



The Role of Reverse Supply Chains in Enhancing Circular Economy Applications: An Applied Study on Jeddah Municipality

Khulud Rashed Mubarak ALGhaneme¹, Abdulnaser S. H. Al-Msloum²

^{1,2} University of Jeddah, College of Business, Jeddah, Saudi Arabia
Email: kholoud.r.g@hotmail.com¹, asalem2@uj.edu.sa²

Abstract:

This study aims to diagnose the current state of reverse supply chains at Jeddah Municipality and assess their role in enhancing circular economy applications, proposing an integrated operational model aligned with Saudi Vision 2030 environmental targets and the Saudi Green Initiative.

The study adopted a descriptive quantitative approach, collecting primary data from two complementary sources: a survey of 55 citizens and residents of Jeddah measuring awareness levels, behavioral practices, and community expectations; and a specialized survey of 38 Jeddah Municipality employees diagnosing the internal operational reality of reverse supply chains and digital technology readiness. The first instrument contained 18 items across four axes, while the second contained 16 items across four axes, supplemented by open-ended questions.

Results revealed a significant strategic gap between high community willingness ($M=4.26$ for participation readiness) and moderate operational reality ($M=3.11$ for service quality assessment). Citizens expressed strong readiness for digital and incentive-based solutions, while the system suffers from inadequate source-separation infrastructure and weak institutional communication. Municipality employees demonstrated relatively high institutional alignment ($M=3.87$), yet acknowledged critical weaknesses in economic incentives ($M=3.43$) and IoT adoption ($M=3.32$), with near-unanimous support for GIS implementation ($M=4.19$, 89.2% agreement).

Based on these findings, the study presents a four-phase integrated operational model beginning with deploying smart classified bins and launching an official digital application, progressing toward building an integrated circular industrial complex and activating Extended Producer Responsibility (EPR) legislation. The study concludes that Jeddah's transition to a circular economy is both feasible and economically justified, provided the gap between strategic ambition and field implementation is systematically bridged.

Keywords: Reverse Supply Chains, Circular Economy, Jeddah Municipality, Waste Management, Saudi Vision 2030, Digital Transformation, Internet of Things.

Introduction

The world is undergoing a radical shift from traditional linear economic models—based on the “extract, manufacture, dispose” principle—toward the adoption of circular economy policies that seek to eliminate waste and restore natural systems. This transition is an urgent necessity to address escalating environmental challenges; estimates indicate that recycling plastic alone could achieve global carbon emissions savings of up to 3,573 kg of carbon dioxide equivalent per metric ton (Ellen MacArthur Foundation, 2019). At the heart of this circular system, reverse supply chains serve as the backbone, ensuring the flow of products and materials from the point of consumption back to the point of origin, with the aim of restoring their economic and environmental value.

At the national level, Saudi Arabia has placed environmental sustainability at the forefront of its development priorities through “Vision 2030” and the “Green Saudi” initiative, aiming to divert 85% of industrial waste and 94% of total waste from landfills by 2035 (National Waste Management Center, 2023). However, major cities such as Jeddah—which generates approximately 1.8 million metric tons of municipal waste annually—face complex logistical challenges in managing municipal, construction, and electronic waste. Despite recent institutional efforts, the logistics sector still urgently needs advanced digital and technological frameworks, such as the Internet of Things (IoT) and artificial intelligence, to track resources, improve sorting and recovery processes, and ensure transparency in reverse value chains (Govindan & Hasanagic, 2018).

Based on the foregoing, there is an urgent need to develop a specialized model for the Jeddah Municipal Secretariat that links municipal governance with the efficiency of reverse supply chains and addresses existing operational gaps in the urban waste management system. The strategic challenge is not limited to waste collection and disposal but extends to transforming waste into reusable resources within a sustainable economic cycle (De Angelis, 2018), which requires a comprehensive redesign of traditional supply chains to accommodate complex reverse flows.

Research Problem:

The dimensions of the problem are evident in the absence of an integrated regulatory model linking the various stakeholders in the system: the Secretariat (as the legislative and regulatory authority), producers, consumers, and recycling

plants. This fragmentation results in economic waste estimated at hundreds of millions annually, in addition to negative environmental impacts such as the depletion of landfill capacity and environmental pollution (Authority, 2022). Accordingly, the research problem can be formulated as the following main question:

“How can an integrated reverse supply chain model be developed to contribute to the promotion of circular economy practices within the municipal jurisdiction of the Jeddah Provincial Municipality?” Research Questions:

The following sub-questions stem from the main research question:

1. What is the current state of reverse supply chain practices in the Jeddah Municipality's waste management system in terms of infrastructure and operational capabilities?
2. What are the barriers (regulatory, logistical, and technical) that limit the efficiency of material recovery and recycling within the municipality?
3. What are the key components and processes of the proposed model for developing reverse supply chains in line with the objectives of Saudi Vision 2030?
4. To what extent are modern technologies (such as artificial intelligence and the Internet of Things) being utilized to enhance the efficiency of the circular economy and enable digital waste tracking at the municipal level?

Objectives of the Study:

This research seeks to achieve the following objectives:

1. To analyze the current status of reverse supply chains in the Jeddah Municipality and identify operational and institutional gaps through an evaluative field study.
2. To identify and prioritize the challenges and obstacles facing the waste management sector in implementing recovery and recycling models.
3. To design an integrated operational model for reverse supply chains (including selective collection, green transportation, and smart sorting) specifically tailored to the urban environment of Jeddah.
4. To propose technical and digital mechanisms to enhance transparency and the efficiency of waste tracking, and to measure the expected environmental and economic impact of implementing the proposed model.

Significance of the Study:

Scientific Significance:

- Enriching the Arabic literature in the field of green logistics and reverse supply chains within the Saudi municipal sector, given the scarcity of similar applied studies (Al-Salem et al., 2022).
- Providing a systematic theoretical framework that integrates sustainability governance, logistics operations for value recovery, and digital transformation.
- Establishing a knowledge base that supports researchers and decision-makers and serves as a reference for Saudi cities seeking to develop urban sustainability systems.

Practical Significance:

- To provide the Jeddah Municipality with a practical model that contributes to achieving the “Saudi Green Initiative” targets for reducing carbon emissions.
- Enhancing economic value-added through the concept of “urban mining” and the recovery of valuable materials, thereby supporting the diversification of income sources and the creation of green jobs (Ghisellini et al., 2016).
- Improving the quality of urban life in Jeddah by reducing visual and environmental pollution and alleviating the burden on landfills.
- Providing a scientific basis for updating public policies related to Extended Producer Responsibility (EPR) and implementing circular economy incentives.

Theoretical Framework

Concept and Definition of Reverse Supply Chains:

Reverse supply chains are defined as a system of organized processes that enable the flow of products, materials, or their components from the point of final consumption back to the point of origin or to specialized treatment centers, with the aim of recovering their economic value or disposing of them in an environmentally safe manner (Rogers & Tibben-Lembke, 2001). These chains differ fundamentally from traditional, linear supply chains, in which products move from the supplier to the manufacturer and then to the consumer without returning, whereas reverse supply chains transform end-of-life products into new inputs within a sustainable production cycle. Guide & Van Wassenhove (2009) provided a more comprehensive definition of reverse supply chains as “activities involving the collection of used products from end customers and the redistribution of their value through reuse, refurbishment, remanufacturing, or recycling.” This definition highlights the economic dimension of recovery operations, which is a fundamental pillar of the sustainability of these chains at the institutional level.

The Importance of Reverse Supply Chains:

Reverse supply chains are of great economic importance, and this importance manifests in several dimensions:

Or: The Economic Dimension:

1. They help reduce raw material costs by reusing recovered components and materials in the production cycle.

2. They generate additional revenue from the sale of refurbished products or recycled materials in secondary markets.
3. It reduces the logistical costs associated with waste disposal amid rising landfill fees and stricter regulatory requirements.
4. It enhances the competitiveness of organizations by adopting green procurement practices and improving their image among stakeholders (Ghisellini et al., 2016).

Second: The Environmental Dimension:

1. Reduces negative environmental impacts by diverting waste from landfills, thereby helping to extend the lifespan of these sites and reduce greenhouse gas emissions.
2. Helps rationalize the consumption of non-renewable natural resources by reintegrating them into the production cycle.
3. It supports the achievement of the 2030 Sustainable Development Goals (SDGs), particularly Goal 12 on responsible production and consumption.
4. It contributes to reducing soil and groundwater pollution caused by the unregulated disposal of electronic and chemical waste (De Angelis, 2018).

The types of reverse supply chains vary depending on the nature of the recovered product and the objective of the treatment processes, and are classified as follows:

- Direct reuse: Recovering intact products and redistributing them without any significant modification, as is the case with platforms selling used books or clothing.
- Repair and Refurbishment: Restoring products to their original functional condition or improving them, particularly electronic devices and industrial equipment.
- Remanufacturing: Disassembling products into their basic components, processing them, and reassembling them to meet the specifications of a new product.
- Recycling: Converting materials into secondary raw materials for use in the production of new products, such as recycling plastics, paper, and metals.
- Energy Recovery: Extracting energy from waste that cannot be recycled, such as waste-to-energy power plants.
- Safe Disposal: Managing hazardous waste or waste that cannot be treated by other methods in environmentally sustainable ways (Govindan & Hasanagic, 2018).

Components of Reverse Supply Chains:

A reverse supply chain consists of six interconnected operational elements that work in a coordinated manner to ensure efficient value recovery:

- (1) Collection: This involves collecting waste from households, commercial establishments, and industrial facilities through specialized networks such as smart containers, return centers, and periodic collection campaigns.
- (2) Sorting and Inspection: Classifying collected materials by type, condition, and quality; this is one of the most influential processes in determining the subsequent treatment path.
- (3) Transportation and Handling: This involves transporting collected materials to sorting centers, factories, or treatment sites, and is considered one of the most costly processes in the reverse supply chain.
- (4) Processing and Value Recovery: This includes reuse, repair, recycling, or energy recovery, depending on the nature of the material.
- (5) Redistribution: Reintroducing processed products or materials into primary or secondary markets to close the economic cycle.
- (6) Information Management: This represents the digital backbone of the chain, encompassing the tracking of material flows, performance measurement, and data-driven decision-making (Guide & Van Wassenhove, 2009).

The Concept of the Circular Economy and Its Evolution:

The circular economy is an economic model that seeks to decouple economic growth from the consumption of finite natural resources by transitioning from the linear model based on “extraction—manufacturing - disposal” model to a circular model focused on the principles of “reduce, reuse, and recycle” in a continuous and organized manner (Ellen MacArthur Foundation, 2019). This concept has evolved over several decades to reach its current form, which integrates considerations of economic efficiency, environmental sustainability, and the regeneration of natural systems.

The roots of the circular economy appeared in the writings of prominent institutions at the end of the last century; however, the most influential institution in establishing it and disseminating its concepts globally is the Ellen MacArthur Foundation, which in 2012 launched its comprehensive conceptual framework known as the “Circular Economy Butterfly,” which depicts the flows of technical and biological materials in two separate, regenerative cycles, each aimed at preserving the highest possible value of resources for the longest possible time.

The Circular Economy in Saudi Arabia:

Saudi Arabia has placed environmental sustainability at the forefront of its development goals under “Vision 2030,” and this approach is reflected in the “Green Saudi” initiative, which aims to achieve a set of ambitious environmental targets, foremost among them: Diverting 85% of industrial waste and 94% of total waste from landfills by 2035 (National Center for Waste Management, 2023). The Industrial and Technology Development Authority and

King Abdullah Economic City were established as models for circular industrial complexes that bring together production partners to convert one partner's waste into another's inputs.

Official reports indicate that the actual recycling rate in the Kingdom remains below the target level, implying a significant operational gap that requires the development of an integrated reverse supply chain system capable of accommodating multiple waste streams and converting them into value-added resources (Waste Management Regulatory Authority, 2022).

The Relationship Between Reverse Supply Chains and the Circular Economy:

Reverse supply chains occupy a central position in the circular economy ecosystem; they represent the operational mechanism that translates the theoretical principles of the circular economy into practical, on-the-ground applications. While the circular economy establishes the strategic vision and overarching goals, reverse supply chains provide the practical infrastructure to realize this vision through organized material flows to and from points of consumption and production. Govindan & Hasanagic (2018) have emphasized that integrating reverse supply chains into the circular economy model increases the system's ability to recover economic and environmental value by 40–70% compared to traditional models.

This integration can be illustrated through two key points: First, the circular economy requires effective reverse supply chains to close the resource loop and prevent materials from leaking out of the economic cycle; and second, reverse supply chains only achieve their full potential when they operate within the framework of an integrated circular economy vision that defines the optimal path for each material within the production cycle.

The Concept of Municipal Governance in the Context of Sustainability:

Sustainable municipal governance refers to the system of rules, institutions, and processes that govern decision-making mechanisms in the management of urban assets and services, striking a balance between the requirements of economic development, environmental protection, and social justice. In the context of waste management, municipal governance is reflected in the regulatory authority's—such as the Jeddah Provincial Secretariat—ability to formulate and implement effective policies and to coordinate the relationship between the public and private sectors and civil society within the waste management system (Al-Salem et al., 2022). The scientific literature identifies three dimensions of municipal sustainability governance in the field of waste: the legislative dimension (establishing binding legal frameworks), the operational dimension (carrying out collection and treatment operations), and the financial dimension (securing the financial resources necessary for the sustainability of the system).

Models of Municipal Governance in Waste Management:

There are numerous governance models used in municipal waste management worldwide, which can be summarized into three main models:

- Direct central management model: The government agency is responsible for all waste collection and treatment operations and for managing recycling facilities,

This model is characterized by ease of coordination but faces financial and operational constraints in large cities.

- Public-Private Partnership (PPP) model: In this model, the municipality delegates part of the operations to private-sector companies under performance contracts documented with standard metrics, thereby improving operational efficiency

- Extended Producer Responsibility (EPR) Model: This model requires producers and distributors to take responsibility for recovering their products at the end of their life cycle and recycling them; it has proven effective in a number of European and Asian countries (Waste Management Regulatory Authority, 2022).

Municipal Waste Management in the City of Jeddah:

The Jeddah Governorate Secretariat undertakes extensive regulatory and operational responsibilities in the field of municipal waste management. According to estimates by the National Waste Management Center (2023), the city produces approximately 1.8 million metric tons of municipal waste annually, in addition to massive quantities of construction and demolition waste and electronic waste. This waste is divided into three main streams: municipal solid waste, construction and demolition waste, and electronic waste. Despite efforts to improve the efficiency of the collection and transportation system, there remains a wide gap in the recovery of recyclable materials, partly due to the system's lack of an integrated digital infrastructure for tracking waste streams and poor coordination among the stages of the reverse supply chain, from collection to recycling (Rogers & Tibben-Lembke, 2001)

The Role of Modern Technologies in Promoting the Circular Economy:

There are numerous applications of artificial intelligence in the waste management system, including:

1. Intelligent automated sorting systems: These rely on computer vision cameras and deep learning algorithms to distinguish between different types of waste on sorting lines with accuracy and speed that exceed the capabilities of manual sorting by a factor of tens.
2. Waste flow forecasting: Machine learning models use historical data, seasonal factors, and demographic data to predict waste volumes in specific geographic areas, which aids in proactive operational planning.
3. Route Optimization: Optimal route-finding algorithms are applied to minimize distance traveled and fuel

consumption on waste collection trips.

4. Predictive Equipment Maintenance: Equipment operating data is continuously analyzed to predict breakdowns before they occur and schedule preventive maintenance, thereby reducing unplanned downtime (Ellen MacArthur Foundation, 2019).

Relevant Theoretical Models:

Product Life Cycle Model:

This model tracks the successive stages a product goes through—from extraction, design, and manufacturing to distribution, consumption, and disposal—and illustrates the environmental and economic impacts associated with each stage. This model is used in the design of reverse supply chains by identifying the most appropriate points of intervention for recovery within the cycle, and it is a central analytical tool in circular economy studies.

Waste Hierarchy Model:

This model ranks waste management options in ascending order from the least to the most impactful: reduction first, followed by reuse, then recycling, then energy recovery, and finally landfilling as the last resort. This priority serves as an established regulatory framework in many European and international environmental laws and guides the work of reverse supply chains toward the options higher up in the hierarchy (De Angelis, 2018).

Industrial Symbiosis Network Model:

This model is based on the idea that one facility's waste can serve as a productive input for another facility within an organized network of industrial partners. This model has been successfully implemented in numerous industrial areas and aligns with the broader vision of the circular economy in transforming waste into resources (Ghisellini et al., 2016).

Research Methodology:

Type of Research:

This study follows the descriptive quantitative approach, which is the most appropriate method for examining relationships between statistically measurable variables. In the context of the present study, this approach aims to:

- Provide an accurate statistical picture of the level of public awareness and the behavioral practices of citizens and residents regarding the circular economy and reverse supply chains.
- Assess the internal operational reality of the Jeddah Municipality in the field of waste management from the perspective of its specialized staff.
- Identify institutional and technical gaps through generalizable statistical data.
- To present proposals supported by figures and evidence that contribute to the design of the proposed operational model.

The research was designed in accordance with the scientific standards for quantitative analytical research, while adhering to the principles of confidentiality and impartiality based on the ethical principles adopted by the University Agency for Graduate Studies and Scientific Research at the University of Jeddah.

Study Population and Sample:

The study population consists of citizens and residents of Jeddah aged 18 and older, who represent the primary target group for circular economy and municipal waste management programs. Jeddah is one of the most densely populated cities in Saudi Arabia, with a population of more than four million according to official estimates, making the exact size of this population difficult to determine.

Given the size of the community and the difficulty of defining its exact boundaries, the study employed an electronic random sampling method by distributing a digital questionnaire via Google Forms across the city's various neighborhoods. The total number of respondents was 55 participants from various neighborhoods, a sample size appropriate for exploratory studies in the field of environmental sustainability (Govindan & Hasanagic, 2018), and care was taken to ensure geographic diversity in order to reach multiple population segments.

Jeddah Municipality

Employee Survey:

The study population for the second survey consists of employees of the Jeddah Municipality in departments related to waste management and reverse supply chains, including: executive and middle management, field supervisors, analysts and information systems specialists, and operational staff with direct field experience. This group represents a specialized knowledge base with an insider's perspective on operational gaps and actual institutional capabilities.

A purposive sampling method was adopted, targeting individuals functionally associated with waste management or supply chains. The survey was distributed in paper form through the Secretariat's official internal channels, and the total number of respondents was 38 employees—both male and female—representing a variety of job categories.

The following are the demographic and job characteristics of the employee sample:

Table (4-1): Demographic and Job Characteristics of the Employee Sample (n = 38)

Group	Row	Percentage (%)	Frequency (N)
-------	-----	----------------	---------------

1	1	76.3	29
1	2	23.7	9
1	Total	100.0	38
2	1	2.6	1
2	2	44.7	17
2	3	34.2	13
2	4	18.4	7
2	Total	100.0	38
3	1	7.9	3
3	2	18.4	7
3	3	57.9	22
3	4	15.8	6
3	Total	100.0	38
4	1	13.2	5
4	2	21.1	8
4	3	18.4	7
4	4	21.1	8
4	5	26.3	10
4	Total	100.0	38
5	1	10.5	4
5	2	31.6	12
5	3	10.5	4
5	4	10.5	4
5	5	34.2	13

Respondents

The data reveal that males constitute the majority (3, 76%), which reflects the actual gender composition in the Secretariat's field sectors. The largest age group is concentrated in the 25–34 age bracket (7.44%), followed by the 35–44 age bracket (2.34%). Bachelor's degrees are the most common academic qualification (9.57%). Long-term experience (more than 10 years) stands out at 2.34%, followed by the 1–3-year category (6.31%), indicating a balanced mix of accumulated experience and young talent.

Data Collection Tool:

The study relied on a questionnaire as the primary tool for collecting primary data, due to its suitability for a quantitative approach and its ease of electronic administration to the two target samples. Both questionnaires were designed based on a comprehensive review of relevant scientific literature (Rogers & Tibben-Lembke, 2001; Guide & Van Wassenhove, 2009; Al-Salem et al., 2022), while also taking into account the local characteristics of the Jeddah environment and the requirements of the municipal context.

Structure of the Citizens' and Residents' Questionnaire:

The first questionnaire consisted of two sections:

Section One: Two open-ended questions to capture participants' views on the most significant barriers and their suggestions for promoting the circular economy.

Section Two: 18 rating items distributed across four main themes, as follows:

Table (4-2): Distribution of Citizen Survey Statements by Theme

Number of Statements	Theme	Topic	M
4	First Theme	Level of Awareness of the Circular Economy	1
5	Axis 2	Actual Behavioral Practices in Waste Management	2
5	Axis 3	Evaluation of Jeddah Municipality Services and Waste Management Infrastructure	3

4	Axis 4	Readiness for Future Participation in the Circular Economy System	4
18	Total		

Design of the Secretariat Staff Survey:

The second survey consisted of two sections:

Section One: Job and demographic data, including: gender, age group, educational qualification, job title, and years of experience in waste management.

Second Section: (6) evaluation statements distributed across four main themes as follows:

Table (4-3): Distribution of Employee Survey Statements Across Themes

Number of phrases	Theme	Topic	M
5	First Theme	The Operational Reality of Reverse Supply Chains in the Jeddah Municipality	1
4	Axis 2	Level of Institutional Alignment with the Principles of the Circular Economy and Vision 2030	2
2	Axis 3	Regulatory and Logistical Barriers to Implementing the Circular Economy	3
5	The Fourth Theme	The Use of Modern Technologies in Reverse Supply Chains	4
16	Total		

Survey Scale:

Both surveys adopted the Five-Point Likert Scale to measure the degree of agreement with each statement according to the following scale: (5) Strongly agree, (4) Agree, (3) Neutral, (2) Strongly disagree, (1) Disagree. The following criteria were used to interpret the arithmetic means: (0.00–1.33, 2) low level, (2.34–2.66, 3) moderate level, (3.67–5.00, 5) high level.

Survey Distribution Method:

The citizen survey was distributed electronically via Google Forms through social media platforms (WhatsApp and Twitter) and university networks, thereby reaching diverse population segments. The employee survey was distributed through the official internal channels of the Jeddah Municipality and professional networks among employees of departments involved in waste management.

Validity and Reliability of the Tool:

To verify the validity of both instruments, two types of validity were considered:

First: Content Validity:

Both questionnaires were presented in their preliminary forms to a number of experts in the fields of supply chain management, the circular economy, and research methods to verify the appropriateness of the statements for the study's objectives, the accuracy of the wording, and the comprehensiveness of the topics. Based on the feedback received, the necessary modifications were made prior to final implementation.

Second: Face Validity:

The clarity and comprehensibility of the statements were verified through a limited pilot test involving individuals outside the original samples, confirming the soundness of the wording and the absence of ambiguity or duality in interpretation.

Instrument Validity:

To verify the reliability of the two scales, Cronbach's alpha was used, which is considered one of the most common measures of reliability in social and administrative research (Nunnally, 1978). The literature indicates that an acceptable value is no less than 0.70, and that values above 0.80 indicate high reliability.

First: Results of the Citizens' Questionnaire Reliability Analysis:

Table (4-4): Cronbach's Alpha Coefficients for the Dimensions of the Citizen Questionnaire

Explanation	Alpha Kronbach	Number of Items	Axis
High stability	0.81	4	Awareness of the circular economy
High stability	0.79	5	Actual Behavioral Practices
High stability	0.83	5	Assessment of Services and Infrastructure

Very high reliability	0.87	4	Readiness for Future Participation
Very high stability	0.84	18	Overall Questionnaire

The results in Table (4-4) confirm that all reliability coefficients for the Citizen Questionnaire exceeded the acceptable threshold (0.70), ranging from (0.79) to (0.87), while the overall reliability coefficient was (0.84), which reinforces confidence in the instrument's reliability.

Second: Results of the Employee Questionnaire's Reliability:

Table (4-5): Cronbach's Alpha Coefficients for the Factors of the Employee Questionnaire

Interpretation	Cronbach's Alpha	Number of Items	Dimension
High reliability	0.82	5	Operational Reality of Reverse Supply Chains
High stability	0.78	4	Alignment with the Circular Economy and Vision 2030
Acceptable stability	0.74	2	Regulatory and Logistical Barriers
High stability	0.80	5	Adoption of Modern Technologies
Very high stability	0.83	16	Overall Questionnaire

The results in Table (5) confirm that the reliability coefficients of the employee questionnaire ranged from (0.74) to (0.82), and the overall reliability coefficient was (0.83), which reinforces the validity of the instrument for institutional field application.

4-6 Statistical Methods Used:

The data collected from the two questionnaires were analyzed using the following descriptive and inferential statistical methods:

4.6.1 First: Descriptive Statistics:

- Frequencies and percentages: to describe the demographic and job characteristics of the employee sample and the distribution of responses from the citizen sample.
- Mean: To measure the general trend of participants' responses to each statement in the two questionnaires.
- Standard Deviation: To measure the degree of dispersion of responses around the mean and determine the degree of homogeneity.
- Agree, Neutral, and Disagree Rates: To analyze the detailed distribution of participants' responses across the five-point Likert scale.

4.6.2 Second: Inferential Statistics:

- Cronbach's Alpha: To verify the stability of the dimensions of both questionnaires and the reliability of the instruments.
- Qualitative Content Analysis: To analyze the open-ended responses in the citizen questionnaire and identify key patterns and themes.

Presentation and Analysis of Field Study Results

Section One: Results of the Citizens' and Residents' Questionnaire (n = 55):

Dimension 1: Level of Awareness of the Circular Economy:

This dimension measures respondents' familiarity with the concept of the circular economy and the Jeddah Municipality's recycling initiatives through four statements addressing theoretical knowledge and awareness of available infrastructure.

Table (5-1): Results of the First Dimension—Level of Awareness of the Circular Economy (n = 55)

Statement	M	SD	Agree (%)	Neutral (%)	Disagree (%)	N
Q1: Understanding the term "circular economy"	2.85	1.34	29.1	36.4	34.5	55
Q2: Awareness of the Jeddah Municipality's recycling initiatives	2.95	1.53	40.0	21.8	38.2	55
Q3: Knowing the locations of gathering points in the neighborhood	2.95	1.45	36.4	25.5	38.2	55
Q4: Regularly following news about the	2.95	1.47	36.4	23.6	40.0	55

environmental transition						
Mean of the first axis	2.92	—	—	—	—	55

Analytical Interpretation of the Awareness Dimension Results:

The data in Table (1) reveal a low to moderate level of awareness across all statements in this axis; the arithmetic means ranged between (2.85) and (2.95), values that fall below the midpoint of the scale (3), indicating a lack of a well-established culture surrounding the term “circular economy” among a broad segment of society.

Regarding the first item (Q1: Knowledge of the Term), the lowest mean in the dimension was 85.2, with a standard deviation of 34.1; 5.34% reported disagreement, compared to only 1.29% who expressed agreement. This wide dispersion in the standard deviation (34.1) reflects a profound disparity in environmental knowledge among the sample participants.

More significantly, awareness of the Jeddah Municipality’s recycling initiatives (Q2) achieved the highest approval rate in the axis (0.40%), yet (2.38%) remain unaware of these initiatives despite their existence; this contradiction demonstrates that the problem lies not in the absence of initiatives but in the weakness of the communication channels that convey them to citizens. This finding is consistent with the assertion by Al-Salem et al. (2022) that the knowledge gap in Saudi Arabia’s circular economy sector requires systematic, multi-channel awareness strategies rather than isolated, seasonal campaigns.

The Second Axis: Actual Behavioral Practices:

This axis examines daily behavioral patterns in waste management, including household sorting, handling of electronic waste, participation in environmental campaigns, and green consumption trends.

Table (5-2): Results of the Second Axis—Actual Behavioral Practices (n = 55)

Statement	M	SD	Agree (%)	Neutral (%)	Disagree (%)	N
Q5: Sorting waste at home (paper, plastic, metal)	2.47	1.44	23.6	27.3	49.1	55
Q6: Delivery of electronic devices to specialized collection points	2.58	1.37	21.8	29.1	49.1	55
Q7: Participation in environmental cleanup campaigns	2.60	1.47	47.3	23.6	29.1	55
Q8: Preference for environmentally friendly products	3.38	1.35	21.8	36.4	41.8	55
Q9: Formal disposal of bulky waste	3.69	1.43	21.8	16.4	61.8	55
Mean of the second axis	2.95	—	—	—	—	55

An Analytical Interpretation of the Behavioral Dimension Results:

Table (2) reveals the most striking contradiction in the entire study: While household waste sorting (Q5) recorded the lowest mean in the entire questionnaire (M = 2.47, refusal rate = 1.49%), as did the disposal of electronic devices (Q6, M = 2.58, refusal rate = 1.49%) and participation in cleanup campaigns (Q7, M = 2.60, refusal = 3.47%), the formal disposal of bulky waste (Q9) jumps to the highest mean in the axis (M = 69.3, agreement = 8.61%).

This numerical discrepancy can be explained by the fact that compliance with formal bulky waste disposal is a necessary channel with no alternative, whereas daily sorting requires an existing infrastructure (sorted bins next to homes) that is absent in most neighborhoods of Jeddah. This is precisely what Rogers confirmed: that the absence of specialized recovery networks is the most significant logistical barrier in reverse supply chains (Tibben-Lembke & 2001).

As for the preference for environmentally friendly products (Q8, M = 3.38, Agree = 8, 41%), it is based on a sound foundation that is hindered by barriers related to price and availability in the local market, which is consistent with the findings of Ghisellini et al. (2016), who noted that stimulating green consumption requires price support mechanisms and tax exemptions.

Third Area: Evaluation of Services and Infrastructure:

This section assesses the quality of municipal services provided in the area of waste management, the effectiveness of institutional communication by the Jeddah Municipality, and the level of satisfaction with the development of infrastructure and digital applications.

Table (5-3): Results of the Third Axis—Evaluation of Services and Infrastructure (n = 55)

The phrase	M	A	Agree	Neutral	Disagree	N
Q1 0: Regularity and Adequacy of Waste Collection Services	3.13	1.32	34.5%	36.4%	29.1 %	55

Q11: Clarity of the Secretariat's information on recycling	2.78	1.45	30.9%	25.5%	43.6%	55
Q12: Improvement in waste management infrastructure	3.18	1.26	38.2%	32.7%	29.1 %	55
Q13: Effectiveness of Smart Apps for Waste Management	2.84	1.24	27.3%	38.2%	34.5%	55
Q14: The Secretariat's Commitment to the Vision 2030 Targets	3.60	1.29	49.1 %	32.7%	18.2%	55
Average of the third axis	3.11	—	—	—	—	55

An Analytical Review of the Results of the Services Assessment Axis:

The data in Table (3) highlight two contradictory phenomena worthy of in-depth analysis: First, the Municipality's commitment to the Vision 2030 targets received the highest rating in this dimension ($M = 60.3$, Disagree = 1, 49%), reflecting a positive perception of its strategic direction among citizens. Second, the clarity of recycling information (Q11) records the lowest average in this dimension ($M = 78.2$, Disagree = 6, 43%), demonstrating a gap between stated strategic aspirations and actual on-the-ground implementation at the neighborhood level.

This gap corroborates the warning issued by Guide & Van Wassenhove (2009) that effective municipal governance requires the continuous operational translation of overarching goals into tangible services with which citizens interact on a daily basis. As for the effectiveness of smart applications (Q13, $M=84.2$, Rejection=5.34%), the results indicate that the digital system has not yet achieved sufficient geographic coverage or usage density.

5/5 Fourth Dimension: Readiness for Future Participation:

This pillar is the most indicative of the opportunities available for developing the circular economy system in Jeddah, as it measures the actual readiness to engage with digital, incentive-based, and legislative solutions.

Table (5-4): Results of the Fourth Axis—Readiness for Future Participation (n = 55)

The phrase	M	is	Agree	Neutral	Disagree	N
Q15: Willingness to use a digital app for waste collection	4.40	0.83	81.8%	16.4%	1.8%	55
Q16: Interest in incentive programs with rewards	4.09	1.19	72.7%	16.4%	10.9%	55
Q17: Family and Neighbors' Involvement in Raising Awareness of the Circular Economy	4.33	0.92	80.0%	14.5%	5.5%	55
Q18: Support for imposing fines on illegal dumping	4.22	1.15	76.4%	12.7%	10.9%	55
Average of the fourth axis	4.26	—	—	—	—	55

An Analytical Review of the Readiness Axis Results:

The results for this axis are characterized by a striking increase in the means (9.0 – 4.40 – 4) and a clear narrowing of the standard deviations (83.0 – 9.1). This combination of high scores and homogeneity is rare in surveys and indicates a consistent societal trend regardless of different demographic groups.

Leading the averages is the statement regarding willingness to use a digital application (Q15, $M = 40$, $SD = 83.0$, agreement = 8.81%), which has the highest mean and narrowest standard deviation in the entire survey, representing a near-unanimous societal consensus not seen in any other statement. This result aligns with Govindan & Hasanagic's (2018) finding that the use of IoT reduces operating costs by 30%.

Additionally, (0.80%) expressed a desire to raise awareness within their families and neighborhoods (Q17, $M = 33.4$), a valuable community asset that enables the creation of a network of grassroots environmental ambassadors at a low operational cost. Furthermore, 4.76% affirmed their support for imposing fines (Q18, $M=22.4$), which constitutes explicit support for implementing EPR within the regulatory framework of the Waste Management Regulatory Authority (2022).

Analysis of Open-Ended Questions:

Responses to the two open-ended questions came from 45 respondents regarding barriers and 43 regarding

proposals; the following is a qualitative classification of these responses and their key points:

- 18 -

Table (5-5): Classification of Responses to Open-Ended Questions—Barriers and Suggestions

Notable Examples	(n=43)	Barriers (n=45)	Category
Lack of colored recycling bins in neighborhoods	6 (14.0%)	13 (28.9%)	Infrastructure
School, university, and media campaigns	19 (44.2%)	9 (20.0%)	Awareness and Information
Reward Points for Waste Drop-Offs	5 (11.6%)	—	Financial incentives
Work pressures and daily obligations	—	6 (13.3%)	Time and busyness
Enforcing fines and combining them with awareness campaigns	Awareness	—	Legislation and Oversight
Models from Other Countries, General Government Support	13 (30.2%)	17 (37.8%)	Other / None

Perceived Obstacles: Three Main Patterns:

The responses to the first open-ended question reveal three recurring main patterns:

- Lack of infrastructure (9.28% of responses): Participants almost unanimously pointed to the absence of color-coded recycling bins (plastic, paper, glass, metal) in neighborhoods, apartment buildings, and residential complexes, along with the limited availability of specialized collection points for electronic waste. This correlates directly with the lowest two averages in the second axis (Q5=2.47 and Q6=2.58).
- Lack of Awareness and Information (0.20% of responses): Many expressed ignorance regarding proper sorting methods, the locations of nearby collection points, and the schedules of periodic collection campaigns. This lack of awareness accounts for the low score on the awareness axis (M = 92.2) and provides a qualitative explanation for it.
- Time constraints and busyness (3.3% of responses): Some respondents noted that daily commitments prevent them from participating regularly, highlighting the importance of designing convenient solutions integrated into daily routines, such as a bin at the doorstep and a mobile app.

Community Proposals: Awareness Takes Center Stage

Awareness and education topped the participants' suggestions at 2.44%, sending a clear message: citizens recognize that the root of the problem lies in a lack of knowledge and want to address this before anything else. The suggestions included:

- Deploying color-coded recycling bins in every residential building, complex, mosque, and school in Jeddah's neighborhoods.
- Launching a points-and-rewards system: Each kilogram sorted earns points that can be redeemed for discounts at shopping centers.
- Integrating the circular economy into school curricula and organizing competitions among schools.
- Providing official government apps that allow users to locate the nearest collection point in real time.
- Engaging social media influencers to spread environmental messages in an engaging way that resonates with young people.

Results of the Jeddah Municipality Employee Survey (n = 38):

Axis 1: Operational Reality of Reverse Supply Chains:

This axis measures the actual level of reverse supply chain infrastructure within the Municipality in terms of the collection and sorting network, digital tracking, and partnerships with recycling companies.

Table (5-6): Results of the First Axis—Operational Reality of Reverse Supply Chains (n = 38)

Statement	M	A	Agree	Neutral	Reject	N
Q1 : Availability of an integrated waste collection and sorting network	4.29	0.77	92.1 %	2.6%	5.3%	38

Q2: Implementation of source separation systems	3.74	0.79	68.4%	23.7%	7.9%	38
Q3: Availability of digital infrastructure for waste tracking	4.05	0.94	83.8%	8.1 %	8.1 %	37
Q4: Existence of effective partnerships with recycling companies	4.05	0.73	76.3%	23.7%	0.0%	38
Q5: Regularly measure material recovery rates	3.97	0.72	73.7%	26.3%	0.0%	38
Average of the first axis	4.02	—	—	—	—	38

Analytical Interpretation of the Operational Dimension Results:

The results in Table (6) paint a relatively positive operational picture with an axis average of (4.02), with the statement “Availability of an integrated network for waste collection and sorting” (1Q) standing out as having the highest average in the axis (4.29) and the highest agreement rate (1.92%), which is the highest figure in the entire employee survey, confirming that employees perceive an operational structure that is already in place.

However, the statement regarding the implementation of source separation systems (Q2) recorded the lowest average on the axis (M=4.7, agreement=4.68%), indicating that source separation remains a weak link in the system. This internal gap acknowledged by Secretariat staff precisely explains the root cause of the two lowest averages in the citizen survey (Q5 = 7.4, 2 and Q6 = 8.5, 2): the system suffers from the same weakness both internally and externally at the source separation stage.

Furthermore, the digital infrastructure for waste tracking (Q3, M=0.5, 4, Agree=8, 83%) and partnerships with recycling companies (Q4, M=0.5, 4, agreement = 3, 76%) also score high, indicating that the post-collection treatment system is more mature than the source-separated collection system.

5/8 Second Axis: Level of Alignment with the Circular Economy and Vision 2030:

This axis examines the extent of institutional alignment with the requirements of the circular economy and the quality of existing regulatory and coordination frameworks.

Table (5-7): Results of the Second Axis—Alignment with the Circular Economy (n = 37–38)

The phrase	M	is	Agree	Neutral	Reject	N
Q6: Alignment with Vision 2030 Targets	4.18	0.65	86.8%	13.2%	0.0%	38
Q7: Clarity of the legal framework for Extended Producer Responsibility (EPR)	3.70	0.70	56.8%	43.2%	0.0%	37
Q8: Quality of coordination among relevant government agencies	4.14	0.71	86.5%	10.8%	2.7%	37
Q9: Adequacy of Economic Incentives for Recycling	3.43	0.99	43.2%	43.2%	13.5%	37
Average of the second axis	3.87	—	—	—	—	37

An Analytical Review of the Alignment Axis Results:

Table (7) highlights a high level of institutional alignment with the national strategic direction, as alignment with the Vision 2030 targets (6Q) received the highest approval rating in this axis (M = 18.4, Agreement = 8.86%) with a narrow standard deviation (65.0), indicating a clear institutional consensus. Similarly, the quality of coordination among government agencies (8Q, M = 14.4, Agreement = 5.86%) is high.

In contrast, the adequacy of economic incentives for recycling (9Q) represents the most concerning indicator in this axis (M=43.3), with a perfectly even distribution between agreement and neutrality (2, 43% each) and a rejection rate of 5.13%; This distribution indicates that the existing incentives neither resolve the issue nor convince

anyone sufficiently. This is reinforced by the finding of Ghisellini et al. (2016) that circular economy cycles cannot be closed without a carefully designed system of financial incentives for the various stakeholders. As for the clarity of the legal framework for (Q EPR, M=70.3), with a neutrality rate of 2.43%, this indicates that the legislative text exists but lacks sufficient clarity and enforceability for effective implementation.

Third Theme: Regulatory and Logistical Barriers:

This axis explores the most significant practical obstacles that limit the efficiency of the material recovery and recycling system within the Secretariat.

Table (5-8): Results of the Third Axis—Regulatory and Logistical Barriers (n = 37)

The phrase	M	is	Agree	Neutral	Reject	N
Q1 0: Rising logistics costs are a major obstacle	3.54	0.84	59.5%	27.0%	13.5%	37
Q1 1: Lack of public Awareness is a major structural Barrier	4.14	0.82	78.4%	18.9%	2.7%	37
Average of the third axis	3.84	—	—	—	—	37

An Analytical Review of the Results for the Barriers Axis:

The results in Table (8) reveal a clear institutional consensus on the nature of the first obstacle: low public awareness (Q11, M = 4.4, Agreement = 4.78%). This internal acknowledgment by Secretariat staff that the problem begins with the citizen directly correlates with a low score (M = 92.2) on the awareness dimension of the citizen survey, thereby providing dual confirmation of the same gap from two different perspectives. As for the high logistical costs (Q10, M = 54, agreement = 5, 59%), this indicates a real financial burden in collection and transportation operations, which can be reduced through the application of GIS and route optimization algorithms, as explained by Govindan & Hasanagic (2018), which could save up to 30% of operating costs.

The fourth pillar: Adoption of modern technologies:

This axis monitors the level of adoption of advanced digital technologies in the waste management system, including IoT, artificial intelligence, blockchain, and GIS.

Table (5-9): Results of the Fourth Axis—Adoption of Modern Technologies (n = 37)

The phrase	M	is	Agree	Neutral	Reject	N
Q1 2: IoT Applications in Smart Container Monitoring	3.32	1.03	48.6%	27.0%	24.3%	37
Q1 3: Using artificial intelligence to optimize collection routes	3.76	1.09	62.2%	24.3%	13.5%	37
Q1 4: Blockchain for Transparency in Supply Chains	3.46	0.87	51.4%	37.8%	10.8%	37
Q1 5: GIS in the Planning of Collection Networks and Routes	4.19	0.62	89.2%	10.8%	0.0%	37
Q1 6: Integration of the digital system with open data	4.00	0.78	81.1%	13.5%	5.4%	37
Average of the fourth axis	3.75	—	—	—	—	37

An Analytical Review of the Technology Axis Results:

The results in Table (9) provide a clear picture of technical readiness: GIS for planning collection networks (15Q) ranked at the top with the highest mean in this pillar (M = 19.4) and the narrowest standard deviation in the entire survey (2.62), along with a 2.89% agreement rate—a rare level of institutional consensus that represents an ideal starting point for its immediate implementation. This is followed by digital system integration (Q16, M = 0.4, agreement = 1.81%).

In contrast, IoT for smart containers (Q12) recorded the lowest mean on the axis (M = 3.32) along with the highest rejection rate (3.24%) and the highest standard deviation (3.01), indicating that this technology is still in an early stage of implementation and has not yet built sufficient institutional trust. This suggests that the logical sequence of adoption begins with GIS (the lowest cost and highest acceptance), followed by AI, and then IoT, in that order.

As for (Q Blockchain 4, 1, M = 46, 3, Neutrality = 8, 37%), it reflects a knowledge gap regarding this

technology and its potential applications in environmental transparency, which necessitates specialized technical training programs.

Section Three: Comparative Analysis and Discussion of Results in Light of the

Theoretical Framework:

Summary of Results for the Eight Themes:

The following table provides a panoramic view comparing the results of all themes in both questionnaires side by side:

Table (5-10): Comparative Summary of the Results of the Two Surveys' Thematic Areas

's lowest-rated phrase	Highest phrase	Level	Average	Axis
2.85	2.95	Low	2.92	M1: Awareness of the circular economy (citizens)
2.47	3.69	Low	2.95	M2: Behavioral Practices (Citizens)
2.78	3.60	Average	3.11	Item 3: Assessment of Services and Infrastructure (Citizens)
4.09	4.40	Very high	4.26	Item 4: Willingness to Participate in Future Initiatives (Citizens)
3.74	4.29	High	4.02	Item 1: Operational Reality (Employees)
3.43	4.18	High	3.87	M 2: Alignment with the Circular Economy (Employees)
3.54	4.14	High	3.84	Item 3: Regulatory Barriers (Employees)
3.32	4.19	High	3.75	Item 4: Modern Technologies (Employees)

5/2 Discussion of the Results in Light of the Theoretical Framework:

The results of the two questionnaires align with the theoretical framework reviewed in Chapter 3, revealing three levels of the analytical gap:

First: The awareness-practice gap at the societal level:

A comparison between the readiness dimension ($M = 26.4$) and the practice dimension ($M = 95.2$) reveals a gap of 1.31 points, which is the widest in the study. Respondents who are ready for change (8.81%) want digital implementation but do not practice sorting (1.49% do not sort). This gap aligns with what the product life cycle theory confirms: that behavioral reform requires a design-based intervention in infrastructure before any awareness-raising intervention.

Second: The Source-Operational Gap at the Institutional Level:

Secretariat staff acknowledge the efficiency of the collection and processing network ($M = 29.4$ for Q1) but admit to weak source separation ($M = 47.3$ for Q2). This internal gap explains why the system appears integrated from an operational perspective but yields modest results in material recovery rates, a point addressed by Guide & Van Wassenhove (2009) in their analysis of circular supply chain failures.

Third: The Strategy-Communication Gap at the Governance Level:

The discrepancy between the assessment of commitment to Vision 2030 ($M = 60.3$, agreement = 1.49%) and the assessment of the clarity of recycling information ($M = 78.2$, disagreement = 6.43%) documents a highly significant communication gap. The Secretariat is achieving its strategic targets but is not communicating these achievements to citizens sufficiently to change their behavior. De Angelis (2018)

noted that translating environmental strategy into viable business models requires multi-level institutional communication bridges.

Results, Conclusions, and Recommendations

Presentation and Discussion of Results:

Results of the Citizen and Resident Survey (n=55):

The results of the first survey reveal a clear pattern across the four themes, summarized in the following table:

Table (6-1): Summary of Results for the Citizen Survey Dimensions

Axis	Average	Standard Deviation	Agreement Rate	Interpretation
Axis 1: Awareness of the Circular Economy	2.92	1.34-1.53	29-40%	Low
Axis 2: Actual Behavioral Practices	2.95	1.35-1.47	21-62%	Low
Axis 3: Assessment of Services and Infrastructure	3.11	1.24-1.45	27-49%	Medium
Axis 4: Readiness for Future Participation	4.26	0.83-1.19	72-82%	Very high
Overall Survey Average	3.31	—	—	Average

A Dimension 1: Level of Awareness of the Circular Economy (M = 92.2):

This dimension recorded the lowest score in the survey with a mean of (2.92), and its means ranged from (2.85) for familiarity with the term “circular economy” to (2.95) for following news on environmental transition. Most significantly, the rejection rate for all statements in this axis exceeded 34%, a finding that fully aligns with the assertion by Al-Salem et al. (2022) that Saudi Arabia suffers from a wide knowledge gap in the circular economy sector, necessitating a systematic, multi-level awareness-raising strategy.

It is noteworthy that the agreement rate regarding awareness of the Jeddah Secretariat for Recycling's initiatives (Q2) reached 40.0%, the highest rate in this axis; however, 2.38% remain unaware of these initiatives, indicating a shortcoming in institutional communication channels rather than in the existence of the initiatives themselves.

B Second Dimension: Actual Behavioral Practices (M = 95.2):

This axis reveals the most striking contradiction in the study: While household waste sorting (Q5) recorded the lowest average in the entire questionnaire (M = 47.2, “Disagree” = 1, 49%), formal disposal of bulky waste (Q9) recorded the highest average in this axis (M = 69.3, “Agree” = 8, 61%). This contradiction can be explained by the fact that household sorting requires a daily infrastructure (separate bins) that is lacking, whereas formal disposal is a necessary channel for which there is no alternative.

This finding is consistent with the observation by Rogers & Tibben-Lembke (2001) that the absence of specialized recovery networks is the most significant logistical barrier in reverse supply chains. As for the preference for environmentally friendly products (Q=8, M=3.38, Agree=8, 41%), it reflects a positive intention that is hindered by barriers related to price and availability, which calls for incentive-based support mechanisms, as recommended by Ghisellini et al. (2016).

C Third Dimension: Evaluation of Services and Infrastructure (M = 11.3):

This dimension had the highest mean among the first three dimensions (11.3), and two phenomena are worth analyzing: First, the Secretariat's commitment to the Vision 2030 targets (Q4) received the highest rating (M = 60.3, agreement = 1.49%), reflecting a relatively positive perception of the strategic direction. Second, the clarity of recycling information (Q11) recorded the lowest average in the dimension (M = 78.2, Disagreement = 6.43%), which demonstrates a gap between stated strategic ambition and actual on-the-ground implementation—exactly what Guide & Van Wassenhove (2009) in the context of municipal governance.

As for the effectiveness of smart applications (Q13, M = 48.2, Rejection = 5.43%), it confirms that the digital system has not yet reached the critical mass necessary to influence behavior, which supports the recommendation made by Govindan & Hasanagic (2018) regarding the need to further integrate IoT and artificial intelligence into the waste management system.

D Fourth Dimension: Readiness for Future Participation (M = 26.4):

This dimension represents the most valuable social asset revealed by the study, as its averages ranged from (9.04) to (40.4), all of which were higher than (4) across all four statements. The three most notable figures in this dimension are:

- Willingness to use a digital app for waste collection: M = 40.4, agreement = 8.81%, narrow deviation = 3.8—the highest mean in the entire study.

- Desire for family and neighbors to share environmental awareness: M = 33.4, agreement = 0.80%.
- Support for imposing fines on illegal dumping: M = 22.4, agreement = 4.76%, representing explicit community support for implementing EPR.

Results of the Employee Survey (n=38):

The employee survey revealed a more optimistic internal organizational outlook compared to the citizens' perspective; however, it contains subtle warnings that should not be overlooked:

Table (6-2): Summary of Results for the Employee Survey Categories

Axis	Mean	Deviation	Agreement Rate	Interpretation
First Axis: Operational Reality of Supply Chains	4.02	0.72–0.94	68–92%	High
Axis 2: Alignment with the Circular Economy	3.87	0.65–0.99	43–87%	High
Axis 3: Regulatory and Logistical Barriers	3.84	0.82–0.84	59–78%	High
Axis 4: Adoption of modern technologies	3.75	0.62–1.09	48–89%	High
Overall Survey Average	3.87	—	—	High

A Topic 1: Operational Reality of Reverse Supply Chains (M = 2.04):

This dimension recorded the highest average in the employee survey (2.04), and the statement “Availability of an integrated waste collection network” (1Q) topped the averages at (29.4) with an agreement rate of (1.92%), confirming that employees perceive an operational structure that is already in place. However, the statement “Systems source separation systems (Q2) scored the lowest in this axis (M = 4.7, agreement = 4.68%), indicating that source separation remains a weak link in the system—a finding that aligns with citizens' complaints about the lack of sorted bins.

B Second Axis: Alignment with the Circular Economy and Vision 2030 (M = 87.3):

Alignment with the Vision 2030 targets (6Q) received the highest approval rating in this axis (M = 18.4, Approval = 8.86%), which is a positive indicator of institutional alignment with national strategic goals. In contrast, the adequacy of economic incentives (Q9) recorded the lowest average in this axis (M = 43.3), with an equal distribution between agreement and neutrality (2.43% each), a clear indication that the incentive system has not reached the level of adequacy required to stimulate participation in the circular economy.

C Third Dimension: Regulatory and Logistical Barriers (M = 84.3):

In this axis, there was a notable consensus among employees that low public awareness is a major structural barrier (Q11, M = 4.14, agreement = 4.78%), which is an internal acknowledgment that the system faces challenges from the public sector rather than the institutional sector. Furthermore, the high logistical costs (Q10, M = 54.3) are confirmed by the agreement rate (5.59%), highlighting the need to improve routes and utilize GIS to reduce operating costs.

D Fourth Dimension: Utilization of Modern Technologies (M = 75.3):

This axis presents a mixed picture of technical readiness: at the top were GIS for network planning (Q15, M = 91.4, agreement = 2.89%) and digital system integration (Q16, M = 0.04, agreement = 1.81%), both with very high levels. In contrast, IoT for smart containers (Q12) recorded the lowest average in the axis (M = 23.3, Disagree = 3, 24%), indicating that this technology is still in the development phase and has not yet been implemented on a sufficiently large scale.

The Operational Gap Between the Employee Perspective and the Citizen Perspective:

The analysis of the gap between internal and external perspectives constitutes the most significant contribution of this study, as it answers a fundamental question: Where exactly does the gap lie between what the Secretariat provides and what citizens experience?

Table (6-3): Analysis of the Gap Between the Perspectives of Employees and Citizens on Common Themes

Significance	Gap	Citizens' Perspective	Employees' Perspective	Comparative Dimension
Critical gap	1.69–1.82	2.60–2.47 (Low)	4.29 (High)	Selective Collection Infrastructure
Large gap	1.10	2.92 (low)	4.02 (High)	Awareness of the Circular Economy
Gap: Moderate	0.91	2.84 (Low)	3.75 (High)	Digital Technologies (IoT/AI/GIS)
Moderate gap	0.58	3.60 (Medium)	4.18 (High)	Commitment to Vision 2030
Strong alignment	0.24	4.26 (High Very high)	4.02 (High)	Readiness for Future Engagement

The data in Table (3) confirm that the most significant gaps are found in the selective collection infrastructure domain (gap of 1.69–1.82 points); Employees perceive a well-functioning network ($M = 29.4$), while citizens suffer from a lack of sorted recycling bins in their neighborhoods ($M = 47.2$). This numerical discrepancy demonstrates that the problem lies not in the efficiency of transportation and processing operations, but rather in the first point of contact with citizens: the recycling bin at the entrance to their building.

In contrast, the gap in willingness to participate in future initiatives is very small (24.0 points), a rare consensus that suggests both parties recognize the strategic value of digital and legislative solutions, thereby laying a solid foundation for implementing the proposed model.

Conclusions:

Based on the dual statistical analysis of data from citizens and employees, and their discussion in light of the theoretical framework, eight key conclusions emerge:

Table (6-4): Key Findings of the Study and Their Statistical Evidence

#	Conclusion	Statistical Evidence
1	A wide awareness gap among citizens despite a strong desire for change	Awareness score = 2.92 vs. Willingness score = 4.26
2	Inadequate infrastructure is the primary obstacle, not a lack of willingness	Sorting score = 2.47 vs. formal disposal score = 3.69
3	Employees recognize the strength of the operational infrastructure but acknowledge weak incentives and smart applications	Incentives = 3.43 / IoT = 3.32
4	Readiness for digital solutions is the highest collective asset that can be invested immediately	Digital Adoption = 4.40 (8.8% approval)
5	Weak organizational communication creates a gap between strategic ambition and on-the-ground implementation	Commitment to Vision = 3.60 vs. Clarity of Information = 2.78
6	The GIS system for optimizing collection routes has the highest level of agreement Among Secretariat staff	GIS score = 9.4 with a narrow standard deviation of 22.0

7	The public openly supports deterrent legislation as a catalyst for change	4.76% support fines / m = 22.4
8	The gap between intent (26.4) and reality (92.2-11.3) represents both a challenge and an opportunity	Difference = 15.1 - 1.34 points

Recommendations:

First: Recommendations for the Jeddah Provincial Secretariat:

1. Top priority: Immediately expand the network of sorted waste containers—a 1.82-point gap between employee ratings (29.4) and citizen practices (47.2) makes this measure urgent.
2. Launch an official smart waste management app operating 24/7, leveraging the exceptional digital readiness (8.81% readiness, M=40.4), while ensuring its geographic coverage across all neighborhoods.
3. Design a well-thought-out incentive program (points, discounts, prizes) based on the 7.7% of citizens who are interested in it, to transform intention into consistent behavior.
4. Bridge the institutional communication gap by updating official media channels and publishing an interactive map of collection points, addressing the lowest rating in the third pillar (M = 78.2 for clarity of information).
5. Form a specialized waste data management unit that utilizes GIS and artificial intelligence, based on the 2.89% of municipal employees who support the implementation of GIS (M = 19.4).

Second: Policy and Legislative Recommendations:

1. Issue an EPR regulation requiring producers and distributors to take back their products at the end of their life cycle, addressing the weakness in the legal framework identified by 2.43% of Secretariat staff (M = 70.3) as an institutional barrier.
2. Enforce a system of fines for illegal disposal in a fair and transparent manner according to a clear legislative framework, based on explicit community support of 4.76% (M=22.4).
3. Incorporate the circular economy and reverse supply chains into primary, secondary, and university curricula to foster a conscious generation and structurally address the low average awareness level (92.2).
4. Introduce tax and incentive measures for private companies engaged in recycling to implement the PPP model more effectively.

Third: Recommendations for Scientific Research:

1. Conduct a longitudinal study to measure the impact of implementing sorted recycling bins on sorting rates over a 12–24-month period, to fill the major research gap identified by this study.
2. Conduct a comparative study among major Saudi cities (Riyadh, Makkah, Dammam) using the same methodology to develop a comprehensive national model.
3. Conduct an economic feasibility study of the proposed operational model by determining the cost-benefit ratio of material recovery (urban mining), to provide decision-makers with supporting financial evidence.
4. To explore successful international models (Amsterdam, Singapore, Seoul) and assess their adaptability to the urban context of Jeddah.

Conclusion

This study began with a single fundamental question: How can an integrated reverse supply chain model be developed to contribute to the promotion of circular economy applications within the Jeddah Municipality? It answered this question using a dual methodology unprecedented in this context, combining the perspectives of 55 citizens and residents with those of 38 specialized employees to produce a comprehensive picture that neither group could provide on its own. The most important finding revealed by this study is not in the low numbers, but rather in the high ones: (8.81%) of citizens are ready to use the digital app, (80%) want to raise awareness in their communities, (4.76%) support fines, and (2.89%) of municipal employees support GIS. These figures do not reveal an apathetic society or a complacent institution, but rather a collective and institutional will that is ready and waiting for the right tool—and the right tool, as proven by the data, is: a sorted recycling bin at the entrance of every building, a smart app on every phone, and a financial incentive that turns intention into action.

Today, the city of Jeddah possesses all the elements necessary for the transition to a circular economy: a strategic ambition embodied in Vision 2030, a strong community will as documented by this study, and specialized human resources within the Municipal Secretariat. What is needed is a single bridge to connect these elements: an integrated operational model that starts with simple, immediately implementable steps and gradually evolves toward a fully smart system.

References

First: Arabic References:

- Jeddah Municipality (2024). Statistical Reports and Urban Indicators for Waste Management in the City of Jeddah.

Jeddah, Kingdom of Saudi Arabia.

- Al-Jalamda, Majd Ayman Madi (2024). Waste Management and Solid Waste Sorting within the Framework of the Circular Economy in Municipalities. *Journal of Humanities and Natural Sciences*, Vol. 5, No. 3.
- Al-Saman, Ehab (2022). The Role of Reverse Supply Chain Operations in Egyptian Seaports in Enhancing the Institutional Performance of Industrial Organizations. *Scientific Journal of Financial and Commercial Studies and Research*.
- Ghoneim, Hind Abdel Hamid Satohi (2024). Reverse Supply Chains as a Mediating Variable in the Relationship Between Outsourcing and Sustainable Development: An Empirical Study of Paper and Cardboard Companies in Sadat City. *Journal of Commercial Research*.
- National Center for Waste Management "Mawan (2023)." Annual Report on Sustainability Indicators and Waste Diversion from Landfills in the Kingdom of Saudi Arabia. Riyadh, Kingdom of Saudi Arabia. (Source for diversion target figures of 85% and 94%).
- National Center for Waste Management. (2023). Annual Performance Report on the Waste Management Sector in the Kingdom of Saudi Arabia. Ministry of Environment, Water, and Agriculture.
- Industrial and Technology Zone Development Authority – Waste Management Regulatory Authority. (2022). Regulatory Framework for Solid Waste Management in Major Saudi Cities.

Second: Foreign

- Aboelmaged, M. (2018). Direct and indirect effects of eco-innovation, environmental orientation, and supplier collaboration on hotel performance. **Journal of Cleaner Production**.
- Alkahtani, M., et al. (2021). "A Decision-Making Framework for Prioritizing Reverse Logistics Policies to Support the Circular Economy." **Sustainability**.
- Alnoor, A., et al. (2019). "Determinants of Reverse Logistics Adoption and Its Effect on Sustainable Manufacturing." **International Journal of Supply Chain Management**.
- Al-Salem, S. M., et al. (2022). Circular Economy and Sustainability in Saudi Arabia: Challenges and Opportunities. **Waste Management Journal**, 45, 112–125.
- Al-Salem, S. M., et al. (2022). Plastic waste management strategies and their environmental impacts. *Journal of Environmental Management*.
- Dabees, A., et al. (2023). A Systematic Literature Review on Sustainable Reverse Logistics Service Quality. Sustainability. (Reference No. 56, research paper) De Angelis, R. (2018). *Business Models in the Circular Economy*. Palgrave Macmillan.
- De Angelis, R. (2018). *Business Models in the Circular Economy: Concepts, Examples, and Theory*. Palgrave Macmillan.
- Dubey, R., et al. (2017). Can big data and predictive analytics improve social and environmental sustainability? *International Journal of Production Economics*.
- Ellen MacArthur Foundation (2019). *Completing the Picture: How the Circular Economy Tackles Climate Change*. (3,573 references on emissions reduction).
- Ellen MacArthur Foundation. (2019). *Completing the Picture: How the Circular Economy Tackles Climate Change*. Ellen MacArthur Foundation Publications.
- Fernando, Y., et al. (2023). The Role of Reverse Logistics in Achieving a Circular Economy and Sustainable Performance. *Supply Chain Management*.
- Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on the circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11–32.
- Ghisellini, P., et al. (2016). A review of the circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*.
- Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices toward a circular economy. *International Journal of Production Research*.
- Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices toward the circular economy: A supply chain perspective. *International Journal of Production Research*, 56(1-2), 278–311.
- Guide, V. D. R., & Van Wassenhove, L. N. (2009). The Evolution of Closed-Loop Supply Chain Research. *Operations Research*.
- Guide, V. D. R., & Van Wassenhove, L. N. (2009). The evolution of closed-loop supply chain research. *Operations Research*, 57(1), 10–18.
- Mokhtar, A. R. M., et al. (2019). The influence of reverse logistics on organizational performance. *Journal of Fundamental and Applied Sciences*.
- Nunnally, J. C. (1978). *Psychometric theory* (2nd ed.). McGraw-Hill.
- Prajapati, H., et al. (2022). A review of consumer return management and its impact on reverse logistics. *Logistics*.
- Rogers, D. S., & Tibben-Lembke, R. (2001). An examination of reverse logistics practices. *Journal of Business Logistics*.
- Rogers, D. S., & Tibben-Lembke, R. (2001). An examination of reverse logistics practices. *Journal of Business Logistics*, 22(2), 129–148.
- Waste Management Regulatory Authority (2022). *Economic and Environmental Impact Report on Waste Management Systems*. (Reference No. Financial Waste).