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How Big Is the Biomass-Based Bioeconomy in National Economies? Concept, Method, and Evidence from Brazil

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Abstract: Measuring the contributions of the bioeconomy depends on the concept and method used. The concept of bioeconomy linked to biomass is widely used, and estimating the bio-based share in sectors, activities, or products is a limitation and a challenge. Therefore, the present study aims to propose a method for measuring the contributions of biomass-based bioeconomy (BmBB) by tracking the direct and indirect flows of biomass embodied in goods and services for intermediate and final demand. Our analysis focused on measuring the impact of BmBB on the gross value of production (GVP) and the value added to biomass through incremental improvements to the input–output models. The development and application of the method used data from Brazil's input–output matrices from 2010 to 2018. The results suggest that the BmBB's GVP shared 5.75% of the GDP, on average, between 2010 and 2018 and more than 6% in recent years. The BmBB accounted for 4.87% of the Brazilian economy's added value. The 'Biomass' aggregate, comprising agriculture, livestock, and forestry, contributes 78.3% of GVP and 8.0% of BmBB's added value. The opposite occurs with the 'BioAgroindustry' aggregate, whose GVP was only 12.3% but contributed 81.5% of the BmBB's value added. The significant volume of direct sales of ''Biomass' in the final demand of households and the foreign market may explain this situation. We concluded that the proposed method contributes to measuring the BmBB, capturing the biomass share involved in producing, manufacturing, and consuming goods and services.

Keywords: bio-based economy; biomass share; gross value of production; value added; input–output model; agribusiness

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1. Introduction

Despite the efforts made by various countries to promote the bioeconomy, measuring its contribution continues to face several challenges. The difficulties start with conceptual limitations and progress to methods, data, and indicators (Leavy et al., 2024). Contemporary discussions on bioeconomy are based on three conceptual approaches or visions: (i) bioresources or biomass, (ii) biotechnology, and (iii) bioecology (Befort, 2020; Bugge

et al., 2016; Vivien et al., 2019). However, the lack of precise definitions and boundaries for each concept is a barrier to its measurement.

In a particular proposition, Leavy et al. (2024) define three concepts: (i) bioeconomy-based biomass (BmBB) as the substitution of non-renewable resources for renewable biological resources with lower environmental impacts, thereby indicating greater sustainability (Bastianoni et al., 2009; Oliveira Neto et al., 2018). This approach is based on animal and plant biomass from the primary economic sectors as input for adding value; (ii) biotechnology bioeconomy (BtBB) involves utilizing biodiversity through knowledge, innovation, and processes to address societal challenges related to human health, agriculture, industry, food and nutrition, and environmental protection, among others; (iii) the biosphere-based bioeconomy (BsBB) approach considers the economic system as an open system that interacts with the biophysical system (biosphere) as well as its impacts, providing substrate for the development and maintenance of biodiversity, with input of both previous approaches.

According to these concepts, the efforts to measure the economic contributions of the bioeconomy are limited to a few countries and focus on the biomass-based bioeconomy (Leavy et al., 2024). The future of a sustainable bioeconomy requires heavy investment in technologies that expand the use and transformation of biomass, especially in the chemical and energy sectors (Kircher, 2019). Due to its natural endowments, the Brazilian economy has historically been linked to biomass production for food, energy, and fibers (CNA, 2023), meeting domestic and foreign demand (Montoya et al., 2021, 2023). Brazil ranks first in producing vegetable biomass, such as soybeans and sugar cane, and animal biomass, such as chicken, beef, and pork meat, and is a large net exporter of biomass (FAO, 2022). However, aiming to boost biodiversity, the Brazilian government launched the Bioeconomy Brazil—Sociobiodiversity Program. The program seeks to encourage the participation of smallholder farmers, indigenous peoples and communities, and their enterprises in productive arrangements involving the concept of the bioeconomy (MAPA, 2019), adding value via industrial transformation, biotechnological solutions, or process sustainability (CNI, 2020).

However, studies measuring the contributions of the Brazilian bioeconomy are scarce. Some of these studies suggest that the bioeconomy accounted for 13.2% of Brazil's GDP in 1995, 12.9% in 2011 (van de Pas, 2015), 13.8% in 2016 (Silva et al., 2018), and 19.6% in 2019 (Lima & Pinto, 2022b; Pinto & Lima, 2022). These studies are based on input–output modeling, the method most frequently used to measure national bioeconomies, which is subject to some limitations (Highfill & Chambers, 2023; Leavy et al., 2024). One of the main limitations lies in estimating the weighting of the bio-based share, i.e., the relative share of biomass in activities, products, or economic sectors. Different strategies have been used to estimate the bio-based share, such as official statistical data (D'Adamo et al., 2022), product and activity classification systems (Lazorcakova et al., 2022; Piotrowski et al., 2018, 2019; Robert et al., 2020; Ronzon et al., 2017), scientific literature (Ronzon et al., 2022), or the opinion of sectoral experts (Capasso & Klitkou, 2020). Others fully account for the primary sectors, such as agriculture, livestock, forestry, and fisheries, as fully belonging to the bioeconomy (Efken et al., 2016). However, some of these approaches lead to a methodological equivalence of the BmBB to the concept of agribusiness (Silva et al., 2018; van de Pas, 2015), which compromises the measurement of the actual value of the BmBB.

Given the scarcity of studies and the need to overcome methodological limitations, this study aims to propose a method for measuring the contributions of biomass-based bioeconomy (BmBB) by tracking the direct and indirect flows of biomass embodied in goods and services for intermediate and final demand. Our analysis will focus on measuring the BmBB contributions from the gross value of production (GVP) and the value added to biomass. Considering the high level of sectoral interdependence in the economy, biomass

can be found to have a greater or lesser intensity in production, manufacturing, and consumption processes. The proposed model innovates (i) by tracking biomass from primary sectors and valuing its transformations in the manufacturing and service sectors through the value-added perspective and (ii) by incorporating the intermediate and final goods and services of the economic system, considering the sectoral forward and backward linkages based on direct and indirect sales and purchases of biomass as an input–output estimate of the BmBB flows in the economic system. Therefore, the values attributed to the BmBB are assumed to be distributed in the intermediate and final demand of the input–output model (IOM). The methodological procedures lead to an unprecedented and comprehensive database from which it is possible to measure the economic, social, and environmental impacts of the BmBB, avoiding the false equivalence between the value of the bioeconomy and agribusiness.

After this Introduction, the article is organized as follows: the Materials and Methods section outlines the methodological procedures, focusing on how the biomass-based bioeconomy (BmBB) is derived from input–output flows, analyzing sales in final demand and the gross value product (GVP) of the BmBB. It applies an extended input–output model to measure BmBB, estimate its value added or GDP, and detail the sources of research data. The Results section is divided into subsections: 'How Big is the Biomass-based Bioeconomy in Brazil?', 'The Composition of BmBB's GVP', and 'Value Added by BmBB'. Finally, the Discussion and Conclusions sections address the size of the bioeconomy along with the methodological contributions and limitations.

2. Materials and Method

2.1. The IOM and the Bioeconomy

The IOM describes the flows of goods and services between sectors in monetary units yearly (Table 1). The intersectoral flows in the model can be represented as follows. Equation (1) indicates that the sum of intermediate demand and final demand equals the total demand for the product of sector *i*. Equation (2) indicates that intermediate consumption plus the contributions of the factors of production (value added) equals the gross output of sector *j*. Finally, Equation (3) indicates the equilibrium condition between supply and demand for each economic sector.

$$\sum_{j=1}^{n} X_{ij} + \sum_{s=1}^{n} Y_{is} = X_i \tag{1}$$

Table 1. Generic Input–Output Matrix.

Sectors		Intermediate Demand ($X_{i,j}$)					Final Demand ($Y_{i,s}$)			GVP (X_i)
		Agriculture (1)	**Sector (2)**	⋯	**Sector (*n*)**	**Total**	**Domestic Consumption (*C*)**	**Exports (*E*)**	**Total**	
Supply of Goods and Services	Agriculture (1)	$x_{1,1}$	$x_{1,2}$	⋯	$x_{1,n}$	$X_{1,j}$	$y_{1,C}$	$y_{1,E}$	$Y_{1,s}$	X_1
	Sector (2)	$x_{2,1}$	$x_{2,2}$	⋯	$x_{2,n}$	$X_{2,j}$	$y_{2,C}$	$y_{2,E}$	$Y_{2,s}$	X_2
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Sector (*n*)	$x_{i,1}$	$x_{i,2}$	⋯	$x_{i,n}$	$X_{i,j}$	$y_{i,C}$	$y_{i,E}$	$Y_{n,s}$	X_n
	Total	$X_{i,1}$	$X_{i,2}$	⋯	$X_{i,n}$	$X_{i,j}$	$Y_{i,C}$	$Y_{i,E}$	$Y_{i,s}$	X_i
Value Added		$v_{r,1}$	$v_{r,2}$	⋯	$v_{r,n}$	$V_{r,j}$				
GVP		X_1	X_2	⋯	X_n	X_j				
Employment		$l_{r,1}$	$l_{r,2}$	⋯	$l_{r,n}$	$L_{r,j}$				

Source: Elaborated by the authors.

Intermediate Demand + Final Demand = Total Demand.

$$\sum_{i=1}^{n} X_{ij} + \sum_{r=1}^{n} V_{rj} = X_j \tag{2}$$

Intermediate Consumption + Primary Factors (Value Added) = Total Supply.

$$X_i = X_j \tag{3}$$

Total Demand = Total Supply.

To extract economic and social aspects related to the BmBB, the intersectoral transactions of intermediate and final demand were highlighted and two line vectors on the primary factors side (Table 1).

The first vector contains the value added ($V_{r,j}$) by each sector, and the second, the employment in each sector ($L_{r,j}$). The solution of the interdependencies between the sectors in the classic IOM can be expressed in a matrix, as shown in Equation (1).

$$X = (I - A)^{-1} Y \tag{4}$$

where X is a vector containing the GVP and Y is the final demand vector. In addition, Equation (4) shows two important matrices:

(a) the matrix of technical coefficients (Equation (5)).

$$\begin{array}{c} A = (a_{ij}) \text{ or} \\ a_{ij} = \frac{x_{ij}}{X_j} \end{array} \tag{5}$$

where the coefficient a_{ij} represents the quantity of inputs from sector i required to produce one unit of output from sector j, and X_j represents the gross output of sector i.

(b) the inverse Leontief matrix (Equation (6)).

$$(I - A)^{-1} \tag{6}$$

where the coefficients of the inverse matrix indicate the production in sector i needed to meet one monetary unit of final demand. The coefficients are also called total production requirements, i.e., the direct and indirect requirements necessary for production. Equation (4) indicates that the final demand is exogenous, and the link with total production is constructed using the inverse matrix.

2.2. Retrieving the BmBB from Input–Output Flows

Biomass originates in the agriculture, livestock, forestry, and fisheries sectors and is aggregated in the Agriculture (1) line vector in Table 1. From the primary sectors, biomass is used to a greater or lesser extent by the various sectors of the economy, making it necessary to retrieve its participation in the forward and backward intersectoral linkages. To do this, the direct (direct effect) and indirect (indirect effect) sales and purchases of BmBB in intermediate demand are calculated for all sectors, retrieving the intersectoral flows of biomass.

2.2.1. Direct Effect

In the IOM, each sector has a production function integrated with the production functions of the other sectors of the economic system. The biomass share in each sector is estimated by the direct effects ($b_{i,j}$), represented in Equation (7).

$$b_{1,1} = x_{1,1} - \left(\frac{x_{1,1}}{X_1}\right) * x_{1,1};\ b_{1,2} = x_{1,2} - \left(\frac{x_{1,2}}{X_1}\right) * x_{2,1};\ \cdots;\ b_{1,n} = x_{1,n} - \left(\frac{x_{1,n}}{X_1}\right) * x_{i,1} \quad (7)$$

For instance, $b_{1,2}$ indicates the direct effect of biomass on Sector (2), defined by the sale of goods and services from Agriculture (1) to Sector (2), $x_{1,2}$, minus the share of biomass that Agriculture (1) bought from Sector (2) in the total input of its activities, $\left(\frac{x_{1,2}}{X_1}\right) * x_{2,1}$, contained in $x_{1,2}$. This circular operation avoids double counting the direct effect and generates a line vector containing the direct effect of BmBB for each intermediate demand sector (Equation (7)).

2.2.2. Indirect Effect

The indirect effect of the BmBB is calculated from the total share of the primary sectors in the total output of their activities, $P_{1,j}$, according to Equation (8).

$$P_{1,1} = \left(\frac{b_{1,1}}{X_1}\right);\ P_{1,2} = \left(\frac{b_{1,2}}{X_1}\right);\ \cdots;\ P_{1,n} = \left(\frac{b_{1,n}}{X_1}\right) \quad (8)$$

For example, $P_{1,2}$ indicates the biomass share of Sector (2) in the total activity of the primary sectors; $b_{1,2}$ indicates the direct effect of the BmBB on Sector (2); and X_1 represents the total value of the BmBB in the primary activities. Equation (8) gives a line vector containing the sectoral biomass share allocated to intermediate demand. Therefore, the indirect effect of the BmBB is represented by Equations (9) and (10).

$$b_{2,1} = (P_{1,1} * x_{2,1}) - \left(\frac{P_{1,1} * x_{2,1}}{X_2}\right) * x_{1,2}\ ;\cdots;\ b_{1,n} = (P_{1,n} * x_{2,n}) - \left(\frac{P_{1,n} * x_{2,n}}{X_2}\right) * x_{i,2} \quad (9)$$

$$b_{i,1} = (P_{1,1} * x_{i,1}) - \left(\frac{P_{1,1} * x_{i,1}}{X_n}\right) * x_{1,n}\ ;\ \cdots;b_{i,n} = (P_{1,n} * x_{i,n}) - \left(\frac{P_{1,n} * x_{i,n}}{X_n}\right) * x_{i,n} \quad (10)$$

For example, $b_{2,1}$ indicates the indirect effect of the BmBB on Sector (2) concerning Agriculture (1), defined by the share of biomass incorporated into Sector (2) sold to Agriculture (1), $(P_{1,1} * x_{2,1})$, minus the share of biomass that Sector (2) bought from Agriculture (1) in relation to the total inputs of its activities, $\left(\frac{P_{1,1} * x_{2,1}}{X_2}\right) * x_{1,2}$. This circular operation avoids double counting the indirect effect and generates a set of line vectors containing the indirect effects of the BmBB on the intermediate demand of each sector, as shown in Equations (9) and (10).

Matrix B (11) is constructed from Equations (7), (9), and (10) and compiles the set of direct and indirect sales and purchases of BmBB in intermediate demand.

$$B = \begin{bmatrix} b_{1,1} & b_{1,2} & \cdots & b_{1,n} \\ b_{2,1} & b_{2,2} & \cdots & b_{2,n} \\ \vdots & \vdots & \cdots & \vdots \\ b_{i,1} & b_{i,2} & \cdots & b_{i,n} \end{bmatrix} \quad (11)$$

The information in Matrix B shows the input–output flows of the BmBB in the intermediate demand of the economic system in an integrated manner. The column vector of Equation (12) indicates the sales of each sector, while the row vector of Equation (13) indicates their purchases.

$$B_j = \begin{bmatrix} B_{1,j} \\ B_{2,j} \\ \vdots \\ B_{n,j} \end{bmatrix} \quad (12)$$

$$B_i = \begin{bmatrix} B_{i,1} & B_{i,2} & \cdots & B_{i,n} \end{bmatrix} \quad (13)$$

The consistency of the method in retrieving the BmBB's intersectoral flows can be verified by meeting the equilibrium condition presented by the components of Matrix B, where the total sum of BmBB sales is equal to the total sum of purchases (Equation (14)).

$$\sum_{j=1}^{n} b_{ij} = \sum_{i=1}^{n} b_{ij} \quad (14)$$

2.2.3. Sales in Final Demand and GVP of BmBB

The IOM database (Table 1) shows Agriculture's (1) direct sales for each component of final demand. However, these sales include non-biomass inputs embodied in the final goods and services. Therefore, it is necessary to retrieve the BmBB share from the sales of Agriculture (1) and the other sectors of the economy.

However, only a fraction of the biomass embodied in intermediate goods and services will support final demand. So, the biomass embodied in final goods and services (BF) can be extracted based on the ratio between the sales of the BmBB contained in the main diagonal of Equation (11) and the corresponding sales of intermediate demand (Table 1), and then multiplied by the components of final demand, as shown in Equation (15).

$$BF = \begin{bmatrix} \frac{b_{1,1}}{x_{1,1}} & 0 & \cdots & 0 \\ 0 & \frac{b_{2,2}}{x_{2,2}} & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & \frac{b_{i,n}}{x_{i,n}} \end{bmatrix} * \begin{bmatrix} Y_{1,s} \\ Y_{2,s} \\ \vdots \\ Y_{n,s} \end{bmatrix} = \begin{bmatrix} BF_{1,S} \\ BF_{2,S} \\ \vdots \\ BF_{n,S} \end{bmatrix} \quad (15)$$

Next, the total sales, or GVP of the BmBB in the economic system as a whole, VBE, is given by the sum of BmBB sales in intermediate demand (Equation (12)) and final demand (Equation (15)), according to Equation (16).

$$VBE = \begin{bmatrix} B_{1,j} \\ B_{2,j} \\ \vdots \\ B_{n,j} \end{bmatrix} + \begin{bmatrix} BF_{1,S} \\ BF_{2,S} \\ \vdots \\ BF_{n,S} \end{bmatrix} = \begin{bmatrix} BE_1 \\ BE_2 \\ \vdots \\ BE_n \end{bmatrix} \quad (16)$$

In the IOM, Equation (16) shows the arrangement of the values attributed to the BmBB in sectoral intermediate and final demand components, as detailed in Table 2.

Table 2. BmBB flow matrix in the IOM.

Sectors		**Intermediate Demand ($B_{i,j}$)**					**Final Demand ($BF_{i,s}$)**			**GVP (*VBE*)**
		Agriculture (1)	**Sector (2)**	...	**Sector (*n*)**	**Total**	**Domestic Consumption (*C*)**	**Exports (*E*)**	**Total**	
Supply of Goods and Services	Agriculture (1)	$b_{1,1}$	$b_{1,2}$	...	$b_{1,n}$	$B_{1,j}$	$bf_{1,C}$	$bf_{1,E}$	$BF_{1.s}$	BE_1
	Sector (2)	$b_{2,1}$	$b_{2,2}$	...	$b_{2,n}$	$B_{2,j}$	$bf_{2,C}$	$bf_{2,E}$	$BF_{2,s}$	BE_2
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Sector (n)	$b_{i,1}$	$b_{i,2}$	...	$b_{i,n}$	$B_{i,j}$	$bf_{i,C}$	$bf_{i,E}$	$BF_{n,s}$	BE_n
	Total	$B_{i,1}$	$B_{i,2}$	...	$B_{i,n}$	$B_{i,j}$	$BF_{i,C}$	$BF_{i,E}$	$BF_{i,s}$	BE_i

Source: Elaborated by the authors.

Considering the deep technological, productive, financial, and business relationships that the BmBB has in the economic system, the flows and transfers of inputs and products

from one sector to another can be grouped according to their productive nature. As such, the BmBB's GVP in its transformation process was grouped into:

(a) Aggregate I—Biomass;
(b) Aggregate II—BioAgroindustry;
(c) Aggregate III—BioTechnology;
(d) Aggregate IV—BioIndustry;
(e) Aggregate V—BioServices.

The sectors comprising the BmBB aggregates can be seen in Appendix A.

2.3. Extended Input–Output Model (EIOM) for Measuring BmBB

Various analyses can be carried out considering that Matrices *B* (Equation (11)) and *BF* (Equation (15)) present the integrated flows of the BmBB in the economic system. One hypothesis is replacing final demand flows with the respective BmBB flows, *BF*, in the IOM. The advantage of incorporating the BmBB into final demand as a demand shock lies in consistently showing the direct and indirect impacts of the BmBB on the economic system (Miller & Blair, 2009).

On the other hand, adopting the hypothesis of inserting biomass flows into intermediate demand as part of primary factors using a line vector makes it possible to measure the intersectoral linkages of BmBB in the economic system (Guilhoto, 2004; Montoya et al., 2021). The advantage of incorporating the BmBB into intermediate demand lies in retrieving the technical coefficients of the BmBB from the inverse Leontief matrix, allowing for a broad analysis of intersectoral linkages.

In this context, it should be noted that our method complements the classic indicators used by Piotrowski et al. (2016) and Scarlat et al. (2015) to measure sales attributed to the bioeconomy. However, our study, by systemically recovering the biomass incorporated into the goods and services of all economic activities of intermediate and final demand, provides a database that makes it possible to assess the impacts of the BmBB on the economic system and vice versa, the different forms of sectoral linkages, and various branching hierarchies. It also allows for assessing different forms of environmental impacts, such as the value chain, technological and structural changes, the international market, and the biomass footprint, among others.

2.4. The Value Added or GDP of BmBB

Obtaining the BmBB's income requires estimating the value added to biomass in each economic sector. To do this, we calculated the technical coefficients of the value added based on Table 1 and Equation (17).

$$V_j = \frac{v_{r,j}}{X_j} \tag{17}$$

where v_{rj} denotes the value added by sector j, X_j is the gross product of sector i, and V_j denotes the technical coefficient of the value added in sector i, by the increase of one monetary unit of production in sector j. Next, we calculate the value added by the BmBB based on Equations (6) and (15), expressed mathematically in Equation (18).

$$VB = V * (I - A)^{-1} BF \tag{18}$$

where VB is the column vector of value added by the BmBB, V represents the matrix of technical coefficients of value added $\frac{v_{r,j}}{X_j}$, $(I - A)^{-1}$ is the Leontief inverse matrix, and BF (Equation (15)) is the matrix of biomass purchases and sales between all economic sectors and the final demand.

2.5. About the Data

The data used in this research were taken from the 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, and 2018 input–output matrices (IPMs) estimated by Guilhoto and Sesso Filho (2005, 2010). The Brazilian Institute of Geography and Statistics (IBGE) has published the Brazilian matrices over the last few decades. It is the most complete continuous database of economic data available in the country (IBGE, 2024). The level of disaggregation of Brazil's input–output matrices is 67 sectors, and the data are in BRL million basic prices of 2018, based on the GDP deflator. These are the most up-to-date input–output data available for Brazil.

3. Results

3.1. How Big Is the Biomass-Based Bioeconomy in Brazil?

In some ways, the BmBB is the same as agribusiness. The key primary sectors are common to both. Thus, the importance of agribusiness and the potential of the BmBB encourage relativizing the contributions of these two driving forces in the Brazilian economy. Table 3 shows the results of the GVP of the BmBB, agribusiness, and the Brazilian economy. In 2010, the BmBB's GVP or turnover was BRL 590.2 million, increasing to BRL 722.3 million in 2018. The BmBB's growth rate was 2.52% p.a. in the period, more than three times higher than that of agribusiness (0.72%) and the Brazilian economy (0.81%).

Table 3. GVP of BmBB, agribusiness, and the Brazilian economy, 2010 to 2018, in BRL Million and percentage (base = 2018).

Dimensions	Gross Value of Production, BRL Million									Annual Growth Rate %
	2010	2011	2012	2013	2014	2015	2016	2017	2018	
BmBB	590.2	646.4	662.0	700.7	694.8	700.5	722.2	694.6	722.3	2.52%
Agribusiness	2716.5	2808.4	2839.3	2891.4	2860.2	2848.4	2880.2	2823.9	2877.3	0.72%
Brazil	11,259.8	11,718.4	12,006.9	12,367.0	12,458.2	11,975.5	11,419.6	11,515.2	12,010.0	0.81%
BmBB/ Agribusiness (%)	21.73	23.02	23.32	24.23	24.29	24.59	25.08	24.60	25.10	
BmBB/ Brazil (%)	5.24	5.52	5.51	5.67	5.58	5.85	6.32	6.03	6.01	

Source: Elaborated by the authors based on the research data.

In relative terms, the BmBB's importance in the national economy increased from 5.24% to 6.01%. Concerning agribusiness, the BmBB is gaining more economic relevance as it accounted for 21.73% in 2010 and rose to 25.10% in 2018. Therefore, it can be deduced that agribusiness's economic dynamism has increased based on the production and value added to renewable biomass inputs.

The BmBB's GVP comprises the total GVP of the 67 sectors of the Brazilian economy. Figure 1 shows the mean values and standard deviation of sectoral GVP from 2010 to 2018. Over the nine years, only six sectors had annual GVP higher than Brazil's average GVP of the BmBB. The restricted calculation of the BmBB based on biomass makes the primary sectors more relevant. Thus, the Agriculture (1) and Livestock (2) sectors had an average GVP of BRL 348.0 million and BRL 149.8 million, respectively, making them the only sectors with an average GVP above the mean + 1SD. Together, the average GVP of these sectors corresponded to 73% of the average GVP of Brazil's BmBB between 2010 and 2018.

Other sectors with a remarkable share in the BmBB's GVP were Forestry, Fishery (3), Slaughtering, Meat Products, Milk, and Fish (8), Other Food Products (10), and Wholesale and Retail Services (41). The average GVP of these sectors ranged from BRL 40.8 million (6%) for Sector (8) to BRL 26.7 million (3.9%) for Sector (41). Together, these four sectors

produced an average of 20.7% of Brazil's BmBB GVP. The other sectors had an average GVP below the sectoral average of Brazil's BmBB between 2010 and 2018. Together, the GVP of the remaining 61 sectors represents less than 7% of the average GVP of the BmBB. Even so, it is worth highlighting the contribution of sectors involved in the provision of Land Transportation Services (42) and Financial Intermediation and Insurance (52), as well as the Sugar Production and Refining Sector (9), which is also biomass-intensive.

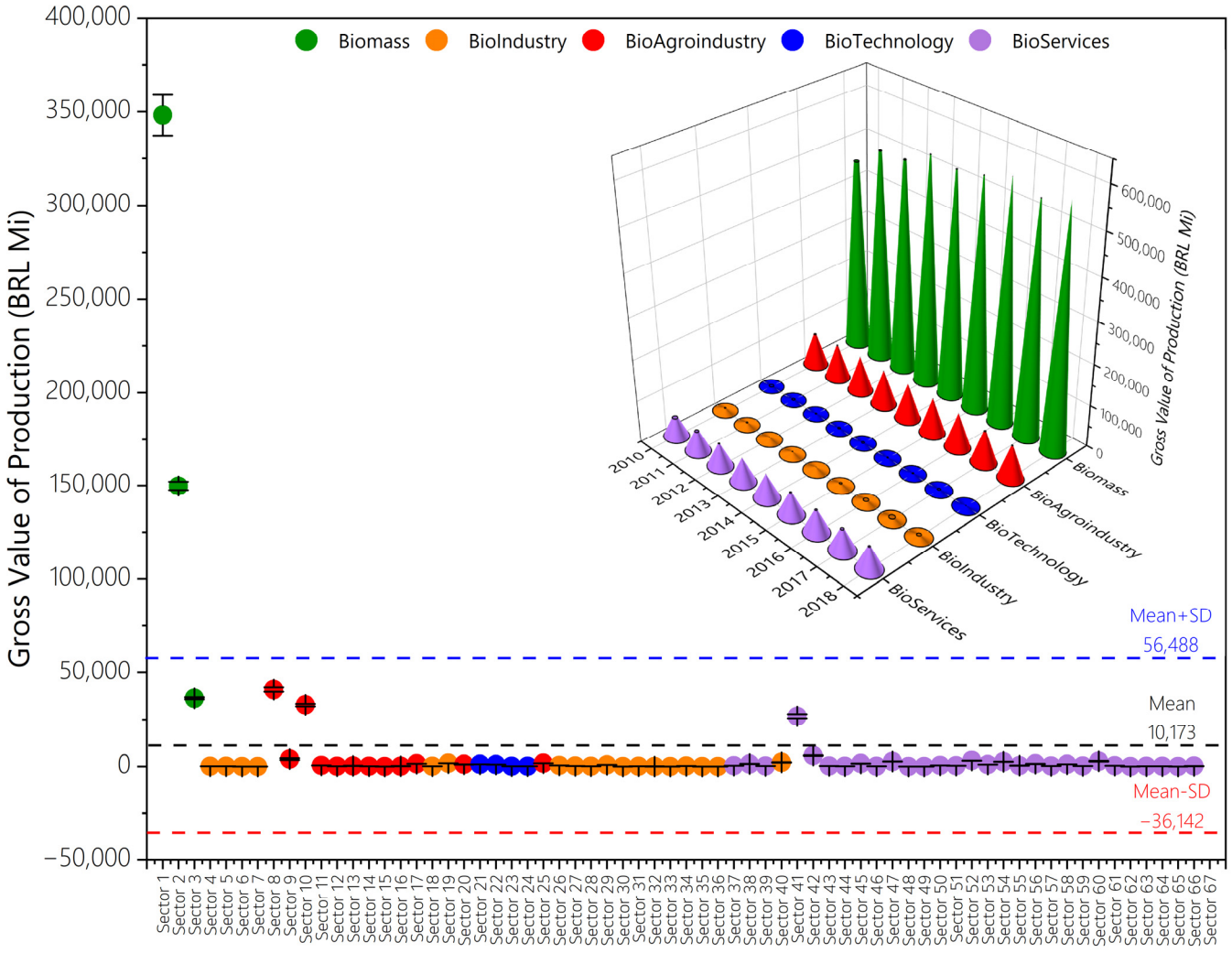


Figure 1. Mean ± standard error of GVP by sector and the evolution in the main aggregates of the BmBB, Brazil, 2010 to 2018—in BRL million (base = 2018). Source: Elaborated by the authors based on research data.

The inner detail of Figure 1 shows the evolution of the GVP of the five BmBB aggregates. The 'Biomass' aggregate has the largest relative share in the composition of the BmBB's GVP, with average values of BRL 534.2 million between 2010 and 2018; relatively, this aggregate share was between 77% and 80% of the BmBB's GVP. 'BioAgroindustry' is the aggregate with the second largest relative share. Between 2010 and 2018, it had an average annual GVP of BRL 83.4 million, between 11% and 13% of the BmBB's GVP. With an average yearly GVP of BRL 54.6 million, 'BioServices' has consolidated its position as the BmBB's third largest GVP, accounting for 8 and 9%. 'BioTechnology' and 'BioIndustry' accumulated less than 2% of the BmBB's GVP over the period analyzed.

3.2. The Composition of BmBB's GVP

The economic dynamics of the BmBB begin with the production of biomass. The biomass produced by the sectors in the 'Biomass' aggregate is sold directly to the sectors in the other aggregates and final demand. The results show that the most significant volume of direct sales of biomass is to the 'Agroindustry' sectors, with an average value of BRL 246,448 million and 82.9% of direct sales (see the thickness and direction of the arrows of the intermediate flows shown in Figure 2 and the data in Tables 4 and 5). The biomass flow between the two aggregates was relatively stable between 2010 and 2018, given the SD = BRL 8.0 million.

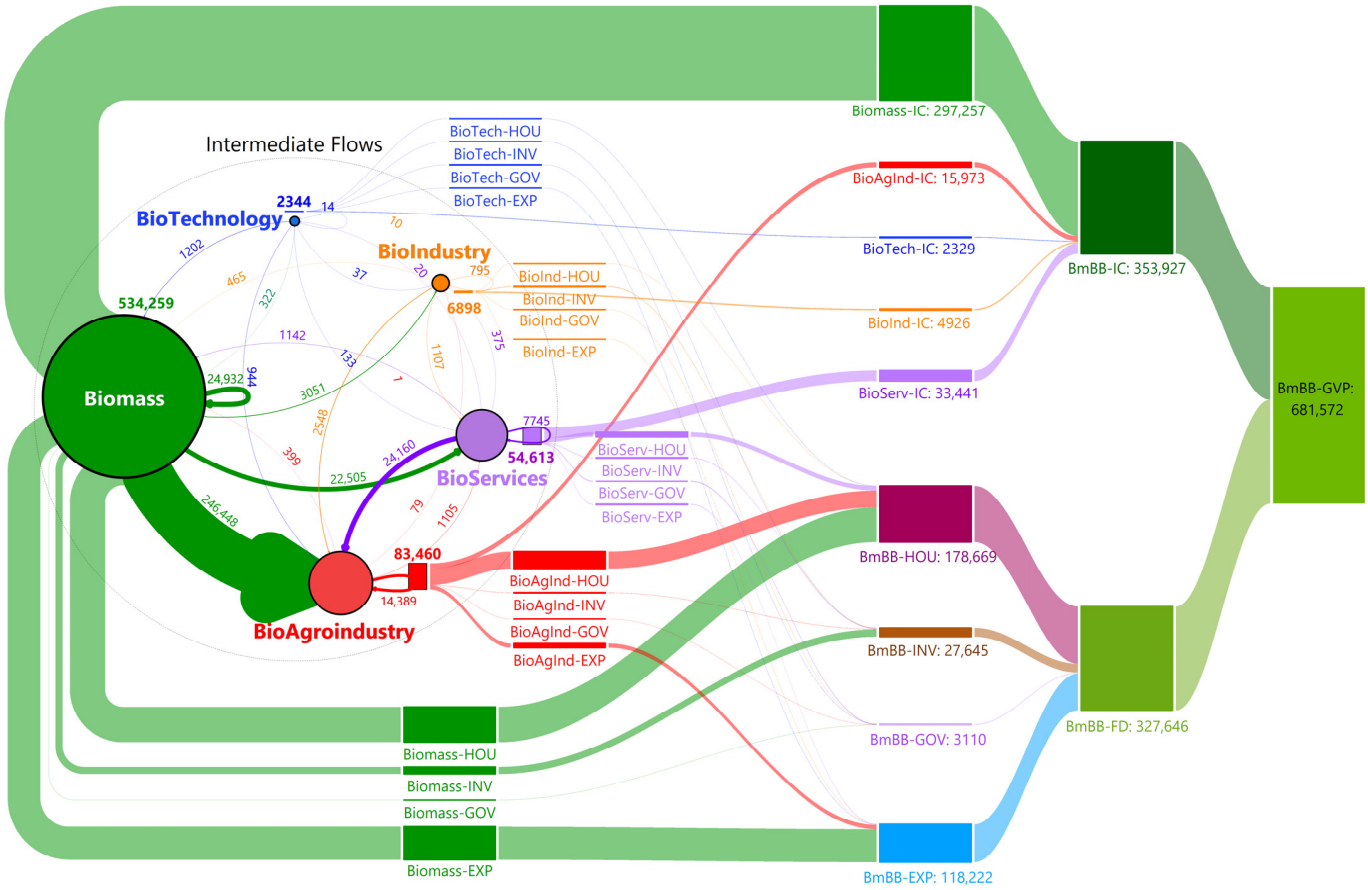


Figure 2. Diagram of the BmBB's GVP composition in the economic aggregates, Average values from 2010 to 2018 (Base = 2018). Notes: GVP = Gross Value of Production. FD = Final Demand. IC = Intermediate Consumption. HOU = Household Consumption. GOV = Government Consumption (public sector). INV = Investments. EXP = Exports. Source: Elaborated by the authors based on research data.

Biomass sales of BRL 24.9 million (SD = BRL 1.1 million) were the second highest direct sales and occurred among the 'Biomass' aggregate sectors. Direct sales to sectors in the 'BioServices' aggregate represent the third largest volume, with an average annual value of BRL 22.5 million (SD = BRL 2.0 million). The 'BioIndustry' and 'BioTechnology' aggregates have relatively low direct sales and, together, the value of BRL 3.7 million represented just 1.13% of the total annual direct sales of biomass in the Brazilian economy.

Therefore, the average total direct sales of biomass for intermediate consumption made by the 'Biomass' aggregate were around BRL 297.2 million, sharing 83.99% of intermediate consumption. The remaining 16.01% of intermediate consumption (BRL 56.6 million) comprises indirect biomass sales between the aggregates. In other words, the biomass acquired primarily from the 'Biomass' aggregate undergoes some processing and is traded

again between the aggregates for final use or tertiary transformation. Therefore, most of the biomass produced in Brazil for intermediate consumption has been destined for final use and not for adding value.

The 'BioServices' aggregate had the highest rate of indirect sales concerning direct sales. On average, 44.8% of this sector's intermediate sales come from sales of biomass processed and resold to the other aggregates. 'BioIndustry' had the second highest rate, with 42.1%, followed by 'BioAgroindustry' with 17.1%. Direct and indirect sales for intermediate consumption among the economic aggregates amounted to an annual average of BRL 353.9 million, corresponding to 51.9% of the BmBB's annual GVP. 'Biomass' sales directly for final consumption accounted for 48.1% of the yearly GVP. Of the BRL 327.6 million in final demand, 72.3% (BRL 237.0 million) corresponds to sales made directly by sectors in the 'Biomass' aggregate. Brazilian households were responsible for most of the final demand for biomass, with an annual average of BRL 111.0 million (46.8% of the final demand for the 'Biomass' aggregate). Direct exports of biomass to the foreign market have been close to the domestic demand of households, with an annual average of BRL 102.9 million (43.4%).

Table 4. Evolution of intermediate demand, final demand, and GVP of the Brazilian BmBB from 2010 to 2018, in BRL million (Base = 2018) and percentage.

Years	Intermediate Demand		Final Demand												GVP				
			Exports			Government			Households			Investments			Total				
	$	%	$	%	%	$	%	%	$	%	%	$	%	%	$	%	%	$	%
2010	325.5	55.16	71.5	27.02	12.12	4.4	1.67	0.75	157.5	59.53	26.69	31.1	11.78	5.28	264.6	100.0	44.84	590.2	100.0
2011	355.1	54.94	89.2	30.64	13.81	3.8	1.33	0.60	167.2	57.40	25.87	30.9	10.63	4.79	291.3	100.0	45.06	646.4	100.0
2012	360.8	54.51	101.5	33.73	15.35	3.2	1.07	0.49	170.7	56.68	25.79	25.6	8.51	3.87	301.1	100.0	45.49	662.0	100.0
2013	366.8	52.35	113.5	34.00	16.20	3.4	1.04	0.50	186.0	55.72	26.55	30.8	9.23	4.40	333.8	100.0	47.65	700.7	100.0
2014	359.6	51.76	114.2	34.08	16.44	3.0	0.92	0.45	187.2	55.85	26.94	30.6	9.14	4.41	335.2	100.0	48.24	694.8	100.0
2015	352.7	50.35	142.5	40.98	20.35	2.3	0.67	0.33	184.5	53.07	26.35	18.3	5.27	2.62	347.8	100.0	49.65	700.5	100.0
2016	368.1	50.97	125.2	35.36	17.34	2.3	0.66	0.32	193.0	54.51	26.73	33.5	9.47	4.64	354.1	100.0	49.03	722.2	100.0
2017	343.1	49.40	133.0	37.86	19.16	2.7	0.78	0.39	182.7	51.97	26.30	33.0	9.39	4.75	351.5	100.0	50.60	694.6	100.0
2018	353.2	48.91	172.9	46.87	23.94	2.4	0.67	0.34	178.9	48.48	24.77	14.6	3.98	2.03	369.0	100.0	51.09	722.3	100.0
Annual Growth Rate	1.02%		11.04%			−7.28%			1.59%			−9.40%			4.16%			2.52%	

Note: The values in green represent the relative decomposition of GVP by intermediate and final demand, while the values in blue account for final demand only. Source: Elaborated by the authors based on research data.

Table 5. The relative share of intermediate demand, final demand, and GVP of BmBB in the Brazilian economy from 2010 to 2018, in percentage.

Years	Intermediate Demand	Final Demand					GVP
		Exports	Government	Households	Investments	Total	
	%	%	%	%	%	%	%
2010	7.04	9.93	0.35	4.64	2.48	3.99	5.24
2011	7.41	11.18	0.30	4.74	2.37	4.21	5.52
2012	7.36	12.17	0.25	4.65	1.97	4.24	5.51
2013	7.33	13.35	0.25	4.90	2.28	4.53	5.67
2014	7.13	14.25	0.22	4.78	2.37	4.52	5.58
2015	7.34	15.74	0.17	4.81	1.77	4.85	5.85
2016	8.09	14.79	0.17	5.13	3.84	5.16	6.32
2017	7.50	15.45	0.20	4.78	3.79	5.06	6.03
2018	7.30	16.87	0.18	4.62	1.67	5.15	6.01
Mean	6.69	13.75	0.23	4.78	2.50	4.63	5.75

Source: Elaborated by the authors based on the research data.

'BioAgroindustry' is the second largest aggregate in biomass sales for final consumption. The aggregate's average annual sales have been around BRL 67.5 million, or 20.6% of final demand. Similarly to the final sales of the 'Biomass' aggregate, BioAgroindustry's

biomass sales are intended to satisfy the consumption of domestic and foreign households, with values corresponding to BRL 53.1 (79%) and BRL 13.3 million (19%), respectively. Similar behavior is seen in the final demand structure of the other aggregates. Of the whole BmBB, 54.5% of the biomass destined for final demand is consumed by domestic households, and 36.1% is destined to meet foreign demands via exports.

Therefore, regarding the average annual destination of BmBB products, 82.6% or BRL 563.4 million of biomass sales go to the domestic market. The remaining 17.4%, or BRL 118.2 million, go to foreign markets, with the largest shares of primary biomass from the 'Biomass' and 'BioAgroindustry' aggregates.

3.3. Value Added by BmBB

The value added captures the economic income added to the biomass produced, processed, and consumed. Table 6 shows the value added by the BmBB, agribusiness, and the Brazilian economy between 2010 and 2018. On average, the BmBB added BRL 291.0 million a year in income to biomass. In comparison, agribusiness had an average annual value added of BRL 1400.0 million, compared to BRL 5900.0 million for the Brazilian economy.

Table 6. Value added by BmBB, agribusiness, and the Brazilian economy, 2010 to 2018, in BRL million (Base = 2018) and percentage.

Dimensions	Value Added (BRL, Millions)									Annual Growth Rate %
	2010	2011	2012	2013	2014	2015	2016	2017	2018	
BmBB	274.6	295.6	295.9	301.8	295.6	285.2	306.0	283.0	280.8	0.28
Agribusiness	1422.2	1426.2	1340.6	1353.9	1354.9	1404.6	1500.4	1417.0	1403.1	−0.17
Brazil	5635.4	5861.5	5978.1	6185.2	6265.5	6037.1	5871.0	5926.5	6011.1	0.81
BmBB/Agribusiness (%)	19.31	20.73	22.08	22.29	21.82	20.31	20.40	19.98	20.02	
BmBB/Brazil (%)	4.87	5.04	4.95	4.88	4.72	4.72	5.21	4.78	4.67	

Note: The agribusiness figures refer to the broad perspective of the value chain, while the BmBB figures derive from a narrow perspective of calculating the value added to biomass. Source: research data.

Therefore, regarding the value added, the BmBB represents approximately one-fifth of agribusiness, ranging from 19.31% (2010) to 22.29% (2013). Regarding the Brazilian economy, the value added by the BmBB has represented an average of 4.87% of the national economy's value added, varying between 4.67% in 2018 and 5.21% in 2016. In the last two years, the value added by the BmBB varied negatively, possibly due to the performance of the Brazilian economy itself. Despite this, the annual growth rate of value added by BmBB has demonstrated a positive variation of 0.28% per year between 2010 and 2018. Although the growth rate of value added by the BmBB was lower than the Brazilian economy (0.81%), it was higher than agribusiness (−0.17%).

Analyzing the GVP and the value added by aggregates allows us to contrast the flow of biomass sales with the aggregation of income to biomass. The greater the value added by an aggregate, the greater the processing intensity and, consequently, the greater the income added to the raw material. Figure 3 compares the relative share of economic aggregates in the GVP and value added of the BmBB and the Brazilian economy and the annual growth rate from 2010 to 2018.

A point to note is that while the 'Biomass' aggregate has the highest relative share in the composition of GVP (78.3%), 'BioAgroindustry' has the highest relative share in the value added (81.5%) of the BmBB. This result suggests that the primary sectors generate high sales volumes of biomass but with low value added. The agroindustries buy the biomass and add income by manufacturing and adding value. These two aggregates have been more relevant to the BmBB's GVP and value added than the Brazilian economy. On the other hand, the annual growth rate of 'Biomass' GVP has been higher than that of value

added, both in the Brazilian economy and in the BmBB, suggesting a mismatch between the production and sale of raw biomass and its processing with added value. Value addition in 'BioAgrondustry' seems to have hit the ceiling, given that the annual growth rate was almost zero in the period analyzed, even though the generation of GVP kept pace with the performance of the aggregate in the Brazilian economy.

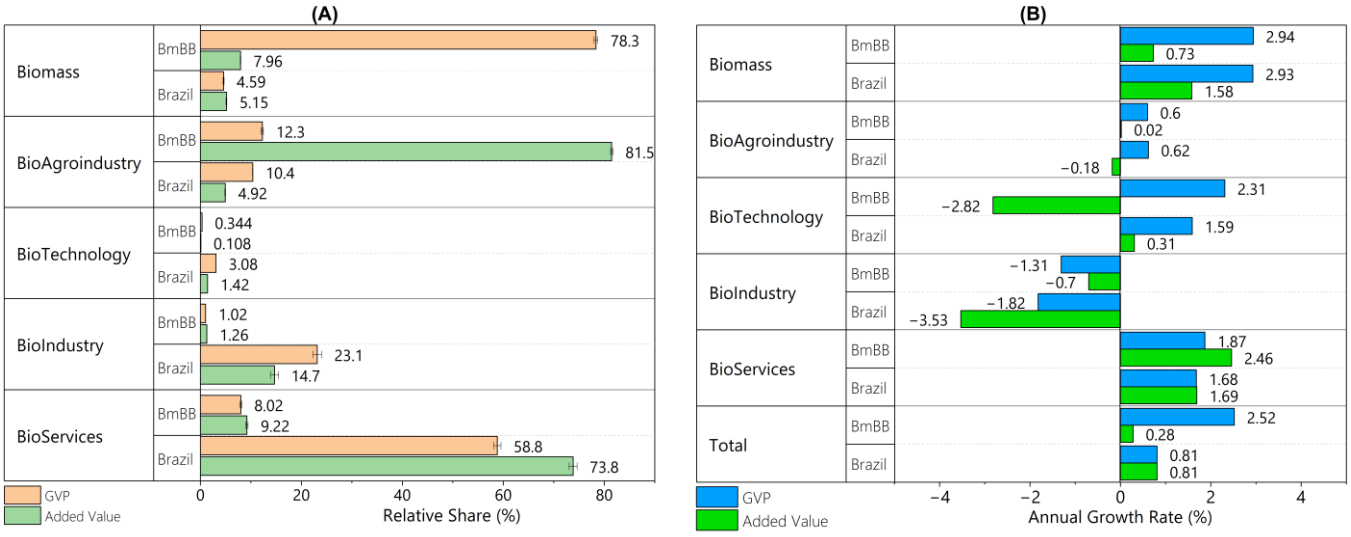


Figure 3. The relative share of economic aggregates in the GVP and value added of the BmBB and the Brazilian economy (**A**) and the annual growth rate of value added and GVP of the Brazilian economy and the BmBB (**B**). Source: prepared by the authors based on the research results.

The relative share of the other aggregates in GVP and value added is higher in the Brazilian economy than in the BmBB. Despite the third position in the BmBB's GVP, 'BioServices' had a greater share in value added (9.2%) than in GVP (8.0%). In comparison, services were the most relevant sector to the GVP (58.8%) and value added (73.8%) of the Brazilian economy. Although the relative share of 'BioServices' was small, the annual growth rate was higher in the BmBB than in the Brazilian economy. 'BioServices' was the only aggregate to show an annual growth rate in value added higher than GVP, both in the BmBB and the economy.

'BioIndustry' is the second aggregate used to generate GVP and add value to the Brazilian economy. However, its relative importance to the BmBB has been negligible. The annual growth rate shows negative changes for both GVP and value added in the BmBB and the Brazilian economy, with negative growth in value added standing out. Despite the prominence in the context of the global bioeconomy, 'BioTechnology' has played a limited role in the composition of GVP and value added in the Brazilian economy and even less in the BmBB. Although positive, the annual growth rate in the value added by biotechnology is low and lower than that of GVP. In the BmBB, this relationship is even more intriguing, showing a high negative growth rate in added value compared to one of the highest growth rates in GVP.

Between 2010 and 2018, the annual growth rates of GVP and value added in the Brazilian economy grew positively and at the same rate. In contrast, in the BmBB fraction, the positive growth in GVP was nine times greater than that observed in value added. As shown in the previous section, the higher growth in biomass-related GVP can be explained by the high flows of biomass sold directly for household consumption in the domestic and foreign markets.

4. Discussion

4.1. The Biomass-Based Bioeconomy in the Brazilian Economy

Primary biomass production is the basis of the BmBB. Although Brazil is a major producer of plant and animal biomass, BmBB has made a relatively small contribution to the country's GDP. The figures found in this study show that, although growing, the BmBB represented around 6% of the national GDP and a quarter of the agribusiness GDP. Despite the potential of the bioeconomy in Brazil, studies have yet to be dedicated to measuring it. Even so, the figures found in our study differ substantially from those found in previous studies on the Brazilian bioeconomy. For example, Silva et al. (2018) calculated that the bioeconomy shared 13.8% of the national GDP in 2016 while Pinto and Lima (2022) and Lima and Pinto (2022b) reported that the GDP of the bioeconomy value chain shared 19.6% of the Brazilian GDP in 2019.

The BmBB's share of GDP found in our study is closer to those obtained by Pellerin and Taylor (2008). The authors estimated the share of the bio-based economy by selecting bio-based sectors and activities listed in the North American Industry Classification System (NAICS) and Statistical Office of the European Communities. The figures obtained for seven countries indicate that, on average, the bio-based economy contributed 5.8% of GDP. In the United States, the share was the highest (8.46%), and in the United Kingdom and Germany, the lowest (3.75% and 4.33%, respectively). The share of the bio-based economy in the GDP of Canada, Japan, France, and India was closer to what we found for Brazil (6.40%, 6.18%, 5.88%, and 5.60%, respectively) and also close to Poland's 5.5% (Ludwik & Wicka, 2016). Explaining the similarity of the results is challenging. This approximation may be partially attributed to the economy structure, rather than the applied methodology, which involved an arbitrary selection of sectors and economic activities. In contrast, the methodology used in this study effectively measured both the direct and indirect flows of biomass produced in Brazil.

Value added has been one of the leading indicators explored in measuring the bioeconomy (Leavy et al., 2024). On average, the BmBB contributed 4.87% of the Brazilian economy's value added. This result differs significantly from that calculated by van de Pas (2015) for the Brazilian bioeconomy. The author measured the value added based on five bioeconomy definitions, including agriculture and agroindustries, imports and domestic production of inputs, direct and indirect effects, and bioeconomy from final demand. Following these definitions, the results indicated that the bioeconomy accounted for 11.9% of the value added to the Brazilian economy in 2011, varying between 10.4% and 12.9%, depending on the definition. According to the figures found in our study, the contribution of the Brazilian BmBB is closer to the average in 2011 for the bioeconomy of Belgium (4.68%), France (6.52%), Germany (4.74%), Great Britain (4.18%), Japan (6.3%), and the US (4.48%). On the other hand, it falls short of the figures for China (17.6%), Hungary (11.0%), Indonesia (25.4%), the Netherlands (7.8%), and Russia (10.7%).

Other studies report on the share of the bioeconomy in the value added of national economies. In Spain, the bioeconomy (agrifood + other bio-based sectors) accounted for 14.30% of the value added in 2000 and 10.74% in 2007 (Cardenete et al., 2014). The value added by the Polish bioeconomy accounted for 10.9% from 2000–2014 (Ludwik & Wicka, 2016), while in the Netherlands, it ranged from 6.6% to 7.2% from 2008–2012 (Heijman, 2016). The North American bioeconomy accounted for 2.2% of the value added to GDP in 2013 (Golden et al., 2015). The bioeconomy accounted for 8% of the value added of the German economy from 2000–2015 (Bringezu et al., 2021), a figure close to the 7.6% found by Efken et al. (2016) for 2007. In Belgium, the bioeconomy accounted for 1.8% of the value added in 2010 (Vandermeulen et al., 2011). In the aggregate of the EU-28 countries, the value added by the bioeconomy was around 11% in 2015 (Kuosmanen et al.,

2020). A detailed study of the value added by the bioeconomy for each EU-28 country from 2005–2015 was carried out by (Cingiz et al., 2021). In some countries, the relative share of value added is low, such as Luxembourg (±1.3%), and high in others, such as Romania (±14%).

The value-added structure also differs between our study and that of van de Pas (2015). While we found that the 'Biomass' and 'BioAgroindustry' aggregates accounted for 5.1% and 4.9% of the value added by the Brazilian economy, respectively, the results of van de Pas (2015) indicate a similar contribution for agriculture (5.6%) but a smaller one for agroindustry (2.2% or 2.8%, depending on the definition of bioeconomy). In Norway, the manufacturing of food and beverages and fishing and aquaculture sectors contributed the most to the value added by bioeconomy, according to Capasso and Klitkou (2020). In contrast, health, medical, and pharmaceutical was the main component of the Canadian bio-based economy, accounting for 63%, followed by agriculture and crops (14%), food and beverage bioprocessing (13%), and organic chemical manufacturing (10%) (Pellerin & Taylor, 2008). On the other hand, our results are close to those of Lima and Pinto (2022a), who indicate that bioagroindustry and the primary production of animal and plant biomass make the most significant contributions to the GDP of the bioeconomy.

The fact that our findings indicate a relatively smaller share of the bioeconomy in the Brazilian economy is due to (i) the refinement of the method used in this study and (ii) the conceptual delimitation proposed for a biomass-based bioeconomy (Leavy et al., 2024). Our BmBB was concerned with measuring the GVP and value added to biomass as a fundamental input embodied in the economic activities of sectors. At the same time, the studies cited above include a concept of bioeconomy close to agribusiness, measuring the bioeconomy value chain. In addition, methodological choices and definitions of the bioeconomy affect the results even within the same economy; the study by Alviar et al. (2021) is an excellent example in this direction. Finally, the structure of each country's economy influences the results. When applying the same method and comparing the contributions of the bioeconomy in different countries, the difference in the share of value added is due to the structure of the national economies (Cingiz et al., 2021; van de Pas, 2015).

4.2. Suitability, Novelties, and Limitations of the Method

In comparison with other methods used to measure the bioeconomy, the method used in this study meets the requirements set out in the studies cited in the previous section and presents important methodological innovations. One of the main challenges in measuring the bioeconomy is overcoming subjectivity in estimating the bio-based share. For example, Highfill and Chambers (2023) and Vargas et al. (2023) propose the creation of 'satellite accounts' for bioeconomy. Adjustments to the national accounts seem inevitable for the standard measurement of national bioeconomies. However, methodological alternatives need to be considered while this solution is unavailable.

In this sense, the first innovative contribution lies in clearly linking the measurement method to the concept of a BmBB. In doing so, biomass is considered a critical input of the BmBB. By focusing on the input, processes become less relevant, mitigating the bias in selecting the bioeconomy sectors, activities, or products. A similar approach was used by Alviar et al. (2021), particularly with the third scenario analyzed, which assumes that bio-based shares include inputs from the primary sector and a proportion from the others according to the bio-based content.

Although an approximation with the method of Alviar et al. (2021) exists, our method explores the direct and indirect effects of biomass's use, transformation, and consumption on GVP and added value. This is a second distinctive contribution of the method compared to the other methods. The downstream and upstream effects were analyzed by Cingiz

et al. (2021) to measure the share of the bioeconomy in the national income upstream and downstream of the sectors considered fully bioeconomic. Although the upstream and downstream effects indicate where the most outstanding relative contribution occurs, they are limited in showing the dynamics of the bioeconomy. In our case, the direct and indirect effects show the economic dynamics of generating GVP and adding value to the vegetal and animal biomass.

The third contribution lies in GVP analysis, corresponding to the sum of intermediate and final demand. Although our method is close to some aspects of the one used by Alviar et al. (2021), these authors only measured the intermediate demand of the bioeconomy. In economies like Brazil, where exports account for an average of 36% of final demand and 17% of the BmBB's GVP, analyzing the structure of intermediate demand and final demand separately adds value to the method and the results.

The methodological differences and the findings have particular repercussions when compared with other studies measuring the bioeconomy in Brazil. Agribusiness has been widely studied due to its importance in the Brazilian economy. Common features lead to some overlap between agribusiness and the bioeconomy. Agriculture, livestock, and forestry sectors are assumed to be exclusively of biological origin, attributing 100% of the GDP of these sectors to the bioeconomy (Lima & Pinto, 2022b; Pinto & Lima, 2022). This assumption overestimates the 'bioeconomy share' in the national economy. In practice, the method used by the authors is closer to the broad agribusiness measurement method, which encompasses the entire value chain, including non-biological inputs. For this reason, the 'bioeconomy share' of 19.6% found by the authors cannot be compared with the 6% in our study. In this sense, our method seems less prone to overestimating the 'bioeconomy share'.

It is also worth noting that Pinto and Lima (2022) and Lima and Pinto (2022b) assume a share of inputs from the Agriculture, livestock, and forestry sectors of 5% as the added value of the bioeconomy for all manufacturing industry sectors. In other words, the authors only consider the direct consumption of biomass, discarding the indirect or residual consumption that exists in other inputs. This arbitrary cut disregards the biomass incorporated into the various inputs consumed by a large part of the manufacturing industry. Therefore, such a method underestimates the added value of the bioeconomy in the manufacturing industry. In this sense, our method makes it possible to precisely recover the added value generated from biomass by tracking the direct and indirect purchases of the bioeconomy throughout the economic system.

Additionally, to calculate the added value of bioeconomy services, Pinto and Lima (2022) and Lima and Pinto (2022b) used the relative share of the bioeconomy in the agriculture, livestock, and forestry sectors and the manufacturing sectors in the marketing and transportation margin of the entire economic system. This procedure leads to both overestimating and underestimating the added value of the bioeconomy in these sectors. By tracking biomass in trade and services, the methodology used in this study minimizes these problems by estimating value added directly and indirectly without the need for weighting.

Despite the innovative contributions, our method has limitations. The first is that it only measures one part of the bioeconomy, particularly that based on the concept of the BmBB in which biomass is the aggregating element. Consequently, it may be leaving out the contributions of the bioeconomy relating to BtBB and BsBB concepts (Leavy et al., 2024). In addition, Wesseler and von Braun (2017) criticize the BsBB concept and advocate a pervasive approach, although they acknowledge that it is the most demanding. Secondly, only the biomass with market value is considered in the analysis, excluding other biological resources and assets related to the bioeconomy but not priced. In this sense, biodiversity stocks, for example, play a relevant role for sectors of the modern bioeconomy but were not accounted for by the method used. Thirdly, the method did not capture ecosystem services

relevant to the cycling materials and the absorption of waste and pollution generated by the economic system, which can aggregate value through sustainability, and the market may remunerate for this. However, some studies have considered these aspects (Alviar et al., 2021; Lazorcakova et al., 2022).

Finally, the GVP and value added by 'BioTechnology' may have been underestimated due to (i) the arbitrary choice of the sectors considered to belong to this aggregate, (ii) the nature of the biotechnological solutions developed and used in the various economic sectors, which imply that part of the GVP and the value added in the other aggregates may derive from biotechnology solutions, and (iii) the assumption that the sectors in 'BioTechnology' develop solutions applied only to biomass or proportional to the biomass they consume. In this respect, high-value-added biotechnology solutions used in sectors such as health are outside the scope of the method's measurement. Another potential point for future analysis refers to residues as biomass sources. Biotechnology is exponentially enhancing solutions to water, sewage, and waste management (Sufficiency et al., 2022; Zhang et al., 2023). Not only does public health benefit with contaminant risk reduction (Cao et al., 2021) but the energy sector does through thermal processes (Agarwal et al., 2015; Ronda et al., 2023) and even agriculture with biofertilizers (Izydorczyk et al., 2022; Upadhyay et al., 2024). The economic Sector 39 (Water, Sewage, and Waste Management), which composes the 'BioServices' aggregate, reveals a potential for GVP and value added in a circular bioeconomy that is still unmeasured.

This study highlights the importance of targeted public policies and private investments to enhance Brazil's biomass-based bioeconomy (BmBB). Despite Brazil's abundant biomass production, its economic impact is still limited. This situation presents an opportunity for developing policy-driven incentives and investment strategies. The improved measurement methods offer a clearer evaluation of the sector's role, which can inform government actions aimed at promoting innovation, sustainability, and competitiveness. Furthermore, comparing Brazil's BmBB with international examples provides valuable insights for crafting policies that boost value-added contributions and attract private investment, ensuring that national strategies align with global sustainability objectives.

5. Conclusions

Regarding the Brazilian BmBB, we can conclude that:

a. The primary sectors are responsible for over three-quarters of the BmBB's GVP.
b. 'BioAgroindustry' adds the most value to biomass, accounting for more than four-fifths of the value added by the BmBB.
c. 'BioServices' ranks third in GVP and value added to biomass.
d. The contribution of 'BioTechnology' to the BmBB may have been underestimated due to methodological particularities. The development of specific methods to measure the BtBB is recommended. A fair assessment of the BtBB's contribution to the national bioeconomy requires a method capable of capturing the GVP and value added in the activities carried out by the other sectors of the economy.
e. The annual growth rate of the BmBB was twice that of agribusiness and three times that of the Brazilian economy. This finding could be a point of attention for bioeconomy strategies in Brazil, as it could signal that value is being added to basic products rather than manufactured ones.
f. Similarly, the relationship between GVP and value added is a challenge for the Brazilian bioeconomy. Although exports play a relatively important role in the final demand for Brazilian BmBB, most of the products destined for the foreign market come from the 'Biomass' aggregate, whose GVP exceeds the added value.

g. Biomass includes various biological products of animal and vegetal origin, but not all of them. Many biological assets can participate in the bioeconomy by providing ecosystem services that are not computed because they are not priced on the market. In the same way, through biotechnology, domestic and industrial residues or wastes from production processes can potentially increase the GVP and the value added of the Brazilian bioeconomy. It can create value through sustainability using the BsBB methodological approach, emphasizing the significance of future BsBB assessments in consolidating sustainability value.
h. Measuring the contributions of the bioeconomy to national economies depends on the method but fundamentally on the concept used to delimit the bioeconomy.

Regarding the method used to measure the BmBB, we conclude that:

a. It meets the fundamental requirements observed in similar methods used to measure the 'bioeconomy shares' of national economies.
b. The main differential of the method used in the study is measuring the BmBB share based on biomass and its direct and indirect effects, considering intermediate demand and final demand. This helps to reduce the bias of measuring the 'bioeconomy share' based on arbitrary choices of specific economic sectors, activities, or products.
c. The study innovates in recognizing the existence of conceptual approaches to the bioeconomy that require specific methods aligned to the bioeconomy concept. The integral bioeconomy involves the development of methods capable of measuring its specificities and complexities.
d. Besides measuring GVP and value added, the method allows for measuring environmental impacts, the value chain, technological and structural changes, the international market, the biomass footprint, etc. These analyses were not explored here but could be developed in future studies.
e. The method allows us to determine the contribution of the fundamental input of the biomass-based bioeconomy. In other words, the biomass share is determined by the method and not estimated by experts or based on classification systems of sectors, activities, or products.
f. The method helps overcome a limitation of similar methods by avoiding the definition of bio-based shares of sectors, activities, or products.
g. To enhance the analysis, it is recommended that future research includes data on biomass imports within the Brazilian economy or investigates the concept of the bio-based bioeconomy footprint. This approach will lead to a deeper understanding of international biomass flows and their effects on the national bioeconomy, ultimately supporting a more thorough assessment of resource utilization, trade dynamics, and sustainability factors.

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Appendix A. The Sectoral Composition of BmBB's Aggregates

Aggregates	Sectors	Sectoral Biomass Share (Mean 2010–2018, %)	Sectoral Biomass Share (SD 2010–2018)	Relative Sectoral Biomass Share in the Economic Aggregate (%)
Aggregate I: 'Biomass'	1—Agriculture	98.15	0.012	68.00
	2—Livestock	97.16	0.011	25.66
	3—Forestry and fishery	95.49	0.024	6.33
				100.00
Aggregate II: 'BioAgroindustry'	8—Slaughter and meat products, including dairy and fishery products	14.56	0.009	46.59
	9—Manufacture and refining of sugar	5.52	0.009	2.62
	10—Other food products	10.91	0.005	43.43
	11—Manufacture of beverages	0.75	<0.001	0.68
	12—Manufacture of tobacco products	0.95	0.001	0.16
	13—Manufacture of textile products	0.59	0.001	0.41
	14—Manufacture of clothing and clothing accessories	0.14	<0.001	0.11
	15—Manufacture of footwear and leather goods	0.03	<0.001	0.01
	16—Manufacture of wood products	0.67	<0.001	0.25
	17—Manufacture of pulp, paper, and paper products	1.51	0.001	1.80
	20—Manufacture of biofuels	2.49	0.002	1.66
	25—Manufacture of rubber and plastic products	1.45	0.001	2.27
				100.00
Aggregate III: 'BioTechnology'	21—Manufacture of organic and inorganic chemicals, resins, and elastomers	0.69	<0.001	51.28
	22—Manufacture of pesticides, disinfectants, paints, and chemicals	1.19	0.001	40.44
	23—Manufacture of cleaning, cosmetic/perfumery, and personal hygiene products	0.20	<0.001	3.62
	24—Manufacture of pharmochemical and pharmaceutical products	0.17	<0.001	4.66
				100.00
Aggregate IV: 'BioIndustry'	4—Extraction of mineral coal and non-metallic minerals	0.43	<0.001	1.45
	5—Oil and gas extraction	0.06	<0.001	1.77
	6—Extraction of iron ore	0.03	<0.001	0.47
	7—Extraction of non-ferrous metallic minerals	0.04	<0.001	0.11
	18—Printing and recording	0.68	0.001	2.60
	19—Oil refining and coking	0.42	<0.001	29.84
	26—Manufacture of non-metallic mineral products	0.55	<0.001	7.74
	27—Production of pig iron/iron alloys, steel, and seamless steel tubes	0.19	<0.001	4.73
	28—Non-ferrous metallurgy and metal casting	0.24	<0.001	3.01
	29—Manufacture of metal products	0.77	0.001	14.24
	30—Manufacture of computer, electronic, and optical equipment	0.03	<0.001	0.37
	31—Manufacture of electrical machinery and equipment	0.12	<0.001	1.55
	32—Manufacture of machinery and mechanical equipment	0.06	<0.001	1.08
	33—Manufacture of automobiles, trucks, and buses	0.01	<0.001	0.26
	34—Manufacture of parts and accessories for motor vehicles	0.29	<0.001	5.44
	35—Manufacture of other transportation equipment	0.02	<0.001	0.18
	36—Manufacture of furniture and industrial products	0.07	<0.001	0.86
	40—Construction	0.30	<0.001	24.29
				100.00

Aggregates	Sectors	Sectoral Biomass Share (Mean 2010–2018, %)	Sectoral Biomass Share (SD 2010–2018)	Relative Sectoral Biomass Share in the Economic Aggregate (%)
Aggregate V: 'BioServices'	37—Maintenance, repair, and installation of machinery and equipment	0.64	<0.001	0.87
	38—Electricity, natural gas, and other utilities	0.50	<0.001	2.80
	39—Water, sewage, and waste management	0.32	<0.001	0.44
	41—Wholesale and retail trade	2.10	0.002	49.63
	42—Land transportation	1.52	<0.001	11.22
	43—Water transportation	1.34	0.002	0.55
	44—Air transportation	0.35	<0.001	0.29
	45—Storage, transportation activities, and mail	1.19	0.001	2.78
	46—Accommodation services	0.48	<0.001	0.25
	47—Food services	1.00	0.001	5.17
	48—Editing and publishing	0.08	<0.001	0.03
	49—Television, radio, cinema, and sound and image recording/editing services	0.01	<0.001	0.00
	50—Telecommunications	0.28	<0.001	0.86
	51—Systems development and other information services	0.28	<0.001	0.84
	52—Financial services, insurance, and pension plans	0.48	<0.001	5.43
	53—Real estate services	0.17	<0.001	1.92
	54—Legal, accounting, consultancy, and head office services	1.18	0.001	4.58
	55—Architectural, engineering, technical testing/analysis, and R&D services	0.63	0.001	0.58
	56—Other professional, scientific, and technical services	1.30	0.001	2.59
	57—Non-real-estate rentals and management of intellectual property assets	0.55	<0.001	0.47
	58—Other administrative and complementary services	0.48	<0.001	2.33
	59—Surveillance, security, and investigation services	0.65	<0.001	0.51
	60—Public administration, defense, and social security	0.34	0.001	4.06
	61—Public education services	0.12	<0.001	0.61
	62—Private education services	0.04	<0.001	0.09
	63—Public health services	0.07	<0.001	0.33
	64—Private health services	0.06	<0.001	0.26
	65—Artistic, creative, and entertainment services	0.10	<0.001	0.08
	66—Membership organizations and other personal services	0.13	<0.001	0.44
	67—Domestic services	0.00	<0.001	0.00
				100.00

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