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ARTICLE

Economic, social and environmental dimensioning of Agribusiness in Paraná and the Rest of Brazil

Dimensionamento econômico, social e ambiental do Agronegócio no Paraná e Restante do Brasil

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Abstract: The study measures agribusiness in Paraná and the rest of Brazil through a multidimensional approach, articulating economic, social and environmental variables. Using data from the input-output matrix, economic relevance, sustainability, and possible strategies and public policies are evaluated. The results indicate that agribusiness has a greater weight in the economy of Paraná, representing 44% of production, 41% of value added and 49% of jobs, compared to 24%, 21% and 28% in the rest of the country. Economic indicators such as labor productivity and average income of Paraná's agribusiness are lower than those of the rest of the state economy and agribusiness in the rest of the country. Environmentally, agribusiness has high impacts considering the consumption of blue water and greenhouse gas emissions. Even so, Paraná's agribusiness demonstrates greater relative environmental efficiency, with lower impacts per unit of income and per worker. It is concluded that agribusiness is essential for the generation of wealth and jobs, but imposes challenges to sustainability, especially in rural areas. The adoption of more efficient technologies, qualification of the workforce and incentives for production with low environmental impact are recommended as ways to reconcile economic development, social inclusion and conservation of natural resources.

Keywords: sustainability, environmental impact, economic performance, social indicators.

Resumo: O estudo dimensiona o agronegócio no Paraná e no restante do Brasil por meio de uma abordagem multidimensional, articulando variáveis econômicas, sociais e ambientais. Utilizando dados da matriz insumo-produto, avalia-se a relevância econômica, a sustentabilidade e possíveis estratégias e políticas públicas. Os resultados indicam que o agronegócio tem maior peso na economia paranaense, representando 44% da produção, 41% do valor adicionado e 49% dos empregos, frente a 24%, 21% e 28% no restante do país. Indicadores econômicos como produtividade do trabalho e rendimento médio do agronegócio paranaense são inferiores aos do restante da economia estadual e do agronegócio no restante do país. Ambientalmente, o agronegócio apresenta impactos elevados considerando o consumo de água azul e as emissões de gases de efeito estufa. Ainda assim, o agronegócio paranaense demonstra maior eficiência ambiental relativa, com menores impactos por unidade de renda e por trabalhador. Conclui-se que o agronegócio é essencial para a geração de riqueza e empregos, mas impõe desafios à sustentabilidade, sobretudo no meio rural. Recomenda-se a adoção de tecnologias mais eficientes, qualificação da mão de obra e incentivos à produção de baixo impacto ambiental como caminhos para conciliar desenvolvimento econômico, inclusão social e conservação dos recursos naturais.

Palavras-chave: sustentabilidade, impacto ambiental, desempenho econômico, indicadores sociais.

Introduction

Agribusiness is one of the pillars of the Brazilian economy, driving economic growth, job creation, and technological innovation. This sector not only diversifies the country's economy but also plays a strategic role in international trade, contributing to the trade balance and global food security. The efficiency and productivity of agricultural activities make agribusiness a driver of income and development, capable of fostering social and economic progress in several regions of Brazil. In the state of Paraná, the importance of agribusiness is even more evident. Renowned for its high productivity and crop diversity, Paraná stands out as a major agro-industrial hub that is part of robust production chains. This dynamic not only strengthens the regional economy but also promotes sustainable development and social inclusion by leveraging investments, modernizing infrastructure, and fostering innovative practices (Sesso Filho et al., 2011, 2019).

In this context, this study aims to conduct a detailed and comparative analysis of agribusiness in Paraná and the rest of Brazil, using an approach that integrates distinct variables to assess agribusiness in economic, social, and environmental fields. To provide comprehensive analysis, the production chain was divided into four aggregates: inputs, agriculture and livestock, manufacturing, and services. An important contribution of the study is that it incorporates an environmental perspective addressing current issues related to climate change. Variables such as blue water consumption and greenhouse gas emissions are measured, incorporated into the analysis, and used to develop environmental sustainability indicators. This approach makes it possible to assess the efficiency of different agribusiness aggregates and compare them with one another and across regions.

The methodology is based on the input-output matrix, which is an important analytical tool that maps the relationships between various productive sectors, highlighting how the output of certain segments serves as an input for others and, at the same time, how these sectors are responsible for supplying the inputs needed to produce final goods and services. This approach provides a detailed view of economic flows and the impact that each sector has on the economy. By translating complex interrelationships into quantifiable data, the matrix facilitates the estimation of the impacts of economic policies, strategic development planning, and the evaluation of sectoral policies, by demonstrating the importance of each segment in a country's economic composition and dynamism (Miller & Blair, 2022).

By outlining the main contributions of each segment of the production chain, the study aims not only to build a robust body of findings, but also to provide insights for the formulation of more targeted public policies and to guide strategic private investments. The analysis of the results identifies the most significant agribusiness aggregates for each variable under consideration and compares them across regions. It is hoped that this research will provide information that can inform the development of public policies and guide private investments aimed at agribusiness development.

Theoretical Basis

Sustainability in agribusiness is understood in terms of three interdependent dimensions: economic, social, and environmental. Economic sustainability refers to the ability to maintain the financial viability of agro-industrial activities over time, ensuring productivity and competitiveness (Castillo-Díaz et al., 2024). The social dimension encompasses aspects such as working conditions, equity, inclusion, and the well-being of rural communities (Massuça et al., 2023). Environmental sustainability, on the other hand, refers to the preservation of natural resources, the reduction of negative impacts such as greenhouse gas emissions, and the rational use of water and soil (Karwacka et al., 2020; Sree Lakshmi, 2024).

An analysis of sustainability in agribusiness reveals tensions between economic growth and social and environmental responsibility. Ioris (2018) argues that the discourse on sustainability is often exploited by agribusiness to legitimize practices that perpetuate inequality and environmental degradation. On the other hand, studies such as that by Bajan & Mrówczyńska-Kamińska (2020) focus on methodologies that represent advances in measuring the carbon footprint of agro-industrial systems and have found that environmental performance has improved in certain countries. Latruffe et al. (2016) highlight the importance of integrated indicators for assessing agricultural sustainability, proposing metrics that take all three dimensions into account simultaneously. Therefore, the measurement of sustainability indicators is an important topic in recent studies on agribusiness, and there is no consensus on the metrics or their results.

By comparison, the studies differ in their methodological approach and analytical focus. While Castillo-Díaz et al. (2024) propose a quantitative and consensus-based framework for measuring sustainability, Massuça et al. (2023) focus on the social dimension, using indicators of quality of life and inclusion. Ioris (2018) takes a critical and political perspective, questioning the interests behind the rhetoric of sustainability. On the other hand, Karwacka et al. (2020) and Bajan & Mrówczyńska-Kamińska (2020) focus on the environmental dimension, with an emphasis on the carbon footprint. Latruffe et al. (2016) provide a comprehensive review of indicators, emphasizing the need for multidimensional approaches. Taken together, the studies show that sustainability in agribusiness requires the integration of metrics, public policies, and production practices that balance economic efficiency, social justice, and environmental conservation.

These studies identify various public policies and private initiatives aimed at promoting sustainability. Notable public policies include incentives for low-carbon agriculture, environmental certification programs, subsidies for the adoption of clean technologies, and investments in rural education (Sree Lakshmi, 2024; Ioris, 2018). The studies also recommend policies to support family farming and social inclusion in rural areas (Massuça et al., 2023). In the private sector, initiatives such as the implementation of environmental management systems, the use of sustainability indicators in decision-making, voluntary certifications, and investments in technological innovation are considered important for enhancing the sustainability of agribusiness (Castillo-Díaz et al., 2024; Bajan & Mrówczyńska-Kamińska, 2020).

The issue of scaling and sustainability in agribusiness has been studied at the national and regional levels in Brazil; numerous studies have been conducted, featuring advances in methodology and the inclusion of economic, social, and environmental variables. Research on the scale of agribusiness in Paraná has evolved both in terms of methodology and analytical scope; this analysis follows the chronological sequence of previous studies to examine this evolution. Early studies, such as that by Nunes & Parré (2013), served as the starting point for this research by estimating the Gross Domestic Product (GDP) of the state's agribusiness sector for the year 2007. The authors demonstrated that, in a scenario of expansion, agribusiness could account for up to 30% of the state's GDP, highlighting the transformative potential of the production chain for the economy of the state of Paraná. The results highlighted the strategic importance of agribusiness in terms of income and job creation, setting a benchmark for future analyses. Subsequently, Sesso Filho et al. (2011) applied an agribusiness measurement methodology based on the input-output matrix for southern Brazil, using 2004 as the base year, and demonstrated that agribusiness in the Southern Region accounted for 27% of the national agribusiness GDP and 39% of the regional GDP.

In the study by Kureski et al. (2013), the authors measured the agribusiness GDP of Paraná and identified structural characteristics characterized by concentration in certain production chains. This study revealed a significant share in relative terms, suggesting that, despite fluctuations inherent in the dynamics of these activities, their economic importance remained high within the state context. Sesso Filho et al. (2019) expanded their analysis to include all Brazilian states and quantified the agro-industrial sector of Brazilian states in 2008 across various indicators (GDP, employment, taxes). The results indicated that job creation and tax revenue increased over time in the Southern Region. The study highlighted that the agribusiness sector was able to increase direct and indirect job creation by approximately 18% during the period analyzed, underscoring the agribusiness' role in the regional economy.

The interregional approach adopted by Gonçalves Jr. *et al*. (2022) marked another milestone in the methodological evolution and research on agribusiness in Paraná. Using interregional input-output systems for the years 2011 and 2015, the authors estimated that Paraná's agribusiness sector accounted for approximately 28% of the state's GDP in 2011, while in 2015 this percentage was estimated at 34%, indicating positive growth despite external fluctuations. Furthermore, the analysis revealed that agribusiness' contribution to income and job creation was consistently higher than the average observed for the rest of Brazil, with the agriculture and livestock and agro-industrial sectors standing out in particular.

The inclusion of environmental indicators in the study of agribusiness in Paraná was introduced by Pompermayer Sesso et al. (2022), who combined an analysis of economic performance with a measurement of the carbon footprint for the year 2013. The authors noted that the carbon footprint associated with the state's agribusiness production structure reached approximately 18.7 million tons of CO_2 equivalent, a figure representing about 12% of total emissions from the productive sector. The inclusion of environmental factors in the analysis of agribusiness in Paraná revealed that the growth in income generation (GDP)—both in absolute terms and relative terms (share of the state economy)—was accompanied by significant environmental impacts. Therefore, the study demonstrated the need for agribusiness metrics to go beyond income alone and incorporate environmental factors that, in the long term, influence the sector's sustainability.

Studies published since 2023 have reaffirmed the methodological evolution and the need to update the indicators for Paraná's agribusiness sector, given the dynamics of the economy. Oliveira et al. (2023) analyzed the growth of agribusiness GDP in the state between 2012 and 2017 using a regional input-output matrix. The results showed that, in 2012, the GDP of Paraná's agribusiness sector was R$ 32.5 billion, rising to R$ 48.9 billion in 2017. The cumulative growth of approximately 50.5% not only demonstrates the sector's absolute expansion but also reflects a relative increase in its share of the state's GDP, rising from 20% to 27%. The figures showed that Paraná's agribusiness sector has grown stronger thanks to technological advances and the reorganization of supply chains, although its vulnerability to fluctuations in international input prices remains a risk factor. At the same time, the study by Kureski et al. (2023) focused on the specific contribution of the agriculture and livestock sectors and the food industry to the economy of Paraná in 2020. The authors identified agribusiness as the main driver of the state's economy, with approximately 85% of the total revenue generated by agribusiness coming from activities directly related to agricultural production and industrial processing. The quantitative results also demonstrated the structural diversity and resilience of the agribusiness sector in the face of external impacts.

A chronological analysis of the studies conducted on this topic shows that the absolute and relative figures for agribusiness in Paraná have shown significant growth. Initially, estimates by Nunes and Parré (2013) pointed to a significant potential contribution, which was confirmed in subsequent studies with figures in the range of 27% of the national total. Estimates for 2011 and 2015, based on the interregional approach proposed by Gonçalves Junior et al. (2022) showed a percentage increase in agribusiness' share of the state's GDP, rising from 28% to 34%, which demonstrated not only growth in absolute terms but also a rise in the sector's relative importance within Paraná's economic setting. Methodological developments show that most studies have focused on the direct impacts on Gross Domestic Product without taking environmental and social factors into account. The analysis by Pompermayer Sesso et al. (2022) showed that economic importance comes with environmental costs, with an estimated 18.7 million tons of CO_2 equivalent in 2013, accounting for 12% of emissions from the manufacturing sector, which points to the need to expand the indicators used to analyze agribusiness.

Given this situation, it is important that advances in research on agribusiness in Paraná incorporate environmental and social variables, in order to enable a more comprehensive and integrated analysis. While previous studies have clearly demonstrated the evolution of absolute and relative figures—from initial projections to recent data, which show growth in agribusiness' GDP in both absolute and relative terms, these results must be supplemented by indicators that measure the impacts of production processes not only from an economic perspective, but also from social and environmental perspectives. The integration of environmental and social indicators is emerging as an important strategy to ensure that future research can provide a more comprehensive analysis of the positive and negative impacts resulting from the expansion of agribusiness. This multidimensional approach will be essential for guiding public policies that seek to balance economic growth, environmental sustainability, and social equity, ensuring that agribusiness contributes not only to economic development but also to improving living conditions and preserving natural resources in the state of Paraná.

Methodology

The input-output matrix (IOM) is an important analytical tool for the study and planning of production chains, especially in the context of agribusiness, a sector characterized by its structural complexity and high degree of interdependence among primary, industrial, and service activities. By quantifying the flows of goods and services between the various sectors of the economy, the IOM makes it possible to accurately map the interactions between the links in the agro-industrial chain, from agricultural production through industrial processing to final distribution. In agribusiness, the IOM enables the measurement of demand for agricultural inputs, as well as the impacts of the supply of goods and services on agricultural and agro-industrial production. This ability to measure forward and backward linkages in supply chains is important for understanding the multiplier effects of public policies, market impacts, or technological changes across the entire supply chain. For example, the growing demand for processed food products can have significant impacts not only on the food industry, but also on agriculture, the fertilizer sector, transportation, and financial services. In addition, IOM makes it possible to measure the economic, social, and environmental impacts of different agribusiness development scenarios. By using environmental extensions of the matrix, it is possible to assess, for example, the use of natural resources, greenhouse gas emissions, and energy consumption associated with each segment of the production chain. This is particularly relevant in the context of growing demand for sustainability and traceability in agri-food production (Leontief, 1951; Miller & Blair, 2022).

The national matrix was constructed using preliminary data from the National Accounts, based on the methodology of Guilhoto & Sesso Filho (2005). Next, the interregional input-output matrix was estimated using the methods proposed by Haddad et al. (2018) and Guilhoto et al. (2019), covering 68 economic sectors. To measure both intermediate and final demand trade flows between regions, the IIOAS (Interregional Input-Output Adjustment System) method was applied, which estimates the origin and destination data of interregional transactions using a trade impedance matrix and subsequently adjusts them to ensure consistency with national and state total. This estimate is based on information from the Regional Accounts, tax data, the Annual Report on Social Information, and household surveys, ensuring consistency with national aggregates.

The database, as initially estimated, contained 68 sectors with financial figures and employment data. The environmental data—blue water consumption in millions of cubic meters (Mm^3) and greenhouse gas emissions in kilotons (kt) of CO_{2eq}—were obtained from GLORIA (Global Resource Input-Output Assessment Database), a multi-regional input-output (MRIO) database (Lenzen & Li, 2022) covering 120 sectors. The integration of the databases resulted in a matrix with 42 sectors, which are listed in Table 1.

Table 1. Sectors of the input-output matrices for the Paraná-Rest of Brazil interregional input-output system, 2020.

Sectors
(1) Agriculture
(2) Livestock
(3) Forestry, fishing, and aquaculture
(4) Mineral extraction
(5) Food industry
(6) Textiles, clothing, and accessories
(7) Wood products
(8) Paper, pulp, and printing
(9) Oil refining and biofuels
(10) Chemicals
(11) Pharmacists
(12) Rubber and plastic
(13) Non-metallic mineral products
(14) Metallurgy
(15) Metal products
(16) Electronic products
(17) Electrical products
(18) Machinery and mechanical equipment
(19) Cars, trucks, and buses
(20) Other transportation equipment
(21) Maintenance, repair, and installation of machinery and equipment
(22) Electricity, natural gas, and other utilities
(23) Water, sewage, and waste management
(24) Construction
(25) Commerce
(26) Land transport
(27) Waterway transport
(28) Air transport
(29) Warehousing, transportation support activities, and postal services
(30) Accommodation and food
(31) Audiovisual

Source: Prepared in-house.

Table 1. Continued...

Sectors
(32) Telecommunications
(33) Systems development and other information services
(34) Financial intermediation, insurance, and supplemental pension plans
(35) Real estate activities
(36) Services provided to businesses
(37) Rent, administrative tasks, and security
(38) Public administration, defense, and social security
(39) Education
(40) Health
(41) Artistic, creative, and performing arts' activities
(42) Associations and other personal services

Source: Prepared in-house.

In Table 1, the primary sectors within agribusiness, referred to as Aggregate II, are (1) Agriculture, (2) Livestock, and (3) Forestry, Fishing, and Aquaculture, which purchase inputs that are part of Aggregate I (inputs), thereby supplying goods and services for agricultural production. The agro-industrial sectors are (5) Food Industry, (6) Textiles, Apparel, and Accessories, (7) Wood Products, and (8) Paper, Pulp, and Printing, which constitute Aggregate III. The other sectors listed participate in various supply chains as buyers and suppliers of goods and services, forming a complex network of intersectoral relationships. The service sectors involved in agribusiness supply chains make up Aggregate IV, which includes trade, transportation, administrative, rental, and other services.

Given its heterogeneity and complexity, the services sector is estimated as a share of final demand, based on consumption in sectors I, II, and III, as described in Montoya et al. (2016).

The calculations for estimating the scale of the agribusiness sector using input-output matrices were based on the studies by Furtuoso & Guilhoto (2003) and Bajan & Mrówczyńska-Kamińska (2020). In developing the estimates, the agribusiness sector was divided into four aggregates, based on the concept developed by Davis & Goldberg (1957): (I) Inputs, (II) Agriculture and Livestock, (III) Industry, and (IV) Services. Aggregate (I) consists of the inputs used in the primary agricultural sectors.

For this study, the regional input-output matrices for Paraná and the Rest of Brazil were used in the calculations; therefore, only regional flows between sectors within each region are accounted for. The estimate values of the Gross Domestic Product (GDP) of Aggregate I (inputs) for each primary agricultural sector (PIB_{Ik}) is calculated by multiplying the input values of the sectors (1) Agriculture, (2) Livestock, and (3) Forestry, Fishing, and Aquaculture by their respective sectoral value-added coefficients at market prices (CVA_i), which are then summed, as shown in Equation (1).

$$PIB_{Ik} = \sum_{i=1}^{n} z_{ik} \times CVA_i \text{ to } k=\left[1,2,3\right] \tag{1}$$

In Equation (1), the elements are defined as follows: PIB_{Ik} is the GDP of aggregate I (inputs) for Agriculture (*k=1*), Livestock (*k=2*), and Forestry, Fishing, and Aquaculture (*k=3*), z_{ik} is the total value of inputs from sector i for Agriculture *(k=1)*, Livestock *(k=2)*, and Forestry, Fishing, and Aquaculture *(k=3)*, CVA_i is the value-added coefficient of sector *i, i = 1, 2, ..., 42* sectors of the economy.

The Value Added Coefficients for each sector (*CVAi*) are calculated by dividing Value Added at Market Prices (VA_{PMi}) by the sector's output (*Xi*) according to Equation (2). Value Added at Market Prices (VA_{PM}) or Gross Domestic Product is calculated by adding Value Added at Basic Prices (VA_{PB}) to Net Indirect Taxes (*IIL*) on products as follows: $VA_{PM} = VA_{PB} + IIL$.

$$CVA_i = \frac{VA_{PM_i}}{X_i} \tag{2}$$

The total Gross Domestic Product of Aggregate I, inputs for the primary agricultural sectors, is defined by Equation (3):

$$PIB_I = \sum_{k=1}^{3} PIB_{Ik} \tag{3}$$

The terms in Equation (3) are defined as PIB_I = PIB (GDP) of Aggregate I, which consists of inputs to agricultural production; this is the sum of $PIB_{I\,1}$ = PIB of Aggregate I, inputs to Agriculture (*k=1*), $PIB_{I\,2}$ = PIB of Aggregate I, inputs to livestock (*k=2*), $PIB_{I\,3}$ = PIB of Aggregate I, inputs from forestry, fishing, and aquaculture production (*k=3*).

The calculation of Aggregate II's Gross Domestic Product (as shown in Equation (4)) includes the value added at market prices of the primary sectors and subtracts the value added corresponding to the inputs used by those sectors themselves.

$$PIB_{IIk} = VA_{PMk} - \sum_{l=1}^{3} z_{lk} \times CVA_k \text{ to k=}\left[1,2,3\right] \tag{4}$$

The terms in Equation (4) are $PIB_{II\,k}$, the PIB of aggregate II for Agriculture *k=1*, Livestock *k=2*, and Forestry, Fishing, and Aquaculture *k=3*, and $VA_{PM\,k}$ is the Value Added at market prices for the sectors. The total Gross Domestic Product (GDP) of Aggregate II is calculated by summing the value added of the primary sectors, according to Equation (5):

$$PIB_{II} = \sum_{k=1}^{3} PIB_{IIk} \tag{5}$$

In Equation (5), PIB_{II} is the PIB of Aggregate II, the Gross Domestic Product of the agricultural sector resulting from the sum of $PIB_{II\,1}$ = PIB of Aggregate II, (1) Agriculture, $PIB_{II\,2}$ is the PIB of Aggregate II, (2) Livestock, and $PIB_{II\,3}$ is the PIB of Aggregate II, (3) Forestry, fishing, and aquaculture.

Aggregate (III) covers the industrial sectors for which the main sources of raw materials come from Aggregate (II): (5) Food industry, (6) Textiles, apparel, and accessories, (7) Wood products, and (8) Paper, pulp, and printing. The calculation of Aggregate III's Gross Domestic Product is the sum of the value added at market prices of the agribusiness industrial sectors, minus the value added from these sectors that was used as inputs for Aggregate II. Equation (6) performs this calculation:

$$PIB_{III\,k} = \sum_{q=5}^{8} \left(VA_{PM_q} - z_{kq} \times CVA_q\right), \text{k} = 1,2,3 \tag{6}$$

In Equation (6), $PIB_{III\,k}$ represents the Gross Domestic Product of the agro-industrial aggreagte (III), where *k = 1, 2, 3*. Agriculture with *k=1*, Livestock with *k=2*, and Forestry, fishing, and aquaculture with *k=3*. *q* represents the sectors belonging to the agribusiness industry (5, 6, 7, and 8). The total Gross Domestic Product of Aggregate III is calculated using Equation (7):

$$PIB_{III} = \sum_{k=1}^{3} PIB_{IIIk} \tag{7}$$

In Equation (7), PIB_{III} = PIB of Aggregate III, which is the agro-industrial Gross Domestic Product, calculated as the sum of the individual PIB (GDPs) of the industrial sectors related to the primary sectors of agribusiness.

Aggregate (IV) encompasses the trade and services sectors within agribusiness that correspond to sectors 25 through 42 in the input-output matrix for the regions of Paraná and the Rest of Brazil. The Gross Domestic Product of the services aggregate (IV) will be proportional to the share of the total value of the agricultural and agro-industrial sectors in the value added at market prices of the trade and services sectors in domestic final demand *(DFD)*, which is the value of global final demand *(DFD)* minus net taxes (IIL_{DF}) and imports (IM_{DF}); thus, we have that $DFD = DFG - IIL_{DF} - PI_{DF}$ The value added at market prices for the service sectors is calculated using Equation (8):

$$VA_{PMS} = \sum_{s=25}^{42} VA_{PMs} \tag{8}$$

In Equation (8), the elements are defined as: VA_{PMS} is the value added at market prices for the service sectors, *m* is the number of service sectors (sectors 25 through 42 of the twenty-six sectors in the input-output matrix), and VA_{PMs} is the value added at market prices for each service sector. The Gross Domestic Product (GDP) of the agribusiness aggregate (IV) will be calculated as the share of agribusiness sectors in domestic final demand multiplied by the total Gross Domestic Product of the service sectors, as estimated in Equation (9):

$$PIB_{IV} = \left(VA_{PMS} - \sum_{s=25}^{42} \sum_{k=1}^{3} z_{ks} \times CVA_k \right) \times \left(\frac{\sum_{k=1}^{3} DF_k + \sum_{q=5}^{8} DF_q}{DFD} \right) \tag{9}$$

In Equation (9), PIB_{IV} is the Gross Domestic Product of aggregate IV, VA_{PMS} is the Value Added at Market Prices of the service sectors, *n* is the number of primary agricultural sectors, *q* is the number of agro-industrial sectors, DF_k is the final demand of the Agriculture sector *k=1*, Livestock sector *k=2*, and Forestry, Fishing, and Aquaculture sector *k=3*, DF_q is the final demand of the agro-industrial sectors, and *m* is the number of service sectors (sectors 25 to 42 of the input-output matrix, Table 1).

The total PIB(GDP) of agribusiness is the sum of its aggregates, which is:

$$PIB_{AGRO} = PIB_I + PIB_{II} + PIB_{III} + PIB_{IV} \tag{10}$$

In Equation (10), PIB_{AGRO} is the Gross Domestic Product of agribusiness, and the other elements of the equation were calculated and defined previously.

The calculations were performed for the two regions, Paraná and the Rest of Brazil, using data from regional matrices and various economic, social, and environmental variables, similar to those presented for the assessment of agribusiness based on Gross Domestic Product (PIB/GDP).

Results and Discussion

Table 2 presents the results of the economic, social, and environmental assessment of agribusiness in the state of Paraná in 2020, and Figure 1 illustrates the contribution of the aggregates for each variable of interest. The relative importance of agribusiness in Paraná's economy is evidenced by the percentages presented in Table 1. In 2020, agribusiness accounted for approximately 44% of the state's total production, 41% of value added, 32% of taxes collected, 36% of compensation paid, and 49% of jobs generated. These figures demonstrate that nearly half of Paraná's economy is directly or indirectly linked to agribusiness, participating in the several production chains that make up this complex system, highlighting its economic and social relevance. On the other hand, Agribusiness accounted for 78% of carbon dioxide equivalent (CO_{2eq}) emissions and 96% of the blue water consumed by the production system, indicating significant environmental impact.

Table 2. Results of the environmental assessment of Agribusiness in Paraná, 2020.

Variable	Aggregates				(E) Total Agribusiness	(F) Total Paraná[5]	(G) % (E/F)
	(A) Inputs	(B) Agriculture and Livestock	(C) Industry	(D) Services			
Production[1]	8.52	94.00	179.86	129.73	412.11	936.15	44%
Value added[1]	4.04	56.23	33.18	80.58	174.03	426.37	41%
Taxes[1]	0.40	4.40	8.29	3.63	16.71	52.32	32%
Compensation[1]	1.55	7.31	19.09	41.83	69.79	191.88	36%
Jobs[2]	62.05	1597.77	664.71	1195.79	3520.32	7129.19	49%
GHG[3]	0.78	61.39	5.38	2.39	69.94	90.08	78%
Water[4]	4.35	855.80	234.51	0.79	1095.45	1146.43	96%

[1]Monetary values in billions of reais, [2]Jobs in thousands, [3]Greenhouse gases (GHG) in megatons, [4]Water in millions of cubic meters, [5]Total for the production system.

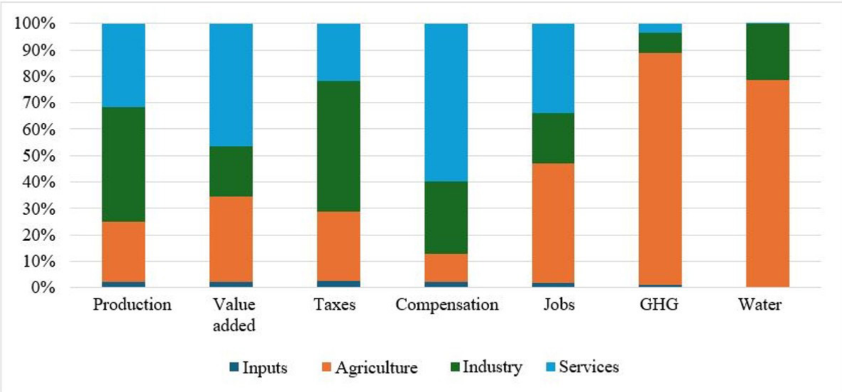

Figure 1. Share of aggregates in the total values of Agribusiness for Paraná, 2020.

An analysis of Table 1 shows that, for the Production variable, the sector with the largest contribution is Industry, with a value of R$ 179.86 billion, followed by Services with R$ 129.73 billion. This indicates that industry is the most important sector in terms of production within Paraná's agribusiness. Regarding Value Added, the Services sector stands out as the leading sector, contributing R$ 80.58 billion, highlighting its importance in generating wealth in the state. Considering the results for tax revenue generation, Industry again stands out as the largest contributor, with R$ 8.29 billion, reflecting its fiscal relevance with the largest share of Agribusiness tax revenue (Figure 1). For the Compensation variable, the Services sector is the most significant, distributing R$ 41.83 billion in wages and benefits, which highlights its fundamental role in generating income for workers. As for Jobs, Agriculture is the predominant aggregate, employing 1,597,77 thousand people, highlighting its social importance as the largest generator of jobs in Paraná's agribusiness. Environmental impacts occur mainly in rural areas, Agriculture is the primary aggregate in terms of both greenhouse gas (GHG) emissions and water consumption, emitting 61.39 megatons of GHG and consuming 855.80 million cubic meters of water, with the largest shares of these impacts, according to Figure 1.

Agribusiness is a cornerstone of the state of Paraná, contributing significantly to production, wealth creation, tax revenue, and income distribution. Socially, the sector plays a vital role as the largest source of jobs, particularly in agriculture and livestock, which benefits thousands of families and sustains rural communities. However, the analysis also reveals the environmental challenges associated with production processes, with 78% of the state's total greenhouse gas emissions and 96% of its total water consumption attributed to Agribusiness, highlighting the need to implement sustainable practices. The adoption of more efficient technologies, responsible management of natural resources, and mitigation of environmental impacts are essential to ensuring the sustainability of agribusiness and environmental preservation.

Table 3 presents the results of the economic, social, and environmental assessment of Agribusiness in the rest of Brazil, Figure 2 illustrates the contribution of the aggregates for each variable of interest. The relative importance of agribusiness in the economy of the rest of Brazil is evidenced by its substantial contributions across various sectors. Agribusiness accounts for 24% of total production and 21% of value added, demonstrating its economic importance. Furthermore, it generates 28% of jobs, highlighting its social significance. In terms of tax revenue, agribusiness contributes 24% of taxes, and in terms of compensations, its share is 19%.

Considering the absolute values for Agribusiness in the Rest of Brazil in Table 3, the following main aggregates can be identified for each variable: for the Production variable, the predominant aggregate is Industry, with R$ 1,111.68 billion. In terms of Value Added, the Services sector is the most significant, with R$ 637.88 billion. For Taxes, Industry holds the leading position, contributing R$ 52.17 billion. Regarding Compensations, the Services sector stands out again, with R$ 346.51 billion. As for Jobs, Agriculture is the most significant sector, generating 10,466,860 thousands jobs. In terms of Greenhouse Gases (GHG), Agriculture is predominant, emitting 563.59 megatons. In terms of water use, Agriculture also stands out as the largest consumer, with 13,982.05 million cubic meters.

From an economic perspective, agribusiness is of great importance to the rest of Brazil, making significant contributions to production, value added, taxes, and compensations. From a social perspective, job creation in the agricultural sector underscores the importance of agribusiness to the labor market, providing stability and income for many families. From an environmental perspective, there are considerable impacts; agriculture is the primary contributor to greenhouse gas emissions and water use. These data highlight the need for more sustainable practices to mitigate adverse environmental effects, while maintaining agribusiness' essential economic contribution to the rest of Brazil.

Table 3. Results of the environmental assessment of Agribusiness in the rest of Brazil, 2020. Aggregates: (I) Inputs, (II) Agriculture and Livestock, (III) Industry, and (IV) Services.

Variable	Aggregates				Total Agribusiness	Total Rest of Brazil[5]	%
	Inputs	Agriculture and Livestock	Industry	Services			
Production[1]	243.39	671.93	1111.68	976.25	3003.26	12370.19	24%
Value added[1]	83.04	361.70	235.35	637.88	1317.97	6168.57	21%
Taxes[1]	11.52	22.89	52.17	25.45	112.02	460.53	24%
Compensation[1]	30.96	46.99	133.04	346.51	557.51	3000.47	19%
Jobs[2]	1290.70	10466.86	4875.55	9172.03	25805.14	92125.49	28%
GHG[3]	37.36	563.59	30.88	9.85	641.67	1073.08	60%
Water[4]	561.03	13982.05	1487.20	7.85	16038.13	16791.38	96%

[1]Monetary values in billions of reais, [2]Jobs in thousands, [3]Greenhouse gases (GHG) in megatons, [4]Water in millions of cubic meters, [5]Total for the production system.

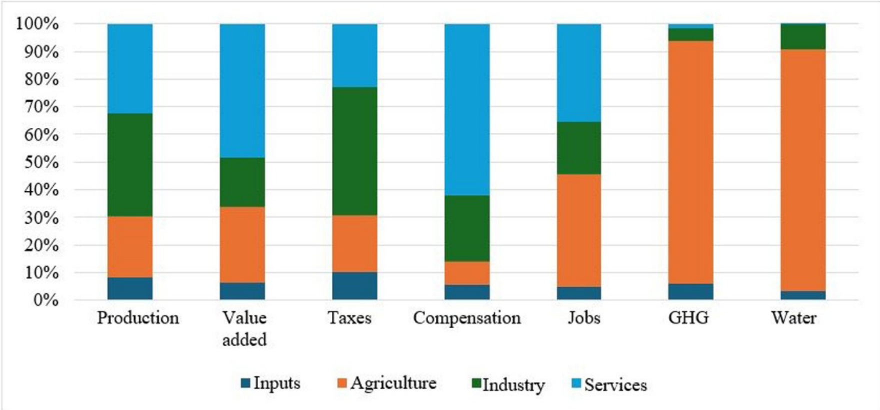

Figure 2. Share of aggregates in the total values of Agribusiness for the Rest of Brazil, 2020.

A comparative analysis of the importance of agribusiness to the two regions covered by the study indicates that, in 2020, the state of Paraná was more dependent on agribusiness in economic and social terms and also experienced greater relative environmental impacts. Paraná accounted for 41% of the value added and 49% of the jobs created across the various Agribusiness supply chains, compared with 21% and 28% in the rest of Brazil, respectively. In addition, 96% of blue water consumption in the two regions occurred in Agribusiness, and approximately 78% and 60% of GHG emissions occurred in Paraná and the rest of Brazil, respectively. The absolute figures and the share of these variables in the regions analyzed do not allow for conclusions to be drawn regarding the sustainability of Agribusiness, which underscores the importance of developing indicators that can be evaluated in relation to agribusiness and the economy, as well as between Paraná and the rest of Brazil.

Table 4 presents the results of the estimates for economic, social, and environmental indicators for the Agribusiness sector in Paraná and the rest of Brazil, as well as for the respective regional economies in 2020. An analysis of the indicators shows that agribusiness in Paraná performed below the state economy's average, as value generation per real of production (0.42) was lower than the 0.46 observed for the economy as a whole; Similarly, labor productivity (R$ 49.400/worker) and average annual income (R$ 19.800/worker) were below the state economy's levels of R$ 59.800 and R$ 26.900, respectively. On the other hand, the agribusiness sector in Paraná generated more jobs per R$ 1 million in production (8.54 jobs) than the state average (7.62 jobs), which is a positive development from a social perspective. In environmental terms, agribusiness in Paraná showed higher relative blue water consumption (6.294 m^3 per R$ 1 million) and greenhouse gas emissions (401.9 t CO_2eq per R$ 1 million) than the state economy as a whole (2.688 m^3 and 211.3 t CO_2eq per R$ 1 million), while the per-worker indicators were lower for the Paraná economy, at 160.81 m^3 and 12.64 t CO_2eq per worker.

In the rest of Brazil, the agribusiness income per unit of production 0.44 was below the economic aggregate's figure of 0.50; labor productivity, measured in value added per job (R$ 51.100), and average income (R$ 21.600) were lower than the R$ 66.960 and R$ 32.570 recorded in the economy. Job creation per unit of output is higher in agribusiness, estimated at 8.59 jobs per R$ 1 million, compared with 7.45 in the economy. In environmental terms, agribusiness in the rest of Brazil consumes 12.169 m^3 of water and emits 486.9 t CO_2eq per R$ 1 million in income (Gross Domestic Product), figures that exceed the estimated values of 2.722 m^3 and 173.96 t CO_2eq for the regional economy. When considering environmental variables per worker, the agribusiness figures for the rest of Brazil are also higher than those for the state economy.

Table 4. Sustainability indicators for the Agribusiness in the state of Paraná and the rest of Brazil, 2020. Aggregates: (I) Inputs, (II) Agriculture and Livestock, (III) Industry, and (IV) Services.

Sustainability indicator		Aggregates				Agribusiness	Economy
		I	II	III	IV		
Agribusiness in Paraná	Revenue per unit of output[1]	0.47	0.60	0.18	0.62	0.42	0.46
	Labor productivity (income per worker)[2]	65.13	35.19	49.91	67.39	49.44	59.81
	Average worker's income[3]	25.01	4.58	28.72	34.98	19.82	26.91
	Jobs by unit of output[4]	7.28	17.00	3.70	9.22	8.54	7.62
	Blue water consumption per unit of income[5]	1075.95	15218.78	7068.34	9.80	6294.45	2688.82
	Emissions per unit of income[6]	193.51	1091.79	162.08	29.63	401.88	211.27
	Blue water consumption per worker[7]	70.07	535.62	352.81	0.66	311.18	160.81
	Emissions per worker[8]	12.60	38.43	8.09	2.00	19.87	12.64
Agribusiness in the Rest of Brazil	Revenue per unit of output[1]	0.34	0.54	0.21	0.65	0.44	0.50
	Labor productivity (income per worker)[2]	64.34	34.56	48.27	69.55	51.07	66.96
	Average annual income per worker[3]	23.99	4.49	27.29	37.78	21.60	32.57
	Jobs by unit of output[4]	5.30	15.58	4.39	9.40	8.59	7.45
	Blue water consumption per unit of income[5]	6756.36	38656.11	6319.08	12.31	12168.80	2722.09
	Emissions per unit of income[6]	449.93	1558.15	131.19	15.44	486.86	173.96
	Blue water consumption per worker[7]	434.67	1335.84	305.03	0.86	621.51	182.27
	Emissions per worker[8]	28.95	53.85	6.33	1.07	24.87	11.65

[1] R$ of value added per R$ 1 of output. [2] Thousands of reais (R$) per year. [3] Thousands of reais (R$) per year. [4] Number of jobs per R$ 1 million. [5] Cubic meters per R$ 1 million. [6] Tons of CO_{2eq} per R$ 1 million. [7] Cubic meters per job. [8] Tons of CO_{2eq} per job

A comparative analysis of agribusiness in Paraná and the rest of the country shows that economic indicators such as income per unit of output (0.42 versus 0.44), labor productivity in terms of income per job (R$ 49.400 versus R$ 51.100), and average worker income (R$ 19.800 versus R$ 21.600) were lower in the state's economy. In contrast, Paraná's agribusiness sector outperforms the rest of Brazil in terms of environmental efficiency, consuming just under half as much blue water per million generated (6.294 m^3 versus 12.169 m^3) and emitting less CO_2eq (401.9 t versus 486.9 t) per R$1 million in revenue. In addition, the agribusiness sector in Paraná emitted approximately 19.87 t CO2eq per job, compared with 24.87 t CO2eq per job in the rest of Brazil.

A closer look at the results for the four agribusiness aggregates in Paraná reveals that Inputs (I) and Services (IV) posted the best results in terms of value added (0.47 and 0.62) and labor productivity (R$ 65.100 and R$ 67.400 per worker). In social terms, the Services sector generated the highest incomes (R$ 34,980) and had moderate job creation capacity (9.22 jobs per R$ 1 million), while the Agricultural sector (II) combines high job creation (17.0 jobs) with low average incomes (R$ 4.580). From an environmental perspective, the Agriculture and Livestock segment stands out for its consumption of 15.219 m^3 of blue water and 1.091.8 t CO_2eq per R$ 1 million in revenue, in contrast to the Services segment, which consumes only 9.8 m^3 and emits 29.6 t CO_2eq. The Industry (III) ranks in the middle range in almost all categories, but its value added per unit of output (0.18) and relative employment generation (3.7 jobs per R$ 1 million) were lower than the state economy's figures.

In the rest of Brazil, the profile of agribusiness aggregates indicates that Inputs (I) and Services (IV) lead in terms of value added per unit of production and labor productivity, while the Agriculture and Livestock (II) has the greatest relative environmental impacts, with consumption of 38.656 m^3 of blue water and 1.558.1 t CO_2eq per R$ 1 million in revenue (value added). The Services (III) aggregate in the rest of Brazil recorded low environmental intensity (12.3 m^3 and 15.4 t CO_2eq) and high average output (R$ 37.800), while Industry (III) remains at average levels of productivity (R$ 48.300 per worker) and impact (6.33 t CO_2eq per worker).

Paraná's agribusiness sector demonstrates strengths in terms of relative job creation and environmental efficiency compared to the rest of Brazil, but it still faces challenges in matching the state and national economies in terms of value added and labor productivity. In the Brazilian context, the social importance of job creation coexists with low water efficiency and high carbon emissions, highlighting the need to balance income generation, social equity, and the conservation of natural resources in the region.

Based on the estimated economic, social, and environmental indicators, it can be concluded that, although Paraná's agribusiness sector outperforms the rest of Brazil in environmental terms, its labor productivity and value added are in line with the state and national averages. Agriculture and Livestock, from Aggregate II, emerged as the main critical area in environmental terms, combining intense water consumption with high emissions, while Services and Inputs represent potential drivers for increasing value added and reducing environmental impacts. In order to enhance the economic and social impacts and mitigate the negative environmental effects of the state's agribusiness, public policies and private investments must converge on the training the rural workforce, through training in precision agriculture, property management, and value chains; on the dissemination of technologies that reduce blue water consumption, such as the use of more efficient irrigation systems, remote sensing, and water monitoring software; and on financing renewable energy sources to power production processes, thereby reducing CO_{2eq} emissions. Furthermore, tax incentives for adopting agro-ecological practices, credit lines tied to low-carbon metrics and certifications, can mobilize private capital for the use of agro-forestry systems, environmental preservation, the restoration of deforested areas, and the use of bioinputs, simultaneously enhancing the economic efficiency, social equity, and environmental resilience of agribusiness in the two regions analyzed.

Conclusions

Agribusiness in Paraná played a significant role in the state and national economies in 2020, accounting for 44% of total production, 41% of value added, 32% of tax revenue, 36% of compensations, and 49% of jobs created in the state. These figures show that nearly half of Paraná's economy is directly linked to agribusiness, with agriculture and livestock standing out in job creation and industry and services in production and compensation. Compared to the rest of Brazil, where agribusiness accounted for 24% of production and 21% of value added, Paraná demonstrates greater economic and social dependence on this sector, which reinforces its centrality in regional production chains.

An analysis of sustainability indicators reveals that agribusiness, both in Paraná and in the rest of Brazil, performs worse environmentally than the economy. In Paraná, blue water consumption per unit of revenue in agribusiness was 6.294 m^3, more than double the state economy's average (2.688 m^3), and greenhouse gas emissions reached 401.9 t CO_2eq per R$ 1 million, compared to 211.3 t CO_2eq for the economy. In the rest of Brazil, agribusiness' environmental indicators were even more intense, with water consumption of 12.169 m^3 and emissions of 486.9 t CO_2eq per R$ 1 million in revenue, exceeding the regional economy's average values. These data indicate that agribusiness, while economically essential, places greater pressure on natural resources and the climate.

When comparing agribusiness in Paraná with that of the rest of Brazil, it is evident that the sector in Paraná is relatively more sustainable from an environmental standpoint. Blue water consumption and CO_2eq emissions per unit of income in Paraná are approximately half those recorded in the rest of the country. In addition, emissions per worker are also lower in Paraná (19.87 t CO_2eq) compared to 24.87 t CO_2eq in the rest of Brazil. However, Paraná's economic indicators, such as income per unit of output (0.42 vs. 0.44), labor productivity (R$ 49.400 vs. R$ 51.100) and average income (R$ 19.800 vs. R$ 21.600), are slightly lower, suggesting that Paraná's greater environmental efficiency has not yet translated into greater economic efficiency.

Based on the results obtained in the study, it is possible to outline concrete guidelines for public policies and business strategies aimed at promoting more sustainable and competitive agricultural production chains. The promotion of public policies and private investments aimed at training the rural workforce, adopting precision agriculture technologies, and efficiently managing natural resources. The implementation of more economical irrigation systems, the use of remote sensing for water monitoring, and the financing of renewable energy sources are fundamental strategies for reducing water consumption and carbon emissions. In addition, tax incentives and credit lines linked to sustainability metrics can stimulate agro-ecological practices, the restoration of degraded areas, and the use of bioinputs, simultaneously promoting economic gains, social inclusion, and environmental conservation.

In the business sector, it is strategic to invest in precision agriculture, efficient water management, the use of bioinputs and renewable energy sources, as well as to implement environmental monitoring systems and sustainable certifications. Coordination between the state, the productive sector, and civil society is essential to transform Paraná's environmental gains into competitive advantages, promoting a development model that balances economic growth, social inclusion, and environmental conservation.

New research on the topic could focus on the scale of agribusiness across states and the interaction between regions in terms of economic dependence on inputs and natural resources (virtual water and emissions generation). In addition, new studies of specific global supply chains, such as soybeans and animal protein, can improve understanding of regional and interregional economic, social, and environmental impacts.

Authors contribution

UASF: Conception and design of the study, Methodology, Formal analysis and interpretation, Writing of the manuscript, and Critical review. RLL: Analysis and interpretation, Writing of the manuscript, and Critical review. CAGJ: Analysis and interpretation, Writing the manuscript, and Critical review. PPS: Writing the manuscript and Critical review. EGZE: Writing of the manuscript, Critical review.

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Data availability:

Research data is not available.

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