International Journal of Technology
http://ijtech.eng.ui.ac.id

Research Article

A Fuzzy Delphi Model for Prioritizing Uncaptured Value in Circular Manufacturing: Decision-Making in the Heavy Equipment Industry

Yudi Syahrullah[1,2], Udisubakti Ciptomulyono[1*], Ratna Sari Dewi[1]

[1]Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia

[2]Department of Industrial Engineering, Universitas Jenderal Soedirman, Purbalingga, 53371, Indonesia

[*]Corresponding author: udisubakti@ie.its.ac.id; Tel.: +62-81553399326; Fax.: +6231-5923465

Abstract: Manufacturing remains a major contributor to greenhouse gas emissions and resource depletion, accelerating the transition toward circular business models. Although circular manufacturing seeks to generate economic, social, and environmental value, significant uncaptured value persists and is insufficiently prioritized. This study systematically identifies and prioritizes uncaptured values within circular manufacturing business models. A literature review identified 35 uncaptured values related to sustainable manufacturing business models targeting six captured values aligned with the SDGs. A Fuzzy Delphi survey involving nine experts in heavy equipment and machinery recovery operations was conducted to ensure industrial relevance. Nine uncaptured values met the consensus ($\geq$75%) and threshold ($\leq$0.2) criteria and were subsequently prioritized using fuzzy evaluation scores. The retained values primarily reflect core operational constraints, particularly weak quality control in recovery activities, limited availability of viable end-of-life products, and unfavorable recovery end-of-life characteristics. These findings indicate that bottlenecks in reverse supply and recovery execution predominantly drive uncaptured value in circular manufacturing rather than downstream market factors. By providing an expert-consensus prioritization framework, this study advances research on circular business models and offers a practical foundation for targeted mitigation strategies to strengthen value capture and enhance the long-term resilience of circular manufacturing systems.

Keywords: Circular economy; Fuzzy delphi; Manufacturing; Uncaptured value

1. Introduction

The UN Global Resources Outlook 2024 highlights that global consumption of natural resources is expected to rise by approximately 60% by 2060 relative to 2020, largely driven by urbanization, industrialization, and population growth (Charlton, 2024). Such rapid growth in material extraction and use is closely associated with higher production and consumption levels, which in turn generate increasing amounts of post-consumer and industrial product waste (UNEP, 2024). Stakeholders must implement waste management strategies, especially for industrial waste (Yatoo et al., 2024). The transition to a circular economy is becoming increasingly important with dwindling natural resources, global warming, and the demand for competitive advantage (Suzanne et al., 2020). Extending the value chain of industrial waste, extending the product life cycle (Fernando et al., 2022), and closing the end-of-life material loop can reduce waste generation (Mayanti and Helo, 2024). Therefore, the implementation of a circular economy is believed to address waste problems while creating a competitive advantage. A circular economy is a systematic approach that benefits both the environment and society (Berawi, 2020). In the manufacturing sector, adopting CEPs lowers expenditures on raw materials, energy, and end-of-life product disposal (Tolio et al., 2017). It also delivers wider strategic gains, such as improved competitive positioning, more robust regulatory compliance and associated risk miti-

https://doi.org/10.14716/ijtech.v17i3.8363
Received January 2026; Revised February 2026; Accepted March 2026

gation, a stronger corporate image, and greater scope for innovation (Wandji et al., 2025; EMF, 2021).

In the European Union, a circular economy approach can save hundreds of billions of dollars in raw material procurement costs while providing significant environmental benefits (EMF, 2021; Asif et al., 2021). The Ellen MacArthur Foundation predicts that a circular economy could save $ 700 billion in material costs and reduce emissions by 48% by 2030 (Rutgers and John, 2021). Aligned with these macro-level benefits, remanufacturing is among the most effective product-level circular strategies. In diesel engine applications, remanufactured units can match new-product performance while achieving savings of up to 50% in cost, 60% in energy, and 70% in raw materials under favorable conditions (Zhang and Chen, 2015). Remanufacturing advances the circular economy by delivering economic (cost efficiency), environmental (resource conservation), and social (sustainable business model) benefits, making it a vital response to resource scarcity and related challenges (Sakao et al., 2024).

As a relatively new approach, the circular business model faces significant transition challenges; its successful adoption by firms, manufacturers, and consumers depends on effective value creation and capture (Moloney, 2021). Consistent with this view, the International Organization for Standardization has issued ISO 59004 to guide the implementation of the circular economy, emphasizing the central role of value creation and value to be captured (ISO, 2024). Prior research has emphasized value creation rather than how value is captured within business models (Sjödin et al., 2020). In contrast, uncaptured value provides a broader and more strategic perspective by revealing missed, destroyed, and surplus value that cannot be explained by revenue-based measures alone (Yang et al., 2017a). Failure to identify uncaptured value can undermine business sustainability; therefore, uncaptured value is more critical than captured value when developing strategies for a circular economy transition. Uncaptured value provides a technical basis for innovation and value optimization in circular business models by revealing missed, destroyed, and surplus value (Bertassini et al., 2021; Kvadsheim et al., 2021). Accordingly, organizations should systematically assess both captured and uncaptured value to identify opportunities for improvement and convert negative value into positive outcomes.

A qualitative and conceptual approach to identifying and mapping uncaptured potential value in various industrial contexts (Borchardt et al., 2024; Gennari and Bocchi, 2023; Yang et al., 2017a). However, this study remains exploratory, focusing on identifying the forms and sources of uncaptured value rather than quantitatively prioritizing those most relevant to specific business models. Uncaptured value can threaten the sustainability of circular business models, and identifying it can help organizations create value (Gennari and Bocchi, 2023). Nevertheless, studies on uncaptured value are lacking. The value obtained is limited to identification, and the highest-priority value for follow-up has not yet been determined. Furthermore, existing research has not specifically examined the application of a circular economy to manufacturing, nor has it examined the company's success in identifying and capturing uncaptured value.

Existing studies on uncaptured value are context-specific and predominantly conceptual, lacking quantitative prioritization and robust expert consensus to inform circular manufacturing decision-making. Circular economy decisions on technology selection, strategic options, and resource management scenarios are often supported by classical MCDM methods, such as AHP, ANP, TOPSIS, and PROMETHEE (Tighnavard Balasbaneh et al., 2025). However, these approaches are generally less suited for the early research stage, where iterative expert consensus must identify and screen relevant factors and barriers. The fuzzy Delphi method can define diverse indicators, potentially creating ambiguity and incoherent conclusions (Padilla-Rivera et al., 2021), while also validating key challenges in circular economy implementation (Bui et al., 2025). By integrating fuzzy logic, it strengthens the Delphi technique in refining factors and managing uncertainty in expert judgments (Behl et al., 2023). Therefore, this method is particularly suitable for assessing the relevance of uncaptured values in circular manufacturing business models, a domain that remains underdeveloped in the literature. Accordingly, this study aims to:

1. Uncaptured values in circular manufacturing business models are identified.
2. Prioritize their relevance in the heavy equipment and machinery manufacturing industry using the Fuzzy Delphi Method.

This study enables a quantitative prioritization of value losses in circular manufacturing business models by integrating decision-making methods into uncaptured value assessment. The proposed approach assists practitioners in formulating targeted operational mitigation strategies in the heavy equipment sector. The remainder of this paper is structured as follows: Section 1 presents the research background and context of the problem. Section 2 reviews the relevant literature that underlies this study. Section 3 describes the research method and its main stages. Section 4 reports and discusses the identified uncaptured values and their relevance prioritization. Section 5 concludes the paper and outlines directions for future research.

2. Literature Review on Uncaptured Values

A framework was proposed to conceptualize uncaptured value in sustainable business model innovation (SBMI) within manufacturing firms implementing product–service systems (Yang et al., 2017b). The framework is designed around the product life cycle, namely the beginning-of-life, middle-of-life, and end-of-life stages (Yang et al., 2017a). This research will serve as a reference for subsequent research on uncaptured value. The uncaptured value of the sustainable fashion industry, which produces and sells products made from recycled textile waste, lies in its ability to combine economic and social-environmental aspects (Borchardt et al., 2024). In the economic dimension, the analysis focuses on revenue, cost efficiency, and financial viability-related potential value losses. The socio-environmental dimension examines underutilized social and environmental value, including impacts on beneficiaries, unassessed product and process effects, and limited community engagement. Identify uncaptured values that emerge in circular business models, including environmental trade-offs, hidden social costs, governance conflicts, and dependency on bio-resource supply chains (Gennari and Bocchi, 2023) . Table 1 summarizes the uncaptured value studies reviewed by context, conceptual structure, and research outputs.

The priority values for follow-up still need to be explored to achieve the circular manufacturing business model's sustainability. Burhan et al., 2021 identified uncaptured value in furniture manufacturing using a multi-criteria decision-making model to capture opportunities for new value in sustainable business model innovation. Uncaptured value becomes captured value in the circular business model, which can be realized through the implementation of the circular economy (Burhan et al., 2020). Based on a systematic literature review, research on uncaptured value and sustainable business models is currently conceptual (Osmanovic et al., 2024); operational exploration is still needed to measure uncaptured value in these models. Recent research on uncaptured value in a more specific area, namely the circular economy in small and medium manufacturing industries, provides a framework for identifying circular strategies that can help companies reduce material waste, promote sustainable industry implementation, and support low-carbon innovation (Hamwi et al., 2025). Previous studies were limited to conceptual framework development and qualitative validation in manufacturing. Building on bibliometric insights, this study integrates qualitative and quantitative methods to identify uncaptured value in a measurable circular manufacturing business model, providing a robust basis for strategic decision-making.

3. Methods

This research was conducted through several stages, as shown in Figure 1. The Fuzzy Delphi Method (FDM) extends the traditional Delphi approach by integrating fuzzy set theory to capture uncertainty in expert judgments and reduce the need for multiple Delphi rounds in exploratory studies (Fatemi et al., 2017). However, as this expert-based research is exploratory, the single-round design and limited panel size primarily support the internal consistency of the prioritization results rather than statistical generalizability (Manyara et al., 2024) fuzzy Delphi method can also be used to identify the most determining factors in a system (Huang et al., 2021). The FDM is not just a data-collection tool, but a quantitative validation approach (Jailani and Loy, 2023). It is explicitly designed to assess an instrument's content validity by transforming expert judgments into fuzzy numbers and quantifying the expert panel's degree of consensus.

Table 1 Uncaptured Value Research in Business Models

Authors	Industry Context	The UV Concept Structure	Output
(Yang et al., 2017b)	Manufacturing (production and consumption)	Sustainable business model innovation (SBMI), product life cycle (Bol. Mol. and EoL)	Conceptual framework for tools for sustainable value analysis
(Yang et al., 2017a)	PSS manufacturing	SBMI, product life cycle (Bol. Mol. and EoL)	Identification of uncaptured value in the product life cycle
(Burhan et al., 2021)	Manufacturing industry (furniture company)	SBMI (value proposition), Design, the house of value, and the product sustainability index matrix	Framework: Determining captured sustainability value based on uncaptured value
(Gennari and Bocchi, 2023)	Circular bioeconomy (biofuel)	Product life cycle (Bol. Mol. and EoL) ESG Dimensions: Environmental, Social, and Governance	Identification of uncaptured values as the dark side of CBM
(Borchardt et al., 2024)	Social enterprise–sustainable fashion	BM elements (e.g.: product/service features, internal activities, resources, channels, cost structure, and revenue)	Empirical: Uncaptured value in business models
(Osmanovic et al., 2024)	Theoretical and practical implications	SBMI (systematic literature review)	Uncaptured value literature review on the SBMI
(Hamwi et al., 2025)	Manufacturing (small- and medium-sized manufacturing and agri-food enterprises (SMEs))	Business model innovation (circular business model), uncaptured value, innovation perspectives, and circularity strategies	Design of tools (framework) for the identification of circular strategies and framework validation

3.1 Expert Appointment

The uncaptured value assessment was conducted by soliciting the opinions of experts in the OEM manufacturing industry and related industries that implement circular manufacturing principles. Heavy equipment manufacturing involves established end-of-life (EoL) product returns, making it a valid context for selecting an expert panel with direct remanufacturing experience (Difrancesco and Huchzermeier, 2016). Circular economy implementation requires a systemic perspective (business models, stakeholder relations, and reverse flows) (Kirchherr et al., 2017). Therefore, industries with mature remanufacturing practices provide a more relevant setting for identifying uncaptured value than sectors still at an early stage or focused mainly on recycling. Based on the initial literature review, the results of this study were assessed for relevance by 9 experts using the criteria shown in Table 2. There is no fixed panel size requirement in the Fuzzy Delphi Method, and studies have employed panels of seven to eight experts (Yusoff et al., 2024; Hasim et al., 2023). Given the limited availability of circular manufacturing specialists, this study engaged nine experts from industry, academia, and research, each with over ten years of experience in circular heavy equipment manufacturing. This composition was considered sufficient to support the validity of the judgments elicited.

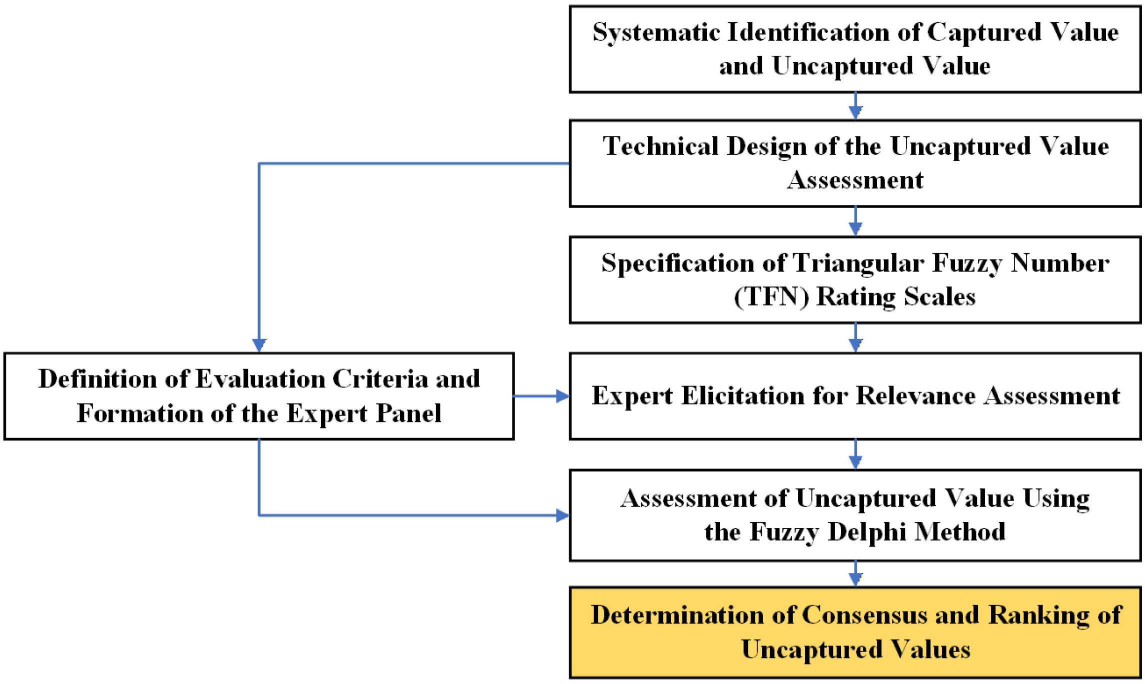

Figure 1 Research framework and stages for uncaptured value relevance assessment

Table 2 Expert profile and criteria

Experts	Organization Type	Title and Position	Professional experience
Expert 1	Remanufacturing Company (OEM-affiliated remanufacturing facility)	R&D Division Head	21 years
Expert 2	Heavy Equipment Distributor/Dealer/Service Provider (OEM representative / after-sales service)	Remanufacturing Manager	23 years
Expert 3	Mining contractor/heavy equipment use company (fleet operator/mining services)	Manager, Rebuild Center	25 years
Expert 4	Industrial Equipment and MRO Service Provider (rotating equipment services, repair, and engineering services)	Director of Sustainability	31 years
Expert 5	Heavy Equipment Distributor, Dealer, and Service Provider	Department Head Remanufacturing Dept.	20 years
Expert 6	Heavy Equipment Manufacturer (OEM)	Supervisor Manager	14 years
Expert 7	Heavy Equipment Manufacturer (OEM)	Manager	15 years
Expert 8	National Research Institute (Environmental / Sustainability Focus) (Government Research Institute)	Senior Researcher	10 years
Expert 9	Public university/higher education institution (academia)	Associate Professor	21 years

3.2 Assessment Criteria for Relevance Level and Triangular Fuzzy Number

The relevance level assessment scale uses the scale listed in Table 3. The relevance level shows how closely and importantly the factor relates to the circular manufacturing business model, especially the manufacturing industry that applies circular principles through recovery activities such as repair, reconditioning, refurbishment, and remanufacturing. After the assessment is carried out by determining the level of relevance from the previous stage, it is converted to triangular fuzzy number (TFN). The linguistic scale is converted into a triangular fuzzy number (TFN), which refers to previously conducted related research, as shown in Table 3 (Tuni et al., 2023).

Table 3 Definition of linguistic scale level relevance of uncaptured value in circular remanufacturing and triangular fuzzy number (TFN) business models

Linguistic Scale	Explanation	Triangular fuzzy number		
		l	m	u
Totally Irrelevant	Uncaptured value is closely related to or does not influence the remanufacturing company.	0	0.1	0.3
Irrelevant	Uncaptured value that is unrelated or has a minimal influence on the remanufacturing company	0.1	0.3	0.5
Enough Relevant/Neutral	Uncaptured value has a moderate or ordinary relationship with the remanufacturing company's activities	0.3	0.5	0.7
Relevant	Uncaptured value is directly related to remanufacturing companies' performance and can cause disruption	0.5	0.7	0.9
Very Relevant	Uncaptured value has a significant strategic impact on the sustainability of circular business models and remanufacturing companies.	0.7	0.9	1

3.3 Uncaptured Value Relevance Level Data Collection

In the initial stage, a closed questionnaire was sent to the experts to assess the relevance of 35 uncaptured value items. Table 3 lists the uncaptured values identified using the linguistic scale. In this assessment, 9 experts provided opinions based on their respective knowledge and experience regarding the relevance of uncaptured value in the circular manufacturing business model, specifically for heavy equipment and machinery. Ratings provided by the 9 experts were subsequently subjected to reliability analysis using Cronbach's alpha and were deemed acceptable when the coefficient (α) exceeded 0.60 (Natsir et al., 2021). Cronbach's alpha was calculated using Equation (1) (Bland and Altman, 1997).

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_{y_i}^2}{\sigma_x^2}\right) \tag{1}$$

Information:
k = the number of scale items
$\sigma_{y_i}^2$ = the variance associated with item i

σ_x^2 = the variance associated with the total observed scores

3.4 Assessment of Uncaptured Value Relevance Level

The uncaptured value relevance level assessment that 9 experts against 35 uncaptured values will be converted into a fuzzy triangular number (TFN), referring to Table 3. After the experts responded to a questionnaire designed based on the validation results, the initial uncaptured values identified in the interviews were displayed. Responses were then recorded on a Likert scale and converted to a fuzzy scale to calculate the average fuzzy response. (Hasim et al., 2023) . The formula used in this process is as follows:

$$M = \frac{\sum_{i=1}^{n} m_i}{n} \tag{2}$$

Information:

m_i= conversion value into fuzzy form given by the expert, representing the lower, middle, and upper limits of the aggregate fuzzy value

n= number of experts

The triangular form of the fuzzy number (TFN), namely m_1,m_2,m_3, which is obtained based on n(number of experts)

Next, based on the values of m and n, the threshold value (d) is determined, and the d-construct assessment is used to determine the consensus on the uncaptured value stated and selected for the ranking process using the following formula (Hasim et al., 2023) :

$$d(\bar{m}, \bar{n}) = \sqrt{\frac{[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}{3}} \tag{3}$$

$$d\text{-construct} = \frac{\text{sum of average } (d)}{\text{total experts} \times \text{total items in the construct}} \tag{4}$$

Information:

$d(\bar{m}, \bar{n})$ = Measures the level of difference between two fuzzy numbers (usually two opinions or two fuzzy average values). The smaller the d value, the higher the consensus level among experts.

m_1, m_2, m_3 = Components of the first fuzzy number representing the lower, middle, and upper limits of the aggregate fuzzy value.

n_1, n_2, n_3 = Components of the second fuzzy number representing the lower limit, middle value, and upper limit of an expert's individual fuzzy value.

In general, the fuzzy method Delphi uses a consensus threshold of ≤ 0.2 and a consensus percentage of $\geq 75\%$ for agreed-upon factors. However, the fuzzy approach remains acceptable with a threshold value ≤ 0.299, which falls within the allowable range (Yusoff et al., 2024). This study used a threshold of ≤ 0.2 and a consensus percentage of $\geq 75\%$ to achieve higher levels of consensus, rigor, and validity. The uncaptured value will be ranked and selected as the most relevant in circular manufacturing business models, particularly in OEM manufacturing of heavy equipment. Furthermore, uncaptured values accepted at the previous stage will be ranked based on their fuzzy evaluation scores.

Determination and prioritization of the uncaptured value rankings are performed through the defuzzification process. The central method is used in the defuzzification process. gravity (center of gravity) to perform defuzzification, i.e., changing the triangular fuzzy numbers, which consist of the lower limit value (m_1), middle value (m_2), and upper limit value (m_3) into a single value (Tsai et al., 2020) using the following formula:

$$DF = \frac{(m_1 + m_2 + m_3)}{3} \tag{5}$$

Information: m_1= lower limit of the fuzzy number (lowest value) m_2= the middle value of the fuzzy number (the most likely value) m_3= upper limit of the fuzzy number (highest value).

4. Results and Discussion

4.1 Uncaptured Value Identification

Uncaptured value identification starts with the captured value. Uncaptured values transform into captured values (Table 4), which are defined by three aspects of sustainability: economic, environmental, and social (Evans et al., 2017). In business model innovation, revenue potential arises when value capture mechanisms are explicitly designed so that revenue flows align with the value created and delivered, for example, through a profit formula that governs the allocation of revenue and costs in an outcome-based model (Sjödin et al., 2020; Geissdoerfer et al., 2018). From the cost (reduction) side, material and energy efficiency, accompanied by waste control in processes and operations, contribute to reducing material, operational, and ownership or lifecycle costs, especially in organizations with limited resources (Borchardt et al., 2024; Sjödin et al., 2020; Bocken et al., 2014). The value of personal development can also be realized when the business model positions human well-being as a social outcome, such as improving employee well-being, more meaningful work, and professional and personal development (Geissdoerfer et al., 2018; Murray et al., 2017; Bocken et al., 2014). Meanwhile, the quality of stakeholder engagement is strengthened through proactive, structured stakeholder engagement. As a social layer on the business model canvas, the stakeholder perspective helps define relationships and create value with partners, customers, and related institutions (Joyce and Paquin, 2016; Bocken et al., 2014). Reducing environmental burdens is achieved when business model design adopts a lifecycle perspective and circular-economy principles to reduce waste, emissions, and energy leakage while increasing operational resource efficiency (Geissdoerfer et al., 2018; Joyce and Paquin, 2016). Reducing natural resource use relies on efforts to minimize resource inputs by strengthening resource cycles (e.g., closing or slowing down cycles) and converting waste streams into valuable inputs (Geissdoerfer et al., 2018).

At the initial stage of uncaptured value (UV) identification (Table 5), a literature review was conducted across various business models and classified according to opportunities for achieving CV in circular business models. The uncaptured value presented in Table 5 was adapted and synthesized from previous studies on uncaptured value, as listed in the "Source(s)" column. Cost efficiency (CV1) is linked to UV1–UV11, which, if unmanaged, can increase operational costs due to dismantling inefficiencies, overproduction, and high technology and infrastructure investments. Revenue generation (CV2) relates to UV12–UV23, wherein issues such as poor end-of-life recovery quality, ineffective customer incentives, and weak product take-back systems can reduce customer trust, repurchase rates, and potential revenue.

Individual development and well-being (CV3), associated with UV24–UV27, highlight risks related to insufficient human resource development, limited training investment, and inadequate technological capabilities, which can hinder operational performance and business sustainability. Stakeholder engagement (CV4), linked to UV28–UV32, emphasizes the impact of weak stakeholder involvement, particularly due to regulatory uncertainty in the implementation of the circular economy. Environmental performance (CV5) and material efficiency and circularity (CV6), represented by UV33–UV35, reflect environmental and resource inefficiencies arising from ineffective logistics, lack of design for disassembly, low recovery yields, and increased waste, ultimately undermining circularity and sustainable value capture.

4.2 The Heavy Equipment Industry

Uncaptured value was identified through a literature review of three studies in the manufacturing and textile industries that applied circular principles. Interviews with nine experts from heavy equipment and machinery manufacturing firms, along with researchers and academics, resulted in the identification of 35 uncaptured value in the heavy equipment industry. The uncaptured values identified in the previous stage will be assessed for their relevance to a manufacturing circular business model. Table 2 describes the expert profiles, and Table 3 presents the uncaptured relevance assessment criteria. A reliability test was conducted by calculating

Cronbach's alpha based on the relevance ratings of 35 uncaptured value items provided by nine experts using Equation (1). The resulting alpha coefficient was 0.97 (exceeding the commonly accepted threshold of 0.60), indicating that the collected data demonstrate excellent reliability.

The uncaptured values are explained in Table 5. The experts were asked to conduct assessments based on the distributed questionnaires and the designed assessment instruments. The collected data were then processed and converted into a triangular scale, a fuzzy number to determine the threshold value, and the percentage consensus for each uncaptured value. The threshold value (d) is calculated using Eqs. (2), (3), and (4). The consensus percentage is calculated based on the threshold percentage assessment results of experts who are at the threshold used, compared to the total number of experts involved, and the relevance level assessment results for 35 uncaptured values. The results indicate strong expert agreement, as the threshold values are ≤ 0.2 and the consensus level exceeds 75%. Table 6 presents the threshold and consensus results for uncaptured value.

Table 4 Target captured value in sustainable business models (SBMs)

Dimensions	Captured Value Goals	Description	Source
Economy	Cost Efficiency (CV 1)	Costs to be incurred include materials, process and operating costs, and ownership costs.	(Borchardt et al., 2024; Sjödin et al., 2020; Bocken et al., 2014)
	Revenue (CV 2)	Profit from the selling price, results from new products/services.	(Borchardt et al., 2024; Sjödin et al., 2020; Geissdoerfer et al., 2018)
Social	Individual Development and Well-being (CV 3)	Customer awareness, employee and customer happiness, employee well-being, and loyal customers.	(Sjödin et al., 2020; Geissdoerfer et al., 2018; Murray et al., 2017; Bocken et al., 2014)
	Stakeholder Engagement (CV 4)	Relationships between companies and partners, customers, and the government.	(Sjödin et al., 2020; Joyce and Paquin, 2016; Bocken et al., 2014)
Environment	Environmental performance [CV 5]	Energy efficiency, waste reduction, and emissions reduction	(Geissdoerfer et al., 2018; Joyce and Paquin, 2016; Bocken et al., 2014)
	Efficiency and Circularity (CV 6)	Reuse of raw materials (material recovery)	(Geissdoerfer et al., 2018; Joyce and Paquin, 2016; Bocken et al., 2014)

Thirty five Uncaptured values based on uncaptured literature review value in 3 previous studies that are most relevant to this study. Furthermore, 35 uncaptured values will be assessed for their relevance to the circular manufacturing model, specifically the heavy equipment and heavy machinery industry, based on initial identification. The fuzzy evaluation and average fuzzy values were calculated using Equation (5), and the resulting fuzzy scores are presented in Table 7.

Table 5 Uncaptured value identification (based on CV opportunities)

Code	Uncaptured Value	Source	Targeted CVs
UV 1	The coordination and control of EoL delivery/transport are weak, resulting in an inadequate lead time.	(Yang et al., 2017a)	Cost Efficiency [CV1]
UV 2	The standardization method works, but the capabilities of dismantling (disassembly) EoL are low, so the process is inefficient and expensive.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	
UV 3	The planning and management of logistics/transportation collection EoL are not optimal, leading to increased costs and uncertainty.	(Gennari and Bocchi, 2023)	
UV 4	The efficiency of technology recovery is low, resulting in high unit costs and product prices, making it more challenging to become competitive.	(Gennari and Bocchi, 2023)	
UV 5	Dependence on materials: Without adequate mitigation strategies (contracts/alternatives), raw materials/components are valuable and volatile.	(Gennari and Bocchi, 2023)	
UV 6	Inaccurate planning and control of spare parts/component procurement leads to overbuying and early buying.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	
UV 7	Planning capacity production based on demand and availability data EoL resulting in overproduction or output mismatch.	(Gennari and Bocchi, 2023)	
UV 8	Management schedules production and projects poorly, resulting in low usage and late output.	(Yang et al., 2017a)	
UV 9	Investment capital for technology/infrastructure recovery is not adequate, so facilities and capabilities are delayed.	(Borchardt et al., 2024; Gennari and Bocchi, 2023)	
UV 10	The quality of service and the logistics supply chain are low; thus, the circular material flow is disturbed.	(Gennari and Bocchi, 2023)	
UV 11	Weak reverse logistics capabilities (SOP, collection network, and IT tracking), so take-back is not possible or stable.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	
UV 12	System control quality remanufacturing/repair/refurbish/reconditioning is still weak, so the product is disabled or the quality is low.	(Borchardt et al., 2024; Burhan et al., 2021)	Revenue [CV2]
UV 13	The capability analysis indicates that the trend request is low, so the supply–demand strategy lacks precision.	(Gennari and Bocchi, 2023)	
UV 14	Limitations in R&D facilities/partners and in ecosystem innovation slow and make remanufacturing development expensive.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	
UV 15	Communication strategy, product value proposition, results, recovery: not effective, so the WTP is low.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	

Table 5 Uncaptured value identification (based on CV opportunities) (cont.)

Code	Uncaptured Value	Source	Targeted CVs
UV 16	Incentive design customers (buyback, discount, warranty, and service) lack an appropriate target, so adoption is low.	(Gennari and Bocchi, 2023)	
UV 17	Failure to identify segment/customer potential and latent needs so that the market is not formed/fragile.	(Yang et al., 2017a)	
UV 18	Circular design and processes are not optimal; thus, the product's performance is low.	(Gennari and Bocchi, 2023)	
UV 19	No mechanism exists for managing market risk despite external shocks that trigger demand volatility.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	
UV 20	The system acquisition product EoL is weak; thus, the number of components is not worth recovering. There is insufficient information available.	(Gennari and Bocchi, 2023)	
UV 21	Structural costs and internal price-making policies increase the price of the remanufactured product over that of new competitor components.	(Borchardt et al., 2024; Gennari and Bocchi, 2023)	
UV 22	The capability determination price is low; therefore, the reman pricing strategy is not optimal, and an income opportunity is lost.	(Gennari and Bocchi, 2023)	
UV 23	Understanding consumer preferences is low; thus, reman marketing/sales are ineffective. (Borchardt et al., 2024; Gennari and Bocchi, 2023)		
UV 24	The low-literate public is unaware of the recovery of product results, so they still prefer new products.	(Gennari and Bocchi, 2023)	Personal Development (CV3)
UV 25	Limit investment in training and development competence related to circular reman, so the capability does not increase.	(Borchardt et al., 2024; Yang et al., 2017a)	
UV 26	The availability of superior human resources in the field is limited, and circular/remanufacturing operations are similarly limited.	(Borchardt et al., 2024; Gennari and Bocchi, 2023)	
UV 27	Lack of knowledge/expertise and mastery of recovery process technology at the operator–engineer level.	(Gennari and Bocchi, 2023; Yang et al., 2017a)	
UV 28	Dependence on performance partners for take-back and supply components without SLA and strong monitoring is high.	(Gennari and Bocchi, 2023)	Stakeholder Engagement (CV4)
UV 29	A lack of understanding of the interests of stakeholders in regulations and the circular economy leads to a high risk of non-compliance.	(Gennari and Bocchi, 2023)	
UV 30	Ambiguity/uncertainty regulations product results recovery lower consumers' and industry users' trust.	(Gennari and Bocchi, 2023)	

Table 5 Uncaptured value identification (based on CV opportunities) (cont.)

Code	Uncaptured Value	Source	Targeted CVs
UV 31	Stakeholder collaboration is marked by a weak interest chain (data sharing, joint planning, contracts).	(Borchardt et al., 2024; Gennari and Bocchi, 2023)	
UV 32	Absence/delay regulations that encourage the use of product recovery by customers to prevent demand from forming.	(Gennari and Bocchi, 2023)	
UV 33	Election modes and patterns of transport are inefficient in terms of energy costs; thus, operational costs increase, and sustainability is a target to achieve.	(Gennari and Bocchi, 2023)	Environmental performance (CV5)
UV 34	The product begins with no disassembly or design, so demolition is complex, and yield recovery is low.	–	Material Efficiency and Circularity (CV6)
UV 35	Variability/characteristics of the product EoL tall, such that the component is not worth restoration.	(Gennari and Bocchi, 2023)	

Note. Uncaptured value identification was developed by the authors and adapted from multiple prior studies (see "Source(s)" column).

4.3 Discussion

Cost Efficiency [CV 1], Revenue [CV 2], Individual Development and Well-being [CV 3], Stakeholder Engagement [CV 4], Environmental Performance [CV 5], and Material Efficiency and Circularity [CV 6] are the values captured in a sustainable business model that aims to achieve economic, social, and environmental sustainability development goals. Achieving business sustainability in manufacturing requires addressing multiple value dimensions; however, uncaptured values that hinder value capture constrict circular manufacturing.

Based on a review of three prior studies, this study identified 35 uncaptured values, predominantly related to cost efficiency and revenue, with fewer values associated with individual development and well-being, stakeholder engagement, environmental performance, and material efficiency and circularity. Most of the uncaptured value (>65%) is related to the economic dimension of the SDGs, namely, cost efficiency and revenue. 25% relates to the social dimension, and the remaining less than 10% relates to the environmental dimension.

Not all uncaptured values are equally relevant to circular manufacturing in the heavy equipment and machinery industry; therefore, prioritization is essential for effective management strategies. This study uses the fuzzy Delphi method to identify the most relevant uncaptured values and their mitigation priorities. Experts with more than 10 years of experience in the heavy equipment and heavy machinery industry, consisting of practitioners, academics, and researchers, agreed upon the value. Using a consensus standard of ≥75% and a threshold value of ≤0.2, 9 Uncaptured values were obtained. The most frequently stated value aligns with the experts' agreement and is not captured. Based on data processing of 35 uncaptured values using the fuzzy Delphi method, as shown in Table 6, 9 uncaptured values were identified as relevant to the circular manufacturing business model, particularly in the heavy equipment and machinery industry.

Only nine of the 35 uncaptured values were retained as relevant to circular manufacturing business models. The accepted items primarily reflect core daily operations, particularly spare-part availability and end-of-life component supply for recovery. This pattern aligns with the expert panel profile, which was dominated by heavy-equipment practitioners who frequently encounter these issues and treat them as key operational performance indicators. Therefore, the retained uncaptured values represent critical bottlenecks shaping circular inflows, processing stability, and outflows. In contrast, the rejected items mainly concerned market factors (pricing and demand), tactical internal processes, and supporting investments or infrastructure, which are more context-dependent and perceived as operational priorities by experts are less consistent. Overall, the findings suggest that in mature circular manufacturing settings, uncaptured value is most strongly driven by operational constraints in reverse supply and remanufacturing execution rather than by downstream market mechanisms.

Table 6 Consensus status of uncaptured values relevance levels in CBMs

Uncaptured Value	Threshold (d)	% Consensus	Status
UV 1	0.20	89%	Accepted
UV 2	0.16	45%	Rejected
UV 3	0.17	89%	Accepted
UV 4	0.19	34%	Rejected
UV 5	0.15	56%	Rejected
UV 6	0.19	78%	Accepted
UV 7	0.32	45%	Rejected
UV 8	0.27	12%	Rejected
UV 9	0.21	23%	Rejected
UV 10	0.17	45%	Rejected
UV 11	0.16	45%	Rejected
UV 12	0.08	100%	Accepted
UV 13	0.19	34%	Rejected
UV 14	0.17	45%	Rejected
UV 15	0.32	12%	Rejected
UV 16	0.18	89%	Accepted
UV 17	0.19	56%	Rejected
UV 18	0.31	12%	Rejected
UV 19	0.20	45%	Rejected
UV 20	0.16	89%	Accepted
UV 21	0.23	56%	Rejected
UV 22	0.23	67%	Rejected
UV 23	0.16	67%	Rejected
UV 24	0.17	45%	Rejected
UV 25	0.28	23%	Rejected
UV 26	0.16	45%	Rejected
UV 27	0.19	78%	Accepted
UV 28	0.13	56%	Rejected
UV 29	0.18	89%	Accepted
UV 30	0.23	67%	Rejected
UV 31	0.23	67%	Rejected
UV 32	0.19	34%	Rejected
UV 33	0.24	12%	Rejected
UV 34	0.27	56%	Rejected
UV 35	0.15	89%	Accepted

Note: The green colour is used only to clarify that the uncaptured value has been accepted (i.e., has reached consensus) and will therefore be evaluated using the fuzzy evaluation scores.

The higher the score, the more relevant the uncaptured value is and should be addressed. The fuzzy assessment evaluation score for controlling the poor quality of the remanufacturing process so that the product remanufacturing is of high quality [UV 12] is 7.47, with an average fuzzy of 0.83, which is a significant issue that needs to be addressed to ensure a sustainable circular manufacturing business model. Poor quality control reduces customer acceptance of remanufactured products and shifts demand toward new alternatives. Since remanufacturing promises near-new quality at a lower price, uncaptured quality assurance value becomes a critical risk. Moreover, quality control in new OEM components and genuine parts determines the condition, traceability, and recoverability of end-of-life products, as tighter tolerances, standardized materials, and robust documentation improve inspection, disassembly, and reprocessing reliability. Consequently, remanufactured components are more likely to achieve the intended goal of remanufacturing, delivering performance comparable to new products at a lower cost (Zacharaki et al., 2021). Therefore, strong collaboration between OEM manufacturers and remanufacturing firms is essential, for example, through shared quality standards, traceability systems, and recovery and acceptance criteria.

Second, the next issue to be prioritized is the limited availability of EoL products suitable for remanufacturing (the number of EoL products that can be processed is minimal) [UV 20], with a value of 6.93 and an average Fuzzy of 0.77. The lack of regulations and product ownership rules means that customers cannot simply recall end-of-life products. Regulations governing these provisions are required. This value can hinder a company's ability to capture revenue. Consequently, the company fails to maximize profits and can threaten business sustainability. A weak EoL acquisition system limits the availability of recoverable components suitable for remanufacturing, repair, refurbishment, and reconditioning (Östlin et al., 2009). Inadequate EoL recovery weakens the performance of the circular supply chain and limits value capture. Strengthening EoL ownership through buy-back contracts and regulatory schemes (e.g., EPR) can increase return rates, stabilize material flows, and improve the availability of remanufacturing feedstock. Mandatory take-back and ownership transfer also enhance acquisition predictability, ensuring a more reliable supply of quality EoL inputs.

Third, the characteristics of end-of-life products that do not allow for return or restoration [UV 35], with a value of 6.77 and an average of fuzzy 0.75, are not considered. This UV value can cause manufacturing companies to fail to capture the value of material efficiency and circularity, thereby impacting environmental sustainability. Design for remanufacturing and product modularity can reduce EoL product complexity and variability by enabling easier disassembly, protecting critical components, and standardizing materials to better tolerate diverse EoL conditions (Kim et al., 2021). Ranked fourth, management delivery component or end-of-life products that are not effective, which often results in delays between companies and customers (product users) scored 6.73 and frequently causes delays between companies and customers. This issue is mainly driven by uncertain lead-time planning for remanufacturing, unpredictable reverse logistics arrival, and lengthy inspection and return-shipping processes (Bao et al., 2022). Designing an EoL collection network aligned with customer profiles may help mitigate these delays (Chen et al., 2021).

In the social dimension, the fifth-ranked uncaptured value is the lack of knowledge, expertise, and technological capability related to remanufacturing and CEPs (UV 27), with a fuzzy evaluation score of 6.73 and an average fuzzy value of 0.75. This condition may hinder the realization of the CPV of individual development and well-being. As a relatively new and complex concept, the circular economy often leaves employees without sufficient understanding of relevant business models, technical processes, and performance indicators (Rexhepi-Mahmutaj et al., 2025). Triple-helix collaboration among industry, universities, and government through curricula and short courses in remanufacturing and circular economy, applied research projects, and internships can strengthen workforce capabilities for circular manufacturing (Melati et al., 2021). Two uncaptured values were jointly ranked sixth, each scoring 5.67: suboptimal logistics and transportation planning for collecting EoL products, which increases costs (UV 3), and inadequate procurement planning and control of critical spare parts, leading to premature or excessive purchases (UV 6). UV 3 is mainly driven by an inefficient reverse logistics network, where collection points, sorting facilities, and transport routes are not aligned with customer distribution and EoL volumes (Angouria-Tsorochidou et al., 2018). A systematic redesign of the reverse logistics network using cost-environment optimization models may mitigate these issues (Dat et al., 2012). Management may prefer overstocking to avoid the high cost of heavy-equipment downtime. Therefore, a stronger coordination among maintenance, operations, and procurement must minimize this trade-off and prevent UV 6.

Table 7 Prioritization of uncaptured value using fuzzy evaluation scores

Uncaptured Value	Fuzzy Evaluation	Average Fuzzy	Ranking
UV 1: Ineffective management delivery component or end-of-life products that often result in delays between companies and customers (product users).	6.73	0.75	4
UV 3: Planning and management of logistics/transportation for collecting suboptimal end-of-life products, resulting in additional costs.	5.67	0.63	6
UV 6: Planning and controlling the procurement of harmful components/spare parts so that excessive or excessively early purchases do not occur.	5.67	0.63	6
UV 12: Poor quality of the remanufacturing process is controlled so that the product manufacturing is of high quality.	7.47	0.83	1
UV 16: Companies' inadequacy in designing effective incentives and strategies for motivating customers to buy products through remanufacturing.	5.47	0.61	8
UV 20: Limitations: the availability of viable remanufactured end-of-life products (the quantity of EoL products that can be processed is very low).	6.93	0.77	2
UV 27: Knowledge, expertise, and mastery of relevant technology with remanufacturing and circular economic processes are lacking.	6.73	0.75	5
UV 29: Lack of understanding of the interests of stakeholders in laws and regulations related to the circular economy (especially remanufacturing).	5.47	0.61	8
UV 35: End-of-life product characteristics that do not allow for return or restoration.	6.77	0.75	3

Finally, two uncaptured values were jointly ranked eighth, each scoring 5.47: inadequate incentives and strategies to encourage customers to purchase remanufactured products (UV 16) and limited understanding of stakeholder interests in circular economy regulations, particularly remanufacturing (UV 29). Both relate to key stakeholders, namely, customers and regulatory actors. Strengthening awareness and understanding of the benefits of the circular economy may help address these gaps. Several uncaptured values are interrelated. For instance, weak delivery coordination (UV 1), suboptimal logistics management (UV 3), and excessive spare-part procurement (UV 6) reflect supply chain and purchasing issues that increase operational costs. Similarly, ineffective customer incentives (UV 16) may worsen EoL acquisition constraints (UV

20), whereas limited employee skills (UV 27) can weaken quality control (UV 12) and increase EoL product variability (UV 35). These linkages indicate that mitigation should target the root causes of the prioritized uncaptured values.

This study contributes to theory by advancing a novel approach for identifying and prioritizing uncaptured value within CBMs, particularly in the heavy equipment manufacturing sector and other industries adopting similar circular principles and business model configurations. Prior studies have primarily focused on developing frameworks and identifying uncaptured value without explicitly determining which uncaptured value dimensions are most relevant for this type of circular business model. From a practical perspective, especially for heavy equipment and machinery industries, the findings provide a useful reference for creating value-capturing strategies by addressing and improving prioritized uncaptured value areas. This study also proposes an implementation framework that translates the prioritized uncaptured values into actionable managerial interventions to enhance practical applicability. The framework guides practitioners through (i) diagnosing the dominant uncaptured value categories, (ii) linking them to operational root causes across the remanufacturing process, (iii) selecting targeted improvement initiatives, and (iv) monitoring value capture through measurable performance indicators.

5. Conclusions

This study confirms that circular manufacturing business models target six captured values, which represent the economic, social, and environmental dimensions of the SDGs. Through a literature review, 35 uncaptured values were identified, predominantly within the economic dimension (more than 65 percent), followed by the social dimension (more than 25 percent), while environmental aspects accounted for less than 10 percent. A Fuzzy Delphi survey with nine industry experts identified nine prioritized uncaptured values meeting the consensus ($\geq$75%) and threshold ($\leq$0.2) criteria, with the highest ranking being weak quality control, limited viable end-of-life products, and unfavorable recovery characteristics. The findings highlight quality management, end-of-life input supply certainty, including regulatory support, and enhanced knowledge and technological capabilities as key mitigation areas to strengthen value creation and capture, particularly in revenue, material circularity, and individual development, thereby improving the long-term resilience of circular manufacturing business models. This study provides a prioritized list of uncaptured values based on expert consensus and offers a practical foundation for developing targeted mitigation strategies in the heavy equipment and machinery industry. Nevertheless, limitations remain, including the reliance on a limited literature base and the absence of direct industrial observation. Future research may incorporate broader empirical evidence and quantitative approaches to further develop mitigation strategies. This study identifies uncaptured values as key opportunities for value capture in circular manufacturing business models. It also contributes an expert consensus prioritization framework to determine the most relevant uncaptured values in circular manufacturing. Beyond its practical relevance for mitigation strategy design, this study theoretically contributes by conceptualizing uncaptured values as a structured, prioritizable construct in circular manufacturing business models and by introducing a fuzzy Delphi–based expert-consensus framework that enables quantitative assessment of these values and provides a reference point for future research.

Acknowledgements

The authors gratefully acknowledge financial support from the Indonesian Education Scholarship (BPI, Grant ID: 202209090729), the Center for Higher Education Funding and Assessment (PPAPT) of the Ministry of Higher Education, Science, and Technology, Indonesia, and the Indonesian Endowment Fund for Education (LPDP) 2022.

Author Contributions

The author and corresponding author have contributed to the writing of this article. YSH: writing– original draft, conceptualization, and methodology; UCM: writing– review and editing, conceptualization and framework in research, and methodology; RSD: writing– grammar review and editing, providing structure and ideas for writing articles.

Conflict of Interest

The authors have no conflicts of interest to declare. The funding body played no role in the study design, data collection, analysis, results interpretation, or decision to publish.

References

Angouria-Tsorochidou, E., Cimpan, C., & Parajuly, K. (2018). Optimized collection of EoL electronic products for circular economy: A techno-economic assessment. *Procedia CIRP, 25th CIRP Life Cycle Engineering (LCE) Conference*, *69*, 986–991. https://doi.org/10.1016/j.procir.2017.11.020

Asif, F. M. A., Roci, M., Lieder, M., Rashid, A., Mihelič, A., & Kotnik, S. (2021). A methodological approach to design products for multiple lifecycles in the context of circular manufacturing systems. *Journal of Cleaner Production*, *296*, 126534. https://doi.org/10.1016/j.jclepro.2021.126534

Bao, X., Wei, W., & Liu, Y. (2022). Remanufacturing lead time planning of the medical device with multi-refurbishing steps. *Journal of Cleaner Production*, *379*, 134697. https://doi.org/10.1016/j.jclepro.2022.134697

Behl, A., Singh, R., Pereira, V., & Laker, B. (2023). Analysis of Industry 4.0 and circular economy enablers: A step towards resilient sustainable operations management. *Technological Forecasting and Social Change*, *189*, 122363. https://doi.org/10.1016/j.techfore.2023.122363

Berawi, M. A. (2020). Managing Nature 5.0: The role of digital technologies in the circular economy. *International Journal of Technology*, *11*, 291–319. https://doi.org/10.14716/ijtech.v11i4.4385

Bertassini, A. C., Zanon, L. G., Azarias, J. G., Gerolamo, M. C., & Ometto, A. R. (2021). Circular business ecosystem innovation: A guide for mapping stakeholders, capturing values, and finding new opportunities. *Sustainable Production and Consumption*, *27*, 436–448. https://doi.org/10.1016/j.spc.2020.12.004

Bland, J. M., & Altman, D. G. (1997). Statistics notes: Cronbach's alpha: Table 1. *BMJ*, *314*, 572. https://doi.org/10.1136/bmj.314.7080.572

Bocken, N., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, *65*, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Borchardt, M., da Silva, M. G., de Carvalho, M. N. M., Burdzinski, C. S., Kirst, R. W., Pereira, G. M., & da Silva, M. A. (2024). Uncaptured value in the business model: Analysing its modes in social enterprises in the sustainable fashion industry. *Journal of Creating Value*, *10*, 79–101. https://doi.org/10.1177/23949643231220777

Bui, T.-D., Rosiana, R., Tsai, F.-M., Chiu, A. S. F., & Tseng, M.-L. (2025). Circular economy challenges under uncertainty in the Indonesian fashion industry: A causal hierarchical model. *International Journal of Production Economics*, *288*, 109719. https://doi.org/10.1016/j.ijpe.2025.109719

Burhan, Ciptomulyono, U., Singgih, M. L., & Baihaqi, I. (2020). Potential for changing value uncaptured to value captured through circular economy practices. *IOP Conference Series: Earth and Environmental Science*, *472*, 012049. https://doi.org/10.1088/1755-1315/472/1/012049

Burhan, Ciptomulyono, U., Singgih, M. L., & Baihaqi, I. (2021). Sustainable business model innovations in the value uncaptured manufacturing industry: Fitting gains—gain creators. *Sustainability*, *13*, 5647. https://doi.org/10.3390/su13105647

Charlton, E. (2024). Our resources are running out and these charts show how urgently action is needed [World Economic Forum]. https://www.weforum.org/stories/2024/03/sustainable-resource-consumption-urgent-un/

Chen, X., Goh, M., Li, B., & Cheng, Y. (2021). Collection strategies and pricing decisions for dual channel EOL products. *Computers & Industrial Engineering*, *159*, 107477. https://doi.org/10.1016/j.cie.2021.107477

Dat, L. Q., Truc Linh, D. T., Chou, S.-Y., & Yu, V. F. (2012). Optimizing reverse logistic costs for recycling end-of-life electrical and electronic products. *Expert Systems with Applications*, *39*, 6380–6387. https://doi.org/10.1016/j.eswa.2011.12.031

Difrancesco, R. M., & Huchzermeier, A. (2016). Closed-loop supply chains: A guide to theory and practice. *International Journal of Logistics Research and Applications*, *19*, 443–464. https://doi.org/10.1080/13675567.2015.1116503

EMF, E. M. F. (2021). The circular economy as a de-risking strategy and driver of superior risk-adjusted returns. https://www.ellenmacarthurfoundation.org/the-circular-economy-as-a-de-risking-strategy-and-driver-of-superior-risk

Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E. A., & Barlow, C. Y. (2017). Business model innovation for sustainability: Towards a unified perspective for creation of sustainable business models. *Business Strategy and the Environment*, *26*, 597–608. https://doi.org/10.1002/bse.1939

Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2017). Constructing the indicators of assessing human vulnerability to industrial chemical accidents: A consensus-based fuzzy Delphi and fuzzy AHP approach. *PLoS Curr*, *9*, ecurrents.dis.526884afe308f8876dce69c545357ecd. https://doi.org/10.1371/currents.dis.526884afe308f8876dce69c545357ecd

Fernando, Y., Tseng, M.-L., Aziz, N., Ikhsan, R. B., & Wahyuni-TD, I. S. (2022). Waste-to-energy supply chain management on circular economy capability: An empirical study. *Sustainable Production and Consumption*, *31*, 26–38. https://doi.org/10.1016/j.spc.2022.01.032

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. https://doi.org/10.17863/CAM.27629

Gennari, F., & Bocchi, E. (2023). The dark side of the circular economy: The value uncaptured in bioeconomy business models. *Problems and Perspectives in Management*, *21*, 516–531. https://doi.org/10.21511/ppm.21(4).2023.39

Hamwi, M., Lizarralde, I., & Allais, R. (2025). The circular value navigator: A tool for identifying and transforming linear practices in the circular economy. *Sustainability*, *17*. https://doi.org/10.3390/su172210209

Hasim, M. A., Jabar, J., Sufian, A., Ibrahim, N. F., & Khalid, F. A. (2023). Employing fuzzy Delphi techniques to validate the components and contents of E-learning antecedents and usage behavior towards E-learning performance. *European Journal of Educational Research*, *12*, 467–480. https://doi.org/10.12973/eu-jer.12.1.467

Huang, Y.-F., Azevedo, S. G., Lin, T.-J., Cheng, C.-S., & Lin, C.-T. (2021). Exploring the decisive barriers to achieve circular economy: Strategies for the textile innovation in Taiwan. *Sustainable Production and Consumption*, *27*, 1406–1423. https://doi.org/10.1016/j.spc.2021.03.007

ISO. (2024). ISO 59004:2024. https://www.iso.org/standard/80648.html

Jailani, M. A., & Loy, C. K. (2023). The application of fuzzy Delphi method in content validity analysis. *IADIS International Conference Cognition and Exploratory Learning in Digital Age 2023*, 84–90.

Joyce, A., & Paquin, R. L. (2016). The triple layered business model canvas: A tool to design more sustainable business models. *Journal of Cleaner Production*, *135*, 1474–1486. https://doi.org/10.1016/j.jclepro.2016.06.067

Kim, J., Park, S., & Kim, H. M. (2021). Optimal modular remanufactured product configuration and harvesting planning for end-of-life products. *Journal of Mechanical Design*, *144*. https://doi.org/10.1115/1.4052389

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kvadsheim, N. P., Nujen, B. B., Powell, D., & Reke, E. (2021). Realizing value opportunities for a circular economy: Integrating extended value stream mapping and value uncaptured framework. In *Advances in production management systems. artificial intelligence for sustainable and resilient production systems* (pp. 739–747). Springer International Publishing. https://doi.org/10.1007/978-3-030-85874-2_81

Manyara, A. M., Purvis, A., Ciani, O., Collins, G. S., & Taylor, R. S. (2024). Sample size in multistakeholder Delphi surveys: At what minimum sample size do replicability of results stabilize? *Journal of Clinical Epidemiology*, *174*, 111485. https://doi.org/10.1016/j.jclinepi.2024.111485

Mayanti, B., & Helo, P. (2024). Circular economy through waste reverse logistics under extended producer responsibility in Finland. *Waste Management & Research*, *42*, 59–73. https://doi.org/10.1177/0734242X231168801

Melati, K., Nikam, J., & Nguyen, P. (2021). Barriers and drivers for enterprises to transition to circular economy. https://doi.org/10.51414/sei2021.029

Moloney, P. (2021). Capturing value in the circular economy [Ramboll Group]. https://ramboll.com/ingenuity/capturing-value-in-the-circular-economy

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics*, *140*, 369–380. https://doi.org/10.1007/s10551-015-2693-2

Natsir, U., Dipoatmodjo, T., Arjang, A., Hidayat, M., & Mustafa, M. (2021). Eight days a week: Eustress and distress among the athletes. *International Journal of Human Movement and Sports Sciences*, *9*(5), 912–920. https://doi.org/10.13189/saj.2021.090512

Osmanovic, S., Barth, H., & Ulvenblad, P. (2024). Uncaptured value in sustainable business model innovation: The missing link. *Technological Sustainability*, *3*, 262–285. https://doi.org/10.1108/TECHS-02-2024-0010

Östlin, J., Sundin, E., & Björkman, M. (2009). Product life-cycle implications for remanufacturing strategies. *Journal of Cleaner Production*, *17*, 999–1009. https://doi.org/10.1016/j.jclepro.2009.02.021

Padilla-Rivera, A., do Carmo, B. B. T., Arcese, G., & Merveille, N. (2021). Social circular economy indicators: Selection through fuzzy Delphi method. *Sustainable Production and Consumption*, *26*, 101–110. https://doi.org/10.1016/j.spc.2020.09.015

Rexhepi-Mahmutaj, L., Jusufi, N., Krasniqi, B., Mazrekaj, L., & Krasniqi, T. (2025). Barriers to transitioning to circular economy within firms in Western Balkans countries. *Frontiers in Sustainability*, *6*. https://doi.org/10.3389/frsus.2025.1546110

Rutgers, V., & John, C. (2021). Sustainable manufacturing: From vision to action.

Sakao, T., Bocken, N., Nasr, N., & Umeda, Y. (2024). Implementing circular economy activities in manufacturing for environmental sustainability. *CIRP Annals*, *73*, 457–481. https://doi.org/10.1016/j.cirp.2024.06.002

Sjödin, D., Parida, V., Jovanovic, M., & Visnjic, I. (2020). Value creation and value capture alignment in business model innovation: A process view on outcome-based business models. *Journal of Product Innovation Management*, *37*, 158–183. https://doi.org/10.1111/jpim.12516

Suzanne, E., Absi, N., & Borodin, V. (2020). Towards circular economy in production planning: Challenges and opportunities. *European Journal of Operational Research*, *287*, 168–190. https://doi.org/10.1016/j.ejor.2020.04.043

Tighnavard Balasbaneh, A., Aldrovandi, S., & Sher, W. (2025). A systematic review of implementing multi-criteria decision-making (MCDM) approaches for the circular economy and cost assessment. *Sustainability*, *17*, 5007. https://doi.org/10.3390/su17115007

Tolio, T., Bernard, A., Colledani, M., Kara, S., Seliger, G., Duflou, J., Battaia, O., & Takata, S. (2017). Design, management and control of demanufacturing and remanufacturing systems. *CIRP Annals*, *66*, 585–609. https://doi.org/10.1016/j.cirp.2017.05.001

Tsai, H.-C., Lee, A.-S., Lee, H.-N., Chen, C.-N., & Liu, Y.-C. (2020). An application of the fuzzy Delphi method and fuzzy AHP on the discussion of training indicators for the regional competition, Taiwan National Skills Competition, in the trade of joinery. *Sustainability*, *12*, 4290. https://doi.org/10.3390/su12104290

Tuni, A., Ijomah, W. L., Gutteridge, F., Mirpourian, M., Pfeifer, S., & Copani, G. (2023). Risk assessment for circular business models: A fuzzy Delphi study application for composite materials. *Journal of Cleaner Production*, *389*, 135722. https://doi.org/10.1016/j.jclepro.2022.135722

UNEP. (2024). Global resources outlook 2024: Bend the trend – pathways to a liveable planet as resource use spikes [International Resource Panel]. https://doi.org/20.500.11822/44901

Wandji, C., Riel, A., Ben Rejeb, H., Kanso, M., & Pitis, F. (2025). Maximizing circular economy benefits for manufacturing companies: A simulation tool for defining and implementing a circular product strategy. *Sustainable Production and Consumption*, *53*, 78–98. https://doi.org/10.1016/j.spc.2024.12.002

Yang, M., Evans, S., Vladimirova, D., & Rana, P. (2017a). Value uncaptured perspective for sustainable business model innovation. *Journal of Cleaner Production*, *140*, 1794–1804. https://doi.org/10.1016/j.jclepro.2016.07.102

Yang, M., Vladimirova, D., & Evans, S. (2017b). Creating and capturing value through sustainability: The sustainable value analysis tool. *Research-Technology Management*, *60*, 30–39. https://doi.org/10.1080/08956308.2017.1301001

Yatoo, A. M., Hamid, B., Sheikh, T. A., Ali, S., Bhat, S. A., Ramola, S., Ali, M. N., Baba, Z. A., & Kumar, S. (2024). Global perspective of municipal solid waste and landfill leachate: generation, composition, eco-toxicity, and sustainable management strategies. *Environmental Science and Pollution Research*, *31*, 23363–23392. https://doi.org/10.1007/s11356-024-32669-4

Yusoff, H. M., Heng, P. P., Hj Illias, M. R., Karrupayah, S., Fadhli, M. A., & Hod, R. (2024). A qualitative exploration and a fuzzy Delphi validation of high-risk scaffolding tasks and fatigue-related safety behavioural deviation among scaffolders. *Heliyon*, *10*, e34599. https://doi.org/10.1016/j.heliyon.2024.e34599

Zacharaki, A., Vafeiadis, T., Kolokas, N., Vaxevani, A., Xu, Y., Peschl, M., Ioannidis, D., & Tzovaras, D. (2021). RECLAIM: Toward a new era of refurbishment and remanufacturing of industrial equipment. *Frontiers in Artificial Intelligence*, *3*, 570562. https://doi.org/10.3389/frai.2020.570562

Zhang, J.-H., & Chen, M. (2015). Assessing the impact of China's vehicle emission standards on diesel engine remanufacturing. *Journal of Cleaner Production*, *107*, 177–184. https://doi.org/10.1016/j.jclepro.2015.03.103