



Transforming Vocational Education towards Green TVET: A Global Bibliometric Analysis

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ABSTRACT

Technical and Vocational Education and Training (TVET) plays a strategic role in supporting the transition towards sustainable development. This study aims to analyse developments in the literature on the transformation of vocational education towards Green TVET using a bibliometric approach. Data were collected from international publications indexed in the Web of Science (WoS) database and analysed using a combination of VOSviewer and RStudio software. The analysis was conducted through keyword co-occurrence, network visualisation, and thematic mapping to identify key trends and the direction of research development. The results indicate that research themes focus on education, skills, competences, vocational education, impact, and policy. Keyword trends suggest a shift from a conceptual approach towards a practical orientation, characterised by the strengthening of green skills and cross-disciplinary competences. The thematic map confirms that skills and competences occupy the position of driving themes, reinforcing the role of Green TVET as a vital instrument in supporting the achievement of the Sustainable Development Goals (SDGs), particularly SDG 4, SDG 8, SDG 9, and SDG 13. This study provides a comprehensive overview of the direction of research into Green TVET and its implications for policy, curriculum, and strategies in sustainability-oriented vocational education.

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Introduction

Technical and Vocational Education and Training (TVET) is a strategic sector in supporting economic development and serves as a vital instrument in driving the transition towards sustainable development. As the urgency of environmental issues and the transition to a green economy grows, TVET functions as the primary pathway for preparing a skilled and competent workforce that meets the needs of industry [1], [2]. In recent years, global challenges such as climate change, environmental degradation, and the energy crisis have driven a shift in the educational paradigm towards sustainable development [3]-[5]. One significant response to these changes is the transformation of vocational education towards a more environmentally friendly direction through the Green TVET approach. Green TVET is an educational approach that integrates sustainability principles into all aspects of learning, from the curriculum and teaching methods to industry practice [6]-[8]. The aim is to equip learners with green skills, including environmental awareness, energy efficiency, waste management, and the use of environmentally friendly technologies [1], [9]. The transition to Green TVET is not merely an adaptation to the needs of the labour market, but also a tangible contribution by the education sector towards achieving the Sustainable Development Goals (SDGs), particularly the fourth and thirteenth goals relating to quality education and climate action.

Globally, various international organisations have demonstrated their commitment to promoting the implementation of Green TVET. Programmes such as 'Greening TVET and Skills Development' by UNESCO-UNEVOC and 'Education for Sustainable Development (ESD) 2030' emphasise the importance of vocational education in addressing environmental challenges and climate change [10]. However, the development of Green TVET varies considerably across different countries. Developed countries are relatively more progressive in adopting sustainability principles within their vocational education systems, whilst developing countries still face structural constraints, including limited resources, teacher capacity, and supporting infrastructure [11], [12]. As interest in Green TVET grows, so too has the body of scientific literature in this field. However, these studies remain scattered across various academic disciplines, such as education, environmental engineering, sustainable development and public policy [13], [14]. Consequently, systematic mapping of research developments in Green TVET remains limited. Therefore, an analytical approach is required to review the scientific landscape comprehensively in order to identify trends, key actors, and the direction of Green TVET research globally. A bibliometric approach is the appropriate method to address this need.

Bibliometrics is a quantitative technique used to analyse scientific publications in order to reveal the dynamics of development within a field of study [15], [16]. This method is capable of identifying publication trends, collaboration between authors or institutions, and grouping

the main themes emerging in the literature [17], [18]. In the context of sustainable education, this approach has been used to analyse the development of Education for Sustainable Development [19], but has not yet been widely applied specifically to the context of TVET. Against this background, this study aims to conduct a bibliometric analysis of the scientific literature relating to the transformation of vocational education towards Green TVET within the context of global sustainability issues. This study seeks to provide recommendations for future research directions to support the strengthening of policies and practices in sustainable vocational education. The results of this study are expected to make a scientific contribution to the development of TVET that is more adaptive to environmental and social challenges. Furthermore, this study can serve as a reference for policy-makers, including the government, educational institutions, and industry, in designing strategies for the transformation of vocational education that align with the principles of sustainable development.

Material and Methods

This study employs a bibliometric approach to analyse scientific literature relating to vocational education and sustainability. This approach was chosen as it provides a quantitative and visual overview of the structure, dynamics and trends of knowledge within a field of study. The study adopts a bibliometric framework based on science mapping, which aims to explore relationships and patterns within a body of literature through performance analysis and network analysis, such as co-authorship, co-occurrence, and co-citation.

A. Data Sources

The data for this study were retrieved from the Web of Science (WoS) database, which was selected for its extensive coverage of international scholarly publications, comprehensive bibliographic metadata, and support for exporting bibliometric data in formats compatible with bibliometric analysis software. The search was conducted on 25 June 2025, with no restrictions on publication year, to capture both historical developments and current trends related to the topic under investigation. The search query used was: ("TVET" OR "Technical and Vocational Education and Training" OR "Vocational Education") AND ("Green Skills" OR "Green TVET" OR "Sustainable Skills" OR "Sustainable Development" OR "Education for Sustainable Development"). The search was performed across the title, abstract, and keyword fields to ensure the thematic relevance of the retrieved documents. The initial search identified 235 documents. The retrieved records were subsequently screened according to predefined eligibility criteria. Only articles, review articles, and conference proceedings written in English were retained, while documents that did not meet these document-type and language criteria were excluded. Following this screening process, 23 documents were excluded, resulting in a final dataset of 212 documents for bibliometric analysis. The selected records were exported from Web of Science in BibTeX and plain-text formats and subsequently analyzed using

bibliometric analysis techniques and VOSviewer. The overall data collection, document selection, and bibliometric analysis procedures are presented in Fig. 1.

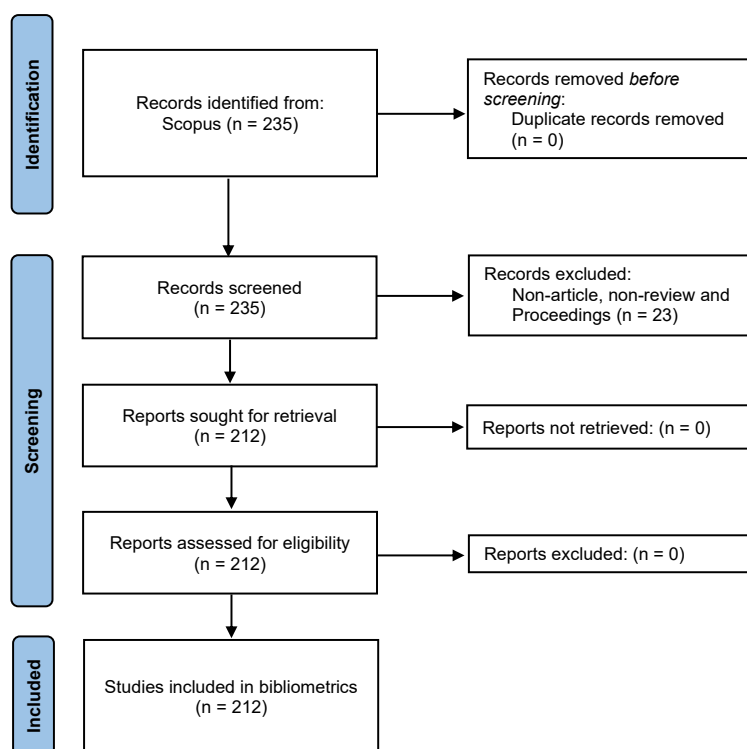


Fig. 1. PRISMA flow diagram

B. Analysis Process

Bibliographic data obtained from Web of Science was exported in BibTeX and plain text file formats. The data was then analysed using RStudio software with the Bibliometrix and VOSviewer packages. The analysis was conducted in two main stages: performance analysis and network visualisation analysis. First, performance analysis was used to evaluate publication productivity based on quantitative indicators such as the number of publications per year, the most productive authors, the most active institutions and countries, and the journals with the highest contribution to this topic. Other indicators taken into account included the number of citations and the H-index of authors and institutions. Secondly, science mapping was used to reveal the intellectual and thematic structures within the Green TVET and SDGs literature, with the following four questions:

1. What are the trends in scientific publications regarding the transformation of vocational education towards Green TVET in the context of global sustainable development?
2. Which countries, institutions and authors have contributed most to the development of the literature on Green TVET and education for sustainable development?

3. What are the main themes, dominant keywords, and fields of study that frequently appear in scientific articles related to Green TVET?
4. What are the directions and trends for future research topics in studies on the transformation of vocational education towards Green TVET?

The visualisations of the analysis results are presented in Fig. 2 in the form of graphs and network visualisations, including growth trends, collaboration maps and thematic evolution. These results are interpreted in a descriptive and critical manner to illustrate the direction of research development, the strength of collaborations, and potential research gaps that can serve as a basis for further studies.

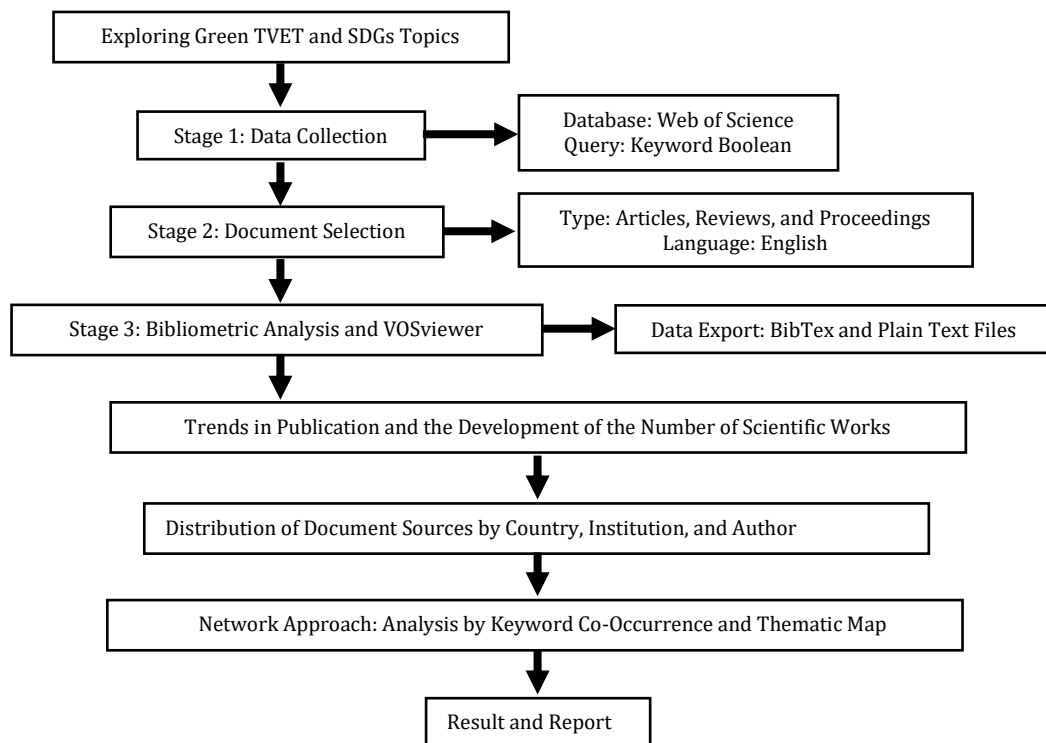


Fig. 2. Research framework

Results and Discussion

A. Trends in Publication and the Development of the Number of Scientific Works

To determine the growth in publications, an analysis was carried out on 212 documents. The first analysis conducted was to identify the number of document types. Based on the analysis in Fig. 3, a total of 212 academic publications were produced, comprising 127 journal articles (59.91 %), 80 review articles (37.74 %), and 6 conference proceedings (2.83 %). The dominant proportion of journal articles indicates that empirical and field-based studies constitute the primary form of scientific contribution within this topic. The high number of review articles also reflects significant attention to literature mapping and the development of systematic conceptual frameworks, which are crucial for strengthening the theoretical

foundation and guiding future research directions. Meanwhile, the number of publications in the form of conference proceedings is relatively low, indicating that the dissemination of knowledge through conference forums has not yet become a primary channel in this field of study. Overall, this trend indicates growth in the literature that is not only quantitative but also qualitative, with a balance between primary and secondary studies. This reflects the dynamics of scientific development that is progressing gradually, both through the exploration of new findings and the synthesis of previous research.

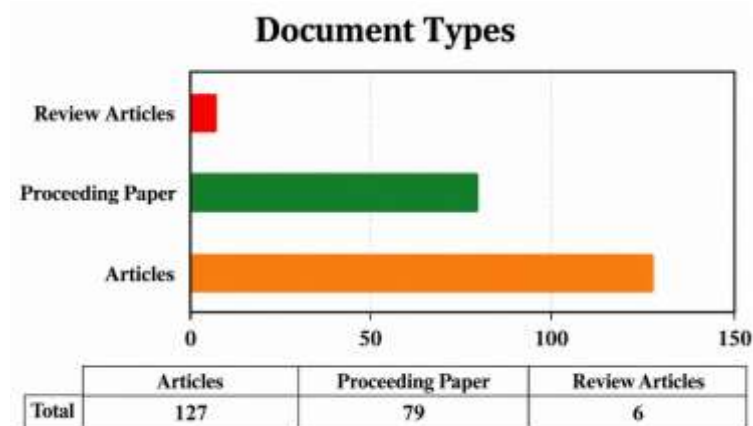


Fig. 3. Type of research document

Based on Fig. 4, the growth in publications can be divided into three developmental phases: Early Growth (1997–2010), Moderate Growth (2011–2017), and Rapid Growth (2018–2025). In the Early Growth phase, the number of publications was still very low, with a total of only 11 documents (5.19% of the total), indicating that this research topic was still in its initial stages. In [20] research conducted by Parkin & Lawrence developed a curriculum to raise students' awareness and sense of responsibility regarding environmental protection. Meanwhile, Viertel [21] undertook a reform of the European Training Foundation's (ETF) education and training policies in economic, social, and environmental aspects. These findings confirm that sustainable development in technical and vocational education requires a holistic approach involving the strengthening of technical competencies, the development of soft skills, and the involvement of various stakeholders [22]. At this stage, the first countries to initiate research were China, Malaysia, and European states [21]-[23].

Entering the Moderate Growth phase, the number of publications rose to 53 documents (25%), reflecting the emergence of consistency in scientific contributions and growing interest among researchers in this field. This phase collectively emphasised the importance of integrating the principles of sustainable development into vocational education through technology and the adoption of environmentally friendly innovations, highlighting the need for a shift in focus towards a green economy, social justice, and energy awareness that influences

the use of energy-efficient technologies, whilst also underscoring the need for targeted sustainability strategies [26]-[28].

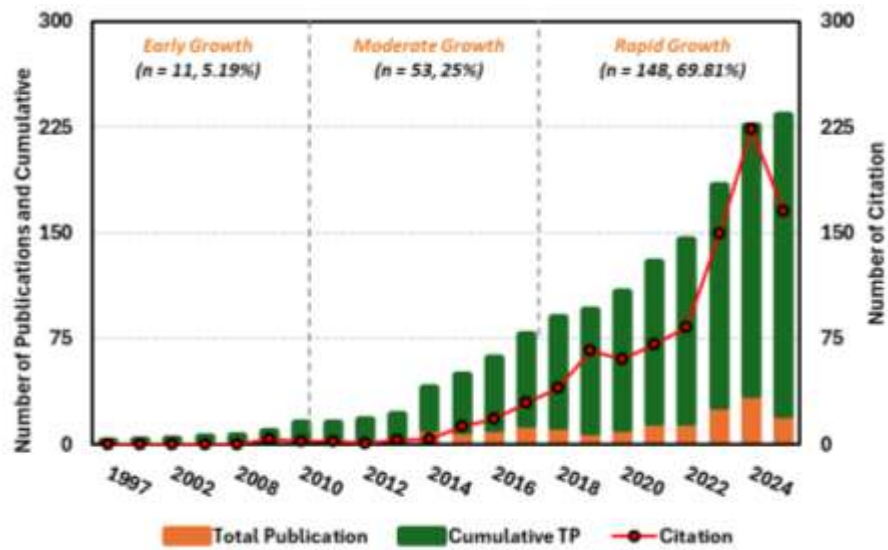


Fig. 4. Growth in publications and citations over the past 22 years

The peak of development occurred during the Rapid Growth phase, with the largest contribution being 148 publications (69.81%) and a significant upward trend each year. The cumulative total of publications (Cumulative TP) showed exponential growth, whilst the number of citations also surged, particularly during the 2022–2023 period, before declining slightly in 2025. This pattern indicates that the research field of green TVET is increasingly focusing on skills and the environment and is currently at a mature stage with high productivity and growing scientific influence, although the fluctuation in citations in the final year may reflect a natural time lag in the accumulation of academic recognition.

Table 1 lists the top 10 research areas across various disciplines from 1997 to 2025. The data show that the most dominant research is in the field of Education and Educational Research (TP = 102; TC = 303, HI = 10), followed by Environmental Sciences and Ecology (TP = 40; TC = 314, HI = 10) and Science, Technology and Other Topics (TP = 38; TC = 405, HI = 11). These three fields have seen a significant increase since 2011 and have become the main focus of global academic literature. Meanwhile, other fields such as Business and Economics, Engineering, and Social Sciences have developed more moderately, whilst Computer Science, Arts and Humanities, Psychology, and Public Administration have shown limited contributions, although some have relatively high citation impacts.

These findings suggest that research on green TVET in relation to the environment and technology has become a key focus in the global academic literature, with a significant upward trend over the past decade in line with the urgency of issues such as sustainability, technological innovation, and the transformation of vocational education systems.

Table 1. The top 10 research areas

No.	Research Area	1997-2010	2011-2017	2018-2025	TP	TC	HI
1.	Education Educational Research	9	32	61	102	303	10
2.	Environmental Sciences Ecology	1	6	33	40	314	10
3.	Science Technology Other Topics	1	4	33	38	405	11
4.	Social Sciences Other Topics	-	27	6	33	39	3
5.	Business Economics	-	14	13	27	64	5
6.	Engineering	1	6	13	20	112	4
7.	Computer Science	-	6	4	10	6	1
8.	Arts Humanities Other Topics	-	6	2	8	17	2
9.	Psychology	-	2	6	8	60	4
10	Public Administration	2	-	3	5	13	1

B. Distribution of Document Sources by Country, Institution, and Author**1. The Most Influential Countries in the Field of Research**

Table 2 lists the top 10 countries contributing to research on Green TVET and global sustainability issues, based on the number of publications (TP), citations (TC) and H-index (HI). According to the data in Table 2, China ranks first with 58 publications and 105 citations. It is followed by Malaysia with 35 publications, 99 citations and an H-index of 6. Next is Germany, which stands out for its higher quality compared to China and Malaysia, particularly in terms of the number of citations and H-Index, namely 165 citations and an H-Index of 7. The fourth country is Indonesia with 13 publications, 21 citations and an H-Index of 3. Although the number of citations is still low, this indicates the potential for Green TVET research in Indonesia, even though it has not yet received global attention. Romania (TP = 11; TC = 54; HI = 4) and Taiwan (TP = 9; TC = 137; HI = 5) stand out. In the case of Taiwan in particular, the number of publications remains low, yet the number of citations is quite high. This indicates that the quality of research in Taiwan is very good. Next are Russia (TP = 8; TC = 5; HI = 1) and Spain (TP = 7; TC = 29; HI = 3), indicating that these two countries have relatively low influence in the field of Green TVET and global sustainability issues. Then there are the USA (TP = 7; TC = 59; HI = 5) and South Africa (TP = 6; TC = 115; HI = 4), showing that Green TVET research is also developing in the Americas and Africa, although their contributions remain limited in number.

Table 2. The 10 countries with the highest number of publications

No.	Country	TP	TC	HI
1.	China	58	105	6
2.	Malaysia	35	99	6
3.	Germany	17	165	7
4.	Indonesia	13	21	3
5.	Romania	11	54	4
6.	Taiwan	9	137	5
7.	Russia	8	5	1
8.	Spain	7	29	3
9.	USA	7	59	5
10	South Africa	6	115	4

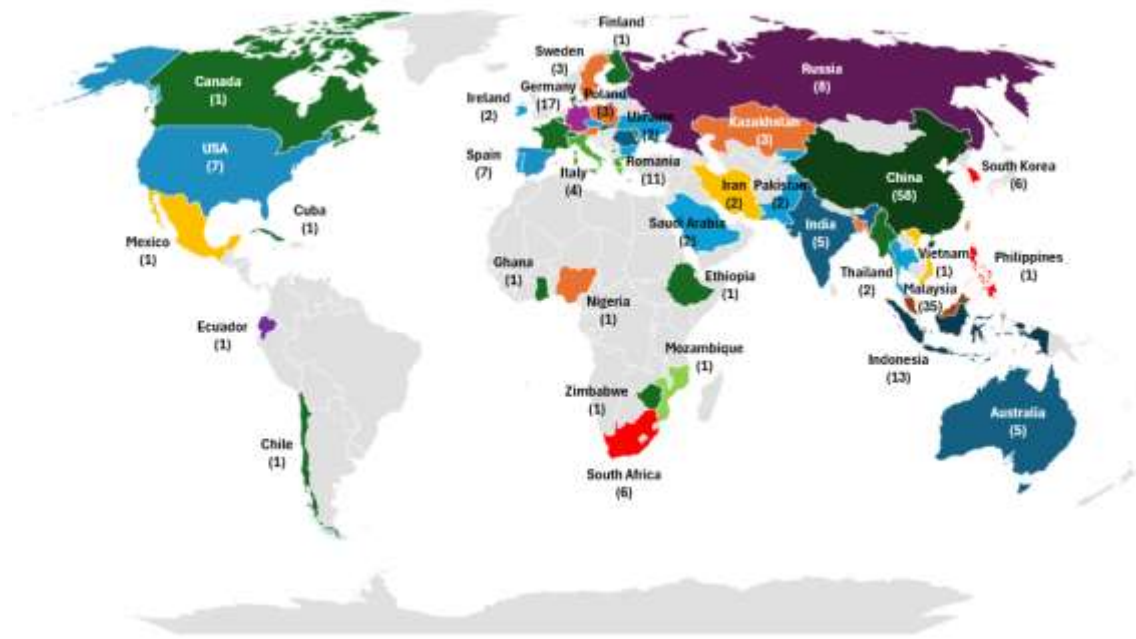


Fig. 5. Distribution of green TVET publications by country (WOS database)

The world map in Fig. 5 shows that research on Green TVET is spread across various countries. In Asia, dominant countries such as China ($n = 58$) rank highest globally; this demonstrates the significant role China plays in Green TVET research and is consistent with China's strong policies on sustainable development. Next is Malaysia ($n = 35$), a centre for Green TVET research in the ASEAN region, focusing on the integration of vocational education with the green development agenda. Then there are Indonesia ($n = 13$), India ($n = 5$), Thailand ($n = 2$), Vietnam ($n = 1$), and the Philippines ($n = 1$), indicating that Green TVET is also a focus for developing nations. In the European region, Germany ($n = 17$), Romania ($n = 11$), Spain ($n = 7$) and Italy ($n = 4$) represent Green TVET in Europe. Although the number of publications is lower than in Asia, the number of citations is higher, indicating that Europe has better quality and impact in the field of Green TVET.

As for Sweden ($n = 3$), Ireland ($n = 2$), Poland ($n = 3$) and Finland ($n = 1$), although the number of publications is relatively low, these countries also contribute to Green TVET research in the European region. In the Americas, there are the USA ($n = 7$), Mexico, Ecuador, Cuba, Chile and Canada, each with one publication. This indicates that Green TVET research is not limited to the Asia-Europe region. Although the number of publications is small, the citation rate is very high. Meanwhile, in the African region, South Africa ($n = 6$) has the highest number of publications in the region, confirming that Green TVET is a priority in this country. Meanwhile, Nigeria, Ghana, Ethiopia and Zimbabwe have also contributed to Green TVET research, although each country has only one publication. In the Middle East, countries such as Iran ($n = 2$), Saudi Arabia ($n = 2$) and Pakistan ($n = 2$)

also show that Green TVET is a focus of attention in this region, although the number of publications is relatively low.

2. Most Influential Institutions in the Field of Research

Table 3 lists the top 10 institutions based on the number of publications (TP), the number of citations (TC) and the H-index (HI). Publication trends show that, of the 10 affiliations, Malaysia has the most, with six institutions. The University of Tun Hussein Onn Malaysia ranks first with 10 publications, 29 citations and an H-index of 3, followed by the National University of Malaysia with 7 publications, 13 citations and an H-index of 2, which also demonstrates a strong influence in this field. Next is Sultan Idris Education University with 4 publications, 20 citations and an H-index of 2. The other three institutions Malaysia University of Technology, Universiti Teknologi Mara and University of Northern Malaysia also demonstrate their interest in the topic of Green TVET.

Table 3. The 10 institutions with the highest number of publications

No.	Affiliation	TP	TC	HI
1.	University of Tun Hussein Onn Malaysia	10	29	3
2.	Universitas Pendidikan Indonesia	7	13	2
3.	Universiti Kebangsaan Malaysia	7	34	3
4.	Free University of Berlin	4	74	4
5.	George Emil Palade University of Medicine, Pharmacy, Science, Technology of Targu Mures	4	35	3
6.	Universiti Pendidikan Sultan Idris	4	20	2
7.	Universiti Teknologi Malaysia	4	12	2
8.	Universiti Teknologi Mara	3	12	2
9.	Universiti Utara Malaysia	3	1	1
10	University of Cologne	3	16	3

On the other hand, the Indonesian University of Education (UPI) emerged as Indonesia's leading representative with seven publications, although the citation impact it generated remains limited (TC = 13). From Europe, the Free University of Berlin stands out with 74 citations from just four publications, making it the institution with the highest academic impact, whilst the University of Cologne and George Emil Palade University of Medicine, Pharmacy, Science and Technology of Targu Mures also made significant contributions.

3. Most Influential Authors in the Field of Research

Table 4 shows the top 10 authors based on the number of publications (TP), the number of citations (TC) and the H-index (HI). Liviu Moldovan ranks highest among the other nine authors with four publications, 33 citations and an H-index of 3. This underscores his contribution and involvement in TVET research. Next is Singer-Brodowski, Mandy (TP = 3; TC = 67; HI = 3), who has also made a significant contribution to Green TVET research, followed by Kamis, Arasinah (TC = 20; HI = 2); Hasif, Nik (TC = 10; HI = 1);

Brock, Antje (TC = 44; HI = 3); Hasan, Muhammad (TC = 10; HI = 1); Holst, Jorrit (TC = 44; HI = 3) and Chinedu, Caleb Chidozie (TC = 13; HI = 2), each with 3 publications.

Table 4. The 10 authors with the highest number of publications

No.	Author	TP	TC	HI	WOS-ID
1.	Moldovan, Liviu	4	33	3	AAI-5773-2020
2.	Singer-Brodowski, Mandy	3	67	3	DWJ-1505-2022
3.	Kamis, Arasinah	3	20	2	JFN-2209-2023
4.	Hasif, Nik	3	10	1	KIG-7604-2024
5.	Brock, Antje	3	44	3	CHP-8323-2022
6.	Hasan, Muhammad	3	10	1	T-1407-2019
7.	Holst, Jorrit	3	44	3	CTX-9754-2022
8.	Chinedu, Caleb Chidozie	3	13	2	AGK-0341-2022
9.	Kob, C.	2	18	2	CZL-0666-2022
10	Lee, Adrian Yen Xian	2	11	1	DBN-3496-2022

However, these authors differ in terms of impact, particularly as seen in the number of citations. Antje Brock is in a more advantageous position with 44 citations, whilst Arasinah Kamis has 20 citations. This demonstrates that, although the number of publications is the same, their contributions to research differ. At the bottom of the list are Kob, C (TP = 2; TC = 18; HI = 2) and Lee, Adrian Yen Xian (TP = 2; TC = 11; HI = 1); although they have few publications on the topic of Green TVET, both authors have contributed to this research.

4. Network Approach: Analysis by Keyword Co-Occurrence and Thematic Map Co-Occurrence

a. Keyword Co-Occurrence Analysis

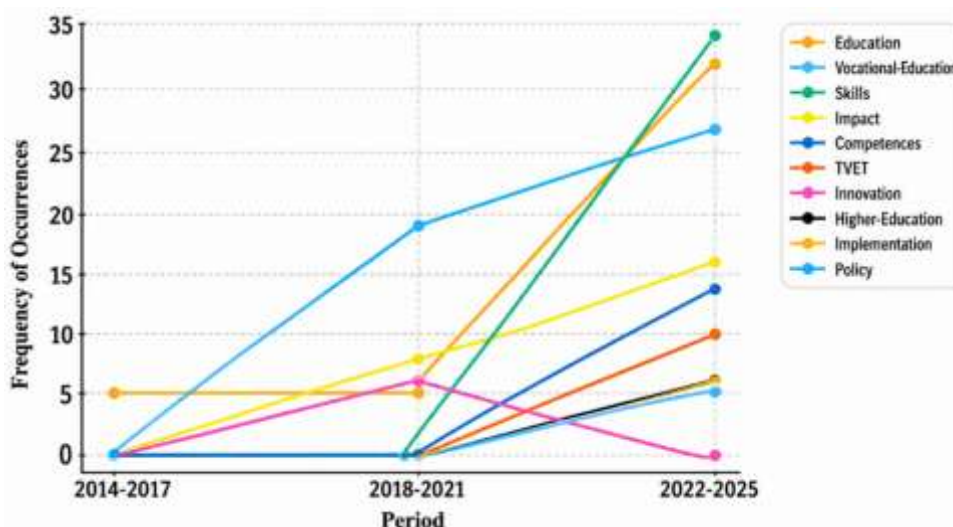
An analysis of keyword co-occurrence mapping provides an overview of the evolution of research focus over time. Patterns in keyword occurrence can reflect the dynamics of issues of concern to researchers, whilst also indicating a shift in the direction of research from conceptual to practical aspects. By examining the distribution of keywords across three periods (2014–2017, 2018–2021, and 2022–2025), trends in the evolution of research on TVET and global sustainability issues can be identified, including how vocational education is transforming to respond to the need for green skills and sustainable competencies.

2014–2017: The dominant keywords remained general and conceptual in nature, such as ‘Education’, ‘Systems’, ‘Model’ and ‘Choice’. This indicates that research on TVET and sustainability issues was still in the early stages of conceptualisation, focusing on educational frameworks, models and systems approaches [24], [25]. The emergence of ‘Campus Sustainability’ and the ‘Capability Approach’ began to signal growing attention to sustainability dimensions, although the scale remained limited. 2018–2021 period: A significant shift is evident with the emergence of keywords such as ‘Vocational Education’, ‘Impact’, ‘Innovation’, and ‘TVET’ [26], [27].

Table 5. Top 10 keywords

Keyword	2014-2017	Keyword	2018-2021	Keyword	2022-2025
Education	5	Vocational-Education	19	Education	32
Methodology	2	Impact	8	Skills	34
Model	4	Innovation	6	Vocational	27
Performance	3	Tvet	6	Impact	16
Systems	5	Community	4	Competences	14
Big	4	Early-Childhood	7	Sabah	6
Campus	2	Education	5	University	8
Campus Sustainability	1	Framework	5	Higher-Education	10
Capability Approach	2	Key Competences	8	Implementation	10
Choice	4	Management	4	Policy	6

Research in this phase began to emphasise the relationship between TVET, innovation, and the impact of education on society and industry. The keywords Early-Childhood Education and Community indicate the broad spectrum of educational research, although it is not entirely focused on TVET. The emergence of Framework and Key Competences confirms that research is beginning to focus on the development of standards and core competencies in vocational education, which form the basis for the concept of Green Skills [28], [29]. 2022–2025 period: Dominant keywords have expanded significantly in the direction of skills and sustainability: Skills, Vocational Education, Competences, Higher Education, and Implementation [30]. The increase in the keyword ‘Education’ indicates that the theme of education remains central, but is now more focused on the development of sustainability skills and green competences [31]. The emergence of ‘University’ and ‘Policy’ highlights the role of higher education institutions and national policy in supporting the integration of Green TVET [32], [33], [34]. The keyword ‘Impact’ reinforces that the focus is no longer merely on conceptualisation, but on measuring the tangible impact of green-oriented TVET implementation.

**Fig. 6.** Trends in green TVET research keywords based on 3 periods

The analysis of keyword trends in Fig. 6 shows that 'Education' has consistently been the primary focus throughout the research period, with a significant increase, confirming its role as an overarching framework in supporting green skills and sustainable development. In the most recent period, the dominance of 'Skills' and 'Competences' reflects a shift in research from conceptual aspects towards strengthening practical competencies relevant to the needs of the green economy. The surge in 'Vocational Education' from 2018–2021 to 2022–2025 indicates that vocational education is increasingly recognised as a strategic sector in achieving the Sustainable Development Goals (SDGs). Meanwhile, the emergence of 'Policy' underscores the importance of regulatory support in integrating Green TVET into national development policies. The rise in the keyword 'Impact' indicates that research is now oriented towards evaluating the tangible impact of vocational education on skills, society, and sustainable transition. Thus, the evolution of this keyword signifies that Green TVET is shifting from conceptual discourse towards skills- and policy-oriented implementation tools.

Meanwhile, the results of the topic trend analysis in Fig. 7 show that research on Green TVET is developing in various directions. The most prominent central themes include TVET, education, skills, and impact, which underscore the focus on the role of vocational education in developing green skills whilst delivering tangible benefits for sustainable development [35], [36]. Furthermore, topics such as SDGs, universities, and models indicate links to the global agenda, the role of higher education institutions, and the development of learning models that support the implementation of green TVET [34]. Meanwhile, the issues of innovation, competences, and frameworks demonstrate a focus on the development of innovation, green competences, and frameworks that can serve as a reference in educational practice and research [37], [38]. Overall, these trends illustrate that Green TVET is positioned as a strategic research field that contributes to the strengthening of sustainable skills, educational innovation, and the achievement of global development goals.

The results of the analysis using network visualisation in Fig. 8a show that research on Green TVET centres on key terms such as technical and vocational education, education, skills, impact, and competences, which are closely linked to the themes of innovation, the environment, policy, and sustainable development. The resulting network illustrates that TVET is viewed not only as an educational instrument but also as a catalyst for transformation towards a green economy through the development of new skills and competences relevant to global needs. On the other hand, keywords such as policy, higher vocational education, and sustainability form a distinct cluster, emphasising that institutional and policy dimensions are crucial components in the implementation of

sustainability-oriented TVET.

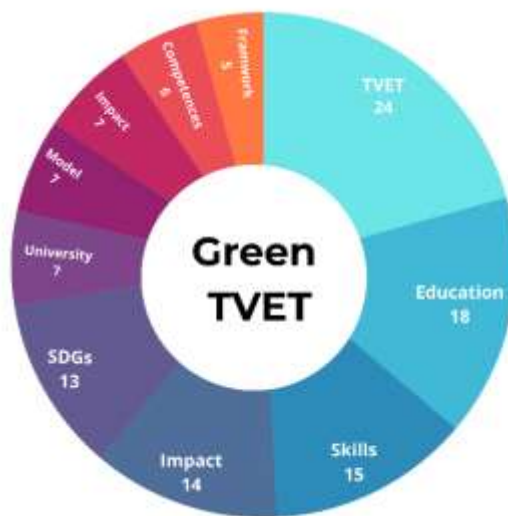


Fig. 7. Ten tren topik green tveet pada isu-isu keberlanjutan secara global

Meanwhile, the density visualisation analysis in Fig. 8b shows that the keywords with the highest intensity are found in the areas of technical and vocational education, education, skills, and impact, as indicated by the bright yellow colour. This suggests that global research is primarily focused on the core aspects of education and skills development, as well as the evaluation of the impact of Green TVET implementation on society and the labour market. Conversely, areas coloured green to blue, such as community colleges, teacher education, women's empowerment, and methodology, indicate themes that have been relatively under-explored but hold potential as new research avenues. Thus, the combination of these two visualisations confirms that Green TVET has evolved into a global strategic issue, yet still leaves ample scope for research to strengthen social, pedagogical, and methodological perspectives in supporting the transformation of sustainable vocational education.

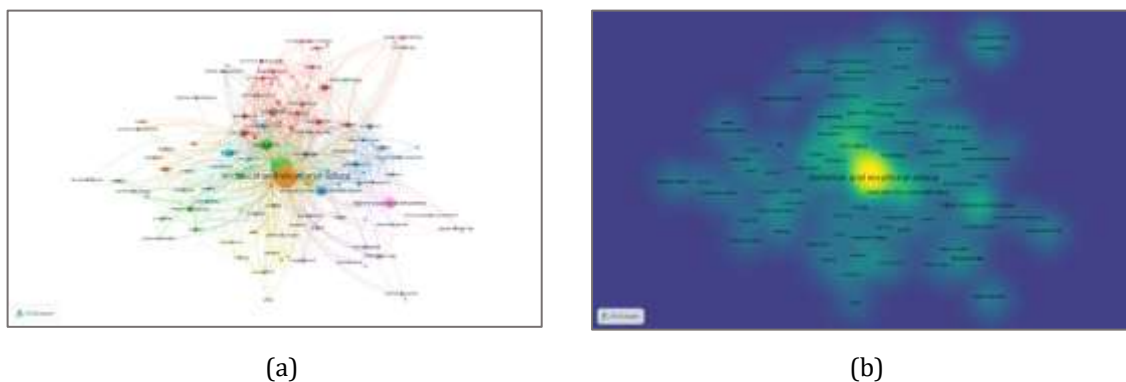


Fig. 8. VOSviewer Analysis: a) network visualization; b) density visualization

b. Thematic Map

Thematic map analysis divides research themes into four main quadrants: Motor Themes, Niche Themes, Basic Themes, and Emerging or Declining Themes. Using this framework, interpretations can be made to gain a more comprehensive understanding of the direction of Green TVET research.

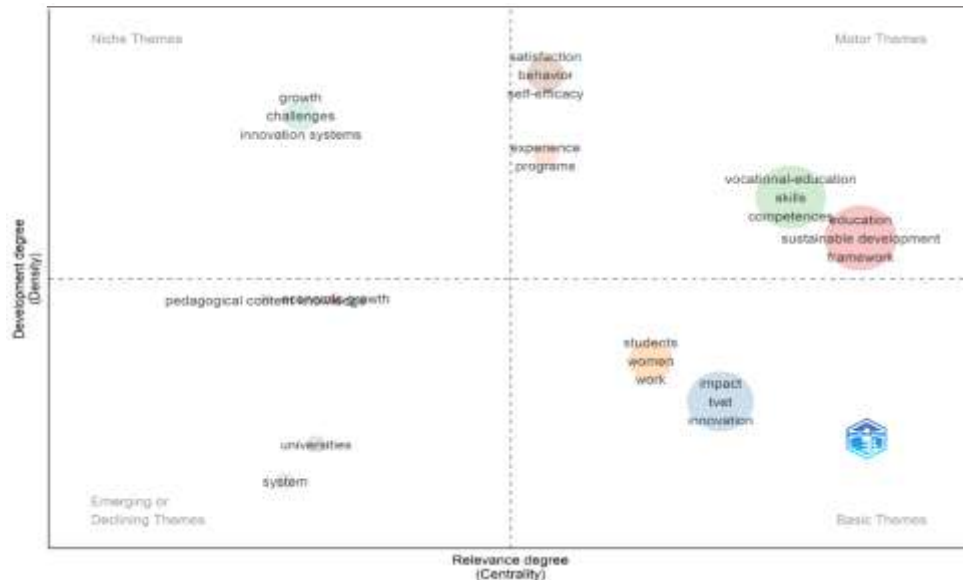


Fig. 9. Thematic map analysis

In the Motor Themes quadrant, it is evident that keywords such as vocational education, skills, competences, education, and sustainable development [28], [37] occupy a dominant position. This indicates that these themes are relevant and have strong conceptual and practical development within the global literature. This position confirms that vocational education is now viewed as a pathway towards sustainable development [36]. The keywords 'skills' and 'competences' represent the real-world demands of the labour market, which require graduates not only to master technical skills but also to possess cross-disciplinary competences related to environmental awareness, adaptability, and the integration of digital technology into workplace practices [39]. Similarly, the link to sustainable development underscores that Green TVET is positioned as a key strategy in supporting the achievement of the Sustainable Development Goals, particularly in the areas of quality education (SDG 4), decent work and economic growth (SDG 8), and climate action (SDG 13). Therefore, TVET is a strategic instrument in addressing global challenges related to the green transition [38], [40], [41].

Furthermore, the 'Niche Themes' quadrant features keywords such as growth, challenges, and innovation systems. These themes demonstrate a high level of development but have not yet taken centre stage in the research landscape. This suggests that the scope of research remains relatively limited. For example, 'innovation systems'

appears more frequently in studies linking Green TVET with industrial, university, and government innovation ecosystems, whilst 'challenges' relates to barriers to policy adoption or structural constraints in integrating green skills into vocational curricula [42], [43], [44]. In the Basic Themes quadrant, keywords such as impact, TVET, innovation, students, women, and work are evident. This position indicates that conceptual development remains relatively limited. For example, research on impact shows that many studies have explored the impact of sustainable vocational education on skills, society, and the economy, but have not yet fully produced a well-established conceptual model [35], [45]. Similarly, TVET and innovation emerge as central keywords, but the density of the literature is still at an early stage of development and therefore requires further theoretical exploration [44]. Meanwhile, social dimensions such as students, women and work indicate that, although relevant, research on gender engagement, student experiences and workplace dynamics has not yet been fully integrated into the main framework of Green TVET [46]. Thus, the Basic Themes highlight research areas that have already received widespread attention but require further development in terms of models, theories, and cross-contextual applications.

The final quadrant, 'Emerging or Declining Themes', features keywords such as 'universities' and 'system'. This theme highlights topics that are beginning to emerge. Universities play a role in supporting the development of TVET, but the focus is on secondary-level vocational education and labour market policies. Overall, this thematic map indicates that research on Green TVET is currently in a phase of consolidation. Core themes such as education, skills, competences, sustainable development, and vocational education have evolved into Motor Themes that dominate academic discourse and make strategic contributions to practice. This demonstrates a global consensus that vocational education is a key pillar in the transition towards a green economy. On the other hand, themes such as impact, innovation, and social issues (gender, students, employment) are still at a foundational stage, thus opening up significant scope for further research to strengthen the theoretical foundations and broaden the practical context. Meanwhile, Niche Themes and Emerging Themes underscore the need for deeper interdisciplinary exploration, particularly regarding systemic innovation, the role of universities, and cross-sectoral policy dynamics.

5. The Prospects for Green TVET

Green TVET offers several key benefits. Firstly, in terms of its contribution to SDG 4 (Quality Education), Green TVET broadens the definition of educational quality by incorporating a sustainability dimension. Vocational education focused on green skills ensures that graduates master the skills required in their field, as well as the competencies

needed to address the challenges of climate change, renewable energy, and resource efficiency. Secondly, Green TVET supports SDG 8 (Decent Work and Economic Growth) by producing a workforce ready to meet the demands of the green labour market, thereby strengthening economic competitiveness whilst creating environmentally friendly jobs. Thirdly, the relevance of Green TVET to SDG 9 (Industry, Innovation, and Infrastructure) is evident through its role in integrating digital skills, system innovation, and green industrial practices into the vocational education curriculum. Furthermore, the fourth prospect is its contribution to SDG 13 (Climate Action), where TVET serves as an educational tool that drives behavioural change, raises environmental awareness, and promotes the adoption of environmentally friendly practices within both the industrial sector and society. The results of the thematic map confirm that skills and competences are driving themes that are not only conceptually dominant but also represent the most relevant direction for research development. This implies that Green TVET has the potential to become a key driver in building the capacity of the green workforce across various sectors. Furthermore, the framework and education that also emerge as key themes underscore that the development of policy frameworks and the integration of sustainable curricula present a significant opportunity to strengthen the position of Green TVET in achieving the SDGs.

6. Challenges Facing Green TVET

Despite its strong prospects, Green TVET also faces various challenges that need to be addressed in order to optimise its contribution to the SDGs. Firstly, policy challenges. Analysis shows that 'policy' has only recently emerged as a dominant keyword in the most recent period (2022–2025). This indicates that policy support for Green TVET remains relatively limited. Without a strong and consistent policy framework, the integration of green skills into vocational education will be difficult to implement on a large scale. Second, challenges regarding impact evaluation. Although 'impact' has emerged as a relevant topic within the basic themes, this position suggests that research on the impact of Green TVET remains limited to the conceptual level. This means there is still little empirical evidence directly measuring the contribution of Green TVET to the achievement of the SDGs, whether in the form of improved green job skills, the creation of new jobs, or the reduction of carbon emissions. This lack of evidence may hinder the academic legitimacy and political support needed to expand Green TVET programmes. Thirdly, systemic innovation challenges. The thematic map places innovation systems within niche themes, which means that research in this area is developing well but remains specific in nature and has not yet become mainstream. In fact, the success of Green TVET depends heavily on an innovation ecosystem involving industry, universities, government, and the community. Without systemic cross-sector collaboration, Green TVET will struggle to

meet the complex demands of the transition to a green economy. Fourth, social and institutional challenges. The themes of students, women, and work that emerge in the basic themes indicate that the involvement of certain social groups in Green TVET remains limited. For instance, the involvement of women in green vocational programmes has not been extensively researched, despite the SDGs emphasising the principle of inclusivity. Furthermore, the fact that universities feature in the 'emerging/declining' themes suggests that the role of higher education institutions in supporting the Green TVET ecosystem remains suboptimal, despite universities having the potential to serve as centres for research, innovation, and vocational teacher training.

Conclusion

This study highlights the important role of Green TVET in supporting the transformation of vocational education towards sustainable development. The bibliometric analysis shows that the major topics emerging in the global literature centre on skills, competences, education, innovation, policy, and impact, reflecting the growing importance of green skills and educational frameworks that are responsive to sustainability challenges. The thematic map further indicates that skills and competences are positioned as driving themes, suggesting the strategic potential of Green TVET to contribute to the achievement of the Sustainable Development Goals (SDGs), particularly quality education (SDG 4), decent work and economic growth (SDG 8), industry, innovation and infrastructure (SDG 9), and climate action (SDG 13). However, several challenges remain, including inconsistent policy frameworks, limited empirical evidence regarding the contribution of Green TVET to SDG achievement, insufficient collaboration within innovation ecosystems, and persistent limitations in social inclusivity, particularly in relation to the participation of women and vulnerable groups. Accordingly, future Green TVET development should focus on: (1) strengthening comprehensive and coherent policy frameworks; (2) developing measurable impact assessment tools; (3) strengthening cross-sectoral innovation ecosystems; and (4) enhancing inclusive participation among diverse social groups.

This study has several limitations that should be acknowledged. First, the bibliometric data were obtained exclusively from the Web of Science database and were not cross-validated with other scholarly databases, such as Scopus or Google Scholar. Consequently, relevant publications indexed elsewhere may not have been captured. Second, the analysis was limited to English-language documents, which may have excluded relevant national and regional literature published in other languages, including studies from countries such as Indonesia and China. Third, because this study employs a descriptive bibliometric approach, the findings primarily reveal patterns, trends, thematic structures, and relationships within the existing literature and cannot be used to establish causal relationships between Green TVET initiatives

and the achievement of the SDGs. Future studies could address these limitations by integrating multiple databases, incorporating multilingual publications, and combining bibliometric analysis with empirical or explanatory research designs.

Conflict of Interest

The authors declare no conflict of interest.

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