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A Scientometric Analysis of the Intersection between Circular Economy and Technical & Vocational Education

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ABSTRACT

Ensuring the integration of circular economy principles into Technical and Vocational Education and Training (TVET) education is essential to provide a skilled workforce for the future. Therefore, there is a need for a comprehensive scientometric study of the intersection between circular economy and TVET education, despite the fact that the number of studies in this field continues to increase. Using a scientometric approach, this study reveals significant research patterns and identifies areas of inadequacy in the current literature on the integration of circular economy principles into TVET education. A total of 2177 datasets obtained from Web of Science (WoS) and Scopus were analyzed using VOSviewer and ScientoPy. Since the 1990s, there has been a steady increase in the amount of literature related to the circular economy and TVET education. In 2021, a large number of publications across both databases, totaling 71, were documented, indicating a growing interest in this topic. It was found that most of the articles in this field were published by authors from developed countries, majority from the United States, China and Germany. The subject "Vocational education" has reached the highest position, with 260 publications. The top five keywords associated with this subject are "vocational education", "sustainable development", "professional education", "employability" and "training". In terms of theory, "Vocational Skills Queuing Theory" and "Sociocultural Theory" have received significant attention over the past few years, especially in 2022 and 2023. While the models that have received the most attention from most researchers are "Learning model" and "Circular business model". The scientometric study has revealed that research at the intersection of the circular economy and TVET education has received consistent and ongoing academic attention. This study recognizes the need for future research to explore different frameworks that explain the relationship between circular economy practices and TVET education.

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1. Introduction

In recent years, the idea of the circular economy (CE) has attracted a lot of attention, emphasizing the value of sustainable practices across various industries, including education. Defined as an economic system that aims to eliminate waste and the continuous use of resources, the circular economy is very different from the 'take-make-throw' model of the traditional linear economy [1-3]. This transition to a sustainable model requires the development of specific competencies, especially among professionals in the fields of design and engineering. These competencies include knowledge, abilities and attitudes that are essential for efficient problem solving and performance in a sustainable context, which is essential for designing in a circular economy [4,5]. Such a competence framework is essential to integrate circular economy principles into the educational curriculum, especially in technical and vocational education and training, where practical skills are paramount.

Integrating circular economy concepts into technical and vocational education is essential to educate students to meet the demands of the rapidly changing labor market. TVET is the main force behind sustainable development, especially in developing countries, by giving people the skills they need to promote environmental sustainability and economic progress [6]. This view is consistent with research by Jiang *et al.,* [7] which calls for curriculum changes that integrate sustainability principles and highlight the importance of sustainable development in China's vocational education and training (VET).

Educational institutions play an important role in advancing the principles of a circular economy. As an example of how higher education can take the lead in incorporating sustainability into professional training, Finland is a pioneer in establishing a degree program centered on the circular economy [8]. By integrating sustainability into their curriculum, engineering programs can also respond to the socio-economic environment, as demonstrated by the integration of circular economy principles [9]. Making these adjustments is critical to guaranteeing that graduates have the skills needed to thrive in the circular economy.

However, the challenges of implementing circular economy principles within technical and vocational education are multifaceted. Barriers such as inadequate policy frameworks, a lack of financial resources, and insufficient consumer interest have been identified as significant obstacles to the transition [10]. Additionally, the gap between educational institutions and industry needs can hinder the effectiveness of vocational training programs. Inflexible vocational education programs and lack of practical training opportunities contribute to this gap, highlighting the need for a more integrated approach that aligns educational outcomes with industry needs [11]. There have been relatively few scientometric studies focusing on the intersection of circular economy and technical and vocational education. Therefore, this scientometric review is dedicated to explore the publication trajectory of this subject. This refinement is necessary as various circular economy technologies are being implemented to identify and analyze risks associated with vocational education and training.

A comprehensive picture of past, present, and future research challenges can be obtained through scientometric reviews, which can show research trends and breakthroughs, create links between research clusters, and highlight research needs for future studies. Scientometric studies have several benefits, such as demonstrating the impact of research [12,13], forecasting future research paths based on gaps found [14], guiding funding allocation for impactful research at both local and international levels [15], and promoting cooperation with fruitful research networks, institutions, and nations [16,17]. The number of publications in this study that contain specific keywords is used as a scientometric analysis indicator. This study employs scientometric analysis to assess the impact of journals, authors, author keywords, nations, and organizations in order to fill in

current knowledge gaps. Specifically, this review identifies significant gaps such as the insufficient integration of circular economy practices in specific vocational training programs and the lack of comprehensive evaluations of educational outcomes related to sustainability in TVET. These gaps underscore the urgent need for more targeted research that explores the practical implementation of circular economy principles within vocational education frameworks and assesses their impact on sustainability competencies among students.

2. Materials and Methods

2.1 Dataset Collection and Initial Analysis

On February 11, 2025, data collection was initiated from two research databases, Web of Science (WoS) and Scopus. The search string ("circular economy" OR sustain*) AND vocational AND (educat* OR teach* OR learn* OR instruct*) was used in this study. The preference for using Scopus and WoS in scientific research is driven by the comprehensive coverage, high-quality peer-reviewed content, robust analytical tools, and the credibility these databases provide to research findings [18,19]. By focusing on these primary sources, researchers increase the reliability and impact of this scientometric assessments in the academic arena. Using the title of a journal article, conference proceeding, book, or book chapter, a title search is used to browse and choose pertinent publications. To draw attention to particular study subjects pertaining to content and structure development, title-based data set retrieval is crucial [20-22]. ScientoPy was then used to preprocess the downloaded dataset in order to look at the factors influencing the development of popular articles and topics. To ensure reliable analysis, ScientoPy, a Python-based scientific analysis tool, eliminates bias from individual publications.

Publications based on both databases from 1919 to February 2025 were produced using the data that was gathered. The publications of this study, which include book chapters, proceedings, conference papers, review papers, and articles, default to this publishing type in the ScientoPy program [23-25]. It should also be mentioned that language is not a crucial analysis parameter. One explanation could be that, unlike scoping or systematic literature reviews, which read the full text, scientific reviews evaluate the impact of articles. Not every document was discovered to be a duplicate. ScientoPy can eliminate all duplicate documents in order to solve this issue [26,27]. During the pre-processing phase, the data were then aligned by eliminating duplicate samples with the same title and author, replacing commas in author names with semicolons, and eliminating periods, commas, and odd accents from author names. The dataset's correctness and dependability were improved by this process [28]. Following pre-processing, the data were compiled into a new dataset.

The final sample examined in this study, which comprises 2177 documents after duplicate data has been removed, is shown in Fig. 1. This study includes 879 Scopus datasets and 1298 WOS datasets. The ScientoPy pre-processing script favored WoS publications, which led to the discovery of more papers from the WoS database after data duplication was eliminated. Notably, the total number of papers with more than 300 metadata satisfied the metric analysis minimal criteria after duplicates were eliminated [29].

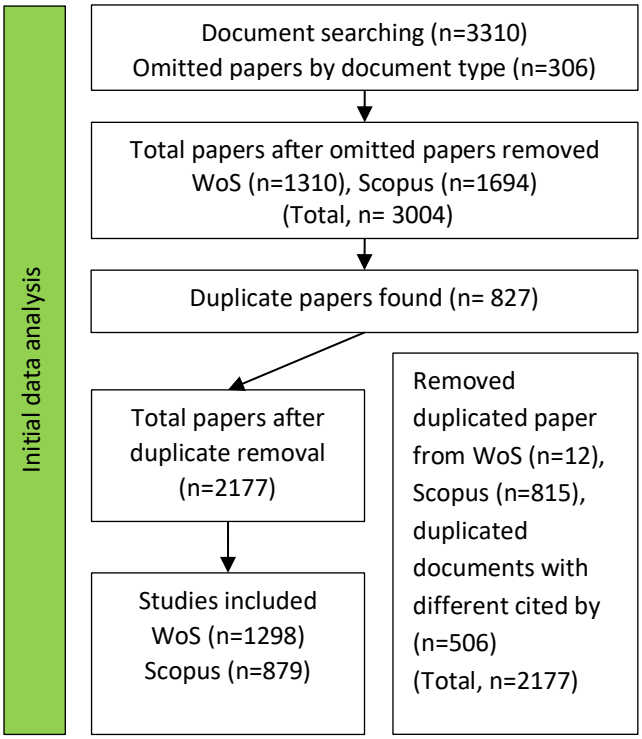

Fig. 1. Information on initial data analysis

3. Results

3.1 The Development of Publications

The development of publication trends from 1992 to 2028, as indexed by the WoS and Scopus databases, is illustrated by the blue circles and orange triangles respectively in Fig. 2. Initially, the number of publications was low in both databases, with less than 20 documents per year until the early 2000s. Then there was a gradual increase in the number of publications. In 2021, the increase was accelerated with a large number of publications across both databases, totaling 71, indicating a growing interest in this topic. The large growth in publications began around 2004 and continued to increase sharply, especially after 2016 for WoS, which is expected to exceed 100 documents per year by 2028. Scopus also shows an upward trend, although the growth is more gradual. This illustration clearly outlines the significant developments in research activity over nearly four decades. The growth in scholarly interest in the past two decades reflects the academic advancement in this field.

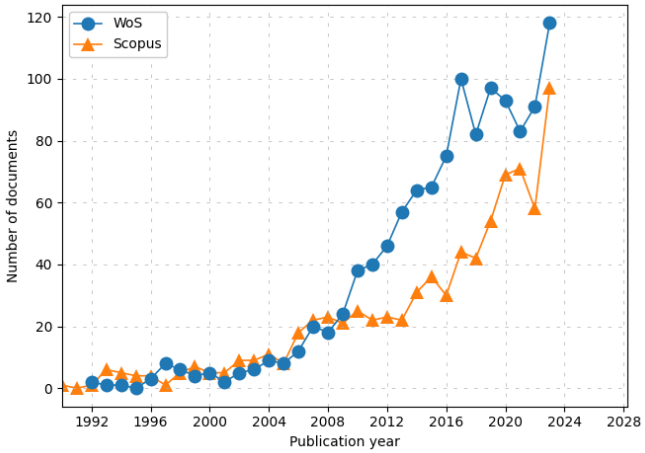

Fig. 2. The number of documents published by year

3.2 Analytical Descriptive Category

The study's initial descriptive category looks at the source titles of published papers related to vocational education and its intersection with circular economy (Table 1). The analysis revealed several key journals that significantly contribute to the dissemination of research in this area. At the top of the list, the journal 'Sustainability' leads with a total of 70 publications, although it experienced a negative Annual Growth Rate (AGR) of -2.5, yet maintains a high h-index of 13. Following closely, the 'Journal of Vocational Education and Training' holds the second position with 37 publications and a positive AGR of 2.5, reflecting its expanding influence, underscored by an h-index of 15. 'International Journal of Training Research' and 'Journal of Technical Education and Training' both show healthy growth rates of 1.0 and 1.4 respectively, with publication totals of 24 each.

'E3S Web of Conferences' appears next with 22 publications and an AGR of 1, demonstrating steady output in conference proceedings, though its h-index stands at 3, indicating a more nascent stage in its academic influence. The 'Journal of Vocational Rehabilitation' has published 18 papers and also shows an AGR of 1 with an h-index of 6. Further down the list, the 'International Journal of Educational Development' and the 'Journal of Physics: Conference Series' both have 13 publications each, with an AGR of 0, suggesting stable output over the years. The h-indexes are 9 and 2 respectively, highlighting different levels of citation impact. 'Education Sciences' with 10 publications and an AGR of 1, alongside an h-index of 4, and 'Rethinking Work and Learning: Adult and Vocational Education for Social Sustainability' also with 10 publications but an AGR of 0 and a lower h-index of 1, round off the list. This data will help future readers and scholars to obtain current information from a variety of sources to enhance their research with the latest findings and related problems. The dynamic nature of publications in this topic is demonstrated by the different AGR values, which indicate different patterns in research interest and scholarly impact.

Table 1
The most productive source titles

Position	Source Title	Total	AGR	h-Index
1	Sustainability	70	-2.5	13
2	Journal of Vocational Education and Training	37	2.5	15
3	International Journal of Training Research	24	1	8
4	Journal of Technical Education and Training	24	1.4	7
5	E3S Web of Conferences	22	1	3
6	Journal of Vocational Rehabilitation	18	1	6
7	International Journal of Educational Development	13	0	9
8	Journal of Physics: Conference Series	13	0	2
9	Education Sciences	10	1	4
10	Rethinking Work and Learning: Adult and Vocational Education for Social Sustainability	10	0	1

The study's second descriptive category looks at how publications are distributed among nations in the field of circular economy and TVET education. The graph provides a compelling visualization of the cumulative number of documents published by various countries from 1992 to 2028, with a special focus on the years 2022-2023, highlighting recent research trends.

From the analysis, it is evident that the United States, China, and Germany are the predominant contributors, with the United States leading significantly in the total number of publications. It was found that most of the articles in this field were published by authors from these developed

countries, emphasizing their central role in shaping the scientific discourse in this area. These nations have shown a steep increase in publications particularly after the year 2000.

Furthermore, the right side of the Fig. 3 illustrates the percentage of documents published in the last two years (2022-2023) compared to total publications since 1992, providing insights into recent research activity. Australia, although not leading in total publications, shows a high percentage of recent publications, suggesting a growing focus and contribution to this research area in the most recent years. This study highlights the vital global contributions to research in vocational education, particularly regarding sustainability. It points to the collaborative efforts among countries, showing significant global interactions among researchers. These international collaborations are essential for enhancing knowledge and effectively incorporating sustainability into vocational education systems.

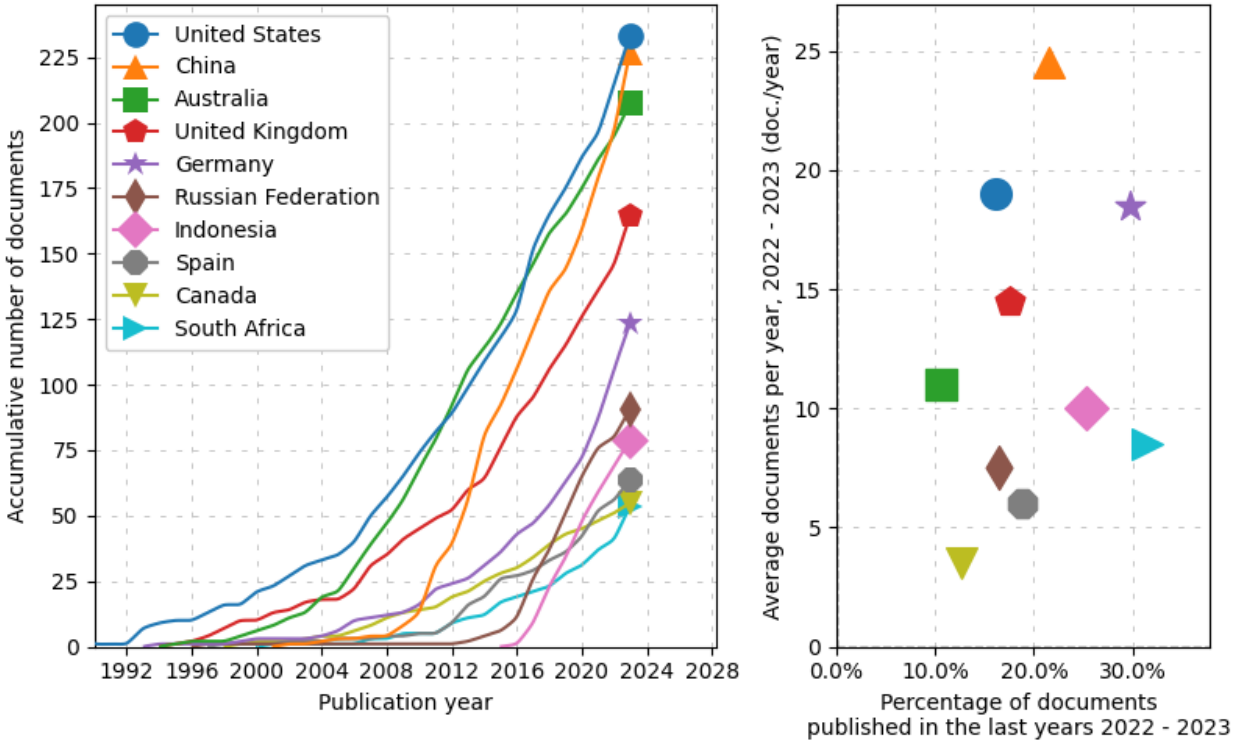

Fig. 3. The distribution of publications across countries

This study includes a co-authorship analysis to underscore the significance of collaborative research across various scientific fields. Co-authorship, in this context, refers to a joint effort among multiple authors from different countries to achieve specific research objectives. This collaborative approach not only fosters the sharing of diverse perspectives but also enhances the development of comprehensive solutions to complex research questions. The co-authorship network visualized in the provided figure utilizes VOSviewer software to map the interactions between countries based on their collaborative publications. The analysis set a minimum threshold of 20 publications per country, with no minimum citation requirement, allowing for a broad inclusion of collaborative efforts. As a result, 14 of the 99 countries analyzed met these criteria.

The network diagram illustrates the global landscape of co-authorship with countries represented as nodes connected by lines, where the size of each node indicates the volume of documents produced by that country, and the line thickness reflects the strength of collaborative ties between them. The nodes are color-coded into four distinct clusters (red, blue, green, and yellow) to demonstrate the different regional or thematic groupings within the global co-authorship network. This detailed visualization in Fig. 4 provides insights into how countries like the United States, China,

Germany, and Australia are central to the network, indicating their key roles in producing collaborative research. Such analyses are crucial for understanding the dynamics of international research partnerships and for identifying influential players in specific scientific domains.

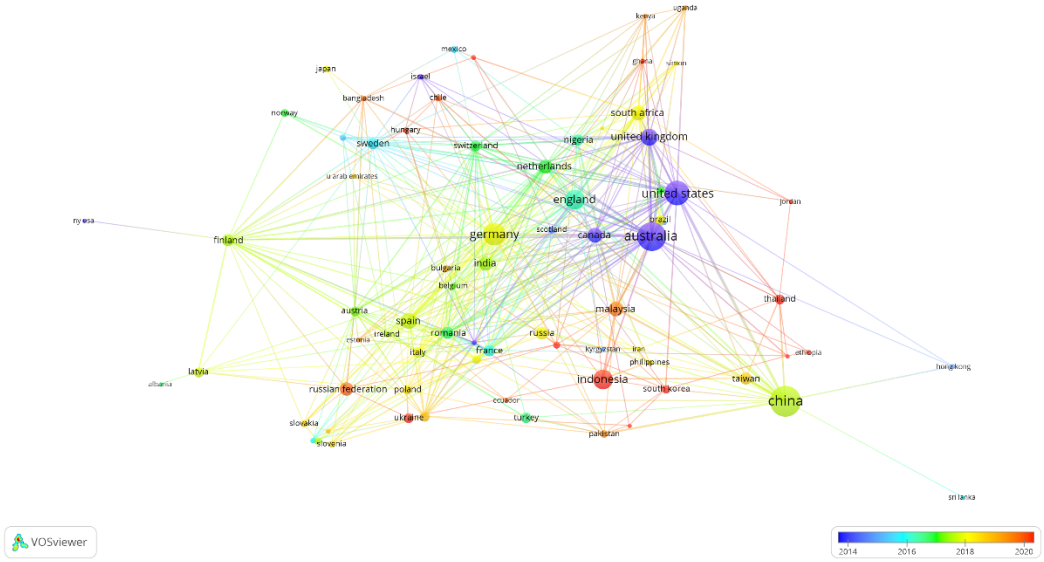

Fig. 4. Network visualization of co-authorship by country

This analysis delves into the contributions of institutions to research in the fields of vocational education and the circular economy. Fig. 5 displays the ten institutions that have published the most documents on this subject. Leading the chart is Universiti Tun Hussein Onn Malaysia, which has the highest number of publications, indicating its prominent role in advancing research in this area. Close behind, Universiti Pendidikan Indonesia also shows significant contributions, underlining a strong focus on integrating vocational education with circular economy principles.

The University of Helsinki in Finland, together with the University of Nottingham in the United Kingdom and the University of Melbourne in Australia, are also key players, with considerable numbers of publications. This suggests a robust interest and ongoing investment in research at these institutions. Similarly, universities like Griffith University and Queensland University of Technology highlight the global nature of this research, with contributions coming from various parts of the world. This study highlights that these institutions are not only contributing to but also shaping the direction of research in these interconnected fields. The data implies that their efforts are pivotal in driving advancements in vocational education and the circular economy.

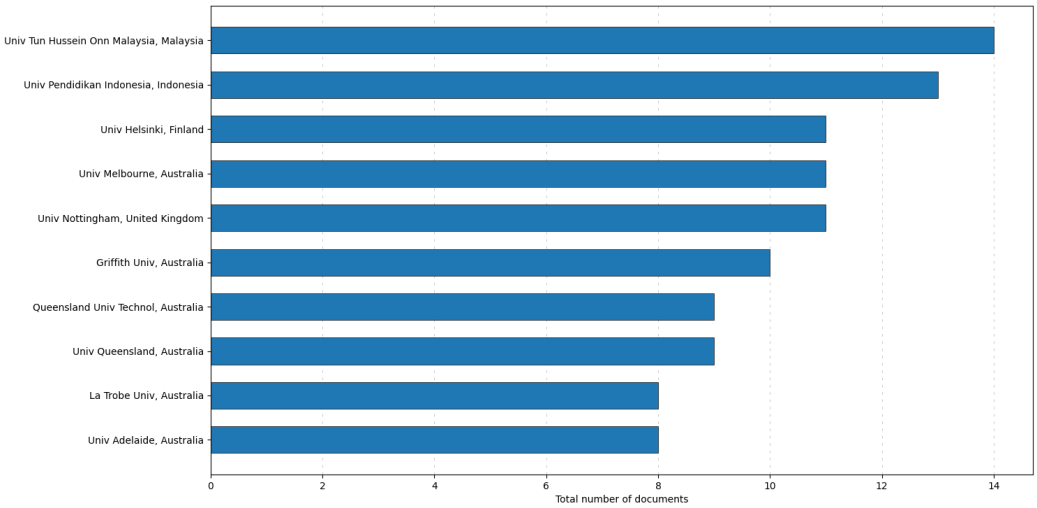

Fig. 5. The most productive institutions

3.3 Analysis of the Authors' Keywords

The keywords in scholarly articles serve as crucial indicators of the article's focus areas, significantly aiding researchers in locating publications that align with their specific interests [30]. This analysis interprets the top author keywords in the context of vocational and sustainable education by examining their frequency and recent prominence. Fig. 6 illustrates the total number of documents associated with each keyword and the percentage published in the most recent years, 2022-2023. From the data, the keyword "Vocational education" appears most frequently, featuring in 250 documents with 21% of these published in the last two years, highlighting its ongoing relevance in current research. Other significant keywords include "Sustainable development" and "Professional education", both illustrating substantial engagement with 18% and 17% of their recent publications respectively. These keywords underscore a strong and growing research interest in integrating sustainability into professional and vocational training contexts.

Further, keywords like "Employability" and "Training" are also notable, each reflecting an upward trend in recent publications, indicating a responsive shift in research focus to address contemporary educational challenges. "Innovation", although represented in a smaller total number of publications, shows a 4% recent publication rate, suggesting a niche but emerging area of focus. This keyword analysis offers a snapshot of the dynamic shifts and enduring interests in vocational and sustainable education research, helping researchers identify both established and emergent areas of study within this evolving field.

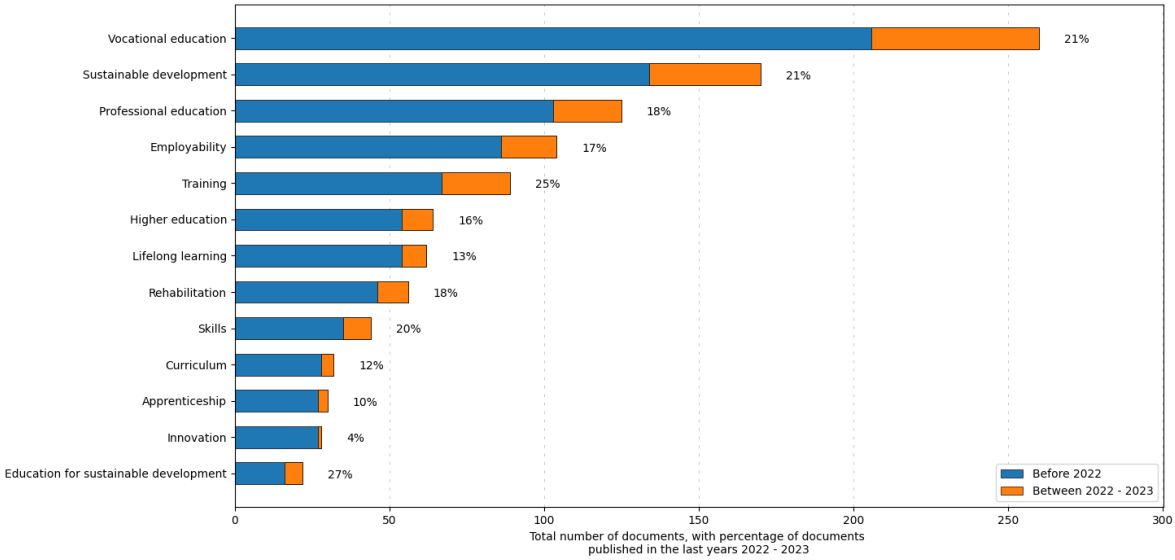

Fig. 6. The most frequently used of authors' keywords

This study utilizes VOSviewer to conduct a co-occurrence analysis of authors' keywords, providing a visual representation of how keywords are interconnected within the dataset. This graphic visualization, displayed in Fig. 7 is essential for researchers aiming to understand the relationships between various concepts and the broader scope of their implications within vocational education and sustainable development research. The visualization employed in this study is an overlay visualization, which illustrates the nexus of keywords across the temporal dimension of publication. The resulting visualization identifies 17 keywords meeting this criterion, highlighting the most significant terms used in recent literature. In the visual map, different colors indicate the temporal progression of the keywords' usage. Keywords within the red nodes represent those that have gained prominence in publications from 2020 to 2023, signaling current research foci. Conversely, keywords depicted in blue nodes were frequently used before 2020, indicating their foundational role in earlier research.

The size of each node in the visualization correlates with the keyword's occurrence frequency—the larger the node, the more frequent the keyword's appearance in the literature. The lines connecting the nodes represent the strength of the linkage between keywords, with thicker lines denoting stronger associations. In this analysis, central keywords such as "vocational education," "sustainable development," and "professional education" are prominently linked, underscoring their crucial roles in current research within this field. Keywords like "employability" and "skills" are also closely connected, reflecting their importance in discussions on vocational education and its impact on the job market. Furthermore, the nexus between "education" and "sustainability" highlights the growing emphasis on integrating sustainability principles into educational curricula and practices.

This detailed co-occurrence mapping offers valuable insights into the evolving trends in vocational education research, particularly in how sustainability is increasingly being integrated into educational frameworks. Researchers and scholars can utilize this visualization to explore emerging research areas and to better understand the interconnected nature of these critical educational and developmental topics.

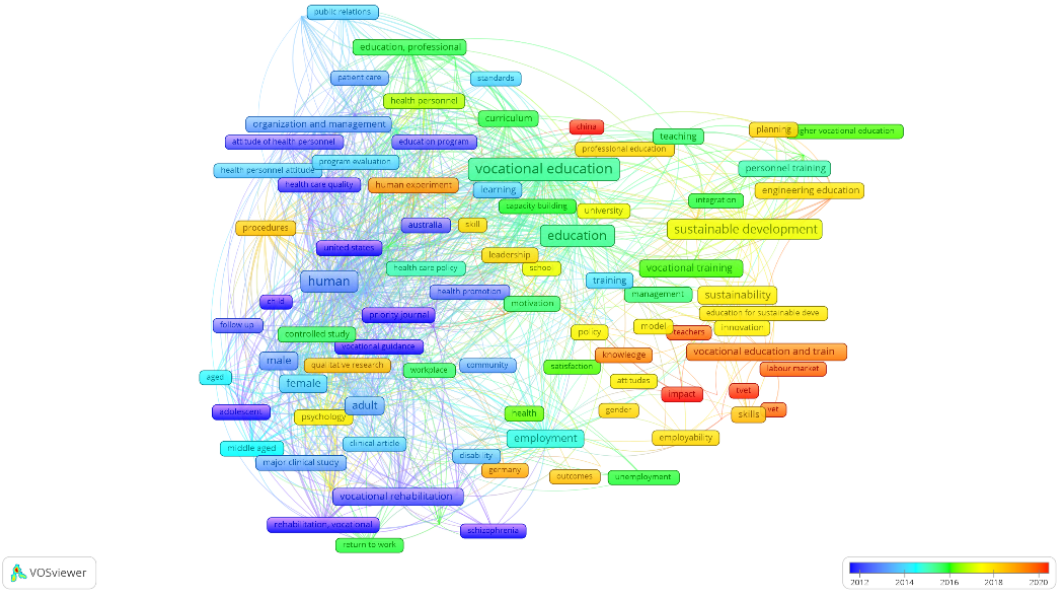

Fig. 7. *Overlay visualization of Authors' Keywords*

3.4 Analysis of the Theory and Model

Analysis of the most widely used theories and models allows researchers and academics to identify current trends and changes in research focus. Fig. 8 illustrates the distribution and focus on various theoretical frameworks within scholarly research. Notably, the "Queuing Theory Vocational Skills " and "Sociocultural Theory" have emerged as significant areas of focus, particularly in the years 2022 and 2023, where they received substantial attention, as indicated by the percentage of recent publications related to these theories. This highlights a growing academic interest in how these theories apply to vocational skills and social cultural contexts within educational settings.

Other theories such as "Expectation Confirmation Theory," "Gender Theory," and "Gradual Institutional Change Theory" show a 100% recent publication rate, suggesting that these areas have seen a resurgence or new interest in the last two years. However, many theories such as "Self-Determination Theory," "Constructivist Learning Theory," and several others have not been featured in recent publications, indicating a potential shift in research focus away from these areas.

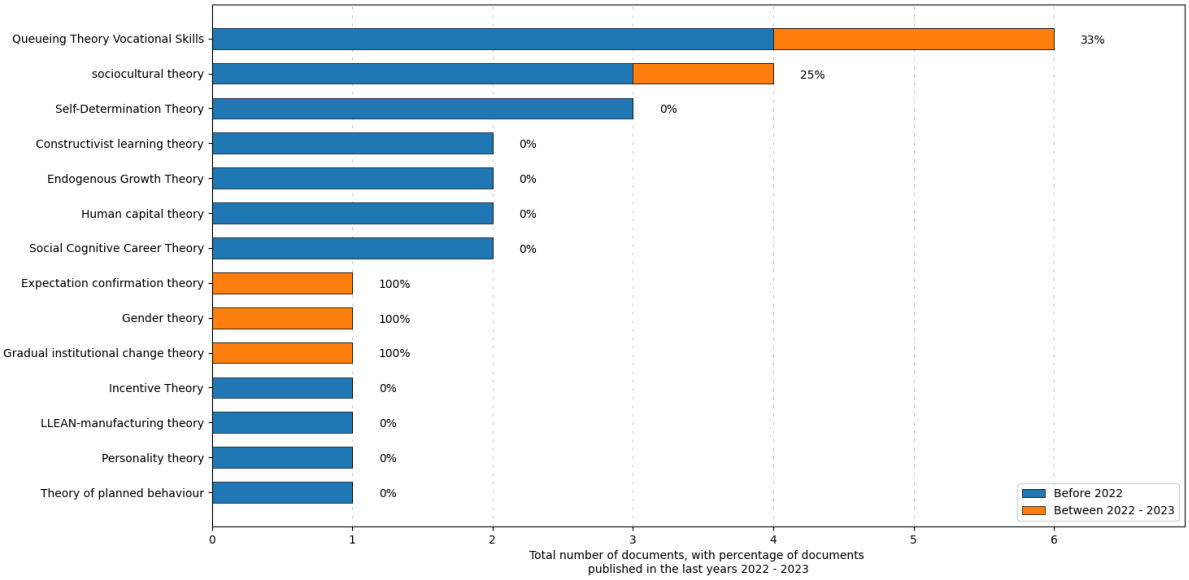

Fig. 8. The most widely used theories in circular economy and TVET education

This study has further analyzed the various models used within the research community. Fig. 9 illustrated the "Learning Model" and "Circular Business Model" stand out, receiving the most attention from researchers, particularly in the most recent years. This suggests a strong and growing interest in exploring effective learning strategies and sustainable business practices within educational and professional training environments. Moreover, several models such as the "CIPP IEST Model," "Cohesion Model," "GB-US-SBM Model," "Sister-Cousin Model," and "Technology Acceptance Model" also indicate a 100% publication rate between 2022 and 2023. This reflects a vibrant and dynamic research interest in these models, showcasing their relevance and applicability to contemporary educational challenges and technological adaptations. These figures collectively reveal trends and shifts in theoretical and model-based research within educational and professional contexts, underscoring the evolving nature of scholarly inquiry as it adapts to new challenges and opportunities in the field of education.

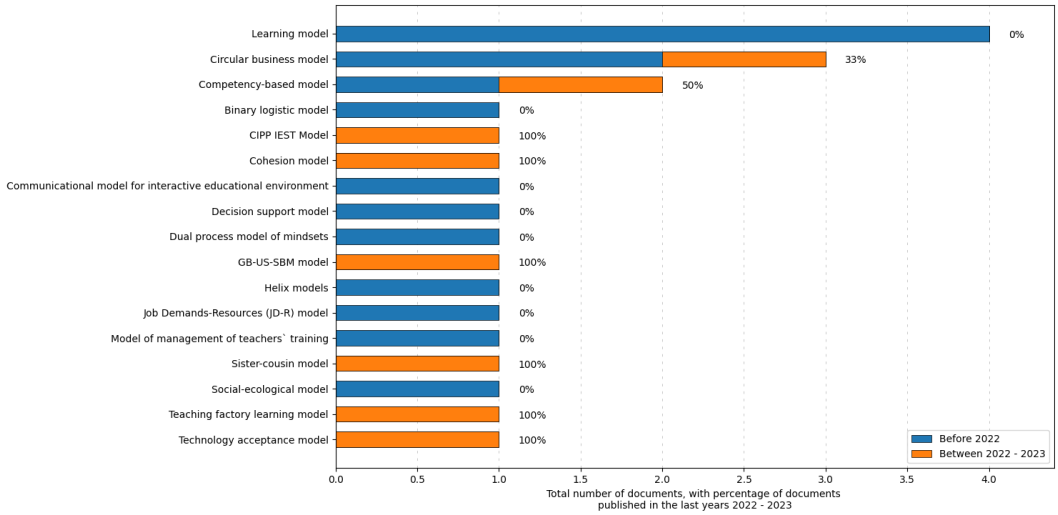

Fig. 9. The most widely used models in circular economy and TVET education

4. Discussion

Circular economy and TVET education practitioners and researchers have used traditional approaches to address the skills gap in the workforce for many years. Often the focus has been on direct application of skills without integrating broader sustainability goals. However, the increasing importance of environmental sustainability and economic resilience requires a paradigm shift towards incorporating circular economy principles into TVET curricula [31]. This is to enable students to be equipped with the skills needed to succeed in a sustainable economy [32,33]. Integrating circular economy principles into TVET education faces several key barriers, notably institutional resistance, inadequate resources and gaps in educator expertise, which hinder the adoption of innovative educational approaches [34]. Initiatives have included industry-TVET collaborations in India that have increased curriculum relevance and resource sharing [35], and in Malaysia, investments in educator upskilling programmes have significantly improved teaching efficiency [36]. This approach is seen as essential for implementing effective educational strategies and policies that foster sustainability in the vocational and technical workforce.

The history and development of papers on circular economy in TVET education indexed in Scopus and WoS databases are reviewed in this study. VOSviewer was customized to perform the evaluation and display of all data collected throughout the review process [37,38], while ScientoPy was used to monitor the publication flow [25]. This study offers a brief synopsis of the concept of circular economy in TVET to help researchers, educators and policymakers gain essential knowledge for developing future curricula and teaching methods. Importantly, it emphasizes the need for multidisciplinary research on the incorporation of circular economy concepts into Technical and Vocational Education and Training (TVET) and the importance of this integration in promoting sustainable career practices. Therefore, it is considered beneficial to further integrate circular economy into TVET education.

The exponential increase in publications since 2016 demonstrates the development and expansion of the circular economy concept in TVET education. Notably, the trajectory of articles in WoS has increased significantly compared to the Scopus database. This trend makes sense as governments, businesses and educational institutions increasingly recognize the importance of incorporating circular economy into curricula to reduce risks and create a workforce equipped to address today's environmental issues [39,40]. Consequently, research into the circular economy in TVET has surged in recent years, underscoring the critical role of such education in promoting sustainable practices in any organization.

The analysis reveals an increasing scholarly focus on integrating circular economy competencies into TVET, highlighting the role of education in driving economic growth and environmental sustainability, particularly in developing countries. This shift is supported by evidence presented in recent publications and the educational reforms advocated by scholars like Jiang *et al.,* [7], who stress the importance of sustainable development in Chinese vocational education. Moreover, initiatives like Finland's development of degree programs dedicated to the circular economy [8,41] exemplify how educational institutions can lead in cultivating these necessary competencies.

Publication trends from 1992 to 2028 in the WoS and Scopus databases indicate a rise from initial low activity to a peak in 2021, with significant growth since 2004. The significant increase in publications in recent years shows that the United States, China, and Germany are the main contributors to research in the circular economy and TVET education. This is consistent with other research that shows how important these three countries are to the advancement of TVET and vocational education [42-44]. The analysis highlights leading institutions like Universiti Tun Hussein Onn Malaysia and underscores the pivotal role of keywords such as "Vocational education" and

"Sustainable development" in shaping current research directions. Similar keywords identified by other researchers, such as “Technological and Vocational Education” and “Education for sustainable development,” indicate broad consensus on critical themes in this field [45-47]. The use of VOSviewer for co-occurrence analysis reveals significant keywords and their interconnections, reflecting a shift towards integrating sustainability into educational practices. Research interest in theories like "Queuing Theory Vocational Skills" and models such as the "Learning Model" and "Circular Business Model" showcases evolving trends in educational research focused on sustainability and effective learning strategies.

The use of scientometric analysis in this study provides a comprehensive overview of the research landscape, illustrating the evolution of themes and the depth of investigation into the synergies between circular economy and TVET education. This approach not only highlights the critical areas of research but also identifies gaps where further scholarly work is needed, thus guiding future research directions.

5. Conclusions

Scientometric methods are a practical approach to mapping published research on circular economy in TVET education. In addition, key concepts from the literature were acknowledged, as well as an understanding of the evolution and interaction of research trends in the field. In this study, key concepts of circular economy in TVET education were examined; where the most trending keywords were “vocational education”, “sustainable development”, “professional education”, and “employability”. Also, “skills”, “education”, “sustainability”, “training”, “innovation” have all been highlighted as strengths in previous TVET studies. Through scoping studies or systematic literature reviews, future researchers need to take a closer look at these keywords to understand their relationships.

This study can help scientists, engineers, environmental health and safety experts, and anyone involved in research work to study in more detail to understand vocational and technical education and its relationship with the circular economy concept. In line with the development of circular economy principles and the requirements of sustainable development goals, the circular economy will continue to be a focus of future research and development as it gradually changes the way people think, work, and interact. Concerns about vocational and technical education can and should be developed and prioritized to keep pace with the rapid changes in educational practices and sustainability. This is because vocational and technical education is an important subject to ensure and promote the development and competence of personnel in academia and industry. Importantly, it should be seen as a step forward to strengthen measures to protect and improve aspects of education and the workforce in the workplace at both the macro and micro levels, which can also help the global education community.

This study serves as a foundation that could be enhanced by a more thorough analysis of thematic content. The findings of the study may offer theoretical perspectives on the topic, a state-of-the-art map and highlight any possible gaps in scientific knowledge. The potential of this scientific analysis to serve as a basis for further research on the circular economy in TVET education and the identification of current educational, cognitive and cultural anthropological philosophies relevant to this field of study is one of its main features. Future research should focus on exploring diverse frameworks that elucidate the relationship between circular economy practices and TVET education. This exploration is vital for providing a structured theoretical foundation for integrating sustainable practices into vocational training. By examining various theoretical frameworks, researchers and educators can develop tailored educational strategies that align with global sustainability goals and

the specific needs of the workforce, effectively bridging the gap between theoretical constructs and practical application in TVET programs.

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