

## Sustainable Packaging as a Driver of Circular Economy Performance: An Integrated Material, Design, and System-Level Analysis

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### ABSTRACT

In this study, material selection, packaging design, and system-level enablers are evaluated in tandem to investigate sustainable packaging as a key driver of circular economy performance.<sup>1</sup> As environmental deterioration, resource depletion, and waste generation increase, packaging systems are a crucial point of intervention for shifting from linear “take–make–dispose” paradigms to regenerative circular frameworks.<sup>2</sup> By prioritizing recyclability, reusability, lifecycle transparency, and stakeholder involvement, sustainable packaging lessens environmental impacts, improves long-term resource efficiency, and makes it easier to close material loops.<sup>3</sup>

Using a structured pilot perception survey (n = 40)<sup>4</sup> with a five-point Likert scale, the research builds on synthesized insights from established empirical and conceptual literature to validate key sustainability dimensions related to material sustainability, circular-oriented design strategies, and institutional and technological coordination mechanisms.<sup>5</sup> Descriptive statistical analysis is used to evaluate perceived effectiveness and levels of agreement among constructs that represent materials, design, systems, and the overall impact of the circular economy.<sup>6</sup>

The results show that packaging with improved recovery potential, lifetime visibility, and reduced material complexity significantly enhances circular outcomes by reducing waste and strengthening resource retention.<sup>7</sup> Furthermore, the findings highlight the need for design-for-circularity principles supported by digital, policy, and supply-chain infrastructures in addition to sustainable material selections.<sup>8</sup> By combining empirical validation with a unified analytical approach, this study offers evidence-based insights for industry practitioners, packaging designers, and policymakers seeking scalable and systemically linked circular packaging solutions..

**Keywords:** Sustainable Packaging, Circular Economy, Packaging Design, Material Sustainability, System-Level Enablers.

### INTRODUCTION:

A major topic in sustainability discourse is the global shift away from linear production-consumption patterns and toward circular economic systems, which is being driven by the growing accumulation of solid waste, environmental contamination, and resource depletion.<sup>1</sup> Raw materials are harvested, turned into goods, consumed, and then disposed in traditional linear economies, which follow the “take–make–dispose” paradigm.<sup>2</sup> This paradigm has become more and more unsustainable as the demand for materials continues to rise and natural resources become more limited. Packaging systems are a major contributor to this problem among the numerous sectors because of their high material intensity, limited lifespan, and disproportionate contribution to industrial and municipal waste streams. Packaging has therefore become a crucial area of intervention for putting the concepts of the circular economy into practice.<sup>3</sup>

The circular economy emphasizes closed-loop systems where materials and products maintain value for as long as feasible, suggesting a radically new strategy.<sup>4</sup> By using regenerative, restorative, and efficiency-focused

techniques, circular models aim to design waste out of the system rather than viewing it as an unavoidable byproduct of economic activity. This framework is based on fundamental concepts including lifetime optimization, material efficiency, reuse, recycling, and system-wide coordination. Packaging is essential to this shift because it has a direct impact on end-of-life recovery pathways, customer contact, product protection, material selection, and logistics effectiveness. Thus, the sustainability performance of packaging systems directly and quantifiably affects how well the circular economy is implemented.<sup>5</sup>

Sustainable packaging in this sense goes beyond merely replacing materials or reducing waste.<sup>6</sup> Throughout its whole existence, it embodies an integrated design concept that balances environmental responsibility with functional excellence. Assuring compatibility with current recovery infrastructures, limiting material complexity, choosing recyclable or renewable materials, and designing for disassembly and reuse are all part of this process. It is crucial that sustainable packaging strikes a compromise between environmental goals and practical needs including supply chain effectiveness, product safety, durability, and price. Theoretically plausible solutions that are neither feasible nor financially viable in actual

applications could arise from failure to strike this equilibrium.<sup>7</sup>

End-of-life issues have historically been subordinated in favor of commercial appeal, branding distinction, and customer convenience in packaging design. While composite materials, multi-layer laminates, and single-use formats have improved barrier performance and aesthetics, they have also produced structural obstacles to material recovery and recycling. These design methodologies are becoming more widely acknowledged as systemic inefficiencies that call for intentional *design-for-circularity interventions*. A significant amount of a product's environmental impact is determined by decisions made during the early design stage, as empirical and conceptual research constantly shows. This emphasizes the importance of including circular principles from the very beginning of packaging creation.<sup>8</sup>

In addition to materials and design, packaging serves as a link between systems for production, distribution, consumption, and recovery.<sup>9</sup> Stakeholder behavior, policy frameworks, and digital infrastructure all have an impact on its efficacy in addition to its physical makeup. Digital traceability systems, data-sharing platforms, and smart labeling are examples of technological enablers that improve coordination and transparency throughout value chains. Legislative tools, such as extended producer responsibility programs, recycling requirements, and eco-design guidelines, also influence corporate incentives and innovation paths. The effectiveness of sorting, returning, and reusing processes also depends on consumer participation. Sustainable packaging needs to be assessed from a wider *socio-technical systems perspective* rather than in isolation, as these interrelated aspects demonstrate.<sup>10</sup>

Although there has been a significant growth in knowledge of sustainable packaging and the concepts of the circular economy, there is still inconsistent practical application.<sup>11</sup> Instead of implementing a complete redesign, many businesses choose to make little, gradual changes, which hinders their progress toward true circularity. Studies that integrate material, design, and system-level viewpoints with empirical validation are still scarce, despite the fact that academic literature offers insightful information on particular facets of materials, design techniques, or policy mechanisms. This disparity emphasizes the necessity for studies that, in addition to synthesizing academic knowledge, look at stakeholder perceptions and practical viability within a *comprehensive analytical framework*.<sup>12</sup>

In light of this, the current study examines *material sustainability, circular-oriented design methods, and system-level enablers* in order to uncover how sustainable packaging influences the performance of the circular economy in multiple dimensions.<sup>13</sup> Through the integration of conceptual synthesis and pilot empirical validation, the study seeks to offer a comprehensive knowledge of how packaging solutions might promote waste reduction, resource efficiency, and long-term environmental sustainability. The report adds to the

current conversation on sustainability by presenting packaging as a strategic tool that might hasten the shift to a circular economy across sectors and regulatory frameworks, rather than just as a functional need.<sup>14</sup>

### Research Objectives

- To assess the perceived contribution of sustainable packaging materials to improving the performance of the circular economy.
- To investigate how packaging design that is circular affects resource retention and waste reduction.
- To evaluate how system-level and technology enablers contribute to the successful adoption of circular packaging.
- To verify a complete analytical framework that connects the total results of the circular economy to materials, design, and systemic coordination.

**Paper Structure.** This paper's remaining sections are structured as follows: the methodology, which describes the research design and data gathering processes, is shown after a review of pertinent scholarly literature. Results and data analysis are presented in the following parts and examined in light of current theoretical viewpoints. Key conclusions, restrictions, and suggestions for further study are included in the paper's conclusion.

### LITERATURE REVIEW

Nowadays, packaging solutions are at the forefront of the conversation about the circular economy due to the increased focus on resource efficiency and environmental sustainability. Previously thought of as a marketing-focused and functional aspect of product delivery, packaging is now more widely acknowledged as a structural factor influencing waste production, material flows, and environmental performance over the course of a product's lifecycle.<sup>1</sup> The sustainability of packaging cannot be sufficiently evaluated by making cosmetic design changes or substituting individual materials.<sup>2</sup> Rather, it calls for a *multifaceted assessment integrating design architecture, material composition, and system-level coordination mechanisms*.<sup>3</sup> The conceptual basis for investigating sustainable packaging as a factor in the performance of the circular economy is this integrated viewpoint.

A large amount of research has focused on sustainable packaging materials, specifically on lifecycle consequences. Recyclability, energy intensity, emission profiles, and fiber or polymer recovery efficiency are important markers of package sustainability, according to empirical and lifecycle assessment-based research.<sup>4</sup> Research on paper-based and printed packaging systems shows that reduced chemical additives and simplified material composition significantly improve circular performance.<sup>5</sup> According to these results, *upstream material selection disproportionately influences downstream environmental impacts*, making material

sustainability a fundamental component of circular packaging frameworks.<sup>6</sup>

However, supremacy in terms of the environment is not assured by material renewability alone. Lifecycle trade-off analyses show that sustainability outcomes are frequently mediated by energy consumption, transportation impacts, and end-of-life processing efficiency.<sup>7</sup> Because of this, researchers recommend a holistic lifecycle assessment (LCA) approach, emphasizing that material sustainability is *context-dependent and system-dependent rather than inherently beneficial*.

In addition to material-focused studies, a strong body of research highlights the strategic importance of *design-for-circularity frameworks*, including mono-material configurations, modular construction, dimension standardization, and reuse-oriented formats.<sup>8</sup> Empirical evidence consistently indicates that environmental impacts are largely predetermined during the early design phase, reinforcing the superiority of proactive design interventions over reactive waste management strategies.

Recent scholarship further emphasizes that sustainable packaging operates within a *broader socio-technical system*, where digital traceability systems, governance mechanisms, and stakeholder coordination collectively determine circular outcomes.<sup>9</sup> Without supportive system-level infrastructure, even technically recyclable packaging may fail to deliver meaningful circular performance.

Although awareness of sustainable packaging has expanded significantly, comprehensive empirical studies integrating materials, design, and systemic enablers remain limited. This fragmentation reveals a research gap in multidimensional validation approaches capable of linking theoretical frameworks with stakeholder perceptions and practical feasibility.

By synthesizing established theoretical insights and empirically examining stakeholder perspectives, the present study evaluates the combined influence of material sustainability, circular-oriented design, and system-level enablers on circular economy performance.

## METHODOLOGY

### Research Design and Conceptual Framework

The perceived impact of sustainable packaging on the functioning of the circular economy is investigated in this study using a *descriptive-explanatory research approach*.<sup>1</sup> Stakeholder perceptions may be systematically identified and quantified thanks to the descriptive component, and the explanatory dimension makes it easier to understand how *material sustainability, circular-oriented design, and system-level enablers* collectively contribute to circular results. Because sustainable packaging operates within interconnected socio-technical systems rather than as a standalone

technological variable, such a combined approach is methodologically appropriate. The design is *validation-oriented rather than predictive*, emphasizing perceptual trends and conceptual alignment instead of causal hypothesis testing.<sup>1</sup>

This study's conceptual framework is based on a synthesis of established literature on circular economy implementation and sustainable packaging systems.<sup>2</sup> Four analytical constructs were defined: (i) *Sustainable Packaging Materials*, (ii) *Circular-Oriented Packaging Design*, (iii) *System and Technological Enablers*, and (iv) *Overall Circular Economy Impact*.<sup>2</sup> The framework assumes that material substitution alone is insufficient to achieve circular performance; rather, effective circularity emerges from the coordinated alignment of design simplicity, material compatibility, and enabling infrastructural support. This *integrated analytical perspective* ensures theoretical coherence between the literature review and the empirical measurement structure.<sup>3</sup>

### Instrument Development and Measurement Scale

Twenty perception-based items from a *structured questionnaire* were used to gather data. The instrument was developed through *literature-grounded item construction* to ensure conceptual relevance and content validity.<sup>4</sup> Each construct was represented by five items coded as A1–A5 (Materials), B1–B5 (Design), C1–C5 (System Enablers), and D1–D5 (Circular Economy Impact).<sup>4</sup> The questionnaire was designed to capture stakeholder perceptions regarding recyclability, reuse potential, lifecycle efficiency, digital traceability, policy support, and integrated sustainability outcomes.

Every item was scored on a *five-point Likert scale* ranging from 1 = “Strongly Disagree” to 5 = “Strongly Agree.”<sup>5</sup> The Likert format was selected because it allows gradation of opinion, facilitates numerical coding, and supports descriptive statistical interpretation of attitudinal constructs. The scale also enables aggregation across items to approximate interval-level analysis when constructs are theoretically coherent. Clear and non-technical item phrasing was used to reduce response bias and enhance comprehension across diverse respondent backgrounds.

### Sampling Design and Respondent Profile

The study employed *convenience sampling*, a non-probability sampling technique appropriate for exploratory and perception-based academic investigations where the primary objective is conceptual validation rather than population generalization.<sup>6</sup> Respondents were selected based on accessibility and fundamental familiarity with sustainability, packaging systems, environmental management, or circular economy principles. The sample primarily consisted of university students, academic researchers, and early-career professionals who possessed sufficient contextual awareness to evaluate sustainable packaging practices.

A total of 40 valid responses were obtained and retained for analysis. Participation was entirely voluntary and anonymous, and no personally identifiable information was collected. The resulting dataset comprised 800 individual item responses (40 × 20), providing adequate breadth for descriptive statistical interpretation and construct-level aggregation.<sup>7</sup>

### Data Preparation and Screening Procedures

To guarantee internal consistency and data completeness, the dataset was systematically screened before analysis began. To ensure data transparency, traceability, and replicability, responses were coded numerically and arranged in a structured spreadsheet format. Verification of missing values, outlier detection, and answer range cross-checking were all part of the screening process. Since no entries were found to be missing or invalid, all 40 responses were retained for further examination. This data preprocessing step ensured integrity and minimized computational bias.

### Analytical Techniques and Interpretation Criteria

The analytical strategy relied on descriptive statistical methods, particularly mean values and standard deviations, which are widely applied in perception-based sustainability research.<sup>9</sup> Mean scores were used to determine central tendency and overall agreement levels for each item and construct, while standard deviation values assessed response dispersion and participant consensus strength. Construct-wise scores were calculated by averaging the five corresponding items within each dimension, and an overall grand mean was subsequently derived to represent aggregated perception toward sustainable packaging and circular economy alignment.

Interpretation thresholds were defined as follows:

- 1.00 – 2.49: Low Agreement
- 2.50 – 3.49: Moderate Agreement
- 3.50 – 5.00: High Agreement

The analytical perspective emphasized validation and trend identification rather than inferential modeling. This approach aligns with the study's objective of assessing perceptual coherence with theoretical constructs rather than establishing predictive or causal relationships.<sup>10</sup>

### Reliability, Validity, and Ethical Considerations

Measurement validity was ensured through literature-based item development, consistent construct mapping, and theoretical alignment between questionnaire dimensions and conceptual foundations. Given the pilot nature of the dataset and the relatively homogeneous response distribution, the study prioritizes content and construct validity over advanced psychometric purification techniques.<sup>11</sup> Future research involving larger and more heterogeneous samples may incorporate confirmatory factor analysis or structural equation

modeling to enhance generalizability and internal reliability metrics.

Ethical standards were maintained throughout the research process. Participation was entirely voluntary, confidentiality was preserved, and collected data were used exclusively for academic purposes.<sup>12</sup> These safeguards ensured compliance with responsible research practices and reinforced the integrity of the empirical investigation.

## DATA ANALYSIS AND INTERPRETATION

### Dataset Description

The empirical component of this study is grounded in a structured perception survey designed to capture stakeholder attitudes toward sustainable packaging and its relationship with circular economy performance.<sup>1</sup> The final dataset comprises 40 valid respondents (n = 40) and 20 questionnaire items, resulting in 800 item-level observations (40 × 20).<sup>2</sup> The instrument was organized into four constructs—Sustainable Packaging Materials (A1–A5), Circular-Oriented Packaging Design (B1–B5), System & Technological Enablers (C1–C5), and Circular Economy Impact (D1–D5)—to reflect the integrated conceptual framework established in the literature review.<sup>3</sup> Responses were measured using a five-point Likert scale (1–5) ranging from Strongly Disagree to Strongly Agree, enabling quantification of subjective perceptions while preserving gradations of agreement.<sup>4</sup>

Prior to analysis, the dataset underwent systematic screening to ensure analytical integrity.<sup>5</sup> Checks were performed for missing values, out-of-range entries, and logical inconsistencies, and none were detected. Consequently, all responses were retained, strengthening internal completeness and eliminating the need for imputation or case deletion. Preliminary distributional inspection revealed that responses predominantly clustered within the 3–5 range, indicating a generally favourable orientation toward sustainability and circularity concepts. This concentration in the agreement spectrum supports the suitability of descriptive statistical techniques—particularly mean and standard deviation—for interpreting central tendency and consensus.<sup>6</sup>

### Quantitative Dataset Representation

For computational transparency, the dataset can be represented as a response matrix:

$$\mathbf{X}_{40 \times 20} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1,20} \\ x_{21} & x_{22} & \dots & x_{2,20} \\ \vdots & \vdots & \ddots & \vdots \\ x_{40,1} & x_{40,2} & \dots & x_{40,20} \end{bmatrix}$$

Here, 404040 represents the number of respondents and 202020 represents the number of observed variables

(items), where each element  $x_{ij}$  denotes the response of the  $i^{th}$  respondent to the  $j^{th}$  variable.

Where  $(x_{ij} \in \{1,2,3,4,5\})$  denotes the Likert response of respondent  $i$  to item  $j$ .<sup>7</sup> This matrix formulation enables column-wise aggregation for item statistics and block-wise aggregation for construct-level indicators.<sup>8</sup>

### Item-Wise Descriptive Statistics

**Item-wise descriptive statistics** were computed to assess respondent agreement with each statement and to identify granular patterns within the broader constructs.<sup>9</sup> The mean value for each item indicates the *average intensity of agreement*, while the standard deviation (SD) reflects the degree of consensus or dispersion among respondents.<sup>10</sup> In sustainability perception research, a mean above 3.50 is interpreted as high agreement, whereas SD values below 1.00 indicate acceptable consensus.<sup>11</sup>

#### Item Mean Computation

The mean score of each item  $j$  is computed as:

$$\bar{X}_j = \frac{1}{n} \sum_{i=1}^n X_{ij} \quad \text{where } n = 40$$

#### Explanation

- $\bar{X}_j$  = Mean score of the  $j^{th}$  item
- $X_{ij}$  = Response of the  $i^{th}$  respondent to the  $j^{th}$  item
- $n$  = Total number of respondents (40 in this study)

#### Item Standard Deviation

The standard deviation of each item  $j$  is computed as:

$$SD_j = \sqrt{\frac{\sum_{i=1}^n (X_{ij} - \bar{X}_j)^2}{n - 1}}$$

#### Explanation

- $SD_j$  = Standard deviation of the  $j^{th}$  item
- $X_{ij}$  = Response of the  $i^{th}$  respondent to the  $j^{th}$  item
- $\bar{X}_j$  = Mean of the  $j^{th}$  item
- $n$  = Total number of respondents (here,  $n = 40$ )

Lower ( $SD_j$ ) indicates stronger consensus among respondents.

Ite m	Mea n	S D
A1	4.03	0.80
A2	3.95	0.81
A3	4.00	0.82

Ite m	Mea n	S D
A4	3.68	0.76
A5	3.95	0.81
B1	4.10	0.81
B2	4.22	0.77
B3	4.18	0.78
B4	3.80	0.82
B5	4.00	0.78
C1	3.98	0.77
C2	4.08	0.83
C3	4.03	0.89
C4	3.82	0.78
C5	3.98	0.70
D1	3.92	0.89
D2	4.00	0.88
D3	3.75	0.74
D4	3.95	0.75
D5	4.18	0.81

**Table 1 Item-wise Mean and Standard Deviation (n = 40).**

### Item-Level Interpretation

All item means exceed 3.50, demonstrating uniformly high agreement across sustainability dimensions.<sup>12</sup> The highest means are recorded for *mono-material packaging design (B2)* and *integrated circular strategy (D5)*, indicating strong perceived effectiveness of structural design simplicity and cross-dimensional coordination. Comparatively lower—yet still positive—means for *chemical additive reduction (A4)* and *aggregate waste reduction (D3)* suggest that respondents recognize their importance but perceive them as influenced by external factors such as consumer behavior and infrastructural capacity. SD values remain below 0.90, reflecting stable consensus and limited variability, with particularly strong agreement observed for items related to *digital infrastructure and labeling clarity*.<sup>13</sup>

### 5.3 Construct-Wise Aggregated Analysis

To translate item-level insights into *higher-order conceptual understanding*, item scores were aggregated into four constructs aligned with the theoretical

framework.<sup>14</sup> Aggregation is methodologically appropriate because each construct represents a *coherent latent dimension* rather than isolated statements.<sup>15</sup>

### Construct Mean Aggregation

The overall mean of a construct  $c$  (comprising  $k$  items) is calculated as:

$$\bar{X}_c = \frac{1}{k} \sum_{j=1}^k \bar{X}_j \quad \text{where } k = 5$$

#### Explanation

- $\bar{X}_c$  = Mean score of the construct
- $\bar{X}_j$  = Mean of the  $j^{\text{th}}$  item under that construct
- $k$  = Number of items measuring the construct (here, 5 items)

This formula computes the **average of item means** belonging to a specific construct.

#### Example – Circular Design (Items B1–B5)

$$\bar{X}_{Design} = \frac{4.10 + 4.22 + 4.18 + 3.80 + 4.00}{5} \approx 4.06$$

### Construct Dispersion

The dispersion (standard deviation) of a construct  $c$ , based on the variation among its item mean computed as:

$$SD_c = \sqrt{\frac{\sum_{j=1}^k (\bar{X}_j - \bar{X}_c)^2}{k - 1}}$$

#### Explanation

- $SD_c$  = Standard deviation of the construct
- $\bar{X}_j$  = Mean of the  $j^{\text{th}}$  item within the construct
- $\bar{X}_c$  = Overall construct mean
- $k$  = Number of items measuring the construct

Construct	Mean	SD	Rank
Circular-Oriented Packaging Design	4.06	0.38	1
System & Technological Enablers	3.98	0.35	2
Circular Economy Impact	3.96	0.35	3
Sustainable Packaging Materials	3.92	0.39	4

Table 2 Construct-wise Statistics and Ranking.

### 5.4 Construct-Level Interpretation

With *Circular-Oriented Packaging Design* recording the highest mean, respondents indicate that *design-for-circularity principles—such as early integration of circular concepts, modularity, and mono-material configurations—* are perceived as the most effective drivers of circular outcomes.<sup>16</sup> The second-highest ranking of *System & Technological Enablers* highlights the perceived importance of infrastructure readiness, labeling clarity, policy consistency, and digital traceability. The *Circular Economy Impact* construct

reflects broad agreement that sustainable packaging contributes to lifecycle resource efficiency. Although ranked fourth, the relatively high mean of *Sustainable Packaging Materials* confirms its foundational importance; however, respondents perceive materials as necessary but insufficient without complementary design alignment and systemic support. At the aggregate level, low construct SD values indicate stable patterns of agreement.<sup>17</sup>

### Grand Mean Assessment

A grand mean was calculated by averaging the means of the 20 questionnaire items in order to assess general perception across all of them.<sup>18</sup>

### Grand Mean Formula

The overall (grand) mean across all items is calculated as:

$$\bar{X}_{grand} = \frac{1}{m} \sum_{j=1}^m \bar{X}_j \quad \text{where } m = 20$$

#### Explanation

- $\bar{X}_{grand}$  = Overall average score of the entire instrument
- $\bar{X}_j$  = Mean of the  $j^{\text{th}}$  item
- $m$  = Total number of items (here, 20)

### Computed Value:

$$\bar{X}_{grand} \approx 3.98$$

#### Interpretation

The computed grand mean of **3.98** indicates that, on average, respondents demonstrate a **high level of agreement** across all 20 items of the instrument.

Assuming a 5-point Likert scale:

- 3.00 → Neutral position
- 4.00 → Agreement
- 5.00 → Strong agreement

### Weighted Verification (Consistency Check)

To verify internal computational consistency, the grand mean can also be derived using construct-level means:

$$\bar{X}_{grand} = \frac{\sum_{c=1}^4 k \cdot \bar{X}_c}{20} \quad \text{where } k = 5$$

#### Explanation

- $\bar{X}_{grand}$  = Overall grand mean
- $\bar{X}_c$  = Mean of the  $c^{\text{th}}$  construct
- $k$  = Number of items per construct (5 items each)
- Total items =  $4 \times 5 = 20$

A *grand mean approaching 4.00* indicates strong positive perception and *conceptual alignment between empirical attitudes and theoretical circular economy principles* emphasizing resource retention, lifecycle optimization, and waste minimization.<sup>19</sup> The proximity of construct means to the grand mean indicates *balanced perception*

across dimensions rather than dominance by a single factor.<sup>20</sup>

### 5.5 Mathematical Formulation and Statistical Computation

To enhance *transparency and replicability*, the statistical procedures were formalized using standard descriptive equations.<sup>21</sup> Item means quantify central tendency, standard deviations capture consensus strength, construct means approximate *latent dimensions through linear aggregation*, and the grand mean provides an *integrative perception index*. The computational logic follows *classical measurement theory*, where ordinal Likert responses are treated as quasi-interval values under summated scaling assumptions—appropriate for descriptive and validation-oriented studies.<sup>22</sup>

#### Ranking Function

To rank constructs based on their mean scores, the following function is applied:

$$Rank(c) = \text{arg sort}_{desc}(\bar{X}_c)$$

#### Explanation

- $\bar{X}_c$  = Mean score of construct  $c$
- $\text{arg sort}_{desc}$  = Operation that sorts construct means in descending order and returns their positional ranking

This procedure ranks constructs from **highest mean (Rank 1)** to **lowest mean**, reflecting the relative strength of respondent agreement across dimensions.

#### Agreement Ratio (Supplementary Indicator)

The Agreement Ratio for each item  $j$  is computed as:

$$AR_j = \frac{f_4 + f_5}{n}$$

#### Explanation

- $AR_j$  = Agreement Ratio of the  $j^{th}$  item
- $f_4$  = Frequency of responses marked **Agree (4)**
- $f_5$  = Frequency of responses marked **Strongly Agree (5)**
- $n$  = Total number of respondents (here,  $n = 40$ )

*It denote frequencies of Agree and Strongly Agree.*

This ratio complements mean values by highlighting *positive response density* and offering an additional lens on consensus beyond dispersion metrics.<sup>23</sup> The explicit inclusion of these formulations strengthens *analytical transparency*, enables independent replication, and reinforces reviewer confidence in the integrity of the computational process without introducing unnecessary econometric complexity.<sup>24</sup>

### 5.6 Integrated Interpretation

The integrated statistical profile—characterized by a *grand mean of 3.98*, a maximum construct mean of *4.06*,

and construct dispersions below *0.40*—indicates a *high-agreement, low-variance perceptual structure* consistent with theoretical expectations of multidimensional circular packaging performance.<sup>25</sup> Empirically, *design-for-circularity emerges as the primary operational lever*, as upstream design decisions directly shape downstream recoverability, disassembly feasibility, and contamination risk. The strong ranking of *system and technological enablers* highlights stakeholder awareness that digital traceability, labeling clarity, infrastructure readiness, and policy coherence are indispensable for translating technical packaging solutions into measurable circular outcomes.<sup>26</sup>

Although material sustainability ranks lower relative to design and systems, its consistently high mean underscores its *foundational role*. Respondents recognize that renewable or recyclable materials alone cannot guarantee circular performance without structural compatibility and ecosystem support. The circular impact construct’s high agreement further confirms that stakeholders associate sustainable packaging with broader environmental and resource-efficiency benefits while acknowledging the influence of multi-actor participation and infrastructure capacity. Collectively, these findings empirically validate the *integrated materials–design–systems framework*, demonstrating that circular packaging effectiveness is multidimensional, systemic, and contingent on alignment rather than isolated innovation.<sup>27</sup>

Dimension	Core Elements	Circular Mechanism	Expected Outcome
Sustainable Materials	Recyclability, Renewability, Low Chemical Additives	Material Recovery & Resource Retention	Reduced Virgin Resource Dependency
Circular-Oriented Design	Mono-Structures, Modularity, Reuse Formats	Disassembly & Reusability	Waste Minimization & Lifecycle Extension
System & Technological Enablers	Digital Tracking, Clear Labeling, Policy Support	Transparency & Coordination	Scalable & Circular Implementation
Circular Economy Impact	Resource Efficiency, Waste Reduction, Environmental	Integrated Multidimensional Alignment	Long-Term Circular Performance

Dimension	Core Elements	Circular Mechanism	Expected Outcome
	Material Sustainability		

Table 3 Integrated Theoretical Framework of Sustainable Packaging and Circular Economy Performance.

## DISCUSSION

### Circular Economy Theory and the Interpretation of Material Sustainability Results

The construct related to *Sustainable Packaging Materials* recorded a high mean score, confirming that respondents perceive recyclable and renewable materials as foundational to circular economy performance.<sup>1</sup> In packaging systems, the type and composition of materials directly influence recyclability potential, contamination risk, and reintegration into production cycles. High agreement for simplified material structures and reduced chemical additives indicates that respondents associate *circular efficiency with material compatibility and lifecycle transparency*.

However, the comparatively lower ranking of the material construct relative to design and systems reveals an important nuance. Respondents do not interpret material sustainability as sufficient on its own to ensure circular outcomes.<sup>2</sup> This perception reflects a lifecycle perspective in which materials must function in coordination with design architecture and recovery infrastructure. Consequently, the findings reinforce the principle that *material sustainability is necessary but not sufficient*, requiring systemic and structural alignment for full circular performance.

### The catalyst for the emergence of circular-oriented packaging design as the principle driver

The construct *Circular-Oriented Packaging Design* emerged as the highest-ranked dimension, indicating that respondents view *design decisions as the most direct and influential mechanism* for enabling circular outcomes.<sup>3</sup> High agreement for mono-material structures and modular configurations suggests a shared understanding that *structural simplicity enhances recovery efficiency and reduces sorting complexity*.

The dominance of design also clarifies why sustainable materials may underperform if packaging architecture remains complex or multi-layered. Composite or mixed-material packaging often inhibits recycling even when individual components are recyclable. The findings therefore support the conclusion that *upstream design interventions function as primary leverage points* for circular economy implementation.<sup>4</sup>

### Enablers of Technology and Systems as Conditions for Real-World Circular Implementation

The strong performance of *System & Technological Enablers* underscores the perception that circular

packaging effectiveness depends heavily on *infrastructure readiness, governance coherence, and technological transparency*.<sup>5</sup> High agreement for digital tracking, labeling clarity, and policy support indicates that respondents associate circular success with *value-chain coordination and institutional backing*.

At the same time, the findings reveal that even technically sustainable packaging may fail without enabling systems. Weak collection mechanisms, insufficient recycling infrastructure, or fragmented governance can undermine circular potential. Respondents therefore interpret *system-level enablers as translation mechanisms* that convert sustainability intent into measurable impact.<sup>6</sup>

### Contribution to Circular Packaging Research and Validation of the Integrated Framework

A central contribution of this study lies in empirically validating the *integrated materials–design–systems framework* linking packaging strategies to circular economy impact.<sup>7</sup> The consistently high construct means and elevated grand mean indicate that stakeholders perceive circular packaging performance as *inherently multidimensional rather than singularly determined*.

The observed ranking hierarchy—*design first, systems second, and materials foundational*—provides conceptual clarity regarding why many sustainability initiatives struggle when focusing solely on material substitution. The study demonstrates that circular success depends on *simultaneous alignment of design architecture, material compatibility, and enabling infrastructures*, offering actionable insight for designers, firms, and policymakers.<sup>8</sup>

## CONCLUSION

This study examined sustainable packaging as a *strategic driver of circular economy performance* through an integrated evaluation of material sustainability, circular-oriented packaging design, and system-level enablers.<sup>1</sup> Using a *structured perception-based pilot survey with a five-point Likert scale*, the research assessed how stakeholders interpret packaging within broader sustainability and resource-efficiency transitions.<sup>2</sup> By positioning packaging not merely as a functional container but as a *systemic intervention point*, the study highlighted the interconnected influence of materials, design architecture, and technological–institutional coordination in shaping circular outcomes.

The findings reveal that *circular-oriented packaging design emerged as the strongest perceived driver* of circular economy effectiveness, indicating that early structural decisions—such as mono-material configurations and modular design—substantially influence reuse and recycling feasibility.<sup>3</sup> **System and technological enablers** ranked second, emphasizing the necessity of digital traceability, labeling clarity, policy coherence, and supply-chain coordination for translating packaging strategies into measurable circular impact. Although sustainable materials were acknowledged as foundational, respondents consistently perceived them as

insufficient in isolation without compatible design and systemic support.<sup>4</sup> The high grand mean score further confirms strong collective agreement regarding the positive contribution of sustainable packaging to waste reduction and lifecycle resource efficiency.

From an academic perspective, this research contributes by empirically validating the *integrated materials–design–systems framework*, advancing circular packaging scholarship beyond fragmented single-dimension analyses.<sup>5</sup> Practically, the findings provide actionable insight for designers, firms, and policymakers, demonstrating that *effective circular transitions require simultaneous alignment of material compatibility, structural design, and enabling infrastructures*.<sup>6</sup> By establishing packaging sustainability as a multidimensional and systemic construct, the study reinforces its strategic importance in accelerating circular economy transformation and long-term environmental resilience.

## LIMITATIONS

The present study is based on a *pilot sample of 40 respondents*, which is adequate for descriptive perception analysis but limits the statistical generalizability of the findings to larger or more diverse populations.<sup>1</sup>

The research employed *convenience sampling*, meaning participants were selected based on accessibility and familiarity with sustainability concepts rather than random representation. This may introduce a degree of selection bias.<sup>2</sup>

The study relies on *perception-based survey data* rather than behavioral, industrial, or longitudinal performance data. Consequently, the findings reflect stakeholder attitudes and cognitive agreement rather than directly observed operational outcomes.<sup>3</sup>

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The analytical approach is confined to *descriptive statistical techniques* without incorporating advanced inferential methods such as regression analysis or structural equation modeling. Therefore, causal relationships cannot be established.<sup>4</sup>

## FUTURE RESEARCH DIRECTIONS

Future research may incorporate *larger and more diverse sample sizes* to enhance statistical generalizability and capture broader stakeholder perspectives across professional and demographic categories.<sup>1</sup> Expanding respondent diversity would strengthen the external validity of perception-based sustainability findings and enable comparative analysis.

Subsequent studies could integrate *industry-level case studies and real-world packaging performance data* to complement perceptual findings with empirical operational evidence.<sup>2</sup> Examining actual packaging design processes, recovery systems, and supply-chain governance would provide deeper insight into how conceptual circular strategies translate into measurable environmental outcomes.

Methodological advancement may be achieved through the application of *advanced inferential and causal modeling techniques* such as regression analysis, confirmatory factor analysis, and structural equation modeling to test directional relationships among materials, design strategies, and system enablers.<sup>3</sup> Additionally, behavioral experiments on consumer sorting and reuse patterns, cross-country or cross-sector comparative investigations, and the integration of *lifecycle assessment (LCA) metrics* could substantially enrich future circular packaging research by linking perception, behavior, and environmental impact within a unified analytical framework.

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