Structural Decomposition Analysis of Brazilian Greenhouse Gas Emissions

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ABSTRACT

This paper aims to verify the long run structural changes in Greenhouse Gas (GHG) emissions in Brazil which presents the particularity of high emissions in the agriculture and livestock sectors, and low emissions in energy sectors. We used an additive Structural Decomposition Analysis (SDA) to verify the sectorial changes in emissions derived from the effects of economic intensity, final demand structure effect and technological change by component i.e., household consumption, exports, gross fixed capital formation, government consumption, inventory change and total final demand. The database is composed of a series of input-output matrices at constant prices for the period 2000-2017, with comparable production structure of 42 sectors. Our results show that agriculture had the most remarkable effects on emissions, followed by industry sectors for all SDA effects and components except for inventory change. Finally, we discuss relationships between energy, GHG emissions and production structure towards development policies to reduce emissions and improve energy use.

RESUMO

Este trabalho tem como objetivo verificar as mudanças estruturais de longo prazo nas emissões de Gases de Efeito Estufa (GEE) no Brasil, país que apresenta a particularidade de altas emissões nos setores agropecuário e baixas emissões nos setores de energia. Usamos uma Análise de Decomposição Estrutural (SDA) aditiva para verificar as mudanças setoriais nas emissões derivadas dos efeitos da intensidade econômica, efeito da estrutura da demanda final e mudança tecnológica por componente, ou seja, consumo das famílias, exportações, formação bruta de capital fixo, consumo do governo, variação de estoques e demanda final total. A base de dados é composta por uma série de matrizes insumo-produto a preços constantes para o período 2000-2017, com estrutura produtiva comparável de 42 setores. Nossos resultados mostram que a agricultura teve os efeitos mais notáveis nas emissões, seguida pelos setores da indústria para todos os efeitos e componentes do SDA, exceto pela variação de estoques. Por fim, discutimos as relações entre energia, emissões de GEE e estrutura produtiva para políticas de desenvolvimento para reduzir emissões e melhorar o uso de energia.

Keywords: GHG emissions; Structural Decomposition Analysis; Brazil.

Palavras-chaves: Emissões de GHG; Análise de decomposição estrutural; Brasil.

Área 9: Meio ambiente, recursos naturais e sustentabilidade.

JEL: C67; Q01; Q50; R10.

1. Introduction

One of the main causes of climate change is Greenhouse Gas (GHG) emissions produced by human actions, and Brazil presents one of the highest GHG emissions in the world. In 2019 the country emitted about 2.175 $MtCO_2e$, accounting for 4% of global emissions (SEEG, 2021). The country is ranked as the 7th largest emitter in the production processes. Despite the increasing demand for energy in the recent development process, and the increasing use of thermoelectric generation, the effects of energy production on emissions is not a central concern in the environmental debate in Brazil. As a developing economy, the country needs to improve income generation and modernize the production structure. This challenge makes new investments in sectoral and structural linkages of the economy an important element for the international debate about emissions. In addition, Brazil is also one of the biggest suppliers of agriculture and livestock commodities in the world (Ribeiro et al., 2018), and the emissions of the agriculture sector, including land use and forest change, amount to 73.1% of total GHG emissions. Thus, we consider that the decomposition of the structural effects of emissions focusing on the long run evolution of Input-Output (IO) linkages among agriculture, industry, energy and services sectors, for instance, will provide important insights for the debate about GHG emissions, the energy matrix and the mitigation of climate change effects.

Global efforts and international cooperation policies are constantly being drawn up to mitigate the effects of energy use on climate change on the planet and outline perspectives for sustainable development (Tourinho et al., 2003; UNFCCC, 2015; Ward, 2019; Liu, et al., 2020; Steffen, 2020). Despite this, the biggest sources of energy remain fossil fuels and the energy sectors are the biggest emitters of GHG in most countries of the world. In 2017, the sectors of electricity, transport, manufacturing, construction, fugitive emissions[1] and other fossil fuels accounted for approximately 73% of global GHG emissions (WRI, 2020). Thus, from large productive sectors to small commercial activities all are directly or indirectly linked to energy use and consequently to GHG emissions. In Brazil, agriculture stands out as the segment that emits the most GHG, 503.2$MtCO_2e$ or 1.09% of all global emissions (WRI, 2020).

Leontief (1970) described relationships between the agricultural and manufacturing sectors to exemplify Input-Output relationships in the environmental field. The production of automobiles, metal, paper, textiles and other industries that required significant amounts of water also posed technological challenges to mitigate environmental impacts since the beginning of the 20th century. Such externalities associated with production should be incorporated into traditional IO accounts, bringing advances to the technique when applying the use of energy and emissions (Leontief and Ford, 1986).

The IO structure and the complex and interdependent relationships between energy, environment and economic well-being were described by Hawdon and Pearson (1995). The authors simulated the effects of hypothetical impacts of policy changes on energy demand and emissions. These involved issues of energy efficiency, changes in final expenditure, changes in the industry's electrical structure, the mix of changes in expenditure and fees, among others. Thus, it was possible to observe that the IO approach provides a broad possibilities for adopting strategies that may include: (i) policies that change the level or patterns of demand; (ii) policies that change the available mix of technology or energies; (iii) possibility of investments in measures that increase the efficiency of the energy produced or in its distribution channels; (iv) waste treatment policies (recycling); (v) other alternatives that

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[1] Sotoodeh defines fugitive emissions as “the unintentional and undesirable emission, leakage, or discharge of gases or vapors from pressure-containing equipment or facilities, and from components inside an industrial plant such as valves, piping flanges, pumps, storage tanks, compressors, etc.”
See more in “Prevention of Valve Fugitive Emissions (2021)”.

reduce pollutants and (vi) spatial changes in the most polluting activities, such as the creation of production zones.

The advances of Rose and Chen (1991) and Casler and Rose (1998) introduced hybrid IO energy/values tables to decompose sources of changes in the USA CO_2 emissions between 1972-82. The SDA based on an OI structure provided the substitution effects within the energy sector and between energy and other inputs regarding emissions of CO_2 in the USA. The interest of policy-makers in energy policy is related to alternatives to improve the efficiency or regulation of energy use or price to result in productive, social well-being and environmental gains. Labandeira and Labeaga (2002) also applied SDA techniques to verify the intensity effect of energy-related CO_2 emissions for the Spanish economy in the 1990s. The results suggest that in the absence of efficient environmental policies, a GHG emission tax is a feasible instrument to mitigate the effects of pollutants.

Hoekstra and Van Den Bergh (2002) highlighted the importance of demand effects and technological changes in SDA models to verify the long-term determinants of physical flows in economic activities in the IO tables. According to the authors, demand effects often exceed environmental improvements due to technological changes. Thus, it could suggest (i) policies aimed at technological development, such as investment in renewable energies, (ii) policies that modify the final demand mix, or (iii) a combination of technological progress and demand policies. Therefore, SDA techniques aid policy-makers in economic changes that move in the most acceptable environmental direction.

Recent research has also addressed relevant questions about the effects of GHG or CO_2 emissions on the economy using SDA for several advanced countries as well as developing economies, such as Jeong and Kim (2013), Wang, Chiu and Chiu (2015), Hu *et al.* (2016), Liobikiene, Butkus and Bernatoniene (2016), Shahiduzzaman and Layton (2017), Zhu, Su and Li (2018) Leal, Marques, Weasel (2019), Talaei, Gemechu and Kumar (2020). Su and Ang (2012) also address relevant issues about methodological advances in SDA. For Brazil, few studies relate economy, energy and emissions using SDA techniques (Silva and Perobelli, 2012; Lenzen et al., 2013; Freitas et al., 2016). Other authors compare the Brazilian energy matrix with other emerging and advanced economies and emphasize the country's potential in terms of low-polluting energy generation capacity (Lin, Ankrah and Manu 2017; Sesso et al., 2020).

For the present research, the advances in SDA can facilitate the understanding of the relevant economic and structural changes in Brazil regarding GHG emissions in the long run. When inserting environmental issues into the SDA method, a broad view is gained of the environmental repercussions across the economy resulting from different economic activities or sectors (Hoekstra and Van der Bergh, 2002; Weber, 2009; Yamakawa and Peters, 2011). Thus, SDA can be applied to analyze the intensity effect, technological effects, the additive final demand structure effect and total changes in emissions. We applied SDA techniques to verify the structural changes in GHG emissions in the Brazilian economy in the period 2000-to 2017 and by final demand structure component. This is the longest period ever used in an IO analysis for GHG emissions in Brazil. The IO matrices were estimated and matched at constant prices by Alves-Passoni (2019) and Alves-Passoni and Freitas (2020) for 42 productive sectors.

This study contributes to research into structural changes in GHG emissions through IO methods and discusses policies to mitigate GHG emissions. Identifying sectorial demand and technological effects is crucial to supporting sustainable development policies, increasing factor productivity and economic competitiveness. Furthermore, overcoming structural bottlenecks will be a major challenge for the long-term economic growth of the Brazilian economy.

2. The Energy and Emissions Structure in Brazil

The structural indicators of the Brazilian energy and emissions structure are presented in Table 1. The analysis was carried out using data from 1990 to 2020, an interval of 30 years of the available data for emissions by aggregated economic sectors provided by the *Brazilian Climate Observatory* (AZEVEDO, 2015). As we can see, in 2020 the estimated population in Brazil was about 212.5 million inhabitants and the Gross Domestic Product (GDP) was 2.85 US$ trillion, and despite GDP growth of 88.4% in the period, per capita GDP grew only 32.8%. Following the patterns of a developing economy, agricultural and industrial sectors saw a fall in their share of GDP over time while services and energy sectors increased their shares. The growth in energy use (all sources) and electricity was about 105.8% and 148.2%, respectively. The economy became more energy and electricity intensive, compared to the smaller growth of the GDP. However, the increase in per capita use of electricity (86.9%) was considerably higher than the per capita growth in use of energy (55%). The growth in use of electricity use in agriculture is mainly associated to the universalization of access to electricity to rural areas and the increase in agribusiness activities in the country, which strongly influenced the discussion about emissions (Pereira *et al*., 2020; Rajão *et al*., 2020).

The 2.175 MtCO$_2$e emissions in Brazil in 2019 represented a growth of 16.8% compared to 1990. The economic intensity and per capita emissions decreased by 38% and 12%, respectively, which means a “cleaner” economic structure. However, at the sectoral level it is important to highlight the high share of emissions from agriculture (agriculture, land use and forest change) and livestock. Although this share decreased by 14.6% in the period, it is considerably high in Brazil, mainly due to land use and deforestation in the Amazon region and livestock production (Ribeiro *et al*., 2018; Pereira *et al*., 2019). This is a central issue in the global debate related to environmental policies and climate change. The small share of the energy sector in the emissions constitutes an important structural element of the Brazilian energy matrix, which makes the 178.4% growth in the share of emissions less of a concern.

Table 1: Structural Indicators of the Brazilian Energy and Emissions Structure 1990 - 2020

Variable	**Unit**	**1990**	**2020**	**Change (%)**
Population	Million inhabitants	149.8	212.5	41.9
GDP	US$ (2010)	1,517,083.9	2,858,335	88.4
GDP per capita	US$ (2010)	10,128.3	13,448.7	32.8
Sector share (%)				
Agriculture		7.7	6.3	-17.6
Industry		31.6	18.5	-41.4
Services		55.5	69.2	24.7
Energy sectors		5.2	5.9	13.3
Energy use (all sources)	(10^3 Toe)$^{(a)}$	117,582.3	242,016.4	105.8
Energy intensity	(10^3 Toe)/GDP	0.08	0.08	9.2
Per capita energy use	(10^3 Toe)/pop	11.6	18.0	55.0
Sector share (%)				
Agriculture		5.1	5.4	4.8
Industry		37.0	33.8	-8.8
Services		47.6	49.1	3.1
Energy sectors		10.2	11.8	14.8
Electricity use	GWh	217,696.18	540,285.8	148.2
Electricity intensity	GWh/GDP	0.14	0.19	31.7
Per capita use	GWh/pop	21.5	40.2	86.9
Sector share (%)				
Agriculture		3.1	6.0	96.6
Industry		51.6	36.6	-29.1
Services		42.2	51.6	22.2

Energy sectors		3.1	5.9	86.5
Total emissions (*for the year 2019)	$MtCO_2e$	1,862.2	2,175.6	16.8
Emissions intensity	$MtCO_2e$/GDP	0.0012	0.0008	-38.0
Per capita emissions	$MtCO_2e$/pop	0.18	0.16	-12.0
Sector share (%)				
Agriculture		85%	73%	-14.6
Industry		5%	7%	37.6
Services		8%	15%	97.1
Energy sectors		2%	5%	178.4

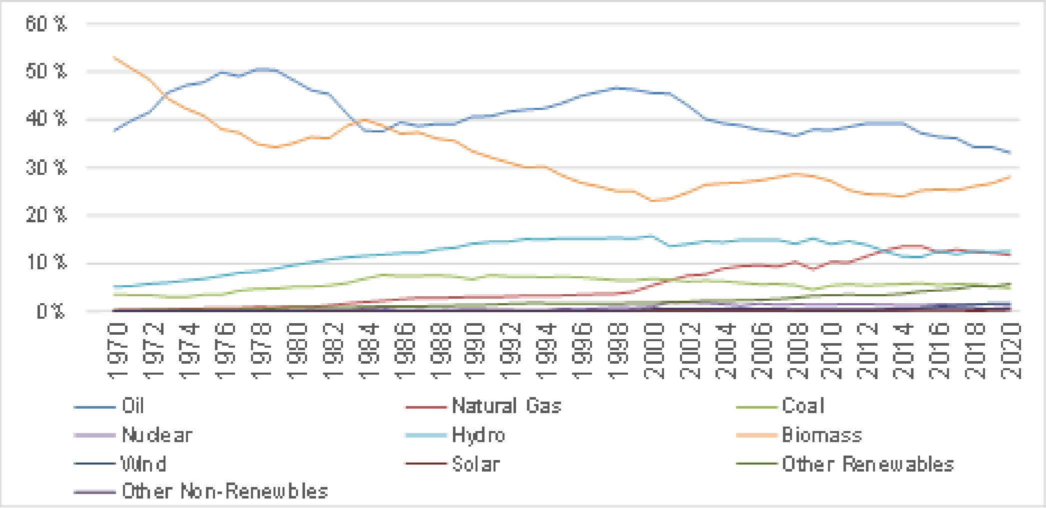
(a) Toe: *Tonne of oil equivalent.*

Sources: Population; GDP (constant prices for 2010), Total Energy Use, and Electricity Use from *Brazilian Energy Balance* (https://www.epe.gov.br/). Total and sectoral emissions from the Greenhouse Gas Emission and Removal Estimation System (SEEG) of *Brazilian Climate Observatory* (http://seeg.eo.br/).

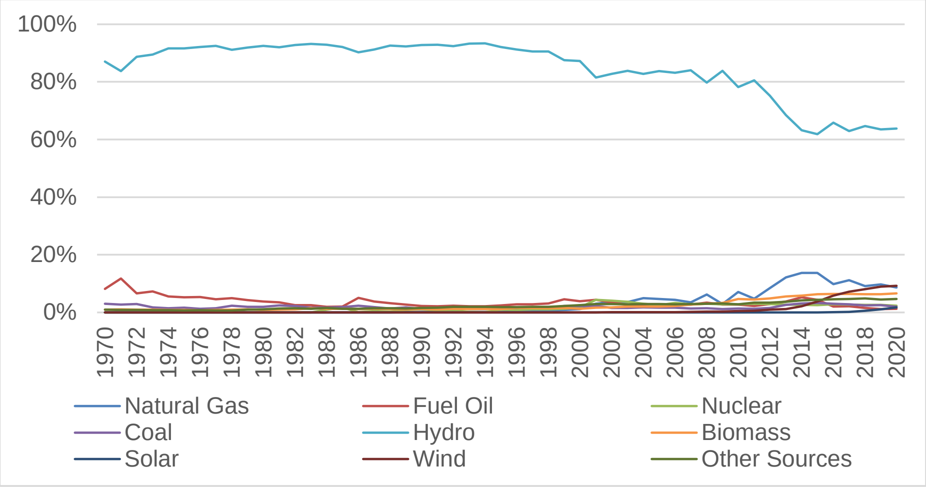
In 2020, 48.4% of the energy supply was from renewable sources and 51.6% from non-renewable. This balance is mainly because of the 12.6% share of hydroelectric sources and 28% of biomass in the energy matrix (firewood and charcoal + sugar cane derivate). However, as can be seen in Figure 1(a), this balance is decreasing mainly due to the increasing use of natural gas, which is less polluting than other sources based on oil. In Figure 1(b) it can be seen that electricity is mainly generated by hydroelectric sources, 63.8%, then thermoelectric generation using natural gas, 8.6%, and wind generation, 9.6%. The combination helps to maintain emissions in the energy sector considerably low.

Figure 1: Brazilian energy and electricity supply by source (energy matrix) - 1970-2020

(a) Energy supply



(b) Electricity supply

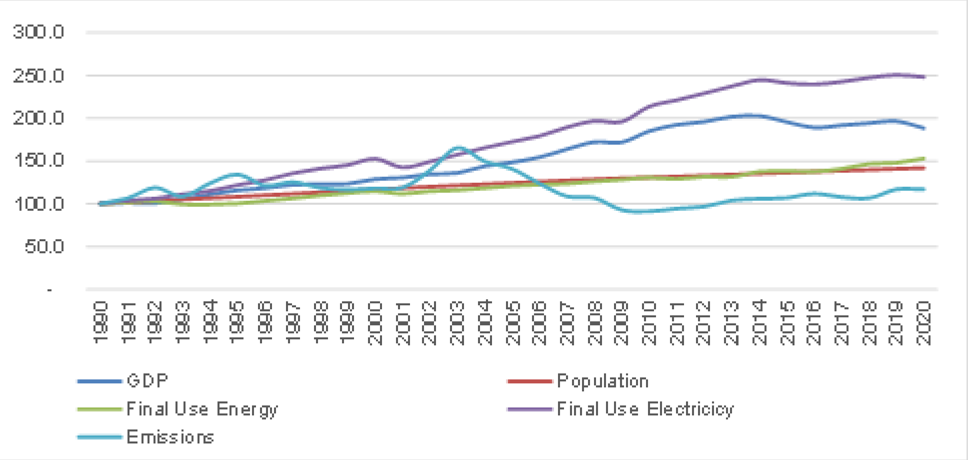


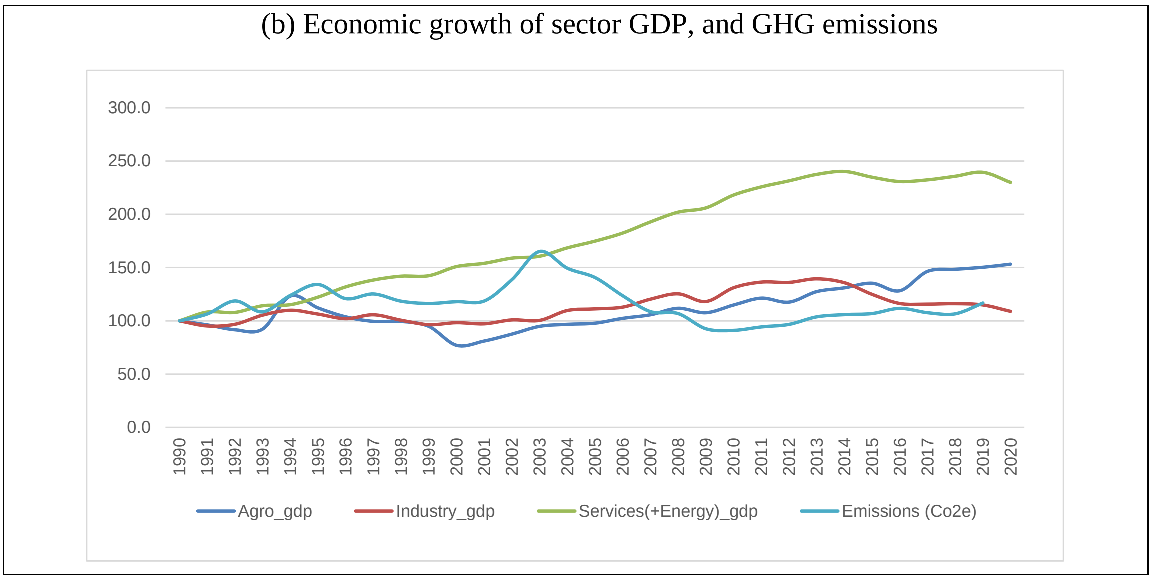
Source: Brazilian Energy Balance (https://www.epe.gov.br/).

The analysis of the accumulated growth of economic, energy, and emissions indicators in Brazil, in Figure 2(a), shows that the emissions did not grow considerably compared to GDP, population, and energy and electricity use from 1990 to 2020. The increasing use of natural gas by industry sectors and for thermoelectric generation, the continued use of ethanol fuel from sugarcane without the use of fire in the harvesting of sugarcane helped in the control of emissions in the country. However, the deforestation policy control in the Amazon rainforest, which reduced the deforested area by 4.9 times from 2004 to 2012, was the main driver of emissions reduction (Freitas *et al*., 2016; Souza *et al*., 2016; Ribeiro *et al*., 2018). Despite a period of decline and stability in emissions from 2010, in 2019 GHG emissions increased again. As can be seen in Figure 2(b) this new trend in Brazilian emissions is closely related to the growth in the share of agriculture in GDP. In addition, as pointed out by Pereira *et al*. (2019; 2020) a set of policies started in 2019 made deforestation control more flexible and allowed the expansion of soybean cultivation and cattle rearing in forest areas, for instance. These factors have threatened the conservation of the Amazon rainforest and, consequently, have contributed to GHG emissions. Thus, it is important to investigate how the structural changes in the economy are associated to the structural changes in emissions in Brazil.

Figure 2: Accumulated growth (1990=100) of the energy and emissions economic indicators in Brazil, 1990-2020

(a) Energy and emissions economic indicators




(b) Economic growth of sector GDP, and GHG emissions

Sources: Population; GDP, Total Energy Use, and Electricity Use from *Brazilian Energy Balance* (https://www.epe.gov.br/); Emissions form the Greenhouse Gas Emission and Removal Estimation System (SEEG) of *Brazilian Climate Observatory* (http://seeg.eo.br/).

In summary, the pattern of sectoral development defined by new investment in the country might result in a permanent structural change in the sectoral composition of emissions. The high level of GHG emissions by the agriculture sector place it at the core of environmental analysis and policy design in Brazil. This sector needs to be included in the debate of policies related to deforestation control, the strength of input-output relations of agriculture with other economic sectors and commercial policies with other countries. For this reason, long term structural analysis can provide important insights for policy design, considering the emissions in a context of input-output intersectoral relations.

3. Methods and Data

The evolution of structural decomposition methods is discussed by Dietzenbacher and Los (1998), Hoekstra and Van Der Bergh (2003), Weber (2009). The method allows us to separate the variables into smaller parts and analyze the sectorial development through the desired components. Studies that evaluate policies for sectoral growth, employment, energy efficiency, emissions of polluting gases, imports and exports, technological services, among others, are essential for the advancement of structural decomposition techniques.

Therefore, according to Zhu, Su and Li (2018) the traditional Leontief model can be reformulated as:

$$x = Z_d.1 + y = A_d x + y \tag{1}$$

Where x is the vector of total output, Z_d is the matrix of intermediate consumption, $A_d = Z_d.(\hat{x})^{-1}$ is the matrix of production coefficients and y is the vector of final demand. Thus, Leontief's standard I-O model can be obtained as:

$$x = (i - A_d)^{-1} y = L_d\left(y_{hc} + y_{gc} + y_{gfcf} + y_{ic} + y_{ex}\right) \tag{2}$$

Where $L_d = (I - A_d)^{-1}$ is the inverse Leontief matrix, y_{hc} is the consumption vector (or household consumption), y_{gc} is the vector of government consumption, y_{gfcf} is the vector of gross fixed capital formation (or investment), y_{ic} is the vector of inventory change, y_{ex} is the vector of exports, and therefore, $y = y_{hc} + y_{gc} + y_{gfcf} + y_{ic} + y_{ex}$ is the vector of total final demands.

With the emission intensity vector f_v representing emissions per unit of value-added, the total GHG emissions can be formulated as:

$$\begin{aligned} GHG &= f_v'v = f_v'(\hat{k} \cdot x) = f_v'k \cdot L_d y = f_v'H_d y = f_v'H_d(y_{hc} + y_{gc} + y_{gfcf} + y_{ic} + y_{ex}) \\ &= f_v'H_d y_{hc} + f_v'H_d y_{gc} + f_v'H_d y_{gfcf +} f_v'H_d y_{ex} \\ &= GHG_{hc} + GHG_{gc} + GHG_{gfcf} + GHG_{ic} + GHG_{ex} \end{aligned} \tag{3}$$

Where v is the vector of value added, $k = (\hat{x})^{-1}v$ is the vector of input coefficient, $H_d = \hat{k} \cdot L_d$ is the matrix of value-added requirement coefficient, $GHG_{\cdot} = f_v'H_d y_{\cdot}$ is the GHG emissions embodied in the final demand$\cdot$, including the household consumption (*hc*), government consumption (*gc*), gross fixed capital formation (*gfcf*), inventory change (*ic*) and exports (*ex*). The emission embodiment by final demand GHG in equation 3, can also be written as the sum of sectoral emission embodiment, i.e., $GHG_{\cdot} = \sum_j GHG_{\cdot j}$.

3.1 Additive structural decomposition analysis method

For the purpose of this paper, we use the additive SDA technique in order to assess the absolute changes in GHG in the economic structure of the Brazilian economy. Taking equation 3, the changes embedded in emissions between year t_1 and t_2 can be calculated as $\Delta GHG_{tot\cdot} = GHG_{\cdot}^{t2} - GHG_{\cdot}^{t1}$, where $\cdot$ represents the components of the final demand.
Using four decomposition factors we can identify the changes embedded in emissions:

$$\begin{aligned} \Delta GHG_{tot,\cdot} &= GHG_{\cdot}^{t2} - GHG_{\cdot}^{t1} = f_v^{t'2}H_d^{t2}y_{\cdot}^{t2} - f_v^{t'1}H_d^{t1}y_{\cdot}^{t1} \\ &= f_v^{t'2}H_d^{t2}(y_{s,\cdot}^{t2} . y_{tot,\cdot}^{t2}) - f_v^{t'1}H_d^{t1}(y_{s,\cdot}^{t1} . y_{tot,\cdot}^{t1}) \\ &= \Delta GHG_{eint,\cdot} + \Delta GHG_{lstr,\cdot} + \Delta GHG_{ystr,\cdot} + \Delta GHG_{ytot,\cdot} \end{aligned} \tag{4}$$

Where $y_{s\cdot}^t$ is the final demand structure of component $\cdot$ at tome t, $y_{tot\cdot}^t$ is the total final demand of category $\cdot$ at time t, $\Delta GHG_{eint,\cdot}$ is the additive emission intensity effect, $\Delta GHG_{lstr,\cdot}$ is the additive Leontief structure effect $\Delta GHG_{ystr,\cdot}$ is the additive final demand structure effect, and $\Delta GHG_{ytot,}$ is the additive total final demand effect.

Finally, the sub-effects of the total emissions change $\Delta GHG_{tot} = GHG^{t2} - GHG^{t1}$ can be calculated as:

$$\Delta GHG_{eint} = GHG_{eint,hc} + GHG_{eint,gc} + GHG_{eint,gfcf} + GHG_{eint,ic} + GHG_{eint,ex} \tag{5a}$$

$$\Delta GHG_{lstr} = \Delta GHG_{lstr,hc} + \Delta GHG_{lstr,gc} + \Delta GHG_{lstr,gfcf} + \Delta GHG_{lstr,ic} + \Delta GHG_{lstr,ex} \tag{5b}$$

$$\Delta GHG_{ystr} = \Delta GHG_{ystr,hc} + \Delta GHG_{ystr,gc} + \Delta GHG_{ystr,gfcf} + \Delta GHG_{ystr,ic} + \Delta GHG_{ystr,ex} \tag{5c}$$

$$\Delta GHG_{tot} = \Delta GHG_{tot,hc} + \Delta GHG_{tot,gc} + \Delta GHG_{tot,gfcf} + \Delta GHG_{tot,ic} + \Delta GHG_{tot,ex} \tag{5d}$$

Where $\Delta GHG_{tot} = GHG_{tot}^{t2} - GHG_{tot}^{t1} = \Delta GHG_{eint} + \Delta GHG_{lstr} + \Delta GHG_{ystr} + \Delta GHG_{ytot}$

Thus, the change in the level of emissions of GHG by sector is decomposed into three effects: $\Delta GHG_{tot} = (\Delta GHG_{eint}; \Delta GHG_{lstr}; \Delta GHG_{ystr})$. The first term is the intensity that measures changes in emissions per unit of output per sector. The second term refers to the influence of changes in input-output coefficients on emissions. In this sense, it captures changes in the production structure as changes in the quantity of inputs that lead to changes in the level of sectoral emissions. Finally, the third term refers to the additive final demand structure effect and measures the effect on sectoral emissions given a change in the level of demand.

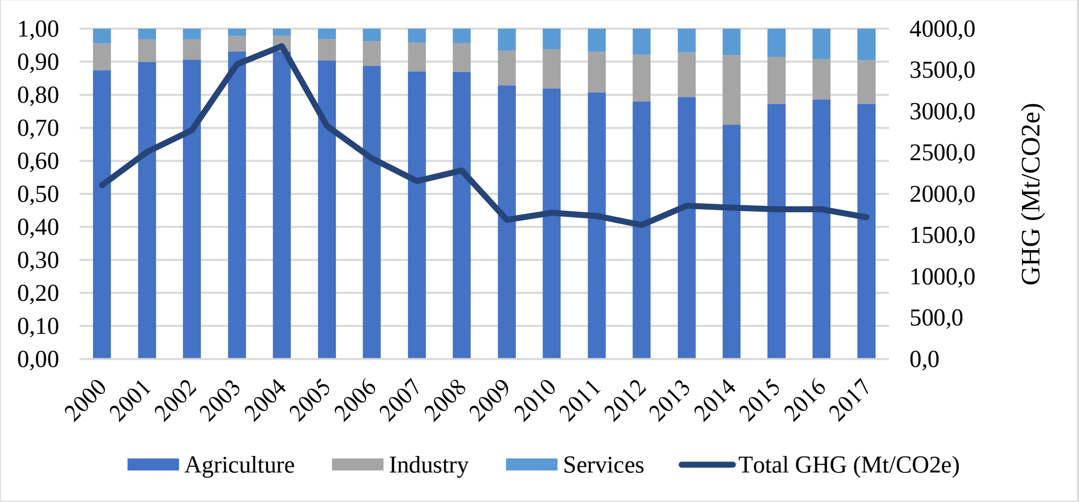
3.2 Emissions data

The emissions from fossil fuels were distributed among the input-output table (IOT) sectors following Montoya *et al.* (2014) and Pereira *et al.* (2020). The correspondence between the Energy Balance demand sectors and the 42 sectors of IOT was made according to the National Classification of Economic Activities (CNAE). The emissions from Land Use Change and Forestry (LUCF) were set for the agriculture and livestock sector. The Industrial Processes emissions were distributed according to each type of process. The emissions of Chemical industries were set to the sector manufacture of organic and inorganic chemicals, resins and elastomers. According to the National Commission of Classification (CONCLA) this sector produces the chemical elements listed on the Brazilian emissions inventory. The emissions from metal production were set to the following sectors: Cement and other non-metallic mining products; Manufacture of steel and derivatives; Metallurgy of non-ferrous metals, and Metal products, excluding machinery and equipment.

Figure 3 shows the GHG emissions behavior between 2000 and 2017 both in Mt/CO_2e and per sector. We can clearly see a considerable drop in total emissions starting in 2004 and relative stability in the period 2009-2017. As said earlier, the main justification for this fall was the deforestation control policy in the Amazon rainforest (Freitas et al., 2016; Souza et al., 2016; Ribeiro et al., 2018).

We can also see a change in terms of sectorial source of GHG emissions between 2000 and 2017 (see Figure 3). Agriculture's share in 2000 was 87% and dropped to 77% in 2017. On the other hand, Industry and Services' share grew from 8% and 4% in 2000, respectively, to 14% and 10% in 2017.

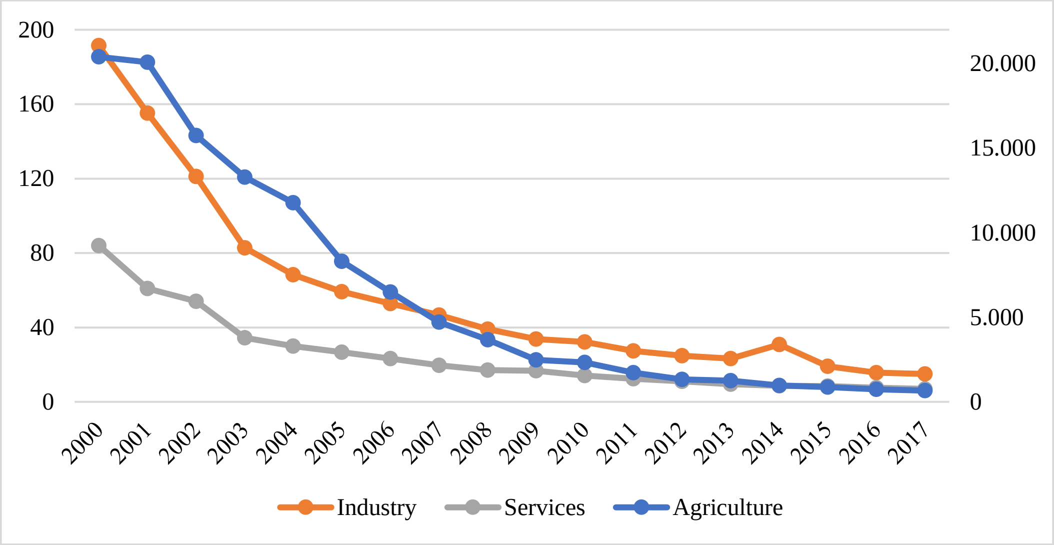
Figure 3: Brazilian GHG emissions, 2000-2017



Source: Author's own based on emissions data.

Figure 4 shows the GHG emissions coefficient per sector, i.e., the ratio between emissions and gross output. To improve the visualization of the graph, the coefficient values of the agriculture sector were put on the right axis.

Figure 4. Brazilian GHG emissions coefficient per sector



Source: Author's own based on emission data and IO matrices.

In all sectors we observe a drop in the emissions coefficient, which is a very important indicator. This means that Brazilian economic structure became less emissions intense in the period analyzed or its production became "cleaner". This has already been pointed out in section 2. In Brazil total emissions per R$ 1 million of gross output in 2000 was 1,007 t/CO_2e. In 2017, this coefficient was 42 t/CO_2e

Despite this relevant drop, the most intensive sector in terms of GHG emissions in Brazil remains Agriculture. In 2017, for instance, for each R$ 1 million of gross output 663 t/CO_2e was generated. On the other hand, Industry and Services was 15 t/ CO_2e and 7t/ CO_2e, respectively. Rajão et al. (2020) have mapped the properties responsible for deforestation. They found that most of Brazil's agricultural output is deforestation-free and that "2% of properties in the Amazon and Cerrado are responsible for 62% of all potentially illegal deforestation".

3.3 Estimation of Input-Output tables

The input-output tables were estimated by Alves-Passoni and Freitas (2020) following a series of technical recommendations based on Grijó and Bêrni (2006). Thereby, the estimations of the tables make the IOTs compatible over time, despite changes in the methodology of the System of National Accounts. All methodological procedures have been described in detail and are publicly available. Since preparing the database, the analysis of the Supply and Use Tables (SUT), calculating structural information regarding the technical coefficients, transport structure, commerce, and taxes, among others, until the estimation and adjustment of the tables.

Annual IOTs estimations are important because the official Brazilian IOTs are prepared by the Brazilian Institute of Geography and Statistics (IBGE, Portuguese acronym) only every 5 years. However, revisions and methodological changes make analyzes with these tables difficult to be comparable (Sousa Filho, Santos and Ribeiro, 2020). As an example, the changes in the SNA. SNA-1993 was used to estimate the IOTs of 2000 and 2005, while for the tables of 2010 and 2015 the IBGE used SNA-2008.

Alves-Passoni and Freitas (2020) also emphasize the limitations existing in the estimation methodology initially proposed by Grijó and Bêrni (2006) but highlight the effectiveness of the method and the importance of having compatible information for mean and long-terms for the Brazilian economy. In addition, the method can be applied to other datasets to estimate tables for other economies. Finally, we will use the estimated IOTs according to the SNA-2008 at constant 2010 prices for the period 2000 to 2017 aggregated with 42 sectors.

4. Results

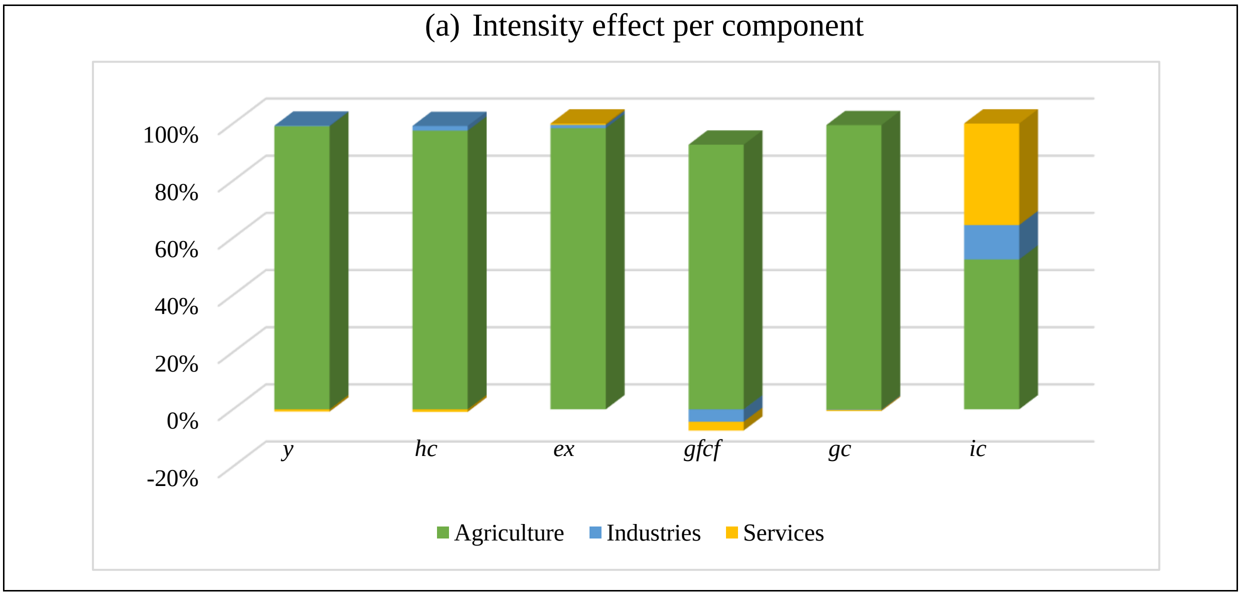
We aggregate the results into three macro-sectors, agriculture, industrial sectors and services, as there is a concentration of emission effects and on the structural demand components regarding the agriculture sector. However, the disaggregated results are presented in Appendix A, as well as the nomenclatures for the respective sectors. In general, the long-run effects of structural changes observed in the agricultural sector were the most striking. Emissions embedded mainly in the final demand component, household consumption, exports, and government consumption were the main drivers of the intensity effect in the agricultural sector (Figure 5a). In the inventory change component, the service sectors stood out with a variation of 35% in emissions but less yet than the agriculture sector (52.4%).

The agricultural sector showed a positive change in all components regarding the technological effect (Figure 5b), indicating a greater need for technological improvement in production to reduce emission levels further. We observed negative changes in the services sectors for the components of final demand, household consumption, exports and government consumption; at the same time, it indicates that the service sectors increased their technologies and managed to produce more while polluting less. Despite this, we highlight that these sectors already had low emissions compared to agriculture or industry.

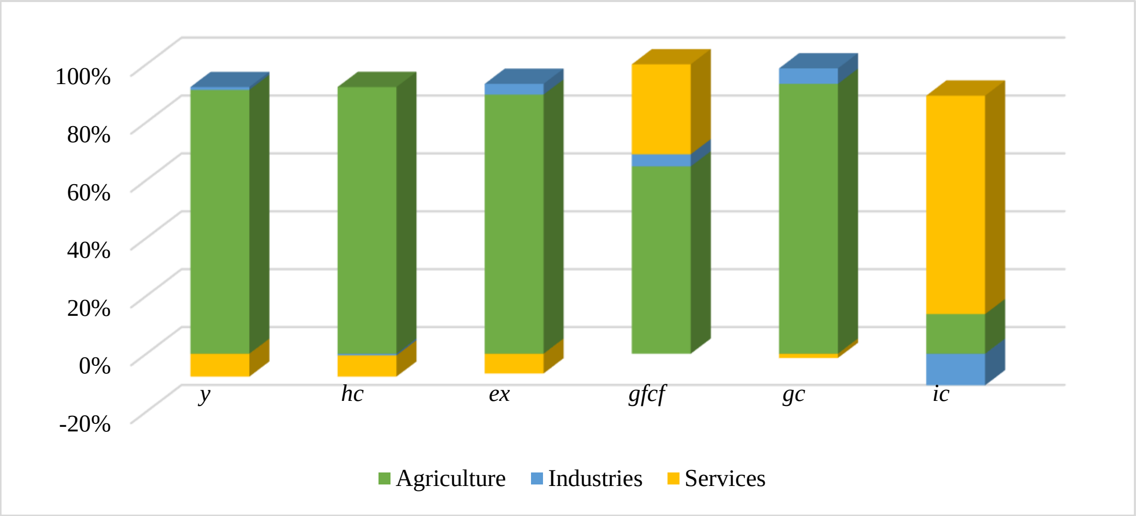
The agricultural sector assumes almost all emissions embedded per components of the final demand structure effect (Figure 5c). Emissions by industrial sectors are more common when looking at the component of gross fixed capital formation (12.3%) (or investment), government consumption (9.0%) and household consumption (8.0%). The service sectors have some prominence in gross fixed capital formation (13.6%) and inventory change (32.1%).

In the total effect (Figure 5d), emissions embedded in the components of final demand, household consumption, exports, and government consumption were the main drivers for the structural change in emissions from the agricultural sector. There was no relevant change to the industrial sectors. For the services, emissions embedded in the gross fixed capital formation and mainly in inventory changes were relevant for structural changes.

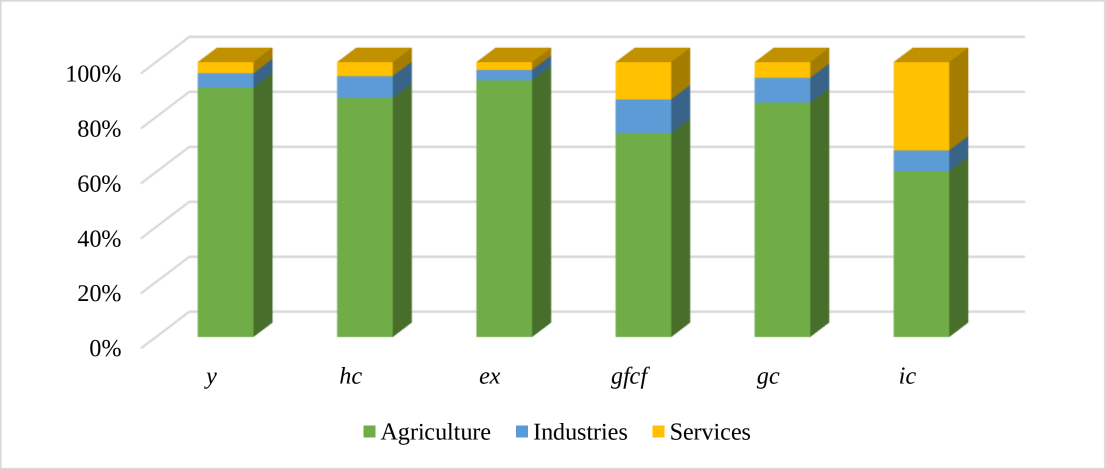
Figure 5. Aggregated results of the structural effects of GHG emissions per sector and components.



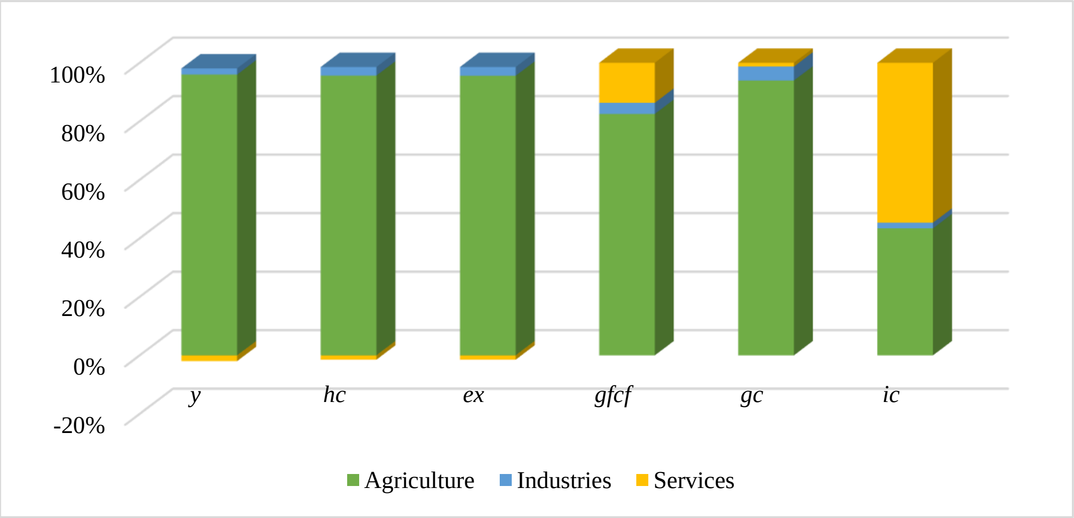
(b) Technological effect per component



(c) Demand structure effect per component



(d) Summary of the total variation per component



When we look at the disaggregated results presented in Appendix A, in addition to the agricultural sector, the manufacturing of organic and inorganic chemicals, resins and elastomers (AT15), manufacturing of steel and derivatives (AT21), electricity and gas, water, sewage and urban cleaning (AT29), transport, storage and mail sector (AT32) had a notoriety intensity effect.

Disaggregating the technological effects, we can also include as prominent sectors the manufacturing of organic and inorganic chemicals, resins and elastomers (AT15), cement and other non-metallic mineral products (AT20), electricity and gas, water, sewage and urban cleaning (AT29), transport, storage and mail sector (AT32). Most of these sectors are from the energy supply chain in Brazil, showing that there were technological improvements that led to a cleaner energy supply. Thus, despite the increase in thermoelectric generation in recent years, the increase in renewable sources, such as wind and solar, has helped maintain emissions at a low level in the energy sectors in Brazil. However, it is worth mentioning that this statement should be viewed with caution since these sectors did not have as much significant technological effect as the agricultural sector.

In the demand structure effect, the oil refining sector (AT13), cement and other non-metallic mineral products (AT20), manufacturing of steel and derivatives (AT21), electricity and gas, water, sewage and urban cleaning (AT29), transport, storage and mail sector (AT32) also are highlighted. The sectors showed a positive effect for all components, mainly for inventory change, government consumption, gross fixed capital formation, and changes in demand from household consumption.

The disaggregated total effect points to structural changes on emissions in the manufacturing of organic and inorganic chemicals, resins and elastomers (AT15), cement and other non-metallic mineral products (AT20), electricity and gas, water, sewage and urban cleaning (AT29), transport, storage and mail sector (AT32), besides agriculture (AT01). Identifying potential sectors where improvements can be made and introducing techniques that reduce emissions to provide financial and technical support is essential to increase production efficiency. Finally, at a disaggregated level, the industrial sectors also proved to be relevant for elaborating policies for energy improvement and reduction of emissions. However, the agricultural sector excels in all structural effects and disaggregated demand components. Essential for humanity, economy and even animal and plant breeding management, Brazilian agriculture still has significant environmental impacts due to its expansion and methods for farming and raising animals.

5. Discussion

Our study performed an additive structural decomposition analysis between 2000 and 2017, with Input-Output tables for 42 sectors of the Brazilian economy. We present possibilities for the occurrence of relevant productive changes both in technological terms and in energy efficiency for the formulation of efficient energy consumption policies in the production and reduction of GHG emissions. It is important to highlight the results of the agricultural sector for the study period. Despite the reduction in absolute emissions, its share on the total of the effects were the biggest. It revealed the extent to which the agricultural sector contributed to the increase in emissions in relation to other sectors of the economy. Technological progress has not contributed to a reduction in emissions. Several complex political issues surround the agricultural sector in Brazil. There is an ongoing struggle for land use in all regions, deforestation and fires aggravate the situation and actively contribute to adverse climate effects on the entire country.

Despite the considerable opening of the input-output tables in 42 sectors, there are no remarked differences between the results presented in the previous section and appendix A results. Besides agriculture (AT01), we highlight few sectors with relevant effects for structural changes in emissions even when we opened the final demand structure: the oil refining sector (AT13), the manufacturing of organic and inorganic chemicals, resins and elastomers (AT15), cement and other non-metallic mineral products (AT20), manufacturing of steel and derivatives (AT21), electricity and gas, water, sewage and urban cleaning (AT29), transport, storage and mail sector (AT32).

Variations in the structural components of aggregate demand had different results depending on the sector and effects analyzed. For example, the intensity effect, final demand, gross fixed capital formation, and government consumption drove GHG emissions in the agricultural sector. Inventory changes were a relevant factor for the intensity effect in the manufacturing of steel and derivatives (AT21), electricity and gas, water, sewage and urban cleaning (AT29), transport, storage and mail sectors (AT32) sectors. All demand components influenced variations in technological change in sectors AT01, AT13, AT15, AT20, AT29, and AT32. The effects of technology proved to be null (0%) in the vast majority of the other productive sectors. We can transpose this same analysis to demand structure effects and the total effect.

Few studies have applied SDA for GHG or CO_2 emissions focusing on the production structure of the Brazilian economy. Silva and Perobelli (2012) used a structural decomposition method to estimate the variation in CO_2 reduction in effects of intensity, final demand and technological effect on 17 sectors of the Brazilian economy in the period from 2000 to 2005. According to the authors, all sectors reduced the amount of emissions for the production of the same amount of products. In the demand effect, which measures the variation in emissions in the face of changes in the level of demand for products and services, the steel, transport, food and beverage sectors, and the energy sector had greater positive variations in terms of the magnitude of growth. In terms of technology, the non-metallic mineral, paper and cellulose, textile, trade and services sectors showed the greatest results in reducing emissions due to some technological progress.

Lenzen et al. (2013) applied SDA techniques to measure key long-term drivers that led Brazil to have an energy matrix with unique characteristics. According to the authors, population growth, changes in Brazilian living standards can lead to increased emissions as well as a strong dependence on agricultural exports. Therefore, the authors investigated the effects of the intensity of CO_2 emissions, the production structure, the composition of demand, the destination of demand and its total level, and the population. The structural components related to population growth and per capita consumption growth had the greatest influence to the increase in emissions in the Brazilian economy between the periods of 1970-2008.

Through the Structural Path Decomposition (SPD) method, Lenzen et al. (2013) found that the supply chains with the greatest links to CO_2 emissions are cattle breeding and the meat industry, both for export and for domestic consumption. The deforestation of forests for large agricultural plantations such as soybeans, the burning of fuels for the transport sector and the burning of coal, coke and charcoal are also featured as sectors with highly polluting supply chains.

Other studies have compared the evolution of GHG or CO_2 emissions among the BRIC or developed economies and concluded that the Brazilian economy has advantages in terms of factors promoting sustainable production development or generating less polluting energy (Lin, Ankrah and Manu 2017; Perdigão et al., 2017; Sesso, 2020). However, it is important to note that these studies used SDA methods and databases constructed or estimated in different ways, which compromises any comparative analysis. It is also worth noting that, despite the positive results of Brazil in relation to other economies, the country provides no guarantees in the formulation of consistent national policies and projects for the reduction of GHG.

Concerns from the international community about the preservation of the Amazonian rainforest and the other natural biomes are growing (Montibeller et al., 2020).

6. Conclusion and Policy Implications

In a context marked by the presence of discussions and efforts to reduce GHG emissions and mitigate climate change effects, global initiatives gain relevance in supporting countries for implementing sustainability policies based on the generation of renewable energy. The Paris Agreement, initiated in 2015, brought new perspectives in this regard. Liu et al. (2020) outlined possible scenarios of effects of the Paris Agreement in large economies, such as the USA and China. According to the authors, the co-benefits of staying and complying with the Agreement are greater than a unilateral withdrawal aimed at increasing GDP in the short-term. Thus, the multilateral construction of policies to reduce CO_2 and other greenhouse gases permeates important initiatives at the international level and has a positive impact on the economy and the well-being of the population.

In terms of competitiveness, Ward, Steckel and Jakob (2019) estimated that the taxation of CO_2 emissions, the main component of GHG, is beneficial for countries that already have an energy matrix more focused on renewable energies, such as Brazil, Japan, US and advanced EU economies. For highly polluting countries such as China and other economies of Asia in process of industrialization, a policy of taxing CO_2 emissions may mean losses in jobs and competitiveness in the short-term. Thus, countries with low-carbon energy systems would have important industrial advantages for the development of production chains with less volatile production costs and prices.

Although energy consumption per capita in Brazil is below the world average, overall energy consumption has increased and consequently energy generation has expanded in the country. According to the Ministry of Mines and Energy (2021), Brazilian energy consumption grew by around 3% per year between 1995 to 2019. It is also expected that energy demand will continue to grow until 2050 at an average growth rate of 2.2% per year. However, it should be noted that while in large energy-consuming economies such as the United States, China and India the energy matrix is essentially based on burning fossil fuels and other pollutants, Brazil has the advantage of having an energy matrix based on hydroelectric power generation (Paul and Bhattacharya, 2004; Szklo et al., 2005; Wang, Chiu and Chiu, 2015; Shahiduzzaman and Layton 2017; Lin, Ankrah and Manu, 2017).

We contribute to the analysis of structural decomposition of GHG for the Brazilian economy in order to provide evidence to support the improvement of policies regarding identification of most polluting economic activities. In addition, addressing a dynamic context in which the whole of society operates is essential for political progress that seeks the sustainable development. Cooperation between these entities will be essential to mitigate the effects of climate change that are already a reality worldwide. Productive economic development must be part of the global and local agendas and encourage the sustainability of an energy matrix with low emission of pollutants.

As a developing country, there is a growing demand for energy in Brazil. Investing in the production of renewable energy and betting on environmental sustainability can be a path that brings greater expectations for development in the medium or long term. The production sectors are growth drivers that need to adapt to the policies and mechanisms for reducing emissions and energy efficiency. We recognize that this has to be a shared effort between the Government and private organizations to promote policies for insertion and technological absorption in machinery and equipment, working conditions and qualification of human capital, improvement of factor productivity as well as broad environmental policies.

Finally, this research presents a comparative statistical analysis using an Input-Output approach. Therefore, this presumes a constant return function and fixed production structure.

These are the main limitations of the methodology. Future studies should expand the analysis by incorporating other methods and discussion on the topic.

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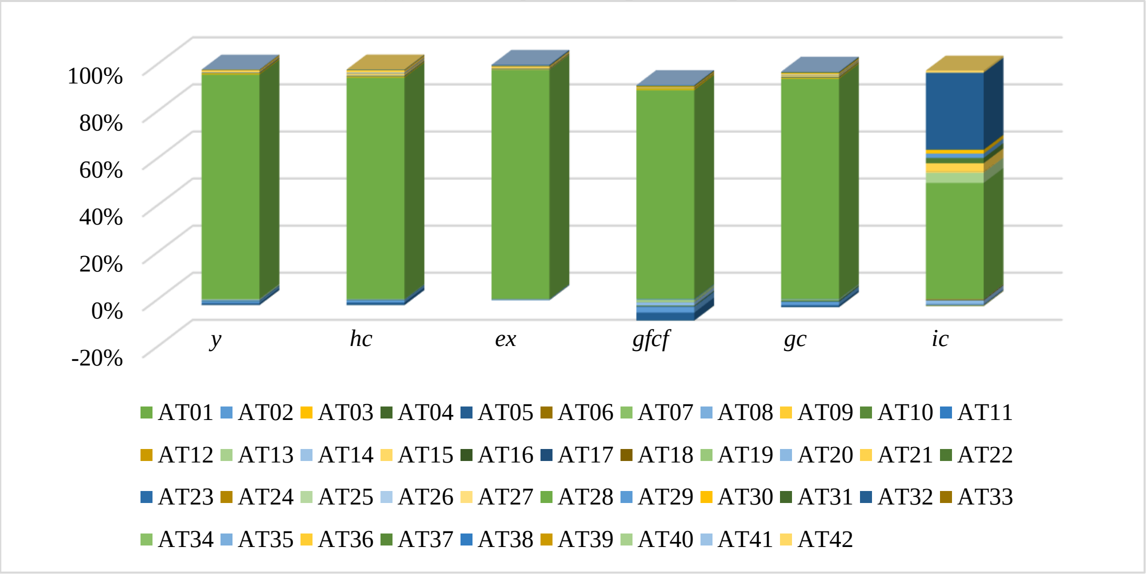
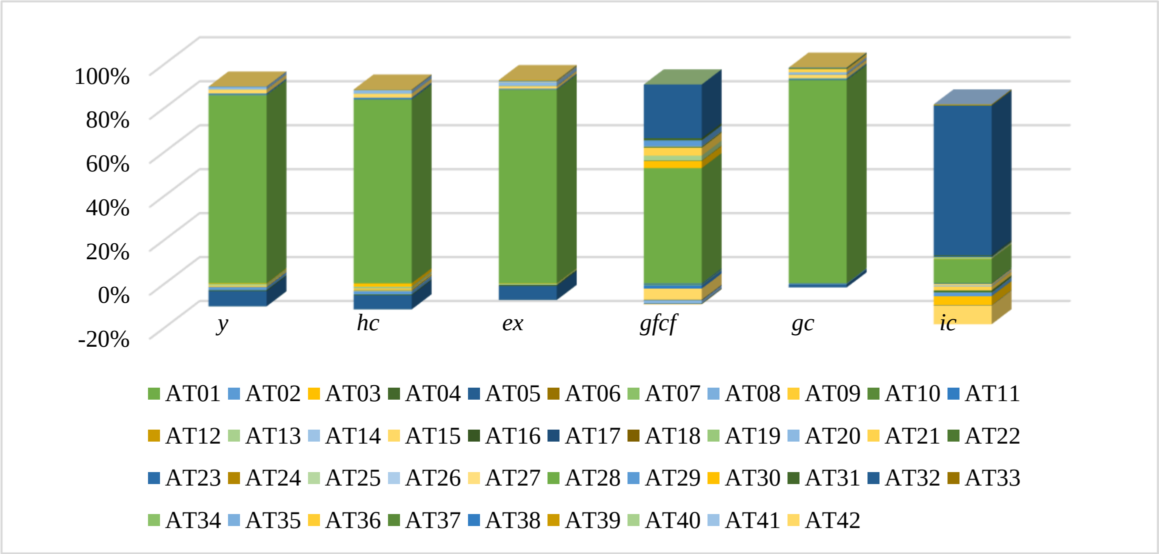
Appendix A.

Disaggregated results of the structural effects of GHG emissions per sector and components.

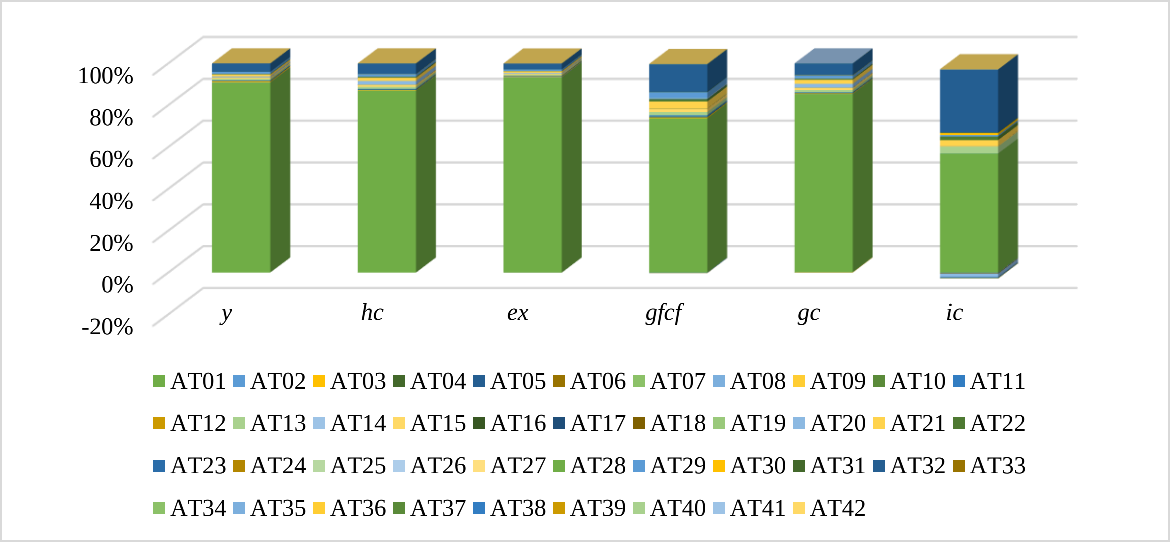
(a) Intensity effect per component



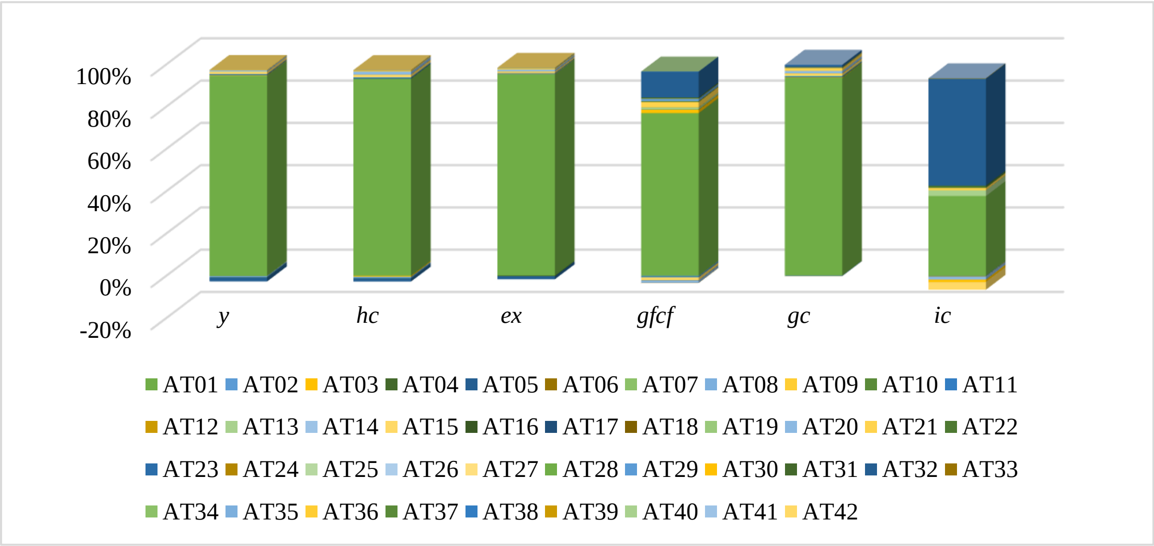
(b) Technological effect per component



(c) Demand structure effect per component



(d) Summary of the total variation per component



Nomenclature of the 42 productive activities of the input-output tables

Code	Economic activity
AT01	Agriculture, forestry, forestry, livestock and fishing
AT02	Oil and gas extraction, including support activities
AT03	Iron ore extraction, including beneficiation and agglomeration
AT04	Others from the extractive industry
AT05	Food and beverages
AT06	Manufacturing of tobacco products
AT07	Textile manufacturing
AT08	Manufacture of apparel and accessories artifacts
AT09	Manufacture of footwear and leather goods
AT10	Wood Products Manufacturing
AT11	Manufacture of pulp, paper and paper products
AT12	Printing and reproduction of recordings
AT13	Oil refining and coke ovens
AT14	Biofuel manufacturing
AT15	Manufacture of organic and inorganic chemicals, resins and elastomers
AT16	Pharmaceutical products
AT17	Perfumery, hygiene and cleaning
AT18	Manufacture of pesticides, disinfectants, paints and various chemicals
AT19	Rubber and plastic
AT20	Cement and other non-metallic mineral products
AT21	Steel and steel manufacturing
AT22	Non-ferrous metals metallurgy
AT23	Metal products - excluding machinery and equipment
AT24	Machines and equipment and furniture and products from various industries
AT25	Home Appliances and Electronic Material
AT26	Automobile van trucks and buses
AT27	Motor vehicle parts and accessories
AT28	Other transport equipment
AT29	Production and distribution of electricity gas water sewage and urban cleaning
AT30	Construction
AT31	Commerce
AT32	Transport, storage and mail
AT33	Accommodation and food services
AT34	Information services
AT35	Financial intermediation insurance and supplementary pension and related services
AT36	Real estate activities and rentals
AT37	Business and household services and maintenance services
AT38	Public administration, defense and social security
AT39	Public education
AT40	Private education
AT41	Public health
AT42	Private health