UFRJ ie. | DIP DECARBONIZATION & INDUSTRIAL POLICY

DECARBONIZATION AND INDUSTRIAL POLICY: CHALLENGES FOR BRAZIL

Working Paper DIP-BR 01/2024

THE KEY-SECTORS FOR A LOW-CARBON TRANSITION IN THE BRAZILIAN ECONOMY

Kaio Glauber Vital da Costa

OPEN SOCIETY FOUNDATIONS

DECARBONIZATION AND INDUSTRIAL POLICY: CHALLENGES FOR BRAZIL

About the Project DIP-BR

"Decarbonization and Industrial Policy: Challenges for Brazil" (DIP-BR) is a policy-oriented research-action project aimed at influencing public debate on industrial, innovation, and trade policies in Brazil and selected Latin American countries that promote decarbonization and energy transition in the region. The initiative seeks to inform and induce efficacy, efficiency, effectiveness, and innovativeness in policy design and implementation. The methodology encompasses critical benchmarking analyses of past and present policy experiences from an international comparative perspective, regional trade studies, and economic analyses of productive sectors and chains, combining structural analysis of traditional production, employment, and trade statistics and simulation models of sectoral impacts using input-output approach.

Funded by the Open Society Foundations (OSF), Project DIP-BR is executed by the Research Group of Industry and Competitiveness at the Institute of Economics, Federal University of Rio de Janeiro (GIC/IE-UFRJ, **https://www.ie.ufrj.br/gic**) and is currently managed through José Bonifácio University Foundation (**https://www.fujb.ufrj.br/**).

Project DIP-BR Team

Head Investigator

Carlos Frederico Leão Rocha,
Professor at IE-UFRJ

Research Team

João Carlos Ferraz,
Professor at IE-UFRJ

Marta Castilho,
Professor at IE-UFRJ

Fabio Freitas,
Professor at IE-UFRJ

Kaio Vital,
Professor at IE-UFRJ

Julia Torracca,
Professor at IE-UFRJ

Wilson Peres,
Research Fellow at GIC/IE-UFRJ

Research Assistants

Bruna Ribeiro,
Ph.D. student at IE-UFRJ

Gabriel Pessanha,
Ph.D. student at IE-UFRJ

Tatiana Fleming,
Ph.D. student at IE-UFRJ

Nilo Bezerra Neto,
Undergraduate student at IE-UFRJ

Project Manager

Carolina Dias,
Ph.D. student at ECO-UFRJ

DECARBONIZATION AND INDUSTRIAL POLICY: CHALLENGES FOR BRAZIL

Working Paper DIP-BR 01/2024

THE KEY-SECTORS FOR A LOW-CARBON TRANSITION IN THE BRAZILIAN ECONOMY

Kaio Glauber Vital da Costa *

Introduction

Climate change consists of a gradual increase in global temperature, causing sea levels to rise and precipitation patterns to change, as well as the frequency, magnitude, and intensity of extreme weather events such as droughts and floods. Since the initial recording of global warming in 1985 by the World Meteorological Organization (WMO), it has become evident that the cause of this phenomenon is long-standing and a result of atmospheric concentrations of greenhouse gases. Several gases have this effect, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs). They all occur naturally but are also produced by human activities, notably the burning of fossil fuels.

Established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) (IPCC, 2012), the Intergovernmental Panel on Climate Change (IPCC) has set rules for measuring the emissions of greenhouse gases

* Professor and researcher at the Institute of Economics, Federal University of Rio de Janeiro (IE-UFRJ) and researcher at the Research Group on Industry and Competitiveness at IE-UFRJ. Rio de Janeiro, Brazil. ORCID: https://orcid.org/0000-0002-9390-0555. E-mail address: kaio.costa@ie.ufrj.br.

Climate change consists of a gradual increase in global temperature, causing sea levels to rise and precipitation patterns to change, as well as the frequency, magnitude, and intensity of extreme weather events such as droughts and floods. Since the initial recording of global warming in 1985 by the World Meteorological Organization (WMO), it has become evident that the cause of this phenomenon is long-standing and a result of atmospheric concentrations of greenhouse gases. Several gases have this effect, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs). They all occur naturally but are also produced by human activities, notably the burning of fossil fuels.

Established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) (IPCC, 2012), the Intergovernmental Panel on Climate Change (IPCC) has set rules for measuring the emissions of greenhouse gases in all UN member states, compiled information, convened meetings of countries - the so-called Conference of Parties (COP) - to reach agreements, and recommended policies to address the issue. According to IPCC experts (IPCC, 2012), two central policies are crucial in the transition to low-carbon economies: mitigation and adaptation. Both policies are essential to meet the challenges of climate change. Mitigation refers to “technological changes and substitutions that reduce inputs and emissions per unit of product” (IPCC, 2007, p. 84).

Brazil’s greenhouse gas (GHG) emissions are not strongly related to energy production but rather to land use change (deforestation) and agriculture, which account for 73% of the country’s total emissions (Observatório do Clima, 2023). While the energy sector was responsible for 76% of GHG emissions globally, Brazil’s energy matrix accounted for 18% of the country’s gross GHG emissions in 2020 (Observatório do Clima, 2023). Energy emissions in Brazil reached 393.7 million **tCO2eq**[1] in 2020 (Observatório do Clima, 2023). The sectoral breakdown of energy emissions allows to understand better how each consumption segment contributes to the success of climate targets. Transport (47%), fuel production (18%), electricity generation (8%), and industry (17%) accounted for almost 90% of emissions from energy use in Brazil in 2020 (Observatório do Clima, 2023). Nearly half of Brazil’s energy matrix comes from renewable energy.

All factors causing fuel combustion are related to economic activity in the broadest

---

[1] CO_2 equivalent (CO_2eq) is a metric measure to compare the emissions of various greenhouse gases based on their global warming potential (GWP). It converts the amount of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

sense: production, trade, and consumption. Designing a mitigation scenario requires identifying the production sectors that generate GHG emissions first. The Brazilian government launched a green taxonomy based on previous experience in Colombia, Mexico, and Union Europe. The main purpose is to select sectors critical to achieving the climate neutrality targets in the Nationally Determined Contributions (NDC) (UNCC, 2023).

Increased CO_2 emissions are often a prominent cause of observed warming. Although one can pinpoint the primary sources of CO_2 emissions (or key sectors) by ranking various emission indicators of industries and imposing emission reduction targets on these main polluters, a technological threshold exists for how much they can reduce emissions independently. That is a major challenge faced by climate policy. Therefore, it is crucial to decrease CO_2 emissions by promoting industrial clusters oriented toward decarbonizing the main environmentally important paths, linkages, and key sectors.
Identifying and analyzing the industries that emit the most CO_2 in Brazil are within the scope of the present document. This policy brief is part of the research project entitled "Decarbonization and Industrial Policy: Challenges for Brazil" (DIP-BR), conducted by the Research Group on Industry and Competitiveness at the Institute of Economics of the Federal University of Rio de Janeiro, Brazil. Our aim here is to identify the leading emitting sectors in Brazil, assess their direct and indirect emissions, and discuss the significance of this approach concerning to the design and implementation of green industrial policies.

Green industrial policies require investments, incentives, regulations, and policy support to promote and facilitate the development of environmental technologies (Harrison; Martin; Nataraj, 2017; Rodrik, 2014, 2022). The unique characteristic of green industrial policies, as opposed to other environmental actions, is their focus on restructuring and transforming the economy into a green economy. Domestic economic priorities, global competitiveness pressures, and the desire to secure a better position in global production and trade networks are often the driving forces behind such transformation.

Industrial restructuring aims to adjust the proportions of various sectors to meet specific targets. Effectively reducing CO_2 emissions requires restricting high-emission sectors while expanding low-emission sectors. However, reducing emissions through output restrictions may impact the economic income of certain sectors and potentially hinder national economic growth. Therefore, it is paramount to weight both economic and emission performance when discussing the roles of different sectors in a country. As countries transition from agriculture to industry, complexity increases, particularly in medium and high-tech manufacturing, which only sometimes results in more environmentally friendly production. Industries with reduced carbon emissions include the

Analysis by sector group: An aggregate perspective of Brazilian emissions

As shown in Table 1, China, the United States, India, Russia, and Japan are the countries with the highest emissions in 2020 – a position they have been holding for many years. In 2015, they signed the United Nations Framework Convention on Climate Change, also known as the Paris Agreement, along with other participants. The following year, they confirmed their commitment to annual emissions reduction targets through 2025 in letters called 'Intended Nationally Determined Contributions' (UNCCC, 2016). The United States' withdrawal from the agreement in 2017 put the compliance with the commitments made by signatories at risk, especially the largest emitters. As a result, GHG emissions continued to grow, despite many countries experiencing a decline in emissions in 2020 due to the Covid-19 pandemic, which severely affected all economies.

Table 1 - GHG emissions in selected countries, 2017/2020

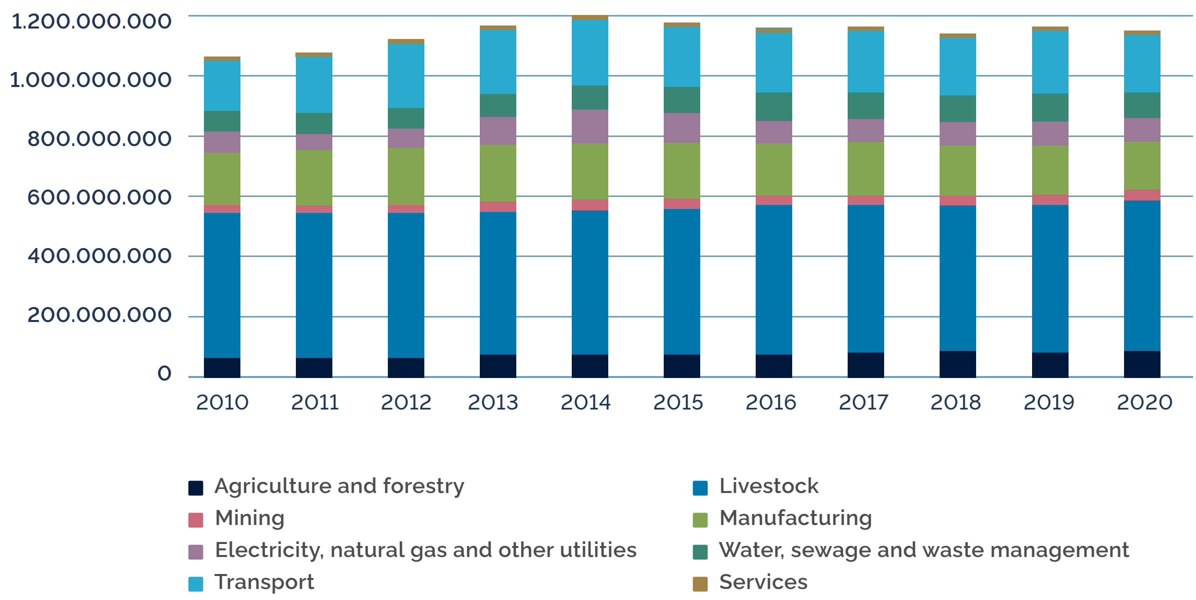
		EMISSIONS IN 2017		EMISSIONS IN 2020		Population (millions)
		Total	Per capita	Total	Per capita	
		TCO_2 eq.	Kg CO_2 eq.	TCO_2 eq.	Kg CO_2 eq.	
1	China	10,877.2	7.7	11,680.4	8.2	1,448,471.4
2	USA	5,107.4	15.7	4,535.3	13.68	334,805.3
3	India	2,454.8	1.8	2,411.7	1.74	1,406,631.8
4	Russia	1,764.9	12.3	1,674.2	11.64	145,805.9
5	Japan	1,320.8	10.4	1,061.8	8.39	125,584.8
6	Iran	671.5	8.3	690.2	8.26	86,022.8
7	Germany	796.5	9.7	636.9	7.72	83,883.6
8	South Corea	673.3	13.2	621.5	12.07	51,329.9
9	Saudi Arabia	638.8	19.4	588.8	16.96	35,844.9
10	Indonesia	511.3	1.9	568.3	2.09	279,134.5
11	Canada	617.3	16.9	542.8	14.43	38,388.4
12	Brazil	492.8	2.4	451.8	2.11	215,353.6
13	South Africa	467.7	8.2	435.1	7.41	60,756.1
14	Mexico	507.2	3.9	407.7	3.05	131,562.8
15	Turkey	429.6	5.3	405.2	4.83	85,562

Source: own elaboration based on data extracted from World Population Review (2022).

Numerous factors play a crucial role in shaping the emissions trajectory of each industrial sector under scrutiny. They encompass domestic and international economic growth, technological advancements, changes in trade patterns, and changes in the composition of final demand. An analysis of Brazil's emissions profile shows a consistent upward trend across all industrial sectors (Graph 1). It is worth noting that such upward trajectories vary considerably in their baseline emissions, acceleration rates, turning points, and deceleration phases. It shows that each grouping has different dynamics and trends in its emissions path.

Between 2010 and 2020, agriculture and forestry had the highest growth rate in emissions (30%), followed by water, sewerage, and waste management (22%), services (20%), electricity, gas, and other utilities (15%), mining (13%), transport (8%), and livestock (3%). Manufacturing was the only sector with a decreasing growth rate of emissions (-3%), probably due to the economic downturn that started around 2014-2015.

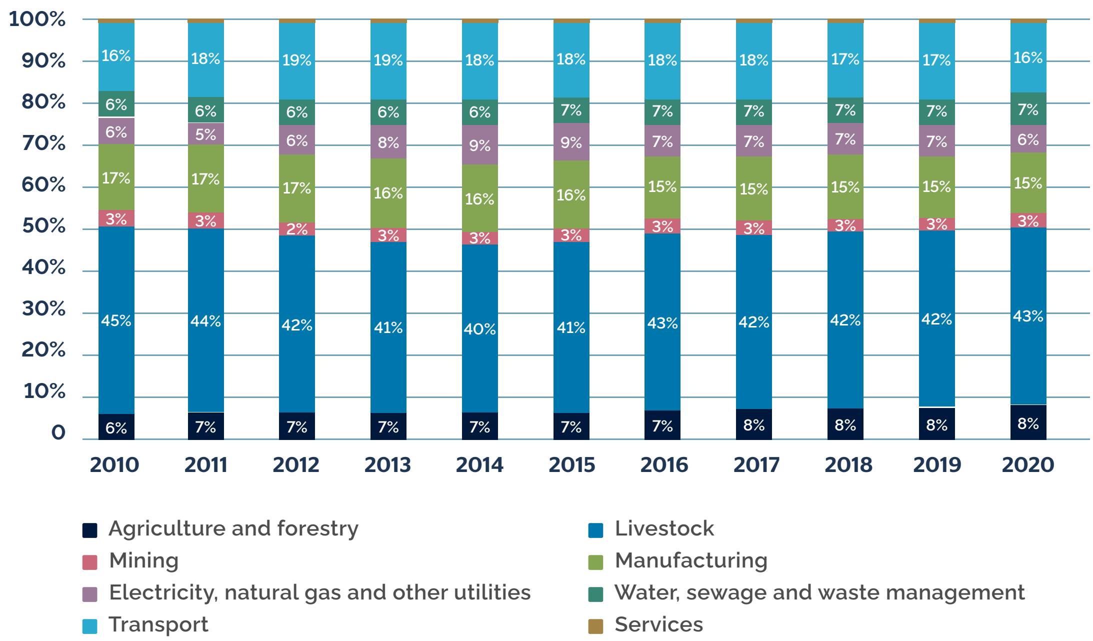
Graph 1 - Total emissions by group in TCO_2 eq., Brazil, 2010-2020



Source: own elaboration based on data extracted from the Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa (SEEG) database (Obsevatório do Clima, 2023) and input-output tables (Alves-Passoni; Freitas, 2020).

Concerning the emissions share in total emissions, livestock has consistently been the leading industry, with a share of nearly 43% in the period. The **manufacturing**[2] and transport industries account for about the same share of total emissions. **Within the latter**,[3] about 90% of the emissions come from land transport, where subsidies by the Brazilian government to fossil-fuel-based private cars and trucks are likely to be behind the increase in emissions (INESC, 2022). IEA (2021) points out that road freight transport is among the most challenging decarbonizing sectors.

Graph 2 - Emission share by group in % total emissions, Brazil, 2010-2020



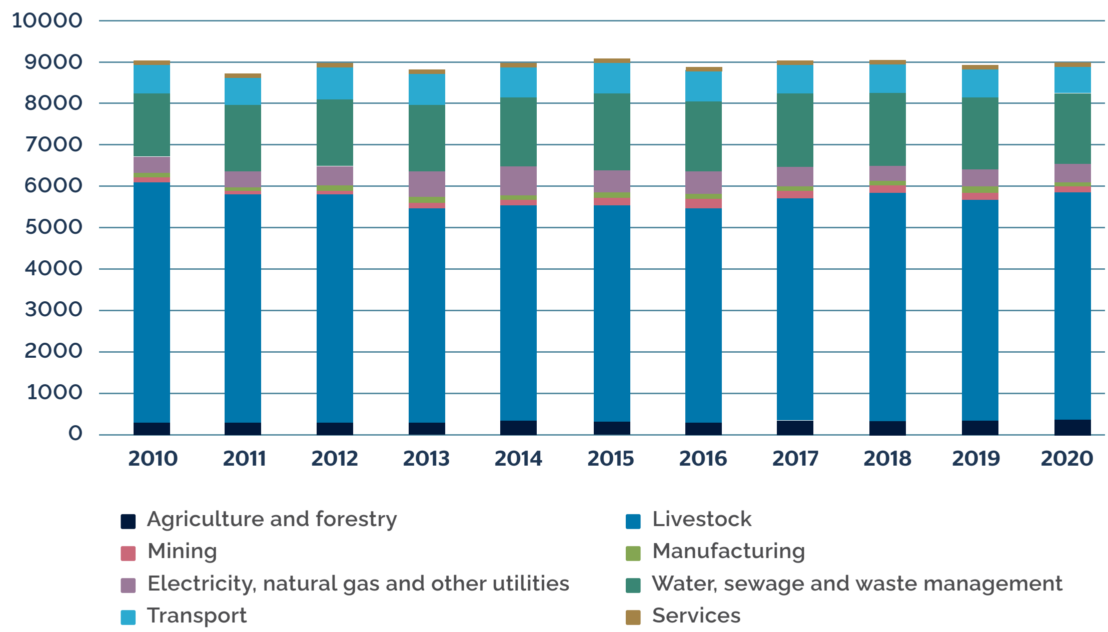
Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2023) and input-output tables (Alves-Passoni; Freitas, 2020).

[2] It is worth noting that in the manufacturing industry, the manufacture of non-metallic mineral products and pig iron/iron alloys, steel, and seamless steel tubes are the two leading industries in total emissions, followed by oil refining and coking.

[3] The consumption of various fossil fuels causes the emissions of this sector. Since the consumption of fossil fuels is the primary source of greenhouse gas emissions, especially CO_2 emissions, developing relevant energy and environmental policies requires studying the relationship between economic activity and CO_2 emissions in terms of fossil fuel consumption. The transport sector is the largest oil consumer, accounting for 60% of global demand. Oil consumption by private cars (27% of demand) and road transport (3%) recovered from the effects of the Covid-19 pandemic in late 2021 and early 2022 (IEA, 2023).

A slightly different pattern emerges when the analysis focuses on emission intensity. The leading sectors in emission intensity are livestock, water, sewage, and waste management, transport, electricity, natural gas and other utilities, agriculture, mining, manufacturing and services. The trend in emissions intensity started to break down in 2015 due to the economic crisis in Brazil and remained stable throughout the whole period, exception made to livestock, the only sector showing an increasing trend in the period. If this trend in livestock continues, other industries are expected to meet Brazil's government target of zero emissions by 2050 (IEA, 2021).

Graph 3 - Emission intensity by group, in TCO2 eq. per million R$, Brazil, 2010-2020



Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2022) and input-output tables (Alves-Passoni; Freitas, 2020).

From industry groups to individual sectors

The analysis by groups of sectors in the previous section gives a general picture of the sectoral emissions patterns in the Brazilian economy. Typically, green taxonomies use only the ratio of CO_2 emissions to gross production value to select critical sectors for decarbonizing the economy. The aim of this section is twofold: to show the importance of a more detailed analysis for specific sectors and use other measures, based on the input-output methodology, to analyze key sectors regarding GHG.

Table 2 - Average emission coefficient in TCO_2 eq. per million R$, 2010-2020, Brazil

Ranking	Industries	Average 2010-2020	%	Cumulative Frequency
1	Livestock	5,378.79	40	0.41
2	Water, sewage and waste management	1,699.65	13	0.54
3	Non-metallic minerals	864.67	7	0.60
4	Land transport	838.12	6	0.67
5	Production of pig iron/iron alloys, steel	682.63	5	0.72
6	Power Generation, gas, and utilities	490.30	4	0.75
7	Air transportation	446.43	3	0.79
8	Water transport	394.18	3	0.82
9	Agriculture	382.45	3	0.85
10	Mining coal and non metallic minerals	303.73	2	0.87

Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2023) and input-output tables (Alves-Passoni; Freitas, 2020).

Table 3 - Average total emissions in TCO_2 eq., 2010-2020, Brazil

Ranking	Industries	Average 2010-2020	%	Cumulative Frequency
1	Livestock	487,259,845.5	42	0.42
2	Land transport	187,353,822.5	16	0.58
3	Agriculture	81,766,268.96	7	0.65
4	Power Generation, gas, and utilities	81,094,262.99	7	0.72
5	Water, sewage and waste management	77,026,722.7	7	0.79
6	Production of pig iron/iron alloys, steel	52,875,732.45	4	0.84
7	Non-metallic minerals	50,104,501.87	4	0.88
8	Oil refining and coking	24,180,563.12	2	0.90
9	Oil and gas extraction, including support activities	21,861,044.94	2	0.92
10	Manufacture of organic and inorganic chemicals, resins and elastomers	13,765,175	1	0.93

Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2023) and input-output tables (Alves Passoni Freitas, 2020).

Tables 2 and 3 show the ranking of **ten industries**[4] based on the cumulative frequency and the share in total emissions and emission coefficient. Interestingly, regardless the measure used (whether total emissions or emission coefficient), the ranked industries are practically the same. Six industries emerge as hotspots in GHG emissions: **livestock**,[5] production of pig iron/iron alloys, steel, non-metallic minerals, land transport, agriculture, and power energy. However, the ranking order changes according to the measure

[4] These ten sectors account for over 80% of Brazil's total greenhouse gas emissions.

[5] Livestock is responsible for more than 40% of greenhouse gas emissions.

used, particularly concerning agriculture, land transport, and non-metallic minerals. The first two industries gained importance in terms of total emissions, while the latter lost. Ranking order changes are due to the higher share of agriculture and land transport in gross production value (over 3%) and non-metallic minerals **(less than 1%)**.[6]

The selected industries have one feature in common: their GHG footprint is significantly larger than the weighted average of the whole Brazilian economy in 2019 (Table 4). The emission coefficient of livestock is 32 times bigger than the economy's weighted average, followed by non-metallic minerals (5.6 times), land transport (4.7), production of pig iron (3.9), power generation (2.5), and agriculture (2.3).

Industrial restructuring should prioritize sectoral linkages alongside multiple targets. The close interdependence of sectors in an economy, characterized by complex input-output relationships, means that any initiatives implemented in a particular industry will likely impact others. For example, certain high-emitting sectors entail lengthy industrial chains and assume pivotal roles in the supply chain as primary providers of raw materials and intermediary goods to other sectors. Curtailing the output of these sectors will not only restrict its activities but also impact the expansion of associated sectors via complex intersectoral interdependences and potentially the entire production structure.

Table 4 - Emission coefficient deviation from the weighted average 2019, Brazil

Livestock	32.93
Non-metallic minerals	5.61
Land transport	4.76
Production of pig iron/iron alloys, steel	3.92
Power Generation, gas, and utilities	2.50
Agriculture	2.37

Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2023) and input-output tables (Alves-Passoni; Freitas, 2020).

[6] It is worth noting that an industry may be critical regarding its share in total emissions but not necessarily regarding its emission intensity. As such, the growth rate of emissions can be calculated as an elasticity, that is, the degree of sensitivity to the growth rate of emission intensity and Gross Value-Added (GVA).

Accordingly, industry restructuring should address distinct sectors' positions and intersectional connections. One should analyze such connections to effectively identify the necessary direction of industrial restructuring toward a **low-emissions economy**.[7]

There is mounting concern for reducing carbon dioxide (CO_2) emissions, which requires understanding an economy's production structure. The level and changes in CO_2 emissions present an intricate relationship through input-output connections in the economy. Developed by Leontief (1936) and Leontief (1970), the input-output (IO) model has been thoroughly employed to examine CO_2 emissions in various industrial sectors. This model enables the monitoring of direct and indirect emissions in the economy, providing valuable insight into the overall structure of emissions.

Table 5 - Direct and indirect emissions in selected industries, 2019, Brazil

Industries	Direct and indirect emissions	Direct emissions	Indirect emissions	Direct/indirect emissions
Agriculture	540.62	395.17	145.45	2.72
Livestock	5,877.93	5,479.66	398.27	13.76
Non-metallic minerals	1,223.87	934.31	289.56	3.23
Production of pig iron /iron alloys, steel	933.92	653.05	280.86	2.33
Power Generation, gas, and utilities	685.74	415.83	269.91	1.54
Land transport	978.47	792.02	186.45	4.25

Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2023) and input-output tables (Alves-Passoni; Freitas, 2020).

[7] One of the most significant social impacts of industrial restructuring is emissions, which has attracted growing attention. In recent times, the literature on sectoral emission patterns has increased considerably. Emission effects are categorized into direct and indirect impacts based on the relevance of economic impacts. Take sector *j* as an example: an increase in final demand for one of its products will increase the sector's output as producers react to meet the demand. This boost in output will generate new emissions within the sector as a direct effect. As the sectors output increases, greater demand for its domestic suppliers and throughout the supply chain will follow, resulting in increased emissions in these sectors (indirect effect). Such indirect effect and the direct emission growth will increase emission levels throughout the whole domestic economy.

The six selected industries share a common feature often overlooked in the green taxonomies drawn up by governments: their pattern is marked by direct rather than indirect emissions **(Table 5)**.[8] Regarding the coefficient of emissions, the leading industry is livestock, where direct emissions are 13 times higher than indirect emissions. The second most prominent sector is land transport, in which direct emissions are four times bigger than indirect emissions. It is worth noting that these industries are suppliers of agricultural commodities, industrial commodities, and services/utilities.

Table 6 shows direct and indirect emissions for a group of manufacturing industries. In contrast to the selected industries examined in Table 5, indirect emissions dominate the emissions pattern of manufacturing industries. Some manufacturing industries pose a notable global challenge for energy and climate change policymakers. Manufacturing industries act as important geographic hubs for economic activity, clustering medium

Table 6 - Direct and indirect emissions in selected manufacturing industries, 2019, Brazil

Industries	Direct and indirect emissions	Direct emissions	Indirect emissions	Direct/indirect emissions
Manufacture of computer, electronic and optical equipment	60.94	0.85	60.09	0.01
Manufacture of electrical machinery and equipment	159.08	8.20	150.88	0.05
Manufacture of machinery and mechanical equipment	144.52	3.14	141.38	0.02
Manufacture of cars, trucks and buses, except parts	168.86	2.41	166.45	0.01
Manufacture of parts and accessories for motor vehicles	191.36	7.04	184.32	0.04
Manufacture of other transportation equipment, except motor vehicles	109.09	3.17	105.92	0.03
Manufacture of furniture and miscellaneous industrial products	123.64	3.36	120.28	0.03

Source: own elaboration based on data extracted from the SEEG database Observatório do Clima , 2023) and input-output tables (Alves Passoni Freitas, 2020).

[8] The most important difference between direct and indirect emissions is that the latter considers the upstream emissions included in the inputs used in the production process. In contrast, the former only considers the impacts on the sector itself.

and large facilities through indirect linkages **(backward effects[9])**. Regarding emissions, manufacturing industries emit less directly or indirectly than the sectors **selected[10]** for examination in this policy brief. The supply chains of manufacturing industries can promote technological progress, especially in the machinery and equipment sectors, used in the sectors selected. In this case, the key drivers of CO_2 emissions in a specific economic system can be identified by exploring the carbon linkages between industrial sectors through supply chains. The design and implementation of green industrial policies need to consider the role played by manufacturing industries for decarbonization in the Brazilian economy.

Prevailing environmental policies usually regulate the sectors with substantial direct emissions while overlooking the limitations upon the industries generating considerable emissions from other sectors, referred to as indirect emissions. As a result, one fails to reduce overall emissions effectively. Table 7 shows the normalized effects of the backward linkages in 2019 for the six selected industries.

Table 7 - Normalized backward emissions linkages, 2019, Brazil

Industries	BL
Livestock	15.90
Non-metallic minerals	3.31
Land transport	2.65
Production of pig iron/iron alloys, steel	2.53
Power Generation, gas, and utilities	1.85
Agriculture	1.46

Source: own elaboration based on data extracted from the SEEG database (Observatório do Clima, 2023) and input-output tables (Alves-Passoni; Freitas, 2020).

[9] Generally, backward linkages occur when a sector's final demand stimulates output in other sectors. On the other hand, forward linkages occur when an increase in supply in one sector induces other sectors to use the surplus output and produce additional products. Using both the Leontief and the Ghosh models at the same time are open to debate (Oosterhaven, 1996; Altimiras-Martin, 2022), because of the issues with the stability of input-output production and allocative coefficients. For the purpose of our study, it is advisable to analyze linkages from a demand perspective, instead of using the supply-driven Gosh model. As such, this note will predominantly concentrate on the backward linkages utilizing the Leontief model.

[10] Industrial restructuring is a crucial step towards a low-carbon transition. Reducing the output of high-emission sectors can effectively decrease carbon emissions. However, it is essential to consider the socioeconomic impact on these sectors. Industrial restructuring modifies the distribution of sectors to achieve specific objectives. CO_2 emissions can be effectively reduced by restricting high-emission and expanding low-emission sectors without considering other targets. However, emission reduction through output restrictions may harm economic income in some industries and hinder national economic growth to some extent.

Firstly, reducing CO_2 emissions by adapting the industrial structure will limit the development of some sectors, leading to macroeconomic losses. Therefore, to reconcile the conflict between economic growth and CO_2 emission reduction, production and emission linkages should be jointly considered when discussing the role of sectors in an economy. Furthermore, the sectoral allocation of the emission reduction task by industry is unfair and unworkable because all sectors are correlated in backward and forward partnerships or supply and demand relationships.

Green taxonomies often use only the indicator of direct emissions from sectors, ignoring industries' many intersectoral relationships along the supply chain. In other words, direct emissions show only one side of the complex input-output relationship in a country's production structure. One needs to consider the essential role of indirect emissions through (backward and forward) linkages with other industries. For many products, upstream supply chains contribute significantly more to environmental emissions than downstream supply chains. Suppose a sector presents an emissions pattern dominated by indirect emissions. In that case, it is likely to show a more complex supply chain in **terms of linkages**.[11] The transition toward net-zero emissions in 2050 must embrace the notion of industrial clusters of selected sectors.

Governments must evaluate the present situation and improve sector-specific innovation systems to unlock green opportunities (UNCTAD, 2023) for environmentally friendly practices. A "green industrial policy" will certainly open doors to new prospects but will require involving stakeholders, deploying resources, and directing the upgrading of knowledge capacities, amidst significant technological, economic, and political uncertainties.

[11] Indirect emissions are prominent in manufacturing industries, like computers, electronic and optical equipment, electrical machinery and equipment manufacture, and parts and accessories for motor vehicles.

Bibliographic References

Alves-Passoni, Patieene; Freitas, Fabio Neves Peracio. Estimação de Matrizes Insumo-Produto anuais para o Brasil no Sistema de Contas Nacionais Referência 2010. **Texto para Discussão**, IE-UFRJ, n. 25, 2020. Available at: **https://www.ie.ufrj.br/images/IE/grupos/GIC/publica%C3%A7%C3%B5es/2020/TD_IE_025_2020_ALVES-PASSONI_FREITAS.pdf.** Accessed 13 Mar. 2024.

Altimiras-Martin, Aleix. Supply-driven model consuming simultaneously all primary inputs: unfolding analytical potential beyond the Ghosh model. **Economic Systems Research**, p. 1-16, 2022. DOI: **https://doi.org/10.1080/09535314.2022.2137008.**

Costa, Kaio Vital; Costa, Lucas; Young, Carlos Eduardo Frickmann. Identifying the sources of structural changes of greenhouse emissions in Brazil: An input-output analysis from 2000 to 2020. In: Pasqualino, Roberto. (Org.) **Energy transition in Brazil:** Innovation, opportunities and risks. EEIST Project Report. [S.l.] University of Exeter, 2023. Available at: **https://eeist.co.uk/new-report-energy-transition-in-brazil-innovation-opportunities-and-risks/.** Accessed 13 Mar. 2024.

Harrison, Ann; Martin, Leslie; Nataraj, Shanthi. Green industrial policy in emerging markets. **Annual Review of Resource Economics**, v. 9, p. 253-274, 2017. DOI: **https://doi.org/10.1146/annurev-resource-100516-053445.**

Institute of Socioeconomic Studies. **Fossil fuels subsidies in Brazil**: Know, issues and reform. Brasília, DF: INESC, 2022. Available at: **https://www.inesc.org.br/wp-content/uploads/2022/11/INGLES_ESTUDO-COMBUSTIVEIS.pdf.** Accessed 13 Mar. 2024.

Intergovernmental Panel on Climate Change. **Climate change 2007**: Synthesis Report. Geneva: IPCC, 2007. Available at: **https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf.** Accessed 13 Mar. 2024.

Intergovernmental Panel on Climate Change. **Renewable energy sources and climate change mitigation**. Special Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press, 2012. Available at: **https://www.ipcc.ch/site/assets/uploads/2018/03/SRREN_Full_Report-1.pdf**. Accessed 13 Mar. 2024.

International Energy Agency. **Net Zero by 2050**. A Roadmap for the Global Energy Sector. [S.l.] IEA, 2021. Available at: **https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.** Accessed 13 Mar. 2024.

Leontief, Wassily. Quantitative input and output relations in the economic systems of the United States. **The Review of Economic Statistics**, v. 18, n. 3, p. 105-125, 1936. DOI: **https://doi.org/10.2307/1927837.**

Leontief, Wassily. Environmental repercussions and the economic structure: An input-output approach. **The Review of Economics and Statistics**, v. 52, n. 3, p. 262-271, 1970. DOI: **https://doi.org/10.2307/1926294.**

Observatório do Clima. **SEEG – Sistema de Estimativa de Emissões e Remoções de Gases de Efeito Estufa.** Vários Anos. [S.l.] Observatório do Clima, 2023. Available at: **https://plataforma.seeg.eco.br/total_emission**. Accessed 13 Mar. 2024.

Oosterhaven, Jan. Leontief versus Ghoshian price and quantity models. **Southern Economic Journal**, v. 62, n. 3, p. 750-759, 1996. DOI: **https://doi.org/10.2307/1060892.**

Rodrik, Dani. Green industrial policy. **Oxford Review of Economic Policy**, v. 30, n. 3, p. 469-491, 2014. Available at: **https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/green_industrial_policy.pdf.** Accessed 13 Mar. 2024.

Rodrik, Dani. **An industrial policy for good jobs**. The Hamilton Project - Policy Proposal. [S.l.] Brookings Institution, Sept. 2022. Available at: **https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/rodrik_-_an_industrial_policy_for_good_jobs.pdf.** Accessed 13 Mar. 2024.

United Nations Climate Change Conference. Framework Convention on Climate. In: **MARRAKECH CLIMATE CHANGE CONFERENCE**, 2016. Available at: **https://enb.iisd.org/marrakech-climate-change-conference-cop22.** Accessed 13 Mar. 2024

United Nations Conference on Trade and Development. **Technology and innovation report.** Opening Green Windows: Technological Opportunities for a Low-Carbon World. New York: United Nations Publications, 2023. Available at: **https://unctad.org/system/files/official-document/tir2023_en.pdf.** Accessed 13 Mar. 2024.

United Nations. **NDC Registry.** Brazil First NDC 2023 adjustment. [S.l.] United Nations Climate Change, 2023. Available at: **https://unfccc.int/sites/default/files/NDC/2023-11/Brazil%20First%20NDC%202023%20adjustment.pdf.** Accessed 13 Mar. 2024.

World Population Review. **Carbon Footprint by Country.** [S.l.] World Population Review, 2022. Available at: **https://worldpopulationreview.com/country-rankings/carbon-footprint-by-country**. Accessed 13 Mar. 2024.

Appendix

The appendix contains the three databases, their specifications, and the data sources used in the elaboration of this policy brief. One database is the annual input-output tables at constant prices (year-base 2010) estimated by Alves-Passoni and Freitas (2020) and the other contains data on national emissions extracted from the Greenhouse Gas Emissions and Removals Estimation System (SEEG, in Portuguese) published by Observatório do Clima (2023). Both databases cover the period between 2010 and 2020 and provide data for different disaggregation levels: (i) 42 industries and 91 products, and (ii) 67 industries and 127 products. We use a more disaggregate version that allows the of specific industries, such as agriculture and livestock. This step is important to define the key-emitting industries and sheds light on the supply chain of CO_2 emissions in the Brazilian economy. Since no data about the emissions coefficient is available on open access, we used the database compiled by Costa, Costa, and Young (2023) based on data extracted from IOT and SEEG.