

Circular Economy in Action: Transforming Food Production toward Industrial Sustainability

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Abstract

The main goal of this study was to analyze the economic, productive, and environmental impacts of applying circular economy principles in a chocolate manufacturing plant. The specific objective was to develop and validate a standardized method for measuring productivity, operating costs, and environmental sustainability during the production process. The research was driven by the high resource demand and substantial waste generation in the chocolate industry, emphasizing the need to adopt effective models that optimize inputs and reduce losses. To achieve this, a quantitative descriptive-explanatory approach was carried out, conceptualizing the factors that influence the production process and their cause-and-effect relationship, using quantitative tools of industrial engineering, life cycle analysis in various scenarios, flow diagrams and pilot tests in the plant, in order to evaluate the impact of the indicators on costs, productivity and circularity. The findings revealed that adopting circular practices led to significant improvements. These included a 9.1% increase in operational efficiency, reduced operating costs per unit, a higher daily yield, and a 95% increase in the model index. This reflects enhanced resource utilization and emphasizes both economic and environmental benefits. Additionally, cocoa losses translated into economic losses between US\$ 2,914 and US\$ 3,283. The originality of this research lies in presenting a repeatable, measurable procedure that combines productivity, viability, and sustainability, providing a reference model for other food industries aiming to transition toward sustainable, competitive economic models.

Keywords: Circular economy, sustainability, chocolate production, waste reduction, profitability.

I. INTRODUCTION

In recent years, the adoption of the circular economy (CE) has increased worldwide; however, it continues to pose significant challenges. The available tools can be enhanced in terms of transferability, credibility, adaptability, and general applicability across different industrial sectors [1]. In Latin America, this paradigm has gained particular relevance as the transition toward sustainable development models faces major challenges. Previous studies show steady growth in innovative proposals with the potential to generate both economic and environmental benefits in the region [2]. Conversely, the model policies aspire to cultivate closed-loop systems that curtail waste generation and resource consumption. However, their practical implementation remains constrained [3]. Therefore, to achieve a model of sustainable production and consumption (SPC), it is essential to optimize resource use and minimize

losses. In this context, an analysis of the challenges faced by the food industry becomes imperative [4]. Consequently, the food industry must adopt a restorative and regenerative structure to achieve a viable system, redefining goods and services to reduce waste and negative environmental impacts [5]. One possible strategy is the adoption of regenerative practices in food manufacturing, which requires shifting away from viewing products as disposable consumer goods and instead treating them as temporary services [6]. The present research was developed empirically through continuous observation of the chocolate production process to create an economic model that allows the determination of operating costs.

The collaborative economy is a system that aims to decouple economic growth from resource consumption by implementing strategies such as closing material loops, redesigning products for their entire life cycle, and promoting industrial symbiosis [7]. From a production perspective, this model encourages the cascading valorization of by-products and the redesign of processes at the micro level. It integrates economic, social, and environmental measurements to improve system viability and cooperation along the supply chain [8]. In the food industry, the circular economic model is understood as the comprehensive management of agri-food waste throughout the entire chain to reduce resource consumption, reusing and recycling materials to convert waste into high-value products [9]. The relevance of this research lies in its potential to generate economic benefits for chocolate-producing industries, which also cause significant environmental impacts due to intensive resource use and waste generation during production. Consequently, studies demonstrate that raw material production (64.64%) and chocolate manufacturing (28.90%) are the stages that contribute most to environmental impact, particularly through inputs such as powdered milk, sugar, and cocoa derivatives [10]. On the other hand, cocoa production leaves a substantial ecological footprint, as assessed through life cycle analysis (LCA), with emissions, energy consumption, and resource depletion identified as critical hotspots [11]. Given the challenges faced by companies in the food sector, it is essential to study the effects of the economic model in a chocolate manufacturing plant.

This study examines the relationship between recycled material indicators and gross domestic product, thereby analyzing the impact of this model and its contribution to achieving sustainable development [12]. The reuse of resources

provides a transformative approach to the food industry by promoting environmental health, human well-being, and economic prosperity, even reshaping the sector through sustainable waste management practices, supply chain optimization, and efficient resource use to minimize environmental impact [13]. The arguments presented explain why a viable and sustainable economic model should be adopted in a chocolate manufacturing plant. Research on chocolate production indicates that certain processing stages exhibit a disproportionate environmental impact, making them the primary focus for sustainability efforts [14]. Likewise, other studies highlight that an adequate understanding and proper measurement of the model's concepts are essential for transforming food systems and guiding industrial policies [15]. Therefore, the expected results will not only benefit the plant's internal operations by reducing costs and waste but also serve as a reference model for other food companies seeking to transition toward recycled-material-based models with tangible impacts.

The development of this research is organized as follows: Section 2 presents the methodology, using a quantitative descriptive-explanatory approach. Section 3 presents the results through tables and figures. The discussion, including comparisons with other authors and analysis based on the obtained results, is presented in Section 4. Finally, Section 5 outlines the study conclusions and directions for future research.

Literature review

The following section is based on a qualitative review of scientific databases (Scopus, Web of Science, and ScienceDirect), from which relevant information from national and international studies was extracted to support the present research.

1.1 International studies

In a study conducted by researchers [16], a D-optimal mixture design was applied using cocoa pulp juice (91–95%), unfermented cocoa powder (1–5%), and CMC (0.5–4%) as a stabilizer. The optimal formulation consisted of 95% juice, 4% cocoa powder, and 1% CMC, resulting in a sorbet with favorable properties and good sensory acceptance (5.8–7.4). Furthermore, bioactive compounds, including theobromine, catechin, caffeine, epicatechin, and rutin, were analyzed, revealing a sustained increase in viability during storage. These findings underscore the potential of cocoa by-products as sustainable and functional ingredients for the development of probiotic sorbets with nutritional and sensory appeal. In the research conducted by the author [17], the objective was to propose a chocolate cake in which wheat flour was replaced by cocoa bean shell powder (CSp). Five formulations were tested, with varying percentages of CSp: 25%, 50%, 75%, 100%, and 0%. Cakes containing up to 75% CSp exhibited satisfactory sensory acceptance, demonstrating promising potential for the food industry.

A study conducted by [18] investigated the conversion and utilization of empty fruit bunches (EFB) from oil palm within an industrial plant. The results indicated that the hydrocarbon fuel properties were improved. Regarding synthesis gas obtained through air gasification of hydrocarbons, the lower heating value ranged from 4.7 to 6.6 MJ/Nm³, while the cold gas efficiency ranged from approximately 39.1 to 55.1%. The methane accumulated in the liquid products was 213.8 L/kg COD and 154.5 L/kg COD for food/microorganism ratios of 1:2 and 1:3, respectively. Mass and energy balances demonstrated that the overall process is promising for future commercialization. Research by [19] adopted a multimethod approach applied to 285 manufacturing companies, aiming to analyze how organizational capabilities and sustainable manufacturing practices influence environmental performance. The results demonstrated a statistical power of 0.998, which exceeded the 0.950 obtained in the a priori analysis. This finding confirmed the validity of the data and the statistical robustness of the findings.

Conversely, the article developed by researcher [20] examined the feasibility of producing powdered sugarcane pith as a partial substitute for sugar in cakes. The results of the analysis indicated that the pith contains 2.00% protein, 3.20% fat, 30.67% crude fiber, 30.20% dry matter, and 1.97% ash. Concurrently, the sugarcane peel demonstrated higher concentrations of protein (2.56%), fat (4.63%), fiber (63%), and minerals. Replacing 25% of the sugar resulted in a cost increase to USD 2,457, representing a 37.63% rise. Replacing 50% of the sugar led to a cost escalation to USD 3,148, marking a 76.3% increase. In the study by [21], the financial feasibility of artisanal chocolate processing in Ghana was evaluated. The initial investment amounted to 29,776 GHS (USD 5,125), and the annual operating costs totaled 40,415 GHS (USD 6,957), with a cost of capital of 27%. Financial analysis demonstrated a positive NPV of 107,637 GHS (USD 18,525), a BCR of 1.75, and an IRR of 108.62%. These findings suggest that artisanal chocolate production is financially viable and could positively impact local economic development and employment.

On the other hand, the study conducted by [22] analyzed cookie formulations in which defatted cocoa shell flour (DCSF) replaced 10%, 20%, 30%, or 40% of wheat flour and was compared with a control formulation (C0). Compared with C0 cookies, those containing DCSF exhibited 400% higher phenolic compound content, 250% more flavonols, 130% more soluble fiber, and over 1000% more insoluble fiber. In the article developed by [23], the authors illustrate how their revalorization model can close material cycles by valorizing by-products and achieving technical and environmental improvements at low raw material costs. According to researchers [24], a comprehensive literature review on electromobility within the context of the circular economy was conducted, highlighting the benefits of decarbonization in key sectors such as transportation (24% of global CO₂ emissions), construction (37%), and energy (31%). Nurserymen have

expressed interest in transitioning toward a circular economy model. This interest is driven, in part, by the increasing consumption of mineral fertilizers in the European Union. Since 2009, the annual consumption of mineral fertilizers in the European Union has increased by approximately 1.54 million Mg. This increase reflects the growing importance of addressing sustainability in the sector. This point has been noted by scholars [25]. In the article developed by researcher [26], a systematic review was conducted (264 articles from 2010 to 2020, with 53 analyzed in depth) to outline the characteristics of a sustainable city and propose an urban transition framework. Concurrently, the study by [27] proposes a holistic ecodesign strategy that integrates the end-of-life (EOL) and the beginning-of-life (BOL) of products by facilitating information exchange.

The work carried out by [28] presents a roadmap that proposes four key lines of action: closing regulatory gaps, promoting circular economy literacy, optimizing waste management, and regenerating natural flows. This roadmap is designed to support both emerging startups and established companies to facilitate the transition toward sustainable business models.

In the production of white chocolate using by-products extracted from concentrated sea buckthorn juices, these by-products represent functional food ingredients and a rich source of bioactive compounds. This approach is based on a factorial combination of two types of by-products (with or without oil) and three different concentrations (5%, 10%, and 15%), and its effects on the rheological, quality, color, antioxidant, and mineral properties of chocolate were evaluated [29].

1.2 National Studies:

A thorough investigation was conducted by researchers [30] through a systematic review of the application of circular economy in the agri-food supply chain, using databases such as Scopus and Web of Science. Their search identified 1,200 articles, of which 100 studies were selected. The results showed that research is mainly concentrated on waste management (35%), resource efficiency (25%), and sustainable practices (20%), demonstrating that the valorization of by-products significantly contributes to waste reduction and improved sustainability in the food sector. Researchers [31, 32, 33] analyzed the implementation of circular economy strategies in Peruvian agri-food systems through a qualitative case study focused on small producers participating in farmers' markets.

The guide to good practices for the model in the cocoa value chain, developed by Mincetur in 2023 [34], sought to identify strategies applicable to cocoa producers and processors in Peru. This objective was pursued through an analysis of the production cycle, waste flows, and opportunities for valorization. The findings indicated that more than 40% of cocoa by-products can be reintegrated as agricultural or industrial inputs through composting, bio-inputs, and material transformation. It was concluded that reuse represents a pivotal

approach for enhancing the competitiveness and sustainability of the Peruvian cocoa value chain.

A. Problem Statement

Currently, food sector industries face challenges in improving performance through efficient resource use and waste reduction. In this context, there is an increasing need to implement practices aligned with the principles of chocolate production processes. The objective of this implementation is to optimize input utilization and minimize environmental impact. However, studies such as [35] indicate that in the agri-food sector, the application of this model still lacks a uniform methodological framework, as existing proposals are limited to specific contexts or scales and do not define procedures that are replicable in industrial environments. In light of this situation, the following research questions are hereby proposed:

- How can a standardized procedure be structured to quantitatively analyze and evaluate the implementation of circularity in a chocolate manufacturing plant, ensuring its efficiency and sustainability?
- Which stages and techniques should be considered to design a standardized procedure for implementing circularity in a chocolate manufacturing plant?
- Which variables should be considered to measure operational efficiency and waste reduction within the production process under a sustainable economy approach?
- Which variables should be considered to measure productivity in terms of environmental viability and replicability in other chocolate plants within the sector?

B. Objective

The present study aims to quantitatively evaluate the implementation of the economic model in a chocolate manufacturing plant to measure operational efficiency, operating costs, production performance, and long-term environmental sustainability. The research was conducted in three stages: first, designing the model implementation procedure; second, establishing measurement indicators to assess performance and waste reduction; and third, validating the results through empirical observation to ensure environmental effectiveness and potential replicability in other manufacturing plants, thereby contributing to improved sustainable management within the food industry.

C. Hypothesis

The implementation of a sustainability model in a chocolate manufacturing plant makes a positive, measurable impact on productivity, waste reduction, and environmental development. This approach enhances the utilization of raw materials by valorizing by-products and reincorporating them into the production process, thereby minimizing waste management losses and costs. Likewise, measuring and regulating resource traceability through internal recirculation

and control flows enables the assessment of productivity. The employment of standardized techniques within the model has been demonstrated to enhance process management, increase energy efficiency, and promote an organizational culture oriented towards continuous improvement. This study makes a direct contribution to the development of the chocolate production system, indicating that business profitability and environmental stewardship can coexist within a responsible and replicable industrial model.

II. METHODOLOGY

The current research was conducted in a nutrition-focused company, utilizing a quantitative descriptive-explanatory approach to analyze the actions of the economic model implemented in food production and to explain their interaction with environmental viability. This is an applied study insofar as its results are oriented towards optimizing resource use and improving operational performance in the food sector [36]. Regarding information sourcing, both primary and secondary data derived from the analysis of real business processes were utilized. In terms of depth, the study is descriptive, as it details sustainable production procedures, and explanatory, as it identifies cause-and-effect relationships among the factors that determine the effectiveness of reuse in an industrial context. Finally, the research design is non-experimental and cross-sectional, since the variables were observed without direct manipulation and data collection was carried out at a single point in time, to analyze the interactions and effects between sustainable practices and environmental viability. For better understanding, the conceptualization of the relevant factors is presented below.

Operating Cost

The sustainable model has been shown to significantly impact operating costs, with a notable increase in plant profitability. This is a result of the reduction of losses and the valorization of by-products, which directly enhance economic efficiency [37]. Implementing strategies for recycling materials and utilizing reverse logistics can optimize supply chains. This leads to greater efficiency in resource and energy use, reduces operating costs, and minimizes environmental impact [38, 39]. The following formula will be used to determine the operating cost:

$$OC/day = \frac{T.O.C}{U.P.D.} \quad (1)$$

O.C.= Operating cost per day, total cost associated with daily operations (USD/unit).

T.O.C.= Total operating cost, the sum of all operating costs accumulated during one production day (USD).

U.P.D.= Units Produced per Day, the total number of units manufactured in one day (units).

H1: The implementation of practices reduces the operating cost per unit in the chocolate manufacturing plant.

Process Productivity

Given the growing need for sustainable resource management, it is essential to implement innovative approaches within the model paradigm, such as controlling productivity throughout the process. The study addresses the complexity of evaluations based on measurement indicators and highlights the need for robust frameworks to accurately assess reuse in production processes [40]. Consequently, it is detailed how the resilience derived from this transition can drive a transformative change in productivity, demonstrating the model's impact beyond environmental balance and extending its influence to strategic management and organizational performance [41]. The following formula will be used to determine productivity:

$$DY = \frac{GUSD}{EU} \times 100 \quad (2)$$

DY = Daily yield, representing the percentage of inputs converted into final products meeting quality standards (%).

GUSD = Good Units Output per Day, number of units that meet quality standards daily (units).

EU = Equivalent Input Units, total number of units processed per day (units).

H2: The adoption of circular economy strategies increases yield (%) and process productivity in the chocolate manufacturing plant.

Environmental Sustainability

The quantitative aspect of sustainability focuses on measuring waste reduction, resource consumption, and the impact reduction associated with chocolate manufacturing. This is considered a key issue within the sustainable model. The redesign of packaging and the valorization of by-products have been demonstrated to be effective strategies for reducing the ecological footprint of food products [42]. Likewise, the incorporation of such strategies in manufacturing companies is associated with improvements in environmental performance and organizational transformation [43]. To determine sustainability, the following formula will be used:

$$CI = \frac{RMM}{TMM} \quad (3)$$

CI = Circularity Index, measures the efficiency of recycled and reused material utilization in the production process (dimensionless).

RMM = Reused Material Mass, the amount of recycled and reused materials during the daily production process (kg).

TMM = Total Material Input Mass, the total amount of material entering the daily production process (kg).

H3: The implementation of the model increases the reuse index and reduces environmental impacts in the chocolate manufacturing plant.

2.1 Implementation Sequence of the Engineering Tool in the Study

In this context, the established methodological sequence aims to structure a prototype procedure for implementation and continuous evaluation in the chocolate manufacturing plant. This methodology was developed using a sustainable industrial engineering approach, incorporating criteria related to productivity, costs, and environmental balance. The process is organized into six sequential stages, each containing specific activities and control mechanisms supported by applied techniques, such as measurement tools and performance indicators. The operational sequence is described below:

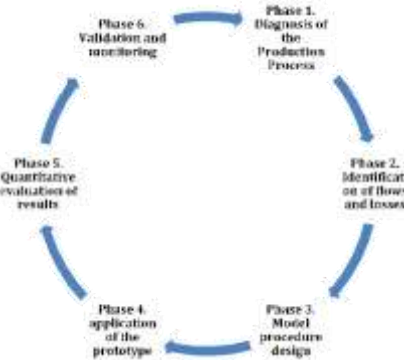


Fig. 1. Methodological sequence for the implementation of stages in the chocolate manufacturing plant

Stage 1. Diagnosis of the Production Process

At this stage, a comprehensive analysis of the production process is carried out to identify inefficiencies in resource use, as well as waste generation and energy losses. Bizagi Modeler software is utilized as a modelling tool to map the workflow (see Fig. 3) and to observe the different process phases. Direct on-site observation was conducted to collect data on material losses, energy consumption, and operational efficiencies in each process activity. A daily record of economic losses is implemented to quantify waste and establish a baseline level of efficiency, which serves as a reference for designing the economic model and defining key performance indicators.

Stage 2. Identification of Flows and Losses

Material and energy flows within the production process are mapped to identify areas to optimize resource use. Tools such as the Ishikawa diagram and the Pareto chart are used to identify the causes and effects that constrain the process and generate inefficiencies, and subsequently to determine the flows with the greatest impact on costs and waste. This phase aims to identify valuable or recyclable flows, thereby contributing to improving process efficiency and viability.

Stage 3. Design of the Model Procedure

At this stage, a procedure for implementing the circular economy model in the chocolate manufacturing plant has been devised. Life Cycle Analysis (LCA) is utilized to evaluate the environmental impacts of each phase of the process. The

objective is to develop a structured model that optimizes resource use, reduces waste, and maximizes material reuse, ensuring that the procedure is both replicable and sustainable.

Stage 4. Pilot Application of the Prototype

The designed model is applied to a pilot production line to evaluate its viability before full-scale implementation. During this phase, indicators such as costs, productivity, and generated waste are monitored. Continuous observation and systematic data recording enable validation of the model's strategies and allow for adjustments to enhance operational and financial effectiveness.

Stage 5. Quantitative Evaluation of Results

At this stage, the results obtained after implementing the model are evaluated using statistical analysis to compare performance before and after its application. Reductions in waste, energy savings, productivity improvements, and decreases in operating costs are measured to quantify the improvements and verify the effectiveness.

Stage 6. Validation and Continuous Improvement

In this final stage, the model is validated through the PDCA cycle (Plan–Do–Check–Act) and internal audits. Sustainable KPIs are evaluated to measure their impact on operational efficiency and environmental sustainability. The goal is to ensure this model can be replicated in other plants and foster continuous improvement over time, thereby reinforcing its long-term viability and effectiveness. The implementation sequence is delineated in Table 1.

Table 1. Summary of the Implementation Sequence

Stage	Main Activity	Applied Tools	Evaluated Indicators	Expected Outcome
1	Process diagnosis	Bizagi Modeler	Waste, energy consumption	Identification of critical points
2	Flow identification	Ishikawa, Pareto	Input/output flows	Detection of valuable flows
3	Procedure design	LCA	Process reuse	Structured CE model
4	Pilot application	Observation, recording	Cost, productivity, waste	Operational validation
5	Quantitative evaluation	Statistical analysis	Quantification of improvements	Measurable results
6	Final validation	PDCA	Sustainable KPIs	Continuous improvement and replicability

III. RESULTS

The findings presented below not only reflect the behaviour of the variables analyzed in the case study, but also allow these patterns to be contrasted with models previously documented in national and international research. Therefore, data interpretation must consider both methodological limitations and the opportunities for practical application that emerge from the results. In this manner, the findings not only provide empirical evidence to validate the hypothesis but also offer relevant insights to support decision-making and the formulation of improvement proposals aimed at productivity, cost efficiency, and environmental resilience.

Figure 2 illustrates production-related losses in relation to the number of affected jars or containers. During September, losses amounted to USD 2,913.83, while in October they increased to USD 3,283.25. This increase indicates a negative trend in process efficiency, associated with both product losses and the number of compromised containers.



Fig 2. Reprocessing Summary by Produced Container

In Fig. 3, the stages that ensure the quality of heminic iron-fortified chocolates are delineated. In the first sequence, within the filtration area, particles larger than 3 mm and metallic particles greater than 30 μm are removed within 15–20 minutes, thereby ensuring product safety. In the molding area, the chocolate defects (e.g., staining and cracking) are detected at temperatures of 50–55 $^{\circ}\text{C}$. Subsequently, in the conditioning area, the subprocess is carried out. At this stage, defective chocolates are identified, separated, weighed, and placed in a container for transfer to the reprocessing area. Conversely, chocolates that are free from defects are packaged. Finally, the packaging is sealed at 60 $^{\circ}\text{C}$, with sealing times of 2.4 seconds for jars containing 40 units and 1.1 seconds for jars containing 12 units.

Figure 4 shows that reprocessing in the manufacturing of heminic iron-fortified chocolates results from multiple interacting factors rather than a single cause, as illustrated in the diagram. Inadequate staff training and mistakes in manual record-keeping lead to inconsistencies in inventory control. When combined with the absence of clear policies and procedures and the lack of periodic reviews of stock levels, these issues increase the risk of waste. Moreover, the absence

of reliable reports and inaccurate demand calculations has a detrimental effect on production planning, resulting in inefficient management.

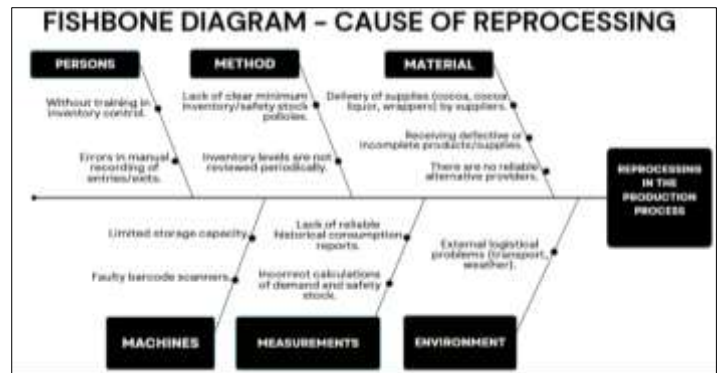


Fig. 4. Ishikawa diagram of reprocessing in the production process

In Fig. 5, the Pareto diagram shows that the main problems in the production process are concentrated in the method and labor categories. Causes such as unclear inventory policies account for nearly 40 cases (19%), while manual recording of inputs and outputs results in approximately 30 cases (34%). Together, these two causes represent more than 50% of the accumulated incidences, confirming their critical impact.

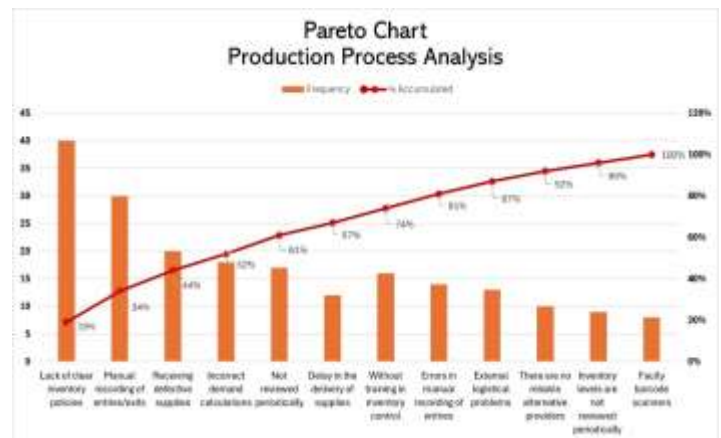


Fig. 5. Pareto diagram related to reprocessing

In Table 2, the Life Cycle Analysis (LCA) shows that implementing reprocessing led to a substantial increase in total production, reaching 7,650.585 kg over two months (compared to 7,355 kg without reprocessing). Concurrently, there was a significant reduction in generated waste, from 312.73 kg to 17.145 kg. Despite a marginal increase in manufacturing costs from USD 264,425.25 to USD 265,699.02, attributable to reprocessing-related expenses, a total of 295.585 kg of chocolate were recovered, thereby attaining a circularity index of 95%. This approach substantially reduced environmental impact, highlighting the benefits of optimizing resource use and minimizing waste in the chocolate manufacturing plant over the two-month production period.

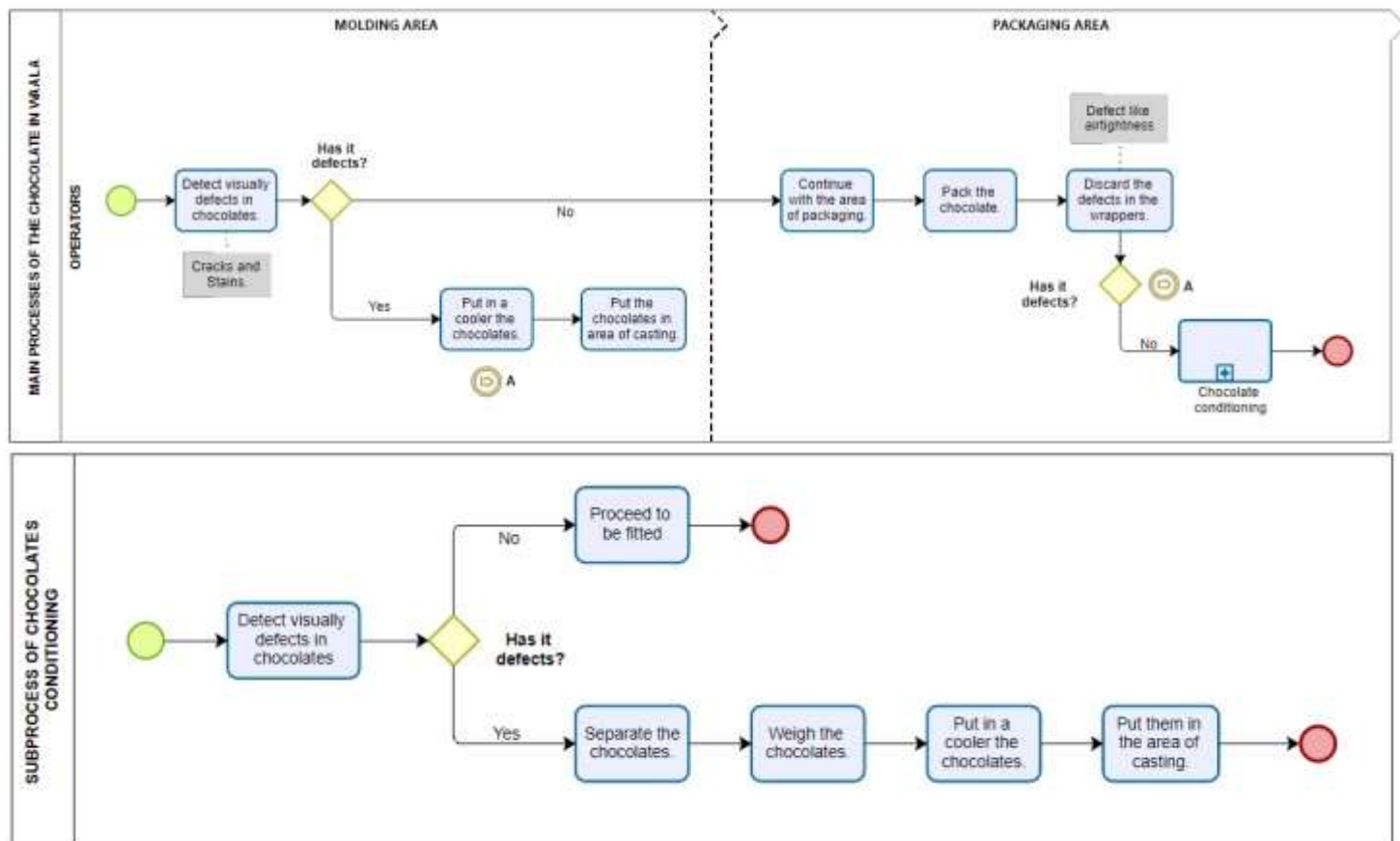


Fig. 3. Production process of the chocolate plant by Bizagi

Table 2. Summary of the Life Cycle Analysis (LCA)

Indicator	Without reprocessing	With reprocessing
Total Production	7,355 kilos	7,650.585 kilos
Generated waste	312.73 kilos	17.145 kilos
Production Cost	S/ 890,175.65	S/ 894,461.63
Chocolate Recovery	0 kilos	295.585 kilos
Reuse Index	0%	95%
Environmental Impact	Higher	Reduced

Reprocessing in the chocolate manufacturing plant is part of the sustainability strategy, wherein generated waste is reincorporated into the production process. As shown in Fig. 6, 94% of the total waste is recovered, significantly reducing losses. This process optimizes resource utilization and minimizes waste generation.

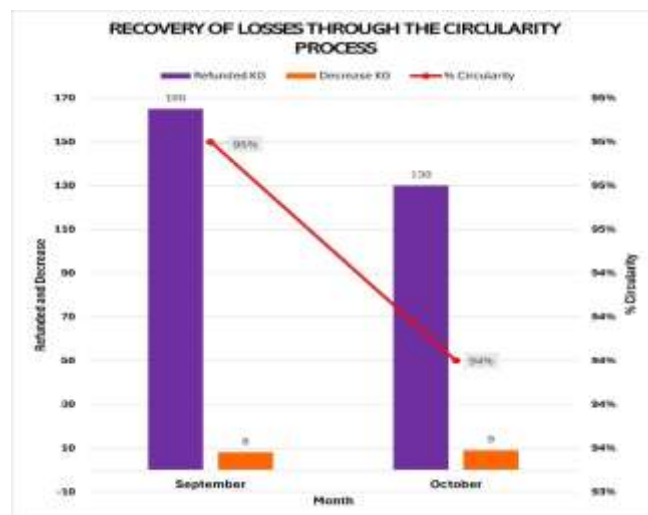


Fig. 6: Reprocessing in the Chocolate Manufacturing Plant

As shown in Figure 7, total production increased by 9.10% due to reprocessing, thereby enhancing operational efficiency.

Waste generation was reduced by 95%, indicating a significant decrease in losses. A 0.48% increase in production costs was observed. However, this increase can be justified by the additional costs of reprocessing, which are expected to generate savings in the long term. The recovery of chocolate materials reached 295.585 kg, previously considered waste, achieving a 95% reuse rate. This demonstrates excellent material reuse. Consequently, the environmental impact was significantly mitigated by reduced waste generation and enhanced resource utilization.

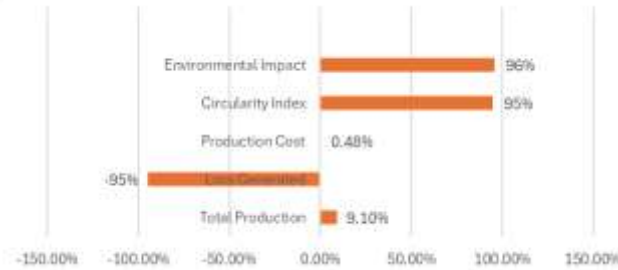


Fig. 7 Post-application test results

As illustrated in Figure 8, a dashboard was used to validate the effectiveness of the model implementation, presenting visual data on the proposed model, operational efficiency, and reduction of environmental impact. The final validation through these KPIs demonstrates that the model is effective and replicable, with positive results supporting its implementation in other chocolate manufacturing plants.

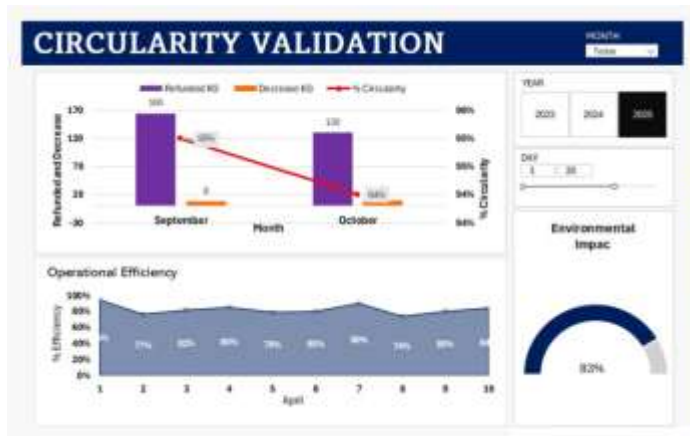


Fig. 8. Final Validation

As demonstrated in Figure 9, fixed costs remain constant over time, while variable costs increase in proportion to the number of units produced. Consequently, the unit cost of chocolate bars tends to decrease as production increases, thereby evidencing economies of scale. Converging conclusions were reported by [44], who observed that analyses of economies of scale demonstrate that market conditions do, in fact, determine selling prices and exert a more substantial influence on manufacturing profitability than production costs themselves.

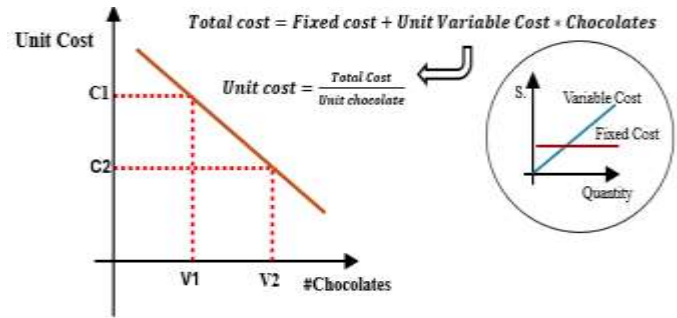


Fig. 9: Cost behavior in relation to the quantity of chocolates manufactured.

IV. DISCUSSION

The main objective of this research was to analyze the implementation of the model in a chocolate manufacturing plant, evaluating its impact on operational efficiency, waste reduction, and environmental footprint improvement. To this end, specific procedures were developed to measure effectiveness within production processes, and the impact across the different phases of chocolate manufacturing was assessed. The results reveal that reprocessing increased total production from 7,355 kg to 7,650.585 kg, improving operational efficiency. In addition, generated waste was significantly reduced from 312.73 kg to 17.145 kg, confirming the system's effectiveness in achieving a 94.5% reduction in waste. Although manufacturing costs increased slightly by 0.48%, 295.585 kg of chocolate were recovered, raising the circularity index to 95%. These findings support the model's effectiveness in the reuse of resources and by-products.

Figure 6 and Table 2 show that reprocessing recovered 94% of the waste, confirming that this approach significantly reduces waste management costs. The research results validate the hypothesis that the revalorization of the model in the chocolate manufacturing plant improves operational efficiency. Even though manufacturing costs have increased slightly, the long-term savings from waste reduction and by-product recovery compensate for this increase. The substantial decrease in waste, observed in both Figure 2 and Table 2, highlights the model's capacity to optimize the resources used in the production process, thereby contributing to the sustainable development of the plant. The results obtained are consistent with those reported by [45], who demonstrated how and when green strategic intent enables public sector organizations to implement circularity practices using the dynamic capabilities perspective. Complementarily, a systems-oriented analytical approach underscores the necessity for diversified sustainability model strategies adapted to transition profiles, particularly in vulnerable ecosystems, thereby providing valuable insights for future research and decision-making [46]. These authors also identified a reduction in waste and environmental impact following the implementation of

sustainable practices in the chocolate industry. Likewise, they suggest that the Product Circularity Indicator offers a more comprehensive assessment of circularity by considering multiple life-cycle stages, efficiency, and unrecoverable waste, resulting in differences in circularity evaluations [47]. On the other hand, three plant layout proposals were highlighted according to the needs of the company and the laminated guadua board manufacturing process, and the alternatives were evaluated in terms of efficiency [48].

Furthermore, researchers [49] determined whether circular model alternatives enhance revenue and resource efficiency in cocoa production. The implementation of the model in the chocolate manufacturing plant not only improved operational efficiency but also provided a holistic approach to sustainability. However, the transition to this model presents challenges, such as the initial adaptation costs and the need to train personnel in new practices. Finally, in response to the economic and environmental challenges posed by the accumulation of organic waste, there has been a growing focus on developing alternative methods for valorizing cocoa bean shells (CBS) and converting them into higher-value products. [50].

V. CONCLUSION

The objective of the present study was to quantitatively evaluate the implementation of the model in a chocolate manufacturing plant, focusing on its impact on productivity, operational efficiency, and environmental responsibility. To this end, a specific implementation procedure was devised, with a set of measurement indicators established to validate the results through empirical observation. A notable finding of the research was a substantial reduction in production losses, from 179.9 kg to 6.7 kg after the implementation of reprocessing, as illustrated in Table 2. This enhancement in operational efficiency resulted in a 9.1% increase in production performance. Furthermore, the circularity index attained a remarkable 96%, signifying optimal utilization of recycled resources. Moreover, the implementation of an information system facilitated data collection and provided a platform for rapidly evaluating indicators against updated benchmarks, enabling the timely identification of opportunities for continuous improvement [51].

The findings presented in this study have significant practical applications in the food industry. The implementation of the model has enabled a long-term reduction in operational costs and has minimized environmental impacts, thus serving as a benchmark for other companies in the sector. The optimization of resource use and the recycling of materials have been shown to enhance plant competitiveness, thereby contributing to the sustainability of the industry. This approach has the potential to be replicated in other food manufacturing

facilities that are seeking to reduce waste and improve operational efficiency. Subsequent research will continue to examine the feasibility of extending the model to other stages of the nutrition sector, following the example of [9] in transforming agri-food residues. Furthermore, the integration of advanced recycling and reuse technologies in the sector, as proposed by [36], will be explored to further improve supply chain efficiency. New approaches to measuring sustainability in production processes will also be investigated, as suggested by [16], to ensure that sustainable models are effective at scale. The integration of the model not only enhances organizational competitiveness but also reduces environmental impacts, improving operational effectiveness, and fostering sustainability in the food sector.

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