TEM Journal. Volume 15, Issue 3, pages 2888-2897, ISSN 2217-8309, DOI: 10.18421/TEM153-72, August 2026.

Indicators of Product Lifespan in a Circular Economy Framework for a Secondary Education Food Waste Management Course

Norzaharah Ab Hamid [1,2], Fathiyah Mohd Kamaruzaman [1], Mohamad Zuber Abd Majid [1], Nik Afiqah Kamil [1,3]

[1] *STEM Enculturation Research Centre, Faculty of Education, Universiti Kebangsaan Malaysia, Malaysia*
[2] *Ministry of Education, Putrajaya, Malaysia*
[3] *Department of Polytechnic and Community College, Ministry of Higher Education, Putrajaya, Malaysia*

Abstract **– Extending product lifespan is vital in the circular economy, and integrating these concepts into secondary education supports the Sustainable Development Goals. This study identifies key indicators for teachers to promote product lifespan within the circular economy framework, with their significance assessed through a literature review and the Modified Delphi Technique (MDT). The MDT analysis involved 13 experts who participated in two rounds. Through the first round of MDT, the response rate of the experts was 100%, resulting in the acceptance of 41 indicators, while 3 did not reach consensus. Of these, 19 indicators received suggestions for amendments. The second round also achieved a 100% response rate, during which the 41 indicators were resent with the suggested changes incorporated. Out of these, 32 indicators were accepted, while 9 items were deleted due to a lack of consensus. The study's findings reveal a total of 32 indicators, categorized into 5 dimensions: 6 items for reuse indicator, 7 items each for repair, refurbish, and remanufacture indicator, and 5 items for repurpose indicator. The results highlight the importance of incorporating these activities into TVET education to promote sustainability.**

DOI: 10.18421/TEM153-72
https://doi.org/10.18421/TEM153-72

Corresponding author: Fathiyah Mohd Kamaruzaman,
STEM Enculturation Research Centre, Faculty of Education, Universiti Kebangsaan Malaysia, Malaysia
Email: fathiyah@ukm.edu.my

Received: 16 August 2025.
Revised: 18 February 2026.
Accepted: 06 March 2026.
Published: 27 August 2026.

Keywords **– Indicator, product lifespan, circular economy education, Modified Delphi Technique, food waste management.**

1. Introduction

In recent years, the circular economy has emerged as a transformative framework aimed at addressing environmental degradation and resource depletion by focusing on extending the lifespan of products and their components. Central to this framework are activities such as reuse, repair, refurbish, remanufacture, and repurpose, which help reduce waste and promote sustainability. As global consumption continues to rise, particularly in the production and disposal of goods, there is a growing need to integrate circular economy principles into various sectors, including education [1], [2]. One of the critical areas where this integration can have a significant impact is in secondary education, where students can be introduced to sustainable practices early on [3], [4]. Incorporating the circular economy into school curricula, particularly in areas such as food waste management, aligns with global initiatives to achieve the Sustainable Development Goals (SDGs), specifically Goal 12, which focuses on responsible consumption and production.

Research in the field of circular economy education has highlighted its potential to shape the attitudes and behaviors of future generations. However, a gap exists in identifying specific indicators that educators should focus on to instill circular economy practices effectively. While several studies have explored the circular economy in various contexts, such as manufacturing and agriculture [5], [6], [7], [8], little attention has been paid to how this concept can be operationalized within secondary education, particularly in teaching about food waste management. Some researchers argue that the lack of clear indicators for educational purposes limits the potential impact of circular economy principles in school settings [9], [10], [11].

Others, however, suggest that integrating these practices without proper contextualization might lead to confusion or resistance among students and educators alike [12], [13], [14], [15].

This study aims to address these gaps by identifying key indicators that secondary school teachers can use to promote the extension of product lifespan through circular economy practices. By focusing on food waste management, this research not only addresses an urgent environmental issue but also provides a structured approach for embedding circular economy concepts into secondary education. The use of the Modified Delphi Technique, coupled with a comprehensive review of literature from Scopus and Web of Science databases, ensures that the indicators proposed are both theoretically sound and practically applicable. The findings of this study will contribute to the growing body of research on circular economy education and provide actionable insights for educators aiming to foster sustainable practices in their classrooms. The ultimate goal is to equip future generations with the knowledge and skills necessary to reduce waste, conserve resources, and support the transition towards a more sustainable circular economy.

2. Conceptual Underpinnings

Integrating circular economy principles into secondary education, especially in relation to product lifespan and food waste management, plays a vital role in nurturing sustainability and environmental awareness among younger generations. The circular economy emphasizes reducing waste, using resources efficiently, and encouraging the ongoing reuse of materials. Theories such as Closed-Loop Supply Chain and Industrial Ecology play a central role in understanding how products and their components can be reused, repaired, refurbished, remanufactured, and repurposed [16], [17], [18], [19]. These theories emphasize the importance of maintaining the value of products for as long as possible, reducing the need for virgin materials and minimizing environmental impact.

The Cradle-to-Cradle (C2C) theory, introduced by William McDonough and Michael Braungart, promotes a transformative approach to product design focused on easy disassembly and reuse at the end of a product's lifecycle [20], [21], [22], [23]. By advocating for a closed-loop system, this theory encourages the elimination of waste, allowing products to continuously cycle through use, similar to natural ecosystems. This approach can be effectively applied in secondary education to teach sustainable practices [24], [25].

Additionally, Behavioral Change Theories, such as the Theory of Planned Behavior and Social Learning Theory, highlight how education can shape students' attitudes and behaviors toward sustainability. These theories suggest that exposure to circular economy concepts increases the likelihood of students adopting sustainable practices, particularly in managing food waste [26], [27], [28]. For example, when students understand the environmental consequences of food waste and learn strategies to reduce it, they are more inclined to practice responsible consumption.

Various models of circular economy education have been proposed in recent years, but the most relevant to this study is the 9R Framework of the circular economy, which includes strategies like refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover as shown in Table 1. This model provides a comprehensive approach to extending the lifespan of products. For educational purposes, the 9R model can be adapted to focus on the second group of R's (reuse, repair, refurbish, remanufacture, and repurpose) as practical activities for students to engage in.

Table 1. 9R framework

R0 Refuse	Smarter product use and manufacture
R1 Rethink	
R2 Reduce	
R3 Reuse	Extend lifespan of products and its parts
R4 Repair	
R5 Refurbish	
R6 Remanufacture	
R7 Repurpose	
R8 Recycle	Useful application of materials
R9 Recover	

Source: [30]

The five main dimensions of product lifespan extension examined in this study are reuse, repair, refurbish, remanufacture, and repurpose. Each of these dimensions encompasses specific skills and knowledge that secondary school teachers need to impart to students. For instance, reuse focuses on finding new uses for existing products without changing their form, while repair emphasizes fixing broken components to restore functionality. Refurbishment involves improving or upgrading products to extend their usability, and remanufacturing refers to the process of restoring products to their original state. Repurposing, on the other hand, involves adapting products or their components for entirely new functions, thus extending their lifecycle.

In the context of food waste management, these elements translate into practical activities for students, such as reusing food scraps in composting, repairing stale crackers, refurbishing food waste, and repurposing leftovers into new meals. These activities not only teach students the value of extending product lifespan but also align with broader goals of reducing food waste and promoting sustainability.

3. Methodology

This section describes the research design, instrument development process, and expert selection procedures used to achieve consensus on the indicators of product lifespan extension within circular economy education.

3.1. Design of the Modified Delphi Technique (MDT) Questionnaire

This study employed the Modified Delphi Technique (MDT), a procedure for reaching consensus among participants through non-face-to-face questionnaires. MDT is also recognized as an effective method for collecting highly valid feedback from a group of experts on a specific problem or set of issues [29]. Unlike the traditional Delphi method, this study bypassed the initial interview round and proceeded directly to the questionnaire phase, marking the beginning of the MDT process.

At first, a literature review was conducted to develop a structured questionnaire. Relevant literature was identified and reviewed from Scopus and WoS databases, ensuring a comprehensive analysis of existing research in this field. Experts were then asked to rate the importance of each item on a scale of 1 to 5, where 5 represented the most important and 1 the least important. Open-ended questions were also included to allow experts to provide recommendations or suggest modifications. Once the responses were collected, the data were analyzed, and the questionnaire was refined for the subsequent rounds.

Product lifespan extension can be categorized into five key activities, based on the 9R Framework proposed by [30]: reuse, repair, refurbish, remanufacture, and repurpose. In line with standard Delphi methodology, two to three rounds of questionnaires are considered optimal, as more than three rounds may lead to participant fatigue and reduced willingness to continue. Nevertheless, opinions tend to stabilize within two or three rounds. In this study, all participating experts reached a consensus after two rounds.

Additionally, seven questions were included to gather demographic and professional information about the experts. These questions addressed their gender, race, highest level of education, job position, field of expertise, institution, state, and years of experience in the food management and teaching industry. This background information helped to provide a comprehensive context for the expert feedback in the study.

3.2. Participant Expert

The nature of the research topic is based primarily on the respondent's experience, authority, and willingness to cooperate. Previous research suggests that the number of experts for a homogeneous group should range between 15 and 30, whereas for a heterogeneous group, the recommended number is between 5 and 10 [31]. Similarly, reliability has been shown to increase linearly between 3 and 11 participants, with accuracy continuing to improve until the maximum tested group size of 29 participants [32]. Furthermore, other studies indicate that 10 to 15 participants are sufficient when participants share similar backgrounds, and most Delphi panels typically consist of 15 to 20 respondents [33].

Purposive sampling was used as the sampling technique for this study, which involved a total of 13 experts in the field of TVET (Technical and Vocational Education and Training) and education management, comprising 6 males and 7 females, all with over 10 years of experience. Two of them are research officers at institutions that focus on innovation and technology, six are senior lecturers teaching TVET courses, two are School Improvement Specialist Coaches Plus (SISC+), while the other three are state education officers responsible for the development of vocational education and technical training. The panelists were invited through email and WhatsApp. Upon agreeing to participate, they were provided with a Google Form questionnaire link via email.

Each expert was invited to express their level of agreement with the 44 items and provide comments, if necessary, on statements related to extending the lifespan of product and its part, such as reuse, repair, refurbish, remanufacture, and repurpose, within the context of the Secondary Educational Food Waste Management Course.

3.3. Data Analysis

In this study, data analysis for the Modified Delphi Technique (MDT) was conducted using the Statistical Package for the Social Sciences (SPSS) software for each round of the process. The results from SPSS were presented in the form of descriptive statistics, including mean scores, median scores and interquartile range (IQR), representing the consensus of the panel members involved in the study.

Mean scores were used to identify the level of expert agreement, with higher mean scores indicating stronger consensus on the importance of an item and lower scores suggesting less significance. Median scores were utilized to determine the necessary statements for developing questionnaire items, and the interquartile range (IQR) was calculated to assess the relationship between each item and the panel experts' responses.

The IQR score reflects the level of agreement among the panel members regarding the questionnaire items. A lower IQR indicates a higher degree of consensus among the experts on the elements presented in the questionnaire. Items with mean scores of 4 or above and median scores of 4 or above were considered important and accepted, whereas items with mean and median scores below 4 were deemed less important and rejected, as shown in Table 2 [34], [35].

Table 2. Score interpretation table for agreement

Score	Interpretation
Mean ≥ 4, Median ≥ 4	Important and accepted
Mean ≤ 4, Median ≤ 4	Less important and rejected

Source: [34] and [35]

The IQR further helped to define the strength of agreement. If the IQR score was between 0 and 1, it indicated a high level of agreement among the panel, while scores between 1.01 and 1.99 reflected moderate agreement. An IQR score of 2 or higher indicated a lack of consensus and led to the rejection of the indicator. Based on these criteria, items that met the threshold for mean scores, median scores, and IQR values were retained, whereas those that did not meet these thresholds were excluded from the final item list [36]. This systematic approach ensured that the questionnaire items were both relevant and agreed upon by the panel of experts, enhancing the reliability of the study's findings. Table 3 represents level of agreement on items.

Table 3. level of agreement on items

IQR Score	level of agreement	Decision
0 to 1	high	accepted
1.01 to 1.99	moderate	accepted
≥ 2	low	rejected

Source: [36]

4. Result and Findings

The application of the Modified Delphi Technique yielded important findings regarding the consensus on the indicators related to extending the lifespan of product and its part.

In the first round, the response rate of the experts was 100%, resulting in the acceptance of 41 indicators, while 3 did not reach consensus.

Of these, 19 indicators received suggestions for amendments. In line with previous studies on the Delphi method, low-consensus items were removed in the first round. This approach is supported by previous studies emphasizing that removing low-consensus items in the early rounds can streamline the Delphi process and ensure greater focus on relevant indicators [33]. Item reduction based on expert feedback at the early stages has also been shown to enhance clarity and improve consensus-building [37], while deleting items with insufficient agreement helps maintain the overall quality of the study [33], [37], [38].

However, in the Reuse domain, low-consensus items were retained to ensure a minimum of five indicators, which was necessary for the study's methodology. Retaining low-consensus items to preserve balanced representation across domains has been reported in other studies [39], [40]. In the second round, these items were reviewed again, and consensus was achieved, ensuring that all domains, including Reuse, met the required minimum number of items while maintaining high consensus across the expert panel. After these adjustments, the second round achieved a 100% response rate, with 41 indicators being re-sent after suggested changes were incorporated. Out of these, 32 indicators were accepted, while 9 items were deleted due to a lack of consensus. The study's findings reveal a total of 32 indicators, categorized into 5 dimensions: reuse, repair, refurbish, remanufacture, and repurpose.

The results from the analysis of the Reuse indicators in Table 4 demonstrate that the average mean scores for all items ranged between 4.00 and 4.46, indicating that the panel of experts generally agreed on the importance of these indicators. The median scores also reflect strong consensus, with all items achieving a median score of 4.0 or higher. The interquartile range (IQR) for most indicators was less than or equal to 1, reflecting a satisfactory level of agreement among the experts. For instance, the indicator "Use leftover cooking water for watering plants" had an IQR of 2.0 in the first round but achieved consensus in the second round with an IQR of 1. All items in the Reuse category, such as "Donate edible surplus food to charity" and "Feed food waste to livestock," were ultimately accepted based on expert feedback.

Table 4. Result of Reuse indicators

R3	Reuse	Mean	Med	IQR	Consensus	Mean	Med	IQR	Consensus	Decision
R301	Use leftover cooking water for watering plants.	4.0	4.0	2.0	Low	4.46	5	1	High	accepted
R302	Donate edible surplus food to charity.	4.1	4.0	1.8	Medium	4.08	4	1	High	accepted
R303	Feed food waste to livestock.	4.0	4.5	1.8	Medium	4.38	4	1	High	accepted
R304	Pack leftover party food to take home.	4.0	4.0	1.5	Medium	4.00	4	1	High	accepted
R305	Buy products with gravy that can be reused.	4.1	4.0	1.0	High	4.00	4	0	High	accepted
R306	Use reusable food containers even if they are more expensive.	4.2	4.5	1.0	High	4.20	4	1	High	accepted

In Table 5, the Repair indicators showed high agreement among the experts, with average mean scores ranging from 4.00 to 4.31. The IQR for all items was consistently less than or equal to 1, which indicates a high level of consensus across the board.

Indicators such as “Improve the texture of food products” and “Improve nutrition” were both rated highly, with all items accepted. The stability in the results, evidenced by median scores consistently reaching 4.0, further strengthens the consensus among the panel.

Table 5. Result of Repair indicators

R4	Repair	Mean	Med	IQR	Consensus	Mean	Med	IQR	Consensus	Decision
R401	Improve the texture of food products.	4.1	4.0	0.8	High	4.10	4	1	High	accepted
R402	Improve the appearance of food products.	4.2	4.0	0.8	High	4.00	4	0	High	accepted
R403	Improve the taste of food products.	4.1	4.0	0.8	High	4.08	4	1	High	accepted
R404	Improve the color of food products.	4.2	4.0	0.8	High	4.00	4	1	High	accepted
R405	Improve the freshness quality.	4.1	4.0	0.8	High	4.31	4	1	High	accepted
R406	Improve the appearance by garnishing food to make it more appealing.	4.2	4.0	0.8	High	4.00	4	0	High	accepted
R407	Improve nutrition.	4.0	4.0	1.0	High	4.00	4	0	High	accepted

The Refurbish indicators, as presented in Table 6, also achieved strong agreement, with all items accepted. The average mean scores ranged between 4.00 and 4.30, and the IQR for all but one item was below 1.

For example, ‘Revive the freshness of old ingredients’ and ‘Restore the value of ingredients’ both had an IQR of 0.8 or lower, showing strong expert agreement. The item ‘Conduct regular maintenance for improved performance’ had the highest mean score of 4.30, indicating its importance to the experts.

Table 6. Result of Refurbish indicators

R5	Refurbish	Mean	Med	IQR	Consensus	Mean	Med	IQR	Consensus	Decision
R501	Revive the freshness of old ingredients.	4.0	4.0	0.8	High	4.00	4	0	High	accepted
R502	Restore the value of ingredients.	4.1	4.0	0.0	High	4.00	4	1	High	accepted
R503	Make conversions, e.g., turning old frying oil into soap.	4.0	4.0	0.0	High	4.08	4	1	High	accepted
R504	Glaze the surface of food products.	4.1	4.0	1.0	High	4.08	4	1	High	accepted
R505	Improve waste, e.g., boiling bones into stock that becomes a nutritious soup.	4.1	4.0	0.8	High	4.08	4	1	High	accepted
R506	Enhance taste, e.g., adding seasoning powder to dishes.	4.2	4.0	0.8	High	4.00	4	0	High	accepted
R507	Conduct regular maintenance for improved performance.	4.3	4.0	1.0	High	4.08	4	1	High	accepted

Table 7 summarizes the results for the Remanufacture indicators, where the panel reached a consensus with mean scores between 4.00 and 4.31. The IQR for all items was within the acceptable range, demonstrating consistency in expert opinions.

Key indicators such as “Disassemble damaged food products to create a new product” and “Replace systems to improve product quality” were highly rated and accepted. The indicator “Substitute existing ingredients with healthier options” had a slightly higher IQR of 1.8 in the first round, but it achieved acceptance after refinement in the second round.

Table 7. Result of Remanufacture indicators

R6	Remanufacture	Mean	Med	IQR	Consensus	Mean	Med	IQR	Consensus	Decision
R601	Disassemble damaged food products to create a new product.	4.2	4.0	1.0	High	4.00	4	0	High	accepted
R602	Reprocess food products by modifying them.	4.0	4.0	0.8	High	4.08	4	0	High	accepted
R603	Replace systems to improve product quality.	4.1	4.0	1.0	High	4.31	4	1	High	accepted
R604	Substitute existing ingredients with healthier options.	4.0	4.0	1.8	Medium	4.08	4	1	High	accepted
R605	Revamp part of the product with trending ingredients to increase market appeal.	4.2	4.0	1.0	High	4.00	4	0	High	accepted
R606	Clean ingredients, e.g., cleaning fish bones from food waste to boil into stock.	4.0	4.0	1.0	High	4.00	4	0	High	accepted
R607	Conduct taste tests on reprocessed products to maintain their quality.	4.2	4.0	0.8	High	4.10	4	0	High	accepted

The Repurpose indicators in Table 8 showed strong consensus, with all items being accepted. The mean scores ranged from 4.00 to 4.46, and the IQR for all items was either 1 or less, signifying a high level of agreement.

Indicators such as "Convert products into new items using creativity" and "Repurpose damaged products" were rated highly by the experts, with their acceptance reflecting the importance of these practices in extending the lifespan of products.

Table 8. Result of Repurpose indicators

R7	Repurpose	Mean	Med	IQR	Consensus	Mean	Med	IQR	Consensus	Decision
R701	Convert products into new items using creativity.	4.00	4	1	High	4.15	4	0	High	accepted
R702	Repurpose damaged products.	4.46	4	1	High	4.00	4	0	High	accepted
R703	Transform food into decorations.	4.38	4	1	High	4.08	4	1	High	accepted
R704	Create decorations of broken eggshells.	4.23	4	1	High	4.00	4	0	High	accepted
R705	Repurpose dough as children's play material to replace plasticine.	4.23	4	1	High	4.00	4	0	High	accepted

In summary, the findings from all categories (Reuse, Repair, Refurbish, Remanufacture, and Repurpose) indicate a strong level of consensus among the experts, as demonstrated by the high mean scores, consistent median values, and low IQRs across the rounds of analysis. These results highlight the critical role these indicators play in promoting sustainability and reducing waste within the context of food waste management in education.

5. Discussion on Delphi Questionnaire Survey

The study's results highlight the importance of reuse indicators in promoting sustainability within the context of a secondary education food waste management course. Indicators such as using leftover cooking water for plants, donating surplus food to charity, and feeding food waste to livestock received strong consensus, reflecting their practicality in reducing waste. The use of reusable food containers, despite higher costs, was also widely accepted, indicating a shift towards minimizing single-use items. These findings align with the broader goals of the circular economy [41], [42], [43], emphasizing the value of teaching sustainable practices to foster environmental awareness and responsible consumption from an early age.

The repair indicators identified in this study received high consensus from the expert panel, emphasizing their importance in extending the lifespan of food products within a circular economy framework.

Indicators such as improving the texture, appearance, taste, color, freshness, and nutrition of food products all achieved strong agreement (IQR $\leq$ 1), demonstrating their relevance in reducing food waste through simple yet effective repair techniques. Practices like garnishing food to enhance its appeal and improving the freshness of products reflect common strategies in food management to maintain product quality. These findings are consistent with previous research that highlights the role of repair in minimizing waste and maximizing resource efficiency [44], [45], [46]. By focusing on repairing food products, these indicators reinforce the importance of teaching practical skills in food waste management, encouraging sustainable consumption behaviors among students.

The refurbish indicators in this study received high consensus across all items, reflecting the experts' agreement on their importance in extending the lifespan of food products within the circular economy. Indicators such as reviving the freshness of old ingredients, restoring the value of ingredients, and making conversions like turning old frying oil into soap all achieved strong support, with IQR values indicating a high level of agreement ($\leq$ 1). Additionally, practices like glazing food surfaces and boiling bones into stock to reduce waste were seen as effective methods to refurbish and repurpose food products. These findings align with previous research that emphasizes the value of refurbishing as a sustainable approach, allowing for the recovery of value from materials that might otherwise be discarded [47], [48], [49], [50].

The consensus on these indicators reinforces the importance of refurbishing skills in food management, ensuring that students are equipped to contribute to waste reduction and resource efficiency in the broader circular economy context.

The remanufacture indicators from this study demonstrate strong consensus among experts, highlighting their importance in extending the lifespan of food products within the circular economy. Practices such as disassembling damaged food products to create new items and reprocessing food through modification received high agreement (IQR ≤ 1), emphasizing their practicality in reducing food waste. The consensus on replacing systems to improve product quality and revamping products with trending ingredients further supports the role of innovation in remanufacturing. Even indicators such as cleaning ingredients and conducting taste tests to maintain product quality were accepted, reflecting their relevance in ensuring that reprocessed products meet consumer standards. These findings align with previous studies that highlight remanufacturing as a key strategy in resource recovery and waste minimization, reinforcing the importance of equipping individuals with the skills to reprocess and innovate within the food industry [51], [52], [53]. The strong support for these indicators suggests that remanufacturing has significant potential to contribute to sustainable food management practices.

The repurpose indicators in this study received high consensus, reflecting the experts' agreement on their importance in promoting sustainability through creative and practical approaches. Indicators such as converting products into new items using creativity, repurposing damaged products, and transforming food into decorations all demonstrated strong support (IQR = 1), emphasizing their potential in reducing waste. For instance, repurposing dough as children's play material or creating decorations from broken eggshells illustrates how food and its components can find new uses beyond their original purpose. These findings align with previous research that highlights the value of repurposing in extending product lifespans and promoting innovative waste management strategies [48], [54], [55], [56], [57]. The high consensus on these indicators reinforces the idea that repurposing can play a significant role in circular economy practices, encouraging the development of creative solutions for managing food waste effectively.

6. Conclusion

This study utilized a combination of literature review and the Modified Delphi Technique to identify key indicators that secondary school teachers should cultivate to extend the lifespan of products and their components within a circular economy framework.

A total of 32 indicators were accepted, categorized into five dimensions: reuse, repair, refurbish, remanufacture, and repurpose. These indicators are essential for promoting sustainable practices in secondary education and aligning with the Sustainable Development Goals. Reuse and repair indicators, such as using leftover cooking water and improving the appearance of food products, were highly rated for their practicality. Refurbishing and remanufacturing practices, such as reviving the freshness of old ingredients and replacing systems to improve product quality, also gained strong consensus. The findings demonstrate the need for educators to incorporate these concepts into their curriculum, emphasizing practical skills that promote sustainability and resource efficiency.

In terms of practical implications, it is recommended that secondary education institutions prioritize training and education on these five dimensions. Schools should provide hands-on activities that teach students how to implement reuse, repair, refurbish, remanufacture, and repurpose strategies in food waste management. Furthermore, policymakers should consider supporting these initiatives by integrating circular economy principles into national educational standards and offering incentives for schools that adopt sustainable practices. Future research could explore the effectiveness of these indicators when applied in real-world classroom settings, as well as their potential to influence students' long-term behaviors toward sustainability.

Acknowledgements

Special gratitude to the Faculty of Education, Universiti Kebangsaan Malaysia and University Research Grant: GG-2024-007 for sponsoring the publication of this article.

References:

[1]. Ijassi, W., Evrard, D., & Zwolinski, P. (2024). Innovative teaching method of circularity design for sustainable manufacturing systems: an application on urban factories. *Procedia CIRP*, *122*, 151-156. Doi: 10.1016/j.procir.2024.01.022

[2]. Renfors, S. M. (2024). Education for the circular economy in higher education: an overview of the current state. *International Journal of Sustainability in Higher Education*, *25*(9), 111-127. Doi: 10.1108/IJSHE-07-2023-0270

[3]. Keramitsoglou, K., Litseselidis, T., & Kardimaki, A. (2023). Raising effective awareness for circular economy and sustainability concepts through students' involvement in a virtual enterprise. *Frontiers in Sustainability*, *4*, 1060860. Doi: 10.3389/frsus.2023.1060860

[4]. Roba, J., et al. (2021). Serious games in secondary education to introduce circular economy: experiences with the game EcoCEO. *Frontiers in Sustainability*, *2*, 690232. Doi: 10.3389/frsus.2021.690232

[5]. Bagheri, N., & Abdelaziz, F. B. (2024). Efficiency rankings of economic sectors: a focus on sustainability and circularity objectives. *International Journal of Energy Sector Management*, *18*(6), 2435-2448. Doi: 10.1108/IJESM-09-2023-0024

[6]. Gopalan, B., Vijaya, G. S., & Tiwary, A. (2024). Food Supply Chain Management, Logistics, and Ecosystems in the Internet Economy. *Digital Technologies for a Resource Efficient Economy*, 36-62. Doi: 10.4018/979-8-3693-2750-0.ch003

[7]. Mohan, J., et al. (2024). Mapping 3R and circular economy policy implementation in Asia and the Pacific. *Circular Economy and Sustainability*, *4*(1), 671-692. Doi: 10.1007/s43615-023-00302-0

[8]. Vijai, & Wisetsri, W. (2024). Circular economy for sustainable development in India. *Global Sustainability: Trends, Challenges & Case Studies*, 61-87. Springer. Doi: 10.1007/978-3-031-57456-6_4

[9]. Luthin, A., Traverso, M., & Crawford, R. H. (2023). Assessing the social life cycle impacts of circular economy. *Journal of Cleaner Production*, *386*, 135725. Doi: 10.1016/j.jclepro.2022.135725

[10]. Rotolo, G. C., et al. (2022). Perception and awareness of circular economy options within sectors related to agriculture in Argentina. *Journal of Cleaner Production*, *373*, 133805. Doi: 10.1016/j.jclepro.2022.133805

[11]. Yamoah, F. A., et al. (2022). Demystifying corporate inertia towards transition to circular economy: A management frame of reference. *International Journal of Production Economics*, *244*, 108388. Doi: 10.1016/j.ijpe.2021.108388

[12]. Blažek, L. (2022). *Innovation in the circular economy*. *Proceedings of the 17th European Conference on Innovation and Entrepreneurship*, 58–65. Academic Conferences and Publishing International. Doi: 10.34190/ecie.17.1.640

[13]. Brunner, P. H., Unterberger, A., & Fellner, J. (2023). Improving waste management by focussing on goals: A mini review of the publication sector. *Waste Management & Research*, *41*(12), 1717-1727. Doi: 10.1177/0734242X231172104

[14]. De Giovanni, P. (2023). Circular networks and engagement strategies. In *Strategies for the Circular Economy*, 25-42. Routledge.

[15]. Hossain, M., et al. (2024). Exploring the barriers to implement industrial symbiosis in the apparel manufacturing industry: Implications for sustainable development. *Heliyon*, *10*(13). Doi: 10.1016/j.heliyon.2024.e34156

[16]. Belhadi, A., et al. (2022). A self-assessment tool for evaluating the integration of circular economy and industry 4.0 principles in closed-loop supply chains. *International Journal of Production Economics*, *245*, 108372. Doi: 10.1016/j.ijpe.2021.108372

[17]. El-Sheikh, L., & Kovačič Lukman, R. (2022). Developing a framework for closed-loop supply chain and its impact on sustainability in the petrochemicals industry. *Sustainability*, *14*(6), 3265. Doi: 10.3390/su14063265

[18]. Lara-Guillén, J., Méndez-Aparicio, M. D., & Jiménez-Zarco, A. I. (2024). Circular economy and closed-loop supply chains in industry 4.0: importance to achieve sustainable development. In *Digital Transformation for Improved Industry and Supply Chain Performance*, 299-333. Doi: 10.4018/979-8-3693-5375-2.ch013

[19]. Suhandi, V., & Chen, P. S. (2023). Closed-loop supply chain inventory model in the pharmaceutical industry toward a circular economy. *Journal of Cleaner Production*, *383*, 135474. Doi: 10.1016/j.jclepro.2022.135474

[20]. Bjørn, A., & Hauschild, M. Z. (2018). Cradle to Cradle and LCA. Life cycle assessment: Theory and practice. *Springer*, 605-631.

[21]. Kitriniaris, A. (2018). Cradle to cradle regenerative design: From circular economy to sustainable construction. *Sustainable Development and Planning X: WIT Transactions on Ecology and the Environment*, *217*, 3–14.

[22]. Kopnina, H. (2019). Green-washing or best case practices? Using circular economy and Cradle to Cradle case studies in business education. *Journal of Cleaner Production*, *219*, 613-621. Doi: 10.1016/j.jclepro.2019.02.005

[23]. Mohajan, H. K. (2021). Cradle to cradle is a sustainable economic policy for the better future. *Annals of Spiru Haret University. Economic Series*, *21*(4), 569-582.

[24]. Laius, A., Saarna, R., & Kont, M. (2024). Secondary school students' understanding of circular economy and recycling at a small rural school. *Interdisciplinary Journal of Environmental and Science Education*, *20*(3), e2409. Doi: 10.29333/ijese/14620

[25]. Tiippana-Usvasalo, M., Pajunen, N., & Maria, H. (2023). The role of education in promoting circular economy. *International journal of sustainable engineering*, *16*(1), 92-103. Doi: 10.1080/19397038.2023.2210592

[26]. Duran, M. K. L., & Mariñas, K. A. (2024). Sustainability integration in Philippine higher education curricula: A structural equation modeling assessing teacher intention to integrate. *Sustainability*, *16*(9), 3677. Doi: 10.3390/su16093677

[27]. Mashwama, X. N., & Omodan, B. I. (2024). Breaking barriers: A systematic review of inclusive practices in higher education for engineering students with disabilities. *International Journal of Learning, Teaching and Educational Research*, *23*(7), 228–249. Doi: 10.26803/ijlter.23.7.12

[28]. Weder, F., et al. (2022). Social learning of sustainability in a pandemic—changes to sustainability understandings, attitudes, and behaviors during the global pandemic in a higher education setting. *Sustainability*, *14*(6), 3416. Doi: 10.3390/su14063416

[29]. Wiersma, W., & Jurs, S. G. (2009). *Research methods in education: An introduction* (9th ed.). Pearson.

[30]. Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: Measuring innovation in the product chain*. PBL Publishers.

[31]. Delbecq, A. L., Van de Ven, A. H., & Gustafson, D. H. (1975). *Group techniques for program planning: A guide to nominal group and Delphi processes*. Scott, Foresman & Company.

[32]. Dalkey, N. C., Rourke, D. L., Lewis, R., & Snyder, D. (1972). *Studies in the Quality of Life: Delphi and Decision-Making*. Lexington Books.

[33]. Hsu, C. C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. *Practical assessment, research, and evaluation*, *12*(1). Doi: 10.7275/pdz9-th90

[34]. Ogden, S. R., et al. (2016). Developing a checklist: consensus via a modified Delphi technique. *Journal of cardiothoracic and vascular anesthesia, 30*(4), 855-858. Doi: 10.1053/j.jvca.2016.02.022

[35]. Ab Latif, R., et al. (2017). The Delphi technique as a method to obtain consensus in health care education research. *Education in Medicine Journal*, *9*(3). Doi: 10.21315/eimj2017.9.3.10

[36]. Peck, R., & Devore, J. L. (2012). *Statistics: The Exploration and Analysis of Data* (7th ed.). Cengage Learning.

[37]. Linstone, H. A., & Turoff, M. (2002). *The Delphi Method: Techniques and Applications (A Note About the Electronic Version)*. Addison-Wesley Publishing Company.

[38]. Keeney, S., McKenna, H. P., & Hasson, F. (2010). *The Delphi technique in nursing and health research*. John Wiley & Sons.

[39]. Tellum, T., et al. (2022). Development of a core outcome set and outcome definitions for studies on uterus-sparing treatments of adenomyosis (COSAR): an international multistakeholder-modified Delphi consensus study. *Human Reproduction*, *37*(9), 2012-2031. Doi: 10.1093/humrep/deac166

[40]. Young, A., et al. (2022). *Establishment of a core outcome set for burn care research: Development and international consensus*. *BMJ Medicine*, *1*(1), e000183. Doi: 10.1136/bmjmed-2022-000183

[41]. Bonoli, A., et al. (2018). End of service scenario for universities' informatic equipment: Recovery and repair as educational and research tool for circular economy and urban mining. *Detritus*, (4), 90–97. Doi: 10.31025/2611-4135/2018.13747

[42]. Navarro, L. V., et al. (2024). Evaluating the impact of a transdisciplinary circular economy course on university students: Enhancing proficiency, awareness, and positive sentiments in sustainable practices. In *2024 IEEE global engineering education conference (EDUCON)*, 1-5. Doi: 10.1109/EDUCON60312.2024.10578651

[43]. Talha, M. (2023). Green financing and sustainable policy for low carbon and energy saving initiatives: turning educational institutes of China into green. *Engineering Economics*, *34*(1), 103-117. Doi: 10.5755/j01.ee.34.1.32837

[44]. Fassio, F., & Minotti, B. (2019). Circular economy for food policy: The case of the RePoPP project in the city of Turin (Italy). *Sustainability*, *11*(21), 6078. Doi: 10.3390/su11216078

[45]. Morganti, P., & Tishchenko, G. (2021). Circular Economy for a Healthy Living Environment. *An Introduction to the Circular Economy*, 97–112. Nova Science Publishers.

[46]. Teleky, B. E., & Vodnar, D. C. (2021). Recent advances in biotechnological itaconic acid production, and application for a sustainable approach. *Polymers*, *13*(20), 3574. Doi: 10.3390/polym13203574

[47]. Jacobs, C., et al. (2022). Challenges to the circular economy: Recovering wastes from simple versus complex products. *Sustainability*, *14*(5), 2576. Doi: 10.3390/su14052576

[48]. Mangla, S. K., et al. (2021). Impact of information hiding on circular food supply chains in business-to-business context. *Journal of Business Research*, *135*, 1-18. Doi: 10.1016/j.jbusres.2021.06.013

[49]. Migliaccio, K. W., Jones, J. W., & Verma, B. P. (2023). Perspectives on transforming the bioeconomy toward circular systems. *Journal of the ASABE*, *66*(3), 765-770. Doi: 10.13031/JA.15100

[50]. Valencia, M., et al. (2023). The socioeconomics of the circular economy. *Journal of Cleaner Production*, *408*. Doi: 10.1016/j.jclepro.2023.137082

[51]. Gilbert, L. A. (2024). The Allotment: A test-bed for the circular economy?. *The Pedagogies of Re-Use*, 9-25. Routledge. Doi: 10.4324/9781032665559-3

[52]. Kayıkcı, Y., et al. (2021). A conceptual framework for food loss and waste in agri-food supply chains: Circular economy perspective. *Challenges and Opportunities of Circular Economy in Agri-Food Sector: Rethinking Waste*, 41-53. Springer Singapore. Doi: 10.1007/978-981-16-3791-9_3

[53]. Sani, D., et al. (2021). An overview of the transition to a circular economy in emilia-romagna region, Italy considering technological, legal–regulatory and financial points of view: a case study. *Sustainability*, *13*(2), 596. Doi: 10.3390/su13020596

[54]. Burggraaf, V. T., et al. (2020). *Application of circular economy principles to New Zealand pastoral farming systems*. *Journal of New Zealand Grasslands*, *82*, 53–59. Doi: 10.33584/jnzg.2020.82.426

[55]. D'Amico, D. A., et al.. (2024). Repurpose of used frying sunflower oil as an ecofriendly plasticizer for polylactic acid. *Industrial Crops and Products*, *214*, 118467. Doi: 10.1016/j.indcrop.2024.118467

[56]. Kumar, S. R., Prajapati, S., & Parambil, J. V. (2021). Sustainable food value chains and circular economy. *Challenges and Opportunities of Circular Economy in Agri-Food Sector: Rethinking Waste*, 77-92. Springer Singapore. Doi: 10.1007/978-981-16-3791-9_5

[57]. Rhodes, C. J. (2017). The imperative for regenerative agriculture. *Science progress*, *100*(1), 80-129. Doi: 10.3184/003685017X14876775256165