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Strategic Sustainable Manage Model, Applying Circular Economy Rate Operating Process: Case Renewable Energy

J. Lu-Chang–Say, Master[1], J. Ugarte-Gomez, Master[2]; N. Chambi-Quiroz, Master[3], E. Lu-Chang-Say, MBA[4]
[1, 3] Universidad Nacional de Ingeniería, Perú, jluc@uni.pe, nchambiq@uni.pe, [4]Universidad ESAN, Peru,elu@esan.edu.per, [2]Universidad Nacional de Ingeniería, Perú, jugarte@ulima.edu.pe

***Abstract:* In the midst of a global systemic collapse, a key factor would be a sustainable process management system, to effectively put in practice, the principles of circular economy, from cradle to cradle. This research, exposes a framework, for create and develop sustainable renewable energy projects, combining Circular Economy (CE), Lean, and Theory of Constraints (TOC) Key accounting indicators, and principles, to manage Rate Operating Process (ROP), Throughput (T), Marginal Benefits (BM), Marginal Consumption (CM), and Operational Consumption (CO). Applied case study, shows how to use and manage biomass from different sources, to recover and generate renewable energy. Through analysis and quantification process parameters, maximize the creation of Value, Benefits and, Profits (VBP), BM and T, under the lens of Circular Economy. The systematic literature review outcome those topics, obtaining a methodological framework for create, design, evaluate and manage strategically the process or renewable and sustainable energy projects.**

***Keywords:* Biomass, Renewable Energy, Strategic Sustainable Management, Theory of Constraints, Lean Manufacturing, Indicators, Profitability, Process Performance Indicators, Circular Economy**

I. INTRODUCTION

In an increasingly uncertain and complex world, organizations are facing unprecedented challenges in their strategic management [1]. The current financial, political, health crises, and ongoing conflicts have further heightened these complexities, making strategic decision-making more challenging than ever [1]. In this context, there arises a need to adopt innovative approaches that enable organizations to navigate these uncertain times and ensure their long-term sustainability.

One key area organization can focus on is the implementation of Circular Economy (CE) practices [1, 2]. CE offers a framework for rethinking business models and designing more efficient systems that minimize waste and maximize resource value [2]. By integrating CE principles into strategic management, organizations can enhance their resilience to environmental, economic, and social challenges [1, 2, 3].

Another important approach is the application of Theory of Constraints (ToC) [4]. ToC provides a systematic framework for identifying and mitigating constraints hindering organizational performance [5]. By understanding and addressing key constraints, organizations can optimize their processes and improve their ability to tackle emerging challenges [6].

Furthermore, Lean Management principles offer valuable tools for waste elimination and operational efficiency improvement [3, 6]. By adopting Lean practices, organizations can streamline their operations and respond more agilely to changing market conditions [3, 7].

In this context, the World Economic Forum (WEF) highlights the urgency of addressing climate change and promoting sustainable business practices [8]. The WEF report underscores the need for organizations to integrate environmental and social considerations into their strategic decision-making to mitigate risks associated with climate change and contribute to a more sustainable future [8].

In this article, we explore how the integration of CE, ToC, and Lean principles in strategic management can help organizations address current challenges and prepare for an uncertain future. We will focus on how these methodologies can enhance organizational resilience and promote long-term sustainability.

Problem Statement:

The central problem revolves around the strategic management of limitations and uncertainties. In today's fast-paced and volatile business environment, organizations grapple with navigating through various constraints and uncertainties that hinder their sustainable growth. Central to this dilemma is the need to effectively manage resources, mitigate risks, and adapt to ever-changing market dynamics.

Purpose:

The primary objective of this study is to propose a strategic management framework that addresses the central challenge of managing limitations and uncertainties effectively. By integrating principles of CE, ToC, and Lean methodologies, this framework seeks to provide organizations with actionable insights and practical strategies to enhance their resilience, optimize resource utilization, and promote sustainable growth in an increasingly complex and changing world.

II. THEORETICAL FOUNDATIONS

Effective management of constraints is central to optimizing organizational performance. The conceptual framework for sustainable management of renewable energies is built upon an innovative approach that recognizes the autonomous growth nature of living matter in contrast to abiotic resources [1, 9]. It involves conceptualizing, nurturing, and enhancing consumption processes to foster a regeneration curve rather than a degradation curve as resource usage increases [1, 10].

This groundbreaking approach aims to minimize waste and optimize the marginal consumption (CM) of resources, thereby maximizing Marginal Benefits (BM) and Throughput (T) achievable through operations [1, 11]. Renewable energies offer the possibility of maintaining a regeneration curve, where resource consumption is accompanied by a constant process of growth and regeneration [1, 11].

Proactive and careful management of natural resources is promoted, aiming to maximize marginal benefits with minimal negative impact on the planet [1, 12]. It fosters a cyclical and synergistic vision with nature, where the consumption of renewable energies becomes a dynamic process of constant regeneration and renewal [1, 12].

This approach challenges conventional conceptions of energy consumption by proposing a model that actively contributes to environmental regeneration and sustainability, while enhancing operational efficiency and adaptability to market dynamics [1, 12]. By adopting this perspective, new possibilities for sustainable management of renewable energies are opened, where growth and regeneration become the fundamental pillars of a more balanced and responsible energy future [1, 13].

The conceptual model articulating the integration of Circular Economy (CE), Theory of Constraints (ToC), and Lean in renewable energy management is based on maximizing value and efficiency while minimizing waste and inefficiencies in processes [2, 3, 6]. By identifying and addressing critical constraints within operational processes, organizations can optimize their resources and prioritize initiatives aimed at eliminating bottlenecks [6, 7]. This holistic and systemic management approach provides a solid foundation for the implementation of sustainable practices and the promotion of a circular economy in the renewable energy sector [2, 3, 6].

Theory of Constraints (ToC) and Lean integration

Strategic management in today's dynamic business landscape requires agile and adaptable approaches to navigate uncertainty and capitalize on emerging opportunities [1,11]. Goldratt's Theory of Constraints (ToC) offers a valuable framework for strategic management by identifying and addressing constraints that limit organizational performance [11]. Integrating ToC with Lean principles further enhances strategic management practices [6].

Goldratt and Fox (1986) introduce metrics such as Throughput, Inventory, and Operating Consumption to assess organizational performance, focusing on profitability and operational efficiency [8]. Ahmad et al. (2023) emphasize the importance of strategic investment decision-making practices that integrate Industry 4.0 technologies with circular economy principles [2]. Integrating ToC with Lean principles can further enhance strategic management practices [2].

Lean and Green in Value Stream Mapping Indicator

Goldratt underscores the need for organizations to adopt a holistic approach that combines ToC's focus on constraints with Lean's emphasis on flow and waste reduction [11]. Integrating Lean Manufacturing and the 6R concept can minimize waste and promote resource efficiency [12, 13]. Ahmad et al. (2023) suggest studying circular economy initiatives to assess their present state and future directions [2].

Hartini et al. (2021) propose integrating Lean Manufacturing principles and the 6R concept to minimize wood waste and promote sustainability [13]. This approach aligns with MacArthur's (2013) principles for accelerating the transition towards a circular economy [12]. Table 1 illustrates key indicators and metrics used to assess the impact of integrating Lean Manufacturing and 6R principles on circularity and sustainability [13, 2].

Table 1.
Lean and green Indicator in value stream mapping

OBJECTIVE	THROUGPUT INCREASE	ELIMINATE WASTE
FOCUS	Singular focus on constraints (until the constraint ceases to be). Constraint determine the throughput?	Focus in the elimination of waste from the Manufacturing process. Elimination of Drains (waste, remains and emissions). with negative impacts to planet?
RESULT	Increase Manufacturing Capacity. Increased Marginal Benefits?	Reduction of resource consumption, in Manufacturing Minimize Marginal Consumption of resources?
INVENTORY	Maintain enough inventory to maximize throughput in the constraint Is inventory only needed in the constraint?	Virtual removal of all Waste with negative impact. Inventory is a waste?
LINE FLOW BALANCE	Create an unbalance to maximize throughput in the constraint Balance the flow in the line, to Maximize the throughput?	Create balance to eliminate waste (excess capacity) Balance the flow to minimize waste. remains and emissions?
CADENCE	The constraint imposes the rhythm or cadence (Drum-Buffer-Rope) Need and demand dictate the rhythm of the effort?	Client determines rhythm and cadence (task time) Purpose determine the Mission?

Note. Adapted from Vorme (20022) LEAN Production Consulting

In their study on the integration of Lean Manufacturing and the 6R concept to reduce wood waste in furniture manufacturing towards a circular economy, Hartini et al. (2021) address the challenge of reducing wood waste in furniture manufacturing processes to promote sustainability and transition towards a circular economy [13]. They propose integrating Lean Manufacturing principles and the 6R concept (reduce, reuse, recycle, recover, redesign, and remanufacture) to minimize wood waste and promote resource efficiency. This integration aligns with the principles advocated by MacArthur (2013) for accelerating the transition towards a circular economy [12].

Using a case study approach, the study analyzes the implementation of Lean Manufacturing and 6R principles in a furniture company. This approach is consistent with the methodology suggested by Ahmad et al. (2023) for studying the present state and future directions of circular economy initiatives [2]. The study presents Table 1, which illustrates the key indicators and metrics used to assess the impact of integrating Lean Manufacturing and 6R principles on circularity and sustainability. These indicators include Unit Cost of Production, Meeting Deadlines, Lead Time, Inventory Level, and Cycle Time. By measuring these aspects, the study evaluates the effectiveness of the integration in reducing waste, improving efficiency, and enhancing sustainability performance within the furniture manufacturing context.

ToC and Lean Sustainable Process Operation Management

These results underscore the effectiveness of integrating Value Stream Mapping with the Theory of Constraints to address challenges related to waste reduction and process optimization, as suggested by Goldratt [11] and Panizzolo [7]. However, it's essential to acknowledge the potential limitations of the findings, especially regarding their generalizability to other industries or sectors beyond furniture manufacturing. Despite this limitation, the insights provided by Table 1 offer valuable guidance for organizations seeking to adopt similar strategies to achieve sustainability goals and promote circular economy principles within their operations. This aligns with the broader discussions on sustainable strategic investment decision-making practices [12] and the business management perspectives on the circular economy [13].

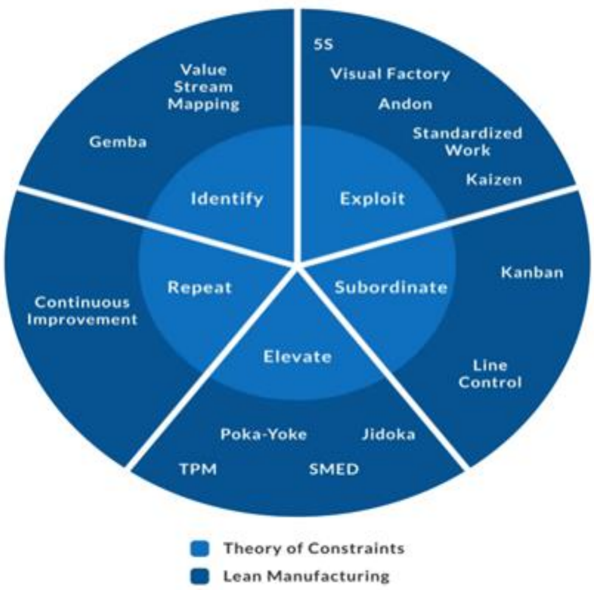

Fig. 1 The five focused steps of ToC can use typical Lean Manufacturing tools.

Note, Adapted from Vorne, LEAN Production Consulting https://www.leanproduction.com/theory-of-constraints/, 2022:

In manufacturing, constraints, often referred to as bottlenecks, are recognized as interconnected activities within complex systems. ToC adopts a scientific approach to systematically improve these constraints until they no longer limit the system's performance (Goldratt & Fox [8]). The proposed metrics for evaluating organizational performance include operational measurements like Throughput, Inventory, and Operating Consumption, along with financial measurements such as Net Income, Return on Investment, and Cash Flow.

Goldratt and Fox [8] propose two sets of metrics for evaluating an organization's performance in meeting primary objectives, such as profitability. These metrics include:

Operational Measurement

- Throughput (T)
- Inventory (I) of incoming resources
- Operating Consumption (CO)

Financial Measurement (Global)

- Net Income (UN)
- Return on Investment (ROI)
- Cash Flow (CF)

Panizzolo (2016 [7]) discusses the application of these metrics in assessing operational performance across different plants globally. He suggests seven measurement scales based on various aspects of ToC for production, including methodologies like Drum-buffer-rope, Time Buffer Management, and Master Schedule optimization.

Similarly, this study employs five indicators to measure the impact of ToC practices in production performance, focusing on dimensions such as Unit Cost of Production, Meeting Deadlines, Lead Time, Inventory Level, and Cycle Time. These indicators have been utilized in assessing projects like the adaptation and recovery of an extrusion plant to provide biofuel.

Lean Manufacturing, as delineated by Black and Phillips (2010 [6]), aims to develop socially and environmentally sustainable products. Similarly, the Theory of Constraints (ToC), introduced by Goldratt (1990 [8]), targets the identification and management of process constraints to optimize throughput and minimize costs. The amalgamation of ToC's meticulous constraint management with the broad application of Lean Manufacturing proves advantageous, as highlighted by Vorne (2022 [4]). This synthesis fosters heightened manufacturing efficiency and profitability.

Furthermore, ToC's emphasis on constraint identification and elimination aligns seamlessly with Lean Manufacturing's goal of waste reduction, facilitating increased manufacturing efficiency and profitability. Additionally, Panizzolo (2016 [7]) presents seven measurement scales for evaluating operational performance, incorporating methodologies such as Drum-buffer-rope and Time Buffer Management.

Mapping Circular Processes

Goldratt and Fox (1986) introduce metrics such as Throughput, Inventory, and Operating Consumption to assess organizational performance, offering insights into profitability and operational efficiency [2]. Panizzolo [7] further discusses their application across different plants globally, enabling effective prioritization of improvement projects and enhancing manufacturing efficiency [13]. Hartini (2020) outlines the Sus VSM framework's method, measuring parameters like time efficiency, quality, energy, material consumption, and waste treatment to identify areas for improvement [3]. Demonstrating the integration of value flow mapping and the 6R concept, Hartini (2020) illustrates how this facilitates waste reduction within a Circular Economy (CE) context. The method evaluates *TOC Circular Operations Processes Performance Indicator*

In "Theory of Constraints (TOC) Production and Manufacturing Performance," Panizzolo [7] explores enhancing production and manufacturing performance through the Theory of Constraints (ToC) methodology. He suggests applying ToC principles to identify and manage constraints within production processes, supported by case studies and theoretical analysis. Panizzolo's findings indicate that ToC implementation improves production performance by increasing throughput and reducing lead times, offering insights into integrating ToC with Lean Manufacturing for operational excellence. However, the article lacks in-depth discussion on challenges and limitations of ToC implementation across diverse contexts. Similarly, "Throughput Accounting: A Case Study" by Islam (2015) addresses improving financial performance and decision-making in organizations through throughput accounting. Islam advocates for adopting throughput accounting principles to maximize throughput while minimizing costs, presenting a case study to illustrate its application. His research demonstrates that throughput accounting enhances financial performance and decision-making, contributing to increased profitability. However, the article could benefit from a deeper exploration of challenges and compatibility issues associated with throughput accounting integration, particularly within different organizational contexts.

production process performance, identifies waste, and explores opportunities for reduction, reuse, recycle, recover, redesign, and remanufacture, culminating in the design of business collaboration towards a CE [3]. A case study in a furniture company underscores the effectiveness of this integration, aligning with Circular Energy indicators proposed by Hartini (2020) [13].

Table 2.
Lean and green indicators in value stream mapping

Manufacturing	Related-metric	Method Measurement
Lead time Efficiency (LTE)	Value-added time during process (VAT)	LTE= VAT/TT $VAT = \sum_{i=1}^{n}(VATi)$
n : process on sawing, construction, assembly, finishing	Non-value-added time (NVAT) Total time during process (TT)	$NVAT = \sum_{i=1}^{n}(NVATi)$ TT = VAT + NVAT
Quality Level Efficiency (QL)	Quality level (QL) Number of defect (ND) Total product/component (TP)	QL = 1 – ND/TP
Material Efficiency (ME)	Material efficiency (ME) Total material used (TMU) Total material (TM) Product/material defect (MD)	ME =TMU/TM $TMU = \sum_{i=1}^{n}(TMUi)$
Energy Efficiency (EME)	Energy efficiency during process (EE) Value added energy (VAE) Non-value added energy (NVA) Energy total during process (ET)	EE = VAE/ET $VAE = \sum_{i=1}^{n}(VAEi)$ $NVAE = \sum_{i=1}^{n}(NVAEi)$ ET = VAM + NVAM
Waste Efficiency (WE)	Number of waste to landfill/river (ML) Total waste during process (TW)	WE = 1 – WL/TW

Note adapted from Hartini et al 2021 IOP Conf. Ser.: Mater. Sci.Eng.

Managing constraints lies at the heart of effective organizational performance optimization. In an initial scenario, organizations may find themselves grappling with resource constraints, technological limitations, or capacity bottlenecks that hinder their ability to overcome constraints effectively. Theory of Constraints (ToC) advocates for a paradigm shift in how organizations perceive and address constraints [2]. Rather than viewing constraints as insurmountable barriers, ToC encourages stakeholders to adopt a proactive stance, leveraging available resources and ingenuity to mitigate constraints and enhance system performance [2]. By identifying the critical constraints within their operational processes, organizations can strategically allocate resources and prioritize initiatives aimed at alleviating these bottlenecks. This targeted approach enables organizations to unlock latent potential and achieve breakthrough improvements in productivity, quality, and customer satisfaction.

Furthermore, the principles of continuous improvement inherent in Lean Management complement the ToC methodology by fostering a culture of relentless optimization and waste reduction [9]. Through practices such as kaizen and value stream mapping, organizations can systematically identify inefficiencies and streamline workflows, thereby enhancing their ability to manage constraints and adapt to changing market dynamics. Incorporating Lean principles into the strategic management framework empowers organizations to cultivate a culture of innovation and adaptability, where teams are encouraged to experiment, learn from failures, and continuously refine their processes to achieve optimal outcomes [9].

This structured overview provides a comprehensive explanation of how Theory of Constraints (ToC) principles have been applied to address operational challenges, citing relevant references to support each assertion.

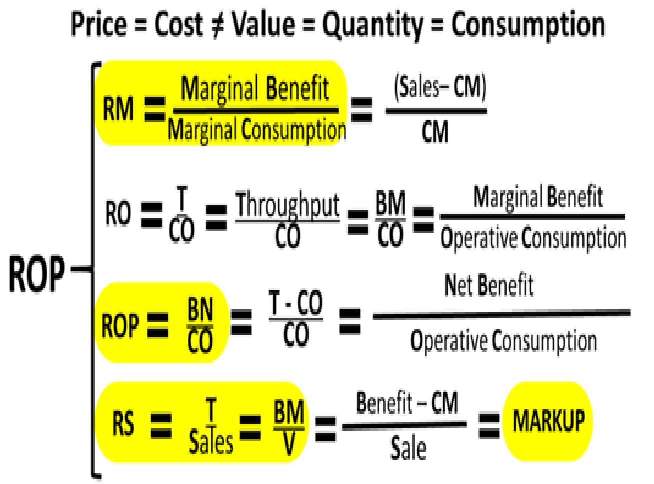

Fig. 2 Calculation of Project Process Operational Performance Indicators
N.ote. Adapted from “DNA Lean Philosophy and TOC for Develop, Innovate and Improve Processes” by Lu-Chang-Say et al (2018) [14]

The TOC Processes Indicator for Sustainable Circular Operations incorporates metrics like Return Operational Performance (ROP), Marginal Return (RM), Sale Return (RS), and Operation Return (RO). These indicators, adapted from the Theory of Constraints (ToC) by Lu-Chang-Say [14], deviate from traditional models to minimize resource and energy consumption while maximizing operational efficiency within a sustainable circular framework.

Conceptual Sustainable Process Value Creation Model

Forgione and Migliardo [15] stress integrating sustainability principles into core business practices, highlighting effective resource management and profit reinvestment for growth [16]. Zhang et al. (2023) Zhang et al. emphasize maximizing benefits while minimizing negative impacts to ensure sustained success in dynamic environments [17]. Chen et al. (2022) discuss 20igning business performance with sustainability objectives for enhanced competitiveness [16].

The integration of the business model cycle with ToC process indicators, as proposed by Goldratt and refined by Lu-Chang-Say, establishes a strategic framework for sustainable business management. This configuration, as depicted in Fig. 1 and 3 [14], delineates financial and operational indicators, optimizing business performance.

Fig. 3 depicts a conceptual model of value and benefit generation within and beyond the company. It integrates the indicators presented in Fig. 2, which address the fundamental aspects of sustainable and circular process management within the organization. This model provides a clear visualization of how operational and financial indicators, derived from the Theory of Constraints (ToC), intersect with principles of circular economy and sustainability to create value for both the company and its surroundings.

This value creation cycle, adapted from Lu-Chang-Say, integrates traditional ROI and financial indicators from the investor's perspective with ToC-based Process Accounting indicators, aimed at maximizing value and marginal benefits generation for all system stakeholders. It also focuses on optimizing Marginal Resource Consumption and minimizing drains (waste, residues, and emissions) with negative impacts on the planet.

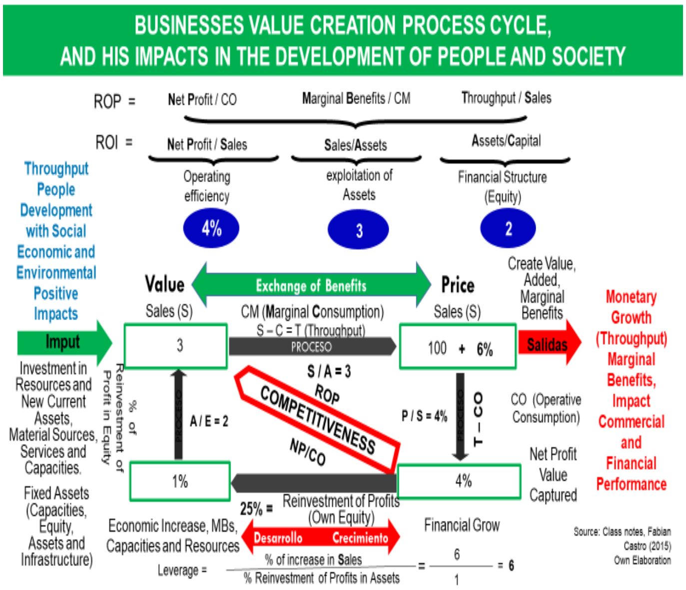

Fig. 3. Conceptual Sustainable Process Value Creation Model
Note. Adapted from “DNA Lean Philosophy and ToC for Develop, Innovate and Improve Processes” by Lu-Chang-Say J., et al (2018)

Through the adoption of circular strategies, organizations endeavor to maximize Throughput (T), Marginal Benefits (BM), and Profits, while concurrently addressing the interests of all stakeholders involved [18][19][4]. This holistic approach underscores the importance of integrating sustainability principles into core business practices to enhance resilience and long-term viability.

Effective management of Marginal Consumption (CM) and Operative Consumption (CO) is crucial for achieving optimal performance and sustainability objectives within this framework [20][21][4]. Furthermore, reinvesting Profits (P) in assets, capacities, and new capital is identified as a pivotal strategy for facilitating growth and development. This reinvestment process contributes to enhancing competitiveness and generating Value, Benefit, and Profits (VBP) in the short, medium, and long terms

[20][21][4]. By minimizing negative impacts and risks associated with operations, organizations can ensure sustained success and resilience in today's dynamic business environment [21][20][4].

Circular Economy (CE) in Macroeconomic Context

Circular Economy (CE) initiatives have gained momentum in various sectors, aiming to foster sustainability and resource efficiency. Pollard et al. [22] shed light on the prevalent use of traditional business models in the electrical and electronic (E&E) sector, with limited adoption of Circular Economy Business Models (CEBMs). However, their research suggests that implementing CEBMs can enhance value creation and delivery in E&E manufacturing by promoting repair, refurbishment, reuse, remanufacturing, and recycling activities, expanding Product-Service-System offerings, and reducing costs associated with raw materials and waste management.

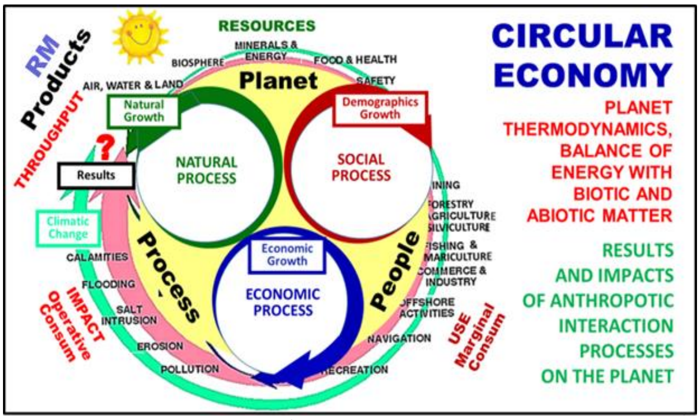

Fig. 4. The CE see from Forrester System Dynamics.
Note. Adapted from Lu-Chang-Say J. (2022) Master Thesis "Reference Socioeconomic Business Strategic Model Increase Competitiveness Sustainability"

Ramos [23] proposed waste management solutions focusing on the entire value chain rather than just end-of-life considerations. Their findings indicate that current product designs often overlook end-of-life considerations, hindering effective sorting and recycling options. They recommend integrating product end-of-life considerations into the design phase.

Muerza et al. [19] proposed parallel supply chains for production and consumption to minimize waste, integrating the circular economic concept of 3R (reduce, restore, and recycle). They validated optimal pricing and packaging strategies to minimize waste, emphasizing the importance of waste reduction and restoration in the Circular Economy. Their optimization approach significantly reduces supply chain costs, offering insights into waste reduction strategies.

Alkaraan et al. [9] introduced circular models to close resource cycles, promoting economic and social benefits, resource security, and environmental performance. Despite advancements in the wind power industry, sustainability research has primarily focused on technological innovation rather than holistic lifecycle assessments.

Ahmad et al. [2] emphasized the Circular Economy (CE) as an economic model replacing the linear take-make-dispose economy, with business management playing a crucial role. They proposed technological domains for sustainable strategic investment decision-making practices, highlighting the synergy between Industry 4.0 technologies and CE techniques in driving sustainable value creation. Muerza [21] developed a model simulating the performance of a multi-product transformation plant, revealing potential profit increases and environmental emission reductions. Their research contributes to supplier selection criteria based on social, environmental, and economic factors, evaluating the economic and environmental viability of Integrated Biomass Center Logistics (IBLC).

Opstal and Smeets [21] explored how Circular Economy strategies and business models can facilitate investments in solar energy while addressing waste challenges. Their findings underscored the importance of viable business cases in driving the adoption of circular solar solutions, highlighting organizational investments driven by lower energy costs, independence, and secure energy access.

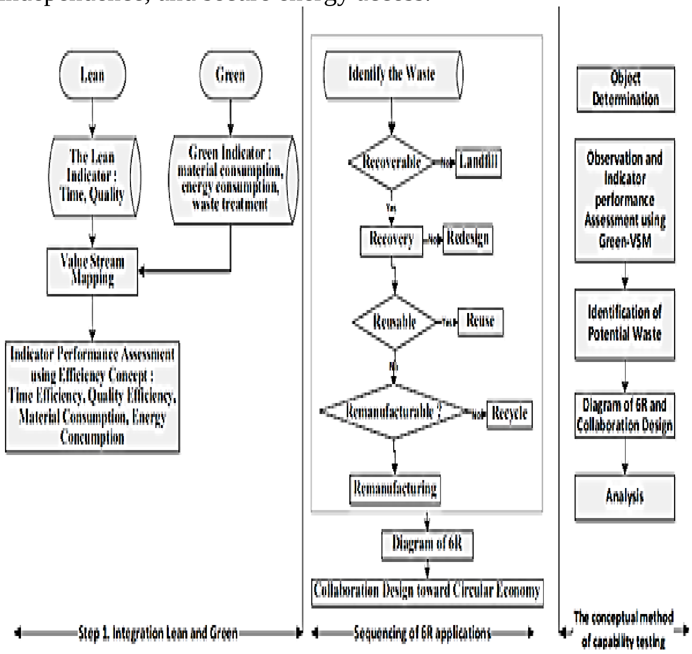

Fig. 5. Research Method
Note. Adapted from "Integration lean manufacturing and 6R to reduce wood waste in furniture company towards circular economy" by Hartini, 2020

This array of studies underscores the diverse applications of Circular Economy principles across different sectors and contexts, emphasizing the importance of integrating sustainability into macroeconomic policies and business strategies to foster economic growth, environmental stewardship, and social well-being.

Forrester's System Dynamics Model in Circular Economy

The illustration in Fig. 4, derived from Forrester's conceptual framework, offers insight into the intricate dynamics among natural, social, and economic processes within the Circular Economy (CE) paradigm. Forrester [10] contends that while these interactions may inherently pose risks to environmental integrity, adept management strategies hold the potential to mitigate negative effects and even spur positive outcomes, thus enhancing the planet's capacity for regeneration.

Moraga [3] elucidates that the CE represents an approach geared towards fostering resource responsibility and cyclical utilization. Over recent years, it has garnered endorsement as a policy mechanism aimed at alleviating environmental burdens while concurrently stimulating economic activity. As articulated by Saidani [24], the CE embodies an economic ethos that transcends the traditional 'end of life' paradigm by prioritizing the reduction, reuse, recycling, and recovery of materials across various sectors and scales, including

- Micro (individual products, companies, consumers),
- Meso (eco-industrial parks), and
- Macro (city, regional, national, and global levels).

Furthermore, according to the EMF [12], CE is based on three shared principles, which can be summarized as follows:

(i) Design waste and contamination,
(ii) Keep products and materials in use, and
(iii) Regenerate natural systems.

The project under study is situated within this cycle of activities. To identify the appropriate and compatible indicators with the project, we see that Moraga [24] states in his classification of EC measurement development Indicators of the European Commission, that the project activity falls into what the classification shows as Recycling Indicators/ Recovery for specific waste streams and as a Sub-indicator we find precisely one related to Biomass Recycling, for which the MATERIALS strategy and REFERENCE strategy elements are suggested, that is, the preservation of materials and the shortening of cycles (reuse). as well as the measurement of the linear economy as a reference scenario (Moraga et al. [3]), for which it is necessary to establish the indicators in SCOPE 1, that is, indicators for measuring the physical properties of technological cycles, for example the RRR indicator reusability, recyclability, and recoverability. For this Scope 1, we must use indicators related to

NTUM: Number of Times of Use of a Material,
CIRC: Material Circulatory Indicator,
Longevity: The time of the Life Cycle,
LMA: Lifetime of Material on Anthroposphere, and
MCI: Material Circulatory Indicator.
NOTE, Adapted from Moraga G et al. [24]

According to Hartini [13], the change from a linear economic model to a CE is beneficial for companies: due to higher profitability, greater competitive advantage, and reduction of environmental impacts (reduction of waste - Lean Manufacturing- and negative impacts in the community). Although the definition of CE has not yet reached a definitive point, but in general, many associate it with a combination of reduce, reuse, and recycle (3R). But additionally, CE is considered a very strong concept because it is based on reducing the use of resources, through efforts to increase the efficiency in the use of these through reuse, reduction, recycling, redesign, and re-manufacturing. In addition to those "5R's," of these we must add other "5R's" because We are all socially responsible for reincorporating and reinforcing the regeneration and recovery of Nature, pursuing the generation of positive impacts and marginal benefits, and minimizing DRAINS (Waste, Scraps, and Emissions) with negative impacts for everyone on the planet.

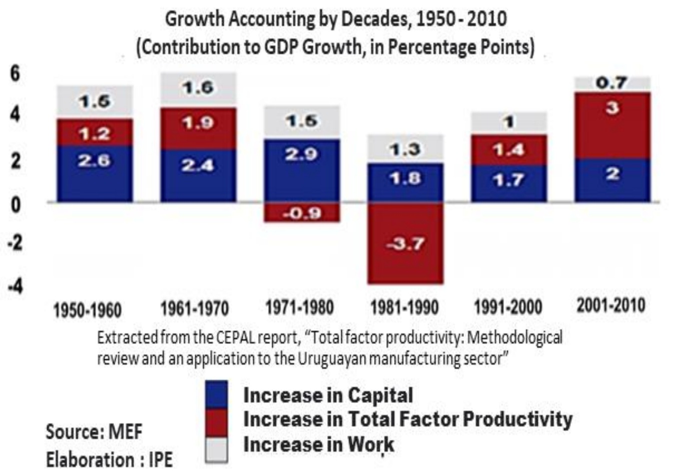

Fig. 6. Evaluation of TFP (Total Factor Productivity) in the Economy
Note: EC Prospective Evaluation Through Markov Chain Adapted KLEMS Key Factors

Muerza et al. [19] proposed parallel supply chains for production and consumption to minimize waste, integrating the circular economic concept of 3R (reduce, restore, and recycle). They validated optimal pricing and packaging strategies to minimize waste, emphasizing the importance of waste reduction and restoration in the Circular Economy. Their optimization approach significantly reduces supply chain costs, offering insights into waste reduction strategies.

Alkaraan et al. [9] introduced circular models to close resource cycles, promoting economic and social benefits, resource security, and environmental performance. Despite advancements in the wind power industry, sustainability research has primarily focused on technological innovation rather than holistic lifecycle assessments. Ahmad et al. [2] emphasized the Circular Economy (CE) as an economic model replacing the linear take-make-dispose economy, with business management playing a crucial role. They proposed technological domains for sustainable strategic investment decision-making practices, highlighting the synergy between Industry 4.0 technologies and CE techniques in driving sustainable value creation.

Conceptual Model for Capital Generation in Circular Economy

The exploration of scholarly literature across platforms such as Scopus, Web of Science, and other academic databases has provided a comprehensive understanding of Circular Economy (CE) and its multifaceted dimensions (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022). Search queries encompassing terms like 'circularity', 'CE Key Performance Indicators (KPI)', and 'Bioenergy Sources KPI' were instrumental in identifying pertinent articles, publications, and books (Forgione & Migliardo, 2022; Zh ang et al., 2023; Chen et al., 2022).

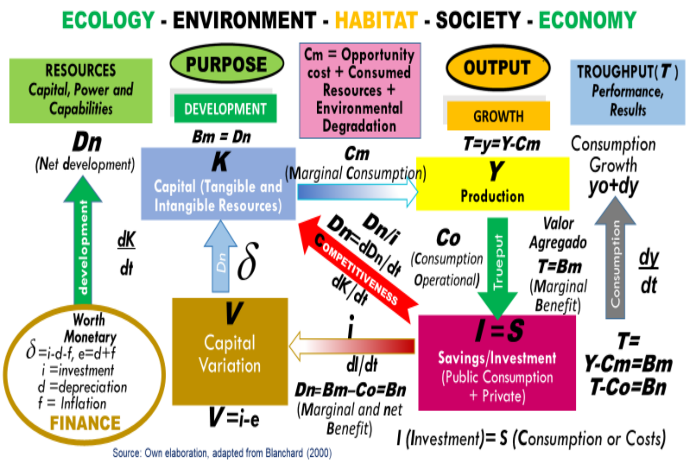

Fig. 7. The cycle of savings and investment, in the creation of value and development of capital in the EC (Circular Economy)
Note. Adapted from "Reference Socioeconomic Business Strategic Model, to Increase Competitiveness, Sustainably Developing the Amazon". Lu-Chang-Say J., 2022

This thorough literature review forms the cornerstone for conceptualizing and developing a holistic approach to implementing circular economy principles. Building upon the conceptual framework depicted in Lu-Chang-Say's Fig. 7 Cycle of Circular Economy for Sustainable Development of Capitals, this study endeavors to quantify Return on Investment (ROI) and manage Total Factor Productivity (TFP) contributors to Gross Domestic Product (GDP) (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022).

The proposed application of Circular Strategic Investment aims to nurture the development of diverse forms of capitals, including Human, Social, Natural Resources, ICT, and Financial, thereby enhancing overall capacities, competitiveness, and infrastructure (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022). Moreover, this approach seeks to foster the prosperity of individuals and communities by fostering partnerships conducive to harmonious living and peace, in synergy with the planet (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022).

By optimizing the Investment of Marginal Consumption (CM) of resources, the objective is to maximize the generation of capitals (K), Business Models (BM), and Value-Based Propositions (VBP) through circular strategies (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022).

Additionally, by mitigating negative impacts, effects, and risks associated with human activities, this approach aims to convert them into positive outcomes, thereby contributing to the sustainability and resilience of socio-economic systems (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022).

In the context of the Circular Economy, as per the cycle proposed by Lu-Chang-Say, there is always an investment of CM (Marginal Consumption) to create and accumulate BM (Marginal Benefits) as marginal value, i.e., K (capital) (Forgione & Migliardo, 2022; Zhang et al., 2023; Chen et al., 2022). Adapting Lu-Chang-Say [14] Fig. 7 Cycle of Circular Economy for Sustainable Development of Capitals, by measuring ROP and managing all GDP contributor TPF, applying a Circular Strategic Investment, for develop all type of capitals (Human, Social, Natural. Resources, ICT, Financial), also improve capacities, competitiveness, infrastructure, for generate Prosperity of People, empowering Partnership to live in harmony and Peace in synergy with the Planet. By optimizing the Investment of Marginal Consumption (CM) of resources, Maximize the T generations of Capitals (K), BM and VBP, applying circular strategies. Also minimizing all negative impacts. effect and risks, generate by the human activities, or better yet, turn them into positive.

Markov Chain Evaluation for CE and TPF

In this section, we delve into integrating Total Factor Productivity (TFP) analysis within Circular Economy (CE) initiatives, aiming to optimize resource utilization and enhance sustainability (Moraga et al., 2019). By leveraging TFP metrics, we gain insights into the comprehensive economic, environmental, and social impacts of CE practices. This approach allows us to assess the efficiency and effectiveness of CE strategies across various dimensions, including Planet, People, Processes, and Products (Alkaraan et al., 2023 [9}).

Fig. 8. The evaluation of the Circular Economy through Total Factor Productivity
Note. Adapted from "Reference Socioeconomic Business Strategic Model, to Increase Competitiveness, Sustainably Developing the Amazon". Lu-Chang-Say J., 2022

As illustrated in Fig.s 4 and 6, the factors of the 4 P's (Planet, People, Processes, and Products) constitute components of a Leontief input-output table (Brown et al., 2014).

When utilizing quantitative values measured in terms of quantity of matter or energy resources, without considering their valuation based on market value, it becomes evident that the planet contributes the majority of inputs in the table. Existing models, predominantly driven by cost considerations, inadvertently foster the maximization of resource consumption, particularly those whose market price tends toward zero (Hartini et al., 2021).

The application of this CE model enables the quantification of the planet's resources utilized, while also discerning trends in processes, products, and people's consumption patterns. This, in turn, facilitates a circular utilization of resources, thereby minimizing marginal consumption of the planet's resources and maximizing marginal benefits. Consequently, cumulative benefits or throughput from operations are optimized.

Integrating Markov Chain Analysis alongside TFP analysis offers a robust methodology to promote sustainable development, as demonstrated in Lu-Chang-Say's study (2023). By analyzing socio-economic and environmental factors using Markov Chain Analysis, strategic pathways for sustainable development can be identified, enhancing competitiveness and sustainability in regions such as the Amazon. This approach provides valuable insights into the dynamics of complex systems, guiding decision-making towards desired outcomes.

The research method used in this article is a systematic review of the literature. The seeks is to find in the literature, aspects Moreover, Forrester's work (1995) sheds light on the application of Markov Chain Analysis in understanding and managing counterintuitive behaviors within social systems. Through case studies and theoretical analyses, Forrester illustrates how Markov Chain Analysis can help identify feedback loops and dynamic interactions, leading to more effective management strategies.

The chosen research methodology involves a systematic literature review, aiming to explore relevant literature on Circular Economy (CE) indicators, productivity and profitability metrics, and Throughput Accounting, all critical for analyzing the project at hand. Subsequently, a comprehensive improvement framework was constructed by integrating Theory of Constraints (ToC) with Lean Manufacturing and Total Factor Productivity (TFP). Utilizing the Value Stream Mapping (VSM) framework facilitated the delineation of 6R indicators, typical within CE practices. This framework establishes a correlation between ToC indicators and those of CE, anchored in the 6R framework.

Additionally, the application of Total Factor Productivity (TFP) metrics, employing ToC's Rate of Production (ROP) indicators, enables the computation of Throughput indicators encompassing the dimensions of Planet, People, Processes, and Products. This computation parallels the Leontief Input-Output table commonly utilized in economics. Furthermore, leveraging Markov Chain analysis aids in discerning the stable state of each scenario, allowing for the projection of their trends. By employing this methodological approach, the cumulative impact of interacting factors can be gauged, thereby facilitating strategic decision-making in the present to steer towards desired future scenarios.

Incorporating Markov Chain analysis enhances methodological rigor by enabling a probabilistic assessment of future states based on current system dynamics. Markov Chain models have been extensively utilized across various fields to analyze sToChastic processes and predict future states based on transition probabilities (Hillier & Lieberman, 2010). By integrating Markov Chain analysis into the research methodology, the study gains predictive power in assessing the long-term implications of strategic decisions on project performance and sustainability.

Furthermore, Markov Chain analysis provides insights into the stability and convergence properties of the system, offering valuable information for formulating robust strategies (Panizzolo [7]). By analyzing the steady-state probabilities of different system states, decision-makers can identify optimal pathways and interventions to achieve desired outcomes while mitigating risks and uncertainties.

III. METHOD

The research adopts a quantitative approach, as empirical data on costs and benefits were collected from field observations at each stage of project implementation. Given its level of abstraction, the research is descriptive, aiming to identify variables influencing the project development process, particularly indicators related to Circular Economy (CE), productivity, profitability, and Throughput Accounting from the Theory of Constraints (TOC). Indicators considered in the project are analyzed to understand their impact on the subject under analysis.

Subsequently, a conceptual model was developed to enhance understanding and guide subsequent analysis. This model combines the Theory of Constraints with Lean Manufacturing and Total Factor Productivity (TFP) metrics to optimize project processes. The Value Stream Mapping (VSM) framework was utilized to map 6R indicators, typical of the Circular Economy, and propose a methodology that correlates TOC indicators with those of CE, focusing on the 6Rs. Additionally, TFP metrics were applied to TOC indicators to measure inputs of Marginal Consumption (CM) and Throughput of Products (BM) across dimensions such as Planet, People, Processes, and Profits (4P).

Furthermore, the study utilized Markov Analysis to forecast future states based on transition probabilities, thereby informing strategic decisions in the present. By projecting stable states for each scenario, organizations can plan actions to achieve desired future outcomes.

The research also explores a conceptual model for Capital Generation in the Circular Economy, drawing upon a comprehensive literature review to quantify Return on Investment (ROI) and manage Total Factor Productivity (TFP) contributors to Gross Domestic Product (GDP). The proposed Circular Strategic Investment approach aims to nurture the development of diverse forms of capitals, including Human, Social, Natural Resources, ICT, and Financial, thereby enhancing overall capacities, competitiveness, and infrastructure. Additionally, this approach seeks to mitigate negative impacts associated with human activities and convert them into positive outcomes, contributing to the sustainability and resilience of socio-economic systems.

In summary, the methodological approach outlined integrates quantitative data collection with a conceptual framework informed by principles of Circular Economy and operational tools from the Theory of Constraints and Lean Manufacturing. Through this integrative approach, the research aims to provide insights and strategies for sustainable management practices in the context of bioenergy consumption.

IV. RESULTS

The searches carried out on Google Scholar have been made using the combinations of the following terms: 'circular economy', 'circularity', 'Circular Economy KPI', 'Renewable Energy KPI', 'measure', 'indicators'. We have based ourselves on scientific articles, web consultant publications and books

As explained in the methodology based on Table 2, we can appreciate the indicators that could be applied in the project, for this case, operational performance management had been seen as part of the indicators, let's remember the equation:

$$ROP = T/V \qquad (a)$$

Where: ROP or Rate Operating Process is described by integrating the variables:

T: Throughput, (expressed in monetary units)
V: Sales, (expressed in monetary units)
TMU: Total Material Used, expressed in quantity of material units (kg, ton etc)
TM: Total Material Obtained, expressed in quantity of material units (kg, ton etc))
ME: Material Efficiency (productivity)
EA: Energy Added by the process (Value of Work and Energy added)
EME; Total energy and work consumed in the process
EE: Energy Efficiency

Where

$$ME=TMU/TM \qquad (b)$$
$$EE=EA/EME \qquad (c)$$

In addition, applying Fig. 2 Marginal Benefits (BM), Marginal Consumption (CM), Operating Consumption (CO) and Throughput (T), are defined by the following equations:

$$CM= \text{Purchases}+\text{Inventory}=TM \text{ (Investment of Necessary Materials)} \qquad (d)$$
$$CO=EME \text{ (Operational investment of materials, work and necessary energy)} \qquad (e)$$
$$T=V-CM = \text{Sale - Marginal Consumption} \qquad (f)$$

Taking the equations (d, e and f) from Fig. 1, we can restate the Marginal Benefit (BM) and Marginal Operative consumption (CO) as:

$$RV= 1- T/V = 1- TM/V \text{ (Rate of the Sale)} \qquad (g)$$
$$RO= 1- T/CO = 1- TM/EME \text{ (Rate of Operation)} \qquad (h)$$

We can see that, with greater material efficiency, TM tends to decrease with respect to TMU, which in turn is part of Sales (V), if the relationship TM with V becomes much less than 1 each time, the value of ROP increases.

However, also taking into account (b, c, d, e, f, g and h), from the perspective of the circular economy, the Net Benefits (U M) and Rate Operating of the Process (ROP).

$$UN = T-CO \text{ (Net Benefits o Income)} \qquad (i)$$
$$ROP = 1- ((T-CO))/CO = 1- UN/CO \text{ (Rate Operational Process)} \qquad (j)$$

In this way, the productivity bias generated by resources whose price tends to zero in the market is eliminated. It must also be understood that among the resources that are consumed, work and energy or carbon footprint equivalence must be included. so that the planet's contribution is adequately calculated.

Through PTF is applied by calculating the ROP and making a Table for Planet, People, Processes and Profits, a ROP 4P IP Table. As a result, after analyzing the TOC indicators, in practice the resource consumption is determined by the required quality level, which establishes a required marginal consumption level, per unit of product. In the same sense, it is always necessary to invest a unit of marginal consumption, to obtain the same mechanical benefits (throughput) per unit of product.

TABLE 3.
MARKOFF CHAIN ACTUAL TREND SCENARIO

	1	2	3	4	5	6	7	8
	P1	P2	P3.	P4.	P1	P2.	P3.	P4.
P1	0.6000	0.6000	0.8900	0.4000	0.6237	0.6237	0.6237	0.6237
P2.	0.3000	0.3000	0.0100	0.5000	0.2763	0.2763	0.2763	0.2763
P3.	0.0900	0.0900	0.0900	0.0900	0.0891	0.0891	0.0891	0.0891
P4.	0.0100	0.0100	0.0100	0.0100	0.0109	0.0109	0.0109	0.0109

Note. Adapted from Lu-Chang-Say [13] "Reference Socioeconomic Business Strategic Model, to Increase Competitiveness, Sustainably Developing the Amazon".

That is, to achieve the same marginal benefit, an additional unit of marginal resources must be consumed (Fig. 2), in addition to the performance and/or profit benefits, are measured by their sale value in the market.

In this sense, from an systemic point of view, the same marginal consumption can generate multiple and diverse marginal benefits as a product, throughout the supply chain, between nature and consumers.

Next, in Fig. 7, we see how development is impacted as a result, having invested the consumption of resources, to generate value and benefits for all those who system impact. This investment promotes a virtuous circle of transformations, which generates more capacities and resources to develop, as we can see in Fig. 7.

TABLE 4
MARKOFF CHAIN PLANET CONSUPTION TREND SCENARIO

	1	2	3	4	5	6	7	8
	P1	P2	P3.	P4	P1	P2.	P3.	P4.
P1	0.300	0.300	0.000	0.000	0.278	0.278	0.278	0.278
P2	0.700	0.600	0.900	0.900	0.650	0.650	0.650	0.650
P3.	0.000	0.090	0.090	0.040	0.064	0.064	0.064	0.064
P4	0.000	0.010	0.010	0.060	0.008	0.008	0.008	0.008

Note. Adapted from Lu-Chang-Say [13] "Reference Socioeconomic Business Strategic Model, to Increase Competitiveness, Sustainably Developing the Amazon".

Applied to the CE principles (Circular Economy) in a dynamic way of Fig. 4, jointly those of TFP (Total Factor Productivity) Fig. 4 and 1.5, for the generation of renewable energies, an observation that, currently, there is a tendency for the planet to always be the one that contributes the resources, in addition, this tendency is increasing on the resources whose price or cost in the market tends to zero.

TABLE 5.
MARKOFF CHAIN CIRCULAR SUSTAINABLE TREND SCENARIO

	1	2	3	4	5	6	7	8
	P1	P2.	P3.	P4.	P1	P2.	P3.	P4.
P1	0.7000	0.6000	0.0000	0.0000	0.6429	0.6429	0.6429	0.6429
P2	0.3000	0.3000	0.9000	0.9000	0.3214	0.3214	0.3214	0.3214
P3	0.0000	0.0900	0.0900	0.0400	0.0318	0.0318	0.0318	0.0318
P4	0.0000	0.0100	0.0100	0.0600	0.0039	0.0039	0.0039	0.0039

Note. Adapted from Lu-Chang-Say [13] "Reference Socioeconomic Business Strategic Model, to Increase Competitiveness, Sustainably Developing the Amazon".

This is how Tables 3, 4 and 5, also Fig. 6 and 8 have been elaborated. They are a simple input-output table. Applied to our project, we find that the contribution of the planet always far exceeds the contribution of the People, the Processes and the Profits of products consumption, for this reason in Fig..4, the negative impacts in red are greater than the positive ones in blue, which are degrading. However, by making strategic decisions, based on the measurement of the independent variable indicators, a process can be prospectively planned to achieve the expected results, where the positive impact is greater than the negative.

Continuing in Table 3 and Fig.. 7, the scenario of the trend of the supply chain of renewable energies is shown, also by applying the Markoff Chain, it has been determined that the stable trend is to increase the planet consumption.

Applying simulation (Table 4 and 5), it has been found that the only way to truly go towards a scenario of circular use process of resources, is that both the people, the process and Profits of products consumption, as well as the forms , as they use the planet's resources, be sustainable, in case the conditions are not changed, how the planet's resources should be consumed, that will not change the current trend.

From Table 5 we will find that going towards CE is not just 6 R or 10 R, it is conceiving, managing and improving things together so that the planet's resources are used cyclically and responsibly.

In this sense, the application of the Markoff chain, to determine a stable state, allows us to anticipate the current trend of a set of interacting factors, through its use it is possible to plan a process that leads to reducing the consumption of the planet, instead of increasing it. as is the case today with the linear economy.

V. CONCLUSIONS

Combining two manufacturing management improvement tools has yielded a more potent instrument, streamlining the utilization of process measurement indicators. The integration of mapping frameworks between improvement theories within manufacturing lines has enabled the correlation of indicators. Thanks to Value Stream Mapping (VSM), the alignment of Theory of Constraints (TOC) indicators with those of Continuous Improvement (CI) has become possible.

The geographical context of the project in Spain, situated within the European Economic Community, has ensured diverse and comprehensive documentation of indicators and scenarios, enriching the depth of project analysis. This extensive information landscape closely mirrors the dynamics of businesses in Bioenergy Sources.

While Lean and ToC primarily focus on internal (microeconomic) aspects of operational management, Circular

Economy (CE) encompasses broader macroeconomic considerations, evaluating systemic impacts. CE integration represents the convergence of micro and macroeconomic realities, aligning with the broader study of economics, which evaluates resource utilization, transformation, and exchange within society and nature.

The application of Total Factor Productivity (TFP) enables the calculation of potential Returns for Planet, People, Processes, and Products (ROPPP). This indicator, a synthesis of Lean and ToC principles initially designed for microeconomic process evaluation, has now been extended to macroeconomic assessment. Consequently, a quantitative methodology has emerged to gauge the future sustainability of the entire proposal, seamlessly integrating micro and macroeconomics with operational and process management.

Implications for Practice:

Combining two manufacturing management improvement tools has resulted in a more potent instrument, facilitating the utilization of indicators for process measurement. The integration of mapping frameworks between improvement theories within manufacturing lines has made it feasible to correlate indicators. Thanks to Value Stream Mapping (VSM), it became possible to align Theory of Constraints (TOC) indicators with those of Continuous Improvement (CI).

The geographical context of the project in Spain, situated within the European Economic Community, has ensured diverse and comprehensive documentation of indicators and scenarios, enhancing the depth of project analysis.

While Lean and ToC serve as operational management tools focusing on internal (microeconomic) aspects, Circular Economy (CE) encompasses broader macroeconomic considerations, evaluating systemic impacts. CE integration represents the convergence of micro and macroeconomic realities, aligning with economics' study of resource utilization, transformation, and exchange within society and nature.

The application of Total Factor Productivity (TFP) enables the calculation probable potential Return for Planet, People, Processes, and Products (ROPPP). This indicator, a fusion of Lean and ToC principles, initially designed for microeconomic process evaluation, has now been extended to macroeconomic assessment. Consequently, a quantitative methodology has emerged to gauge the future sustainability of the entire proposal, seamlessly integrating micro and macroeconomics with operational and process management.

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