provide valuable insights that can be applied to the TVET context. In addition, there is increasing recognition of the importance of education in fostering a CE, as evidenced by studies such as "Towards an Education for the Circular Economy (ECE): Five Teaching Principles and a Case Study" by Kirchherr and Piscicelli (2019). These findings underscored the importance of integrating CE and ST principles into TVET curricula to prepare the workforce for the demands of a more sustainable and resource-efficient economy (Chojnacka et al., 2021; Hamid et al., 2023, 2024; Imoniana et al., 2021; Subbarao et al., 2023).

The integration of CE and ST principles in TVET curricula is of paramount importance for preparing the workforce to address current and future sustainability challenges (Marinette & Xu, 2020). Research has shown that the CE and ST are interconnected concepts that can significantly impact various industries and the environment. For example, a broad review of the literature on blockchain technology and its relationship to the CE shows that the interaction of these concepts can facilitate sustainable practices, such as green manufacturing, recycling, and remanufacturing, thereby improving business operations and environmental performance (Asma et al., 2020, 2021; Rejeb & Zailani, 2023; Tang et al., 2022). This highlights

the potential of integrating CE and ST principles into TVET curricula to equip students with the knowledge and skills needed to contribute to sustainable practices in their respective fields.

Furthermore, research has explored the impact of advertising on the CE, focusing on sustainable and innovative aspects. This study highlights how the CE model aligns the interests of industry, consumers and the environment, as well as its potential to stimulate new technological advances towards innovation and sustainability (Asma et al., 2022, 2024). This underscores the need for TVET programs to incorporate CE and ST principles to ensure that students understand the interconnectedness of economic, environmental, and social factors, and are equipped to contribute to innovative and sustainable solutions in their future careers (Marinette, 2020; Sakellaris, 2021). In summary, the literature review indicates that integrating the CE and ST principles into TVET curricula is essential for preparing a workforce that can effectively contribute to sustainable practices, innovation, and environmental conservation. By doing so, TVET institutions can play a pivotal role in shaping a workforce that is well-versed in the principles of CE and ST and capable of driving positive change across various industries and sectors.

### **1.2 Research Question**

- Q1. What are the research trends in circular economy and sustainable technology studies according to the year of publication?
- Q2. Who has the most relative contribution in the circular economy and sustainable technology in TVET education growth?
- Q3. What are the most documented subject areas in circular economy and sustainable technology studies?
- Q4. Which countries have the highest number of publications related to circular economy and sustainable technology studies?
- Q5. What are the commonly used keywords associated with the study?
- Q6: How are network mappings organized based on citation and document type?

## **2. Methodology**

Bibliometrics includes the aggregation, organization, and analysis of bibliographic data extracted from scientific publications (Verbeek et al., 2002). Beyond basic descriptive statistics, such as publication journal, publication year, and primary author classification (Wu & Wu, 2017), it involves sophisticated methodologies such as document co-citation analysis (Fahimnia et al., 2015). The focus is on high-quality publications to gain a theoretical understanding of the research field's development. Scopus was selected as the primary database due to its extensive coverage of peer-reviewed academic journals, which is essential for capturing the breadth and depth of research on the CE and TVET education (di Stefano et al., 2010). The choice to exclude books and conference proceedings, as suggested by prior studies (Chao et al., 2018; Liu et al., 2015) was made to ensure the consistency and reliability of the data, as journal articles are typically subjected to more rigorous peer-review processes.

Scopus, covering publications since 1990, was chosen for its extensive repository of journals, particularly in the social sciences and humanities, which are crucial for this study (Aghaei Chadegani et al., 2013). Although its impact may be more significant in recent articles, Scopus provides comprehensive data that support the objectives of this research. The analysis included articles indexed in the Social Science Citation Index (SSCI), Expanded Science Citation Index, and Arts and Humanities Citation Index from 2015 to December 2023. The search criteria were carefully set to retrieve all relevant Scopus articles related to the CE and ST in TVET education up to December 2023.

## 2.1 Data Search Strategy

This study used a screening sequence to set search criteria to retrieve articles. It began by querying the online Scopus database using the specific keywords listed in Table 1, resulting in a collection of 3,403 articles. Subsequently, the query string was refined to focus on the search terms “circular economy” and “sustainable” and “technology” in the context of student learning. This refinement resulted in 2,253 results, which were further screened to include only research articles in English, while excluding article reviews. A final filtering of the search string resulted in 958 articles used for bibliometric analysis. All articles from the Scopus database that related to the CE and focused on ST until December 2023 were included in the study.

In this bibliometric analysis, we set the eligibility criteria to focus on English-language journal articles published between 2015 and 2023, excluding non-English language publications and publications before 2015. This selection was limited to definitive publications, excluding publications in the press stage. Adhering to these criteria, we ensured a thorough examination of the latest and most effective scholarly contributions within a specified time frame. The type of literature selected was limited to journal articles, emphasizing the depth and quality of research, while excluding conference papers, books and reviews. This approach enabled a targeted exploration of the most relevant and refined insights, contributing to a rigorous bibliometric examination of the selected academic landscape.

The search string used is shown in Table 1, the selection criteria is shown in Table 2, and the flowchart of study selection is shown in Figure 1.

**Table 1: The search string**

Database	Search string
Scopus	TITLE-ABS-KEY (“circular economy” AND sustainable AND technology AND ( educate* OR study* ) ) AND PUBYEAR > 2014 AND PUBYEAR < 2024 AND ( LIMIT-TO ( DOCTYPE , “ar” ) ) AND ( LIMIT-TO ( LANGUAGE , “English” ) ) AND ( LIMIT-TO ( SRCTYPE , “j” ) ) AND ( LIMIT-TO ( PUBSTAGE , “final” ) )

Table 2: The selection criteria

Criteria	Included	Excluded
Language	English	Non-English
Time frame	2015–2023	< 2015
Type of literature	Journal (Article)	Conference, Book, Review
Stage of publication	Final	In Press

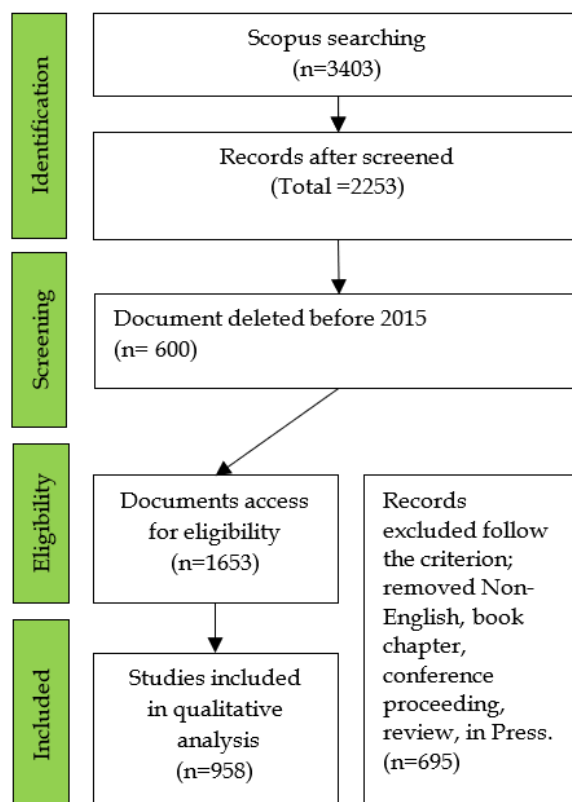


Figure 1. Flowchart of study selection

## 2.2 Data analysis

Data sets containing publication year, title, author, journal, citation, and keywords in PlainText format were extracted from the Scopus database spanning from 2015 to December 2023. These sets underwent analysis using VOSviewer software version 1.6.19, which utilized VOS clustering and mapping methods for analysis and map creation. VOSViewer, as an alternative to the multidimensional scaling (MDS) approach (Van Eck & Waltman, 2007), shares the objective of accurately representing the relatedness and similarity of items in a low-dimensional space (Appio et al., 2016). Unlike multidimensional scaling (MDS), which primarily focuses on computing similarity measures such as Jaccard indexes and cosine, the visualization of similarities (VOS) uses a more appropriate method for normalizing co-occurrence frequencies (Van Eck & Waltman, 2007). One such method is the association strength ( $AS_{ij}$ ), which is calculated as:

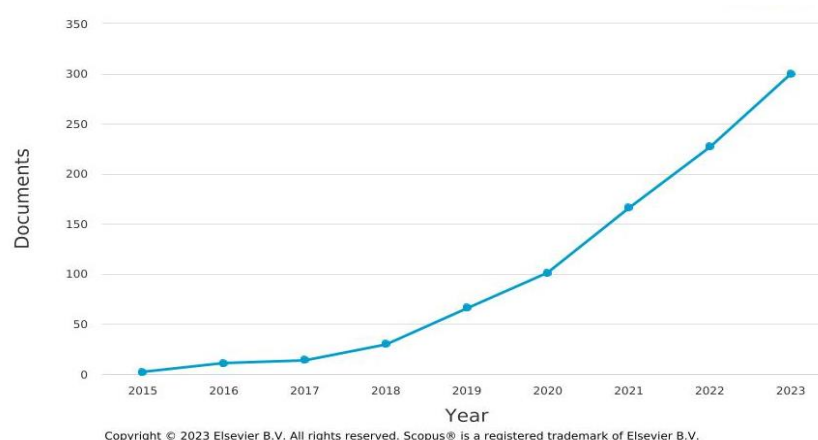
$$AS_{ij} = \frac{C_{ij}}{w_i w_j}$$

Here,  $C_{ij}$  represents the number of co-occurrences of items  $i$  and  $j$ , and  $w_i$  and  $w_j$  are the total occurrences of  $i$  and  $j$ , respectively. The association strength index is proportional to the ratio between the observed co-occurrences of items  $i$  and  $j$  and the expected co-occurrences under the assumption that their co-occurrences are statistically independent (van Eck & Waltman, 2007, 2008). Using this index, VOSviewer arranges items on a visual map by minimizing the weighted sum of squared distances between all pairs of items, effectively creating a clearer and more interpretable representation of the data. In this study, LinLog/modularity normalization, as recommended by Appio et al. (2016), was implemented to improve the clustering and grouping of related items on the map. This normalization technique enhances the ability to identify distinct groups or communities within the dataset.

By employing VOSviewer visualization techniques, patterns derived from mathematical relationships were revealed, enabling analyses such as keyword co-occurrence, citation analysis, and co-citation analysis. The evolution of a research field over time can be examined through keyword co-occurrence analysis, which helps identify prevalent subjects across various disciplines (Li et al., 2016). Simultaneously, citation analysis proves invaluable for identifying important research topics, trends, and methodologies, providing insight into the historical significance and main focus of a discipline (Allahverdiyev & Yucesoy, 2017). The analysis of document co-citation, a frequently applied bibliometric method (Appio et al., 2016; Fahimnia et al., 2015; Liu et al., 2015), utilizes network theory to describe data structures and uncover relationships between frequently co-cited documents (Liu et al., 2015). This method allows researchers to map intellectual structures within a research field, revealing key studies, influential authors, and emerging trends. By analyzing co-citation patterns, researchers gain insights into the field's development and evolution, as well as identify potential gaps or opportunities for future research.

### 3. Result and Finding

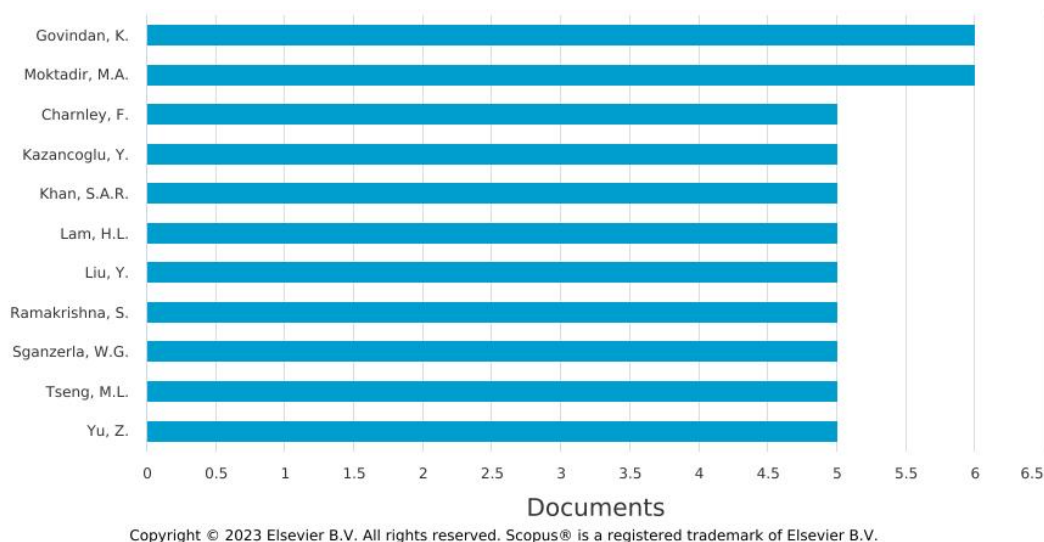
*Q1. What are the research trends in circular economy and sustainable technology studies according to the year of publication?*



**Figure 2. Research trends in circular economy and sustainable technology studies grouping by publication year**

Figure 2 illustrates the yearly distribution of publications on the CE and ST from 2015 to 2023. The figure indicates that research on the CE and ST was substantial and relatively consistent, with the number of publications ranging from two in 2015 to 300 in 2023. While the journal's publication output in the past eight years remained fairly stable, a subtle upward trend emerged in recent data. This consistency in document count reflected a sustained research interest in the journal's field. Possible explanations for this trend may be the journal's rising impact factor, growing field popularity, or even altered editorial policies. Comparing this publication pattern to similar journals in the field would offer valuable context, and exploring the data further for top contributing countries, institutions, and research topics could explain the journal's evolving landscape. Ultimately, analyzing these trends not only confirms the journal's own trajectory but also provides insights into the broader dynamics of its research field.

*Q2. Who has the most relative contribution in the circular economy and sustainable technology in TVET education growth?*

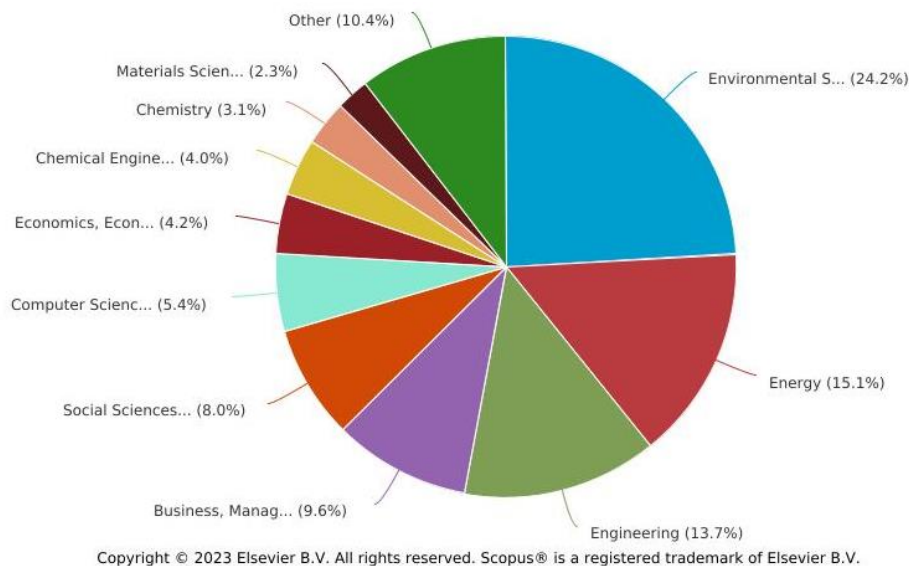


**Figure 3. Author contributions to circular economy and sustainable technology in TVET education**

Figure 3 illustrates the authorship landscape in CE and ST research. Govindan emerged as the most prolific author, indicating a significant influence on the field. Collaboration is evident, with other researchers such as Moktadir, Charnley, and Kazancoglu, making noteworthy contributions. The global distribution of authors, particularly from China, the United States, and the United Kingdom, highlighted the international nature of challenges in this field. While the figure provides valuable insights, it is important to consider bibliometric analysis limitations, such as overlooking research quality. Despite this, understanding the authorship dynamics enhances our comprehension of the field's potential to address 21st-century challenges.



Q3. What are the most documented subject areas in circular economy and sustainable technology studies?



**Figure 4. The most documented subject areas in circular economy and sustainable technology**

The subject area distribution in CE and ST research was diverse and holistic as shown in Figure 4. Environmental science dominated with 24.2%, addressing environmental concerns at the core. Engineering followed at 15.1%, showcasing innovation in circular system design but it is not just about reducing our environmental footprint. Business, management and accounting, at 9.6%, highlighted the need for robust economic models and sustainable supply chains to truly create circularity. A focus on the financial viability of circular practices is essential for widespread adoption.

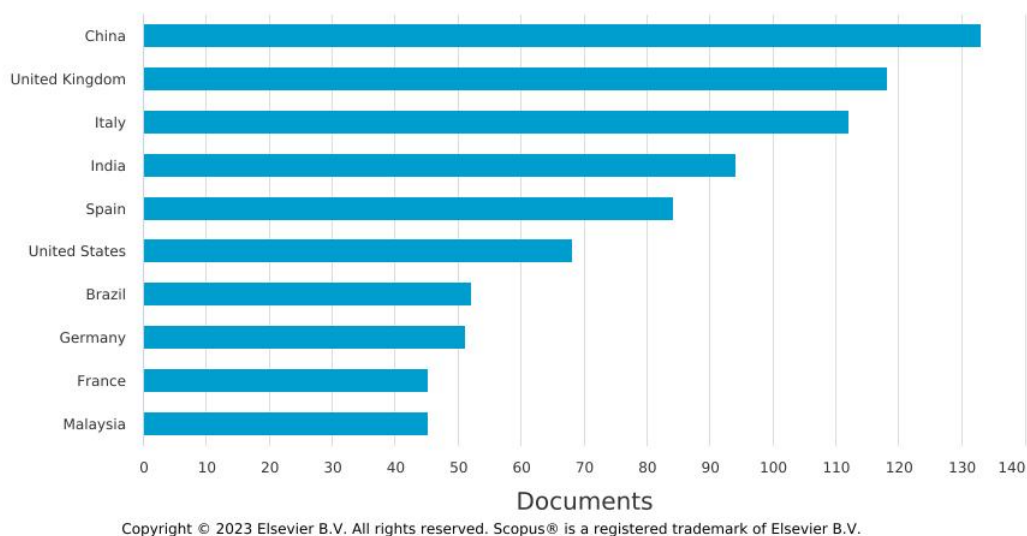
Interestingly, the social sciences, which occupied 8% of the research landscape, reminded us that the transition to a CE was not purely technical or economic. Various disciplines, from computer science and chemistry to law and education, showed the interconnectedness of the challenges and solutions we faced in achieving circularity and sustainability. In essence, the subject area breakdown reflected a vibrant research ecosystem with collaboration and innovation. This is a testament to the fact that addressing the interrelated issues of environmental degradation and resource depletion requires a holistic approach that utilizes multiple perspectives and expertise. The future of the CE and ST lies not only in breakthrough discoveries in individual disciplines, but also in bridging the gaps between them to create truly transformative forces for a better tomorrow.

**Table 3. The most frequently used articles related to the study**

Authors	Title	Year	Source title	Cited by
Bag, Gupta et al. (2021)	Industry 4.0 adoption and 10R advance manufacturing capabilities for sustainable development	2021	International Journal of Production Economics	253
Bag, Pretorius et al. (2021)	Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities	2021	Technological Forecasting and Social Change	283
Bag, Yadav et al. (2021)	Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: An empirical study	2021	Journal of Cleaner Production	193
Despeisse et al. (2017)	Unlocking value for a circular economy through 3D printing: A research agenda	2017	Technological Forecasting and Social Change	306
Esmailian et al. (2020)	Blockchain for the future of sustainable supply chain management in Industry 4.0	2020	Resources, Conservation and Recycling	350
Fatimah et al. (2020)	Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia	2020	Journal of Cleaner Production	265
Fisher et al. (2018)	Cloud manufacturing as a sustainable process manufacturing route	2018	Journal of Manufacturing Systems	199
Ghisellini et al. (2016)	A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems	2016	Journal of Cleaner Production	2984
Hartley et al. (2020)	Policies for transitioning towards a circular economy: Expectations from the European Union (EU)	2020	Resources, Conservation and Recycling	225
Jeswani et al. (2021)	Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery	2021	Science of the Total Environment	193
Khan et al. (2021)	Industry 4.0 and circular economy practices: A new era business strategy for environmental sustainability	2021	Business Strategy and the Environment	192
Lopes et al. (2018)	Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations	2018	Annals of Operations Research	641
Kumar et al. (2020)	Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges	2020	Journal of Cleaner Production	223
Kumar et al. (2021)	To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP	2021	Journal of Cleaner Production	180
Zhang et al. (2019)	Barriers to smart waste management for a circular economy in China	2019	Journal of Cleaner Production	225

Table 3 shows the most frequently used articles related to the study. Circular economy research has evolved significantly, with key articles driving the discourse. "A review on circular economy" (2016) is a cornerstone, garnering 2984 citations. It illuminated the shift toward an equilibrium between environmental and economic systems. Following was "Industry 4.0 and the circular economy" (2018) proposing a roadmap, cited 641 times, highlighting the intersection of technological innovation and sustainability. In conclusion, these highly cited articles indicate a robust global interest in CE paradigms, with a focus on technological integration, sustainability practices, and policy implications. The citations underscore their impact and relevance in shaping contemporary discussions.

*Q4. What are the most publication country related to the study?*



**Figure 5. Countries with the highest number of publications related to circular economy and sustainable technology studies**

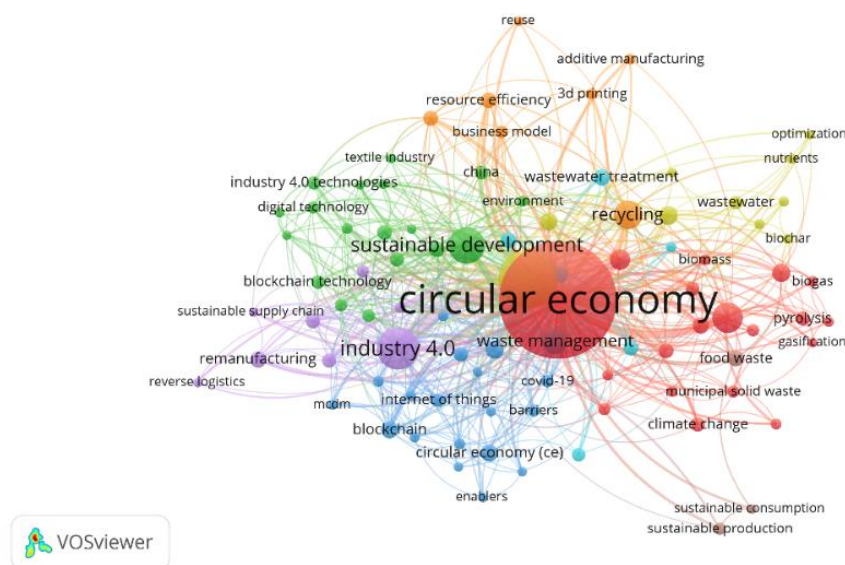
Figure 5 illustrates the countries with the highest number of publications related to circular economy (CE) and sustainable technology (ST) studies, based on data from the Scopus analyzer. The United States leads with 132 publications, followed by China with 122, and the United Kingdom with 96. Other countries in the top 10 include Italy, India, Spain, Brazil, Germany, France, and Malaysia. The prominence of these countries indicated their investment in CE and ST research. While the United States and China dominated, reflecting their global leadership in research and development, countries like India and China still faced challenges in sustainable waste management, despite their significant research contributions. This highlighted a potential gap between research output and practical implementation in some regions, underscored the global importance of continued research and development in CE and ST.

Q4. Which countries have the highest number of publications related to circular economy and sustainable technology studies?

The rapid development of research related to the CE and ST was an encouraging indicator. It showed that there is a growing awareness of the need to shift to a more sustainable economic model. However, it is important to remember that research is only one part of the equation. To create a genuine CE, it is important to enact policies that encourage the adoption of circular practices by businesses and consumers. In addition, investments in infrastructure and technologies that support circularity, such as recycling facilities and renewable energy sources, are essential. In summary, this information offers a valuable insight into the worldwide research prospect related to the CE and ST. It is clear that this is an important and growing area of research and it is encouraging to see that so many countries are investing in it.

Q5. What are the commonly used keywords associated with the study?

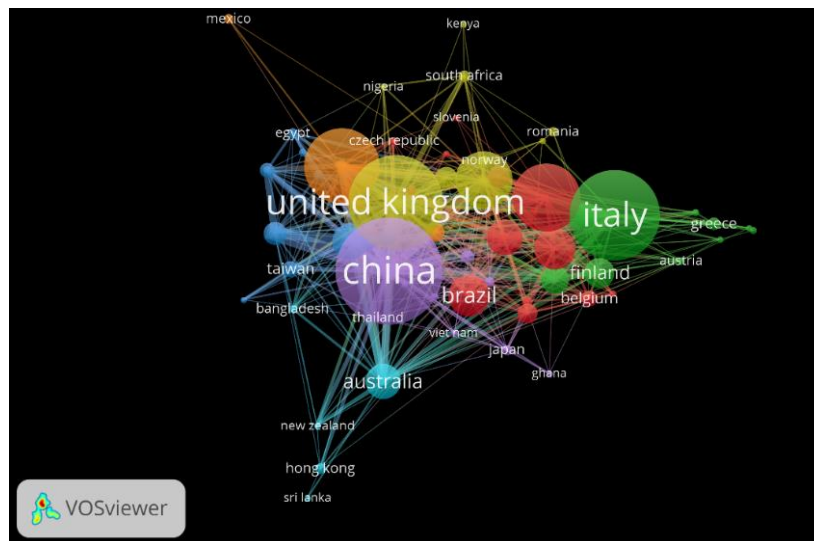
Using VOSviewer and setting a minimum occurrence threshold of 5, author keywords were mapped. Figure 6 displays the strength of association between these keywords. Keywords that share similar colors were often listed together.



**Figure 6. Visualization map depicting the co-occurrence of keywords in the network**

Figure 6 illustrates visualization map depicting the co-occurrence of keywords in the network. The VosViewer-generated network map in the CE and ST revealed a dynamic landscape. The “circular economy core” centralized themes such as circular principles and life cycle assessment. A cluster on “resource recovery and management” focused on waste reduction. Another cluster connected the CE with “sustainable technology and design”, emphasizing ecodesign and renewable energy. Connecting themes such as “policy and governance” stressed the importance of supportive policies and collaboration. “material science and innovation” underscored the role of innovation in circular practices. The periphery introduced emerging trends such as “digitalization and industry 4.0,” indicating the integration of technology. Terms such as “social impact” suggested a growing focus on societal implications. This map not only unveiled the thematic

structure but also hinted at future trends, portraying a field poised to reshape resource relationships and foster sustainability.



**Figure 7. Co-authorship countries' collaboration**

Figure 7 illustrates global collaboration on the CE and ST in education. The “circular economy education core” at the center emphasized foundational themes such as sustainable development and curriculum. Branching out, the “pedagogy and skills” cluster underscored the importance of fostering critical thinking and entrepreneurship education. The “teacher training and professional development” cluster highlighted the need to empower educators through initiatives such as teacher education and knowledge sharing. Bridges connecting clusters, such as “policy integration” and “stakeholder engagement,” stressed the role of supportive policies in embedding CE education. The “assessment and evaluation” theme ensured robust methods for measuring competency development and learning outcomes. Peripheral clusters hinted at emerging trends, with “digitalization and technology” suggesting the potential of e-learning and gamification, and “social and emotional learning” focusing on values and attitudes for a circular future. This network provided a nuanced view of the research landscape, showcasing the potential for reshaping education and empowering future generations for sustainability.

Q6: How are network mappings organized based on citation and document type?

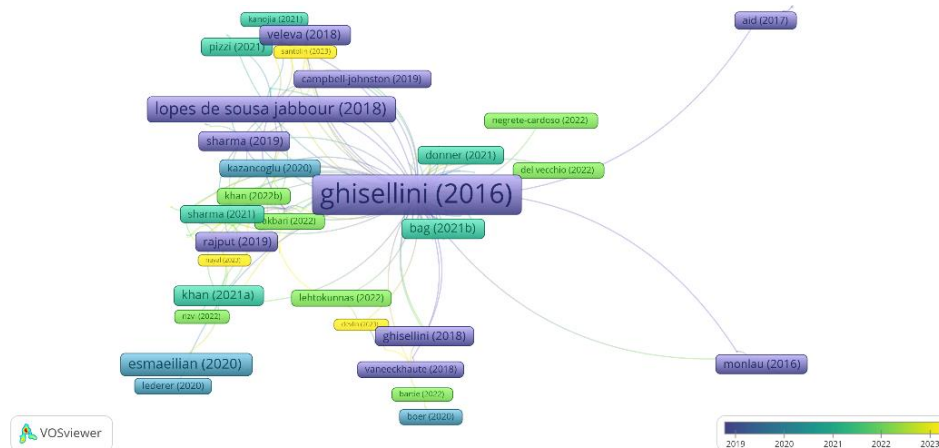


Figure 8. Mapping of networks derived from citations by the document type

Figure 8 presents a VosViewer-generated network map depicting knowledge exchange in CE and ST in education. Central to the map, journal articles drove knowledge dissemination, and focused on themes such as sustainability and CE education. Clusters for conference proceedings, books, and policy documents revealed dynamic exchanges, in-depth explorations, and practical applications, respectively. Citation arrows demonstrate links between academic research and real-world implementation, emphasizing the field's impact on education and policy. The map showcases the interplay of document types, underscoring their collective role in advancing the field and influencing educational practices and policies.

#### 4. Analysis of the Results and Discussion

The bibliometric analysis of the CE and ST in TVET education revealed a steady publication output over the past eight years, with a slight upward trend in recent years. Major contributors, including Govindan, and the distribution of global authorship demonstrated the collaborative efforts in this field. However, the limitations of bibliometric analysis needed to be acknowledged, as it might not have captured all factors influencing publication trends. The subject areas analyzed indicated a multidisciplinary approach, integrating diverse fields to address sustainability challenges. Highly cited articles reflected the growing global interest in the CE, influencing the discourse on sustainability. The top publishing countries—namely the United States, China, and the United Kingdom—highlighted a global commitment to advancing research on CE and ST. However, realizing the potential of circular practices required not only research but also effective policy implementation and infrastructure development. The network visualization of keywords and global collaborations underscored emerging themes and highlighted the potential for reshaping education to better address sustainability challenges.

The study's findings can inform strategies for integrating the circular economy and ST into TVET education, thereby contributing to the ongoing discourse on circularity and sustainability. To achieve this, curricula needed to be updated to

include topics such as waste management, renewable energy, and resource recovery, ensuring an interdisciplinary approach. Collaborations with researchers and institutions, especially those in leading countries such as the United States, China, and the United Kingdom, enhanced educational quality through international partnerships and knowledge exchange. Practical, industry-focused learning, such as project-based approaches emphasizing Industry 4.0 and sustainable manufacturing, prepared students for future challenges. As mentioned by Kamaruzaman et al. (2023), graduates with relevant skills and knowledge will survive and become successful in their future working environment.

Engaging with policymakers and industry stakeholders was essential to aligning TVET programs with national sustainability goals, while ongoing professional development for educators ensured they remained current on the latest CE and ST innovations. Additionally, TVET institutions were recommended to invest in research centers focused on the CE and ST, involve students in these initiatives, and implement green infrastructure on campuses to serve as models for sustainability. Digital tools such as virtual labs and gamification increased student engagement, while promoting green entrepreneurship through innovation challenges encouraged creativity. Lastly, developing robust assessment tools and continuous feedback mechanisms ensured the successful integration of the CE and ST into TVET programs.

Future research could expand upon the current study by using alternative keywords to capture a wider range of publications and integrating content analysis to explore additional facets of CE and ST in education. Incorporating more diverse methodologies, such as content analysis, would provide deeper insights into the evolving role of the CE in education. In conclusion, this analysis provided valuable insights into the field while emphasizing the need for future research to explore influencing factors, research quality, and the practical impact of CE education initiatives.

## **5. Implication, Recommendation and Conclusion**

This study has significant implications for integrating the CE and ST within TVET. By mapping the scholarly landscape, the research provides valuable insights for educators and curriculum developers, helping them design educational programs that aligned with emerging themes and addressed gaps in the literature. The identification of key authors and collaborative networks highlights significant contributors and potential partnerships, promoting interdisciplinary and international research in this field. Furthermore, the analysis of global trends and thematic clusters offers crucial information for policymakers, assisting them in making informed decisions to support the development of a workforce prepared for the demands of sustainable development. These findings emphasize the importance of continuous research and collaboration to strengthen the role of CE and ST in TVET education.

Several recommendations have emerged from this study. Educators and curriculum developers are encouraged to incorporate key CE and ST themes into



TVET curricula to address gaps and better prepare students for careers in sustainable industries. Strengthening interdisciplinary and international collaborations with prolific authors and research networks enhances research quality and fostered innovation. Policymakers are advised to use these insights to craft policies that promote the integration of the CE and ST into TVET programs, including providing incentives and encouraging public-private partnerships. Additionally, continuous research was necessary to track trends and evaluate the effectiveness of educational programs and policies, ensuring that TVET education evolved in response to the demands of sustainable development.

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