Assessing the Socio-Economic and Environmental Impacts of Circularity Interventions: A Country-Level Analysis in Latin America

A case study on Costa Rica and Uruguay

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Abstract

The transition from a linear to a circular economy is essential to confront pressing environmental challenges in Latin American (LATAM) countries, including resource depletion, pollution, deforestation, and biodiversity loss. While circular economy principles have advanced in developed nations, LATAM countries are at an early stage of adoption, facing unique socio-economic and environmental contexts that demand tailored policy approaches. This study focuses on Costa Rica and Uruguay as representative cases, selected for their medium-high income status and their advancement in developing national circular economy strategies. The research evaluates the socio-economic and environmental impacts of nine CIs outlined within these circular strategies, aiming to inform broader regional strategies for sustainable development. This research addresses critical knowledge gaps by evaluating national circular strategies and their broader regional and global implications.

The study applies a mixed-methods approach combining qualitative analysis with a quantitative multi-regional environmentally extended input-output analysis (MR-EEIOA) to evaluate key CIs selected from Costa Rica and Uruguay's circular national strategies.

This thesis employs a qualitative analysis framed by the DE lens, a conceptual model that defines a "safe and just space" for sustainable development by integrating planetary boundaries ceilings with social foundations. This holistic framework complements circular economy principles by emphasizing the need to reduce environmental impacts and to ensure equitable socio-economic outcomes. This integrated methodology provides a comprehensive evaluation of CIs, capturing environmental benefits, such as decreased Greenhouse Gas (GHG) emissions, and their associated socio-economic trade-offs. To elaborate, the analysis measures the economic dimension of the transition by examining the interplay between job creation in new circular sectors and job displacement in traditional linear industries. It also assesses the social dimension by evaluating how these initiatives generate social value-added through the creation of new skills and enhanced local economic resilience.

Out of all circular interventions qualitatively analysed through the Doughnut Economy lens, two are quantitatively modelled using MR-EEIOA. This is done to demonstrate the modelling process and to explore the strengths and limitations of MR-EEIOA as a tool supporting qualitative analysis.

This comparison of quantitative results with qualitative insights generates new understandings of the potential impacts of circular economy interventions in the LATAM region.

Key findings reveal that CIs in Costa Rica and Uruguay yield environmental gains, particularly in climate change mitigation and resource efficiency, and promote socio-economic benefits like job creation and social equity. However, these results are constrained by data limitations - especially concerning social impacts - and structural challenges, such as low recycling infrastructure and unclear policy targets. The results of the MR-EEIOA modelling reveal unexpected trade-offs between environmental and socio-economic impacts of the analysed CIs. This analysis highlights a complex reality where an environmental gain (e.g., lower GHG emissions) can coincide with a socio-economic cost (e.g., job displacement). This finding underscores the need for a more holistic assessment of these initiatives by collecting more qualitative data on the micro- and meso-level impacts of CIs on specific sectors, using methods such as semi-structured interviews and surveys.

This research contributes to Industrial Ecology by assessing the impacts of CIs in underrepresented regions and addressing social dimensions that are often neglected in traditional analyses. Specifically, this research highlights the importance of improving mixed-methods data collection by integrating sector-specific qualitative insights and quantitative metrics on key sectors projected to undergo significant change from the analysed CIs.

These insights provide crucial support for national governments and regional institutions like ECLAC (Economic Commission for Latin America and the Caribbean) in designing effective, inclusive circular economy transitions. This work helps advance sustainable development across the region by applying the DE model, which seeks to meet social foundations while respecting planetary boundaries.

Key words Circular economy, Latin America, National roadmaps, Environmental Extended Input - Output Analysis

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Glossary

Term	Brief definition
AFOLU (Agriculture, Forestry, and Other Land Use)	Sector classification used for reporting resource use and emissions related to land-based activities.
BID (Banco Interamericano de Desarrollo/Inter-American Development Bank)	Regional development bank supporting economic development, social development and regional integration.
CEPALSTAT	The statistical database of CEPAL/ECLAC.
CI (Circular Intervantion)	A Circular Intervention is the practical application of circular economy principles, converting broad concepts into focused actions within specific sectors or systems.
CR	Costa Rica
DE (Doughnut Economy)	Framework for sustainable development that balances meeting people's essential needs within social foundations, while staying within the planet's ecological limits.
ECLAC (Economic Commission for Latin American and Caribbean countries)	United Nations Commission supporting economic development and policy analysis in Latin America and the Caribbean.
EPR (Extended Producer Responsibility)	A policy approach where producers are responsible for the post-consumer stage of a product's life cycle.

EXIOBASE 3	A global multi-regional environmental extended supply-use and input-output table database.
GDP (Gross Domestic Product)	The total value of goods produced and services provided in a country during one year.
GTAP (Global Trade Analysis Project)	A global network of researchers and policy makers conducting quantitative analysis of international policy issues.
IOT (Input-Output Table)	An economic accounting framework that records the relationships between different industries or sectors in terms of inputs purchased and outputs produced.
IRP (International Resource Panel)	A scientific panel providing independent, coherent, and authoritative scientific assessments on the use and sustainable management of natural resources and their environmental impacts over the full life cycle.
LATAM (Latin America)	The region comprising the countries of Latin America.
MARIO (Multifunctional Assessment of Regions through Input-Output)	A Python package for input-output modeling supporting EXIOBASE 3 and other datasets.
MFA (Material Flow Analysis)	Systematic assessment of the flows and stocks of materials within a system defined in space and time.
OECD (Organisation for Economic Co-operation and Development)	An international organization of countries promoting economic growth and policy coordination.
PIOT (Physical Input-Output Table)	Input-output tables describing inter-industry exchanges in physical (mass/energy) units, rather than monetary.
SDGs (Sustainable Development Goals)	The set of 17 global goals set by the United Nations aimed at ending poverty, protecting the planet, and ensuring prosperity for all by 2030.
SME (Small and Medium-sized Enterprises)	Businesses with personnel, revenue, or asset levels below certain thresholds, often key to national economies and innovation.
SOC (Soil Organic Carbon)	Organic carbon component of soil, critical for soil health and a focus of carbon sequestration efforts.
SUT (Supply and Use Tables)	Statistical tables that show the supply (production and imports) and use (intermediate and final consumption) of goods and services in an economy.
UY	Uruguay
WIOD (World Input-Output Database)	A database for global economic analysis that provides international input-output tables.

EEIOA (Environmentally Extended Input-Output Analysis)	A methodology that quantifies the environmental impacts (such as emissions and resource use) associated with economic activities using input-output tables. It extends traditional input-output models by integrating environmental data to assess the environmental footprint of economies, sectors, and products.
MR-EEIOA (Multi-Regional Environmentally Extended Input-Output Analysis)	EEIOA methodology expanded to include multiple countries, capturing cross-border flows and impacts.
A (Technical Coefficients Matrix)	In input-output analysis, a matrix showing the amount of input from each sector required to produce one unit of output in another sector.
k_a (Overall Coefficient Change)	The magnitude of change applied in MR-IO/EEIOA modelling, typically as the product of a technical coefficient and a market penetration rate.
k_p (Market Penetration)	Proportion of relevant actors or market that adopts a certain intervention.
k_t (Technical Coefficient Change)	Parameter representing the maximum potential effect of an intervention on a process/sector.
L (Leontief Inverse)	In input-output analysis, a mathematical construct ($L = (I - A)^{-1}$) showing total (direct and indirect) output required per unit of final demand.
F (Environmental Extension Matrix)	In EEIOA, a matrix representing environmental pressures (e.g., emissions, water use) from each sector.
Y (Final Demand Vector)	In input-output analysis, represents total demand for goods/services from direct consumers.

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1. Introduction

The prevailing linear model of consumption and production, deeply rooted since the Industrial Revolution, is widely acknowledged as a key driver of environmental degradation and climate change, pushing Earth's ecological limits beyond safe thresholds (Andrews, 2015; Steffen et al., 2015). In response to this urgent challenge, the circular economy (CE) concept has evolved to promote systemic change by redefining waste as a resource to be retained and reused within economic systems (Pearce & Turner, 1991). Over recent years, CE has gained significant global attention as a pathway toward sustainable development.

LATAM is a vast region extending from Mexico in the north, through Central America, and down encompassing all countries in South America. It spans over two continents: North America and South America. The region covers diverse geographical features, including the Andes mountain range, the Amazon rainforest, extensive plateaus, tropical rainforests, deserts, and large river basins. The region includes approximately 20 sovereign countries, excluding the Caribbean islands (Britannica, n.d.). LATAM is a region rich in biodiversity and natural resources, which faces critical environmental and socio-economic challenges exacerbated by predominantly extractive and linear economic activities. These have led to deforestation, biodiversity loss, and significant greenhouse gas emissions, especially from agriculture and land use (Circle Economy, 2023b; ECLAC, 2025). The vulnerability and importance of LATAM for global ecological stability make CE a promising alternative development model, aimed at fostering resource regeneration, waste reduction, and economic resilience.

Nevertheless, translating CE principles into effective action in LATAM encounters structural barriers, including social inequalities, diverse levels of infrastructure development, and distinct industrial patterns that differ from those of high-income countries where CE theories often originate (Liu et al., 2018; Muchangos, 2022). Additionally, limited data availability and a lack of thorough quantitative evaluations hinder the understanding and implementation of impactful circular policies. Many existing initiatives remain fragmented, lacking detailed targets or comprehensive implementation roadmaps, which curtails systematic progress (Ospina-Mateus et al., 2023; UNIDO, 2024).

This study evaluates whether Circular interventions (CIs) in national policies yield environmental and socio-economic benefits. It employs a qualitative analysis drawing on literature about the countries' socio-economic and environmental flows and applies the Doughnut Economy (DE) framework, a model integrating planetary boundaries and social foundations, to identify impacts most influenced by the CIs in the national strategies (See further details in Chapter 2).

This thesis addresses these gaps by analysing national CE strategies in two LATAM countries: Costa Rica and Uruguay. These cases were selected for their medium-upper income status, small population sizes, and emerging policy frameworks that reflect broader regional interests. Employing a mixed-methods approach, the study integrates a comprehensive qualitative assessment framed by the DE framework with targeted quantitative modelling. The quantitative component supports and complements the main qualitative analysis by focusing on two specific CIs - one from each country - selected among various initiatives highlighted in their national strategies. Using MR-EEIOA provides detailed scenario-based estimations of the socio-economic and environmental impacts of these interventions. The selection of just two interventions serves as an illustrative example of how quantitative modelling can be applied in future research to assess circular economy impacts more broadly. This approach investigates the feasibility and value of combining qualitative frameworks with quantitative methods to holistically evaluate circular economy policies at national, regional, and international scales.

The central research question is: What are the socio-economic and environmental impacts of Costa Rica and Uruguay's national circular economy interventions across national and broader scales? Insights from this analysis are intended to support national governments within the LATAM region in refining their circular economy policies. Furthermore, regional bodies such as the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), civil society organizations, local industry actors, and international development partners stand to benefit from understanding contextually relevant and effective circular strategies aligned with sustainable development goals and ecological and social priorities.

The thesis is structured to lead the reader through a systematic exploration of the topic. Chapter 2 reviews the existing literature, covering CE theory, the socio-economic and environmental context in LATAM, governance mechanisms, and qualitative and quantitative methods for assessing CIs. Chapter 3 articulates identified research gaps, defines objectives, and formulates the research questions. Chapter 4 details the methodological framework, explaining the qualitative and quantitative tools employed. Chapter 5 presents the empirical analysis and results. Chapter 6 interprets these findings, linking them to existing research and policy implications. Finally, Chapter 7 offers conclusions and recommendations for advancing circular economy adoption in the Latin American context.

2. Literature review

This literature review explores academic and policy works related to the circular economy with a focus on the Latin American context. It aims to establish a clear conceptual foundation, present the regional socio-economic and environmental conditions, and analyse governance frameworks supporting circular economy adoptions in LATAM. Furthermore, it evaluates the qualitative and quantitative methods used for assessing CIs. The review is organized into four subchapters. The first establishes the theoretical foundations of CE, outlining core concepts and classification frameworks that guide CIs globally. The second subchapter contextualizes these principles within LATAM, exploring the region's geographic diversity, economic structure, and environmental challenges that shape its circular economy landscape. The third section critically examines national policies and governance tools that drive CE adoption across LATAM countries, identifying progress and policy gaps. Lastly, the fourth subchapter reviews a range of qualitative and quantitative methodological approaches, including the DE framework and Environmentally Extended Input-Output Analysis (EEIOA), which inform the analytical techniques applied in this study.

2.1. Theoretical Foundations of the Circular Economy

According to the Ellen Macarthur Foundation (2024), CE is a system that redefines waste as a valuable resource to be optimized and kept in a continuous loop. This approach reduces the need for virgin raw materials in production and alleviates pressure on Earth's finite natural resources. Based on this framework, CE operates at multiple levels: the macro level (entire economies), the meso level (sectors and networks), the micro level (individual companies), and the nano level (products) (Blomsma et al., 2019).

Principles of CE are often operationalized through hierarchical "R" frameworks that organize strategies aimed at keeping materials in use. These frameworks, such as the 3R initiative - Reduce, Reuse, Recycle - serve as guiding structures that classify different circular approaches (Ghisellini et al., 2016). More comprehensive frameworks like the 10R approach (Zorpas, 2020) further expand this hierarchy into ten strategies, from Refuse and Rethink to Recycle and Recover. These

"R" frameworks are not themselves direct definitions of CIs, but rather conceptual tools that map out the kinds of circular actions possible in a system, prioritizing strategies based on their circularity and resource efficiency.

This study conceptualizes a four-strategy classification for defining circular economy interventions, as proposed by Aguilar-Hernandez et al. (2018), derived as a variation from the 10R framework. These four strategies - Product Lifetime Extension (PLE), Resource Efficiency (RE), Closing Supply Chains (CSC), and Residual Waste Management (RWM) (Donati et al., 2020) - are used here to guide both qualitative assessment and quantitative EEIOA modelling. These categories provide a clear and operationalizable basis to define specific CIs: measurable actions or policies focused on extending product lifespans, improving resource use, closing material loops, and managing residual waste.

The literature review identifies circular economy interventions as specific strategies that create closed-loop systems to preserve resources. They aim to minimize waste and optimize materials through product lifetime extension, promote reuse and recycling at end-of-life, and reduce raw material extraction (Aguilar-Hernandez et al., 2018). In this way, CIs represent the concrete implementation of principles organized by the "R" frameworks, transforming abstract strategies into targeted actions within particular sectors or systems.

After establishing a conceptual foundation of circular economy principles and intervention frameworks, this study researches the specific socio-economic and environmental contexts of Latin America, which are discussed in the next sub-chapter. This section delves into the region's economic structure and the environmental challenges resulting from its predominantly linear development model. Understanding this context is essential for framing the scope and relevance of CIs within Latin American countries.

2.2. The Circular Economy Landscape in Latin America and the Caribbean

LATAM's economic structure is characterized by a highly extractive and agrarian base due to its abundant natural resources, including mineral deposits, land, fertile soils, and water reserves. Its economy concentrates on satisfying global demand for raw materials, particularly biomass and metal ores (ECLAC, 2023c). In 2024, the region's raw material exports increased, playing an essential role in meeting global demand. Nevertheless, the export basket remains largely concentrated on natural resources and raw materials that are either unprocessed or minimally processed. This reliance on extractive industries for profit causes the region to depend on a heavily linear economic model that poses significant environmental and social challenges (ECLAC, 2024a; Giordano & Michalczewsky, 2025). Indeed, the region's material export footprint is more than double its material import footprint. (Circle Economy, 2023b).

Large-scale mining, monoculture agriculture, and cattle ranching contribute significantly to environmental degradation. For instance, the degradation of forests hinders water supply in urbanized areas and carbon sequestration (UNPD, 2021). Furthermore, activities such as Agriculture, Forestry, and Other Land Use (AFOLU) account for nearly half of the region's net territorial greenhouse gas (GHG) emissions. LATAM records the highest absolute and per capita emissions on a global level from AFOLU (Circle Economy, 2023b). Furthermore, Latin America is home to one of the world's largest forested areas, covering nearly 49% of its land and representing about 22% of the planet's total forest area. Despite this vast coverage, the region has undergone substantial forest loss over the past thirty years. Approximately 150 million hectares of natural forest have been cleared, posing a serious threat to Latin America's ability to absorb carbon dioxide and undermining its contribution to global climate change mitigation efforts (ECLAC, 2025).

This linear economic system directly undermines social well-being and threatens future economic resilience within LATAM. Indeed, the highly globalized nature of LATAM's economic activities increases the region's vulnerability to global economic shifts, crises, and slowdowns (ECLAC, 2023a).

Furthermore, social and environmental challenges are deeply interconnected. It is estimated that Socio-economic inequalities can lead to unfair practices such as land concentration for speculation, which result in further environmental degradation, including deforestation through fires and timber logging (UNPD, 2021). The increasing rates of extraction for global markets, combined with insufficient mitigation measures, are predicted to put LATAM's environment under significant strain (Circle Economy, 2023b).

CE interventions are critical to address environmental challenges experienced in the LATAM area. They are closely linked to Sustainable Development Goals (SDGs), as they provide a way to reach several of the goals set by the United Nations (Preston & Lehne, 2018). According to the United Nations Environment Programme (UNEP) & International Resource Panel (IRP) (2024),12 SDGs are directly related to the systemic management of resources, hence to circular economy-wide changes.

Currently, Latin American countries lag behind other regions, such as East and South Asia, in achieving the Sustainable Development Goals (SDGs) (United Nations, 2022). Furthermore, the same report shows stagnation of the LATAM region in SDG 12 – "Responsible Consumption and Production", which emphasizes the urgent need for targeted interventions (Ospina-Mateus et al., 2023).

In this context, the implementation of the circular economy presents an opportunity to advance SDGs, among which: SDG 12 (responsible consumption and production), SDG 8 (sustainable growth and decent work), SDG 9 (sustainable industrialization) (Schröder et al., 2018). The literature also shows the economic potential in the LATAM area through CE interventions, such as waste reuse and recycling. For instance, LATAM generated a total of around 230 million tonnes of municipal solid waste in 2021, of which around 85% was collected and only over 4% was recycled (Circle Economy, 2023b). Finally, CE interventions also have the potential to enhance new job creation (Circle Economy, 2023a). It is estimated that 8.8 million new formal jobs could be created in Agrifood, Built environment, Mobility, and Waste management (Circle Economy, 2023b).

Building on these regional challenges, the following section examines how policymaking can address them, focusing on the current status of national governance and the policy tools supporting circular economy adoption across Latin American countries

2.3. National Circular Economy Governance and Tools in LATAM

In the LATAM region, existing circular CE research has primarily focused on Brazil, Mexico, Bolivia, and Chile at the national level (Ospina-Mateus et al., 2023). This national-level attention is significant because national policies promoting CIs can significantly enhance a country's economic self-reliance against global value chain fluctuations (Wang et al., 2022).

Evaluating CE interventions often relies on national roadmaps, which offer strategic guidance for achieving circular economy goals. These roadmaps are crucial for assessing long-term intervention outcomes and ensuring coordinated progress. More specifically, CE national roadmaps are policy instruments that outline concrete measures for transitioning to a closed-loop system across various levels, guided by national targets and indicators (Abu-Bakar & Charnley, 2024; Ghisellini et al., 2016).

Currently, only a limited number of LATAM countries have established national CE plans. Driven by the 2021 launch of the Circular Economy Coalition for Latin America and the Caribbean (LAC), the CE has gained significant traction in the region. This is reflected in the numerous formal national action plans - such as strategies and roadmaps for circular economy development that have been implemented by Colombia, Argentina and Uruguay leading the way in 2019, Peru (2020), Chile, Brazil and Ecuador (2021), and Costa Rica (2023) (CEPAL & Gobierno de Uruguay, 2024; GIZ, 2024; Herrera Jiménez et al., 2022; Rezaie et al., 2025).

Expanding these frameworks is essential for supporting consistent and impactful CE strategies throughout the region (Aguilar-Hernandez et al., 2024). The terminology used to describe these policies varies: some are called roadmaps, others national strategies. Roadmaps outline a shared medium- to long-term vision, defining strategic priorities, general strategies into actionable, often measurable goals, and specific implementation plans (Ospina-Mateus et al., 2023; UNIDO, 2024). National strategies typically provide a broader framework with high-level priorities, while roadmaps translate these goals into actionable, often measurable plans (Ospina-Mateus et al., 2023; UNIDO, 2024). This varying level of detail often leads to a fragmented approach in integrating circular practices, making it unclear how effectively these initiatives translate into actionable and impactful strategies (Ospina-Mateus et al., 2023; UNIDO, 2024). At present, Chile, Colombia, and Costa Rica are the only countries in the region with national CE policies that include quantitative targets (UNIDO, 2024). This is a significant issue because the effectiveness of these circular strategies is often hampered by the absence of clear, measurable targets. Unlike broad goals, targets are crucial operational outcomes that provide specific direction, drive commitment, and allow for monitoring progress (Milios, 2016; Morseletto, 2020).

Building on the overview of national circular economy governance and strategic tools in LATAM, this study focuses on two representative case studies: Costa Rica and Uruguay, both of which have established national circular economy strategies featuring specific CIs. The following section outlines a review of the methodological framework for assessing these interventions, integrating qualitative analysis based on the DE conceptual framework with quantitative modelling using environmentally extended input-output analysis (EEIOA) applied to two selected CIs. This combined approach enables a comprehensive evaluation of the socio-economic and environmental dimensions of circularity in both countries.

2.4. Review of Methodological Approaches for CE Assessment

Different research methods have been applied to study the impact that CIs can have on the economy and environment of a country or region. Frameworks such as the planetary boundaries and DE models provide a conceptual basis to identify ecological limits and social needs, guiding the prioritization of CIs within a “safe and just space” for sustainable development (O’Neill et al., 2018). These approaches help frame the challenges and opportunities at national levels by integrating environmental ceilings with social foundations. Building on these qualitative frameworks, Input-Output models - particularly environmentally extended input-output analysis (EEIOA) - are commonly used to quantitatively assess the impacts of circular economy interventions on supply chains across different sectors (Wiebe et al., 2019).

2.4.1 Integrating the DE Framework for Circular Economy Assessment

The planetary boundaries framework identifies a set of nine environmental limits that define a "safe operating space" for humanity on Earth. These boundaries represent a scientific assessment of the key biophysical processes that regulate the stability of our planet. Crossing these boundaries could lead to abrupt and irreversible environmental changes. They serve as an ecological ceiling, a limit on how much we can exploit the planet without causing serious and irreversible harm (Rockström et al., 2009).

The DE builds upon the planetary boundaries concept by adding a crucial social foundation. As Figure 1 illustrates, the outer ring of the doughnut is the ecological ceiling, defined by the nine planetary boundaries. The inner ring is the social foundation, representing the basic needs of all people, such as food, water, education, and social equity, but also economic aspects such as Income and Jobs (Warnecke, 2023).

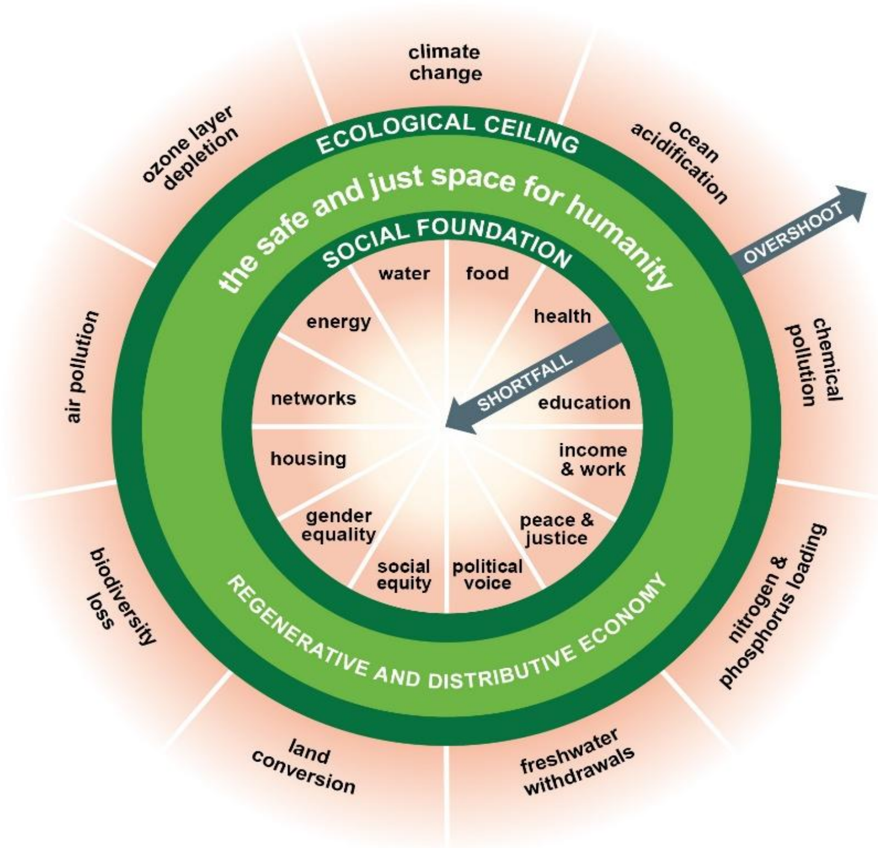


Figure 1: Ecological ceilings and social foundations of the DE framework (Raworth, 2012)

The core idea is to find a "safe and just space" for humanity that exists between these two rings. The goal of a sustainable economy, according to this model, is to ensure that everyone's social needs are met (staying within the inner ring) while not overshooting the planetary boundaries (staying within the outer ring). In short, the DE extends the purely environmental focus of the planetary boundaries to ensure human well-being while operating within the Earth's environmental limits. Due to its holistic design, DE framework serves as a conceptual guide for achieving the Sustainable Development Goals (SDGs) (Ferretto et al., 2022).

Several efforts have been made to downscale the DE and planetary boundaries frameworks, which were initially developed with a global perspective, to a national level. This adaptation is highly relevant for creating practical tools to assess a country's ecological and social priorities for CIs. As

Scheffer et al. (2015) argue, addressing stressors at a local level can significantly contribute to broader climate mitigation and resilience efforts. O'Neill at al. (2018) employed the DE framework as a conceptual guideline to assess the environmental and socio-economic states of nearly 150 countries by downscaling planetary boundaries to the national level using a per capita approach. This assessment utilized data up to 2011. A more recent analysis by Fanning et al. (2022), which follows a similar methodology, extends the data range from 1992 to 2015, offering an improved trend analysis.

2.4.2. MR-EEIOA in CE Research

Environmentally Extended Input-Output Analysis (EEIOA) is a quantitative methodology that integrates environmental data into traditional economic input-output models, providing insights into the interplay between economic activities and environmental impacts (Kitzes, 2013). Unlike conventional input-output analysis (IOA), which focuses solely on intersectoral relationships within an economy, EEIOA broadens this perspective by incorporating environmental extensions. These extensions allow for the translation of monetary values into social and environmental impact categories, such as resource consumption, energy use, and emissions (Leontief, 1970). This approach enables a holistic understanding of how economic systems influence environmental outcomes and vice versa (Kitzes, 2013).

Monetary EEIOA is particularly suited for evaluating circular economy CE interventions, as it captures their economic and environmental effects across interconnected systems in monetary units. It assesses both primary (direct) impacts, such as reductions in raw material use, and secondary (indirect) effects, like changes in upstream industries (Aguilar-Hernandez et al., 2018). For instance, increased recycling can lower raw material demand while stimulating growth in waste management sectors. A hybrid version of EEIOA also exists, which includes physical units. However, it does not contain value-added and employment inputs, which would excessively limit the scope of this study (Merciai & Schmidt, 2018). By modelling such strategies, monetary EEIOA helps identify reductions in emissions, resource extraction, and waste generation while evaluating changes in economic indicators (Aguilar-Hernandez et al., 2018). This multifaceted approach makes EEIOA an essential tool for policymakers. Furthermore, through the simulation of different CE scenarios, EEIOA provides a comprehensive framework for designing and implementing impactful CIs across diverse regions. It is worth noting that scenarios are commonly described as

‘...a coherent, internally consistent and plausible description of a possible future state of the world...’ (Carter et al., 1994).

Empirical applications of environmentally extended input–output analysis (EEIOA) focusing on circular economy interventions remain scarce in LATAM. One notable study Di Stefano et al. (2022) assessed the water, food, and labour nexus in Colombia through EEIOA, analysing flows of virtual water trade (VWT) and virtual informal labour (VIL) across administrative departments and economic sectors. However, this work does not directly address CIs. This highlights a significant literature gap in applying EEIOA specifically to assess circular economy initiatives in the region, underscoring the need for more research using EEIOA to evaluate resource circularity and socio-economic impacts in Latin American contexts.

In the context of multi-regional analysis, EEIOA extends these principles across multiple countries to investigate the environmental impacts of international trade and economic interactions (Wiedmann, 2009). Several databases support such analyses, including CEPALSTAT, a robust statistical repository developed by the Economic Commission for Latin American countries (ECLAC) (Lima et al., 2022). CEPALSTAT centralizes national accounts from 18 Latin American and 3 Caribbean countries, with supply and use tables (SUT) available from 1988 to 2019 and input-output tables (IOT) available for 13 Latin American countries and 1 Caribbean country from 1979 to 2019 (Caribbean Development Portal, s.d.). These datasets provide the foundation for assessing macro-scale impacts of economic activities across the LATAM region (Lima et al., 2022). However, the level of resolution of this database does not allow for an effective analysis of circularity interventions. EXIOBASE 3 3 is a global multi-regional environmental extended supply–use and input–output table database, used for MR EEIOA studies.

3. Research Gap, Objective, and Questions

3.1 Research Gap

Despite growing interest in CE initiatives in LATAM, significant gaps hinder a full understanding of their socio-economic and environmental impacts. Notably, detailed, country-specific data on material and resource flows is scarce, limiting the identification of unique challenges and baseline conditions necessary for assessment. Furthermore, most CE research focuses on developed regions, leaving LATAM underexplored, especially regarding the regional and global trade effects of LATAM national CE policies. These gaps directly obstruct answering the central question: What are the socio-economic and environmental impacts of Costa Rica's and Uruguay's national circular economy interventions at regional (LATAM)and global scales? To fill these gaps, this study applies a mixed-methods approach combining qualitative frameworks with quantitative input-output modelling to assess circular economy interventions in LATAM.

3.2 Research Objective and Questions

The primary goal of this study is to evaluate how national circular economy strategies in Costa Rica and Uruguay influence socio-economic and environmental outcomes across the Latin America and Caribbean (LATAM) region and beyond. The analysis focuses on key material flows and selected CIs within these countries, conducting a comparative literature review through the lens of the DE framework to assess potential regional impacts. To quantify and illustrate these effects, two interventions are modeled using Environmentally Extended Input-Output Analysis (EEIOA), enabling a deeper understanding of their broader implications. By examining the interactions between circular economy initiatives and socio-environmental systems, this research seeks to provide actionable insights that inform sustainable development and policymaking at the regional.

Main Research Question

What are the socio-economic and environmental impacts of Costa Rica and Uruguay's national circular economy interventions at a regional (LATAM) and global scale?

Sub-Research Questions

1. What are the key resource flow characteristics for Costa Rica and Uruguay?

2. What are key circular economy interventions outlined in the national strategies of Costa Rica and Uruguay at the country level?

3. What are the socio-economic and environmental impacts of circular economy interventions in Costa Rica and Uruguay, both nationally and within LATAM?

4. How can the selected interventions be translated into an MR-EEIOA model to assess their impacts in LATAM and beyond the region?

3.3. Scientific Contribution to Industrial Ecology

The CE concept is deeply rooted in fields like ecological and environmental economics, with Industrial Ecology playing a central role in its development (Ghisellini et al., 2016). Industrial Ecology provides a holistic view of industrial systems, examining their complex interactions with the environment rather than just isolated parts (Erkman, 1997). This field focuses on optimizing society's "industrial metabolism" by managing material and energy flows within industrial processes to minimize waste and enhance resource efficiency. The Circular Economy directly builds on this foundational understanding. It takes these principles of resource optimization and systemic thinking, first used in industrial processes, and extends their application across the entire economy (Chatman House, 2012). This thesis contributes to Industrial Ecology by exploring the assessment of socio-economic and environmental impacts of CIs in Costa Rica and Uruguay through an integrated, mixed-methods approach. It combines qualitative frameworks, such as the DE, with quantitative MR-EEIOA. This aggregation of approaches enables evaluation in a context of substantial data unavailability, a common limitation for developing regions like the LATAM area. By testing how well these methods can capture impacts and by identifying their limitations, the study advances understanding of how to robustly assess CE interventions at a national and regional level in the LATAM region. This contribution supports adapting Industrial Ecology principles and methodologies to more data-scarce, diverse socio-economic realities.f

4. Methodology

This chapter details the methodological approach used to answer the main research question and sub-questions outlined in Chapter 3. The analysis focused on Costa Rica and Uruguay, two Latin American countries selected as case studies. It includes country profiling, identification of CIs from national strategies, and analysis of their potential social and environmental impacts through both comparative qualitative and quantitative scenario analyses.

The comparative qualitative assessment, which formed the main evaluation, systematically examined and contrasted CIs to identify similarities and differences in their environmental and socio-economic impacts. This approach used the DE Framework as a consistent conceptual lens to describe and compare the impacts of all interventions. By applying its core dimensions, which are ecological ceilings (planetary boundaries defining environmental limits) and social foundations (minimum standards for human well-being), the analysis translated diverse impact terms found in the literature into a unified set of categories. This standardized terminology facilitated clearer and more systematic comparisons across interventions, overcoming variability in how impacts were described in different sources and enabling a coherent evaluation of their environmental and socio-economic effects.

Supporting this qualitative analysis, the scenario analysis used MR-EEIOA with the EXIOBASE 3 database and MARIO software. This quantitative approach supplemented the main assessment by modelling the environmental and socio-economic impacts of CE interventions in Latin American countries and beyond.

4.1. Country Profiling

This initial phase of the thesis provided an overview of the country profiles for Costa Rica and Uruguay. These nations were selected due to their shared characteristics: both have relatively small populations and are classified as upper-middle-income/high-income countries, reflecting their economic position (Hamadeh et al., 2023; World Bank Group, 2016).

During this phase, an in-depth examination of each country's resource flows has been conducted. Understanding the material flows (the movement of resources into and out of the country) and their associated resource productivity indicators has been crucial. These elements are fundamental for directly linking a country's economic activity with its environmental performance (Schandl et al., 2018).

Key data points analysed for country profiling included:

- Population
- GDP per capita at current and constant prices

- Trade (imports and exports)
- Resource and material flows

By analysing these data points, the study assessed each country's patterns of resource use and the economic dynamics driving them. The research methodology employed multiple search engines, including Google, Google Scholar, AI tools, and the snowball literature search, to comprehensively gather and triangulate relevant information. Snowballing is a search method the reference lists of relevant papers and the citations to those papers are searched to identify additional related studies. This process expands the set of relevant publications beyond initial database searches (Wohlin, 2014).

Data on resource flows were sourced from academic and institutional databases at global, regional, national, and ministerial levels. This multi-scale approach ensured comprehensive and up-to-date data collection. The primary databases included the World Bank, which provides extensive global development and economic data; the United Nations Population Division (UNPD), known for demographic statistics and projections; Trading Economics, which shows economic indicators and forecasts globally; and the International Resource Panel (IRP), focusing on assessments of global resource use and sustainability. Regional and country-specific data were gathered from ECLAC, the Inter-American Development Bank (BID), Uruguay's Ministry of Environment, and Costa Rica's Ministry of Environment and Energy (MINAE). Please refer to Figure 2 to see an overview of the main databases utilized in this research.

Figure 2: Overview of the main databases used for country profiling

4.2. Identification of CIs from National Strategies

This section outlines the process of identifying and extracting CE interventions from the official national circular strategies of Costa Rica and Uruguay to address the second sub-question of this thesis.

The analysis began with a general review of the structure of each national strategy, followed by a focused examination of the specific CIs the policies aim to implement. For Costa Rica, the interventions are detailed in Annex 5: Proposal of quantitative and qualitative targets (Anexo 5: Propuesta de metas cuantitativas y cualitativas), which categorizes 18 quantitative and 6 qualitative targets. From these, five key CIs were selected. Uruguay's interventions appear in Chapter 8: Early actions to implement (Capítulo 8: Acciones tempranas a implementar), where nine CIs are listed, with five chosen for this study.

Since these documents were originally in Spanish, language tools, including DeepL Translator and Excel translation functions supported the translation of challenging sections.

Due to time constraints, the scope of the analysed interventions was narrowed. A key criterion for selecting the CIs was their potential to be modelled using MR-EEIOA. Although this thesis primarily focuses on qualitative analysis, choosing interventions compatible with MR-EEIOA ensures their relevance for future quantitative scenario modelling. This approach not only maintains the utility of the selected interventions for deeper environmental and socio-economic impact assessments but also facilitates replication and comparison in further studies seeking to integrate qualitative findings with robust quantitative methods.

Due to the large number of CIs detailed in the national strategies, it was not feasible to analyse all of them within the scope of this study. Therefore, a selection criterion was applied, prioritising interventions that could be modelled using MR-EEIOA. This approach ensures that the chosen interventions are compatible with future quantitative scenario modelling, providing a dataset foundation for subsequent research. However, this narrowing of scope means that some potentially relevant interventions with significant local or qualitative impacts may not have been assessed here.

4.3. Potential Socio-economic and Environmental Impacts on LATAM and Beyond

This study uses a qualitative comparative analysis approach to evaluate the potential socio-economic and environmental impacts of CE interventions of Costa Rica and Uruguay at a regional level (LATAM). To this end, a comprehensive literature review was conducted, focusing on environmental, socio-economic impacts and macro-economic implications, which refer to the potential changes on exports, imports, and domestic production in both countries as a result of the CIs

A variety of search strategies were employed to gather relevant information. These included Google and Google Scholar searches, the use of AI tools to identify additional sources, and the snowballing method to explore the references of key publications. The search process began with general terms related to each CI, for example, "waste in [country]." When these yielded insufficient results, more specific queries were formulated, for example, "environmental impacts of waste management in Costa Rica". In cases where conventional searching proved insufficient, AI tools were used to identify alternative leads or sources. The search extended beyond academic databases to include institutional and regional reports from organizations such as ECLAC (n.d.), the IDB (BID) (n.d.), and the OECD (n.d.).

Although the study primarily examines impacts at the national level, these findings offer valuable insights into potential regional benefits within Latin America and the Caribbean (LAC) due to strong economic interconnections, shared resource flows, and coordinated policy efforts. The LAC region actively pursues CE transitions through joint initiatives to develop inclusive value chains, promote sustainable resource management, and align with climate and biodiversity goals (Circular Economy Coalition, 2022). Although positive effects in individual countries point to potential regional benefits, differences in contexts and capacities mean outcomes may vary. Hence, national findings serve as indicative insights rather than guaranteed regional results.

For the purposes of this study, the Doughnut Economy's social foundations are used to evaluate socio-economic impacts. This approach is justified because the study's definition of socio-economic impact, which is the combined social and economic effects of an intervention on communities, aligns with the Doughnut's comprehensive view of human well-being, specifically including economic outcomes under categories such as "Income and Work" (Sustainability Directory, 2025).

The collected data on CIs and their various impacts from the conducted literature review are synthesised to enable a consistent evaluation. This is done by mapping the information into the DE framework, which provides a common structure for assessing social and environmental boundaries (see *Table 1*).

Table 1: Definitions of DE's categories based on O'Neill et al. (2018) and Raworth (2012)

DE Dimension	Category	Definition
Ecological Ceilings	Climate Change	Limiting greenhouse gas emissions to avoid dangerous global warming.
	Ocean Acidification	Preventing excess CO_2 absorption by oceans that threatens marine life through lower pH levels.
	Chemical Pollution	Reducing toxic synthetic chemical releases hazardous to health and ecosystems.
	Nitrogen Loading	Avoiding excessive nitrogen runoff causing water pollution and ecosystem eutrophication.
	Phosphorus Loading	Preventing surplus phosphorus pollution leading to waterway eutrophication and dead zones.
	Freshwater Withdrawals	Managing water use to protect rivers, lakes, and aquifers from over-extraction.
	Land Conversion	Protecting ecosystems from habitat loss due to deforestation and land-use change.

	Biodiversity Loss	Halting the decline of species variety and ecosystem resilience.
	Air Pollution	Limiting atmospheric particulate and gaseous pollutants harmful to health and climate.
	Ozone Layer Depletion	Preventing reduction of stratospheric ozone to safeguard from harmful UV radiation.
Social Foundations	Water	Ensuring universal access to clean, safe drinking water and sanitation.
	Food	Guaranteeing all people sufficient and nutritious food.
	Health	Securing access to healthcare and healthy life expectancy for all.
	Education	Providing access to quality early childhood, primary, and secondary education.
	Income & Work	Ensuring decent employment, economic security, and fair incomes.
	Energy	Delivering affordable, reliable modern energy to everyone.
	Networks	Fostering social and community cohesion, connectivity, and supportive relationships.
	Housing	Guaranteeing adequate, safe, and secure shelter and services for all.
	Social Equity	Advancing fairness, justice, and equal opportunity for all, including gender equity.
	Peace & Justice	Upholding safety, legal rights, justice, and democratic participation for every person.
	Political voice	The ability of all people to participate in political decisions affecting their lives.
	Gender quality	Equal rights and opportunities for all genders, ensuring fairness and non-discrimination.

The interventions analysed generate a range of impacts across environmental and socio-economic dimensions.

Table 9 and

Table 11 depict these impacts through the lens of the DE Framework (See Results section 5.3). To construct Figures 9 and 10, each intervention's impact was mapped to its corresponding DE category (for example, CO_2 emissions are classified under “Climate Change”). Once the findings were translated into DE terms, the results were organized into country-specific tables. This structure allowed for a holistic view of each intervention’s environmental, social, and economic dimensions, and for direct comparison across countries to identify recurring themes and differences. For both countries, the results were organized as in Table 2, which summarizes the CE interventions and outlines their environmental impact, socio-economic relevance, economic implications, and expected intensity. For precise definitions of all impact categories used in this assessment, please refer to Table 1.

*Table 2: Layout of Comparative Summary Table for CI**s** for Costa Rica and Uruguay*

Intervention	**Environmental Impact (Doughnut Ecological Ceiling)**	**Socio-economic Impact (Doughnut Social Foundation)**	**Economic Implications**	**Expected Intensity**

In addition, Table 2 provides an indicative assessment of the “Expected intensity” of impacts. This assessment was conducted using three criteria: (i) the relevance of the targeted material flow of the intervention; (ii) the presence of policy targets, where applicable; and (iii) the level of development of the infrastructure required for the implementation of the CI. For each criterion, the intensity of impact was classified on a three-point scale: low, medium, or high.

This study’s methodology has several inherent limitations. The DE framework provides a holistic lens grounded in ecological ceilings with clear planetary boundaries; however, its social foundations are characterized by less precise and universally agreed-upon definitions, introducing variability and uncertainty when assessing social impacts across contexts (Steffen et al., 2015). The ecological ceilings offer clear environmental limits that guide policy and impact assessment. However, the DE is an evolving framework with specific methodological limitations relevant to this study. While the ecological boundaries are precisely defined, the social foundations lack universally agreed-upon definitions and metrics, resulting in variability in their interpretation and measurement (Ferretto et al., 2022; Raworth, 2012)). This flexibility enables the framework to be adapted to diverse contexts but also creates uncertainty when comparing social impacts across different settings, due to variations in how social foundations are defined and measured.

Further, using a qualitative comparative analysis based primarily on literature review carries limitations related to the availability, quality, and selection bias of sources. The reliance on secondary data means findings are constrained by existing studies' scope and methods, which may vary between countries and sectors. Finally, extrapolating national results to infer regional implications for Latin America and the Caribbean involves assumptions about economic and environmental interconnections that may vary in strength and effect across countries, limiting the generalizability of findings.

4.4. Modelling CIs using MR-EEIOA

This section provides a detailed explanation of MR-EEIOA, adapted for modelling the identified CIs and assessing their socio-economic and environmental impacts. MR-EEIOA is used here as a quantitative tool to complement the primary qualitative research presented in the previous section. To illustrate how findings from the qualitative analysis can be quantified, only two CIs were selected for modelling as illustrative examples. This selective modelling demonstrates the integration of qualitative insights with quantitative assessment, showcasing the process and potential insights achievable through MR-EEIOA while maintaining the study's qualitative focus. The use of MR-EEIOA in this manner supports the main analysis by providing a quantitative perspective that can be expanded in future research.

4.4.1 Explanation of Modelling Approach and Equations

Environmentally Extended Input-Output analysis (EEIOA) is a quantitative methodology that measures environmental impact within economic trade (Leontief, 1970). It is founded on Input-Output (IO) analysis, which provides a detailed description of economic activities and the interdependencies between industries. EEIOA accounts for direct and indirect environmental stressors resulting from anthropogenic pressures caused by economic activities along the supply chain of goods and services. The input-output model, or Leontief demand-driven model, can be used to calculate the set of emissions occurring linked to the total output required from each sector to satisfy a given final demand (Donati et al., 2020).

The core mathematical expressions of this model are as follows:

Technical Coefficients Matrix :

$$A = Z/x \qquad (1)$$

This equation defines the technical coefficients matrix (A), where each element aij represents the direct amount of input required from sector i to produce one unit of output in sector j. It's essentially a recipe for production, showing how much of each input a sector needs for its output.

Input-Output Balance Equation:

$$x = Ax + Yi \qquad (2)$$

This is the fundamental input-output balance equation. It states that the total output (x) of an economy (or each sector within it) must satisfy two components: the intermediate demand (Ax) consumed by other industries for their production, and the final demand (Y) from direct users like households or governments. In short, total production must equal the sum of what industries buy from each other plus what final consumers buy.

$$x\,(1 - A) = Yi \qquad (3)$$

$$x = (I - A)^{-1}Yi \qquad (4)$$

By inverting the (I−A) matrix, this equation allows us to directly calculate the total output (x) required from every sector to satisfy a given final demand (Y). The term $(I - A)^{-1}$ is crucial as it represents the Leontief Inverse, capturing not only direct but also all indirect inputs needed across the entire supply chain.

Leontief Inverse Matrix

$$L = (I - A)^{-1} \qquad (5)$$

This equation explicitly defines the Leontief inverse matrix (L). This matrix is important for understanding the total economic linkages within the system. Each element lij in L shows the total output (both direct and indirect) from sector i required to produce one unit of final demand in sector j.

Extension and Footprint Calculation

To extend the economic input-output model to include various types of impact assessments (environmental, social, resource use, etc.), an extension matrix is computed that quantifies the direct pressures associated with each sector's output. The resulting total footprint is then calculated, capturing both direct and indirect impacts embodied in the supply chain to meet final demand.

Direct Environmental Intensity Matrix/Vector:

$$f = F/x \qquad (6)$$

This equation defines the direct intensity matrix/vector (f). It is derived by dividing the total pressures (F) generated by each sector by that sector's total output (x). Each element f_{xi} of the matrix F represents the direct pressure (e.g., kilograms of CO2, liters of water) of type k generated per unit of monetary output in sector *i*.

Total Footprint Calculation:

$$E = f * (I - A)^{-1} * Y \qquad (7)$$

$$E = diag(f) * L * Y \qquad (8)$$

This is the core equation for calculating the total footprint (E). It multiplies the direct intensity matrix (f) by the Leontief Inverse matrix (L) and the final demand vector (Y). This calculation yields the total (direct and indirect) environmental pressures associated with a given final demand. It captures the impacts embodied throughout the entire supply chain, from raw material extraction to final consumption. For example, if E represents carbon emissions, this equation will calculate the total carbon footprint of all goods and services consumed by final demand in the economy.

4.4.2 Data manipulation for modelling

This section outlines the methodological steps undertaken to model two CIs from Uruguay and Costa Rica using MR-EEIOA. It illustrates the choices made to translate them into quantitative scenarios. It should be noted that modelling CE interventions within MR-EEIOA involves several inherent data limitations and challenges, which are discussed in detail in Section 6.2 (See Discussion). Consequently, the modelling scenarios presented here serve as illustrative examples, intended to demonstrate the feasibility of such analyses and to provide quantitative support for the findings derived from the preceding qualitative study.

4.4.2.1 EXIOBASE 3

There are several global multi-regional input–output (MRIO) databases that can be used to model counterfactual scenarios of CIs through EEIOA. World Input-Output database (WIOD), EORA, Global Trade Analysis Project (GTAP) and Organization for Economic Co-operation and Development Inter-Country Input-Output tables (OECD ICIO), and EXIOBASE 3 are among the most used ones as they provide high resolution in either sectoral or regional detail. Unfortunately, in most of these databases, Costa Rica and Uruguay are not included as individual regions, but they are part of bigger regions that are a result of aggregations with other countries. Most of the time, they are included in the "Rest of the world" regions. Only OECD ICIO, GTAP, and EORA include Costa Rica and Uruguay as disaggregated regions in their database (Inomata & and Owen, 2014).

However, in all these databases, further limitations that inhibit the modelling of CIs arise. OECD ICIO has limited sectoral aggregation, with only 45 sectors (Inomata & and Owen, 2014), making it impossible to manipulate the sectors that need to be changed to implement the CIs listed by the national roadmaps. For instance, the waste and recycling sectors are missing (Yamano et al., 2023). The same issue applies to GTAP and EORA, both of which contain a regional disaggregation for Costa Rica and Uruguay but lack sectoral aggregation(Aguiar et al., 2022; Eora, s.d.; Inomata & and Owen, 2014). Tarne et al. (2018) show that EXIOBASE 3 has a more detailed sectoral disaggregation and a comprehensive coverage of environmental and socio-economic extensions (Inomata & and Owen, 2014)(Inomata & and Owen, 2014). (Inomata & and Owen, 2014). Therefore, EXIOBASE 3 is the most suitable database for this thesis because it offers a significantly more detailed sectoral disaggregation compared to alternatives. EXIOBASE 3 was developed to gather data at the country level and global level to estimate the emissions and resource extractions across various industries within national economies. The database classifies economic activities into 163 industries and 200 product categories and provides a time series of input-output tables covering the period from 1995 to 2022 (Yamano & Ahman, 2006).

4.4.2.2 Aggregation

For the study, sectoral aggregation seems to be the most relevant factor as it is necessary to translate CIs from national strategies into quantifiable measures through MR-EEIOA.

Accordingly, the original EXIOBASE 3 sectors were aggregated into broader categories suitable for the targeted CIs. The complete mapping of original sectors to these aggregated categories is available in the "New sectoral aggregations" sheet of the "LATAM_data_entry_final" Excel file (see Appendix). The Excel file contains a "Data" spreadsheet that details the modelling of CIs (see LATAM_data_entry_final, Appendix A). The circular interventions derived from national circular strategies illustrate different ways to model the same CI. This diversity in CI modelling arises from varying assumptions that define each intervention's specific characteristics and impacts. Detailed information about each intervention is organized in the Excel file, with columns specifying crucial attributes and modelling details, as summarized in Table 3.Specifically, this table shows how each CI was disaggregated to model different possibilities of applying the same intervention derived from broader circular strategies.

Table 3:Overview to understand sectors manipulation for modelling CIs

Theme	Intervention's name	Assumptions	Description of the Primary change	Sector (New aggregation)	Description of secondary or ancillary changes	Sector (New aggregation)

This structure means that every thematic intervention (as presented in Table 6 under the "Theme" column) is disaggregated into multiple modelling possibilities based on the underlying assumptions unique to each circular intervention (CI). Following the theme, each intervention is further broken down into sub-sections representing specific actions or approaches to modelling that particular intervention within the CE framework.

The "Primary change" columns specify the exact modifications the intervention induces in industries defined within the original EXIOBASE sectoral aggregation. In parallel, the "Secondary change" columns capture additional or ancillary impacts on other related industries. Adjacent to these change descriptions, the corresponding sector columns indicate the affected industries according to the revised sectoral aggregation used in the analysis.

This detailed disaggregation allows for modelling a range of potential applications and impacts of the same CI, reflecting different assumptions and implementation pathways. It thus provides a granular and nuanced depiction of how CE interventions can differently influence economic sectors under the new aggregation scheme.

EXIOBASE 3 has 44 regions, among which 5 represent "Rest of the World" areas for each continent. "Rest of the world" from America (ROW America) has been aggregated with the individual regions of Brazil and Mexico to create a proxy for LATAM countries. As there is no direct access to the disaggregated national IOTs of Costa Rica and Uruguay through EXIOBASE 3, the study assumes that CIs listed in the national roadmaps of Costa Rica and Uruguay will be implemented in the bigger regional area of LATAM countries. "ROW America", or "WL" region, is assessed based on the technical coefficients of the countries with the highest trade exchange, individually listed in EXIOBASE 3 3 (Stadler et al., 2014).

For simplicity and relevance, the study performed an isolation of the regions in EXIOBASE 3 that are most likely to be affected by changes in the economic system and trade of the LATAM countries. The United States of America, China, and the European Union are the top three trading partners of the LATAM region (Raza & Grohs, 2022). For the analysis, these three regions will be considered separately, alongside LATAM. All other countries will be grouped together under the category Rest of the World (RoW). This setup allows us to examine the effects of the circular national interventions of Costa Rica and Uruguay on LATAM, the USA, China, and the EU, while treating the remaining countries as a single aggregated region.

4.4.2.3 MARIO package

To facilitate the handling of input-output tables, this study employed the MARIO package, a Python-based tool designed for input-output modelling. MARIO is a simple and intuitive tool for processing structured IOTs, supporting automatic parsing of multiple datasets, including EXIOBASE 3 and others (Tahavori et al., 2023)

The model translated CE interventions into specific shocks within the Input - Output Tables (IOTs) of Uruguay and Costa Rica, modifying elements such as final demand, intermediate inputs, or extensions, depending on the interventions outlined in each country's national roadmap. By analysing the resulting changes, this study examined how the country-level policies can affect the environmental and socio-economic dimension of the LATAM region and extend their influence on a global scale.

4.4.3 Scenario analysis

Scenario analysis is an approach within MR-EEIOA used to evaluate the potential impacts of CE interventions on socio-economic and environmental systems. This method enables a structured exploration of direct and indirect effects of interventions, supporting robust policy assessment and decision-making in a systemic, multi-regional context. This section explains how scenario analysis is applied to assess two out of the selected CE interventions in Costa Rica and Uruguay, providing insights into their prospective socio-economic and environmental impacts within the LATAM and globally.

4.4.3.1 Counterfactual scenario and change coefficients

MR-EEIOA modelling analyses CIs through scenario analysis. This approach compares the baseline economic situation, represented by Input-Output Tables (IOTs), with a counterfactual scenario. The counterfactual scenario implements a series of changes impacting production and consumption. These changes align with the CIs collected in Section 5.2 (Donati et al., 2020). Such changes are categorized as:

- **Primary changes:** These refer to the direct, main effect of an intervention (Donati et al., 2020). For example, if a policy promotes using recycled materials, the primary change is the increased demand for recycled input.
- **Ancillary changes:** These concern the secondary effects that result from activities supporting the primary change. For instance, increasing recycled material use might also require new collection systems or processing technologies, which are ancillary changes (Donati et al., 2020).

Changes can be expansive or reductive, depending on whether the change is positive or negative. They can affect the direct environmental intensity matrix (F), the technical coefficients matrix (A), or the final demand vector (Y). Implementing such changes results in a new footprint value, representing the counterfactual scenario.

Scenario analysis can be explained mathematically like this:

$$E = diag[f(I - A)^{-1}] * L * Yi \quad (9)$$

$$E^* = diag\,[f^*(I - A^*)^{-1}] * Y^*i \quad (10)$$

$$\delta E = E - E^* \quad (11)$$

More specifically, modifications to one of the matrices (F, A, or Y), collectively referred to as M, from the baseline to the counterfactual scenario are performed by adding a coefficient change (k_a). The coefficient change (k_a) represents the magnitude of the overall change applied to the baseline. This value is derived by multiplying two elements:

- The **technical coefficient change ($\boldsymbol{k_t}$)**: which represents the maximum potential effect of an intervention on a specific process or sector (Donati, 2021).
- The **market penetration ($\boldsymbol{k_p}$)**: which indicates the proportion of relevant actors expected to adopt the intervention.

$$Mij^* = Mij(1 - k_a) \qquad (12)$$

$$k_a = k_t * k_p \qquad (13)$$

For modelling the two interventions, changes were applied to the final demand vector by adjusting it upwards or downwards by a specified percentage, with the exact values detailed in the LATAM_data_entry_final excel file (See Appendix)

4.4.3.2 Assumptions for modelling CI data in EEIOA

Building on the analysis of CIs within the national strategies (see Section 5.2 for the results of this analysis), key information for modelling these interventions - including their names, countries of origin, and explanations of the interventions - was systematically extracted and compiled into a comprehensive Excel document titled "LATAM_data_entry_final" (see Appendix). This document also details the assumptions applied to translate the interventions into a modellable format, with particular focus on identifying the affected EXIOBASE 3 sectors, geographic regions, and final demand categories.

To develop these assumptions, a detailed investigation of EXIOBASE 3 sectors was conducted to identify which sectors could be directly influenced by the interventions. This process involved a literature review and research using Google, Google Scholar, and AI tools to establish realistic assumptions about how CIs impact the economy, both on the demand side (primary changes) and the supply side (secondary changes). For definitions and further explanations of primary and secondary changes, please refer to section 4.4.3.1.

Label	Theme	Intervention's name	Assumption	Description of the Primary change	Primary change EXIOBASE	Description of secondary or ancillary changes	Secondary change EXIOBASE
b.1	Resource Use Efficiency - Organic Waste Management	CR - Increase Reuse of Biodegradable Waste	Biodegradable waste is re used through composting	Decrease of biodegradable waste in landfills: Food	Decrease in landfill of waste: Food(153)	Increasing composting of bio waste	Composting of food waste, incl. land application
b.2	Resource Use Efficiency - Organic Waste Management	CR - Increase Reuse of Biodegradable Waste	Biodegradable waste is re used through composting	Decrease of biodegradable waste: Wood	Decrease landfill of waste: Wood(158)	Increasing composting of bio waste	Composting of paper and wood, incl. land application
b.3	Resource Use Efficiency - Organic Waste Management	CR -Increase Reuse of Biodegradable Waste	Biodegradable waste is re used through composting	Decrease of biodegradable waste: Paper	Decrease in landfill of waste: Paper(154)	Increasing composting of bio waste	Composting of paper and wood, incl. land application

As an example, consider the CI "b. Resource Use Efficiency - Organic Waste Management" from Costa Rica's national strategy, Achieve a 50% reduction in the tonnage of biodegradable waste sent to landfills (See Table 6 for further details).

This intervention's implementation can be modelled through several assumptions, illustrated in Table 4, which outlines several potential ways of modelling the CI. Firstly, this intervention leads to a decrease in biodegradable waste being sent to landfills, which is indicated as a "primary change" affecting specific waste categories like food waste (landfill decrease in Food sector 153), wood waste (landfill decrease in Wood sector 158), and paper waste (landfill decrease in Paper sector 154). Alongside these primary changes, there are "secondary" or ancillary changes such as increased composting activities, which also affect related sectors including land application of compost.

Table 4: Data entry example for intervention "b. Resource Use Efficiency - Organic Waste management", Costa Rica

Table 4 provides a data entry example for Intervention 'CR - Increase Reuse of Biodegradable Waste' from the 'LATAM_data_entry_final' file (see Appendix). While this table illustrates a segment of the data, the complete database further details for each intervention the geographical region of impact, the origin of the change (primary or secondary), and the market coefficient and market penetration rate. Additionally, a dedicated column, 'Sectors (New aggregations),' located to the right of the 'Primary changes (EXIOBASE 3)' and 'Secondary changes (EXIOBASE 3)' columns, explains the aggregation of specific sectors into new categories.

In addition to conceptual assumptions, specific quantitative assumptions were implemented to estimate the change coefficients required for modelling both primary and secondary effects of the interventions (please refer to the section "Counterfactual Scenario and Change Coefficients"). It is important to remember that this detailed modelling has been conducted for only two interventions, one from Costa Rica and one from Uruguay, serving as illustrative examples of how such scenario analyses can be performed.

Due to gaps in available data, some assumptions were necessary. First, the market penetration rate - the proportion of actors adopting an intervention - is assumed to be the same for both primary effects and any resulting secondary changes, although these changes can occur in opposite directions (e.g., an increase in one input and a decrease in another). Second, it is assumed that the geographic distribution of sectoral imports into Costa Rica and Uruguay does not change after implementing the interventions.

For Costa Rica, the national circular strategy provided quantitative targets for technical coefficient changes (e.g., a specific percentage increase in recycling). These targets guided modifications to the economic model, assuming full adoption (100%) of the new interventions. An exception was the bio-digestion and soil carbon sequestration intervention - 'CR - Increase Reuse of Bio-degradable Waste' (Intervention b in 'LATAM_data_entry_final') - where the technical coefficient was assumed due to lack of explicit targets. Market penetration rates for Costa Rican interventions were estimated, as the strategy did not specify them. For Uruguay, both technical coefficient changes and market penetration rates required assumptions, as its national circular strategy does not specify quantitative targets for either. Detailed values for market penetration rates and technical change coefficients, with assumed values highlighted in bold, are available in the 'LATAM_data_entry_final' dataset.

To illustrate an example of the methodology for parameter selection, the values used for modelling the intervention 'CR - Increase of biodegradable waste from food' are presented here. The assumed market penetration rate for this primary change is 80%, a value informed by data suggesting that 94% of solid waste in Costa Rica is landfilled (Brenes, 2024). The technical change coefficient for the primary change, which is a decrease in landfill waste, is about 50%, as stated in the national strategy of Costa Rica. For the secondary effect, the composting of waste was assumed to increase by the same percentage, while its assumed market penetration rate is also 80% (See *Table 5*). This example demonstrates the application of assumed parameters in the modelling process for CE interventions within this study.

Table 5: Technical coefficient and market penetration coefficient for CI "d. Value chain", Costa Rica

CR - Increase Reuse of Biodegradable Waste			
	Technical coefficient	**Market penetration coefficient**	**Value**
Primary change	0.5(-)	0,8	-0,4
Secondary change	0,5	0,8	0,4

To explore further details about the methodological process used to model the two CE Interventions (CIs) in the MR-EEIOA framework, please refer to all CIs under the label "b. CR - Increase Reuse of Biodegradable Waste" and the CI labelled "c.3 UY - Action Plans for High-Quality Material - Recovery of Plastics" in LATAM_data_entry_final (See Appendix A).

5. Results

This chapter presents the findings derived from the methodology described in Chapter 4 used to answer the main question and sub-research questions. It begins with a country profile of the two case studies, Costa Rica and Uruguay, providing essential context for their CE landscape. Following the country profiles, the chapter presents the results, which include the key CIs selected from each national strategy, a qualitative comparative analysis assessing the environmental and socio-economic impacts of the interventions through the DE lens, and illustrative MR-EEIOA examples that demonstrate how these CIs can be quantitatively modelled.

5.1. Country Profiling

This section provides an overview of Costa Rica and Uruguay's key characteristics relevant to its CE potential and context for the modelling results. This section directly answers Sub-Research Question: "What are the key resource flow characteristics (e.g., population, GDP, imports, exports) for each selected country?"

5.1.1 Costa Rica

Costa Rica is home to approximately 5.11 million people and a land area of roughly 5.11 million hectares (*FAOSTAT*, s.d.). It has a growing economy, with GDP per capita estimated at US$14,438 in constant prices and US$18,178 in current prices for 2024 (CEPAL, s.d.-b). Analysis of recent data (Figure 3 and Figure 4) shows a positive upward trend in GDP from 2020 to 2024, indicating resilient economic growth.

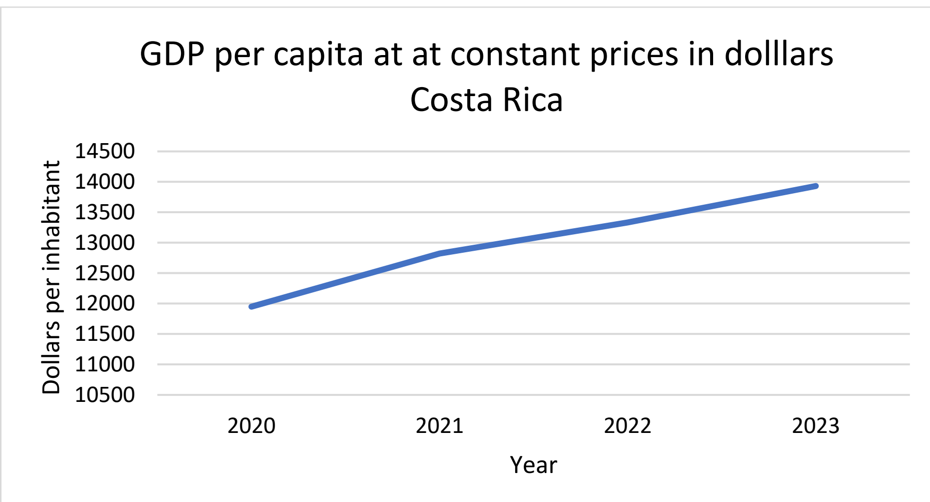


Figure 3: GDP at constant prices ($) 2020 – 2024, Costa Rica (CEPAL, s.d.-a)

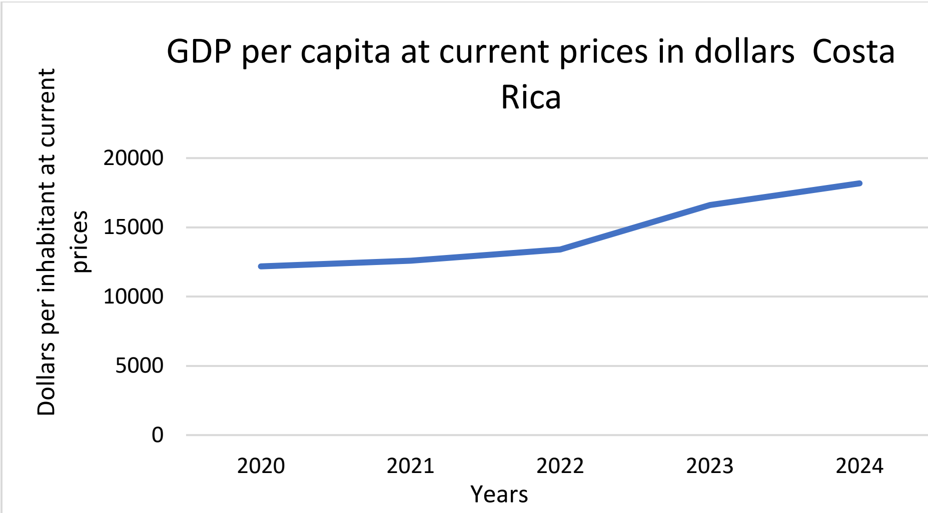


Figure 4: GDP at current prices ($) 2020 – 2024, Costa Rica (CEPAL, s.d.-a)

Costa Rica's economy is primarily driven by manufacturing, construction, agriculture, and related sectors, which represent the main resource-intensive industries aside from services, as shown in Figure 5. These sectors are central to the country's resource flows and provide significant opportunities for CE interventions.

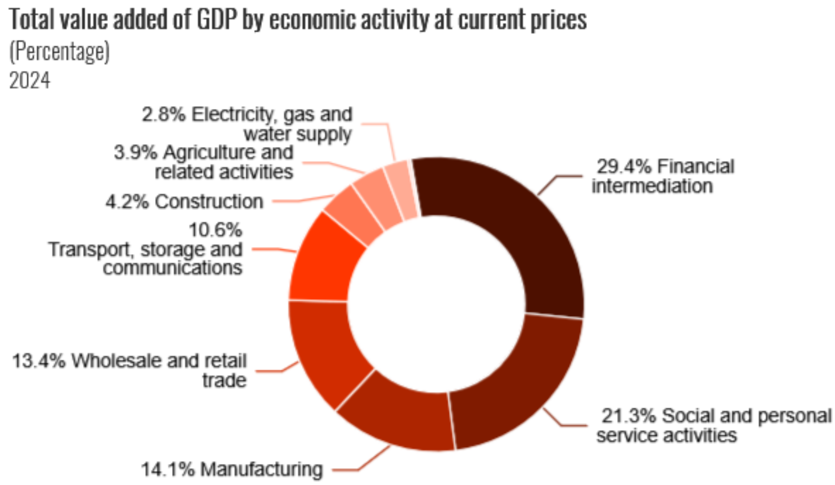


Figure 5: Contribution of sectors by GDP of Costa Rica (CEPAL, s.d.-b)

In terms of international trade, Costa Rica's total exports of goods and services reached approximately US$36.8 billion in 2024, with imports of goods and services at about US$30.5 billion (CEPAL, s.d.-a). As shown in Figure 6, both imports and exports have steadily increased from 2020 to 2024. While Costa Rica is generally a net importer when considering goods alone, it is a net exporter when accounting for both goods and services combined, largely due to its strong service exports, including tourism and business services.

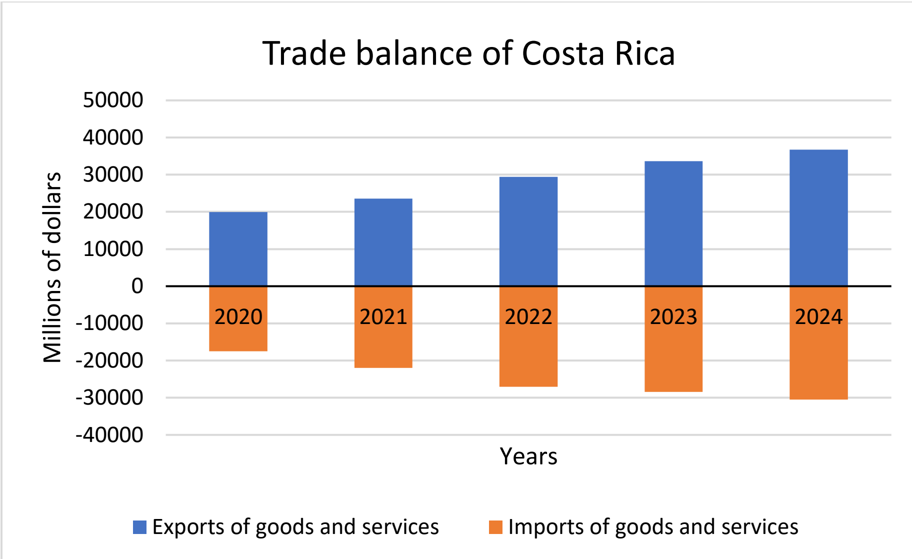


Figure 6: Trade Balance of Costa Rica from 2020 to 2024. Figure by author based on data from CEPAL (s.d.-a).

The country's exports are diverse, dominated by medical devices, food products such as fruit and coffee, pharmaceuticals, and plastics and rubber products (OECD, 2025a). Medical devices have notably become Costa Rica's largest export category, reflecting deepening integration into global value chains (See Figure 7).

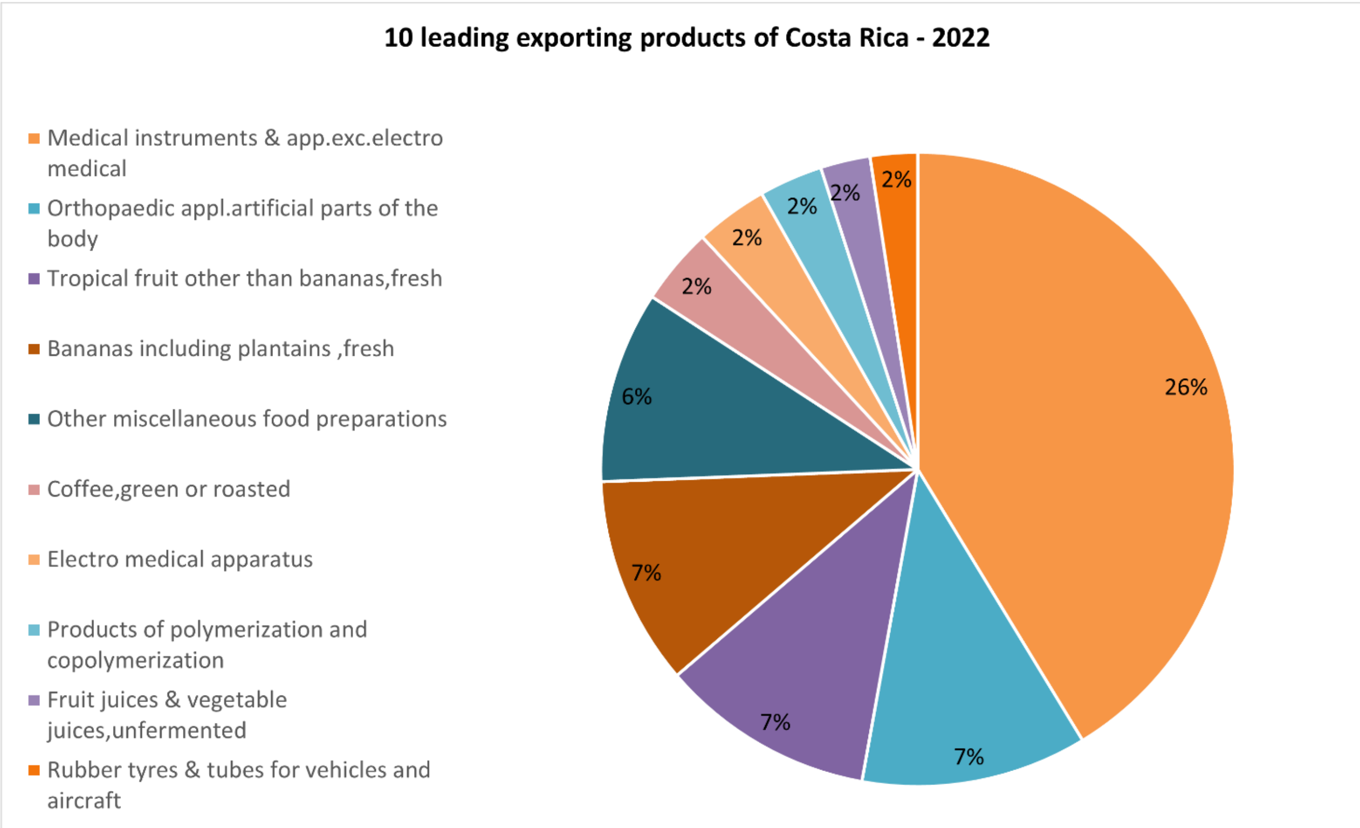


Figure 7: Exports by type of product, % of total good exports. Figure by author based on data from (CEPAL, s.d.-a).

Costa Rica's material flow profile shows domestic production focused mainly on biomass and non-metallic minerals. Its exports primarily consist of biomass, mixed and complex products, and non-metallic mineral products, while imports include significant quantities of mixed and complex products, fossil fuels, and biomass - highlighting key areas relevant for CE interventions (See Figure 8)

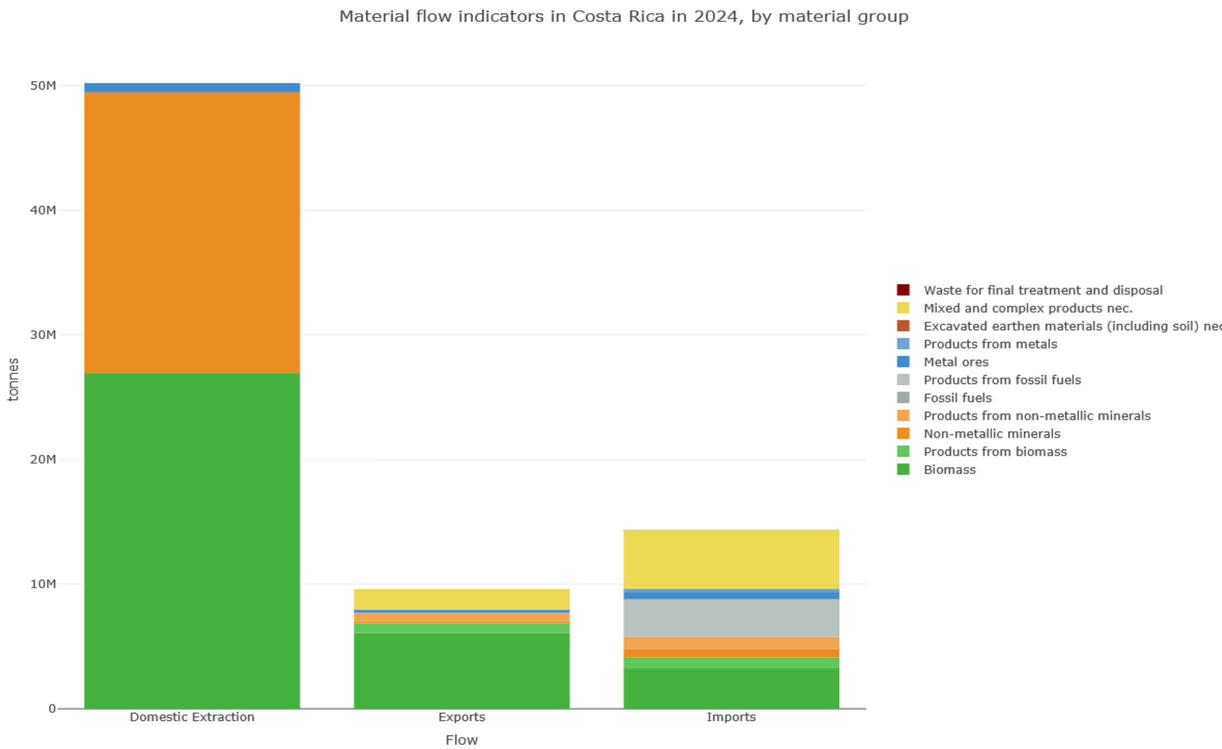


Figure 8: Material flows indicators of Costa Rica, 2024 (WU Vienna, 2023)

5.1.2 Uruguay

Uruguay has a population of approximately 3.38 million people and a land area of 176,000 km² (CEPALSTAT, 2024), resulting in a population density of about 20 inhabitants per km² (World Bank Group, 2022). Compared to other Latin American countries, Uruguay is characterized by relatively low levels of poverty and inequality, reflecting its strong social and economic development indicators (World Bank Group, 2022).

Uruguay's economy demonstrated resilience in 2024, growing by 3.1 percent and rebounding from the severe drought experienced in 2023 (The World Bank, 2025). This growth is reflected in the country's per capita income, estimated at approximately US$20,537 in constant (compared to 2018) prices and US$23,648 in current prices for 2024 (CEPAL, s.d.-a). Both constant and current price GDP per capita have shown an increasing trend since 2020, as illustrated in Figure 9 and Figure 10.

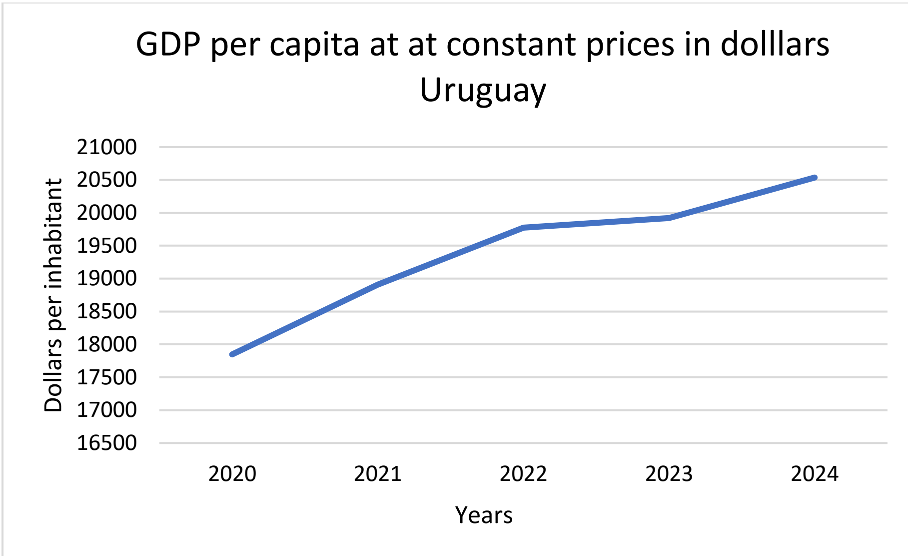


Figure 9: GDP per capita at constant prices in dollars of Uruguay from 2020 to 2024. Figure by author based on data from CEPAL (s.d.-a)

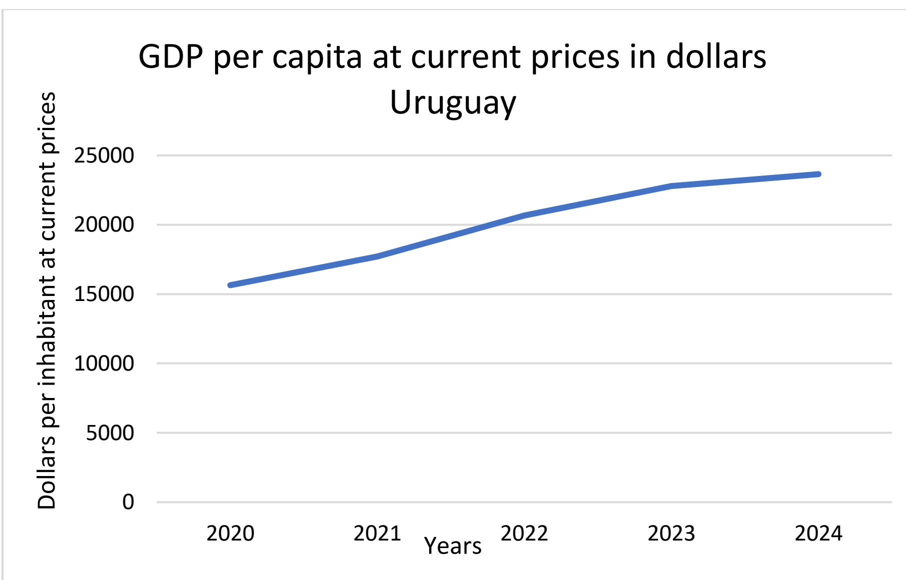


Figure 10: GDP per capita at current prices in dollars of Uruguay from 2020 to 2024. Figure by author based on data from CEPAL (s.d.-a)

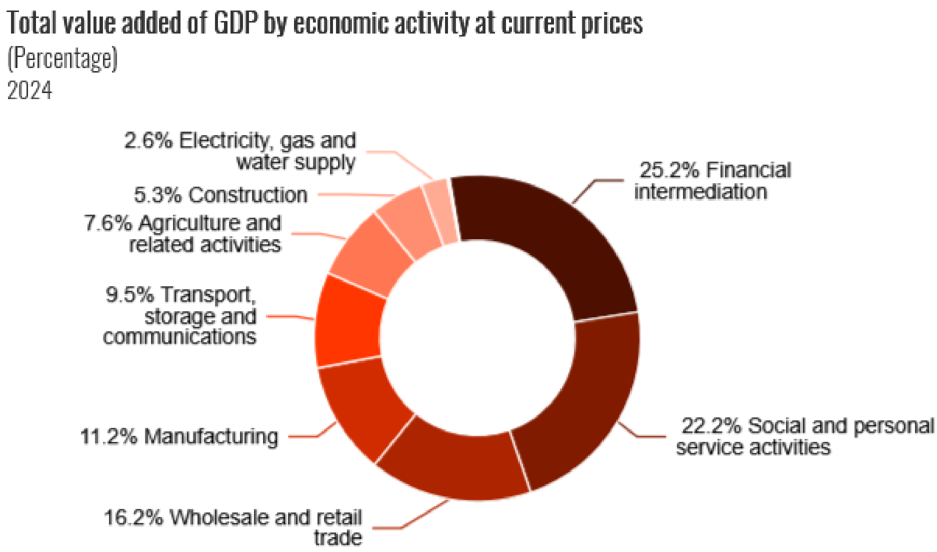


Figure 11: Contribution of sectors by GDP of Uruguay (CEPAL, s.d.-a)

The main drivers of Uruguay's economy are the manufacturing industry, agriculture and related activities, construction, and the electricity, gas, and water supply sector (See Figure 11). Key resource flows include energy, mobility, and consumer goods. Hydrocarbon-based fossil fuels are predominantly imported and mainly consumed in the transport sector (International Trade Administration, n.d.). Consumer goods, such as household appliances, computers, packaging, and textiles, contribute an estimated 4.1 million tons of waste annually, highlighting targets for CIs (Caribe, 2024).

Historically, a major meat exporter, Uruguay continues to play a significant role in the global meat market (Uruguay XXI, 2024b). Recent years have also seen increasing exports of soy, cellulose, and rapeseed (Uruguay XXI, 2022). Figure 12 shows the 10 leading exported products from Uruguay.

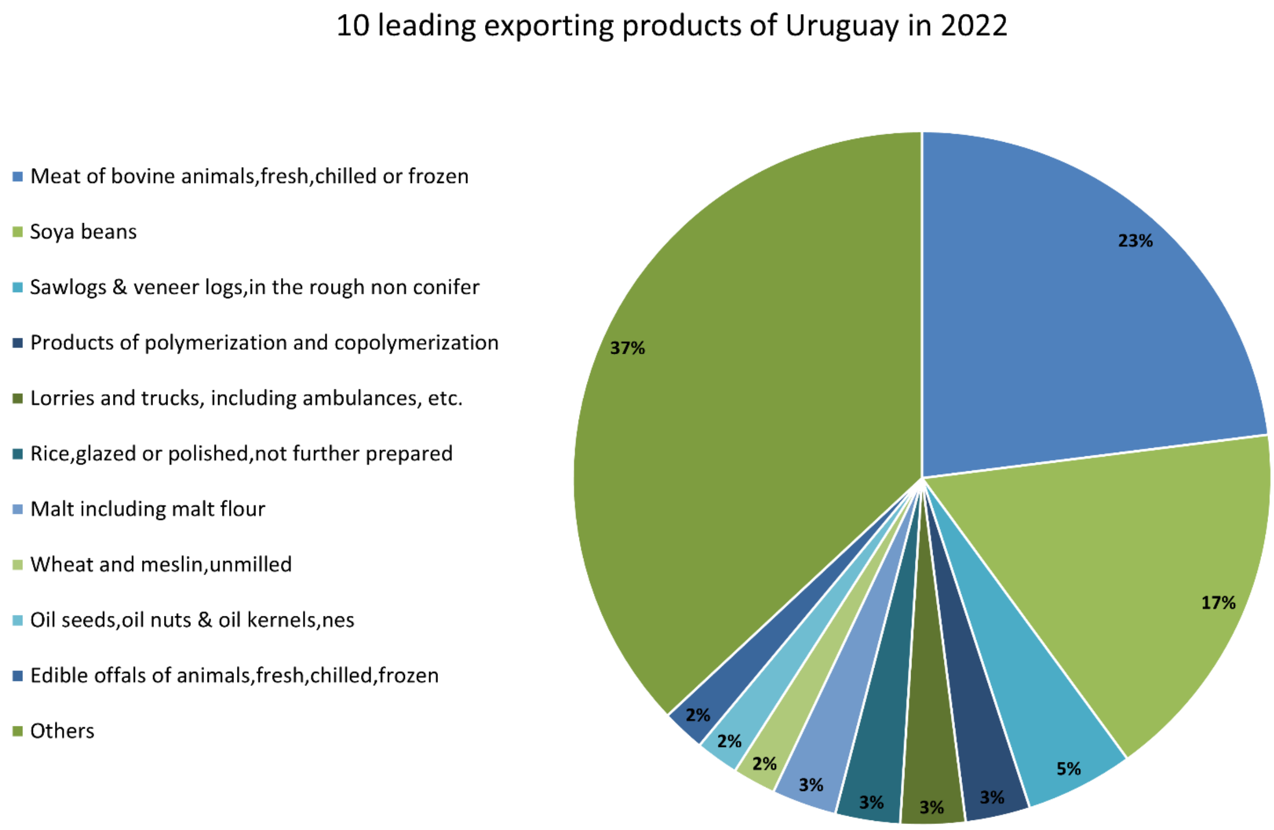


Figure 12:The 10 leading exporting products in Uruguay in 2022. Figure by the author based on data from(CEPAL, s.d.-a).

Total exports of goods and services reached approximately US$23.33 billion in 2024, while imports of goods and services stood at around US$19.12 billion, indicating that Uruguay is a net exporter overall. Specifically, goods exports totalled about US$12.85 billion, with goods imports almost equal at US$12.85 billion, reflecting a narrow trade surplus to (CEPAL, s.d.-a; Uruguay XXI, 2024b). Figure 13 displays recent trends in exports and imports.

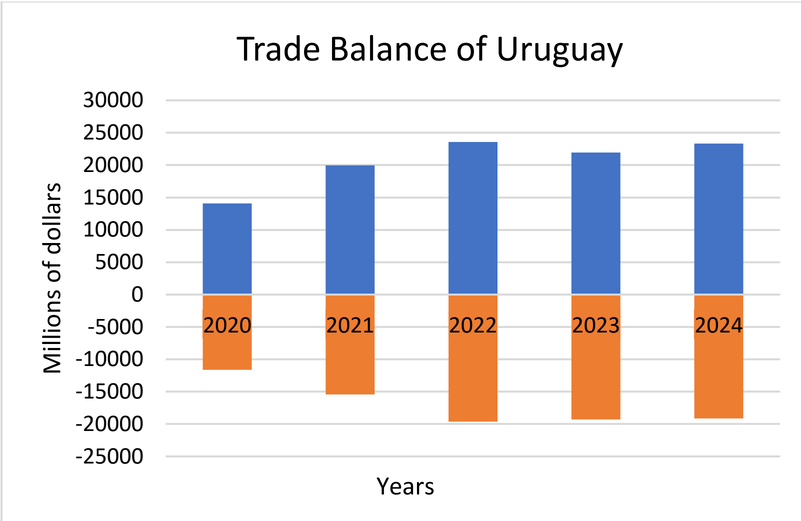


Figure 13: Trade Balance of Uruguay from 2020 to 2024 (CEPAL, s.d.-a)

Biomass plays a key role in Uruguay's economy, with domestic extraction serving as the dominant source of supply. Imports contribute only minimally to the overall biomass pool; yet, Uruguay is a significant exporter of biomass, resulting in a net outflow of these resources (see Figure 14). Most biomass exports derive from forest extraction, particularly wood, with over 80% of these forest products exported internationally, mainly to China and Italy (Uruguay XXI, 2025). Looking at imports in 2024, fossil fuels and mixed and complex products stood out as the most relevant categories.

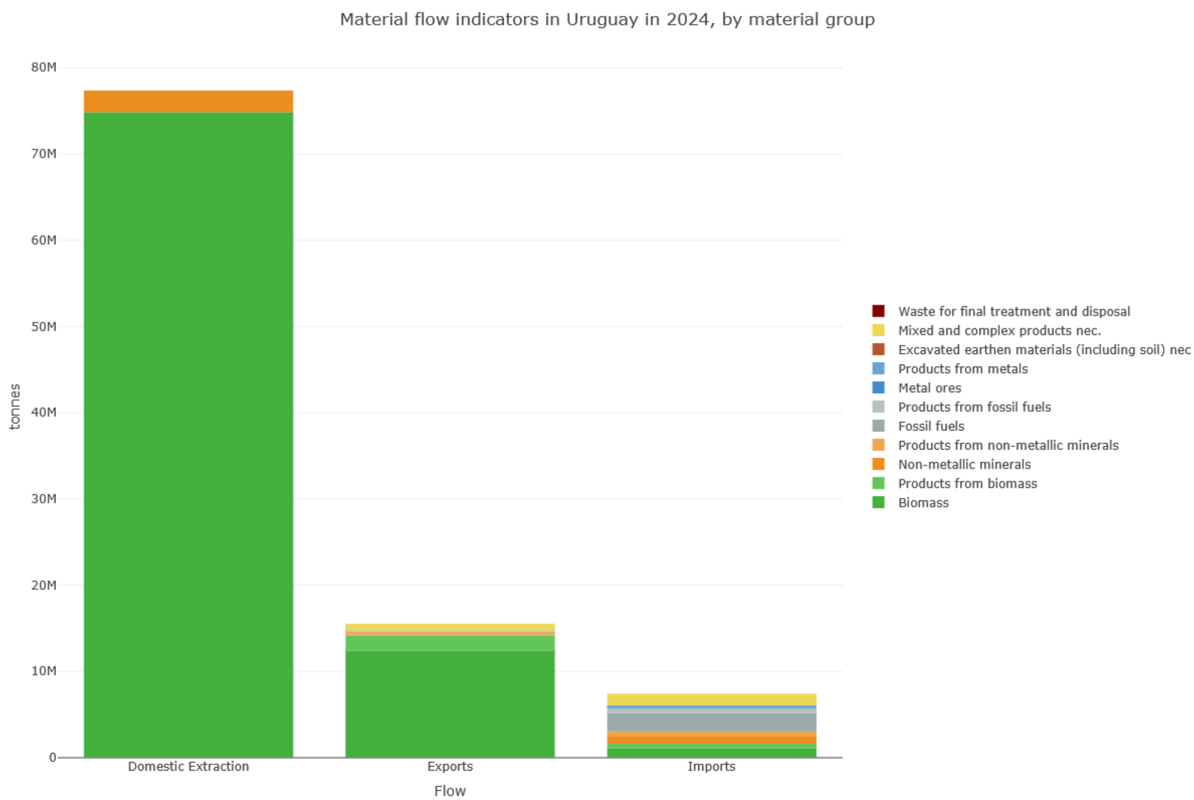


Figure 14: Material flows indicators of Uruguay, 2024 (WU Vienna, 2023)

5.2. Data Collection Results: Circularity Interventions

This section presents the specific CE interventions identified from the national strategies of Costa Rica and Uruguay. It directly addresses the sub-research question: What key CE interventions are outlined in the national roadmaps of Costa Rica and Uruguay at the country level? Table 6 and Table 7 present the CE interventions selected from the National Circular Economy Strategies of Costa Rica and Uruguay, respectively.

Table 6: CIs selected from "Estrategia Nacional de Economía Circular" of Costa Rica to model on EXIOBASE 3 (ENEC, 2023).

Intervention	Theme	Goal
a.	Residuals	By 2021, reduce the presence of plastics in total solid waste generated from 20% to 10%.

b.	Resource Use Efficiency - Organic Waste Management	Achieve a 50% reduction in the tonnage of biodegradable waste sent to landfills by 2050, based on the proportion of municipalities that report this data.
c.	Material	The country will increase the use of wood, bamboo, and other materials (including those from sustainably managed plantations) in buildings by at least 10% by 2025, based on the 2018 baseline.
d.	Value chains	By the year 2025, the country will promote a circular economy system for agricultural and livestock farms, comprehensively considering the process of biodigestion and soil recarbonization through the use of technologies to increase soil organic carbon (SOC) levels, among other strategies.
e.	Productivity	By 2021, achieve a 30% increase (compared to 2017) in the economic activity associated with the production and trade of products manufactured from renewable sources, recycling processes, and that are compostable.

Table 7: CIs selected from "Estrategia Nacional de Economía Circular de Uruguay" to model on EXIOBASE 3 (Caribe, 2024).

Intervention	Theme	Goal
a.	Circularity linked to water use	Promote water circularity through efficiency, reuse, and technological advancements in agriculture, industry, and domestic sectors, aligning with the National Water Plan. Increased water circularity across sectors via efficient and sustainable practices and nature-based solutions.
b.	Sustainable and circular constructions	Build national capacity for circular construction waste management to enable quality recycled material use and reduce landfill waste. Enhance the use of recycled materials in construction and reduce construction waste.

c.	Driving circularity in food and cement production	Reduce resource use and promote material reuse and redesign in industries (prioritizing food and cement) and SMEs through enhanced recycling and recovery. Implement the recycling industry with efficient processes and reduced reliance on raw materials.
d.	Added value in the recycling of post-consumer materials and industrial processing by-products	Enhance the value of recycled post-consumer and industrial by-products by improving high-quality material recovery and enabling new production. Prioritize materials (e.g., plastics, paper), study actions (public procurement, tech, regulation) with a stronger recycling industry using efficient, innovative processes, reducing reliance on raw materials.

Following the selection of these interventions, a qualitative comparative analysis has been conducted to evaluate their environmental and socio-economic impacts. This analysis forms the empirical basis for the following results.

5.3. Qualitative Comparative Analysis

This section presents the results of the qualitative comparative analysis of key CE interventions in Costa Rica and Uruguay. Drawing on a comprehensive literature review, the analysis links each intervention's environmental, socio-economic, and macro-economic impacts to relevant industrial sectors and material flows (see Sections 5.3.1 and 5.3.2). Following this, the findings are summarized and interpreted through the lens of DE boundaries for each country. Socio-economic impacts correspond to social foundations such as employment and income inclusion, while macro-economic impacts relate to trade dynamics, including imports and exports (See Section 4.3 to check the definitions of impacts). Together, these analyses highlight both common and distinct impact patterns, providing insights into their national and regional implications for LATAM.

5.3.1 Costa Rica

a. CI: Residuals

Policy Goal

By 2021, reduce plastics in total solid waste from 20% to 10%.

In 2018, Costa Rica generated approximately 1.45 million tonnes of municipal solid waste annually, with plastics representing about 12% (~174,000 tonnes per year) of this total (Holland Circular Hotspot, 2021). The predominant disposal method for plastic waste remains landfilling, which creates significant environmental challenges through greenhouse gas emissions and biodiversity loss (Jiménez, 2024; Plataforma de Acción sobre los Plásticos de Costa Rica, 2025). Reducing plastic waste in landfills and implementing waste minimization practices such as recycling and composting can alleviate pressure on waste infrastructure.

Beyond environmental benefits, these strategies enable socio-economic opportunities by increasing the value recovered from waste, stimulating business growth, and creating employment (Jiménez, 2024).

While recycled plastics are currently exported in small quantities, expanding production could reduce reliance on imported virgin plastics, which account for about 7.7% of total imports (Holland Circular Hotspot, 2021; International Resource Panel, 2024; Trading Economics, 2023a).

The impacts described below for each CI have been assessed through the lens of the DE framework. A full description of these environmental, socio-economic, and macro-economic results can be found in

Table 9.

As shown in

Table 9, this intervention reduces ecological ceiling pressures related to climate change and biodiversity loss. It supports social foundations by fostering income, work, and social equity in the waste sector. The expected impact intensity is medium, considering the moderate waste stream, an ambitious 50% reduction policy target, and current low recycling rates limiting impact.

b. CI: Resource efficiency

Policy Goal

Costa Rica has set a goal to achieve a 50% reduction in the tonnage of biodegradable (organic) waste sent to landfills by 2050, based on the proportion of municipalities that report this data.

Currently, organic waste makes up 52% of the country's solid waste stream (Holland Circular Hotspot, 2021). Reducing organic waste disposed of in landfills is a critical environmental measure, as it directly lowers methane emissions, a potent greenhouse gas responsible for climate change (Scharff et al., 2023).

Composting is an optimal alternative to reduce the linear waste of organic matter. It has shown economic benefits, including municipal savings exceeding €10,000 monthly. These savings facilitate the expansion of small and medium-sized (SME) enterprises involved in waste collection, processing, and distribution, generating jobs and increasing local economic value and income inclusion (Scharff et al., 2023).

From a macroeconomic and resource perspective, valorising organic waste via composting and biogas production creates domestic value by producing locally organic fertilizers and renewable energy. The International Resource Panel categorizes mineral fertilizers under "non-metallic minerals," which in Costa Rica largely come from domestic production, with imports constituting a smaller proportion (See Figure 8) (CSIRO, 2021). By producing organic fertilizers locally, Costa Rica can reduce its dependence on imported mineral fertilizers, which currently account for about 1.1% of total imports, while simultaneously strengthening domestic renewable energy supply to meet internal demand (Trading Economics, 2023a). This integrated approach supports Costa Rica’s broader strategy to transition toward a sustainable, CE and fulfil its decarbonization commitments by 2050.

According to

Table 9, this intervention decreases pressures on ecological ceilings through reductions in climate change impacts, land conversion, and biodiversity loss. It promotes social foundations by supporting income, work, and equity in composting waste collection and processing. The expected intensity is high, reflecting the large waste stream, a strong 50% reduction target, and some existing operational infrastructure.

c. CI: Material

Policy Goal

Increase the use of wood, bamboo, and other sustainable materials (including sustainably managed plantations) in construction by at least 10% by 2025, based on a 2018 baseline.

The construction sector accounts for 4.2% of Costa Rica's GDP (See

Figure 5) and heavily relies on non-renewable resources, being a major source of CO_2 emissions, primarily from non-metallic mineral extraction (ENEC, 2023; Osorio Gómez et al., 2025). Substituting sustainable materials like wood and bamboo reduces reliance on these carbon-intensive inputs, lowering greenhouse gas emissions (Xu et al., 2022).

From a socio-economic perspective, such a CI can enhance value addition, and create rural jobs while preserving traditional skills and enhancing social inclusion in the bamboo and wood harvesting, farming, and processing sectors (Bredenoord, 2024; World Bank Group, 2023).

The International Resource Panel categorizes construction materials under the "non-metallic minerals" category, as shown in Figure 8 (CSIRO, 2021). This category mainly includes construction materials derived from the extraction of sand and gravel, as well as imported chemicals and fertilizers (CSIRO, 2021). Figure 8 shows that, in Costa Rica, non-metallic minerals are primarily domestically sourced, with imports and exports making up much smaller shares.

Based on this information, increased use of wood and bamboo for sustainable construction could reduce demand for traditional materials such as sand and gravel, potentially lowering both domestic production, imports, and exports of the non-metallic minerals category shown in Figure

8 . At the same time, this shift would likely increase the use of biomass materials, which the figure shows make up a large majority of domestic production. Although imports and exports of biomass materials still occur at notable levels, domestic production significantly exceeds these trade flows.

As detailed in

Table 9, the intervention lowers ecological ceiling pressures including climate change, land conversion, and biodiversity loss. It sustains social foundations through income and work opportunities in bamboo and wood harvesting, farming, and processing sectors. The expected intensity is small to medium due to the sector's small to moderate size, a 10% policy increase target, and knowledge gaps in construction waste management.

d. CI: Value chains

Policy Goal

By the year 2025, the country will promote a circular economy system for agricultural and livestock farms, comprehensively considering the process of bio-digestion and soil recarbonization through the use of technologies to increase soil organic carbon (SOC) levels, among other strategies.

Organic waste is particularly relevant in Costa Rica, particularly since the Agricultural and Livestock Sector contributes to 7.6% of its GDP (See

Figure 5). In this regard, proposed interventions, such as widespread bio-digestion and composting, show significant potential to address these environmental challenges. Bio-digestion uses microorganisms to aerobically break down organic waste, producing renewable biogas and nutrient-rich fertilizer, while soil recarbonization increases soil carbon content, thereby enhancing fertility and carbon storage capacity (Archana et al., 2024; Nikolausz & Kretzschmar, 2020). From an environmental perspective, agriculture and livestock contribute 27% of Costa Rica's CO_2 emissions and cause nitrogen and phosphorus pollution (García & Montero, 2022; O'Neill et al., 2018). Bio-digestion reduces methane emissions by converting waste into energy and fertilizer, while soil recarbonization enhances carbon sequestration and soil health. Together, these technologies can lower greenhouse gas emissions and reduce soil and water contamination. Furthermore, they close the nutrient cycles through fertilizer production and energy recovery (Archana et al., 2024; Nikolausz & Kretzschmar, 2020).

Producing biogas and fertilizer from agricultural and livestock waste also enhances local farmers' businesses by diversifying their income streams and increasing total earnings through cost savings on electricity and reduced reliance on chemical fertilizers (Jarrar et al., 2020).

Although the farming and livestock sector is a significant component of the Costa Rican economy, 2.2% of the country's imports consist of fertilizers, food residues, waste, and animal feed(Trading Economics, 2023a). Increasing the production of byproducts such as organic fertilizers can help reduce imports. As biofuels are already produced domestically in Costa Rica, expanding biogas production can further boost local output and strengthen the country's self-sufficiency (Vega et al., 2024).

Table 9 indicates this intervention reduces ecological ceiling pressures by lowering climate change, nutrient loading (nitrogen and phosphorus), and land conversion. It supports social foundations by generating income and work for local farmers. The expected impact intensity is medium, considering the moderate agriculture sector size, absence of clear policy targets, and underdeveloped infrastructure.

e. CI: Productivity

Policy Goal

By 2021, achieve a 30% increase (compared to 2017) in economic activity linked to the production and trade of products manufactured from renewable sources, recycling processes, and compostable materials.

e.1 Products from renewable sources

Although Costa Rica does not produce fossil fuels domestically, it relies heavily on them to meet its national energy demand. Petroleum and oil products accounted for approximately 50-60% of the country's total energy consumption in 2023, making oil a dominant energy source despite the country's commitment to renewable energy (IEA, 2025; World Future Council, 2020). Costa Rica's imports in 2023 of fossil fuel derivatives - including mineral fuels, oils and distillation products, and fossil fuel-based products - accounted for approximately $2.59 billion, or around

11.5% of imports (Trading Economics, 2023a). These fossil fuel products represent a significant portion of national energy consumption and contribute to CO_2 emissions (García & Montero, 2022). Shifting toward products from renewable sources, recycling, and compostable materials supports national goals to reduce greenhouse gas emissions.

Furthermore, Costa Rica already has strong infrastructure and technical skills in renewable energy. Therefore, expanding its renewable energy manufacturing sector is likely to efficiently increase job creation, innovation, and added value in the industry.

From a macroeconomic perspective, increasing renewable energy production and trade is expected to reduce fossil fuel imports, enhance national energy security, and augment export revenues.

Per

Table 9, this intervention reduces climate change pressures on ecological ceilings and strengthens social foundations by promoting income and work in renewables and expanding energy access. It also contributes macro-economic benefits by decreasing fossil fuel imports, enhancing energy security, and boosting exports. The expected intensity is medium to high, reflecting strong sector potential, a 30% increase policy target, and robust infrastructure.

e.2 Products manufactured from recycling processes

Increasing recycling capacity for the production and trade of products manufactured from recycling processes is likely to diminish landfill waste and, therefore, related land use pressure and CO_2 emissions release. Yet, current recycling rates (~4%) limit immediate environmental benefits (García & Montero, 2022). Waste minimization practices such as recycling create valuable new business opportunities, generating added value and income in the sector (Holland Circular Hotspot, 2021).

These industries stimulate business growth by increasing the economic value retained from waste materials and contributing to job creation (Jiménez, 2024).

Increased recycling reduces the need to import raw materials such as plastic, paper and paperboard, iron, and steel, which together constitute 14.5% of Costa Rica's total imports (Trading Economics, 2023a). Furthermore, enhancing recycling efforts could determine a growth in exports since the majority of recyclables collected in Costa Rica are ultimately exported to final destinations primarily abroad (Holland Circular Hotspot, 2021).

As summarized in

Table 9, the intervention reduces climate change and land use change impacts on ecological ceilings. It generates income and work in recycling industries and reduces raw material imports while increasing recycling exports. The expected intensity is small to medium, indicating substantial sector potential balanced by low current recycling rates and a 30% policy increase target.

e.3 Compostable products

The use of compostable products reduces organic waste in landfills, cutting methane emissions - a significant environmental benefit (Scharff et al., 2023).

Socio-economically, composting operations generate jobs in waste processing and organic fertilizer markets, supporting rural development and sustainable agriculture (Holland Circular Hotspot, 2021).

At the macroeconomic level, industries related to composting help strengthen domestic production, reduce waste disposal costs, and potentially decrease imports, as residues and food waste imports currently account for approximately 1.1% of Costa Rica's total imports (Holland Circular Hotspot, 2021; Trading Economics, 2023a).

According to

Table 9, this intervention alleviates ecological ceiling pressures related to climate change, land use, and biodiversity loss. It supports social foundations through income and work opportunities in waste processing and organic fertilizer markets. It also lowers waste disposal costs and reduces import dependency on food residues. The expected intensity is medium, driven by a high organic waste share, a 30% policy target, and a growing but underdeveloped infrastructure.

Table 8 provides a concise overview of the key CE interventions extracted from Costa Rica's national strategy, summarizing both their environmental, socio-economic, and macro-economic impacts. Please refer to this table for a summary of the results gathered from the qualitative comparative analysis.

Table 8: Summary of impacts from CIs in Costa Rica

Intervention	**Policy Goal**	**Impact Summary (Environmental, Socio-economic, Macro-economic)**
a. Residuals	Plastic reduction of from 20% to 10% in solid waste by 2021	Reduces climate change and biodiversity loss by lowering plastics in landfills; supports job creation and social equity; reduces virgin plastic imports
b. Resource efficiency	50% reduction in organic waste landfilled by 2050	Cuts methane emissions from organics; fosters SME growth and income inclusion; reduces fertilizer imports and boosts renewables
c. Material	Increase sustainable material use by 10% by 2025	Lowers CO_2 emissions via substitution; boosts rural jobs and social inclusion; shifts demand from non-renewable to biomass materials

d. Value Chains		Promote bio-digestion and soil recarbonization by 2025	Mitigates CO_2 and nutrient pollution; diversifies farmer incomes; reduces fertilizer and food residue imports; strengthens self-sufficiency
e. Productivity	e.1 Products from renewable sources	30% economic growth in renewables products by 2021	Reduces CO_2 emissions by cutting fossil fuel use; leverages existing renewable energy infrastructure; promotes job creation and innovation in renewables; decreases fossil fuel imports, enhances energy security, and boosts export revenues.
	e.2 Products manufactured from recycling processes	30% economic growth in recycled products by 2021	Reduces landfill waste and land use pressures; creates new business and job opportunities in recycling sectors; lowers imports of raw materials, potentially increases exports of recycled products.
	e.2 Compostable products	30% economic growth in compostable products by 2021	Cuts methane emissions from organic waste in landfills; supports rural jobs and sustainable agriculture through composting; strengthens domestic production, reduces waste disposal costs, and may decrease imports of organic residues.

Table 9: Impacts of CE Interventions in Costa Rica (DE)

Intervention	Environmental Impact (Doughnut Ecological Ceiling)	Socio-economic Impact (Doughnut Social Foundation)	Macro-economic Implications	Expected Intensity
a. Residuals	Reduction in Climate Change and Biodiversity Loss	Supports Income and Work, Social Equity in the waste sector	Reduces imports of virgin plastics; Increases exports of recycled plastics	Medium — Moderate waste stream); ambitious policy goal (50% reduction); low current recycling rates limit impact.
b.Resource efficiency	Reduction in Climate Change impacts, Land conversion and Biodiversity loss	Supports Income and Work, Social Equity in waste collection, processing, and distribution of the composting sector	Reduces fertilizer imports; Strengthens renewable energy	High — Large waste stream); strong 50% reduction target;and some existing operational infrastructure.
c. Material	Reduction in Climate Change, Land conversion and Biodiversity loss	Supports Income and Work in the bamboo and wood harvesting, farming, and processing sectors	Reduces demand for the extraction/import of non-metallic minerals; increases biomass use domestically.	Small/Medium — Construction sector is small/moderate;10% increase policy target; knowledge gaps on construction waste management.

d. Value Chains		Lowers Climate Change and reduces Nitrogen and Phosphorus Loading and Land conversion	Supports Income & Work of local farmers' businesses	Reduces fertilizer and animal feed imports, increases domestic biofuel production.	Medium — Agriculture sector is moderate; no clear policy target; infrastructure is underdeveloped.
e. Productivity	e.1 Products from renewable sources	Reduces Climate Change	Promotes Income and Work in renewables, increases access to Energy	Decreases fossil fuel imports, enhances energy security, and boosts export revenues	Medium/High — Strong potential for renewables to become a major sector; 30% increase as policy target; strong infrastructure
	e.2 Products manufactured from recycling processes	Reduction in Climate Change and Land use change	Generates Income and Work in recycling industries	Reduces raw material imports (plastic, paper, iron, steel); increases recycling-related exports	Small/Medium — Recycling is a s sector with substantial potential; 30% increase as policy target; Current recycling rates are low
	e.2 Compostable products	Reduction in Climate Change, Land use change and Biodiversity loss	Generates Income and Work in waste processing and organic fertilizer markets	Reduces waste disposal costs and potentially decreases imports (food residues)	Medium — organic waste share is high; 30% increase as policy target; growing market, but underdeveloped infrastructure.

5.3.2 Uruguay

a. CI: Circularity linked to water use

Policy goal

Promote water circularity through efficiency, reuse, and technological advancements in agriculture, industry, and domestic sectors, aligning with the National Water Plan. Increase water circularity across sectors via efficient and sustainable practices and nature-based solutions.

Water circularity reduces pressure on freshwater resources by recycling and efficient management of water flows, helping alleviate environmental challenges like scarcity and ecosystem degradation. Agriculture is the largest contributor to water stress in Uruguay (9.30%), compared to industry (1.61%) and domestic sectors (1.13%) (*FAO AQUASTAT Dissemination System*, 2020). The following CI reduces water scarcity and pollution by improving wastewater treatment and promoting water reuse, especially in agriculture, where water stress is the highest. It can lower the release of untreated wastewater, which protects ecosystems from degradation and eutrophication (OECD, 2025b). Additionally, it can cut greenhouse gas emissions from wastewater breakdown and energy use. Overall, the CI contributes into ensuring sustainable water use and supports climate mitigation efforts (OECD, 2025b).

Water circularity delivers important socio-economic benefits by improving water access in Uruguay, a country that was recently affected by droughts and water quality challenges (Lucero-Méndez et al., 2023). Improvements in water circularity can enhance public health and sanitation, thereby reducing healthcare costs (OECD, 2025b). In Costa Rica, these benefits extend to cost savings through resource use and energy recovery. The agricultural sector can increase productivity and farmer incomes by using treated wastewater for irrigation (OECD, 2025b). The energy sector benefits from biogas and renewable energy generation from wastewater treatment (OECD, 2025b). Additionally, growing demand for water technologies and circular business models can support job creation and innovation.

From a macroeconomic perspective, Uruguay's water circularity policy is expected to strengthen the domestic economy by improving water-use efficiency and promoting water reuse mainly across agriculture. Since Uruguay primarily relies on domestic water sources, optimizing water management through circularity enhances the country's resilience by mitigating the economic risks associated with droughts and water scarcity (Water Action Hub, n.d.).

The results of the qualitative assessment for these CIs in Uruguay, viewed through the DE framework, are summarized in

Table 11. This table presents the environmental, socio-economic, and macro-economic impacts interpreted within the DE lens, reflecting the interventions' contributions to ecological ceilings and social foundations.

As shown in

Table 11, this intervention delivers modest but meaningful reductions in freshwater withdrawals and chemical pollution, supporting access to water as a key social foundation. The expected impact intensity ranges from small to medium, considering Uruguay's moderate water stress and underdeveloped policy and monitoring systems. By enhancing water-use efficiency and reuse, primarily in agriculture, the intervention strengthens economic resilience against drought and water scarcity risks.

b. CI: Sustainable and circular constructions

Policy Goal

Promote sustainable and circular construction practices by building national capacity for circular construction waste management. This includes enabling the quality use of recycled materials and reducing landfill waste, ultimately enhancing the use of recycled materials in construction and minimizing construction waste generation.

In 2024, the construction sector contributed 5.3% to Uruguay's GDP (See Figure 11) and generated 88,000 tons of waste annually, representing 21% of the nation's total waste (Caribe, 2024). The sector significantly contributes to greenhouse gases, with building energy use and cement production responsible for substantial emissions. Energy use in buildings accounts for over 17% of emissions, while non-energy emissions from cement production contribute an additional 3% (Ritchie, 2020). Implementing circular construction practices can reduce demand for new construction materials, thereby mitigating environmental pressures by lowering emissions from material extraction, production, and landfill disposal (Cristobal et al., 2024).

From a socio-economic perspective, Uruguay is a significant producer of construction materials in the region, presenting economic potential to utilize construction waste more effectively. However, the absence of comprehensive data on material flows within the construction sector limits the ability to accurately estimate socio-economic impacts, including value added and employment opportunities, from recycling and CE initiatives in this industry. The National Waste Management Plan and related policy discussions emphasize the need for better information and system improvements to maximize the sector's economic and sustainability potential (Ministero de Ambiente, 2021).

In the context of the Uruguayan macro-economy, a reduction in construction material use would primarily lead to a reduction in domestic production, as construction material falls under the category of "non-metallic minerals" (See Figure 14). This sector represents the second-largest contributor to domestic production. However, despite its relative ranking, the absolute economic contribution of non-metallic minerals remains small (See Figure 14). Therefore, although domestic production is expected to experience the most significant relative change compared to imports and exports, the overall economic impact on Uruguay's economy is expected to be minimal.

According to

Table 11, this intervention reduces pressure on the ecological ceiling related to climate change by lowering demand for virgin construction materials and associated emissions. On social foundations, it supports income and work, providing socio-economic benefits despite the sector's small scale. Macroeconomically, the effects are modest. The expected impact intensity is small owing to the limited sector size, lack of concrete policy targets, and unclear data on construction waste management.

c. CI: Driving circularity in food and cement production

Policy Goal

The intervention aims to reduce resource use and promote material reuse and redesign in priority industries - mainly food and cement production - by enhancing recycling and recovery processes.

The goal is to implement an efficient recycling industry that reduces dependence on raw materials and encourages circular resource flows across industries and SMEs.

c.1 Cement re-use

Cement is a key component of construction materials in Uruguay. While its economic contribution is relatively small compared to other sectors (See Figure 11), its environmental impact is considerable. Cement production is particularly significant due to its high carbon dioxide emissions and the intensive use of natural resources required for manufacturing (Villagrán-Zaccardi et al., 2022). Circularity in cement waste can reduce CO2 emissions and material footprint. Cement production is energy and carbon-intensive; therefore, improved recycling and reuse of cement-containing materials, like concrete, reduces extraction and production emissions.

Since construction waste accounts for a significant share of total waste in Uruguay, enhancing recycling efforts and advancing CE practices, particularly in relation to cement, could foster job creation within an industry that holds economic potential.

Moreover, a reduced demand for virgin cement and associated raw materials can modestly decrease domestic cement production and raw material mining. Import reliance could decline for construction materials if domestic recycled alternatives become common.

Through the DE lens in

Table 11, cement re-use reduces climate change impacts through CO_2 emission reductions and it supports income and work by fostering job creation in construction waste recycling. The expected impact intensity of the intervention is moderate, reflecting cement's high environmental footprint, with a moderate economic role and limited recycling capacities (See

Table 11).

c.2 Food re-use

Organic waste comprises a large portion (43-47%) of urban solid waste in Uruguay, with food waste being a major component, though detailed food waste data is limited. The national recycling rate is low, below 15%, highlighting potential to improve organic waste management and reduce food waste (IDB, 2021). Increasing the reuse of food waste can significantly alleviate environmental pressures. While food waste cannot be directly converted back into food, it can be transformed through processes like composting or anaerobic digestion into valuable resources such as nitrogen, phosphorus, and organic matter. This lowers the demand for new food production by reducing the need for agricultural inputs like fertilizers and decreasing associated greenhouse gas emissions (Conijn et al., 2018).

CIs in organic and food waste management hold the potential to create new value chains within the food waste sector, given the large volume of waste and opportunities for value addition. These initiatives can support local employment growth in emerging sectors such as composting technologies.

Moreover, reducing food waste can alleviate pressure on agricultural imports, such as fertilizers and food residues, which make up 5.1% of Uruguay's total imports, while also decreasing the demand on domestic food production (Trading Economics, 2023a).

See

Table 11 shows that food waste reuse reduces pressures including climate change, nutrient loading (nitrogen and phosphorus) and land conversion and it promotes income and work related to circular waste management. This intervention alleviates pressure on agricultural inputs and domestic food production. The expected impact intensity of the intervention is moderate, driven by the large organic waste volume and the opportunity for socio-economic gains despite current low recycling rates and policy gaps.

d. CI: Added value in the recycling of post-consumer materials and industrial processing by-products

Policy Goal

The intervention aims to enhance the value of recycled post-consumer and industrial by-products by improving high-quality material recovery and enabling new production. It prioritizes key materials such as plastics and paper, focusing on actions including public procurement, *technological innovation, and regulation to build a stronger, more efficient recycling industry that reduces reliance on virgin raw materials.*

d.1 Plastics recycling

Plastics hold relevance in the Uruguayan economy, particularly in the manufacturing and export sectors, with exports being 3.4% (Trading Economics, 2023b). This highlights the sector's contribution to the country's trade balance. However, Uruguay's plastic industry is heavily reliant on imports for its primary raw material, such as virgin plastic pellets, as Uruguay does not produce them (O'Hare, 2024). The raw plastic primary material enters the country through imported products, which are then converted into plastic products and packaging for both the internal market and export (Angelo & Rossi, 2023). The current management of plastic waste in Uruguay poses considerable challenges. The dominant disposal system in Uruguay is landfilling (Coaliciòn cierre de basurales América Latina y El Caribe & ONU, 2021). According to Pittaluga and Pirrocco (2021), 79% of plastic waste produced up to 2015 resides in landfills, dumps, or the environment, primarily the oceans. Reusing plastics would significantly relieve pressure on these disposal waste management systems, consequently reducing the strain on landfills (O'Neill et al., 2018). However, the environmental impact directly caused by the production of plastics within Uruguay seems limited, as the raw material for plastic is primarily imported.

Developing a circular plastic recycling industry can create employment opportunities in collection, sorting, recycling technology, and remanufacturing sectors. Uruguay's current recycling rate for plastics is low, signalling room for growth and new jobs (Ministero de Ambiente, 2021).

On a macro level, expanding recycled plastic production can significantly reduce Uruguay's dependence on imported virgin plastic pellets, lowering raw material costs. Domestic production of recycled plastic products and packaging is expected to grow, strengthening the local industry.

From the perspective of the DE, Plastics recycling alleviates pressures on ecological ceilings such as land conversion and landfill use. It contributes positively to social foundations by creating income and work in collection, sorting, and remanufacturing. The intervention also reduces dependency on imported virgin plastic pellets, strengthening local production capacity. The expected impact intensity is small due to the sector's current scale, low recycling rates, and absence of clear policy guidance, though it holds notable growth potential within Uruguay's CE (See

Table 11).

d.2 Paper recycling

Uruguay is a significant domestic producer and exporter of cellulose, which has become the country's leading export product (Uruguay XXI, 2023). Despite its abundant raw material supply, Uruguay is a net importer of paper and paperboard (Trading Economics, 2023). Cellulose production is directly tied to forestry and, consequently, land use. A reduced demand for virgin cellulose would alleviate the pressure to deforest additional land, thereby relieving stress on land use (Tahvanainen et al., 2024). However, this intervention is not expected to significantly reduce national environmental pressures, as the environmental burden caused by paper production is expected to occur mainly in the importing countries that produce the raw material.

Enhanced domestic recycling is likely to reduce import dependency, retaining economic value inside the country and supporting jobs in recycling and paper processing industries. This intervention is expected to reduce imports of paper and paperboard, which make up 1.4% of the imports (Trading Economics, 2023c).

Using the terms of DE framework, the CI modestly eases pressure on the ecological ceiling related to land use and supports social foundations by contributing to income and work. The expected impact intensity is small, reflecting its limited environmental effect at the national level (See Table 11).

Table 10 provides a concise overview of the key CE interventions extracted from Uruguay's national strategy, summarizing both their environmental, socio-economic impacts, and macro-economic implications. Please refer to this table for a summary of the results gathered from the qualitative comparative analysis.

Table 10: Summary of impacts from CIs in Uruguay

Intervention		**Policy Goal**	**Impact Summary (Environmental, Social, Macro-economic)**
a. Circularity linked to water use		Promote water circularity through efficiency, reuse, and technology	Reduces water scarcity and pollution; improves water access and social benefits; enhances economic value by reducing water losses
b. Sustainable and circular construction		Build capacity for circular construction waste management	Lowers GHG emissions by reducing virgin material use; potential for rural job creation; economic impact is small due to sector scale
c. Driving Circularity in food and cement Production	c.1 Cement re-use	Enhance recycling and reuse in cement sector	Reduces CO_2 emissions and material footprint by lowering extraction and production; fosters job creation in construction waste recycling; decreases demand for virgin cement and raw materials
	c.2 Food re-use	Enhance recycling and reuse in food sector	Lowers greenhouse gas emissions by transforming food waste into compost and biogas; supports local job growth in circular waste management; reduces agricultural input imports and pressure on domestic food production.
d. Added value in the recycling of post-consumer materials and	d.1 Plastics recycling	Improve recycling and material recovery for plastics	Relieves landfill and environmental burden by reducing plastic waste; creates jobs in collection, sorting, and recycling

industrial processing by-products			industries; cuts import dependency on virgin plastic pellets, strengthening local production
	d.2 Paper recycling	Improve recycling and material recovery for paper	Alleviates land use pressure by reducing virgin cellulose demand; supports domestic jobs in paper recycling and processing; decreases imports of paper products, retaining economic value domestically.

Table 11: Impacts of CE Interventions in Uruguay (DE)

Intervention	**Environmental Impact (Doughnut Ecological Ceiling)**	**Socio-economic Impact (Doughnut Social Foundation)**	**Macro-economic Implications**	**Expected Intensity**
a.Circularity linked to water use	Mitigates Freshwater Withdrawals and reduces Chemical Pollution	Supports access to Water	Strengthens economic resilience by reducing water losses and mitigating drought risks across agriculture & industry.	Small/Medium — Water stress is moderate; no policy target, underdeveloped water monitoring system

b.Sustainable and Circular Construction		Reduction in Climate Change, Land conversion and Biodiversity Loss	Supports Income and Work	Small decrease in construction material from domestic production	Small/Medium — Moderate waste sector size, no clear policy target; unclear info on construction waste management.
c.Driving Circularity in Food and Cement Production	c.1 Cement re-use	Reduction in Climate Change, Land conversion and Biodiversity loss	Supports Income and Work in construction waste recycling	Small decrease in demand for virgin cement	Moderate — Small sector size; no clear policy target; unclear info on cement waste management.
	c.2 Food re-use	Reduction in Climate Change and in Nitrogen and Phosphorus loading and Land conversion	Supports Income and Work in circular waste management	Reduces agricultural input imports and pressure on domestic food production	Moderate — Large organic waste volume; no clear policy target; low recycling rates
d. Added value in the recycling of post-consumer materials and industrial processing by-products	d.1 Plastics recycling	Alleviates land conversion	Creates Income and Work in collection, sorting, recycling, and re-manufacturing	Cuts import dependency on virgin plastic pellets; strengthens local production	Small — Small sector; No clear policy target; Low current recycling rates

	d.2 Paper recycling	Alleviates land conversion	Supports Income and Work in the paper recycling and processing industries	Reduces imports of paper products; retains economic value domestically	Small — Small sector; no clear policy target, low current recycling rates

5.4. Modelling Results from CIs

This section presents the quantitative outcomes of selected CIs drawn from the national strategies of Uruguay and Costa Rica, analysed using MR-EEIOA. Addressing the Sub-Research Question: "What are the economic and environmental impacts of these interventions at both regional (LATAM) and global scales?" - this analysis integrates qualitative insights with quantitative modelling. To support and extend the qualitative findings, MR-EEIOA scenarios were developed to simulate the hypothetical implementation of specific national interventions across the entire LATAM region. This assessment assumes that interventions from Costa Rica and Uruguay have regional effects throughout LATAM, which is represented using a dataset proxy due to the unavailability of complete regional data in EXIOBASE 3. This methodology enables a robust quantitative assessment of the potential environmental and socio-economic impacts at regional and global levels, providing valuable complementary evidence that enriches the overall understanding of these CE interventions.

The MR-EEIOA model uses the inverse Leontief matrix to translate changes in final demand resulting from these interventions into total embodied environmental and socio-economic impacts, which include both direct and indirect effects. These embodied impacts, often referred to as footprints, represent the indirect consequences embedded within global supply chains that are triggered by shifts in consumption and production patterns. The results presented here cover multiple key indicators: changes in greenhouse gas (GHG) emissions reflect the carbon footprint associated with these demand shifts; land use impacts capture alterations in the use of agricultural and natural areas; nutrient loading tracks the potential effects on soil and water quality; while employment and value-added indicators reveal the socio-economic effects related to job creation and economic output. This comprehensive approach aligns with established input-output impact assessment methodologies and provides a detailed understanding of how CE interventions propagate environmental and economic effects throughout global value chains.

This section analysed two interventions from the national strategies of Costa Rica and Uruguay. The first, "b. Resource Use Efficiency - Organic Waste Management" from Costa Rica, aims to advance a CE by promoting use of bio-degradable waste from food (see Table 6 for the full intervention). The second intervention, "d.1 Plastics recycling" from Uruguay, focuses on enhancing the value of recycled post-consumer and industrial by-products, particularly plastics, through improved material recovery (see Table 7 for the full intervention).

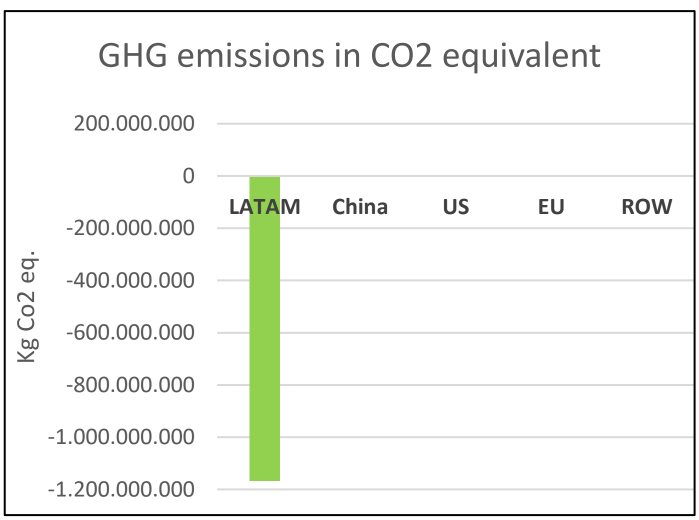
5.4.1. *“b. Resource Use Efficiency - Organic Waste Management”, Costa Rica*

5.4.1.1 Environmental impacts

The scenario analysis for CI b. Resource Use Efficiency - Organic Waste Management from Costa Rica's national strategy, reveals notable regional environmental impacts across multiple indicators. The model projects a significant decrease in greenhouse gas (GHG) emissions within the LATAM region, an effect so pronounced that it dominates the scale of the associated figures and renders minor changes in other regions virtually imperceptible (see Figure 15a and 15b). While China and the US experience minimal decreases in GHG emissions, the rest of the world (ROW) and the EU show insignificant increases in emissions.

Land use changes are projected to be minimal across all regions, with the most substantial effect observed in the ROW, showing a negligible increase on the order of 5×10^{-9} (see Figure 15c).

Similarly, nutrient impacts, considering nitrogen and phosphorus levels in soil and water, are nearly imperceptible globally. The ROW exhibits the largest increase in nutrient loading, whereas the LATAM region experiences a minor reduction, although both changes are quantitatively small (see Figure 15d). Together, these results suggest that the following CI leads to meaningful reductions in GHG emissions in the LATAM region while maintaining stability in other environmental indicators across regions. The modest changes in land use and nutrient loading further indicate limited adverse environmental impacts associated with the intervention.



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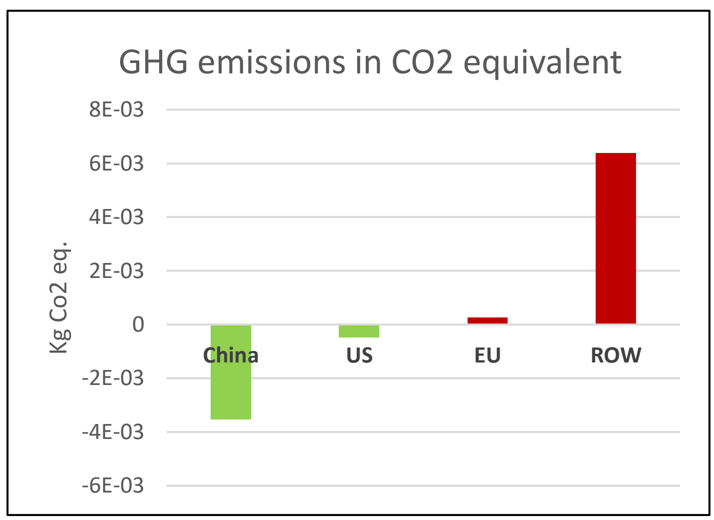

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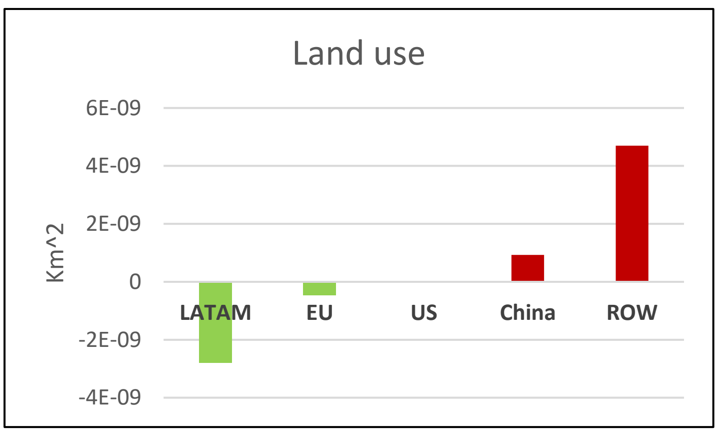

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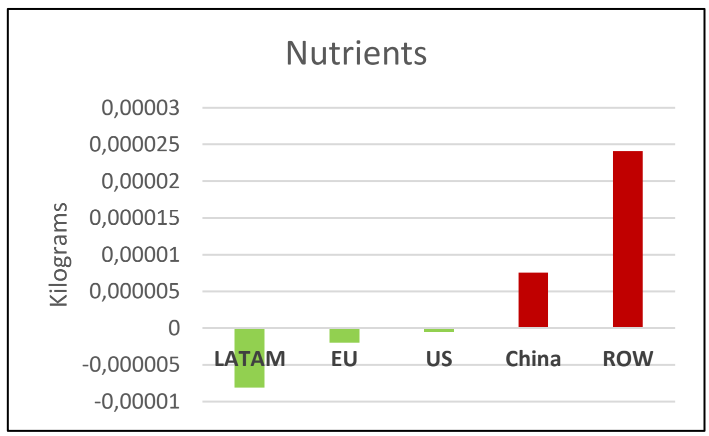


d)

Figure 15: Environmental impacts of CI "b. Resource Use Efficiency - Organic Waste Management", Costa Rica

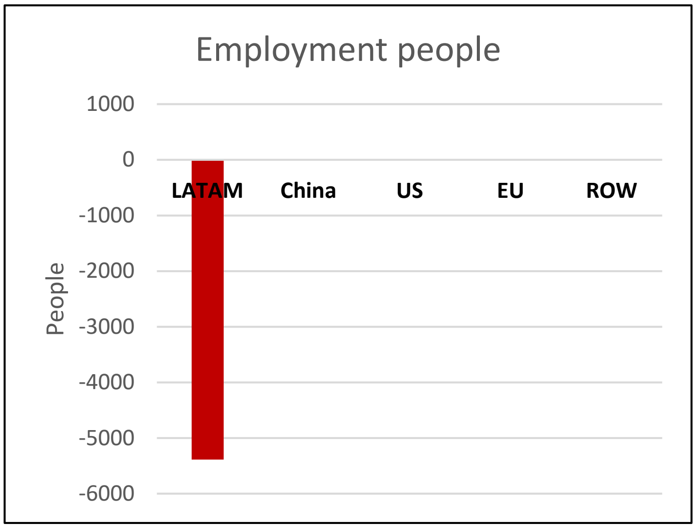
Panels (a) and (b) show greenhouse gas (GHG) emissions, with (a) representing the LATAM region on a larger scale and (b) depicting a smaller scale. Panel (c) illustrates land use changes, which remain minimal across regions, with the most notable increase observed in the Rest of the World (ROW). Panel (d) presents nutrient loading (nitrogen and phosphorus) impacts, which are nearly imperceptible globally, showing a slight increase in the ROW and a minor decrease in LATAM.

5.4.1.2. Socio-economic impacts

The scenario analysis estimates the regional socio-employment impacts of CI d.Value Chains from Costa Rica's national strategy.

The projected employment change in the LATAM region is substantial enough that two separate figures were needed to properly capture and visualize both the major and minor variations across regions. Figure 16a shows a negative employment effect in LATAM, with a projected loss exceeding 5,000 jobs. In contrast, employment impacts in other regions are minimal, with the second-largest change being a very small increase in the Rest of the World (ROW), on the order of 10^{-6} (see Figure 16b).

Regarding economic value, the model estimates the regional impact on Value Added using indicators derived from EXIOBASE 3's 'Factors of Products' matrix (matrix v) (see Table 12, Appendix B). Figure 16c illustrates a nearly imperceptible increase in Value Added within LATAM. Conversely, the EU and ROW experience slightly more noticeable increases, while China and the US show marginal decreases. All these changes are quantitatively minor, with values on the scale of 10^{-8}, indicating limited economic shifts as a result of this CI.



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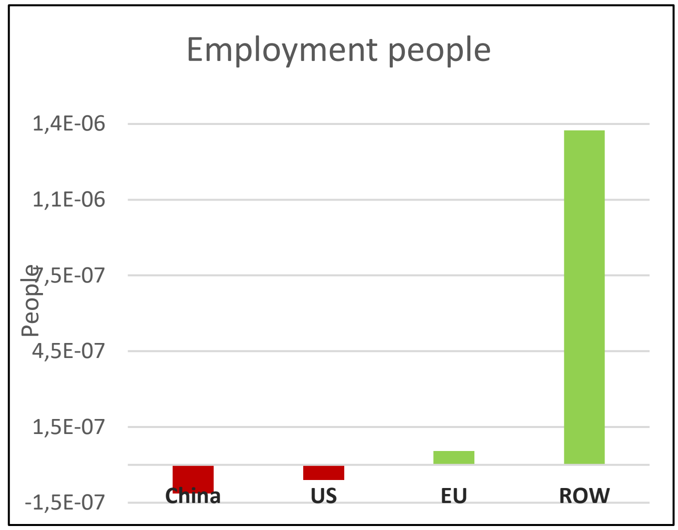

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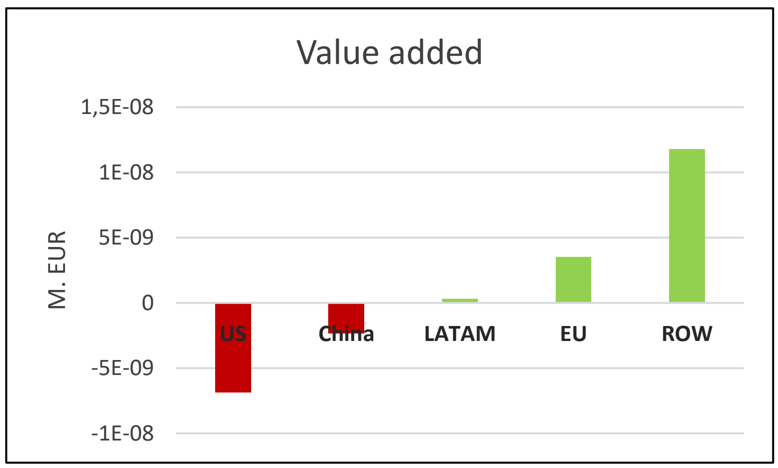


c)

Figure 16: Socio-economic impacts of CI "b. Resource Use Efficiency - Organic Waste Management", Costa Rica

(a) Employment impacts by region shown at a larger scale, highlighting the significant employment loss in the LATAM region (b) Employment impacts by region at a smaller scale, revealing minor employment changes in other regions including a slight increase in the ROW (c) Regional Value Added impacts, illustrating minor increases in the EU and ROW, a slight increase in LATAM, and marginal decreases in China and the US.

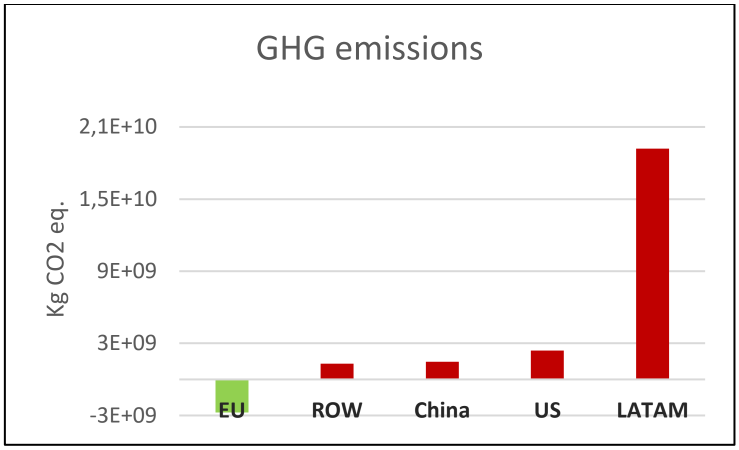
5.4.2 d.1 Plastics recycling, Uruguay

5.4.2.1 Environmental impacts

The model projects that the intervention of replacing virgin plastic with secondary plastic leads to an increase in greenhouse gas (GHG) emissions, with the most significant impact observed in the LATAM region. The projected increase in GHG emissions for LATAM amounts to approximately 19.2 billion kilograms of CO2 equivalent. The United States, China, and the Rest of the World (ROW) also experience smaller but substantial increases ranging between 1.3 and 2.4 billion kilograms of CO2 equivalent. Overall, these results indicate noteworthy environmental impacts attributable to the intervention (see Figure 17a).

Regarding land use, the Uruguayan CI is projected to have a negative effect. Specifically, the required land in the LATAM region is estimated to increase by approximately 1,300 km^2, an area comparable to that of a major city. Other regions demonstrate minimal or negligible changes in land use, indicating that the effect is largely localized within LATAM (see Figure 17b).

The intervention's impact on nutrient loading, assessed in terms of nitrogen and phosphorus in both water and soil, reveals an increase in the LATAM region estimated at about 42.3 million kilograms. Other regions also show increases, albeit at lower magnitudes, ranging from nearly zero in the EU to approximately 4.3 million kilograms in China (see Figure 17c).



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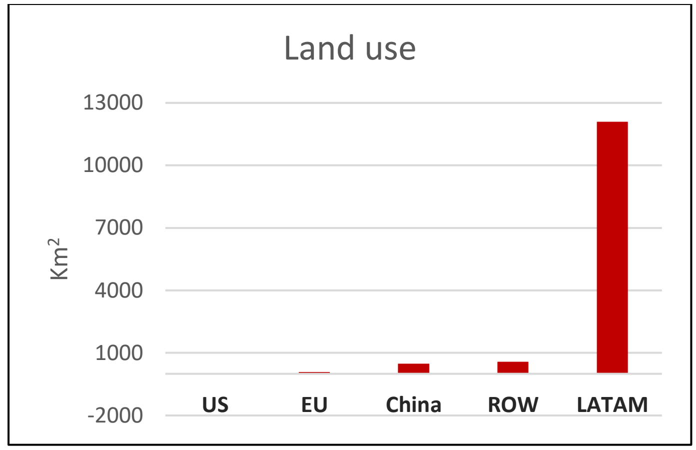

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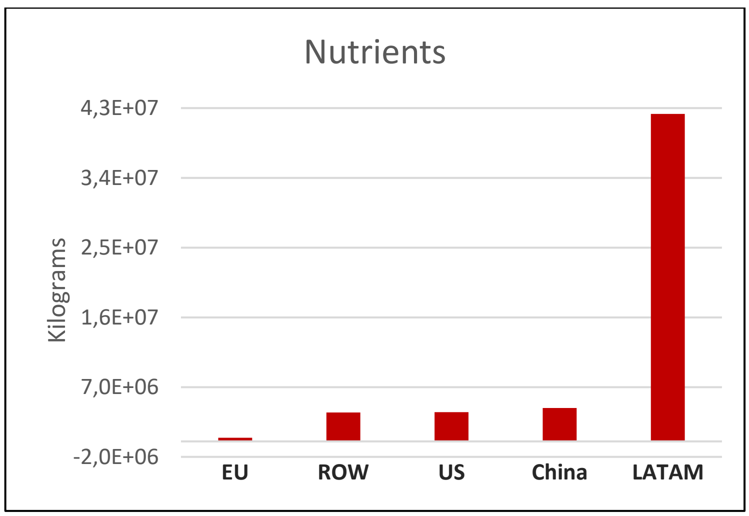

c)

Figure 17: Environmental impacts of CI d.1 Plastics recycling, Uruguay

(a) Greenhouse gas (GHG) emissions increase by region, highlighting a major increase in the LATAM region and substantial increases in the US, China, and Rest of the World (ROW). (b) Land use change by region, showing an increase in LATAM, with other regions exhibiting negligible changes.(c) Nutrient loading in water and soil, with LATAM experiencing a notable increase and smaller increases observed in other regions.

5.4.2.2 Socio-economic impacts

The model estimates the impacts of the analysed CI within Uruguay's national strategy on Value Added, based on the variables that determine value added as described in Table 12. As illustrated in Figure 18b, the most significant changes occur in the LATAM region, where Value Added is projected to increase substantially by approximately 10,000 million EUR. Other regions are also expected to experience growth, though on a smaller scale, with increases ranging from 500 to 3,000 million EUR.

Regarding employment impacts, the model projects a substantial change in the LATAM region, estimating a shift of approximately 20 million jobs as a result of Uruguay's CI. Notably, the LATAM region is the only one to experience a significant employment effect; other regions are either minimally or not affected by this intervention (see Figure 18a).

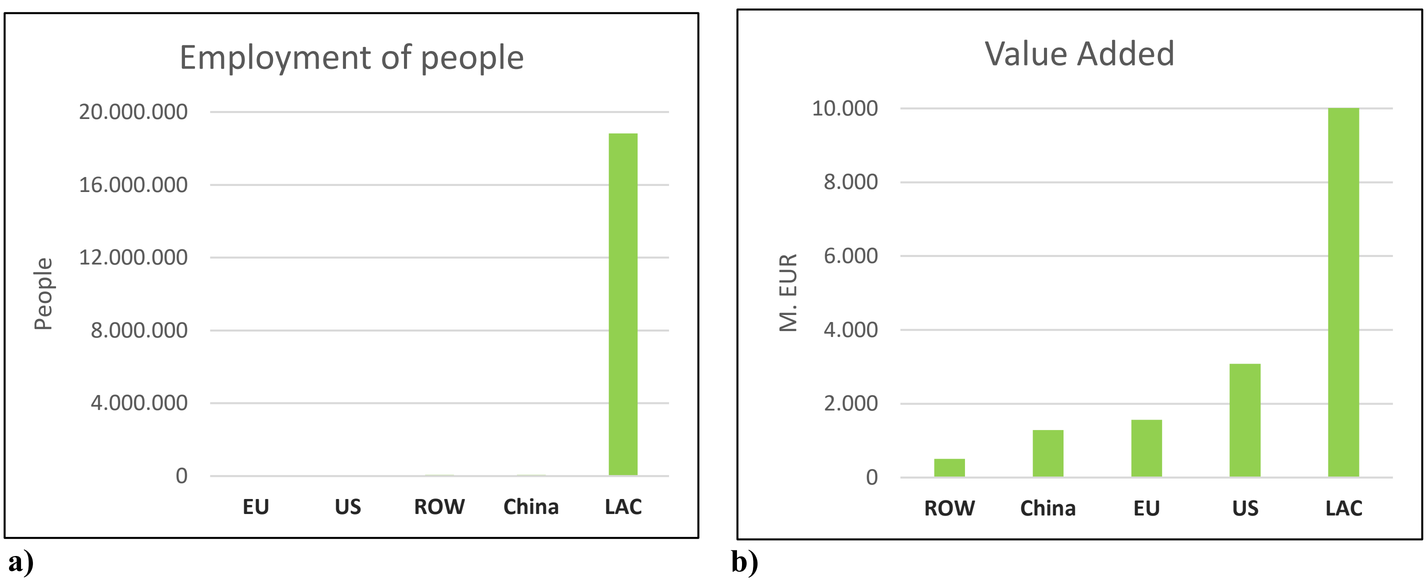

Figure 18: Socio-economic impacts of CI d.1 Plastics recycling, Uruguay

(a) Employment impacts by region, showing a significant increase of job creation in the LATAM region, with minimal changes in other regions (b) Value Added changes by region, with LATAM exhibiting the largest increase and other regions showing smaller but positive growth.

6. Discussion

This chapter interprets the key findings of the study on nine CE interventions in Costa Rica and Uruguay and explores their broader implications. It is structured into three sections for clarity and coherence. First, Section 6.1. Key findings summarizes the environmental and socio-economic impacts identified, framed through the DE lens. It evaluates the validity of the findings by cross-examining qualitative insights and MR-EEIOA quantitative results, addressing the main research question regarding the broader regional and global relevance of these interventions.

Next, 6.2. Considerations for Circular Strategies in Latin America discusses challenges revealed by the comparative analysis of national CE policies. It highlights issues such as policy vagueness, limited regional adaptation of global models, and the overlooked role of the informal economy, emphasizing the need for context-specific and transparent strategies.

Finally, 6.3. Modelling Limitations & Further Research acknowledges the constraints inherent in the mixed-methods approach, including data gaps and modelling assumptions that affect robustness. This section outlines avenues for methodological improvements and future research to enhance CE impact assessments in Latin America.

Together, these sections provide a comprehensive perspective linking empirical evidence with policy and methodological reflections to inform future CE development in the region.

6.1. Key findings

This section analyses the environmental and socio-economic impacts of CE interventions in Costa Rica and Uruguay. It begins by summarizing key findings that highlight observed benefits in emissions reduction and socio-economic gains across various sectors using the DE framework terminology. The interpretation subsection then assesses the reliability of these findings by comparing qualitative analysis with MR-EEIOA outcomes, while also pointing out limitations. Following this, the section addresses the main research question regarding the potential regional and global implications of these interventions, bridging national and broader-scale perspectives. Literature comparisons are integrated throughout, especially within the interpretation and main research question discussions, contextualizing this study within broader CE impact assessments in Latin America and the Caribbean.

6.1.1. Overview of results

As the results from

Table 9 and

Table 11 show, both Costa Rica and Uruguay's CIs have environmental impacts primarily addressing climate change emissions, biodiversity loss, nutrient loading, and land conversion. These critical environmental challenges are closely linked to their continued reliance on landfilling and linear waste management practices. Landfilling generates significant methane emissions, occupies land vital for biodiversity, and contributes to nutrient runoff and soil degradation, thereby exerting strong pressure on the ecological ceilings outlined in the DE framework.

6.1.2. Interpretation of results

6.1.2.1 Environmental Impacts

Waste-focused CIs form a key focal area in the national CE agendas of both Costa Rica and Uruguay. In Costa Rica, qualitative analysis reveals that three of the five selected interventions target organic waste and composting, specifically: b. Resource efficiency, d. Value Chains enhanced by bio-digestion and soil recarbonization technologies, and the development of e.2 Compostable products (see Table 8). This emphasis clearly demonstrates the government's acknowledgment of composting's significant potential to reduce organic waste volumes and lessen environmental impacts. These interventions primarily target organic waste reuse, resulting in notable overlaps as they address similar challenges across multiple implementation levels without clear integrated coordination. They function as interconnected facets of the same process operating synergistically: b. Resource efficiency drives d. Value Chains, which in turn drives e.2 Compostable products. Indeed, promoting value chains facilitates the production of compostable products, which reduces organic waste sent to landfills, thereby lowering methane emissions and fostering circularity. Each intervention's outcome propels the next, presenting a comprehensive yet somewhat fragmented approach to organic waste management. Among these, the organic waste composting intervention b. Resource efficiency (See Table 8) stands out as having the highest expected intensity impact in Costa Rica. This is due to the large organic waste stream, the ambitious target to reduce organic waste by 50%, and the expansion of related infrastructure. Expected outcomes include reductions in fertilizer imports and greenhouse gas emissions, as well as the creation of decent work opportunities spanning waste collection, compost production, and distribution. Beyond organic waste, Costa Rica's CIs also include targeted efforts on residual waste management, particularly the reduction of plastic waste and the promotion of products made from renewable sources. Notably, the "a. Residuals" intervention (See Table 8), which focuses on plastics, shows limited additional environmental efficacy. Its initial target - to halve plastic waste from 20% to 10% - was nearly achieved by 2018. Current plastic recycling rates hover near 12%, indicating the need for more ambitious targets, potentially aiming for the complete elimination of plastic waste to drive further progress. Despite historically low recycling rates, Costa Rica's recycling infrastructure is among the most advanced in the country, with projections anticipating growth through 2030 (OECD, 2025). Continued development of recycling infrastructure is thus fundamental to achieving impactful CE outcomes

Uruguay's CE interventions similarly emphasize the reuse of food and construction materials, recognizing these as having the greatest potential for positive environmental impacts due to their substantial waste contributions. The "c.2 Food re-use" intervention (See Table 10) stands out as the highest-impact CI in Uruguay, with a medium expected intensity that reflects the significant volume of organic waste it addresses. This intervention is anticipated to reduce nitrogen and phosphorus loading while generating circular employment opportunities. However, detailed information on construction material recycling is limited, likely because of the sector's heterogeneity - comprising concrete, wood, metals, glass, and aggregates—which complicates precise assessments of the necessary infrastructure and socio-economic impacts. The report *Circular Built Environment—Highlights from Latin America and the Caribbean* (Penagos et al., 2021) offers valuable insights from diverse regional circular construction solutions that could effectively inform Uruguay's national strategies. In addition to organic and construction materials, plastics and paper recycling initiatives contribute to reducing land use pressures and decreasing dependency on imports (See d.1 Plastics recycling and d.2 paper recycling at Table 10). However, data from 2023 indicate that Uruguay sources much of its plastic and paper raw materials from imports, primarily from major LATAM producers such as Brazil and Argentina (Trading Economics, 2023d; Uruguay XXI, 2023). Consequently, the environmental benefits of recycling these materials are often enhanced abroad by avoiding impacts from production in countries that export to Costa Rica. This transnational dimension emphasizes the need for coordinated national and regional policies within Latin America to maximize the environmental benefits and overall circularity of these interventions. However, these findings require cautious interpretation. Notably, the MR-EEIOA modelling of Uruguay's plastic recycling intervention (See d.1 Plastics recycling at Table 10) suggests environmental impacts such as increases in greenhouse gas emissions, land use, and nutrient depletion, occurring alongside rises in employment and value added for the broader LATAM region. This contrasts with the positive environmental impacts suggested by qualitative analyses for Uruguay alone. Such discrepancies point to methodological challenges or data limitations, underscoring the importance of further research to understand divergent results - especially given the global consensus that plastics recycling generally contributes positively to reducing greenhouse gas emissions (Nicholson et al., 2021).

6.1.2.2 Socio-economic impacts

From a socio-economic standpoint, all the analysed interventions are projected to yield exclusively positive outcomes. However, broader literature cautions against over-optimism. The report by the Circular Economy Coalition for Latin America and the Caribbean (2022) highlights significant socio-economic opportunities but also warns of risks, including the displacement of informal workers and inequitable access to emerging circular jobs. Approximately 50% of the region's recycling stems from about two million informal workers, a crucial demographic often overlooked in official projections. Furthermore, a 2023 report also emphasizes that small and medium-sized enterprises, which dominate LATAM's waste-related industries, often have low productivity - potentially slowing job creation and income growth unless supported by systematic and collaborative development efforts (UN Environment Programme, 2023). While waste-related interventions provide benefits for diverse groups such as waste pickers, composters, recyclers, and renewable energy workers, this uniformly positive outlook contrasts with literature that points to transitional challenges, including job displacement, market shifts, and social inequities, especially in informal economies (Geissdoerfer et al., 2017; Kirchherr et al., 2017). The absence of negative social impact modelling could underline the need for integrating qualitative fieldwork to capture complex social realities better.

Furthermore, the MR-EEIOA scenario analyses for Costa Rica's CIs reveal nuanced results. For example, the modelled promotion of higher re-use of food waste (See b. Resource Use Efficiency - Organic Waste Management at Table 8) shows environmental benefits like reduced greenhouse gas emissions, lower land use, and decreased nutrient depletion across LATAM (See Figure 15). However, employment and value-added effects appear muted or even negative, perhaps reflecting job losses in linear waste sectors not offset by gains in bio-based circular industries. It is important to consider that the qualitative analysis primarily focuses on national-level impacts, whereas the

MR-EEIOA captures regional ones, making direct comparisons complex yet insightful. Notably, the MR-EEIOA model represents LATAM as a proxy composed mainly of Mexico and Brazil - two countries that predominantly rely on landfilling for waste disposal. According to a MRIO research assessing waste management in LATAM countries by Esteves et al. (2024), composting could offer considerable socio-economic benefits by reducing landfill pressure and creating jobs. In In Brazil, the research found that activities that aim to replace landfill disposal systems with circular waste management can lead to strong employment outcomes, with estimates of approximately 20.4 direct and indirect jobs created per $1 million invested in waste-related sectors. Composting is considered part of these improved waste management strategies, contributing to this positive job creation dynamic, although specific multipliers for composting alone are not always provided. Research indicates that improvements in waste management in Mexico - including composting practices - are recognized as key strategies to reduce landfill use and stimulate employment, consistent with observed trends in other LATAM countries. This evidence supports the conclusion that the socio-economic impacts observed or expected in Costa Rica could be similar LATAM countries that were used as proxies in the EXIOBASE 3 MR-EEIOA model. However, despite expectations of comparable employment outcomes, the MR-EEIOA results differ significantly from qualitative analyses in some respects. These discrepancies suggest that further research is needed to understand the causes behind the contrasting results between regional MR_EEIOA models and national-level qualitative assessments. Such investigation is crucial for refining the accuracy and reliability of MRIO models like EXIOBASE 3 when applied to countries with limited detailed input-output data.

6.1.3. Answer to main research question

This section discusses whether the thesis answers the research question: What are the socio-economic and environmental impacts of Costa Rica and Uruguay's national CE interventions at a regional (LATAM) and global scale?

The analysis confirms that the CIs in Costa Rica and Uruguay generate positive environmental impacts, notably in reducing climate change emissions, biodiversity loss, nutrient loading, and land conversion - challenges closely tied to prevalent landfilling and linear waste management practices. Socio-economic benefits also emerge, including job creation and value addition across several waste-related sectors. However, these observed impacts primarily reflect the national level, given that the qualitative analysis mainly focuses on country-specific contexts.

Some of the environmental benefits demonstrated at the national level may be generalizable across the LATAM region due to shared resource constraints and ecological challenges (OECD, 2023). For example, reductions in raw material imports and pollution achieved through CIs in individual countries can cumulatively lessen the region's overall ecological footprint. Import and export data indicate that Costa Rica and Uruguay mainly trade within the LATAM region (Uruguay XXI, 2024a), so reductions in raw material imports through circular strategies - such as those observed in paper and plastics recycling - are likely to positively impact regional supply chains and potentially strengthen the broader LATAM CE. However, it should be noted that results from the MR-EEIOA show contrasting environmental outcomes at the regional level, suggesting complexity in accurately capturing regional environmental impacts through quantitative modelling.

Socio-economic impacts are more complex to generalize regionally compared to environmental impacts, as their transmission depends on intricate economic linkages, including trade, labour mobility, and investment flows that vary widely between countries.

Consequently, the thesis leverages MR-EEIOA to assess these impacts at a broader regional and global level. MR-EEIOA helps capture cross-border economic interdependencies and environmental spillovers that qualitative national analyses cannot fully encompass, thereby providing a fuller understanding of how CE interventions influence both local and multi-country systems.

In particular, MR-EEIOA models represent LATAM largely through proxies such as Mexico and Brazil. For instance, if circular waste management strategies - including composting - in Brazil are associated with substantial socio-economic benefits such as job creation (with estimates around 20.4 direct and indirect jobs per $1 million invested), and Mexico similarly recognizes improvements in waste management, including composting, as critical for reducing landfill reliance and fostering employment growth, then it is reasonable to generalize that similar socio-economic impacts could occur broadly across LATAM.

On a global level, the CE interventions analysed exhibit subtle but important spillover effects beyond the LATAM region. For Costa Rica's intervention about Resource Use Efficiency through circular food waste, greenhouse gas emissions slightly decrease in China and the United States, while the European Union and the Rest of the World experience minor increases. Land use and nutrient loading fluctuations remain negligible, demonstrating limited environmental impact outside LATAM. Socio-economic changes are minimal, indicating stable employment and economic value in these regions.

Uruguay's plastics recycling reveals moderate increases in GHG emissions in China, the US, and the Rest of the World, accompanied by slight rises in nutrient loading, particularly in China. Though land use changes remain localized in LATAM, economic benefits such as value added growth appear modestly in the EU and ROW, with employment impacts outside LATAM being minimal.

On a global level, the CE interventions studied show small but important effects beyond the LATAM region. For example, Costa Rica's value chains intervention results in slight reductions in greenhouse gas emissions in major economies like China and the US. At the same time, Uruguay's plastics recycling causes an increase in nutrient pollution in regions far from LATAM, like China and the Rest of the World. These examples highlight that while LATAM is the main area affected, CE policies can cause environmental and economic changes worldwide and the importance of coordinated international efforts to address global sustainability challenges.

However, quantitative MR-EEIOA results sometimes diverge from qualitative national assessments. This divergence highlights the complexities of modelling socio-economic impacts across diverse economic structures, data limitations, and regional variations. These differences emphasize the need for further research to reconcile quantitative and qualitative approaches and to improve modelling accuracy, especially for countries lacking detailed input-output data. Such refinement is essential for providing more reliable assessments to support CE policies at regional and global scales.

6.2. Considerations for Circular Strategies in Latin America

This discussion presents key challenges and considerations identified in the implementation of CE national strategies in Latin America and the Caribbean, drawing on the detailed analysis of national CIs in Costa Rica and Uruguay. The analysis highlights common issues of vagueness in policy commitments, the prevalence of imitative strategies that reflect Global North models with limited local adaptation, and the significant role of the informal economy, which remains largely unaccounted for in official data and assessments. These factors collectively underscore the importance of clearer, context-sensitive policy design and the recognition of uncertainties tied to specific regional economic and social conditions. The following subsections examine these themes - policy vagueness, strategic development gaps, and the informal sector's impact - in relation to specific interventions and their observed implications.

6.2.1. Vagueness of CIs in circular strategies

This research project faced limitations due to the vague nature of CIs in the national strategies. Vagueness is defined as the use of broad or ambiguous language that lacks clear and actionable guidance. This vagueness was particularly evident in the analysed CIs that referred to general goals such as improving material flows without detailing how these flows would be tracked or measured across various economic dimensions (Wardeberg et al., 2024). For example, Costa Rica's "d. Value Chains" intervention aims to "promote a CE system considering bio-digestion, soil recarbonization, technologies, and other strategies by 2025". However, this language is vague. Terms such as "promote," "use of technologies," and "among other strategies" lack quantitative targets and fail to specify baselines or success criteria. This lack of specificity complicates impact assessment by obscuring what exactly should be measured. Policy evaluators cannot determine the expected soil organic carbon increase, nor clarify which technologies are targeted, undermining the ability to attribute observed outcomes directly to policy interventions. Table 13 and Table 14 (See Appendix B) further highlight vagueness issues across the CIs that the study analysed, ranging from unclear reduction pathways for plastic waste, imprecise targets for construction materials use, to broad goals in water circularity and material reuse. Vagueness of CIs not only constrains assessment but also signals challenges in policy design and implementation. Without specific, measurable, and time-bound targets, policymakers and stakeholders may struggle to align resources, monitor progress, and adjust strategies effectively. This imprecision risks reducing policy coherence and limits accountability, which is particularly critical in LATAM countries where capacity for monitoring and enforcement may be constrained (Losa, 2025). In other global CE contexts, such regulatory and policy vagueness has been linked to fragmented implementation and barriers for CE development (EU, 2018). Consequently, impact assessments rely on assumptions to interpret these broad goals, resulting in inconsistent methodologies and undermining the ability to attribute observed outcomes directly to policy interventions.

6.2.2. Less developed strategies and roadmaps in LATAM compared to Global North

When it comes to a CE, countries in the Global South often try to imitate the strategies of the Global North (Wieczorek, 2018). This approach, however, has proven to be slow and can even be counterproductive (Barrie et al., 2022). Many policies in the Global South focus on building basic waste management infrastructure - things like municipal waste collection, recycling facilities, and training for waste workers - to meet the standards of wealthier nations. This strategy of catching up with the Global North can be harmful. Due to existing structural disparities and inequalities, lower-income countries may struggle to keep pace with CE implementation (Haswell et al., 2024). For example, countries like Costa Rica and Uruguay aim to reduce waste by promoting recycling and composting. Yet, they often set these goals without first assessing if it's even feasible to systematically implement these new systems. As a result, they may be trying to adopt policies that are more difficult and less beneficial in their specific context.

For example, Costa Rica and Uruguay's CIs promote recycling and composting, yet the analysis found that feasibility challenges remain, including limited waste collection coverage and informal sector dynamics that complicate systematic implementation. Thus, despite ambitious targets, there is a risk that adopting policies modelled on Global North frameworks without sufficient local adaptation weakens their effectiveness and socio-environmental benefits. In this regard, it is important to incorporate an uncertainty level in interpreting results to account for such context-specific constraints.

6.2.3. Informal economy

The informal economy is a significant characteristic of the LATAM region. Developing economies typically have a more fragmented private sector and a considerably higher share of informal-sector employment than advanced economies (Chatman House, 2019). In fact, the OECD estimated that over half of LATAM workers were in the formal economy in 2022 (Circular Economy Coalition, 2022; OECD, 2024), while ECLAC projected the informal employment rate to be 46.7% in 2024 (ECLAC, 2024b). The OECD's analysis further indicates that the informal economy in LATAM is present across various sectors, including services, micro-enterprises, and small-scale trading. Its contribution to the region's GDP is substantial, estimated at 34% (UNPD, 2023).

The significant presence of the informal economy is a crucial limitation of this study, as a large portion of economic activities, especially those conducted by informal workers and micro-enterprises, is not captured in official data and thus excluded from this assessment. Consequently, the results of this study underestimate the true scale and socio-economic impact of CIs in the region. This exclusion limits the ability to fully represent how circular strategies affect vulnerable populations heavily reliant on informal employment and may overlook important material flows and economic activities occurring outside formal channels.

Interventions focusing on waste management, recycling, and composting are particularly affected, given the essential role of informal actors in these sectors, whose activities and associated material flows frequently elude formal statistical capture. This exclusion restricts the ability to fully represent the effects of CIs on vulnerable populations heavily dependent on informal employment. This limitation was acknowledged during result interpretation, where the role of informal actors was identified as a fundamental factor influencing intervention feasibility and measured outcomes. Comprehensive integration of the informal economy is essential for future assessments, to better encompass the complexity and equity of CE impacts in LATAM countries.

6.2.4. Data and Methodology Challenges for CE in LATAM

The study findings revealed notable methodological differences between Costa Rica and Uruguay in assessing circular economy interventions. Uruguay utilized a Material Flow Analysis (MFA) to identify critical resource flows within its economy (Caribe, 2024). In contrast, Costa Rica prioritized assessment based on sectoral contributions to GDP, linking these to greenhouse gas emissions (ENEC, 2023). This discrepancy reflects a broader regional challenge: LATAM countries employ diverse methodologies and data collection practices, yet lack standardized approaches. This methodological heterogeneity complicates the identification of regional trends and cross-country comparative analyses.

For cross-country comparison to be meaningful, harmonization of country profiles, data types, temporal periods, classification systems, and data sources is essential. However, achieving this harmonization is more complex than anticipated in the LATAM context. While some countries maintain distinct national classification systems- such as Brazil with its National Classification of Economic Activities (CNAE) and Mexico with the North American Industry Classification System (NAICS) (ECLAC, 2023b) - Costa Rica and Uruguay have adopted economic classification frameworks aligned closely with international standards like ISIC Revision 4 and the System of National Accounts (SNA-2008) (IMF, 2014; OECD, 2019). This alignment facilitates better internal consistency for both countries when analysing economic indicators.

Nonetheless, despite Costa Rica and Uruguay's adherence to these standards, discrepancies in data classification still arise across the region due to differing national adaptations and implementation lags. These differences manifest in how export categories and sectoral data are compiled and reported in regional input-output tables and economic statistics maintained by organizations such as ECLAC. Therefore, while harmonization is relatively more advanced in Costa Rica and Uruguay, the broader regional landscape remains heterogeneous. This complicates comprehensive cross-country comparisons and calls for continued efforts to strengthen data standardization and integration throughout Latin America and the Caribbean.

Moreover, detailed data concerning waste or material flows is scarce, with most indicators limited to sectors with significant GDP contributions. This gap highlights the urgent need for enhancing statistical systems to move beyond conventional economic productivity metrics and better capture CE dynamics.

Consequently, future research should prioritize the development of harmonized frameworks and guidelines for CE assessments across Latin America and the Caribbean. This includes standardized methods for data collection and impact measurement, enabling robust regional analysis of circularity. Notably, a roadmap for CE development tailored to the region has been formulated (Coalición de Economía Circular, 2025). Nevertheless, this roadmap underscores ongoing needs: capacity building and cross-country collaboration are crucial to establish consistent and rigorous assessment frameworks, facilitating effective policy implementation and advancement of CE initiatives.

6.3. Modelling Limitations & Further Research

This research employs a mixed-methods approach to evaluate the impacts of CE strategies in Costa Rica and Uruguay. Utilizing EEIOA, it quantitatively estimates the potential effects of two CIs - one from each country - selected from the nine studied qualitatively. The modelling complements insights drawn from qualitative analyses of national strategies. This discussion section acknowledges key limitations affecting the robustness of this integrated approach, including data constraints, modelling assumptions, and challenges in integrating qualitative and quantitative findings.

6.3.1. Scope limitation of the qualitative analysis

A key limitation of this study is its reliance on qualitative data collected primarily at the national level. While the impact assessment based on this data is robust and reliable for national-scale effects, its applicability to the LATAM regional context remains limited. Environmental impacts, such as increased material and waste circularity, can reasonably be expected to benefit the country's environment and, by extension, potentially produce a net positive effect regionally, especially considering shared resource constraints and ecological challenges across the LATAM region (OECD, 2023). However, the complexity of socio-economic dynamics - including social interactions and cross-border economic linkages - complicates the generalization of socio-economic outcomes from individual countries to the wider LATAM region (UNECE, 2024). Therefore, the third sub-research question is only partially addressed by the qualitative analysis alone. More precise and reliable insights into socio-economic impacts are attainable through MR-EEIOA modelling, which explicitly considers interregional trade and economic linkages. The results of the two modelled interventions presented in Section 5.4 exemplify this, providing a deeper understanding of regional-scale dynamics and complementing the qualitative findings.

6.3.2. DE in the context of a country-level qualitative analysis

The DE has been employed as a conceptual lens to analyse the anticipated impacts of CIs in both countries, offering a comparative framework grounded in the general principles of the Doughnut model. This approach benefits from the robust scientific foundation of ecological ceilings, which are based on the planetary boundaries concept (Steffen et al., 2015) and provide well-defined environmental limits to guide policy assessment.

However, it is important to recognize that ecological ceilings themselves are not universally fixed and are subject to varying definitions and interpretations. Different studies may emphasize distinct Earth system processes, adjust threshold values according to local or regional environmental conditions, or adopt alternative metrics for assessing ecological impact (Shao, 2025). This variability reflects the complexity of scaling planetary boundaries concepts to diverse geographic and socio-political contexts, leading to multiple operationalizations of what constitutes a "safe" ecological ceiling.

In contrast to ecological ceilings, the social foundations within the DE framework remain more ambiguous and less concretely defined. Raworth and Oxfam illustrate social foundations through domains such as food, water, health, education, and equity, but these examples do not represent exact or universally agreed-upon definitions. The flexibility inherent in the framework facilitates its adaptation across diverse contexts but also introduces considerable variability in interpretation and measurement.

In this study, ecological limits are defined based on planetary boundaries science, while social foundations draw on Raworth's (Raworth, 2012) conceptualizations. However, this approach may differ from those used in other research, which reduces the framework's strength in reliably comparing impacts across countries and contexts. Consequently, while the DE facilitates cross-country comparative assessments, particularly on ecological dimensions, it still lacks a universally accepted taxonomy or precise metrics for social impact evaluation, reflecting the evolving and interpretative nature of the social foundation construct.

6.3.3. Resolution of the system

This subsection highlights the limitations posed by sectoral, regional, and temporal resolution in input-output tables, which significantly affect the precision of modelling CE interventions. It outlines the challenges inherent in applying MR-EEIOA to countries and sectors where data availability is limited.

6.3.3.1. Regional resolution

The MR-EEIOA modelling for this research was conducted using the EXIOBASE 3 database. Since this database does not include all countries, it was not possible to perform a country-specific analysis on the impacts of CIs in Costa Rica and Uruguay. This limitation led to a shift in the research focus, with the analysis being conducted at a regional level for the LAC area.

Furthermore, the LAC regional aggregation does not include all countries in the region. Instead, the analysis is limited to the available data for Brazil, Mexico, and ROW WL (Rest of the World Latin America), which aggregates several unspecified countries. Therefore, even at the regional level, the study has important limitations that affect the final results.

6.3.3.2. Temporal resolution

The EXIOBASE 3 3 IOTs are a valuable resource, but they present a limitation in their temporal resolution. While the tables are primarily based on real data up to 2020, data from 2020 onwards are nowcasted or projected. Although the EXIOBASE 3 3 model provides projections up to 2022, the most reliable data currently remains up to 2020 due to the uncertainties in economic conditions during the pandemic and the inherent limitations of nowcasting beyond that period. Given the temporal limitations of the EXIOBASE 3 3 data, the analysis for this study was conducted using

IOTs from 2020. Consequently, this research does not fully account for the significant economic changes caused by the COVID-19 pandemic.

6.3.3.3 Sectoral resolution

While the EXIOBASE 3 database is a highly detailed resource, encompassing 163 industry sectors and around 200 product categories per country, it has limitations that can impact the analysis of CIs. One key issue is its lack of detailed sectoral representation. The database primarily models formal sectors and may not adequately capture informal and micro-scale activities, which are often crucial for CE models, especially in developing regions. Furthermore, the existing sectors may not be granular enough to distinguish between recycling, reuse, and waste collection activities, making it difficult to precisely trace circular flows.

Another limitation is the aggregated nature of institutional flows. The data often lacks fine detail on interactions involving households, governments, and non-market institutions, which can hinder the analysis of their specific material use and consumption patterns.

6.3.4. Modelling assumptions

The MR-EEIOA model contains a set of assumptions that cause several limitations. The technical coefficients and market penetration rates used to generate the modelling results (See section 5.4) are based on these assumptions, which introduce significant uncertainty. The technical coefficient change represents an intervention's maximum potential impact, while market penetration indicates the proportion of actors expected to adopt it. In Costa Rica, the quantitative targets from the national circular strategy were used to inform most technical coefficient changes; however, the market penetration rates were assumed due to a lack of specific guidance. In Uruguay, both the technical coefficients and market penetration rates had to be assumed because the national circular strategy did not provide quantitative targets specific enough to estimate the magnitude of such parameters. This lack of specificity in the national strategies regarding measurable intervention impacts necessitated reliance on assumptions, which contributes to higher uncertainty in the model's outcomes. Furthermore, the model makes additional assumptions increasing complexity: it assumes that the market penetration rate for an intervention's primary effect is equivalent to the rate observed for any resulting secondary changes, and that the geographical distribution of a sector's imports to Costa Rica or Uruguay will remain constant after the intervention.

6.3.5. Suitability of MR- EEIOA for assessing impact of CE interventions

It remains unclear whether MR-EEIOA is fully suited to assess CE interventions in the manner applied in this case. The research models a scenario based on the monetary input-output table used in MR-EEIOA, which captures flows in monetary terms across sectors. Alternatively, MR-EEIOA can be conducted using Physical Input-Output Tables (PIOTs). PIOTs quantify flows of materials, energy, or emissions exchanged between sectors in physical units (e.g., kilograms or tons) rather than monetary values. These physical tables can then be environmentally extended to directly link economic activities with resource use and emissions measured in physical terms. This approach provides a more direct and tangible connection between economic activities and environmental impacts, overcoming some of the limitations inherent to monetary valuations that can sometimes obscure the physical realities underlying CIs. However, developing PIOTs demands significantly more detailed data and entails higher costs and time investments. While PIOTs might better capture the complex dynamics and multidimensional impacts of CE interventions, the effort required to build such detailed physical tables would be prohibitive within the scope of this research (Wachs & Singh, 2018). Thus, despite its limitations, employing monetary-based MR-EEIOA remains a more practical choice given current data and resource constraints.

7. Conclusion and Recommendations

This thesis answers the central research question by demonstrating that Costa Rica and Uruguay's national CE interventions produce meaningful socio-economic and environmental impacts at regional (LATAM) and global scales. The subsequent sections provide a detailed synthesis of the key findings, highlight existing challenges, and propose pathways for advancing CE assessment and policy development in Latin America.

7.1 Key Findings

This thesis sought to answer the question: What are the socio-economic and environmental impacts of Costa Rica and Uruguay's national CE interventions at regional (LATAM) and global scales?

The findings affirm that these national CIs generate positive environmental impacts, including mitigation of climate change emissions, reduction of biodiversity loss, nutrient loading, and land conversion pressures. These benefits are particularly tied to addressing the region's dependence on linear waste management practices such as landfilling. Socio-economic advantages are also evident in increased employment and economic value-addition within organic waste management, recycling, and renewable energy sectors.

However, it is important to note that while the findings are generally positive, the expected intensity of most of the impacts from CIs is not significant when evaluated against specific criteria: (i) the relevance of the targeted material flow for each intervention; (ii) the presence of clear policy targets, where applicable; and (iii) the level of development of the infrastructure required for effective implementation. This indicates that despite promising outcomes, the scale of impacts may be constrained by limitations in material significance, policy specificity, and infrastructural readiness.

At the national level, qualitative analyses highlight positive contributions of specific CIs, especially organic waste composting and recycling initiatives, while also revealing potential gaps such as limited plastic recycling targets and the heterogeneity of construction material reuse. These efforts reflect context-specific priorities and challenges, with Costa Rica and Uruguay making progress in scaling circular practices aligned with their ecological and economic contexts.

Extending beyond borders, the regional analysis utilizing MR-EEIOA modelling captures broader economic interdependencies and spillover effects, revealing complex trade-offs and variations in impact when viewed through the lens of Latin America and the Caribbean. The modelling notes the importance of cross-border circular supply chains and the potential for cumulative environmental benefits across the region, though socio-economic outcomes are more contingent on diverse economic structures and labour dynamics. At the global scale, Latin America's CE pathways contribute to sustainable supply chains critical for the global energy transition, highlighting the region's strategic role in resource and biodiversity stewardship. However, the global spillover effects of these interventions remain limited and mixed. While some regions like China and the US see small environmental improvements, others experience slight increases in emissions or nutrient pollution. Economic and employment impacts outside Latin America are also minimal, reflecting the challenges of achieving broad global influence through regional CE policies alone. This underscores the need for stronger international coordination to fully realize the potential of CE transitions worldwide.

Despite these promising impacts, the research identifies critical barriers to fully realizing CE potential in LATAM. Vague and non-specific policy goals limit effective monitoring and accountability, while the adoption of Global North models without sufficient local adaptation may slow progress and reduce context relevance. The informal economy's large yet underrepresented role creates blind spots in impact assessments and policy designs, underscoring the need for more inclusive and representative frameworks.

Methodologically, the integration of qualitative insights with MR EEIOA quantitative modelling provides a comprehensive assessment framework but faces challenges from data gaps, resolution limitations, and modelling assumptions. Notably, a predominant reliance on national qualitative data constrains regional generalizability, while the use of proxy countries and aggregated input-output data introduces uncertainties in capturing diverse economic dynamics across LATAM.

7.2 Need for Standardisation in Regional CE assessments

Costa Rica and Uruguay currently apply distinct methodologies to evaluate CE interventions, reflecting the absence of harmonized regional guidelines. Costa Rica prioritizes sectors based on GDP contribution, while Uruguay relies on national Material Flow Analysis (MFA). Although these approaches are contextually appropriate, their divergence impedes consistent regional data collection and impact assessment (Caribe, 2024; ENEC, 2023). Future research should prioritize developing standardized frameworks and guidelines for CE assessments throughout LATAM. This includes harmonizing data collection protocols and impact indicators to enable robust cross-country comparisons and facilitate integrated regional research. Furthermore, addressing vagueness requires the formulation of clear, context-specific objectives accompanied by transparent measurement frameworks. Such clarity is essential for enabling evidence-based policy evaluation and adaptive management, thereby strengthening the effectiveness and accountability of CE strategies across Latin America.

7.3 Integrating Mixed Methods for CIs Impact Assessment

This research demonstrates that combining quantitative MR-EEIOA modelling with qualitative inquiry is essential to capture the multifaceted nature of CE impacts. Quantitative models adeptly quantify environmental and economic effects, yet qualitative methods illuminate social dimensions such as employment conditions, informal sector dynamics, and value creation that often elude purely numerical approaches.

To strengthen this mixed-methods framework, future research should incorporate in-depth qualitative studies, including stakeholder interviews, ethnographies, and case studies, that provide micro-level perspectives on how CE interventions affect companies and workers in the waste sectors. Such integration will foster more nuanced impact assessments of socio-economic impacts, improving policy relevance and operational design of CE strategies.

7.4 Advancing DE Research for Cross-Country Comparisons

Recent advances in operationalizing the DE framework - through nationally localized planetary boundaries and social thresholds - present valuable tools for future CE impact assessments in Latin America. Integrating updated, localized datasets at the national level can enhance the framework's applicability and precision, enabling more rigorous and meaningful cross-country comparisons.

Future work should focus on refining social foundation indicators and establishing universally agreed-upon metrics, as variability in defining ecological ceilings and social thresholds currently challenges the framework's robustness. Enhanced data integration and methodological standardization will improve the DE's utility for balancing social and ecological goals across diverse regional contexts.

7.5 Contributions to Industrial Ecology

7.5.1 Scientific Contribution

This thesis contributes to Industrial Ecology by applying systems thinking and material flow analyses to regional CE challenges, addressing critical data gaps in the LATAM region through combined qualitative and MR-EEIOA methodologies. The findings demonstrate the necessity of employing diverse methods to comprehensively evaluate both environmental and socio-economic impacts, aligning with the holistic vision of the DE framework. Moreover, this work reveals the limitations inherent in current approaches, such as qualitative analyses and MR-EEIOA, emphasizing that enhanced data collection, particularly regarding social dimensions, is essential to improve impact assessments.

7.5.2. Stakeholder Contribution to Industrial Ecology

For policymakers in Latin America, this thesis provides critical insights on combining qualitative and quantitative methods to effectively assess CE interventions. The research highlights urgent needs to improve data availability, especially regarding social sustainability dimensions such as informal sector participation, which currently constrain comprehensive evaluation. Policymakers can leverage these findings to design more targeted data collection systems and implement clearer, context-sensitive policy frameworks with measurable objectives. Additionally, the study identifies regional challenges including limited infrastructure capacity and policy vagueness, which policymakers must address to enhance the efficacy, inclusivity, and accountability of CE programs. Ultimately, this research advocates for stronger regional collaboration to harmonize policy frameworks and intervention designs, enabling more coordinated and impactful CE development across LATAM region.

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Appendix A: Repository Description and Modelling Support Information

Appendix Description

This repository includes data and code designed to assess the impacts of two circular economy interventions through a Multi-Regional Environmentally Extended Input-Output Analysis (MR-EEIOA) framework. The analysis covers multiple regions: Latin America & Caribbean (LAC), European Union (EU), China, United States (US), and the Rest of the World (RoW).

Modelled Interventions

- Intervention **d.3**: Uruguay's Plastics Recycling

- Intervention **b.1**: Costa Rica's Increase of Biodegradable Waste from Food

These are based on national circular economy policies and modeled with detailed sectoral and regional aggregations using the EXIOBASE database. The scenarios estimate changes across key socio-economic and environmental indicators — including greenhouse gas emissions, nutrient and material flows, land use, value added, and employment.

Note: The intervention numbering and labeling correspond precisely to those in the Excel file *LATAM_data_entry_final.xlsx* located in the 01_data folder.

Repository structure

- **01_data**: Contains Excel files, including *LATAM_data_entry_final.xlsx*, documenting sectoral assumptions, intervention identifiers, and detailed scenario parameters.
- **02_SectoralAggregations**: Includes mappings to aggregate EXIOBASE's detailed sectors and regions into broader groups aligned with circular economy priorities for efficient analysis.
- **03_Code**: Includes the main MR-EEIOA modelling scripts that simulate the economic and environmental effects of the interventions for Costa Rica (b.1) and Uruguay (d.3).
- **04_Results**: Stores the outputs from the MR-EEIOA simulations, structured for result visualization and interpretation.
- **05_Supporting_graphs**: This section presents graphs based on processed data profiling key economic indicators, such as exports, trade balance, and GDP, for Costa Rica and Uruguay. These visualizations support the thesis by highlighting relevant country-specific socio-economic trends.

Repository link

The full repository and source code on GitHub can be accessed here:
https://github.com/Giulsin/Thesis

Appendix B: Supporting Tables

Appendix Description

This appendix provides supplementary information that supports the main thesis analysis and discussion.

Table 11 presents the composition of Value Added in EXIOBASE 3.

Tables 12 and 13 offer contextual data relevant to the discussion in Section 6.1, which critiques the vagueness found in policy goals within the national circular economy strategies of Costa Rica and Uruguay, respectively.

Table 12: Composition of Value Added in EXIOBASE 3

Value Added
Taxes less subsidies on products purchased: Total
Operating surplus: Remaining net operating surplus
Other net taxes on production
Compensation of employees; wages, salaries, & employers' social contributions: Low-skilled/Medium-skilled/High-skilled
Operating surplus: Consumption of fixed capital
Operating surplus: Rents on land
Operating surplus: Royalties on resources

Tables 12 and 13 show supporting information to the discussion section 6.1 that argues vagueness of policy goals of CIs, respectively, in the national strategies of Costa Rica and Uruguay.

Table 13: Vagueness of CIs selected from Costa Rica's National circular strategy

Intervention	Theme	Goals	Vagueness?
a	Residuals	By 2021, reduce the presence of plastics in total solid waste	Lacks clarity on how the reduction will be achieved

		generated from 20% to 10%.	(e.g., recycling, reduced consumption).
b	Resource (Material) Use Efficiency - Organic Waste Management	Achieve a 50% reduction in the tonnage of biodegradable waste sent to landfills by 2050, based on the proportion of municipalities that report this data.	The target is referring to a specific flow and it's quantifiable. It does not say what is the secondary impact is (e.g., through increasing composting?)
c	Material	The country will increase the use of wood, bamboo, and other materials (including those from sustainably managed plantations) in buildings by at least 10% by 2025, based on the 2018 baseline.	The intervention does not state if wood will replace other materials (like cement) and it's not specific when mentioning "and other materials"
d	Value chains	By the year 2025, the country will promote a circular economy system for agricultural and livestock farms, comprehensively considering the process of biodigestion and soil recarbonization through the use of technologies to increase soil organic carbon (SOC) levels, among other strategies.	The goal is broad and lacks quantifiable targets or a clear mechanism for its implementation.

e	Productivity	By 2021, achieve a 30% increase (compared to 2017) in the economic activity associated with the production and trade of products manufactured from renewable sources, recycling processes, and that are compostable.	Unclear if these products will replace non-renewable, non-recyclable, non-compostable ones

Table 14: Vagueness of CIs selected from Uruguay's National circular strategy

Intervention	Theme	Goal (ENEC)	Vagueness
a	Circularity linked to water use	Promote water circularity through efficiency, reuse, and technological advancements in agriculture, industry, and domestic sectors, aligning with the National Water Plan. Increased water circularity across sectors via efficient and sustainable practices and nature-based solutions.	The goals are general and lack specific, measurable targets for efficiency or reuse.
b	Sustainable and circular constructions	Build national capacity for circular construction waste management to enable quality recycled material use and reduce	The intervention does not provide specific baselines or targets for the use of recycled materials or waste reduction.

		landfill waste. Enhance the use of recycled materials in construction and reduce construction waste.	
c	Driving circularity in food production	Reduce resource use and promote material reuse and redesign in industries (prioritizing food and cement) and SMEs through enhanced recycling and recovery. Implement the recycling industry with efficient processes and reduced reliance on raw materials.	The goals are vague and do not quantify how much resource use will be reduced or how material reuse will be promoted.
D	Added value in the recycling of post-consumer materials and industrial processing by-products	Enhance the value of recycled post-consumer and industrial by-products by improving high-quality material recovery and enabling new production. Prioritize materials (e.g., plastics, paper), study actions (public procurement, tech, regulation) with a stronger recycling industry using efficient, innovative processes, reducing reliance on raw materials.	No quantifiable targets for the increase in value or the rate of material recovery.