

Integrating Circular Economy and Reverse Logistics in Waste Management: A Case Study of the Processed Meat Industry in Panama Toward Sustainable Supply Chains

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Abstract—The processed meat industry faces critical challenges in balancing competitiveness with sustainability, particularly in emerging economies. This study analyzes waste management practices in a leading Panamanian meat processing company, integrating circular economy principles and reverse logistics strategies to strengthen supply chain resilience. Using semi-structured interviews and non-participant observations, the research identifies key waste streams—organic residues, packaging materials, and non-conforming products—and evaluates their operational, economic, and environmental impacts. Findings reveal partial valorization of organic by-products but significant gaps in packaging recovery, traceability, and performance monitoring. To address these deficiencies, the study proposes a framework that embeds reverse logistics into the supply chain, incorporating industrial symbiosis, biorefinery applications, and lean protocols. This approach positions waste not as a liability but as a resource, aligning with Sustainable Development Goals (SDG 12 and SDG 9) and advancing supply chain sustainability in Latin America. The contribution lies in offering the first qualitative evidence for Panama’s meat industry, providing actionable insights for policymakers and firms seeking innovation, competitiveness, and alignment with international standards.

Keywords—Circular economy, reverse logistics, waste management, sustainable supply chain, processed meat industry.

I. INTRODUCTION

Waste management in the processed meat industry has emerged as a global challenge for food security and sustainability. This sector plays a crucial role in meeting protein demand and driving economic growth, while simultaneously generating employment and strengthening agro-industrial value chains. In Panama, the processed meat industry contributes significantly to domestic food supply and rural development. However, its operations produce substantial waste streams that pose environmental, economic, and social challenges, making effective management an increasingly urgent priority.

The prevailing linear production paradigm (take-make-dispose) has demonstrated long-term unsustainability. Rising global demand for animal protein intensifies pressure on critical resources such as water, land, and energy. Waste generation not only reflects economic inefficiency but also contributes to greenhouse gas emissions, soil and water contamination, and biodiversity loss [1]. International organizations, including the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP), have underscored

the magnitude of food waste and the urgent need for systemic change [4]. These calls align with Sustainable Development Goal 12 (Responsible Consumption and Production) and highlight the importance of transitioning toward circular economy models in food supply chains.

This research adopts a localized perspective through a qualitative case study of a leading meat processing company in Panama. By examining its value-added plant, the study diagnoses current waste management practices, identifies root causes of inefficiencies, and proposes a framework for action based on more sustainable production models. The analysis explores the feasibility of integrating circular economy principles, lean manufacturing, and clean technologies as strategic tools to transform waste into resources, thereby aligning profitability with environmental and social responsibility.

Ultimately, this study aims to generate insights that benefit the company under analysis while establishing a precedent for other firms in Panama and Latin America. The findings contribute to building a meat industry that is more resilient, competitive, and aligned with international sustainability standards, positioning waste management not only as an environmental duty but also as a strategic opportunity for innovation and long-term competitiveness.

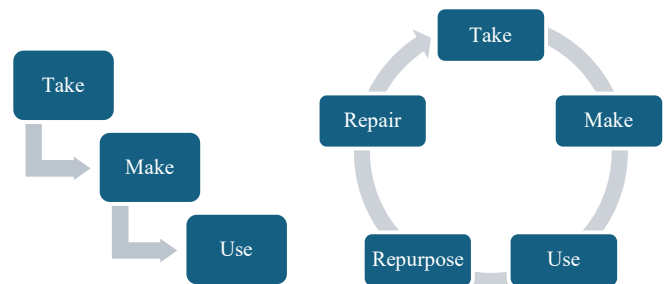


Fig. 1. Linear economy vs. circular economy.

II. STATE OF THE ART

A. Global Background

The processed meat industry has long been recognized for its significant contributions to national economies and global food security. However, it simultaneously faces persistent

challenges in waste management and environmental sustainability. Effective waste management practices are essential to mitigate negative environmental impacts, reduce inefficiencies, and strengthen the sustainability of production processes. Conventional methodologies, such as recycling, valorization, and disposal strategies, have been widely adopted, yet their effectiveness remains limited, highlighting the need for comprehensive evaluations and the integration of innovative solutions.

[8] provides a detailed classification of waste generated in meat processing, including organic residues and packaging materials, noting that conventional strategies often fail to adequately address environmental repercussions. [9] reinforce this perspective through a comparative analysis of sustainability performance before and after wastewater management interventions, demonstrating that innovative practices can significantly enhance the sustainability profile of meat processing systems.

Industrial symbiosis has emerged as a promising approach to sustainable waste management. [10] illustrate this through the Śmółowo Eco-Industrial Park in Poland, where collaboration between industries facilitates waste minimization and resource recovery. This model exemplifies how interconnected systems can advance circular economy principles, extending sustainability beyond waste management into broader environmental strategies.

[11] conducted a systematic review of sustainability practices within the meat supply chain, emphasizing that many existing practices are underutilized or insufficient. Their work highlights the importance of systemic improvements in logistics, supply chain coordination, and cross-sector partnerships as vital elements for elevating sustainability efforts. Similarly, [12] focus on the beef value chain, proposing biorefinery concepts and waste-to-energy technologies to valorize waste streams, thereby reducing waste generation while simultaneously addressing energy needs.

Material flow analysis has also proven useful in identifying inefficiencies. [13] applied this approach to the Italian meat industry, revealing persistent resource inefficiencies and highlighting opportunities to convert waste into high-value products. [14] further demonstrate how poultry waste can be transformed into renewable energy inputs and other value-added products, illustrating the economic and environmental benefits of inter-industry synergies.

[15] broadens the scope by integrating environmental, economic, and social dimensions into meat sector sustainability, advocating for holistic approaches that harmonize objectives across production and consumption. [16] compare conventional wastewater treatment methods with innovative techniques, showing clear advantages in terms of resource conservation and environmental integrity. Emerging technologies also play a transformative role: [17] highlights additive manufacturing as a pathway to optimize production processes, reduce waste, and align with sustainable production principles.

Taken together, these studies demonstrate that while current practices provide partial solutions, they often fail to

fully exploit opportunities for resource recovery and valorization. The transition toward integrated circular approaches, such as industrial symbiosis, biorefinery applications, and advanced wastewater treatment, offers a viable pathway to mitigate the ecological footprint of the meat industry. Achieving sustainable production will require collaborative, multifaceted strategies that combine technological innovation with systemic supply chain improvements.

B. Regional and Local Background

Food waste is a global phenomenon with profound implications. According to FAO, approximately one-third of all food produced for human consumption is lost or wasted annually. Within this scenario, the meat industry presents particularly alarming figures, with nearly 20% of global meat production lost or wasted each year. These losses occur across the entire value chain, from primary production to final consumption, magnifying their environmental, economic, and ethical impacts.

- **Environmental Impact:** Meat production is highly resource-intensive. Losses imply the squandering of water, land, and energy used in animal husbandry, processing, transportation, and refrigeration. Furthermore, the decomposition of organic waste in landfills generates methane (CH₄), a greenhouse gas significantly more potent than carbon dioxide (CO₂).
- **Economic Impact:** The loss of raw materials translates directly into financial losses for producers, processors, and retailers. Waste management and disposal costs further burden profitability.
- **Ethical and Social Impact:** In a world where millions suffer from food insecurity, the waste of nutritious foods such as meat raises profound ethical concerns.

At the national level, Panama reflects these global trends. The country generates more than 122,000 tons of organic waste annually, with the food sector contributing a significant share. The meat industry, due to its reliance on large volumes of highly perishable raw materials, is particularly vulnerable to inefficiencies. Without rigorous control and management systems, losses escalate rapidly. Leading companies in the sector occupy a strategic position to drive change, leveraging their scale and influence to promote sustainable practices and foster a transition toward circular economy models.

III. PROBLEM STATEMENT

The excessive generation of waste in the production of processed meat products in Panama constitutes a multidimensional problem with operational, economic, and environmental implications. These dimensions are deeply interconnected, creating systemic challenges that hinder the sustainability and competitiveness of the sector.

- **Operational Dimension:** Inefficiencies in production processes represent the primary source of waste generation. Common issues include failures in production planning, lack of standardized procedures for cutting and portioning, losses due to overproduction, and products rejected for not

meeting quality specifications. Inadequate management of perishable raw material inventories further exacerbates losses. Moreover, the absence of a strong organizational culture oriented toward continuous improvement and waste prevention perpetuates inefficiencies across the value chain.

- **Economic Dimension:** Every kilogram of discarded meat or packaging material translates into direct financial losses. These losses encompass not only the cost of raw materials but also labor, water, energy, and other inputs consumed during processing. Additional expenses arise from waste management activities, including storage, transportation, and final disposal. Importantly, many of these waste streams, currently treated as costs, could be valorized and transformed into new sources of revenue through recovery and recycling processes [7]. The lack of systematic recovery strategies represents a missed opportunity for economic optimization and innovation.
- **Environmental Dimension:** The environmental consequences of improper waste management are among the most severe. Organic waste, when inadequately handled, can contaminate soils and water sources, while plastic packaging contributes to terrestrial and marine pollution. The absence of adequate technological infrastructure and environmental education policies within the industry perpetuates unsustainable production cycles, exerting undue pressure on Panama's natural resources. Furthermore, the underestimation or lack of knowledge regarding the true magnitude of waste generation hinders the design and implementation of effective mitigation measures. A detailed analysis of critical points of waste generation is therefore essential to guide corrective actions [3].

In the specific case of leading meat processing companies in Panama, there is growing recognition of the need to address this issue. However, a significant gap persists between awareness and the implementation of systemic, formalized solutions that encompass the entire value chain. Bridging this gap requires not only technological innovation but also cultural and organizational transformation, aligning operational efficiency with environmental responsibility and economic resilience.

A. General Objective

To comprehensively analyze the waste generated at the value-added plant of a leading meat processing company in Panama, with the purpose of designing and proposing a set of improvement strategies grounded in sustainability principles, circular economy frameworks, and operational efficiency practices.

B. Specific Objectives

- To identify the main types of waste generated during the production process, quantifying their origin, frequency, and variability across different stages.

- To evaluate the environmental and economic impacts associated with the generation and current management of waste, highlighting inefficiencies and potential risks.
- To analyze critical stages of the production process where the highest levels of losses occur, to prioritize and focus improvement efforts.
- To propose concrete improvement alternatives based on circular economy principles, including the reuse of by-products, recycling of materials, and valorization of waste streams.
- To assess the level of awareness and perception among plant personnel regarding sustainability and waste management, identifying cultural and organizational factors that influence current practices.
- To identify operational and technological gaps in existing waste management systems, emphasizing opportunities for innovation, resource recovery, and revaluation of materials [7].

C. Justification

The execution of this study is justified by the convergence of three strategic factors: competitive necessity, environmental responsibility, and evolving consumer expectations [1]. Together, these dimensions underscore the urgency of addressing waste management in Panama's processed meat industry and highlight the potential benefits of adopting sustainable and circular practices.

- **Business Competitiveness:** Process optimization and waste reduction directly impact the cost structure of companies. In an increasingly competitive market, operational efficiency is not optional but a prerequisite for survival and growth. Proactive waste management reduces expenditures on raw materials, energy, and disposal, thereby improving profit margins and strengthening long-term resilience. Furthermore, valorization of waste streams can transform current costs into new sources of revenue, enhancing innovation and competitiveness.
- **Sustainability and Regulatory Compliance:** Environmental regulations at both national and international levels are becoming increasingly stringent. Companies that fail to adequately manage their environmental footprint face sanctions, fines, and reputational damage. Conversely, adopting sustainable production models ensures compliance while positioning firms as responsible leaders within their sector [1], [3]. This alignment with regulatory frameworks also facilitates access to international markets, where sustainability certifications and compliance with environmental standards are increasingly required.
- **Market Demand and Brand Reputation:** Modern consumers have evolved beyond traditional criteria of price and quality. Ethical and environmental commitment has become a decisive factor in brand choice [5]. Studies show that a growing number of consumers are willing to prefer—and even pay more for—products from companies that demonstrate social and environmental responsibility [3]. Poor waste management therefore poses a serious risk to competitiveness and customer loyalty, while exemplary

practices serve as powerful brand differentiators that enhance reputation and market positioning.

This analysis is not merely an academic exercise, but a practical tool aimed at proposing tangible solutions to strengthen the position of leading meat processing companies in Panama and, by extension, the national food industry in the 21st-century marketplace. By addressing waste management strategically, the industry can simultaneously improve efficiency, reduce environmental impacts, and respond to consumer expectations.

Moreover, this study aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 12.3, which seeks to halve per capita food waste at the retail and consumer levels by 2030 and reduce food losses along production and supply chains [4]. By contributing to this global agenda, the research not only supports national sustainability efforts but also positions Panama's meat industry within the broader international movement toward circular economy and responsible consumption.

IV. MATERIALS AND METHODS

This research was conducted under an applied research approach, designed to address a practical and specific problem within a real industrial context. To achieve this objective, qualitative methods were primarily employed, enabling an in-depth understanding of the phenomena through the interpretation of non-numerical data and the exploration of perceptions, practices, and operational dynamics.

Waste Generation (Production Stages)	Initial Handling and Segregation	Reverse Logistics Pathways
- Cutting and deboning: meat scraps, fat, bones. - Packaging: plastics, carboard. - Quality control: non-conforming products.	- Source separation of organic vs. packaging waste. - Temporary storage in designated areas. - Identification of non-conforming products for rework or discard.	- Valorization as animal feed, potential biogas input, composting. - Partial recycling, potential recovery through supplier take-back programs.
Transportation and Internal Flows	Final Disposal / Valorization Outcomes	Feedback Loop for Sustainable Supply Chain
- Movement of segregated waste to internal collection points. - Transfer to external partners (feed producers, recyclers, energy recovery facilities). - Documentation and traceability gaps identified.	- Organic waste: reused (feed, compost, energy) - Packaging: recycled or landfilled (due to weak traceability). - Non-conforming products: discarded or partially reprocessed.	- Establishment of KPIs for waste reduction. - Supplier evaluation based on sustainability criteria. - Continuous training to staff to embed circular economy practices. - Integration of industrial symbiosis opportunities.

Fig. 2. Logistic flow map of waste (generation to final disposal).

A process-oriented mapping was conducted to identify critical points of waste generation across the value-added plant. Material flow diagrams were developed to trace organic residues, packaging materials, and non-conforming products from origin to disposal, highlighting inefficiencies and opportunities for reverse logistics integration.

A. Data Collection Techniques

The principal technique for collecting primary data was the semi-structured interview. A flexible interview guide was developed and directed at a key informant—an employee of the production plant—selected for his extensive knowledge of daily operations. The interview explored multiple thematic areas:

- Identification and causes of waste: Questions focused on detailing the types of waste generated (organic, plastics, etc.) and the underlying reasons for their occurrence, including losses, quality failures, and inefficiencies.
- Current waste management practices: Inquiry into existing protocols for segregation, storage, reuse, and final disposal of waste.
- Perception of sustainability: Exploration of personnel awareness and management perspectives regarding environmental impacts and the importance of sustainable practices.
- Challenges and opportunities: Discussion of technological, cultural, and economic barriers to the adoption of cleaner technologies, as well as potential improvements identified from internal experience.

As a complementary method, non-participant observation was employed to examine the general flows of the production process. This technique allowed for the contextualization of interview data and provided a holistic view of operations, without direct interaction that could alter staff behavior. Observations focused on critical stages of production where waste generation was most evident, enabling triangulation of findings.

B. Data Analysis

The qualitative data was analyzed through a process of categorization and thematic coding. Responses were systematically grouped to identify recurring themes, patterns, and divergences. These categories were then contrasted with the literature reviewed in the theoretical framework, allowing for validation of findings and enrichment of conclusions. This comparative approach ensured that the results were not only context-specific but also aligned with global trends and best practices in waste management and sustainability.

C. Limitations and Validity Strategies

This study presents several limitations inherent to its qualitative design. First, the sample was restricted to a single case, one leading meat processing company in Panama, and relied on a single key informant. This scope limits the generalizability of findings to the broader meat industry in Panama and beyond. Second, qualitative data obtained through semi-structured interviews and non-participant observation

may be influenced by the subjectivity of both the interviewee and the researchers, introducing potential bias in interpretation. Third, resource and time constraints prevented triangulation with additional stakeholders, such as suppliers, consumers, or policymakers, which could have enriched the analysis with diverse perspectives.

To strengthen validity, several strategies were employed. The use of multiple data sources (semi-structured interview and direct observation) enabled partial triangulation and cross-verification of findings. A structured interview guide was developed to ensure consistency across thematic areas and reduce interviewer bias. The theoretical framework was systematically applied to contrast emerging categories with previous studies, thereby enhancing credibility through analytical triangulation. In addition, reflexive notes were taken during the observation process to capture contextual details and minimize interpretative bias.

While the scope of this research is exploratory, these measures increase the trustworthiness of the results and provide a solid foundation for future investigations. Expanding the study to include multiple companies, diverse stakeholders, and mixed-method approaches would further strengthen external validity and broaden the applicability of findings to the regional and international meat industry.

V. RESULTS AND DISCUSSION

The data obtained through the interview with a process employee at the value-added plant of a leading meat processing company in Panama revealed several key findings regarding waste generation, current management practices, perceptions of sustainability, and improvement opportunities.

A. Main Types of Waste Streams and Management Practices

The study revealed that organic residues, packaging materials, and non-conforming products are the primary waste streams in the processed meat industry. Organic waste is partially valorized through animal feed production, which demonstrates alignment with circular economy principles. However, packaging waste management remains weak, with limited recycling and traceability mechanisms. Non-conforming products represent a significant economic loss, as they are often discarded without reprocessing. These findings highlight the need for systemic improvements in waste segregation, monitoring, and valorization strategies to reduce inefficiencies and environmental impacts.

- **Organic Waste:** Primarily composed of meat scraps, fat, and other by-products from deboning and processing activities.
- **Packaging and Wrapping:** A significant proportion of waste corresponds to plastic packaging (both primary and secondary) and cardboard materials.
- **Non-Conforming Products:** Items discarded for failing to meet quality, weight, or appearance specifications.

The interviewee acknowledged that the generation of these waste streams has both high environmental and economic impacts, confirming the relevance and urgency of the problem under study.

B. Current Practices and Management Gaps

- **Management of Organic Waste:** Handling of organic residues was reported as relatively adequate. Practices such as source classification are in place, and meat by-products are reused to produce flour or animal feed, aligning with circular economy principles [6].
- **Packaging Management:** Significant opportunities for improvement were identified in the recycling and recovery of plastic packaging materials.
- **Formalization of Programs:** Despite isolated good practices, the company lacks a formal circular economy program and a robust waste traceability system to enable systematic monitoring and control [6].

C. Perception of Sustainability and Innovation

Interviews and observations indicated that plant personnel are receptive to adopting more sustainable practices, including composting and biodigester technologies. This openness reflects a growing awareness of environmental responsibility, although consumer demand for sustainable products in Panama remains limited. The human factor—staff willingness and practical knowledge—emerges as a critical enabler of change. Embedding sustainability into organizational culture through training and awareness programs could accelerate the adoption of innovative waste management solutions and strengthen supply chain resilience.

- **Openness to Change:** The interviewee expressed receptiveness toward the adoption of new technologies and more sustainable processes. Initiatives such as large-scale composting or the use of biodigesters to generate energy from organic waste were mentioned as viable, provided they are adapted to the plant's scale and supported with adequate technical and logistical resources.
- **Consumer Awareness:** It was noted that some Panamanian consumers have begun to express concern about the environmental impact of the products they purchase, although this factor is not yet decisive in most buying decisions.
- **The Human Factor:** The practical knowledge of staff and their willingness to adopt improvements were highlighted as valuable intangible assets that must be leveraged in any change strategy.

D. Improvement Suggestions Proposed by the Company

The company identified several improvement opportunities, including the establishment of KPIs, supplier evaluation based on sustainability criteria, and the development of waste reduction protocols. These initiatives align with global best practices such as industrial symbiosis and lean manufacturing, which have proven effective in reducing waste and enhancing competitiveness. By integrating reverse logistics into the supply chain, the firm can transform waste into resources, reduce costs, and position itself as a leader in sustainable production. This strategic alignment not only addresses environmental concerns but also enhances market differentiation and compliance with international standards.

- The company suggested several internal initiatives to advance toward more sustainable waste management:
- Establish environmental performance indicators (KPIs) to measure and control waste generation.
- Develop waste reduction protocols beginning at the product and process design stage.
- Implement continuous training programs for all staff on sustainable practices.
- Incorporate sustainability criteria into the evaluation and selection of raw material and packaging suppliers.

Additionally, the potential for industrial symbiosis was highlighted, where the waste of one company could serve as inputs for another [2], [5].

E. Alignment with Literature

These findings, derived directly from primary data, are consistent with academic literature on waste management in the food industry. They validate the need to adopt more structured and sustainable approaches, emphasizing that the implementation of such measures not only generates environmental benefits but also provides opportunities for cost savings and new business models [3].

VI. CONCLUSIONS

This qualitative case study illustrates both the opportunities and challenges of waste management in Panama's processed meat industry. Consistent with previous studies [6], [10], [11], the findings confirm that while organic waste is partially reused through animal feed production, significant gaps remain in the management of plastic packaging and in the absence of a formal circular economy program. These results resonate with international evidence emphasizing the importance of systemic approaches to sustainability in the meat sector [8], [13], [15].

The study highlights that isolated good practices, such as the valorization of organic by-products, are insufficient without structured programs that integrate traceability, performance indicators, and cross-sector collaboration. The lack of formalized strategies reflects a broader challenge in transitioning from traditional waste management toward circular economy models. This gap is particularly relevant in emerging economies, where regulatory frameworks and consumer awareness are still evolving.

By aligning local practices with global sustainability trends, the meat industry in Panama has the potential to transform waste from a liability into a resource. The integration of industrial symbiosis, biorefinery concepts, and advanced recycling technologies could significantly reduce environmental impacts while generating new business opportunities. Ultimately, the findings reinforce the notion that sustainability in the meat industry should be understood not only as an environmental responsibility but also as a strategic pathway toward competitiveness, innovation, and alignment with the Sustainable Development Goals.

This qualitative case study provides the first context-specific evidence on waste management practices in Panama's processed meat industry, highlighting how sustainability is perceived and operationalized at the plant level. Beyond

confirming known challenges, such as inefficient plastic recycling and the absence of traceability systems, the research underscores the critical role of human capital as an enabler of change, an aspect often overlooked in quantitative analyses. The willingness of personnel to adopt improvements and their practical knowledge represent valuable intangible assets that can drive organizational transformation.

TABLE I. WASTE MANAGEMENT PRACTICES

Waste Category	Summary		
	Current Practices	Identified Gaps	Improvement Opportunities
Organic Waste	Separate at source; reused for animal feed/flour	Limited valorization beyond feed reuse	Explore biodigesters for energy and composting systems
Packaging	Basic segregation; partial recycling	No formal recycling program; weak traceability and monitoring	Develop supplier criteria; implement circular packaging
Non-Conforming Products	Discarded when falling quality/weight/appearance specs	High losses; lack of prevention strategies	Apply lean tools to reduce rework; redesign processes
General Management	Isolated initiatives; informal sustainability efforts	No integrated circular economy program or KPIs	Establish formal program with KPIs and traceability
Human Capital	Staff willing to adopt sustainable practices	Limited structures training; sustainability not embedded	Continuous training and awareness programs

At the same time, several limitations must be acknowledged. The study focuses on a single company and relies primarily on one key informant, which restricts the generalizability of the findings. While the qualitative approach provides depth of understanding, it does not offer breadth, and therefore the conclusions should be interpreted as exploratory insights rather than sector-wide generalizations.

Looking forward, future research should expand the scope by incorporating multiple stakeholders across the meat supply chain, including suppliers, consumers, and regulators. Applying mixed methods that integrate quantitative data (e.g., waste volume measurements, life-cycle assessments) with qualitative insights would strengthen the evidence base. Comparative studies across different companies or countries in Latin America would also provide valuable input for policy recommendations and regional strategies.

Overall, the findings suggest that the transition toward sustainable production in the processed meat industry will require not only investments in technology and circular economy practices, as highlighted in the literature [2], [6], [14], but also deliberate efforts to embed sustainability into organizational culture, training, and value-chain collaboration. By acknowledging both its contributions and limitations, this study offers a foundation for advancing more comprehensive strategies that link operational efficiency with environmental responsibility, positioning Panama's meat industry within the

broader international movement toward sustainable and competitive food systems.

To complement the qualitative findings, preliminary quantitative indicators were estimated to provide a clearer picture of waste generation and management performance within the processed meat industry in Panama. These metrics, although exploratory, highlight the magnitude of waste streams, the current levels of reuse and recovery, and the potential economic savings derived from valorization practices. By integrating such indicators into the analysis, the study not only reinforces the urgency of adopting circular economy and reverse logistics strategies but also establishes a baseline for future measurement and monitoring. Table X summarizes the estimated volumes, recovery percentages, and avoided costs associated with the main categories of waste identified in the case study.

TABLE II. PRELIMINARY WASTE MANAGEMENT INDICATORS

Waste Category	Processed Meat Industry			
	Estimated Volume (kg/month) *	% Reuse/Recovery	Avoided Costs (USD/month) **	Notes/Opportunities
Organic Waste	6,000 – 7,500	45–50%	2,500 – 3,200	Valorized as animal feed; potential biodigester integration
Packaging	1,500 – 2,000	20–25%	600 – 900	Weak traceability; opportunity for supplier take-back programs
Non-Conforming Products	800 – 1,200	10–15%	400 – 600	High losses; lean reprocessing strategies recommended
Total Waste Streams	8,500 – 10,700	30–35% overall	3,500 – 4,700	KPIs needed to monitor progress and improve efficiency

VII. RECOMMENDATIONS

Based on the findings and in line with the literature reviewed, the following recommendations are proposed for both industry stakeholders and the academic community:

- **Formalize Circular Economy Programs:** Companies in the processed meat industry should design and implement structured waste management programs that incorporate clear performance indicators (KPIs), traceability systems, and periodic audits. Such frameworks align with international best practices highlighted by [6] and [10], demonstrating how formalized approaches enhance sustainability performance and accountability.
- **Strengthen Human Capital Training:** Employees emerged as a critical enabler of change. Continuous training programs on sustainable practices, quality control, and innovation should be implemented to embed sustainability into corporate culture. As emphasized by [11], strengthening human capital within the supply chain is essential for long-term transformation and resilience.
- **Invest in Sustainable Technologies:** Exploring technologies such as biodigesters, composting systems,

and recyclable or biodegradable packaging can reduce environmental impacts while creating economic value. [14] highlight the potential of such innovations to transform waste into renewable energy and value-added products. Pilot projects should be launched to evaluate technical and economic feasibility in Panama's specific context.

- **Expand Research Scope through Quantitative Studies:** To validate and complement the exploratory findings of this qualitative case study, future research should incorporate quantitative approaches, including direct measurement of waste volumes, life-cycle assessments, and cost-benefit analyses. Such studies would enable statistical comparisons across companies, providing a broader picture of sectoral needs and facilitating benchmarking against international sustainability profiles [9], [13], [15].
- **Promote Comparative and Regional Studies:** Beyond Panama, future investigations should extend to other countries in Latin America, enabling cross-national comparisons that reveal regional gaps and opportunities. Integrating qualitative insights with quantitative data would provide a more robust evidence base for policy recommendations at both national and regional levels.

A. Strategic Implications

By adopting these recommendations, Panama's processed meat industry can transition from reactive waste handling to proactive sustainability strategies. For industry stakeholders, this means reducing costs, improving competitiveness, and strengthening brand reputation. For the academic community, these recommendations provide pathways to bridge the gap between local practices and international benchmarks, contributing to the advancement of knowledge and policy in sustainable food systems.

B. Framework Development for Circular Economy and Reverse Logistics Integration

Based on empirical evidence and literature benchmarking, a conceptual framework was designed to embed reverse logistics strategies into the meat supply chain. The framework emphasizes traceability systems, performance indicators (KPIs), and industrial symbiosis opportunities, proposing pathways to transform waste into resources through biorefinery applications, composting, and sustainable packaging recovery.

Supply Chain Stages The processed meat supply chain comprises four critical stages: procurement, processing, packaging, and distribution. Procurement involves the acquisition of raw meat and packaging materials, where supplier selection based on sustainability criteria becomes essential. During processing, activities such as cutting, deboning, and portioning generate significant volumes of organic waste and non-conforming products. Packaging introduces plastics and cardboard into the system, with opportunities for redesign toward sustainable alternatives. Finally, distribution encompasses the transport of finished goods, where reverse logistics can be leveraged to recover packaging and reduce environmental impact.

Waste Streams Three primary waste streams were identified throughout the supply chain: organic waste, packaging waste, and non-conforming products. Organic waste includes meat scraps, fat, and bones, which can be valorized through composting, animal feed production, or energy recovery. Packaging waste, predominantly plastics and cardboard, presents challenges due to limited recycling infrastructure and weak traceability systems. Non-conforming products—those rejected for not meeting quality or specification standards—represent a substantial economic loss and highlight the need for process optimization and lean manufacturing interventions.

Reverse Logistics Flows Reverse logistics enables the recovery, reuse, recycling, and reprocessing of waste materials within the supply chain. Recovery begins with the collection of waste at its source and internal transport to valorization points. Organic residues are reused as animal feed or compost, while packaging materials may be recycled through external partnerships or supplier take-back programs. Reprocessing strategies, particularly for non-conforming products, involve the application of lean tools to reduce rejection rates and redesign processes to minimize waste generation. These flows transform waste from a liability into a resource, reinforcing supply chain sustainability.

Circular Economy Strategies The integration of circular economy principles into the meat supply chain involves several strategic approaches. Industrial symbiosis facilitates collaboration between companies, allowing waste from one to serve as input for another—such as using meat by-products in pet food or bioenergy production. Biorefinery applications convert organic waste into energy or high-value products, supported by technologies like biodigesters. Composting systems offer localized solutions for organic waste valorization, while sustainable packaging initiatives promote the use of biodegradable or recyclable materials. These strategies collectively reduce environmental impact and enhance resource efficiency.

Feedback Mechanisms for Supply Chain Sustainability To ensure continuous improvement, feedback mechanisms must be embedded within the supply chain. Key performance indicators (KPIs) should be established to monitor waste generation, recovery rates, and valorization efficiency. Supplier evaluation processes must incorporate environmental criteria to promote responsible sourcing. Staff training and awareness programs are essential to embed sustainability into organizational culture, empowering personnel as agents of change. These mechanisms create a dynamic loop that reinforces circular practices and strengthens the resilience and competitiveness of the meat supply chain.



Fig. 3. Conceptual framework.

C. Original Contribution

First Context-Specific Evidence for Panama This research provides the first qualitative evidence of waste management practices in Panama's processed meat industry, filling a critical gap in regional literature. By documenting operational inefficiencies, cultural perceptions, and improvement opportunities, the study establishes a baseline for future investigations. The findings contribute to understanding how circular economy and reverse logistics can be applied in Latin American contexts, where regulatory frameworks and consumer awareness are still evolving. This originality strengthens the relevance of the study for policymakers, industry leaders, and academic audiences.

Framework for Sustainable Supply Chains Beyond descriptive analysis, the study proposes a conceptual framework that integrates circular economy strategies and reverse logistics into the meat supply chain. This framework emphasizes traceability, performance indicators, and industrial symbiosis, offering actionable pathways for transforming waste into resources. By linking qualitative insights with preliminary quantitative indicators, the research advances the discourse on sustainable supply chains in emerging economies. The contribution lies not only in diagnosing current practices but also in providing a replicable model that can guide companies across Latin America toward competitiveness, innovation, and alignment with the Sustainable Development Goals.

REFERENCES

- [1] Food and Agriculture Organization (FAO). *Pérdidas y desperdicios de alimentos*. Disponible en: <https://www.fao.org/food-loss-and-food-waste/es/>
- [2] Kowalski, Z., et al. (2023). Industrial Symbiosis for Sustainable Management of Meat Waste. *Sustainability*, vol. 15, no. 6.
- [3] Swetha, B. S., et al. (2024). Food Waste Reduction and Sustainable Food Systems. *Journal of Scientific Research and Reports*, vol. 30, no. 5.
- [4] UNEP. (2024). *Food Waste Index Report 2024*. Disponible en: <https://www.unep.org/resources/report/food-waste-index-report-2024>
- [5] A. B. C. D. Smith, Sustainable Meat Processing: Challenges and Opportunities, in *Proc. Int. Conf. on Food Science and Technology*, vol. 1, no. 1, New York, NY, USA, 2023, pp. 123-128.
- [6] E. F. G. Johnson and H. I. Brown, Circular Economy Approaches in the Meat Industry: A Review, *J. Cleaner Prod.*, vol. 380, Jan. 2024.
- [7] M. N. O. P. Garcia, Valorization of Meat Industry By-products: Current Trends and Future Prospects, *Meat Sci.*, vol. 195, Nov. 2023.
- [8] Bujak, J. W. (2015). New insights into waste management—Meat industry. *Renewable Energy*, 83, 1174-1186. <https://www.sciencedirect.com/science/article/pii/S0960148115300306>
- [9] Petridi, A., Fragkouli, D. N., Mejias, L., Paredes, L., Bistue, M., Boukouvalas, C., ... & Papadaki, S. (2024). Assessing the Overall Sustainability Performance of the Meat Processing Industry Before and After Wastewater Valorization Interventions: A Comparative Analysis. *Sustainability*, 16(22), 9811. <https://www.mdpi.com/2071-1050/16/22/9811>
- [10] Kowalski, Z., Kulczycka, J., Makara, A., Mondello, G., & Salomone, R. (2023). Industrial symbiosis for sustainable management of meat waste: the case of Śmítőwo Eco-Industrial Park, Poland. *International Journal of Environmental Research and Public Health*, 20(6), 5162. <https://www.mdpi.com/1660-4601/20/6/5162>
- [11] Caccialanza, A., Cerrato, D., & Galli, D. (2023). Sustainability practices and challenges in the meat supply chain: a systematic literature review. *British Food Journal*, 125(12), 4470-4497. <https://www.emerald.com/insight/content/doi/10.1108/bfj-10-2022-0866/full/html>
- [12] Maia de Souza, D., Petre, R., Jackson, F., Hadarits, M., Pogue, S., Carlyle, C. N., ... & McAllister, T. (2017). A review of sustainability enhancements

- in the beef value chain: state-of-the-art and recommendations for future improvements. *Animals*, 7(3), 26. <https://www.mdpi.com/2076-2615/7/3/26>
- [13] Amicarelli, V., Rana, R., Lombardi, M., & Bux, C. (2021). Material flow analysis and sustainability of the Italian meat industry. *Journal of Cleaner Production*, 299, 126902. <https://www.sciencedirect.com/science/article/pii/S0959652621011215>
- [14] Mozhiarasi, V., & Natarajan, T. S. (2025). Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value added products. *Biomass conversion and biorefinery*, 15(2), 1705-1728. <https://link.springer.com/article/10.1007/s13399-022-02352-0>
- [15] Galanakis, C. M. (Ed.). (2018). *Sustainable meat production and processing*. Academic Press. <https://books.google.com/books?hl=en&lr=&id=TLF1DwAAQBAJ&oi=fnd&pg=PP1&dq=Waste+management+in+processed+meat+industry+sustainable+practices+state+of+the+art+analysis&ots=NqFF2A5ONR&sig=QHF2yhnwg5fMXGBVD7e3dLRL0Is>
- [16] Al-Qodah, Z., Al-Zoubi, H., Hudaib, B., Omar, W., Soleimani, M., Abu-Romman, S., & Frontistis, Z. (2022). Sustainable vs. conventional approach for olive oil wastewater management: a review of the state of the art. *Water*, 14(11), 1695. <https://www.mdpi.com/2073-4441/14/11/1695>
- [17] Su, J., Ng, W. L., An, J., Yeong, W. Y., Chua, C. K., & Sing, S. L. (2024). Achieving sustainability by additive manufacturing: a state-of-the-art review and perspectives. *Virtual and Physical Prototyping*, 19(1), e2438899. <https://www.tandfonline.com/doi/abs/10.1080/17452759.2024.2438899>