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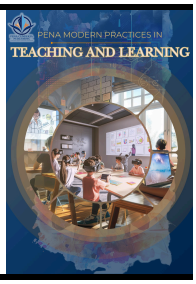

A Systematic Literature Review on Challenges to Circular Economy Implementation for Sustainable Technical and Vocational Education

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ABSTRACT

Circular economy (CE), a strategy that aims to reduce waste while extending the life of consumables, supports the responsible consumption and production of SDG 12. Previous research has shown that effective Technical & Vocational Education and Training (TVET) development can be fostered through the successful application of circular economy principles. However, it is still unclear about the role of the education sector because there is no clear empirical data showing the effective implementation of circular economy principles in TVET education sector. Realizing the great role played by the education sector, this paper emphasizes the challenges of implementing the circular economy in the development of TVET. This study attempts to better understand the role of the education sector in using circular economy practices through a systematic literature review and identify the main barriers to implementing circular practices for the creation of sustainable TVET. This study synthesizes research data from 25 recently published empirical investigations from Web of Science (WoS), ERIC, and Scopus databases published between 2020 to 2024. The findings show that implementation of circular economy faces three main challenges: (1) the importance of education and awareness in the development of sustainable TVET; (2) difficulties in the food sector's waste management and circular economy implementation; and (3) the application of innovation and technology to promote the circular economy. Overall, it implies that scholars and practitioners frequently discuss the application of the circular economy. Future studies suggest that a more focused empirical approach is needed to determine effective strategies to overcome these barriers and promote sustainable TVET development.

1. Introduction

Given its negative effects on the environment and depletion of natural resources, the "take-make-consume-dispose" linear model of resource consumption appears to be unsustainable. By

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2050, the amount of Municipal Solid Waste (MSW) created is predicted to range from 2.89 to 4.54 billion tonnes, a 26%–45% increase compared to 2019 [1,2]. Almost one-third of the MSW created is not collected, and the majority of what is collected is not handled in accordance with modern notions of sound management [3]. Furthermore, uncontrolled burning or open dumping account for nearly 42% of MSW [1,4]. This indicates the urgent need for sustainable waste management solutions [5-7]. To address these challenges, integrating circular economy principles into Technical and Vocational Education and Training (TVET) is essential.

The transition to a circular economy (CE) offers a transformative approach to sustainable development by minimizing waste and maximizing resource efficiency. For TVET institutions, the integration of CE principles is essential to provide a workforce capable of supporting the sustainable development of TVET for a resilient future. However, the implementation of CE in TVET poses various challenges. This forces various studies and innovations to be carried out to ensure its implementation. Hence, this study was conducted to answer the research question, "What are the challenges to circular economy implementation for sustainable technical and vocational education?"

1.1 Successful Implementation of Circular Economy in Various Sectors

The complexity of implementing circular economy (CE) in various sectors is highlighted by various studies. In the food supply chain sector, technical and technological capabilities, financial issues, and production issues are critical barriers [8]. In the construction industry, project success factors and contractual requirements are essential enablers, while design constraints and poor stakeholder experience act as significant barriers [9,10]. Information and Communication Technologies (ICT) can overcome CE challenges but also have limitations [11,12]. Blockchain and smart contract technologies can improve trust and transparency in supply chains.

In Europe, CE implementation is analyzed through specific indicators defined by the European Commission. However, some indicators show progress, while others lag due to insufficient funding and political will [13]. This highlights the need for long-term vision and consistent policy efforts. In Ghana, CE policies can enhance financial efficiency when supported by a conducive organizational culture. TVET institutions should integrate CE into their ethos to promote sustainability and innovation. Deviatkin *et al.,* [14] found that only a quarter of CE strategies were implemented, suggesting the need for practical training in CE strategies.

A comprehensive index has been developed to assess the implementation of the CE, revealing disparities between western and eastern European countries In Brazil [15], analysis of supply chain practices shows advanced economic and risk management, although governance and infrastructure are underdeveloped [16]. The integration of CE principles into the production of building materials highlights the environmental benefits of using by-products [17]. In addition, proposed improvements to ISO 14001 aim to strengthen circular management systems, equipping students to lead future sustainability efforts [18].

Previous research has indicated that the development of effective Technical and Vocational Education and Training (TVET) can be significantly enhanced through the application of circular economy (CE) principles. Nonetheless, the specific role of the education sector remains unclear due to a lack of concrete empirical data demonstrating how CE principles are effectively implemented within the TVET sector. In response, this study conducts a systematic literature review (SLR) aimed at identifying the challenges to adopting circular economy practices in sustainable TVET education. Utilizing this approach helps validate the authors' empirical findings and pinpoints areas of weakness while suggesting directions for future research. One primary focus of this research is on the challenges faced by TVET institutions, which play a pivotal role in

advancing more efficient waste management practices. This study acknowledges the existing gaps in empirical data regarding the effective implementation of CE principles, particularly in rural and developing regions where such research is limited. It highlights critical areas for future investigation, stressing the importance of thoroughly examining sector-specific challenges and assessing the impact of diverse cultural and economic contexts on the integration of CE principles into TVET programs.

2. Methodology

An extensive literature review (SLR) served as an investigative approach. A systematic review and synthesis of studies on waste management, particularly the circular economy, was conducted using the Systematic Literature Review (SLR) technique. By requiring certain rigorous investigation and review methods, SLR makes information analysis easier. Formulating research questions, identifying relevant studies, data extraction, synthesis of findings, and interpretation of results are all necessary steps in the process of creating new theories or insights [19]. In particular, Mohamed Shaffril *et al*., [20] recommendations are followed in a systematic review approach. With increased transparency of review and quality assurance and management, ROSES strives to improve and maintain an efficient SLR generation process.

This study found relevant papers using a flowchart of reporting items recommended for systematic reviews [21-23]. As a result, the identification, eligibility process, screening standards, data collection and data analysis for the collected articles were examined in this SLR research. Scopus, Web of Science and ERIC were used for data compilation purposes. Circular economy, zero waste, food preparation, and food processing education are used to filter data. Journals published between 2020 and 2024 met the inclusion requirements for this study. English publication is a must for articles [23].

2.1 Identification

The systematic review approach was divided into three primary stages in order to choose a number of appropriate publications for this study. Finding relevant terms and searching for them using dictionaries, encyclopaedias, thesaurus, and past research are the first steps in the process. As a result, after identifying every pertinent phrase, a search string was created for the Scopus, Web of Science and ERIC databases (see Table 1). This study project successfully obtained 1096 papers from those databases during the first phase of the systematic review procedure.

Table 1
The search string

Database	Search string
Scopus	TITLE-ABS-KEY (("Circular Economy" OR "zero waste" OR "closed loop") AND (food OR meal) AND (prepar* OR cook* OR process* OR produc*) AND (educat* OR train* OR teach* OR instruct* OR learn*)) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (OA , "all")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD , "Circular Economy") OR LIMIT-TO (EXACTKEYWORD , "Food") OR LIMIT-TO (EXACTKEYWORD , "Education"))
WoS	(("Circular Economy" OR "zero waste" OR "closed loop") AND (food OR meal) AND (prepar* OR cook* OR process* OR produc*) AND (educat* OR train* OR teach* OR instruct* OR learn*)) (All Fields) and 2020 or 2021 or 2022 or 2023 or 2024 (Publication Years) and Open Access and English (Languages) and Education Educational Research or Food Science Technology (Web of Science Categories)
ERIC	"circular economy" education

2.2 Screening

The second step is screening, where papers are either added or removed from the study based on a set of predefined criteria (either manually by the authors or with the use of a database). As highlighted by Kraus *et al.,* [24], "maturity of the field", this assessment limited the screening procedure to papers published between 2020 and 2024. As there were enough published articles to conduct a representative review, this chronology was chosen. Since empirical research articles provide original data, the author decided to review them. Notably, only works written in English are taken into account to avoid confusion. Choosing educational, food science and technology research papers as one of the criteria is considered to increase the possibility of finding more articles about waste management, because the objective of SLR is related to the circular economy. During this stage of review, 962 articles were rejected because they did not meet the inclusion criteria. As a result, 134 items were left for consideration in the next phase.

2.3 Eligibility

A total of 129 papers have been prepared for the third level, which is called eligibility. At this point, the titles and important contents of every article were carefully examined to make sure that the inclusion criteria were met and that the papers fit into the current study and its goals. Consequently, 104 publications were excluded due to their out-of-field content, unimportant titles, unrelated abstracts to the study's goal, lack of open access, and lack of full text availability (refer to Table 2). Lastly, 25 articles are accessible for evaluation.

Table 2
The selection criteria

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2020 – 2024	< 2020
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Subject Area	Educational research, food science and technology	Besides educational research, food science and technology / Others
Access type	All open access	No open access

2.4 Data Abstraction and Analysis

Data abstraction is a crucial step in conducting systematic reviews because the data collected from study reports form the foundation for appropriate conclusions. The diagram below illustrates the complete flow diagram for the process of data abstraction and analysis, showing how data was abstracted and assessed for biases (Fig. 1).

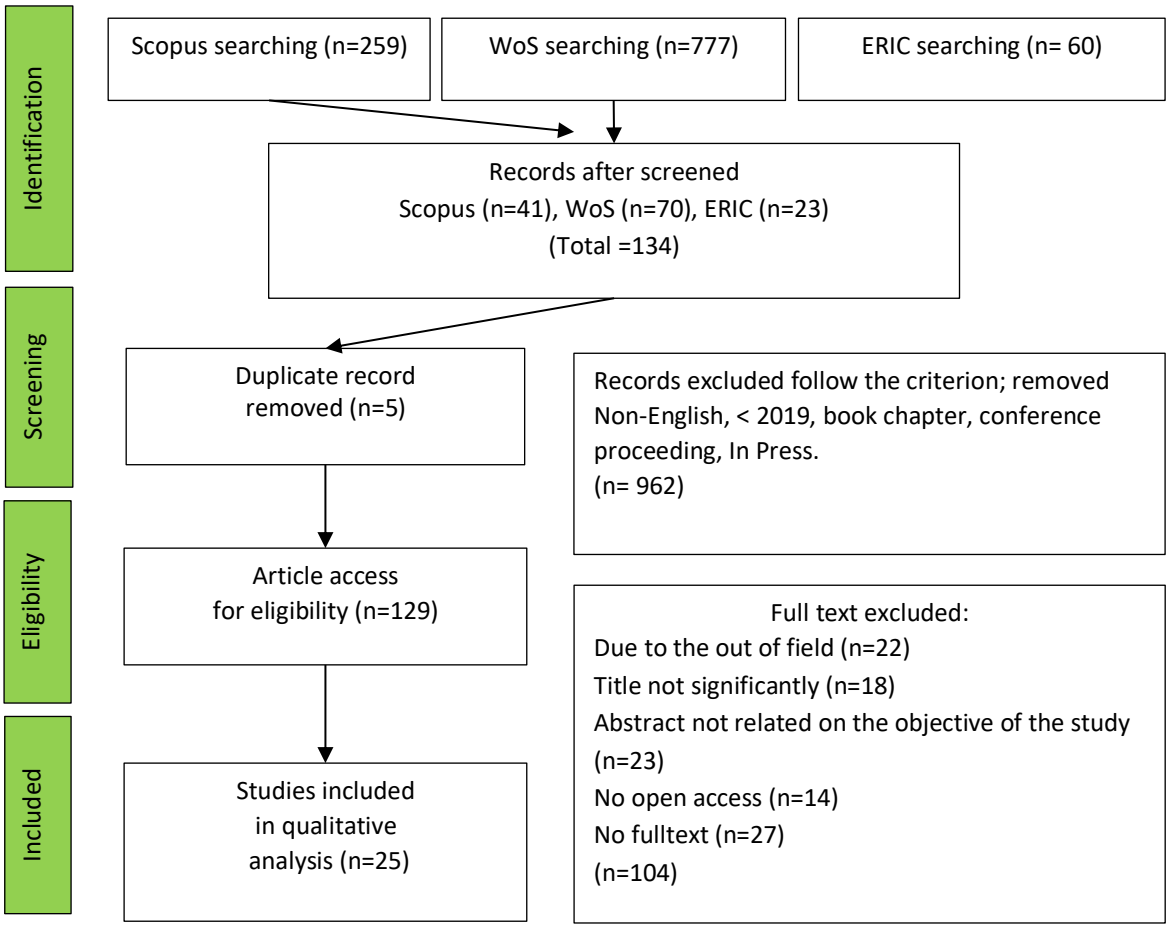

Fig. 1. Flow diagram of the proposed searching study adapted from Moher *et al.,* [21]

3. Results and Findings

All 25 articles selected from the databases are listed below, with Table 3 displaying these items. The main information surrounding these publications, such as the authors, year of publication, key elements of each study, method and results are included. These primary details from the articles are shown in the table.

Table 3
The information of articles

References	Objectives	Key Points	Method	Results	Research Gap
Akter *et al.,* [25]	1. Examine factors influencing organic food purchase. 2. Apply aspects to circular agriculture.	Intensive urbanization leading to waste generation.	1. Well-constructed questionnaire. 2. Survey of 1030 participants.	Climate change concerns, trust, and eco-labels increase preference for organic food.	Significant effect of communication on consumption levels.
Ali *et al.,* [26]	1. Evaluate factors influencing purchase of	Consumer habits can support or hinder CE through	1. Well-constructed questionnaire. 2. Survey of 544 participants.	Younger age group shows greater preference for sustainable	More studies needed on consumer education and its impact on

References	Objectives	Key Points	Method	Results	Research Gap
	sustainable WTV foods.	purchasing decisions.		products; gender does not influence consumption patterns.	sustainable purchasing behavior.
Alruqi and Sharma [27]	1. Demonstrate biomethane synthesis from sugarcane vinasse and organic waste. 2. Optimize machine learning model for prediction.	High uncertainties and costs associated with experimental testing.	1. Bayesian approach for hyperparameter tuning. 2. Gaussian process regression.	Combination of wastes is viable for biomethane production; efficient model prediction.	Need for broader validation of machine learning models in biomethane production.
Alves *et al.,* [28]	1. Assess CE behavior, attitudes, and knowledge of Portuguese university students. 2. Analyze the impact of CE knowledge on behavior and attitudes.	Limited implementation of circular consumption habits such as remanufactured products, second-hand purchases, sharing economy, and PSSs.	1. Probit model to study the influence of CE knowledge on behavior and attitudes. 2. Survey of Portuguese university students.	Positive influence of CE knowledge on behavior and attitudes; influence of age, gender, and education level.	Need for increased implementation of diverse CE practices among students.
Bojanowska and Sulimierska [29]	1. Determine customer awareness of biodegradable packaging.	Consumers declare environmentally friendly attitudes but lack recognition of biodegradable packaging.	1. Diagnostic survey with 1000 respondents.	Awareness depends on age and education, not gender or health status.	Need for better consumer education on biodegradable packaging.
Borowski [30]	1. Analyze production processes using Industry 4.0. 2. Implement innovative solutions in energy and food sectors.	Transition towards intelligent digital enterprises.	1. Surveys and observation.	Implementation of Industry 4.0 solutions improves operational efficiency and environmental impact.	Exploration of long-term impacts of Industry 4.0 on sustainability.
Cordova-Buiza *et al.,* [31]	1. Examine the situation of organic waste management in food services in Lima and Tacna. 2. Promote responsible consumption and production.	Inefficient management and handling of organic waste, lack of awareness and training.	1. Questionnaire administered to 67 restaurants. 2. Quantitative methodological approach.	Restaurants do not separate or reuse organic waste; main disposal methods include surpluses to staff and sanitary landfills.	Need for better awareness and training in organic waste management.
De Cianni *et al.,* [32]	1. Economically characterize the	Fragmented production,	1. Chamber of Commerce	Innovative products like	Need for investments in

References	Objectives	Key Points	Method	Results	Research Gap
	edible mushroom supply chain in Italy. 2. Highlight barriers and opportunities for sustainable development.	reliance on imports, limited species variety.	Register analysis. 2. Qualitative web content analysis. 3. Quantitative analysis.	mushroom-based burgers have limited market presence but potential for growth.	training new mushroom growers and studying new fungal species.
Hajabdollahi Ouderji *et al.,* [33]	1. Integrate AD with ASHP for biogas production. 2. Assess technical and environmental performance.	Need for efficient thermal energy supply in AD systems.	1. Machine learning models. 2. Thermodynamic model of ASHP. 3. Life cycle assessment.	ASHP-based AD systems achieve higher carbon abatement.	Broader application of integrated systems for enhanced sustainability.
Herrera *et al.,* [34]	1. Identify factors affecting CE adoption in farming.	Achieving EU environmental objectives.	1. Semi-structured questionnaire. 2. Sample of farmers in four EU countries.	Adoption linked to environmental objectives, education, experience, and attitudes.	Institutional support crucial for adoption.
Ickowicz *et al.,* [35]	1. Assess multifunctionality and diversity of livestock grazing systems. 2. Identify learning opportunities for Europe.	Livestock grazing systems provide multiple products and benefits, but European systems may overlook some functions.	1. Multifunctional conceptual model. 2. Case studies in Africa, Asia, Latin America, and Europe.	LGS contribute to sustainable food systems with multiple functions.	Need for improved management of interactions and trade-offs in LGS.
Isenhour *et al.,* [36]	1. Explore tension between eco-modernist logics of CE and contemporary waste streams. 2. Rethink modernist logics of CE.	Regulatory, educational, and structural barriers faced by food waste processors.	1. Research with food waste recycling facilities.	Food waste processors face significant problems due to toxicants and the need to police material boundaries.	Need for policy recognition of barriers faced by food waste processors.
Klammsteiner *et al.,* [37]	1. Assess impact of canteen and oil wastes on BSF larvae. 2. Characterize gut microbiome functions.	High larval mortality with oil waste, better performance with canteen waste.	1. Monitoring larval development. 2. Physicochemical analysis of food waste. 3. High-throughput amplicon sequencing.	Canteen waste is optimal diet for BSF larvae; oil waste inhibits biomass gain and increases mortality.	Need for development of decentralized waste-management sites using BSF larvae.
Kopnina [38]	1. Discuss closed-loop systems in education.	Limited discussion on posthumanism in CE.	1. Student assignments on CE models.	Realized limitations of fully circular solutions	Need for critical discussion on postqualitative inquiry.

References	Objectives	Key Points	Method	Results	Research Gap
	2. Apply posthuman ethics.		2. Case studies of Hennes & Mauritz and Protix.	due to thermodynamics.	
Liu *et al.,* [39]	1. Investigate barriers to sustainable food consumption and production.	Multiple barriers to CE implementation in China.	1. Fuzzy DEMATEL analysis. 2. Data from three stakeholder groups.	Key barriers: weak enforcement of regulations, lack of education and accountability.	Need for enhanced regulatory attention and educational initiatives.
Matheri *et al.,* [40]	1. Investigate waste-to-energy via anaerobic digestion. 2. Digitalize biomethane production.	High energy demand and waste generation.	1. Anaerobic digestion experiment. 2. Modified Gompertz, Logistic, and Richards models. 3. Machine learning simulation.	Cow manure substrate provided best biomethane production; Modified Logistic model best fit.	Integration of digital and experimental approaches in biomethane production.
Mykkänen and Repo [41]	1. Identify consumer perspectives on CE activities. 2. Facilitate CE transitions in major consumption domains.	Responsibility for reuse and extending product lifespans varies across domains.	1. Representative survey of 1555 individuals.	Domain-specific strategies attract better consumer response.	Need for tailored strategies to promote circularity based on consumer backgrounds.
Sabol *et al.,* [42]	1. Highlight importance of water, food, energy in CE.	Increased demand due to urbanization, population growth, climate change.	1. Survey on biowaste management awareness.	Society needs further education on sustainable waste management.	Balancing resource demand and environmental sustainability.
Severo and De Guimarães [43]	1. Analyze relationship between product innovation, environmental strategy, and CE. 2. Assess impact on sustainable development.	Need to reduce natural resource consumption and environmental impact.	1. Quantitative and descriptive research. 2. Survey of 557 companies.	Circular economy and environmental strategy positively influence sustainable development.	Need for strategies to enhance the influence of CE on sustainability.
Sijtsema and Snoek [44]	1. Explore application of circular food design in product development. 2. Stimulate creativity and interaction.	Need for consumer interaction in food product development.	1. Series of workshops. 2. Perspectives from company and consumer research.	Interaction and co-creative processes lead to tailored and feasible innovations.	More studies on consumer involvement in circular food design.
Silva-Alvarado *et al.,* [45]	1. Implement CE concepts in	Medium circular economy level in	1. Exhaustive diagnosis. 2.	Various value-adding options	Further research needed to

References	Objectives	Key Points	Method	Results	Research Gap
	Ecuador's banana production chain.	banana production, need for value-adding processes.	Design of prospective. 3. Machine learning techniques (SVM, NN).	proposed, including organic fertilizers and bioplastics.	optimize value-adding processes in banana production.
Soares *et al.,* [46]	1. Evaluate CE knowledge among TR/RTTs. 2. Inform curriculum design.	Lack of comprehensive CE understanding.	1. Survey distributed to TR/RTTs. 2. Analysis of responses.	31%-42% aware of policies, but focus mostly on waste management.	Need to raise awareness about other CE dimensions in healthcare.
Spartano and Grasso [47]	1. Explore attitudes towards eggs from insect-fed hens. 2. Identify factors influencing purchase intentions.	Disgust towards insects as feed, price as main barriers.	1. Focus group discussions with 19 individuals.	Positive influence from environmental benefits, animal welfare, and food waste reduction.	More research needed on consumer education about benefits of insect-fed hens.
Van Bueren *et al.,* [48]	1. Study eco-champions in eco-communities. 2. Identify TBL solutions for sustainable ecosystems.	Need for an eco-innovation network for sustainable transitions.	1. Ethnographies, interviews, surveys, and secondary data from 28 eco-communities.	Thirteen TBL solutions identified; lifestyle of eco-champions pivotal.	Need for initiating eco-innovation networks in mainstream societies.
Walter *et al.,* [49]	1. Increase knowledge of black soldier fly. 2. Promote CE and environmental awareness.	Negative associations with insects, lack of knowledge.	1. Workshops in school classes. 2. Hands-on rearing systems. 3. Monitoring larval growth.	Pupils highly motivated, decreased negative associations with insects, increased excitement.	Insects still underrepresented in curricula.

4. Discussion

Based on the SLR, it is advisable to conduct a thematic analysis [50]. The objective is to categorize the examined articles into groups according to the issues and subjects stated [51] or nature and general views [52]. Some challenges related to the implementation of the circular economy in education have been highlighted in this study. These challenges can be divided into 3 main themes: (1) the importance of education and awareness in the development of sustainable TVET; (2) difficulties in the food sector's waste management and circular economy implementation; and (3) the application of innovation and technology to promote the circular economy.

4.1 Theme 1: The Importance of Education and Awareness in the Development of Sustainable TVET

The literature study highlights how important it is to raise awareness and incorporate circular economy (CE) principles at all levels of education in order to promote sustainable Technical and Vocational Education and Training (TVET). Research indicates that practical courses and all-inclusive continuing education can lessen unfavourable opinions, close knowledge gaps, and encourage

sustainable practices in a variety of industries [38,46,49]. To overcome implementation difficulties and a lack of knowledge in CE practices, calls have been made for lifelong learning and educational reforms [42,53,54]. According to Akter *et al.,* [25], consumer education can have a substantial impact on sustainable consumption behaviours by raising awareness and understanding about climate change and CE. Case study by Kopnina [38] explores closed-loop systems in educational settings, revealing the limitations in achieving fully circular solutions, particularly thermodynamic constraints. It calls for an in-depth discussion of the complexities involved and urges the education sector to adapt their approaches to integrate circular economy principles.

4.2 Theme 2: Difficulties in the Food Sector's Waste Management and Circular Economy Implementation

The literature study highlights challenges in managing food sector waste and implementing circular economy principles, including inadequate infrastructure, regulatory hurdles, and low awareness. In Peru, many restaurants neglect organic waste management due to lack of knowledge and training [31]. Food waste processors in New England face hazardous materials and complicated regulations, contradicting CE ideals [36]. Some waste types, such as black soldier fly larvae, show promise in digesting canteen garbage [37]. Ecuadorian banana supply chain uses some CE techniques, but waste fortification is still an option [45]. Although education alone does not significantly influence purchase intention, consumers, particularly younger demographics, have a preference for sustainable waste-to-value foods [26]. Despite being ecologically beneficial, there is a gap in consumer recognition when it comes to biodegradable packaging [29]. Case study analysis by Ickowicz *et al*., [35] conducted across continents including Africa, Asia, Latin America, and Europe reveals significant disparities and critical weaknesses in the implementation of livestock grazing systems (LGS). The case studies highlight pressing challenges and major obstacles faced in various regions, with a particular emphasis on the European context. A circular design approach, which emphasizes user interaction and co-creation, is beneficial for the development of food products [44]. According to De Cianni *et al.,* [32] Italy's edible mushroom supply chain emphasizes funding innovation and training for sustainable development goals. Informing customers about insect-fed chickens can have a positive effect on purchase attitudes [55]. These results emphasize the need for careful instructions, encouraging legislation, and creative waste management strategies that comply with CE guidelines.

4.3 Theme 3: The Application of Innovation and Technology to Promote the Circular Economy

By increasing resource efficiency and waste management, innovation and technology are critical to the advancement of the circular economy. Air source heat pump (ASHP) and anaerobic digestion together produce more biogas and emit less carbon dioxide [33]. Data-driven sustainability is possible with machine learning techniques like Bayesian approaches and Gaussian process regression, which maximise biomethane generation from organic waste [27]. Industry 4.0 technology improves efficiency and lessens [30]. Sustainable development in Northeast Brazil is greatly impacted by the circular economy in addition to environmental initiatives and product innovation [43]. The EU's adoption of circular agriculture methods emphasises the value of supportive policies as it is driven by institutional support and environmental goals [34]. Mykkänen and Repo [41] found that consumer viewpoints in Finland indicate a preference for individual responsibility in circular activities, particularly in the areas of housing and electronics. This suggests that certain techniques may be effective in promoting circularity. Self-sufficient communities' eco-champions provide priceless eco-

innovative solutions that the general public can embrace to solve sustainability issues [48]. These themes can be summarized as in the Fig. 2 below.

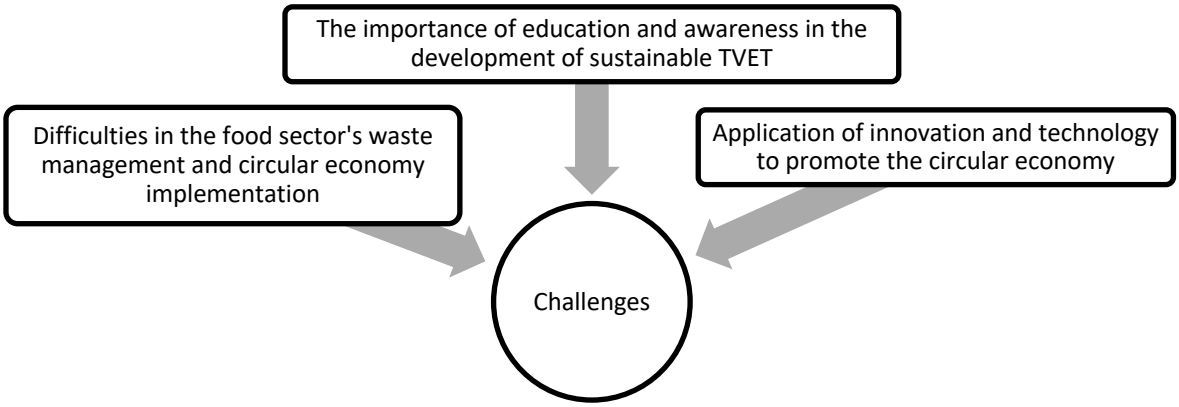

Fig. 2 Summarization of themes

5. Conclusion

The systematic literature review highlights the challenges and opportunities for fostering sustainable TVET development through the application of circular economy principles. Findings from this literature review contribute to the wider field by clarifying the important role of education and awareness in advancing CE principles in TVET. Evidence shows that effective educational interventions can bridge knowledge gaps, reshape attitudes and foster sustainable behavior across multiple sectors.

This review highlights the need for a systematic approach to integrate CE into education, from primary to professional training, thereby ensuring a comprehensive understanding of sustainability issues. Practically, the insights gained from this review support the development of curricula that incorporate CE principles across all levels of education. These include practical workshops, theoretical discussions and practical applications tailored to different age groups and professional sectors. In terms of policy, the findings call for the implementation of educational reforms that prioritize CE and sustainability.

Policy makers should consider integrating the CE concept into national education standards and support lifelong learning opportunities for professionals. Further research is needed to explore the long-term effects of CE education on sustainable behavior and to identify the most effective pedagogical strategies for different contexts. Studies should also investigate the role of cultural, socioeconomic and demographic factors in shaping attitudes towards CE and sustainability. This study could benefit from exploring how different disciplines within TVET can contribute to a holistic approach to CE, providing a more integrated strategy for implementation.

The review identifies key barriers in the education sector and circular economy implementation, as well as the potential of innovation and technology to drive circular practices. It is suggested that a more focused empirical approach is needed to determine effective strategies such as curriculum development and revision, professional development for educators, industry partnership, assessment and certification programs to overcome these barriers thus contributing to the future of sustainable TVET development. Future studies could involve qualitative methods such as interviews or focus groups with stakeholders in TVET to gather more nuanced data on barriers to CE implementation.

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