A Hybrid Energy Input-Output Matrix for Brazil: Analyzing Energy Sectoral Pressures and GHG Emissions

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ABSTRACT

Estimates from the Intergovernmental Panel on Climate Change (IPCC) indicate that human activities have caused about 1.0°C of global warming above pre-industrial levels and warming is likely to reach 1.5°C between 2030 and 2052, if it continues to increase at the current rate. Currently, estimated anthropogenic global warming is increasing by 0.2°C per decade, considering past and current emissions, warns the IPCC. The consequences of climate change caused by global warming pose risks to humanity and natural ecosystems, highlighting the importance of an energy transition. In this context, pressures arising from population growth, increased food production and economic growth have boosted energy consumption and, in turn, greenhouse gas (GHG) emissions. Therefore, this work analyzes the structural changes in the Brazilian economy related to pressures in the energy sector and pollutant emissions. To this end, the methodology used consisted of using a hybrid input-output model with energy data (physical flows) from the National Energy Balance (BEN), based on input-output matrices estimated for Brazil, between 2000 and 2015, and data from the Greenhouse Gas Emissions and Removals Estimation System (SEEG). The analysis will be based on two parts. The first will be based on the hybrid input-output model that will allow checking the direct, indirect and total requirements of the energy sector. The second part will allow us to observe the behavior of the energy sector and other sectors of economic activity in Brazil, in relation to GHG emissions. The results obtained will allow a better understanding of the energy sector in Brazil and its participation in the level of emissions given a global agenda to combat climate change.

Keywords: Energy; Input-output; Hybrid models; GHG emissions.

1. INTRODUCTION

Estimated anthropogenic global warming has been increasing by 0.2°C per decade, considering past and current emissions, warns the Intergovernmental Panel on Climate Change (IPCC). In this context, pressures arising from population growth, increased food production and economic growth have boosted energy consumption and, in turn, emissions.

The IPCC estimates that anthropogenic activities have caused around 1.0°C of global warming above pre-industrial levels and warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. . The consequences of climate change caused by global warming represent risks to humanity and natural ecosystems, highlighting the importance of an energy transition. According to Irena (2019), according to current and planned policies, the transition to a decarbonized

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global energy system will have investments of 110 trillion dollars, which represents 2% of global Gross Domestic Product (GDP) per year, during the period from 2016 to 2050.

According to IEA (2020), in regional terms, in 2018, the main emitters of CO2 were the member countries of the Organization for Economic Cooperation and Development (OECD) and China, being responsible for 35% and 25% of the global share. , respectively. Faced with the large emission of greenhouse gases (GHG) from such sources, an energy transition has been sought to renewable and less polluting sources (solar, wind, biofuels, biomass and waste, small hydroelectric plants, etc.), in order to trying to reduce global warming and its harmful effects on climate change (IRENA, 2019).

As for energy production by primary source, in Brazil non-renewable energy is still higher than renewable energy comparing the years 2015 and 2022. Non-renewable production came to 165,795 million tons of oil equivalent (TEP) in 2015, to 211.79 million TEP in 2022, while renewables jumped from 121.330 million TEP to 143.469 million TEP (EPE, 2023). This highlights the superiority in the production of non-renewable primary sources in relation to renewable ones in the country. According to the Climate Observatory (2023), Brazil remains in a high position in the world ranking of the largest emitters on the planet, occupying seventh place. Given this context, the question arises whether structural changes occurring in the Brazilian economy have influenced greenhouse gas emissions?

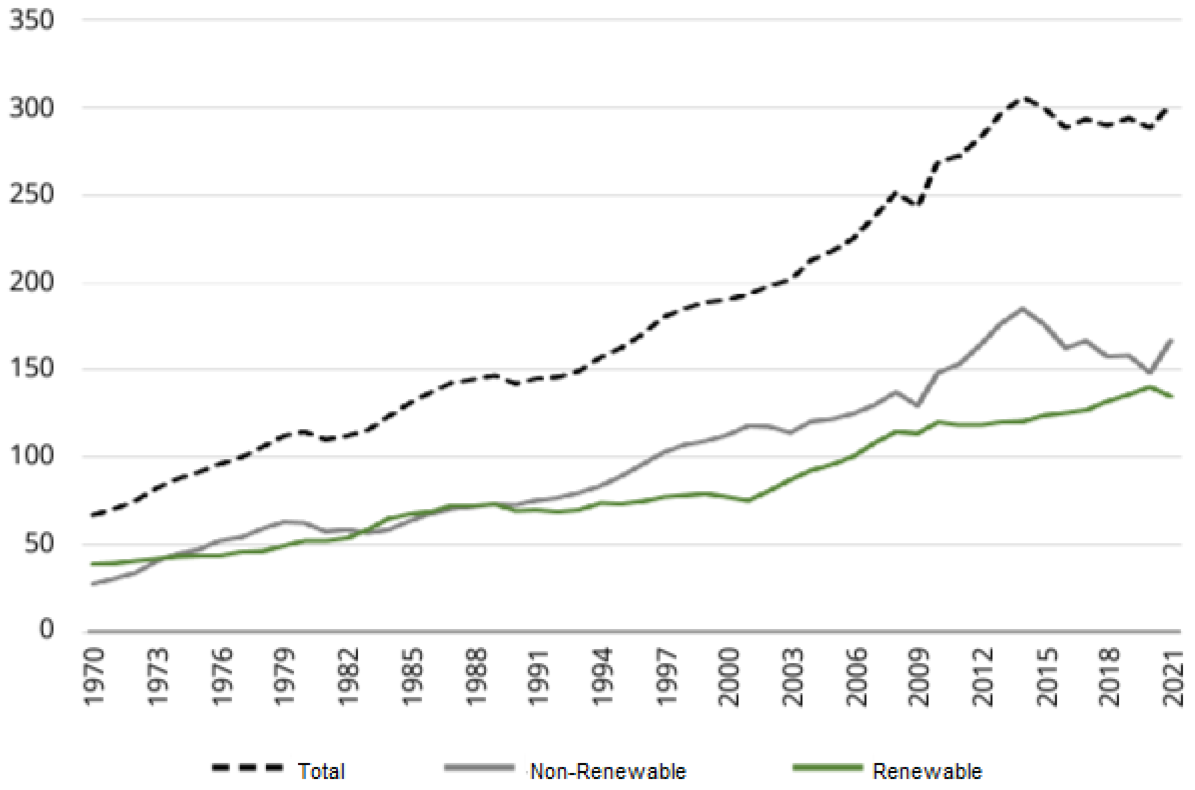
From the above, this work analyzes the structural changes in the Brazilian economy related to pressures in the energy sector and pollutant emissions. To this end, the methodology used consisted of using a hybrid input-output model with energy data (physical flows) from the National Energy Balance (BEN), based on input-output matrices estimated for Brazil, between 2000 and 2015, and data from the Greenhouse Gas Emissions and Removals Estimation System (SEEG).

In this work, some preliminary results of ongoing research are presented.

2. THE ENERGY SECTOR AND GHG EMISSIONS

Energy production in Brazil relies on non-renewable and renewable sources. From 1970 to 2021, in relation to the total produced, it is observed that renewable sources increased, but the majority of production is still from non-renewable sources, as shown in Graph 1. According to data from the 2023 National Energy Balance, the internal supply of renewable energy came consistently growing since 2013, but 2021 broke this cycle: compared to 2020, the supply of renewable energy fell by 4%, while that of non-renewable energy increased by 12% (OBSERVATÓRIO DO CLIMA, 2023). In other words, the observed economic recovery – with growth of around 4.5% in Brazilian GDP in 2021 compared to the previous year – increased energy demand and this demand was met by a greater portion of fossil sources, according to the Climate Observatory (2023). Oil and natural gas stand out among the non-renewable sources, as shown in Table 1. The hydraulic source is the main source of production among the renewable sources, in the period of analysis.

Graph 1 - Production of renewable and non-renewable energy in millions of tons of oil equivalent - TEP



Source: Climate Observatory, 2023.

According to Table 1, from 2006 onwards, there was an increase in the participation of wind sources, but it was from 2012 to 2014 that it became more significant. From 2000 to 2015, wind power had a share of almost 5% in the country's total energy production. It is noteworthy that, in Brazil, during the 2001 energy crisis, there was an attempt to start contracting wind energy generation projects. The Emergency Wind Energy Program (PROEÓLICA) was then created with the aim of complementing hydroelectric flows. However, this program did not obtain the desired result and, in 2002, it was replaced by the Incentive Program for Alternative Sources of Electric Energy, PROINFA. This sought to boost the Brazilian energy matrix by encouraging the development of renewable sources and fixing components and wind turbines in Brazil. In 2009, the first energy trading auction focused exclusively on wind sources took place, justifying the advances in the production of this source in subsequent years observed in Table 1.

Table 1 - Production of primary energy by source (2000-2015)

(Continue)

	Non-renewable energy													
	Oil		Natural gas		Carvão Vapor		Steam coal		Uranium (U_3O_8)		Other Non-Renewable		Total non-renewable (a)	
Year	Production	%	Production	%	Production	%	Production	%	Production	%	Production	%	Production	%
2000	63,85	41,64	13,18	8,60	2,60	1,70	0,01	0,01	0,13	0,09	0,98	0,64	80,76	52,66
2001	66,74	42,68	13,89	8,88	2,17	1,39	0,01	0,01	0,67	0,43	1,07	0,69	84,56	54,07
2002	74,93	43,00	15,42	8,85	1,94	1,11	0,06	0,04	3,34	1,91	1,11	0,63	96,78	55,54
2003	77,23	42,03	15,68	8,53	1,78	0,97	0,04	0,02	2,74	1,49	1,14	0,62	98,62	53,67
2004	76,64	40,29	16,85	8,86	2,02	1,06	0,14	0,07	3,57	1,88	1,13	0,60	100,35	52,75
2005	84,30	42,04	17,58	8,76	2,35	1,17	0,13	0,07	1,31	0,65	1,20	0,60	106,87	53,29
2006	89,21	42,12	17,58	8,30	2,20	1,04	0,09	0,04	2,34	1,10	1,21	0,57	112,64	53,18
2007	90,77	40,58	18,02	8,06	2,26	1,01	0,09	0,04	3,62	1,62	1,37	0,61	116,13	51,92
2008	94,00	39,75	21,40	9,05	2,55	1,08	0,10	0,04	3,95	1,67	1,16	0,49	123,16	52,09
2009	100,92	41,98	20,98	8,73	1,91	0,80	0,17	0,07	4,12	1,71	1,24	0,52	129,34	53,80
2010	106,56	42,10	22,77	9,00	2,10	0,83	0,00	0,00	1,77	0,70	1,08	0,42	134,28	53,05
2011	108,98	42,50	23,89	9,32	2,13	0,83	0,00	0,00	4,21	1,64	1,33	0,52	140,53	54,80
2012	107,26	41,73	25,57	9,95	2,52	0,98	0,00	0,00	3,88	1,51	1,34	0,52	140,57	54,69
2013	104,76	40,57	27,97	10,83	3,30	1,28	0,00	0,00	2,37	0,92	1,59	0,62	140,00	54,22
2014	116,70	42,79	31,66	11,61	3,06	1,12	0,00	0,00	0,68	0,25	1,81	0,67	153,92	56,44
2015	126,13	44,04	34,87	12,18	2,46	0,86	0,00	0,00	0,51	0,18	1,83	0,64	165,80	57,89
Sum and average	1488,97	41,86	337,33	9,34	37,36	1,08	0,84	0,03	39,21	1,11	20,59	0,58	1924,30	54,00

(Conclusion)

	Renewable energy															
	Hydraulic energy		Firrewood		Sugar cane products		Wind		Solar		Other Renewables		Total renewable (b)		Total energy (a+b)	
Year	Production	%	Production	%	Production	%	Production	%	Production	%	Production	%	Production	%	Production	%
2000	26,18	17,07	23,05	15,03	19,89	12,97	0,00	0,00		0,00	3,46	2,26	72,59	47,34	153,34	100,00
2001	23,04	14,73	22,44	14,35	22,80	14,58	0,00	0,00		0,00	3,56	2,27	71,83	45,93	156,40	100,00
2002	24,60	14,12	23,65	13,57	25,28	14,51	0,01	0,00		0,00	3,94	2,26	77,48	44,46	174,26	100,00
2003	26,28	14,30	25,97	14,13	28,36	15,43	0,01	0,00		0,00	4,52	2,46	85,13	46,33	183,74	100,00
2004	27,59	14,50	28,19	14,82	29,39	15,45	0,01	0,00		0,00	4,72	2,48	89,89	47,25	190,24	100,00
2005	29,02	14,47	28,42	14,17	31,09	15,51	0,01	0,00	0,00	0,00	5,11	2,55	93,66	46,71	200,52	100,00
2006	30,00	14,16	28,48	13,45	35,13	16,59	0,02	0,01	0,00	0,00	5,52	2,60	99,15	46,82	211,79	100,00
2007	32,17	14,38	28,62	12,80	40,46	18,09	0,06	0,03	0,00	0,00	6,22	2,78	107,52	48,08	223,65	100,00
2008	31,78	13,44	29,23	12,36	45,02	19,04	0,10	0,04	0,00	0,00	7,16	3,03	113,29	47,91	236,45	100,00
2009	33,62	13,99	24,61	10,24	44,78	18,62	0,11	0,04	0,00	0,00	7,96	3,31	111,08	46,20	240,42	100,00
2010	34,68	13,70	26,00	10,27	48,85	19,30	0,19	0,07	0,00	0,00	9,11	3,60	118,83	46,95	253,11	100,00
2011	36,84	14,36	26,00	10,14	43,27	16,87	0,23	0,09	0,00	0,00	9,57	3,73	115,90	45,20	256,43	100,00
2012	35,72	13,90	25,68	9,99	45,12	17,55	0,43	0,17	0,00	0,00	9,51	3,70	116,46	45,31	257,03	100,00
2013	33,63	13,02	24,58	9,52	49,31	19,10	0,57	0,22	0,00	0,00	10,14	3,93	118,22	45,78	258,21	100,00
2014	32,12	11,78	24,94	9,14	49,27	18,07	1,05	0,39	0,00	0,00	11,41	4,18	118,79	43,56	272,71	100,00
2015	30,94	10,80	24,90	8,69	50,42	17,61	1,86	0,65	0,01	0,00	12,45	4,35	120,58	42,11	286,37	100,00
Sum and average	488,20	13,92	414,74	12,04	608,44	16,83	4,64	0,11	0,01	0,00	114,37	3,09	1630,39	45,87	3554,69	100,00

Source: Own elaboration, based on BEN data, 2023. Note: Measures in TEP

In the recent period, electricity production from wind sources reached 81.6 TWh in 2022, equivalent to an increase of 13% compared to the previous year, when it reached 72.3 TWh. In 2022, the installed power for wind generation in the country expanded by 14.3% (EPE, 2023).

In relation to greenhouse gas emissions, data from the Climate Observatory (2023) indicate that Brazil emitted 2.4 billion gross tons of greenhouse gases in 2021. The increase in deforestation, mainly in the Amazon, was the main responsible for the increase in emissions. The energy sector saw an increase in emissions of 12.5%, representing the biggest jump in 50 years. 435 million tons were emitted, compared to 387 million in the previous year (OBSERVATÓRIO DO CLIMA, 2023). This increase is related to the return of the post-pandemic economy. Another sector that also showed an increase was agriculture, 3.8%.

3. METHODOLOGY

3.1 THE HYBRID INPUT-OUTPUT MODEL

To obtain the sectoral indices and multipliers, first, the input-output model[3] developed by Leontief is derived. This seeks to account for the contributions of the entire production chain for a given demand (MILLER; BLAIR, 2009).

The contribution of many researchers has extended to extensions of the traditional model proposed by Leontief employing physical units in the process. This has provided new research involving energy use, its physical flows in inter-industrial activity and environmental pollution (MILLER; BLAIR, 2009). In general, energy input typically determines the total amount of energy required to deliver a product to end demand, both directly as the energy consumed by an industry's production process, and indirectly as the energy embodied in that industry's inputs.

Thus, in the hybrid model, through the physical flows, it is possible to verify the direct, indirect and total requirements of the energy sector, that is, the sum of the first two. The physical unit adopted was ton oil equivalent (TEP). Analogously to the traditional model, the hybrid model is also composed of matrices, however the characteristics of the matrices in the hybrid model differ from the traditional Leontief model. Because, in this one, the line of energy flows (G) from the National Energy Balance (BEN) is replaced in the matrix of interindustry transactions (Z). With this substitution, a new matrix will be obtained (Z*) containing interindustry energy flows in physical units, in addition to monetary unit flows.

Assuming, for example, a regional model containing two sectors, in which the first is the primary energy sector and the physical production flows are measured in tonne of oil equivalent (TEP). Then, the hybrid model can be expressed as follows:

[3] For more details, see Miller and Blair (2009).

$$Z = \begin{bmatrix} \$ & \$ \\ \$ & \$ \end{bmatrix},\ G = [\text{TEP} \quad \text{TEP}] \tag{1}$$

$$Z^* = \begin{bmatrix} \text{TEP} & \text{TEP} \\ \$ & \$ \end{bmatrix} \tag{2}$$

For total production (X) and final demand (Y) by sector, the same reasoning must be adopted:

$$X^* = \begin{bmatrix} \text{TEP} \\ \$ \end{bmatrix}\ Y^* = \begin{bmatrix} \text{TEP} \\ \$ \end{bmatrix} \tag{3}$$

The matrix of coefficients of direct requirements (technical coefficients) is given by

$A^* = Z^*(\hat{X}^*)^{-1}$ (4), differing from the traditional technical coefficient matrix $A = Z(\hat{X})^{-1}$ (5).

So, the matrix A* is the hybrid matrix of technical coefficients, given by:

$$A^* = \begin{bmatrix} \frac{\text{TEP}}{\text{TEP}} & \frac{\text{TEP}}{\$} \\ \frac{\$}{\text{TEP}} & \frac{\$}{\$} \end{bmatrix} \tag{6}$$

On the other hand, the inverse Leontief matrix, $B^* = (I - A^*)^{-1}$ (7), will follow the same reasoning and will be used in the calculation of the input-output indicators of this work.

The energy requirements of are obtained by subtracting the inverse hybrid matrix from Leontief, B*, of the identity matrix Q*=B*-I* (8), where Q* is the total net requirement matrix. The matrix of coefficients of indirect requirements is given by W*=Q*-A* (9), on what A* is the matrix of direct energy requirements.

3. DATA

To analyze the energy sector in Brazil in the years 2000 and 2015, the input-output matrices estimated by the Brazilian Institute of Geography and Statistics (IBGE) and the physical energy flows from the National Energy Balance (BEN) for both years were used. A compatibility between the two bases was carried out, as the energy data (physical flows) from BEN presented a different sectoral disaggregation from the input-output matrices for Brazil, generating a matrix with disaggregation for fourteen productive sectors. The analysis will be based on two parts. The first will be based on the hybrid input-output model that will allow checking the direct, indirect and total requirements of the energy sector. The second part will allow us to observe the behavior of the energy, agricultural and industrial sectors, as well as waste and change in land and forest use in Brazil, in relation to GHG emissions, based on data from the Emissions Estimation System and Greenhouse Gas Removals (SEEG) is an initiative of the Climate Observatory.

4. RESULTS AND DISCUSSION

4.1 TOTAL ENERGY REQUIREMENTS OF THE POWER SECTOR

The analysis of the evolution, from 2000 to 2015, of the total energy requirements of the energy sector involves direct and indirect requirements. Given the adoption of the hybrid input-output model, the results are in physical units, that is, tons of oil equivalent (TEP). There is a breakdown into fourteen productive sectors. This allows us to verify their pressure on the energy sector, as well as its evolution from 2000 to 2015. From Table 2, it can be seen that there was a reduction in the average of total energy requirements from 2000 (0.004) to 2015 (002) , that is, the fourteen sectors analyzed required less energy during this period. In the same way, it is observed in direct indirect applications, both with a similar reduction, from 0.002, in 2000, to 0.001, in 2015. These results corroborate Firme and Perobelli (2012), showing, in comparison to these, that from 1997 to 2015 has seen a decline in the energy sector's total energy requirements.

Table 2 - Evolution of total (RT), direct (RD) and indirect (RI) energy requirements of the energy sector (2000-2015)

		RT 2000	RT 2015	RD 2000	RD 2015	RI 2000	RI 2015
1	Farming	0,0034	0,0008	0,0021	0,0005	0,0013	0,0002
2	Mining and pelletizing	0,0002	0,0001	0,0000	0,0000	0,0002	0,0001
3	Energy sector	0,0116	0,0050	0,0071	0,0029	0,0045	0,0020
4	Non-metallic minerals	0,0020	0,0011	0,0003	0,0004	0,0017	0,0007
5	Iron and Steel	0,0054	0,0019	0,0002	0,0005	0,0052	0,0013
6	Non-ferrous metals and other metallurgy	0,0036	0,0010	0,0016	0,0004	0,0020	0,0006
7	Other industries	0,0014	0,0004	0,0007	0,0002	0,0007	0,0002
8	Paper And Cellulose	0,0014	0,0007	0,0002	0,0001	0,0011	0,0006
9	Chemical	0,0035	0,0012	0,0010	0,0004	0,0025	0,0009
10	Textile and clothing	0,0001	0,0000	0,0000	0,0000	0,0001	0,0000
11	Food and drinks	0,0014	0,0005	0,0003	0,0002	0,0010	0,0003
12	Trade and services	0,0009	0,0004	0,0005	0,0002	0,0004	0,0002
13	Transport	0,0191	0,0091	0,0118	0,0057	0,0072	0,0034
14	Public services	0,0002	0,0000	0,0001	0,0000	0,0001	0,0000
	Average	**0,0039**	**0,0016**	**0,0019**	**0,0008**	**0,0020**	**0,0008**

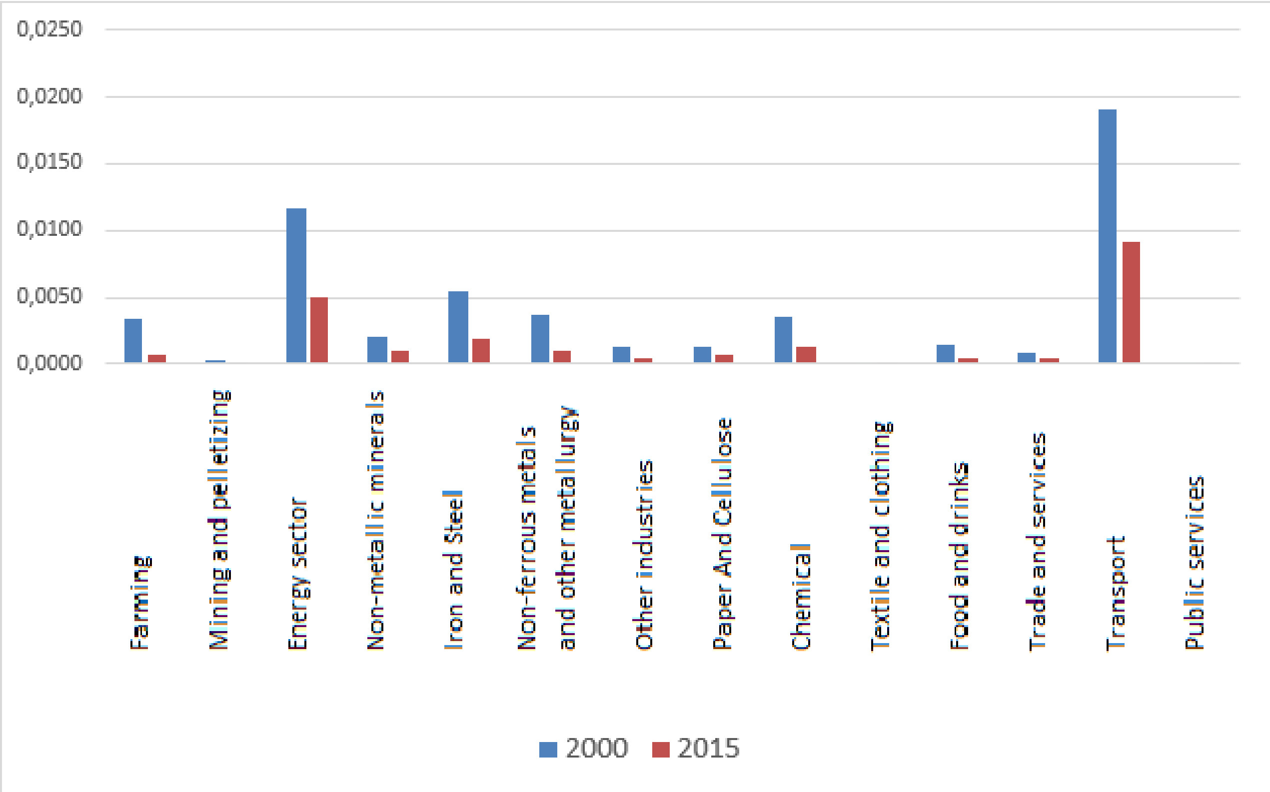
Source: Own elaboration, 2023.

In Graph 2, there is the evolution of the total net energy requirements of the energy sector in 2000 and 2015. The sectors with the highest total requirement rates were: transport (0.019 in 2000 and 0.009 in 2015), energy sector[4] (0.012 in 2000 and 0.005 in 2015) and iron and steel (0.005 in 2000 and 0.002 in 2015), respectively. These three, despite showing a decrease, put pressure on the energy sector. Thus, it is clear that growth in these sectors will require more investments in energy. In relation

[4] The energy sector includes the following sectors: oil and natural gas, mineral coal, liquefied petroleum gas, automotive gasoline, gasohol, fuel oil, diesel oil, other products from petroleum refining and coke, alcohol, electricity and gas.

to the energy sector, in comparison to the work of Firme and Perobelli (2012), it was noted that it showed an increase in energy consumption (increasing RT) from 1997 to 2002, but in the present work it shows a reduction (decreasing RT) from 2000 to 2015.

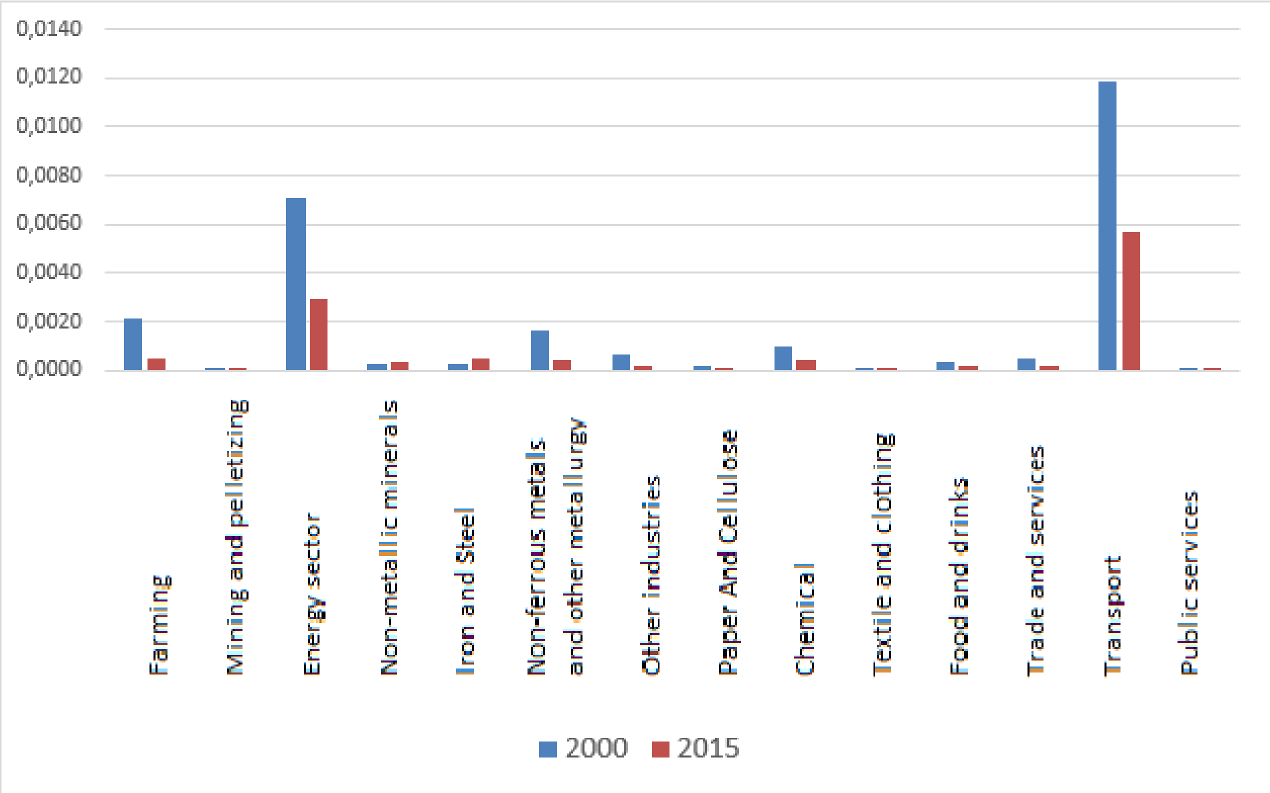
Graph 2 – Total Net Energy Requirements of the Energy Sector (2000 - 2015)



Source: Own elaboration, 2023.

However, it is possible to have a better assessment of the pressure exerted by these sectors on the energy sector by analyzing direct and indirect requirements. In Graph 3, one can analyze the direct energy requirements of the energy sector, it is observed that with the exception of the mining and pelletizing and textile and clothing sectors which remained constant (0.000 in 2000 and 0.000 in 2015, both), and non-metallic minerals and iron and steel that showed an increase in energy consumption, the other sectors had a reduction in their indexes. The transport and energy sectors lead as the sectors with the highest direct requirements, with 0.012 in 2000 and 0.006 in 2015; and 0.007 in 2000 and 0.003 in 2015, respectively. Agriculture had the third highest direct energy requirement in 2000 (0.002), in 2015, as well as the transport and energy sectors also showed a reduction in direct requirements.

Graph 3 – Direct Energy Requirements of the Energy Sector (2000 - 2015)

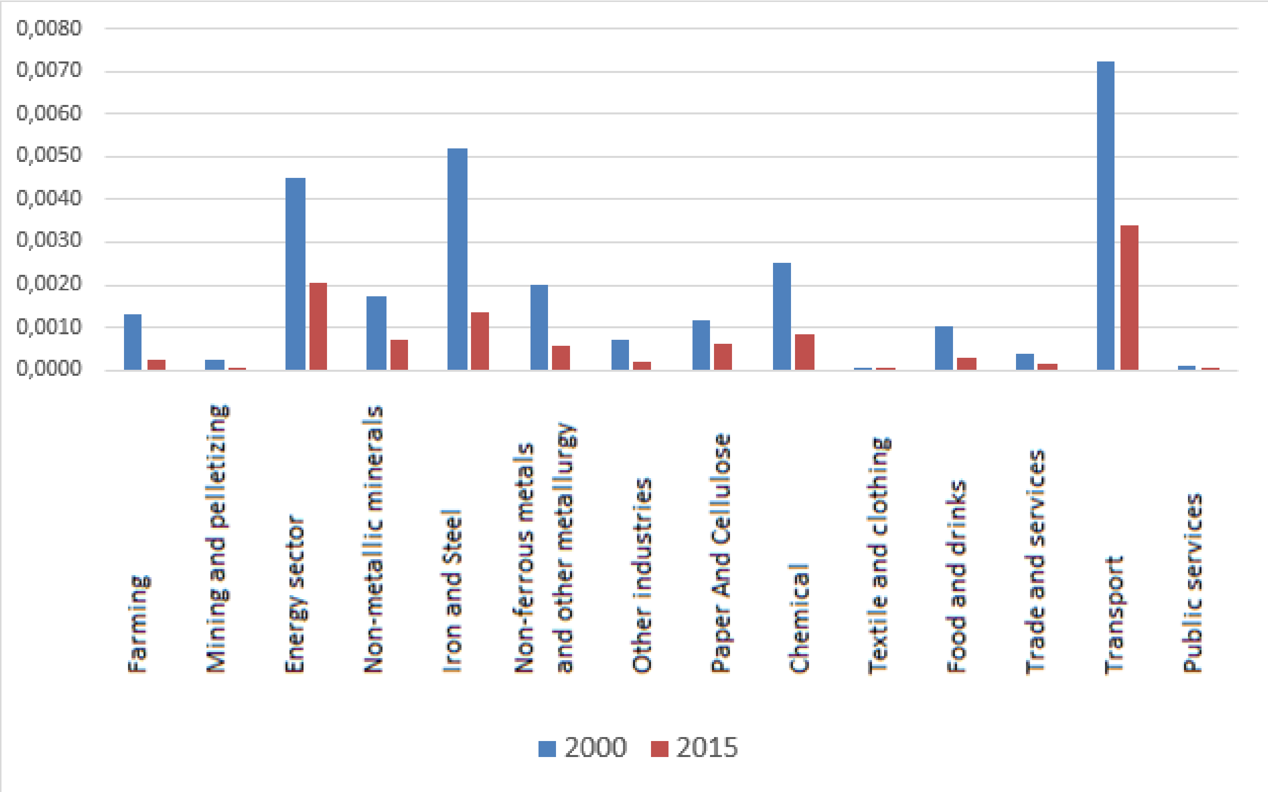


Source: Own elaboration, 2023.

The transport sector is a large consumer of diesel oil, gasoline and ethyl alcohol, while the energy sector includes oil, alcohol, electricity and gas, for example, which explains the high rate of direct energy requirements. This in turn is in accordance with data from the National Energy Balance (BEN).

Already analyzing the indirect energy requirements, Chart 4, some changes in relation to the sectors are evident. The transport sector continues to stand out, with a high rate of indirect requirements: 0.007 in 2000 and 0.003 in 2015. The energy sector, which ranked second among the sectors that stood out most in terms of total and direct requirements, in 2000 presents a lower index (0.004) than the iron and steel sector (0.005), in indirect terms, with the opposite occurring in 2015 (0.002 and 0.001, respectively). It is observed that sectors that did not exert pressure on direct requirements, become more expressive in relation to indirect requirements, such as: chemistry; non-ferrous and other metals from metallurgy; Paper And Cellulose; non-metallic minerals and agriculture. The textile and clothing sector and the public services sector are practically insignificant in terms of indirect requirements.

Graph 4 – Indirect Energy Requirements of the Energy Sector (2000 - 2015)

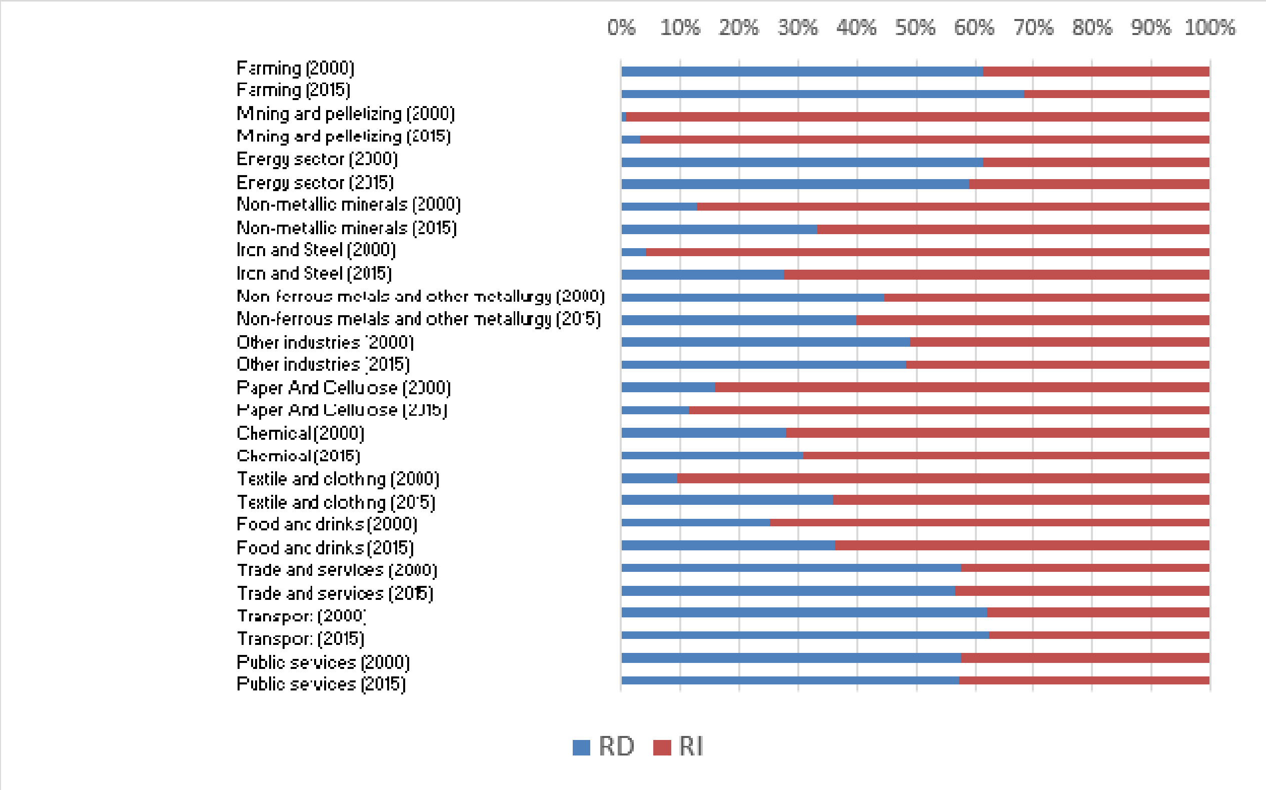


Source: Own elaboration, 2023.

According to Firme and Perobelli (2012), there can be two extremes: on the one hand, sectors with high energy demand and a low ratio of direct versus indirect requirements tend to have strong pressure on the region's energy sector; on the other hand, sectors with low energy demand and a high ratio of direct versus indirect requirements cause low pressure on the local energy sector.

Graph 5 presents the percentage relationship of direct and indirect requirements by sector in 2000 and 2015. It is observed that the mining and pelletizing sector is the one with the lowest relationship between direct and indirect requirements, that is, less pressure on the sector of energy in the region. In 2000, this sector's requirement was 100% indirect, in 2015, less than 5% is direct, demonstrating that the sector has a high power to multiply energy consumption. Sectors such as non-metallic minerals, iron and steel, paper and cellulose, chemicals, textiles and clothing, food and beverages present indirect requirements exceeding 50% of total requirements. Therefore, they have high multiplier power.

Graph 5 – Sectorial Participation of Direct and Indirect Requirements in the Total Energy Requirements of the Energy Sector (2000 e 2015)



Source: Own elaboration, 2023.

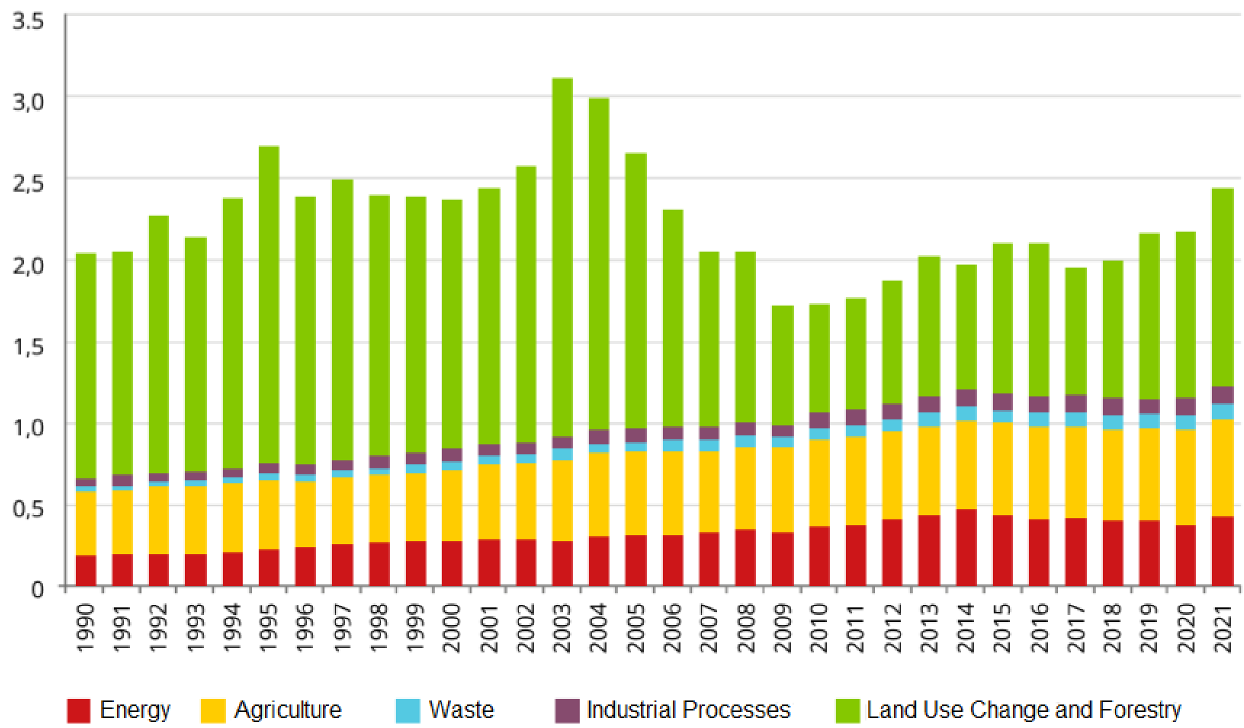
The transport sector, in Graph 5, presents a peculiarity in relation to the others, as in 2000 and 2015 it presented the highest total requirement. However, approximately 62% of this total corresponded to direct requirements in 2000 and 2015. This demonstrates, therefore, that this sector demands a lot of energy from the energy sector, but has a low multiplier power. A similar case was highlighted by Firme and Perobelli (2012), in 1997 and 2002. Agriculture is also another interesting case, in 2000 its direct requirement was approximately 61%, in 2015 it increased, reaching almost 70%, demonstrating greater energy demand and low multiplier power.

4.2 SECTORS OF ECONOMIC ACTIVITY AND GHG EMISSIONS

Even having met the numerical target of its National Climate Change policy, Brazil has not yet changed its emissions trajectory or pollution profile, mainly concentrated on deforestation. The growth in gross GHG emissions was 12.2% in 2021, compared to 2020, while global emissions grew by around 5%, demonstrating that emissions in the country were higher than the world average (OBSERVATÓRIO DO CLIMA, 2023) .

The energy, agricultural, industrial, waste and land use change and forestry sectors in Brazil must be analyzed to understand GHG emissions in the country, considering the Greenhouse Gas Emissions and Removals Estimation System (SEEG) , an initiative of the Climate Observatory. The destruction of Brazilian biomes contributed to increasing the country's emissions. In Figure 1, there are GHG emissions in Brazil from 1990 to 2021 in tons of carbon dioxide equivalent (GtCO2). Land use change and forestry is the sector with the highest GHG emissions in recent decades, linked to the deforestation of different biomes, such as the Cerrado and the Amazon.

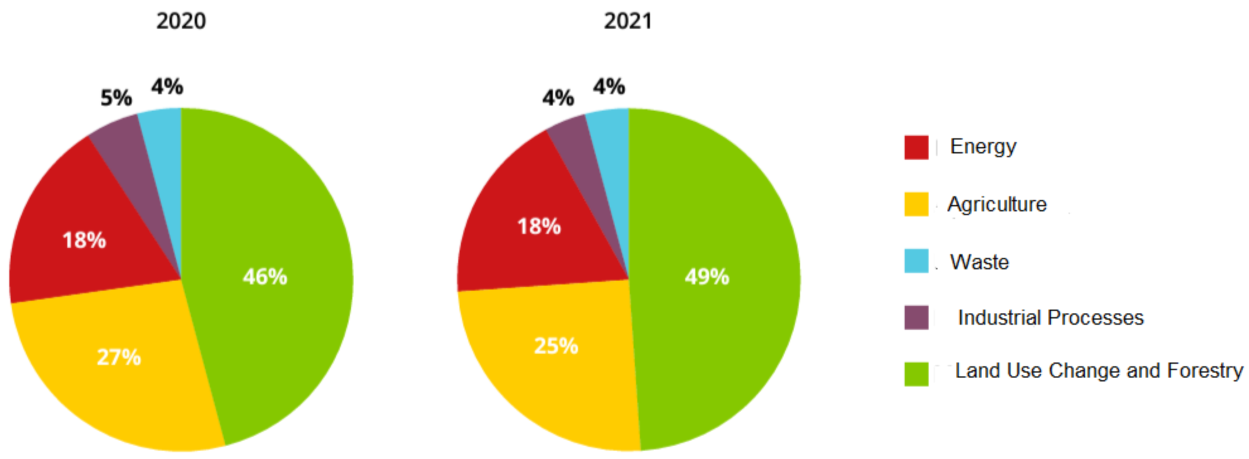
Figure 1 – Greenhouse gas emissions in Brazil from 1990 to 2021 ($GtCO_2$)



Source: Climate Observatory, 2023.

In Figure 2, it is possible to compare emissions by different sectors. In relation to the two years under analysis, it is noted that three sectors remained among the largest emitters.

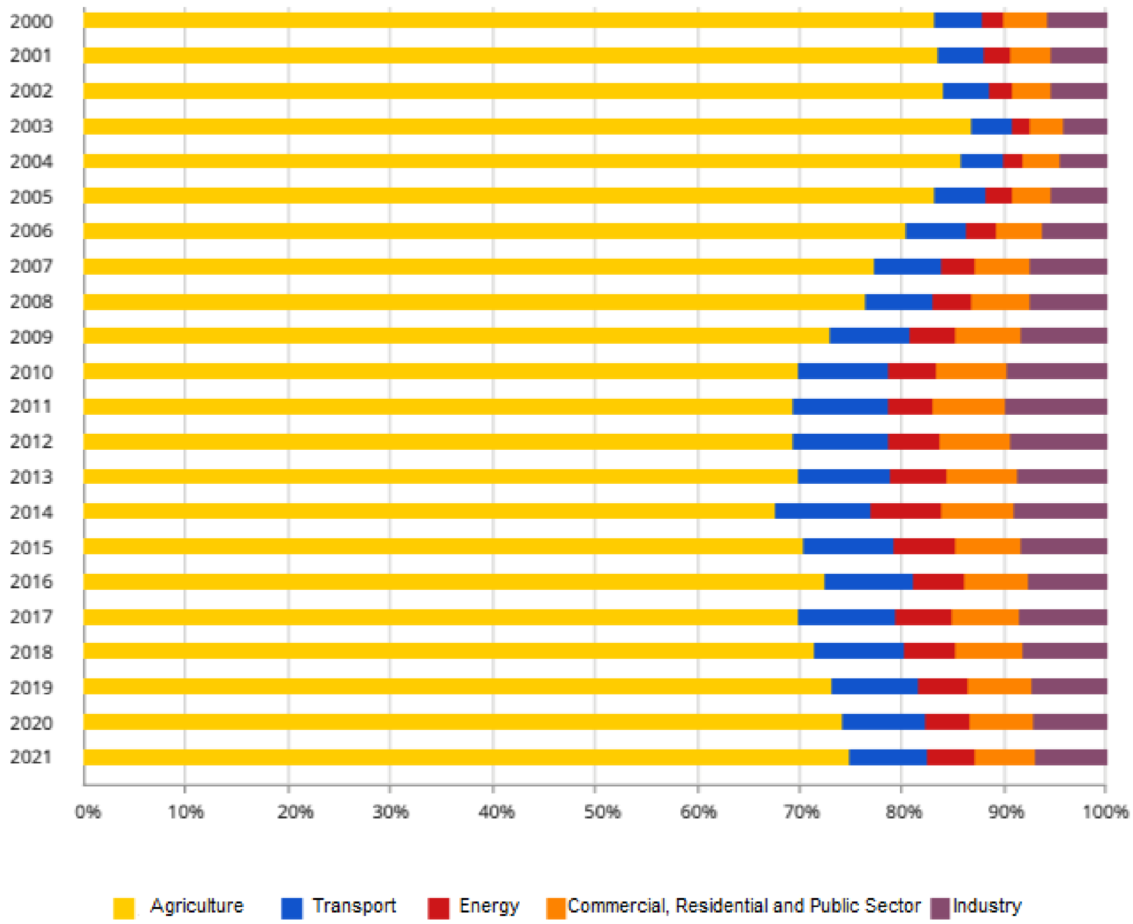
Figura 2 – Participação dos setores nas emissões de GEE brasileiras



Source: Climate Observatory, 2023.

Looking at the profile of emissions by economic activity (Figure 3) considering Gross Domestic Product, it is clear that Brazil still pollutes what is generated in terms of wealth, when compared to the world average (OBERSVATÓRIO DO CLIMA, 2023).

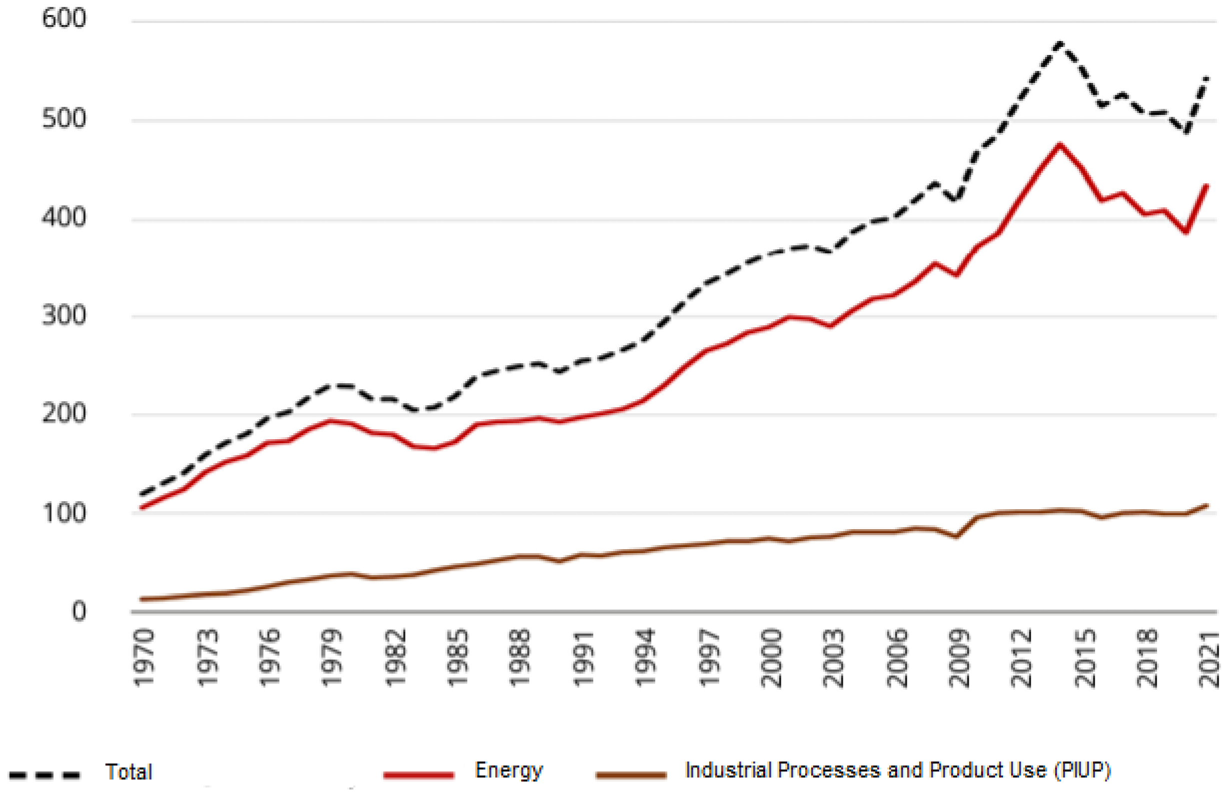
Figure 3 – Emissions from economic activities



Source: Climate Observatory, 2023.

The agricultural sector holds the largest share, followed by transport and energy, as shown in Figure 3. Specifically dealing with the energy sector, this is where emissions from the burning of fuels in activities such as transport, industry and generation are allocated. of electricity. This sector includes gases emitted due to the burning of gasoline in a car engine, as well as gases emitted due to the burning of natural gas in an industrial boiler (OBSERVATÓRIO DO CLIMA, 2023). In Figure 4, it is observed that the energy sector has an upward emissions trajectory, due to the Covid-19 pandemic after 2020 the values are lower than the average.

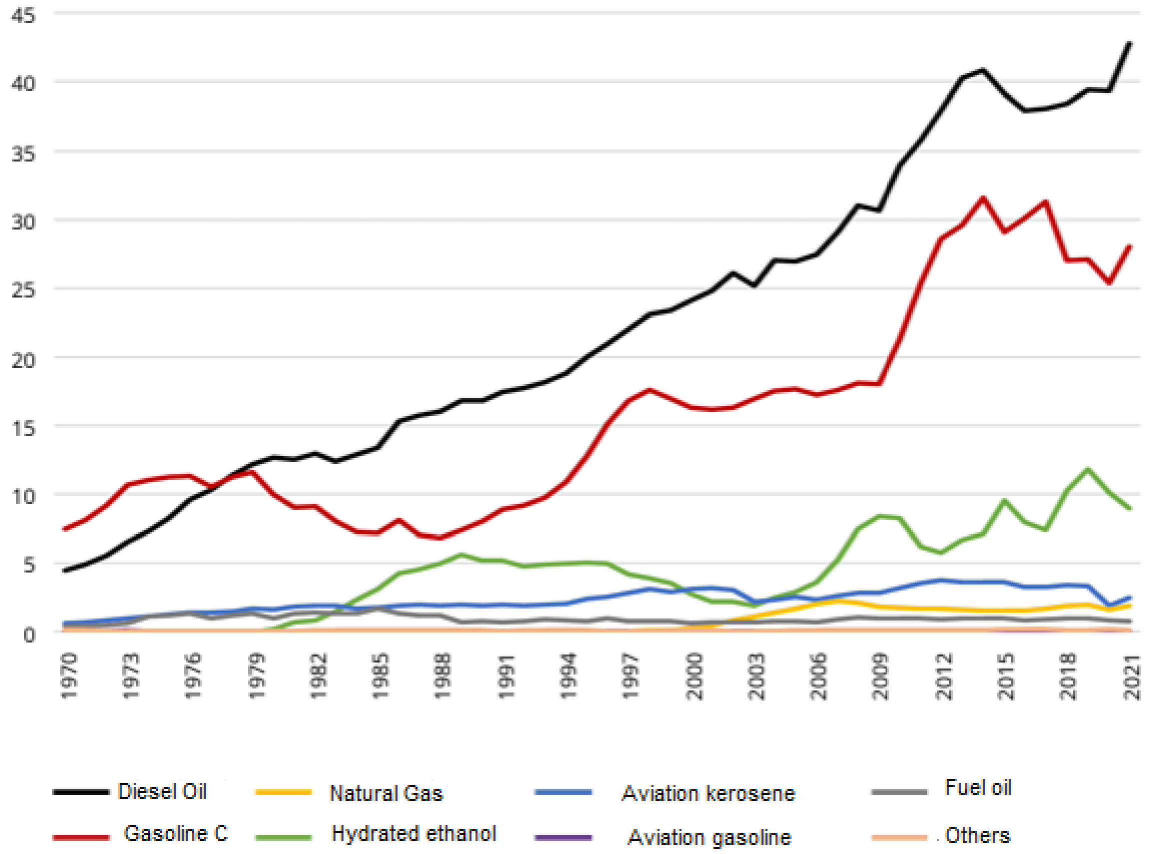
Figure 4 – GHG emissions in the energy and industrial process sectors (PIUP)



Source: Climate Observatory, 2023.

In relation to activities in the energy sector, the transport sector stands out in terms of GHG emissions in Brazil. Transport activity was the one that emitted the most (203.8 million tons of carbon dioxide) within the energy and PIUP sectors (include transport, industry, electricity generation, buildings, agriculture and fuel production). Transport emissions increased by 10%, driven mainly by the consumption of diesel oil in heavy vehicles, surpassing the 2014 level. Furthermore, gasoline consumption also increased, while ethanol consumption was reduced, leading to an increase of emissions, measured in TEP, as shown in Figure 5.

Figure 5 – Use of fuels in transport activities



Source: Climate Observatory, 2023.

Emissions related to the consumption of diesel oil were not even greater due to the portion of biodiesel present in its composition, according to the Climate Observatory (2023). Cars (31%) are the second category in GHG emissions, in first place are trucks (42%). Therefore, new energy sources, which pollute less, must be used and developed with a view to decarbonizing the sector. Actions such as reducing the use of transport and changing less carbon-intensive transport modes.

5. FINAL CONSIDERATIONS

The objective of this work was to analyze pressures in the energy sector and pollutant emissions. To do this, it used Brazil's input-output matrices, aggregated into fourteen productive sectors, for the years 2000 and 2015, aiming to verify the changes that occurred in the energy scenario. Furthermore, investigate the behavior of the energy, agricultural and industrial sectors, as well as waste and change in land and forest use in Brazil, in relation to GHG emissions.

The energy requirements of the energy sector showed a reduction in total requirements of 41% from 2000 to 2015 of the fourteen sectors analyzed. Even the sectors that demand the most energy showed a significant reduction in total energy requirements, such as the transport sector, with a reduction of 48%. A more in-depth analysis must be carried out to define the profile of the sectors with the greatest pressure on the energy sector, as corroborated by Firme and Perobelli (2012). Because, around 62%

of the requirements in this sector come from direct requirements, being a sector with low multiplier power. The mining and pelletizing sector presented more than 95% of its requirements made up of indirect requirements, therefore, it has high multiplier power.

It was also found that the sectors with the greatest power to pressure consumption on the energy sector are the transport and energy sectors, respectively. Analyzing the transport sector in the context of the energy transition, it is observed that the sector exerts pressure on the use of non-renewable energy sources. In other words, even with an electrical matrix with a predominance of renewable energy, the sector that requires the most energy is intensive in non-renewable energy, according to the National Energy Balance. As the transport sector is vital to the country's economy, it is essential to seek to adopt less polluting sources and alternatives to diesel, in order to reduce greenhouse gas emissions and combat climate change.

The use of the hybrid model and analysis with SEEG data highlighted the pressures in the energy sector, including transport. The historical analysis allowed us to observe that gross GHG emissions have been increasing in Brazil. Furthermore, there are warnings about the period from 2019 to 2022 being considered as being marked by the dismantling of the Brazilian climate governance agenda, due to the actions taken by the Bolsonaro government, resorting to changes in the emissions reference in the base year of 2005 that would make the Brazil reaches 2030 emitting more than expected, as the Climate Observatory points out.

Finally, it should be noted that this research is not conclusive and presents preliminary considerations of ongoing investigations at the Study Group on Renewable Energy, Impacts, Conflicts and Climate (GEERICC). Future work will expand the topic studied.

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Appendix A

Table A.1 - Compatibility of the input-output matrices with the BEN sectors

Matriz Brasil 2000		
		55 Setores
1		Agropecuária
1	101	Agricultura, silvicultura, exploração florestal
1	102	Pecuária e pesca
2		Mineração e pelotização
2	202	Minério de ferro
3		Setor energético
3	201	Petróleo e gás natural
3	309	Refino de petróleo e coque
3	310	Alcool
3	401	Eletricidade e gás, água, esgoto e limpeza urbana
4		Minerais não metálicos
4	203	Outros da indústria extrativa
4	320	Outros produtos de minerais não-metálicos
5		Ferro e aço
5	321	Fabricação de aço e derivados
6		Metais não ferrosos e outras da metalurgia
6	319	Cimento
6	322	Metalurgia de metais não-ferrosos
6	323	Produtos de metal - exclusive máquinas e equipamentos
7		Outras indústrias
7	302	Produtos do fumo
7	306	Produtos de madeira - exclusive móveis
7	318	Artigos de borracha e plástico
7	324	Máquinas e equipamentos, inclusive manutenção e reparos
7	325	Eletrodomésticos
7	326	Máquinas para escritório e equipamentos de informática
7	327	Máquinas, aparelhos e materiais elétricos
7	328	Material eletrônico e equipamentos de comunicações
7	329	Aparelhos/instrumentos médico-hospitalar, medida e óptico
7	330	Automóveis, camionetas e utilitários
7	331	Caminhões e ônibus
7	332	Peças e acessórios para veículos automotores
7	333	Outros equipamentos de transporte
7	334	Móveis e produtos das indústrias diversas
7	501	Construção
8		Papel e celulose
8	307	Celulose e produtos de papel
8	308	Jornais, revistas, discos
9		Química
9	311	Produtos químicos
9	312	Fabricação de resina e elastômeros
9	313	Produtos farmacêuticos
9	314	Defensivos agrícolas
9	315	Perfumaria, higiene e limpeza
9	316	Tintas, vernizes, esmaltes e lacas
9	317	Produtos e preparados químicos diversos
10		Têxtil e vestuário
10	303	Têxteis
10	304	Artigos do vestuário e acessórios
10	305	Artefatos de couro e calçados
11		Alimentos e bebidas
11	301	Alimentos e Bebidas
12		Comércio e serviços
12	601	Comércio
12	1102	Serviços de alojamento e alimentação
12	801	Serviços de informação
12	901	Intermediação financeira e seguros
12	1001	Serviços imobiliários e aluguel
12	1103	Serviços prestados às empresas
12	1101	Serviços de manutenção e reparação
12	1104	Educação mercantil
12	1105	Saúde mercantil
12	1106	Outros serviços
13		Transporte
13	701	Transporte, armazenagem e correio
14		Serviços públicos
14	1203	Administração pública e seguridade social
14	1201	Educação pública
14	1202	Saúde pública

Matriz Brasil 2015		
		67 Setores
		Agropecuária
	191	Agricultura, inclusive o apoio à agricultura e a pós-colheita
	192	Pecuária, inclusive o apoio à pecuária
	280	Produção florestal; pesca e aquicultura
		Mineração e pelotização
	791	Extração de minério de ferro, inclusive beneficiamentos e a aglomeração
		Setor energético
	580	Extração de carvão mineral e de minerais não metálicos
	680	Extração de petróleo e gás, inclusive as atividades de apoio
	1991	Refino de petróleo e coquerias
	1992	Fabricação de biocombustíveis
	3500	Energia elétrica, gás natural e outras utilidades
	3680	Água, esgoto e gestão de resíduos
		Minerais não metálicos
	2300	Fabricação de produtos de minerais não metálicos
		Ferro e aço
	2491	Produção de ferro gusa/ferroligas, siderurgia e tubos de aço sem costura
6		Metais não ferrosos e outras da metalurgia
6	792	Extração de minerais metálicos não ferrosos, inclusive beneficiamentos
6	2492	Metalurgia de metais não ferosos e a fundição de metais
6	2500	Fabricação de produtos de metal, exceto máquinas e equipamentos
7		Outras indústrias
7	1200	Fabricação de produtos do fumo
7	1600	Fabricação de produtos da madeira
7	2200	Fabricação de produtos de borracha e de material plástico
7	2600	Fabricação de equipamentos de informática, produtos eletrônicos e ópticos
7	2700	Fabricação de máquinas e equipamentos elétricos
7	2800	Fabricação de máquinas e equipamentos mecânicos
7	2991	Fabricação de automóveis, caminhões e ônibus, exceto peças
7	2992	Fabricação de peças e acessórios para veículos automotores
7	3000	Fabricação de outros equipamentos de transporte, exceto veículos automotores
7	3180	Fabricação de móveis e de produtos de indústrias diversas
7	3300	Manutenção, reparação e instalação de máquinas e equipamentos
7	4180	Construção
8		Papel e celulose
8	1700	Fabricação de celulose, papel e produtos de papel
8	1800	Impressão e reprodução de gravações
9		Química
9	2091	Fabricação de químicos orgânicos e inorgânicos, resinas e elastômeros
9	2092	Fabricação de defensivos, desinfestantes, tintas e químicos diversos
9	2093	Fabricação de produtos de limpeza, cosméticos/perfumaria e higiene pessoal
9	2100	Fabricação de produtos farmoquímicos e farmacêuticos
10		Têxtil e vestuário
10	1300	Fabricação de produtos têxteis
10	1400	Confecção de artefatos do vestuário e acessórios
10	1500	Fabricação de calçados e de artefatos de couro
11		Alimentos e bebidas
11	1091	Abate e produtos de carne, inclusive os produtos do laticínio e da pesca
11	1092	Fabricação e refino de açúcar
11	1093	Outros produtos alimentares
11	1100	Fabricação de bebidas
12		Comércio e serviços
12	4580	Comércio por atacado e varejo
12	5500	Alojamento
12	5600	Alimentação
12	5800	Edição e edição integrada à impressão
12	5980	Atividades de televisão, rádio, cinema e gravação/edição de som e imagem
12	6100	Telecomunicações
12	6280	Desenvolvimento de sistemas e outros serviços de informação
12	6480	Intermediação financeira, seguros e previdência complementar
12	6800	Atividades imobiliárias
12	6980	Atividades jurídicas, contábeis, consultoria e sedes de empresas
12	7180	Serviços de arquitetura, engenharia, testes/análises técnicas e P & D
12	7380	Outras atividades profissionais, científicas e técnicas
12	7700	Aluguéis não imobiliários e gestão de ativos de propriedade intelectual
12	7880	Outras atividades administrativas e serviços complementares
12	8000	Atividades de vigilância, segurança e investigação
12	8592	Educação privada
12	8692	Saúde privada
12	9080	Atividades artísticas, criativas e de espetáculos
12	9480	Organizações associativas e outros serviços pessoais
12	9700	Serviços domésticos
13		Transporte
13	4900	Transporte terrestre
13	5000	Transporte aquaviário
13	5100	Transporte aéreo
13	5280	Armazenamento, atividades auxiliares dos transportes e correio
14		Serviços públicos
14	8400	Administração pública, defesa e seguridade social
14	8591	Educação pública
14	8691	Saúde pública

BEN	
1	Agropecuária
	Agropecuária
2	Mineração e pelotização
	Mineração e pelotização
3	Setor energético
	Setor energético
4	Minerais não metálicos
	Não ferrosos e outras metalurgias
5	Ferro e aço
	Ferro gusa e aço
	Ferro ligas
6	Metais não ferrosos e outras da metalurgia
	Cimento
	Cerâmica
7	Outras indústrias
	Outras indústrias
8	Papel e celulose
	Papel e celulose
9	Química
	Química
10	Têxtil e vestuário
	Têxtil
11	Alimentos e bebidas
	Alimentos e bebidas
12	Comércio e serviços
	Comercial
13	Transporte
	Rodoviário
	Ferroviário
	Aéreo
	Hidroviário
14	Serviços públicos
	Público

Source: Own elaboration, 2023.