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PROPOSTA METODOLÓGICA PARA MENSURAÇÃO DA SUSTENTABILIDADE AGROALIMENTAR: UM ESTUDO DE CASO DO ESTADO DO PARANÁ (2010/2023)

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Sessão Temática 02: Desenvolvimento regional: políticas, escalas e ações

Resumo: Este estudo tem como objetivo estimar um indicador para mensurar a circularidade do setor agroalimentar considerando a sustentabilidade regional. Com base no referencial teórico, desenvolvemos um índice – o Índice Circular de Sustentabilidade Agroalimentar (CASI) – e faremos uma avaliação com base em indicadores econômicos, sociais, ambientais e do setor agroalimentar nas seis Regiões Geográficas Intermediárias (RGInt) do Paraná (Brasil) de 2010 a 2023. Considerando que o modelo CASI sugere competição entre regiões, houve duas RGInts com tendências distintas. Por um lado, a RGInt de Curitiba perdeu posição em todos os indicadores (IA, IE, IS, IAF e CASI) ao longo dos 13 anos. Por outro lado, a RGInt Guarapuava apresentou a melhora mais significativa (exceto na variável IS). Este artigo se mostrou eficaz na mensuração da circularidade no setor agroalimentar, além de mostrar o potencial dessa metodologia em estudos sobre processos ou políticas de desenvolvimento regional com foco em sustentabilidade.

Palavras-chave: indústrias agroalimentares; desenho de indicadores; desenvolvimento regional.

METHODOLOGICAL PROPOSAL FOR MEASURING AGRIFOOD SUSTAINABILITY: A CASE STUDY OF PARANÁ STATE (2010/2023)

Abstract: *This study aims to estimate an indicator for measuring the circularity of the agri-food sector considering regional sustainability. Based on the theoretical background, we developed an index – the Circular Agri-Food Sustainability Index (CASI) – and we will conduct an assessment based on economic, social, environmental, and agri-food sector indicators across the six Intermediate Geographic Regions (RGInt) of Paraná (Brazil) from 2010 to 2023. Considering that the CASI model suggests competition between regions, there were two RGInts with distinct trends. On one hand, the RGInt of Curitiba lost position in all indicators (IA, IE, IS, IAF, and CASI) over the 13 years. On the other hand, RGInt Guarapuava showed the most significant improvement (except for the IS variable). This article proved to be effective in measuring circularity in the agri-food sector, as well as showing the potential of this methodology in studies on regional development processes or policies focusing on sustainability.*

Keywords: *agro-food industries; indicator design; regional development.*

PROPUESTA METODOLÓGICA PARA LA MEDICIÓN DE LA SOSTENIBILIDAD AGROALIMENTARIA: UN ESTUDIO DE CASO DEL ESTADO DE PARANÁ (2010/2023)

Resumen: *Este estudio tiene como objetivo estimar un indicador para medir la circularidad del sector agroalimentario considerando la sostenibilidad regional. Con base en los antecedentes teóricos, desarrollamos un índice – el Índice de Sostenibilidad Agroalimentaria Circular (CASI) – y realizaremos una evaluación basada en indicadores económicos, sociales, ambientales y del sector agroalimentario en las seis Regiones Geográficas Intermedias (RGInt) de Paraná (Brasil) de 2010 a 2023. Considerando que el modelo CASI sugiere competencia entre regiones, hubo dos RGInt con tendencias distintas. Por un lado, la RGInt de Curitiba perdió posición en todos los indicadores (IA, IE, IS, IAF e CASI) a lo largo de los 13 años. Por otro lado, la RGInt de Guarapuava mostró la mejora más significativa (excepto en la variable IS). Este artículo demostró ser eficaz para medir la circularidad en el sector agroalimentario, además de mostrar el potencial de esta metodología en estudios sobre procesos de desarrollo regional o políticas centradas en la sostenibilidad.*

Palabras clave: *Industrias agroalimentarias; design de indicadores; desarrollo regional.*

INTRODUCTION

Sustainable development is defined as humanity's ability "to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 2015, p. 24). Vizeu, Meneghetti and Seifert (2012) argue that this idea supports the capitalist developmental paradigm, which views the environment as a "means" or reservoir of resources to be employed in addressing human needs, by offering a critique of the notion of sustainability. That is, it interprets demands from a Western perspective that is increasingly globalized and overlooks the myriad cultural variations among countries. Lastly, it fails to acknowledge the distinction between needs and desires as well as the fact that needs are socially produced. Above all, this concept seems fundamentally anthropocentric since it disregards the "needs" of other community members.

While recently several studies focused on circularity-related issues concerning different industries, sector-specific dynamics, such as those that occurred within the agri-food sector, were less discussed. This happened mainly at regional levels. In fact, as D'Adamo et al. (2024) stressed, European countries are still very fragmented regarding performance toward CE outcomes, while Ghinoi et al. (2024) demonstrate that there is also a gap in the implementation of the CE at the municipal level. Similarly, Rocchi et al. (2021) applied the Material Circularity Indicator to the poultry sector, showing that intensive rearing does not necessarily achieve better circularity. All these works prove that sectoral and regional methods are necessary for the understanding of circularity in agri-food and food industry.

The conceptual approach to measure four central constructs: economic, environmental, social and Agri-food industry to design an Index. The economic, environmental, and social contexts unique to the regions under consideration are discussed to develop an expanding knowledge base on CE in agri-food industry, particularly in sustainable regional development.

Despite the possibility of measuring the degree of circularity of products and systems being considered a trending topic, there are limited studies focused on measuring the CE at a micro-level (Rukundo *et al.*, 2021). Furthermore, the existing metrics and indicators often cover only specific elements of the socio-economic flow of CE, overlooking key components of the concept. Some frameworks also suggest a single indicator that consolidates and represents multiple dimensions of CE.

In a regional aspect, the organizational structure and spatial distribution of economic units are important factors in determining how long regional economic development may last. The way these units are configured has a big impact on people's quality of life since unpriced externalities that mainly affect local and regional contexts are caused by things like noise, air and water pollution, and other pollutants (Batabyal; Nijkamp, 2009). Consequently, the environment, broadly defined, serves as a fundamental determinant of the pace and scope of regional economic development.

Furthermore, the monitoring and evaluation process serves multiple purposes: assessing whether public in the execution of actions and fostering conditions that promote engagement in the planning process (Marques da Costa, 2011). More quantitative research approaches are needed to follow the dynamics of circular economy business models via a well-defined set of sustainability indicators (Donner; De Vries, 2023). In this context of discussions, there is a recognized need to develop mechanisms to measure sustainability, such as formulating sustainable development indicators (Rodrigues; Ferrera de Lima, 2013).

Despite progress in research, the current studies generally highlight that most of the data used comes from databases (such as FAO, Eurostat), reports, and food balance sheets. (Agovino *et al.*, 2024; Castillo-Díaz *et al.*, 2023; D'Adamo *et al.*, 2024). High-quality data obtained through direct measurement and analysis remains scarce (Chiaraluce; Bentivoglio; Finco, 2023). This raises the key research question: **How can circularity in the agri-food sector be measured from a regional perspective?**

Based on these observations, this study aims **to develop and estimate an indicator for measuring circularity in the Agri-Food sector in a regional perspective: the six Intermediate Geographic Regions (RGInt) of Paraná, Brazil, from 2010 and 2023.** To assess the Circular Agri-Food Sustainability Index (CASI), we will estimate four Partial Indicators, they are: a) Economic; b) Social; c) Environmental; and the d) Circular Economy Agri-Food Sector.

THEORETICAL BACKGROUND

The theoretical background encompasses a brief discussion on sustainable regional development, a reflection of the circular economy with a focus on Brazil, and a review of the empirical literature addressing analytical tools for measuring circularity in the agri-food sector.

SUSTAINABLE REGIONAL DEVELOPMENT

Before delving into the concept of sustainable regional development, we will first contextualize economic development. According to Brazilian economist Celso Furtado (1967), economic development originates in specific locations and then gradually diffuses outward. The pace and extent of this expansion are significantly influenced by the physical environment, particularly through the impact of transportation costs. That is, the "space" matter to regional development. "The practical problem will always be to reconcile general goals of development, defined in terms of the nation as a whole, with the objectives of social welfare directed towards certain sections of the population" (Furtado, 1967, p. 11).

The foundations of sustainable development do not diverge from the ideology of business growth. Instead, by emphasizing the economic-financial importance of profitability, it suggests the feasibility of continuous and unlimited accumulation of profits (Vizeu;

Meneghetti; Seifert, 2012). According to the authors, the term sustainability is paradoxical, as it is promoted as a redemptive truth, as a saving myth in the face of imminent catastrophe.

From a management perspective, the concept of sustainability has evolved to encapsulate a strategic approach aimed at balancing outcomes across three critical dimensions: economic, social, and environmental. These dimensions, often referred to as the three pillars of sustainability or the Triple Bottom Line, underscore the necessity of integrating financial performance with social responsibility and environmental stewardship in decision-making processes. This management strategy, proposed by John Elkington (1994), advocates for the evaluation of an organization's performance not only based on its financial results but also considering the impacts, both positive and negative, on the social and environmental spheres.

That is, in organizational contexts, the need to maintain business continuity makes the concept essential for companies. Businesses, industries, and regions aiming for sustainable development must strive to achieve economic, environmental, and social objectives concurrently (Brown; Dillard; Marshall, 2006).

To Alves (2022, p. 12) the idea of development is linked to "the ability, not only to improve the living standards of its population, but also to make the region more competitive and innovative, maintaining its dynamism/growth over time." That is, development is a multidisciplinary concept with the ultimate objective of the well-being of certain populations. For example, the coordination of projects with a view to a virtuous cycle to promote education, health, employment, social protection, respect for diversity (Ferrera de Lima; Alves, 2012).

The development of a territory, in turn, involves several complex themes that are related to each other, namely: the distribution of wealth, social justice, changes in mentality and the feeling of local belonging, territorial governance with an innovative mentality, visionary, proactive and entrepreneurial (Ferrera de Lima, 2022). Understanding these complex dynamics sets the stage for comprehensively monitoring and evaluating policies, programmes, and projects, necessitating a conceptual framework for enhanced clarity and analysis.

The first aspect to a system of indicators and evaluation is the diagnosis of the initial situation (demographic, geographical positioning, infrastructure, equipment's, employment and economic activities). The second aspect is the evaluation cycle and its positioning in the planning process (SWOT analysis, implementation of the programme and the moment of winding up). The third aspect are connected different types of indicators (relevance, effectiveness, efficiency, utility, sustainability, external coherence). The fourth aspect of indicator is its concept, "an indicator is a measure of synthesis, thus representing an abstraction of a situation" (Marques da Costa, 2011, p. 314).

Also, the increasing complexity of the challenges we face highlights the growing need for efficient planning that considers the capacities and limitations of the public entities and territories involved. So, it is crucial to carefully assess the external coherence among the various plans, programs, and regulatory guidelines as an integral part of the preliminary evaluation conducted during the development of these instruments (Marques da Costa; Antonello, 2020).

Using economic and social variables to measure regional development, Gualda (1995, 2003) proposed the "Regional Development Index" (IDR). This index aims to indicate the level of dynamism of a municipality compared to the state's average performance. In other words, it seeks to determine whether a municipality is dynamic within the regional development process. The IDR was constructed using a methodology like that of the Human Development Index (HDI), as proposed by Amartya Sen, to assess the level of development of countries.

The IDR was used by Ferrera de Lima et al. (2011) to identify and analyze the stage of Regional Development of Brazilian States and examine the profile of regional inequalities between 1995 and 2008. The results highlighted the inequality among states, particularly in the economic indicator. The IDR indicated that the São Paulo State is developing at a faster pace compared to other states in the country. Another study using the IDR and utilizing 14 variables, Eberhardt and Ferrera de Lima (2012) analyzed the 39 microregions from Paraná State, Brazil, between 2000 and 2007. Their findings indicate significant disparities among these microregions, particularly in terms of economic indicators.

Rodrigues and Ferrera de Lima (2013) argue that sustainable development is a long-term process involving economic growth, the preservation of natural resources, improvements in social indicators, and the strengthening of the local productive base. The authors analyzed the stage of sustainable development in the mesoregions of Paraná from 2002 to 2008 by adapting the IDR and incorporating an environmental variable to estimate the Sustainable Regional Development Index (IDRS).

The IDRS of the Southern Region of Brazil (applied to 1,191 municipalities) was analyzed for the years 2000 and 2010, using a total of 30 variables equally distributed among the three partial indices (social, economic, and environmental). According to the authors (Bianco; Ferrera De Lima; Morejon, 2016), proper environmental management, whether in resource preservation or in waste treatment and utilization, can lead to improvements in economic and social indices, as it is intrinsically linked to all productive sectors and social demands.

THE CIRCULAR ECONOMY

While sustainability tries to reconcile the management of productive resources with their increasing consumption, Circular Economy aims to make the productive process more efficient, reducing, reusing and recycling the results of the productive process as much as possible. In this sense, there is growing recognition that the circular economy model may support sustainable development and the 2030 Agenda's SDGs (Schroeder; Anggraeni; Weber, 2019). Also, industrial ecosystems can reach Sustainable Development Goals (SDGs) by adopting the model of circular economy (Babkin *et al.*, 2023).

To ensure that future generations can survive, customers and companies must commit to adopting sustainable practices in order to protect the environment and provide necessities (Marcelino *et al.*, 2023). In this way, circular economy has the potential to contribute significantly to sustainable development.

That is, industrial symbiosis can potentially provide the means for increasing sustainable food production, using locally sub-exploited resources that can reduce the need for land, agrochemicals, transport and energy. In other words, "industrial symbiosis construed as networks of organizations cooperatively sharing wastes has created irresistible imagery and high hopes for a time when virtually all water, energy, and materials will be used more than once, and not to do so will have become societally unacceptable" (Chertow; Park, 2016).

Even though many stakeholders strongly embrace the idea of a circular economy, the concept is still vague and inconsistently defined (Falkenberg; Schneeberger; Poechtrager, 2023). Circular economy is a term coined in the 1990s (Pearce; Turner, 1990), and, since then, it has received increasing attention.

The concept of Circular Economy has long been a topic of discussion within academic and scientific circles, and its significance is increasingly recognized in the contemporary context. This paradigm entails the reduction of resource consumption, with a particular emphasis on natural resources, and the mitigation of waste and effluent generation, except in cases where negative externalities are produced (APDR, 2018).

The majority of experts focus on the following fundamental ideas: the waste hierarchy, the systemic approach (micro, meso, and macro), sustainable development, and the 4Rs framework (Kirchherr; Reike; Hekkert, 2017). Table 1 presents some definitions of the circular economy provided by different scholars and institutions over time. These definitions highlight the core principles of circularity, including resource regeneration, material reuse, and the decoupling of economic growth from environmental degradation. Each definition underscores the systemic and restorative nature of the circular economy, aligning with sustainable development.

Table 1: Circular economy definition

Circular economy is	Source
an economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times	(Ellen MacArthur Foundation, 2015, p. 46)
an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes	(Kirchherr; Reike; Hekkert, 2017, p. 229)
a model for production and consumption (with heavy emphasis on production), whose ultimate goal is to achieve the decoupling of economic growth from natural resource depletion and environmental degradation	(Williams, 2019, p. 2749)
(an) economic system that uses a systemic approach to maintain the circular flow of resources, through the recovery, retention or addition of their value, while contributing to sustainable development	(ABNT, 2022, p. 4)

Source: own design (2024).

It is interesting to note that consumption has received relatively little investigation up to this point, given that popular definitions of the CE – such as those provided by the Ellen MacArthur Foundation (2015) – concentrate more on the flows of materials and energy than on the activities of consuming. It is noteworthy, therefore, that Kirchherr and colleagues (Kirchherr; Reike; Hekkert, 2017) included consumption in their above-cited definition of CE (Dagevos; Lauwere, 2021).

The circular economy, through the adoption of circular sourcing and design strategies, longer and multiple products lives, and the closing of resource cycles, is a fundamental foundation of transformations towards a world where more than nine billion people can live well within the limits of the planet, by 2050 – World Business Council for Sustainable Development (WBCSD, 2023).

The adoption of a circular economy framework has the potential to unlock real economic prospects, enhance the availability of raw materials for industry through waste recovery, generate employment opportunities, and facilitate the shift towards a sustainable green technology sector (Chiaraluce; Bentivoglio; Finco, 2023).

Because it aims to match its activities with the natural cycle, the circular economy model has the potential to support sustainable development on a local, regional, and global scale. The outcomes might not contribute to the sustainable development of the region if circular processes are projected and put into practice without placing people at the center of their decisions (Silva; Franz, 2022).

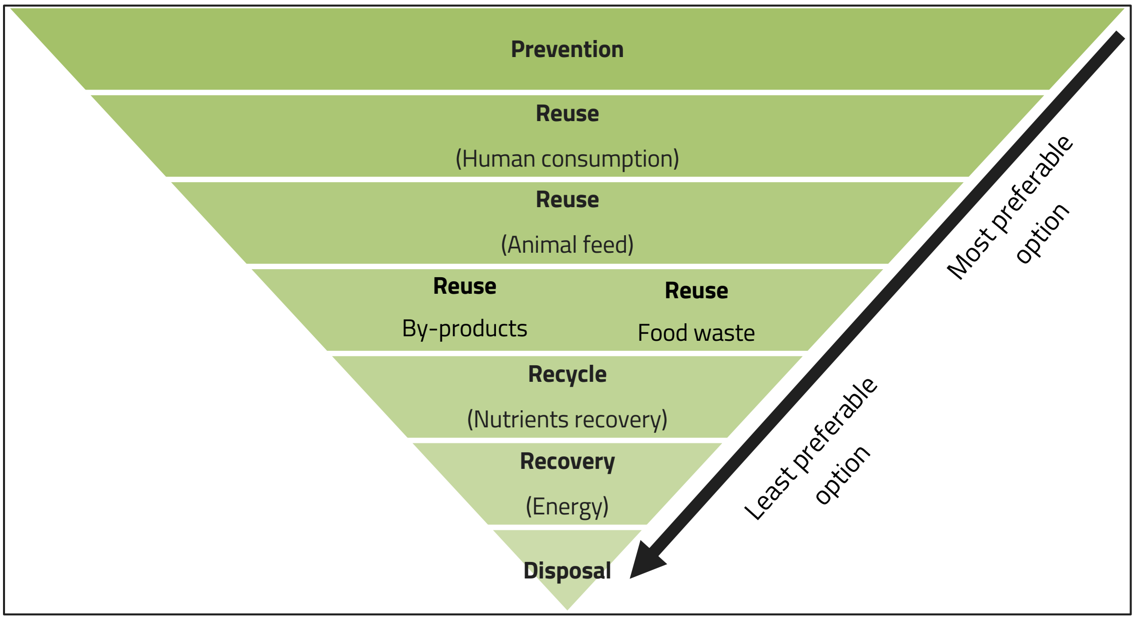
The authors (Silva; Franz, 2022) pointed that the opportunity to make changes and to find vital solutions to the planet's sustainability emerge in the cities due to its relevance on population growth, production and consumption. Also, the circular economy can be applied to large and small enterprises, collectively and individually, worldwide and locally, and it facilitates the development of economic, natural, and social capital.

The city benefits from circular systems in many ways, including increased economic productivity, revenue opportunities, the promotion of urban, social, and environmental health, and support for local production (Williams, 2019). The circular city model is centered on territorializing the ideas of the circular economy, whereby everything that is wasted becomes a resource for inexpensive, regenerative urban systems that combine social fairness, economic productivity, and environmental sustainability to lessen social inequality (Fusco Girard; Nocca, 2019).

Businesses are increasingly recognizing the circular economy as a crucial building block in the transition to a net-zero and nature-positive world. The Circular Transition Indicators (CTI) was designed for business by business to unleash the transformative power of the circular economy, CTI offers a universal and quantitative framework for evaluating how circular a company is. In its fourth edition, CTI empowers companies to unlock the value of circularity and drive progress toward their sustainability goals (WBCSD, 2023).

In line with it, one of the key areas where CE principles can be applied is in addressing food loss and food waste. Food loss, which does not include retail, food service providers, and consumers, is the reduction in the amount or quality of food because of decisions and actions made by food suppliers in the chain. Food waste is the reduction in the amount or quality of food as a result of customer, food service, and store decisions and actions (FAO, 2019). The 'value pyramid' of food waste valorization illustrates the functioning of a circular economy (Figure 1).

Figure 1: Hierarchy of food surplus, by-products and food waste prevention strategies



Source: (Klein; Nier; Tamásy, 2022, p. 196).

As can be seen in the Figure 1, the hierarchy prioritizes the reduction of food waste at its source, advocating for strategies that prevent surplus generation through improved forecasting, production planning, and inventory management. When surplus food is unavoidable, the hierarchy suggests redistribution as a preferable option, ensuring that edible food reaches those in need. Additionally, the utilization of by-products for animal feed or industrial purposes is encouraged before resorting to energy recovery or disposal methods.

"Waste is a significant by-product in any industrial nation" (Batabyal; Nijkamp, 2009, p. 288). As highlighted by the authors while it represents a considerable environmental challenge, waste also has the potential to serve as a valuable input for recycling processes. However, this dual role is influenced by a complex set of locational factors that impact the feasibility and efficiency of recycling activities.

Also, the globalization and competitiveness are not new terms. In closed, non-globalized markets, competitiveness is primarily defined by government actions, which ensure the survival of economic agents through subsidies and tariff and non-tariff protections that burden taxpayers and/or consumers. In globalized markets, corporate competitiveness – and, more broadly, that of economic sectors – is determined by the ability to grow in relation to top international competitors. This requires a mix of pro-competitive public policies (monetary, fiscal, exchange rate, infrastructure, and others) and continuous efficiency gains by agents, including cost reduction, product differentiation, technological innovation, and more. Ultimately, competitiveness is also linked to the systemic ability to organize and coordinate production chains, based on the governance forms established between the different agents (private and public) involved (Jank; Nassar, 2000).

Competitiveness strategies depend on the institutional environment. The increasing significance of non-tariff barriers, phytosanitary regulations, trade retaliation measures, and the broader context of economic bloc formations and transnational corporations' influence is particularly noteworthy. Additionally, the organizational environment (support structures for private businesses) and technological factors shape individual and systemic competitiveness.

Given this context, how do Brazilian regulations address the principles of the circular economy in terms of law, competitiveness and globalization?

THE CIRCULAR ECONOMY IN BRAZIL

With the introduction of the National Solid Waste Policy (PNRS), established by Law No. 12.305 in 2010, the Brazilian regulatory framework encompassed the main guidelines for sustainability. Among the principles and instruments of this law, the shared responsibility for the product's life cycle and reverse logistics stands out, essential links for enabling the reintegration of waste into a new economic cycle (Brasil, 2010).

Based on the regulation, solid waste management in Brazil adopted waste generation reduction and pollution mitigation as its main guidelines to promote sustainability. In addition to the National Environmental Education Policy (PNEA), established in 1999, the National Solid Waste Policy is integrated with the Water Resources Policy (PNRH) of 1997, the National Climate Change Policy (PNMC) of 2009, and the National Basic Sanitation Plan (PLANSAB). The latter, enacted by Federal Law No. 11.445, dated January 5, 2007, establishes the national guidelines for basic sanitation and, in its Article 7, determines that the activities of public services for urban solid waste management include the treatment of domestic waste and the management of solid waste resulting from the cleaning of streets and public roads.

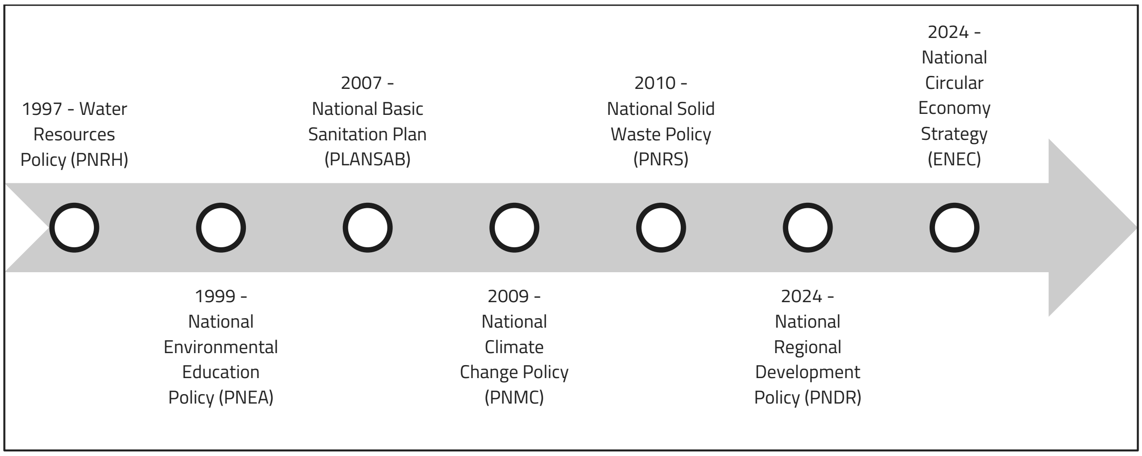
Recently, the Brazilian government issued a decree outlining the National Regional Development Policy (PNDR) (Brasil, 2024a). The PNDR aims to reduce economic and social disparities within and between regions by fostering development opportunities that lead to sustainable economic growth, income generation, and improved quality of life for the population. The decree specifies that the PNDR is grounded in a coordinated and strategic mobilization of federal, state, district, and municipal actions, both public and private. Through this approach, national and local programs and investments will jointly promote and support development processes.

Finally, on the 17th of June 2024, a decree was published creating the country's first National Circular Economy Strategy (ENEC) (Brasil, 2024b). The strategy aims to promote the economic transition from the current linear model to a circular economy, to create lasting and more conscious economic growth. The drafting of the ENEC was inspired by circular economy principles and reports published by the Ellen MacArthur Foundation.

The Strategy is based on the seven guidelines of the circular economy, especially: elimination of waste and pollution, circulation of materials and products at their highest values, and regeneration of nature. The following points of focus stand out in the ENEC, when compared to other circular economy strategies: I) Create a regulatory and institutional environment favorable to the circular economy; II) Promote innovation, culture, education and skills generation to reduce, reuse and redesign how products are made, with the circular economy in mind; III) Reduce the use of resources and the generation of waste, in order to preserve the value of materials; IV) Propose financial instruments to support the circular economy; and V) Promote inter-federative coordination and the involvement of workers in the circular economy.

Figure 2 presents a timeline highlights Brazil's progressive environmental and sustainability policies from 1997 to 2024, marking significant steps toward integrating environmental management, from water resources to solid waste, and culminating in the recent focus on a circular economy.

Figure 2: Brazilian Environmental and Sustainability Policies Timeline (1997/2024)



Source: own design (2024).

Bianco (2018) suggest the implementation of a new urban solid waste management model using advanced methods and technologies has demonstrated its technical and economic viability, transforming urban solid waste from a cost factor into an investment opportunity. This approach not only provides economic incentives but also delivers positive environmental and societal impacts (externality), turning waste into a resource for new business models and industrial processes. It supports sustainable and innovative development in the Western Paraná region of Brazil by generating income, fostering technological advancements, extending landfill lifespan, reducing the need for additional landfill space, and ensuring compliance with Federal Law No. 12.305/2010 (PNRS).

However, in addition to federal legislation, states and municipalities act autonomously to enact their own regulations to govern waste management and reverse logistics within the limits established by the National Solid Waste Policy. Thus, the development of integrated solid waste management plans (Brasil, 2010) follows a priority order of action: (i) non-generation; (ii) reduction; (iii) reuse; (iv) recycling and treatment of solid waste; (v) environmentally appropriate final disposal of waste, which is the residue for which all utilization possibilities have been exhausted, being considered unsuitable for any type of use. Therefore, from the perspective of moving towards a sustainable economy, waste must be reused in some way, according to its characteristics and specificities, meaning it should be reintegrated into production processes or reused for other purposes.

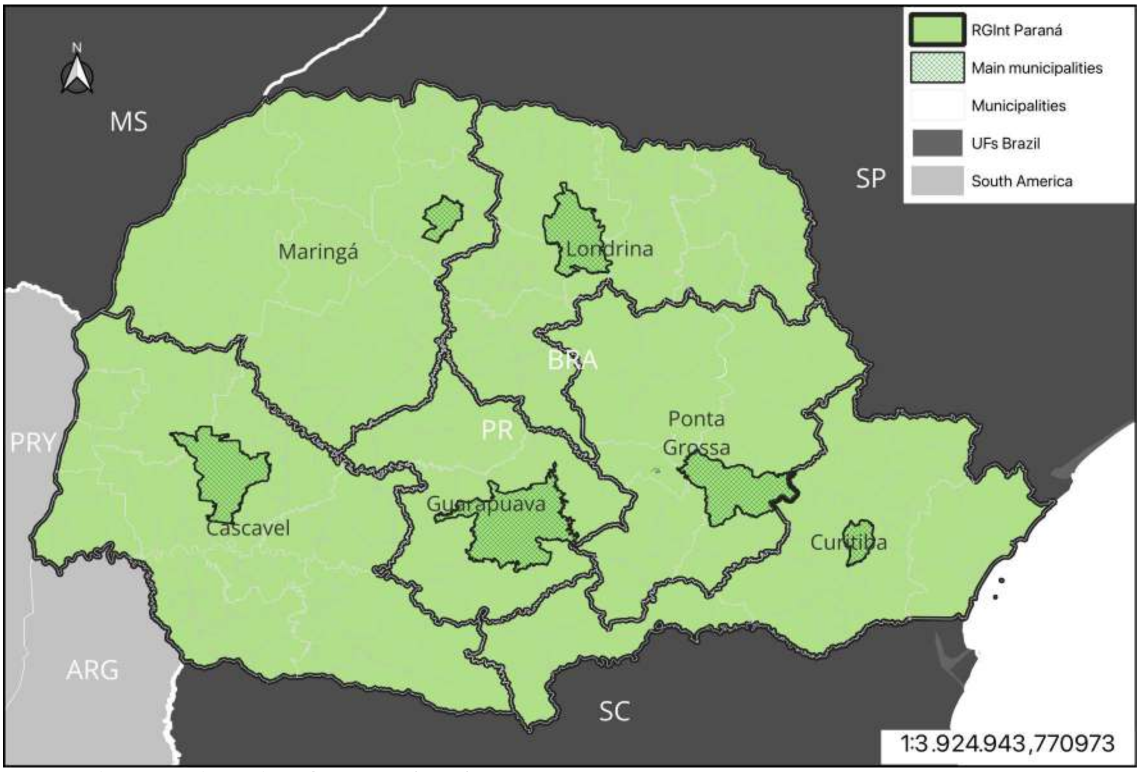
MATERIAIS AND METHODS

This study aims to develop and estimate an indicator for measuring circularity in the Agri-Food sector in a regional perspective: the six Intermediate Geographic Regions (RGInt) of Paraná, Brazil from 2010 and 2023. Year 1 refers to 2010, and for Year 2, the most recent year available was used for each variable. Several variables were found for the year 2023, so Year 2 will be considered as 2023. The choice of these two distinct periods allowed for an assessment of regional changes and developments over time.

The research strategy consists in a comparative case study. This approach is typically used to explore differences and similarities across multiple units of analysis, which may be countries, regions, organizations, or communities, among others (Yin, 2002). The purpose is to understand how contextual factors influence outcomes and to identify generalizable patterns or unique variations.

Paraná State is a key agricultural hub in Brazil, given the relevant contribution of that region to national agri-food production and exports. The range of practices in this region will go from large agribusiness to smaller family-run farms. Sustainability and environmental management have gained increased policy interest, thus promoting initiatives related to better waste management, optimization of resource use, and agroecological practices in Paraná, Brazil (Shikida; Galante; Cattelan, 2020).

Figure 3: Paraná State: the six Intermediate Geographic Regions



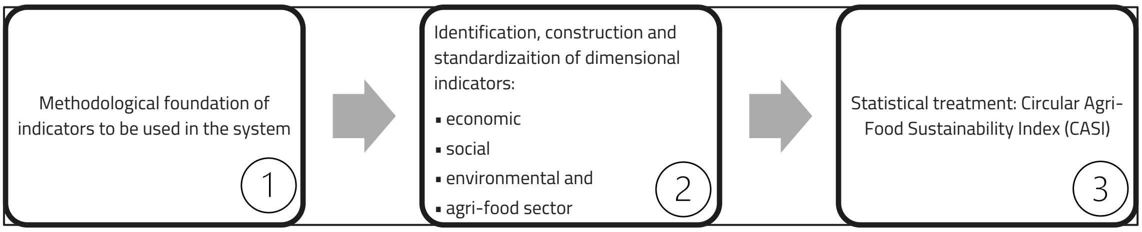
Source: adaptations by authors from IBGE (2024).

As pointed out in the Figure 3, the Intermediate Geographic Regions (RGInt) of Paraná will be used for regionalization. The state of Paraná is divided into six RGInt: Cascavel, Curitiba, Guarapuava, Londrina, Maringá, and Ponta Grossa.

When developing monitoring and evaluation systems, three fundamental questions must be addressed: what to evaluate, how to evaluate, and whom to evaluate (Marques da Costa, 2011). According to Marques da Costa (2011), indicators are necessary to understand and explain key demographic, economic, environmental, and socio-cultural changes (such as population aging and the restructuring of productive systems); to discuss issues and concepts related to sectoral and multi-scale transversality (including sustainability, competitiveness, territorial cohesion, and social equity); and to strengthen information structures that support various stakeholders and the governance system in the decision-making process.

The initial phase of the research (Figure 4) established the methodological foundation for the indicators used in the system, based on a literature review. In the second phase, a set of measurable and indicators was selected to evaluate the economic, social, and environmental aspects of sustainability in the agri-food industry in the regions. Finally, the third stage of the research consisted of applying the statistical treatments to the results.

Figure 4: Methodological stages followed in the research



Source: own design (2024).

The methodology used in this investigation consisted of bibliographic and quantitative research. Regarding data collection, this research is classified as exploratory and descriptive, focusing to understand social, economic, environmental and agricultural phenomena through the identification, evaluation, and synthesis of data across specific time periods and regions. Additionally, the selected indicators were normalized to produce dimensionless values, enabling the construction of a composite index for economic, social, environmental, and overall sustainability of the agri-food regions. The standardization protocol applied is widely recognized by institutions such as the United Nations (UN), the Organization for Economic Co-operation and Development (OECD), and the European Commission, as well as by previous research that assessed the sustainability of various economic activities, including rural activities and food production, in response to climate change.

We will employ sustainable regional development and circular economy as its methodological foundation, particularly the Regional Development Indicator (IDR) proposed by Gualda (1995, 2003); and improved by: Ferrera de Lima et al. (2011), Eberhardt e Ferrera de Lima (2012) and Eberhardt et al. (2023). Also, Rodrigues and Ferrera de Lima (2013) and Bianco et al. (2016) which adapted the IDR to develop the Sustainable Regional Development Index (IDRS).

The partials indicators incorporate variables that describe the economic, social, environmental and agri-food conditions of the respective regions. These variables enable an analysis of each region's capacity to generate investments in infrastructure, healthcare, education, research and development, employment, and natural resource conservation (Frame 1).

Frame 1: Equation that compose the Circular Agri-Food Sustainability Index (CASI)

Equation	Index	Variables
(1)	Index = ((Vi-Vmin)/(Vmax-Vmin)) *100	**Vi** is the value of each region (variable) **V**min is the smallest value of each variable **V**max is the largest value of each variable Therefore, the region that has the largest value in each variable will have an index equal to 100 and the region with the smallest value will have an index of 0
(2)	Partial Score for each dimension = ∑ (Variable 1 + Variable 2 + Variable 3 + Variable 4 + Variable 5 + Variable 6)	**Partial** indicators (IA, IE, IS, IAF) Variable 1 Variable 2 Variable 3 Variable 4 Variable 5 Variable 6
(3)	CASI = (∑ (IEi + ISi + IAi + IAFi) ÷ 600)	**Circular Agri-Food Sustainability Index (CASI)** **IEi** is the partial **economic** indicator **ISi** is the partial **social** indicator **IAi** is the partial **environmental** indicator **IAFi** is the partial **Circular Agri-Food** indicator

Source: own design, adapted from (Eberhardt *et al.*, 2023; Wang, 2007).

Regarding the Equation (1), a simple average method will be adopted for weight determination of field indices and sub-indices. This means that all field indices are equally weighted in constructing the overall index; and all sub-indices in one field are equally weighted to form a field index (Wang, 2007).

To measure the Partial Score, six variables regarding the four partial – economic, social, environmental, and circular agri-food – will be determined in the Equation (2). In other words, the social indicator is the sum of all indexes referring to variables classified as social (Eberhardt *et al.*, 2023). The economic indicator is the sum of all indexes referring to variables classified as economic. The environmental indicator is the sum of all indexes referring to variables classified as environmental. And the Circular Agri-food indicator is the sum of all indexes referring to variables classified as Circular Agri-food.

Equation (3) is the last step in estimating the index. CASI integrates four sustainability dimensions (economic, social, environmental, and circular agri-food) into one comprehensive index, scaled by 600 to maintain consistency and comparability across different analyses. It is dividing the resulting value by 600 scales, standardizing it to a set range. This division ensures that the CASI index provides a normalized sustainability score that can be consistently interpreted across different regions.

The data that will be used for this study (Frame 2) will be collected by the Brazilian Institute of Geography and Statistics (IBGE), the Applied Economic Research Institute database (IPEADATA), the Paraná Institute of Economic and Social Development (IPARDES), the United

Nations Development Programme (UNDP), and the Annual Social Information Report (RAIS) from the Ministry of Labor.

Frame 2: Variables that compose the Circular Agri-Food Sustainability Index (CASI)

V	Dimension			
	Ambiental	**Economic**	**Social**	**Circular Economy**
1	ICMS Ecológico - Recurso do ICMS Repassado aos Municípios (R$ 1,00) pc	Consumo de Energia Elétrica por Classe - Industrial (Mwh) pc	Índice Ipardes de Desempenho Municipal (IPDM) média	Produção da Silvicultura - Resinas - Quantidade Produzida (t) pc
2	Atendimento de Esgoto - Unidades Atendidas pc	Produto Interno Bruto (PIB) (R$ 1,00) pc	Despesas Municipais por Fundo - Educação (R$ 1,00) pc	Fez adubação - orgânica (% do total)
3	Despesas Municipais por Fundo - Saneamento (R$ 1,00) pc	VBP - Agricultura pc	População Censitária - Total	VBP C10 - Fabricação de Produtos Alimentícios (R$ 1,00) pc
4	Despesas Municipais por Função - Gestão Ambiental (R$ 1,00) pc	Fundo de Participação dos Municípios (FPM) (R$ 1,00) pc	Estabelecimentos de Saúde - Total pc	VBP C11 - Fabricação de Bebidas (R$ 1,00) pc
5	% de cobertura vegetal natural	VBP - Total (R$ 1,00) - (1997-2023) pc	Possui ligação à rede geral e a utiliza como forma principal pc	População ocupada no setor de Fabricação De Produtos Alimentícios pc
6	% de domicílios com serviços de coleta de lixo	Receitas Municipais - Total pc	População ocupada no setor agropecuário (pc população rural)	População ocupada no setor de Fabricação De Bebidas pc

Source: own design (2024).

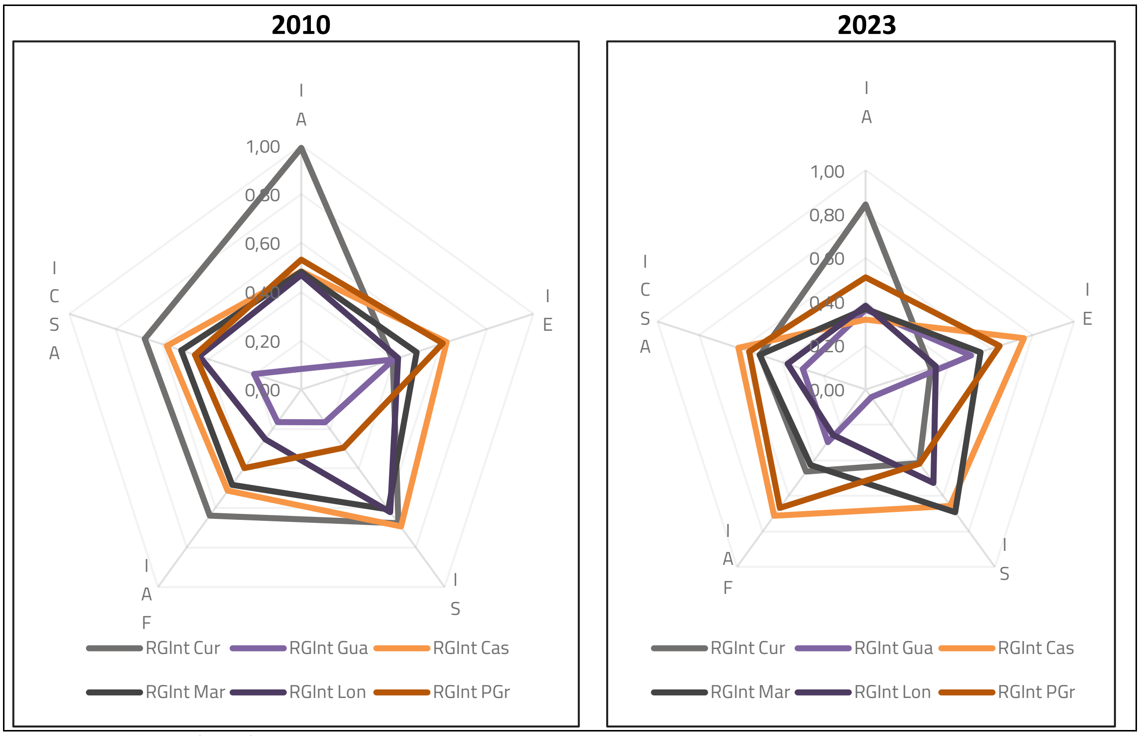
The procedure for estimating the Circular Agri-Food Sustainability Index (CASI) is carried out in four steps: i) Participation of each region (RGInt for Paraná and in relation to the total of the State (Paraná or Italy); ii) Construction of partial indexes for each variable; iii) Construction of social, economic, environmental and agri-food indicators; and iv) Preparation of the Circular Agri-Food Sustainability Index (CASI). Based on the results, the CASI is classified into three categories, reflecting the level of sustainable development of the region: CASI ≥ 0.50 = Advanced; 0.10 ≤ CASI ≤ 0.49 = In transition; and CASI ≤ 0.09 = Lagging.

According to this classification, regions with an CASI above 0.50 are in an advanced stage, exhibiting a dynamic productive base with economic, social, and environmental progress. Regions with an CASI between 0.10 and 0.49 are classified as in transition, indicating that their evolving economic, social, and environmental structures result in lower sustainability dynamics compared to advanced regions. Those with an CASI below 0.099 are considered lagging, facing challenges in attracting and retaining resources, hindering their process of socio-economic and sustainable development (Bianco; Ferrera De Lima; Morejon, 2016; Ferrera de Lima *et al.*, 2011; Gualda, 1995, 2003; Rodrigues; Ferrera de Lima, 2013)

RESULTS

Figure 5 presents a comparative radar chart analysis of the Circular Agri-Food Sustainability Index (CASI) across different Intermediate Geographic Regions (RGInt) of Paraná for the years 2010 and 2023. Each axis represents one of the components of the sustainability index, and the lines depict the performance of various regions: Curitiba (Cur), Guarapuava (Gua), Cascavel (Cas), Maringá (Mar), Londrina (Lon), and Ponta Grossa (PGr); across these components.

Figure 5: Paraná RGInt: Circular Agri-Food Sustainability Index (2010/2023)



Source: own design (2024).

Considering that the CASI model suggests competition between regions, Figure 5 highlights two RGInts with distinct trends. On one hand, the RGInt of Curitiba lost ground in all indicators (IA, IE, IS, IAF, and CASI) over the 13-year period. On the other hand, RGInt Guarapuava showed the most significant improvement (except for the IS variable). In absolute terms, RGInt Guarapuava increased by 0.10 points in the CASI index (2010: 0.20; 2023: 0.30), representing a growth of 48.55%. RGInt Curitiba, however, declined by 0.17 points in the CASI index (2010: 0.67; 2023: 0.51), a decrease of -24.71%.

In 2010, most regions demonstrated a relatively low level of sustainability, with CASIs generally below the 0.500 threshold, indicating that most regions were in transition (0.100 ≤ CASI ≤ 0.499). Curitiba, Maringá and Cascavel show slightly better performance. On the other hand, Guarapuara, Londrina and Ponta Grossa were classified in transition.

By 2023, notable improvements will be evident in several regions. Regions such as Curitiba and Cascavel display an CASI of 0.500 or above in specific components, indicating that they have achieved the "Advanced" level in those aspects. Although the RGInt of Guarapuava remains within the "In transition" category, the region shows steady progress across multiple sustainability dimensions, particularly in environmental aspects. Notably, the "ICMS eco per capita" score for Guarapuava stands out as the highest among the six RGInt, reflecting its leading position in this specific variable.

Regarding the Environmental Partial (IA), the scores have generally decreased for some regions, notably RGInt Curitiba, which dropped from 0.99 to 0.84. This may indicate a decline in environmental performance metrics, such as sewage treatment, sanitation, and waste collection. However, other regions like RGInt Guarapuava and RGInt Londrina show increases in IA, indicating potential improvements in environmental practices in these areas.

Most regions saw an increase in Economic Partial (IE) scores over the period. For instance, RGInt Cascavel's IE improved from 0.63 in 2010 to 0.76 in 2023, suggesting a strengthened economic base, possibly due to higher GDP per capita, increased total municipal revenues, and enhanced local economic activities. The economic index's rise across several regions may reflect growing economic resilience and a capacity to support circular economy practices financially.

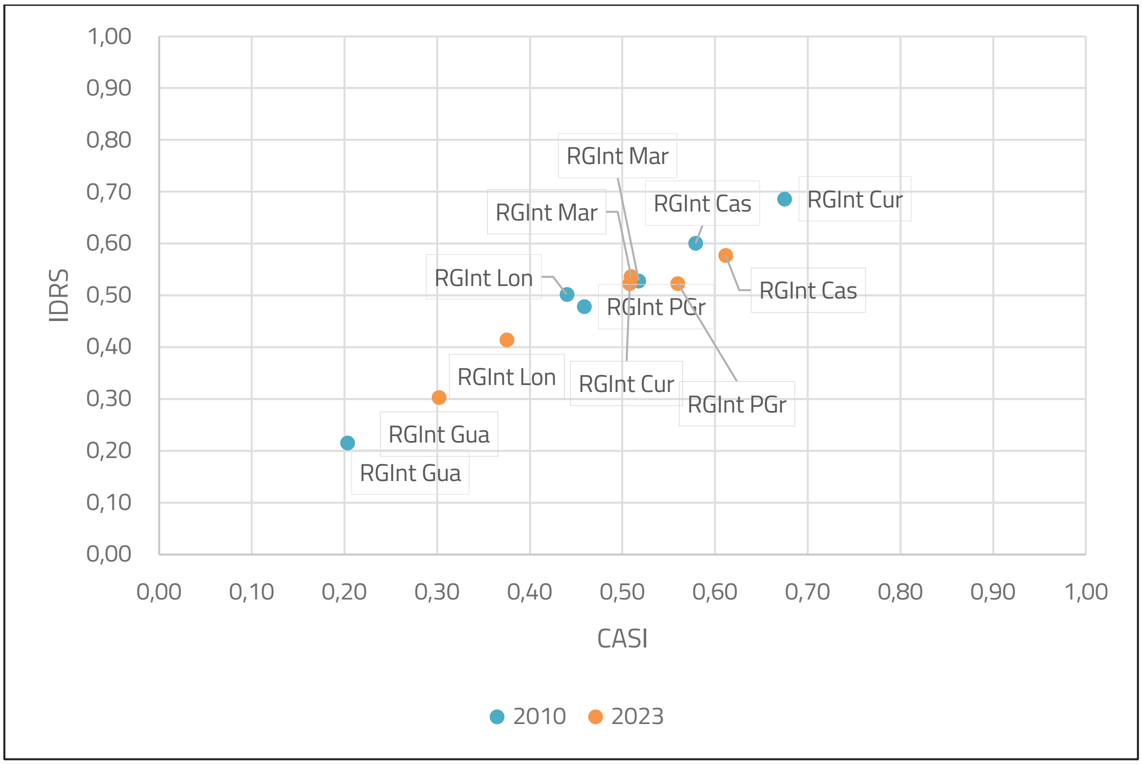
The Social Partial (IS) shows mixed trends, with certain regions such as RGInt Curitiba experiencing a significant drop (from 0.68 to 0.41), implying a potential decline in social aspects like population occupation in the agri-food sector, educational expenditure, and public health infrastructure. Conversely, regions such as RGInt Maringá maintained or improved their IS, suggesting steady social improvements related to agri-food circularity.

The Agri-food Circular Partial (IAF), which directly assesses circular economy progress within the agri-food sector, displays varied regional performances. RGInt Cascavel shows a notable increase from 0.51 in 2010 to 0.71 in 2023, suggesting considerable progress in circular practices such as organic fertilization and forestry-based activities. Some regions, however, experienced slight decreases or stagnation, highlighting areas where circular economy practices may not have advanced as effectively.

The CASI classification shows that, in 2023, more regions achieved an "Advanced" status than in 2010, indicating an overall improvement in circularity and sustainability. Regions like RGInt Cascavel and RGInt Ponta Grossa maintained or upgraded their "Advanced" status, demonstrating consistent circular economy progress. RGInt Guarapuava and RGInt Londrina, however, remain "In transition", indicating that although there may have been some progress, these regions still face challenges in fully implementing sustainable circular economy practices.

Also, the comparative analysis of the indices for sustainable regional development (IDRS) axis y, and circularity in the agri-food sector (CASI) axis x, between 2010 and 2023 shows distinct trends across the six Intermediate Geographic Regions (Figure 6).

Figure 6: IDRS VS CASI (2010/2023)



Source: own design (2024).

Regions such as Curitiba (RGInt Cur) and Londrina (RGInt Lon) show a decline in both CASI and IDRS values, indicating potential sustainability challenges that may stem from decreased circularity and regional development performance over time. The region of Guarapuava (RGInt Gua) demonstrates improvement in both indices, suggesting that strategic interventions may have positively influenced its sustainability and circularity metrics. The regions of Cascavel (RGInt Cas), Maringá (RGInt Mar), and Ponta Grossa (RGInt PGr) exhibit more stable trends, with either slight fluctuations or modest growth, particularly in circularity. These observations underscore varying regional dynamics, highlighting the potential need for tailored sustainability strategies to address each region's unique performance trajectory in agri-food circularity and broader sustainable development.

Despite using a different methodology, we reached converging results from Alves (2022). Specifically, Curitiba's Intermediate Geographic Region concentrated on urban infrastructure. At the same time, the GRInt Guarapuava stood out for its growth over the analyzed period, even as it remained classified as 'in transition' in both timeframes examined.

FINAL REMARKS

A developed region is one that not only improves the quality of life for its population but also fosters greater competitiveness and innovation, ensuring dynamic and sustainable growth over time. This study estimated an indicator for measuring circularity in the Agri-Food sector in a regional perspective: the six Intermediate Geographic Regions (RGInt) of Paraná, Brazil, from 2010 and 2023.

The data provided illustrates the evolution of circularity indicators in the agri-food sector across different Intermediate Geographic Regions (RGInt) from 2010 to 2023. The index system used – comprising IA (Environmental Partial), IE (Economic Partial), IS (Social Partial), IAF (Agri-Food Circular Economy Partial), and CASI (Circular Agri-Food Sustainability Index) – enables a multi-dimensional assessment of regional performance.

Overall, while there has been a general trend towards improvement in the economic and circular economy indices, some regions exhibit weaknesses in social and environmental aspects. This mixed progression emphasizes the need for targeted policies that address specific local challenges, especially in transitioning regions. Strengthening social and environmental components alongside economic improvements could further enhance the regions' circularity and sustainability performance in the agri-food sector.

A limitation of this research lies in the fact that no quantitative model can fully capture reality *ipsis litteris*. Additionally, the databases lacked variables that accurately represent the circular economy in the agri-food sector. However, with the implementation of the national circular economy strategy, this situation may improve in the coming years.

Future research could address, for example, whether agri-food industries are adopting new business models to transition from a linear to a circular model. If so, it could also explore how this transition is being implemented and the motivations behind it.

This article proved to be effective in measuring circularity in the agri-food sector, as well as showing the potential of this methodology in studies on regional development processes or policies focusing sustainability.

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