CHAPTER 1

MAIN STATIONARY CO_2 EMISSION SOURCES IN SOUTH-SOUTHEAST BRAZIL

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ABSTRACT

Adequate knowledge of the geographical location of stationary CO_2 emitting sources, the emission clusters impacts costs and the general viability of CCS projects is a fundamental part of planning a CCS project. This chapter seeks to comment on mapping the state of the art stationary sources of CO_2 emissions in the south-southeast region of Brazil. It presents a compilation of the data distributed by the state governments of South-southeastern Brazil on CO_2 emissions in five sectors: energy sector, industrial processes, agricultural sector, land use and waste. The origins of emissions in the south-southeast Brazilian states are distinct, suggesting different approaches for these locations. This effort aims to facilitate the dynamics of energy planning associated with CCS by promoting an understanding of the dynamics of emissions. Understanding emissions and their origins are one step closer to making a capture and storage project a reality.

Keywords: GEE inventory, CO_2 emission sources, CO_2 emission clusters.

1. INTRODUCTION

Understanding the geographical location of stationary CO_2 emitting sources is a fundamental part of planning a CCS (Carbon Capture, Transport and Storage) project (GALE et al., 2005). The reason is that the location of the CO_2 to be injected in geological reservoirs implies different costs, different transport procedures, different logistics, etc. There was a 9.6% increase in 2020 in gross greenhouse gas emissions released into the atmosphere: 2.17 billion tons of carbon dioxide equivalent (tCO_2e) compared to 1.98 billion in 2018. In the same year, the national GDP (greenhouse gas emissions produced to Gross Domestic Product) rose by 1. 1%, suggesting that Brazil's emissions are disconnected from wealth generation, unlike most other major economies (SEEG, 2020).

The difficulties approaching this endeavour arise from the lack of compilation and publication of Brazilian data on emissions. The data made available by the states governments in the south-southeast region of Brazil are not homogeneous and present different temporal and categorical relationships. This chapter depends on data obtained from the Ministry of Mines and Energy, information compiled by the energy research company, especially on the data of Brazilian emissions analysis developed by the climate observatory, and the System of Estimates of Emissions and Removals of Greenhouse Gases (SEEG, from the acronym in Portuguese). It allows identifying the sectors with the highest CO_2 emissions. Several pieces of information are compiled in this text to provide an overview of the situation of emissions in seven Brazilian states: Paraná, Santa Catarina, Rio Grande do Sul (formers in the southern region), São Paulo, Minas Gerais, Espírito Santo and Rio de January (trainers from the southeast region). These states are directly related to the sedimentary basins of Paraná and Santos with potential geological reservoir units for CO_2 storage; therefore, it reveals the need for knowledge of the emissions associated with these regions. This work aims to homogenise and standardise information regarding emissions from these regions as much as possible. The southern states (Paraná, Santa Catarina, and the Rio Grande do Sul) present a simplified analysis considering the absence of accurate data (in the case of Santa Catarina) and relatively lower levels of emission from industrial and energy processes in the data available to the other two states in the region (Paraná and the Rio Grande do Sul).

2. OBJECTIVES

The main objective of this chapter is to map the primary sources of CO_2 emissions in south-southeast Brazil. Thus, the aim is to understand the proximity of these CO_2 emission sources to possible geological storage sites to provide the basis for future CCS planning in the area. Therefore, the study involves compiling data on emissions in the south-southeastern Brazilian States published disorganizedly by state agencies and academic publications, understanding the relevance of the various sectors categorised in the total emissions, and defining critical areas for future carbon capture planning.

3. METHODOLOGY

The working methodology consists of the following steps: (i) literature review on the history of emissions in south-southeastern Brazil; (ii) search for data in the various state bodies; (iii) organisation of CO_2 emissions data relevant to the CCS universe; and (vi) data presentation.

4. THE HISTORICAL RECORD OF STATIONARY CO_2 EMISSIONS IN SOUTH-SOUTHEASTERN BRAZIL

Historically, South-southeastern Brazil has had a powerful influence on its economy and, therefore, has a long history of associated greenhouse gas emissions. The first efforts to map greenhouse gas emissions from the South-southeastern Brazilian states are recent, dating back to 2008. Moreover, it is essential to comment on the outdatedness of these data, which should have changed considerably within a decade.

The First Inventory of Anthropic Emissions of Direct and Indirect Greenhouse Gases in the State of São Paulo, a project coordinated and carried out by PROCLIMA/CETESB/SMA, with support from the British Embassy in Brazil, is a fundamental part of the commitment made by São Paulo to actively participate in efforts to protect the global climate system and to promote the transition to a low carbon economy in the state (CETESB, 2011). This document contains estimates of Greenhouse Gas (GHG) emissions in the São Paulo territory between 1990 and 2008, based on the methodology approved by the IPCC - Intergovernmental Panel on Climate Change.

In turn, the first inventory of greenhouse gas emissions in Minas Gerais was published in 2008 by the State Government, through the State Foundation for the Environment - FEAM, an entity of the State Secretariat of Environment and Sustainable Development - SEMAD (FEAM, 2008).

Espírito Santo's first greenhouse gas inventory was published in 2013 by the Espírito Santo State Government. It was published through the State Secretariat of Environment and Water Resources (Seama), the State Institute of Environment and Water Resources (Iema) and the Jones dos Santos Neves Institute (IJSN), in cooperation with the Foundation for the Coordination of Projects, Research and Technological Studies (Coppetec). Other associated bodies included the International Virtual Institute for Global Change of Coppe/UFRJ, linked to the Alberto Luiz Coimbra Institute (Coppe - UFRJ) and the National Agency for Technological to Economic and Social Development and Defense Environmental (Andesa) (LORENA et al., 2013).

The Inventory of Greenhouse Gas Emissions of the State of Rio de Janeiro was prepared based on the IPCC-2006 Guidebook (IPCC, 2006), a methodology conceived initially for countries. Although published at different times, these inventories follow a similar method and are the most reliable sources of emissions in Southeast Brazil.

Furthermore, the most recent effort to categorise Brazilian emissions came from the System of Greenhouse Gas Emissions and Removals Estimates (SEEG). SEEG is an initiative of the Climate Observatory which comprises the production of annual estimates of greenhouse gas emissions in Brazil, analytical documents on the evolution of emissions and an Internet portal to make the system's methods and data available simply and clearly. The Greenhouse Gas Emissions and Removals Estimates are generated according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC) based on the methodology of the Brazilian Inventories of Anthropic Greenhouse Gas Emissions and Removals, prepared by the Ministry of Science, Technology and Innovation (MCTI), and on data obtained from government reports, institutes, research centres, sector entities and non-governmental organisations (SEEG, 2020).

5. STATIONARY CO_2 EMISSIONS IN SOUTH-SOUTHEAST BRAZIL

All five sectors that are sources of emissions - Agriculture and Livestock, Energy, Land Use Change, Industrial Processes and Waste - are evaluated with the same level of detail contained in the emission inventories. The data available in SEEG Collection 8 constitute a series covering the period from 1970 to 2019, except for the Land Use Change sector that has the series from 1990 to 2019.

The period before 1990 is not covered by the emission inventories (SEEG, 2020). The data that was accessed from other sources are broken down as such, with simplified data for the south region and in-depth data for the southeast region.

5.1. South Brazil States emissions

In terms of gross emissions allocation in the state, Santa Catarina has the amount of 7,750,278 $MtCO_2e$, placing it in the 26th position in the ranking of most CO_2 emitting states. The state of Rio Grande do Sul appears with 89,425,462 $MtCO_2e$, placing it in the7th position. The state of Paraná, in turn, shows the amount of 73,267,990 $MtCO_2$, which puts it in the 10th position in the ranking of most emitting states. The figure indicating the gross emissions statistics of the state of Santa Catarina has been omitted due to the unavailability of data.

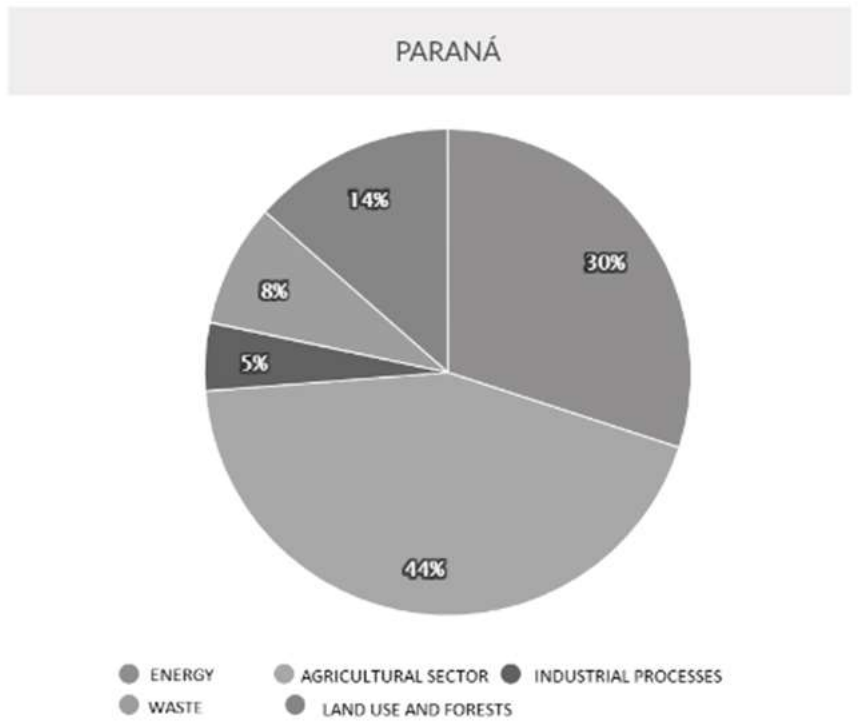

Figure 1. Gross emissions in Paraná State (Source: adapted by the authors from SEEG, 2020).

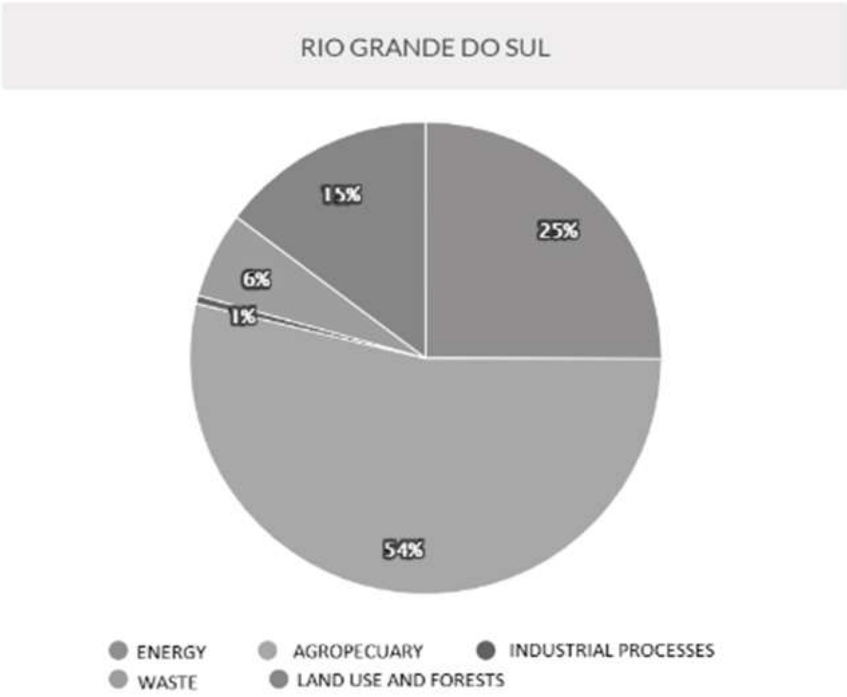

Figure 2. Gross Emissions in the Rio Grande do Sul State (Source: adapted by the authors from SEEG, 2020).

5.2. Energy sector in Southeast Brazil

In this Sector, all anthropic emissions from production, transformation, and energy consumption are estimated. It includes emissions resulting from the combustion of fuels and leakages in the production, transformation, distribution and consumption of energy (BRAZIL, 2010). The analysis of this sector requires special care because some of the subsectors involved are stationary and others are not (CETESB, 2011).

In Espírito Santo, the energy sector corresponds to only 3% of the emissions in CO_2eq, far behind other sectors such as industry (51%) and transport (30%) (LORENA et al., 2013). But we must consider that 99.98% of emissions are CO_2 in the energy sector and that fossil fuels are responsible for 98.97% of emissions.

In Minas Gerais, the inventory accounts for emissions due to the burning of fossil fuels and biomass in the production, transformation, and consumption of energy and emissions from the refining, transportation, and distribution of fossil fuels. CO_2 was the most emitted gas by the sector, with a 94.1% participation, followed by

CH_4, with 3.5% and N2O, with 2.5% (FEAM, 2008). In Rio de Janeiro, excluding transport, final energy consumption emitted 18728.8 Gg CO_2 in 2015 (INEA, 2015).

In São Paulo, the estimate of the CO_2 emissions from the burning of fossil fuels in 2008 stood at 79,690 GgCO_2. These emissions grew about 47% from 1990 to 2008, i. e., an annual average increase of almost 2.15% (CETESB, 2011). The fuel that had the most significant participation in CO_2 emissions was diesel oil (33% in 2005), presenting an increase of 54% from 1990 to 2005. The second in the rank of fuel that contributed the most was gasoline (16%), with a growth rate of 65%. Natural gas with 12% ranked third in the contribution of CO_2 emissions. The fuel presented the highest growth in the period analysed (1,870%) (CETESB, 2011).

Fossil Fuel Power Plants by Southeastern State					
State	The amount	Installed Power (MW)	Generated energy (MWh*10^3)(1)	Calculated Emissions (tCO2/year)(2)	CO2e emissions (tCO2e/year)(3)
São Paulo	482	6,294	6,606	495,450	1,279,000
Rio de Janeiro	54	5,175	28,566	2,142,450	8,026,000
Minas Gerais	131	1,817	3,049	228,675	676,000
Espírito Santo	15	1,093	5,745	430,875	757,000
Total	**682**	**14,379**	43,966	3,297,450	10,738,000

Table 1. Fossil Fuel Power Plants by Southeastern State

Source: Table based on data from (MME, 2021).

5.3. Industrial processes in Southeast Brazil

Industrial activities can generate atmospheric emissions by burning fuels (generation of heat or electricity), the disposal of waste (treatment of industrial effluents and waste incineration) and processes of chemical and physical transformation of materials. For each of these three types of procedures, emissions occur under a wide variety of specificities: the product in production, the inputs that feed the processes, the type of technological route used in production, the equipment of the industrial plant and the efficiency levels (SEEG, 2020). Among the industrial activities of great relevance for CCS projects, cement production, iron and steel, oil refineries, and some other sectors stand out of the chemical industry. They are typically stationary sources of emission of large blocks of CO_2 into the atmosphere.

In Espirito Santo, the industrial processes sector was the leading emitter, with 40.1% of emissions (10,877.19 GgCO_2eq) IN 2006 (LORENA et al., 2013). The metallic minerals transformation industry was the most important, with 9,866.08 GgCO_2eq (90.7%) of the sector's emissions. Next comes the production of coke, with 998.06 (9.18%). Lubricants and non-metallic minerals contributed only 0.1% and 0.02% of emissions, respectively (LORENA et al., 2013).

In Minas Gerais, the total emissions from the Industrial Processes and Product Use Sector reached the value of 7,086 Gg CO_2eq, being CO_2 responsible for 89.8% of this total. Cement production was mainly responsible for the sector's emissions, with 43.9%, followed by lime, 38.2%, and the aluminium industry, with a 13.0% share (FEAM, 2008).

Concerning Rio de Janeiro, the total CO_2 emissions associated with the industrial process sector in Rio de Janeiro were 11,514.4 GgCO_2 (INEA, 2015). In São Paulo, the emissions associated with industrial processes are divided into the following production subsectors: cement, lime, chemicals, metallurgy, food and beverages, glass, paper and cellulose, solvents and other products (CETESB, 2011). In 1990, CO_2 emissions associated with the industrial processes sector in the state of São Paulo were around 3,396 Gg/year and reached 12,218 Gg/year in 2008 (CETESB, 2011).

5.4. Agricultural sector

Emissions in this sector involve rice cultivation, enteric fermentation, animal waste management, burning of agricultural waste and soil management. In 2019, emissions from the agricultural sector totalled 598.7 million tons of CO_2 equivalent, an increase of 1.1% over 2018. (SEEG, 2020).

In Espírito Santo, the agriculture and livestock sector is sensitive to address in terms of CO_2 equivalent because most of the associated emissions are of CH_4. In Minas Gerais, the Agriculture, Forestry and Other Land Use Sector were responsible for the emission of 63.221 Gg CO_2eq. The main gas emitted was CH_4 (42.4%), followed by CO_2 (39.9%) and N2O (17.7%) (FEAM, 2008). In São Paulo, the CO_2 emissions associated with the agriculture and cattle raising sector in the state of São Paulo varied from 931 Gg/year to 1,462 Gg/year in 2006. The sector has its most significant emissions expressed in CH_4.

5.4.1. BECCS

Bioenergies have an important role to play in the face of the need for substantial cuts in greenhouse gas emissions and even to achieve negative emissions of these gases, which can partially offset emissions from fossil sources.

According to Pelissari et al. (2020), the use of bioenergy (whose net emission is considered neutral due to the sequestration of atmospheric CO_2 that occurs during photosynthesis), associated with the capture and geological storage of CO_2, known as BECCS, has the potential to reduce net CO_2 emissions to levels below zero.

Considering the production chain of ethanol in Brazil, CO_2 capture can be done in two stages: 1) in the process of fermentation of sugarcane must for the production of ethyl alcohol, used as fuel in automobiles, and 2) in the process from burning sugarcane bagasse to produce process heat and electricity (DAVID, 2016).

Moreira, J. R. et al. (2016) affirm that BECCS could reduce Brazil's emissions from energy production by roughly 5% because it is currently possible to eliminate 27.7 $MtCO_2$ per year through capture and storage of CO_2 released during the fermentation process of sugar cane-based ethanol production.

5.5. Land use

Changes in land use accounted for 363 million tons of CO_2 and national net emissions and 968 million tons of gross emissions in 2019. Most of the gross emissions (93%) are from changes in land use, most of which consist of the deforestation of the Amazon biome, which concentrates 87% (841 $MtCO_2e$) of the sector's gross emissions (SEEG, 2020).

In Espírito Santo, the planted forests remove more CO_2 (246.5 $GgCO_2eq$) than emissions (199.3$GgCO_2eq$). It is verified, therefore, that the removals exceeded emissions by 47.2 $GgCO_2eq$. The process of deforestation or burning of natural forest cover in the initial, medium and advanced stages of regeneration in 3,200 hectares generated the emission of 139.93 $GgCO_2eq$ in 2006 (LORENA et al., 2013).

The Minas Gerais and Rio de Janeiro's inventory dealt with land use issues alongside the agriculture sector. Finally, in São Paulo, anthropic nature's average annual net anthropic emissions totalise -10,663.29 $GgCO_2$, -11,753.35 $GgCO_2$ and -9,846.08 $GgCO_2$ in the first, second and third periods, respectively. The negative number indicates that there was a net removal of CO_2 (CETESB, 2011).

5.6. Waste

Total emissions calculated for the waste sector were 1669.68 $GgCO_2$ eq (6.2% of total). The percentage distribution was 50% from municipal solid waste, 32.15% from industrial effluents, 17.83% from domestic and 0.01% from industrial solid waste (LORENA et al., 2013).

In Minas Gerais, the Waste Sector emitted 7,294 Gg CO_2eq, 65.0% from solid waste and 35.0% from industrial, domestic, and commercial effluents. Urban solid waste was the one that most contributed to the emission of greenhouse gases, with a participation of 40.9% of the total, and CH_4 was the main gas emitted, with a share of 82.9% (FEAM, 2008). Total CO_2 emissions from the waste and effluent sector in the state of São Paulo varied from 0.01Gg/year in 1990 to 19.69 Gg/year in 2008 (CETESB, 2011).

6. POLICIES IMPLICATIONS

Law No. 12,187 of 2009 institutes the National Policy on Climate Change-PNMC, which foresees mitigation via lay down principles, objectives, guidelines and instruments. It involves technological changes and substitutions that reduce resources that contribute to CO_2 emissions to serve as the basis for the production unit. It implements measures that reduce the GHG effect's and increase sinks, including CCS (Carbon Capture and Storage) technologies. Currently, decree no 9578/2018 regulates the policy that provides the action plans for prevention, mitigation and adaptation to climate change. Article 18 says that the projection of national greenhouse gas emissions for the year 2020, referred to in the sole paragraph of art. 12 of Law No. 12,187 of 2009, will amount to 3,236 million ton CO_2eq composing of projections for the following sectors: I - land-use change - 1,404 million tonCO_2eq; II - energy - 868 million tonCO_2eq; III - agriculture - 730 million ton CO_2eq; and IV - industrial processes and waste treatment - 234 million ton CO_2eq.

An essential ally of industries and organisations regarding the voluntary responsibility and verification of the studied effect of gases is the norm ISO 14064. It supports the industry and the government with tools to develop programs focused on reducing GHG conditions. The ISO 14064 standard consists of three parts: Part 1 - specifies the requirements for designing and developing inventories for organisations or GHG agencies; Part 2 - detailed requirements for quantifying, monitoring and reporting on emission reductions and improvements in reducing GHG projects; and Part 3 - provides the requirements and guidelines for conducting the validation and verification of GHG information. In Brazil, the standard is provided with the name "Greenhouse Gases - Principles and requirements for the quantification and reporting of emissions and removals of greenhouse gases (GHG) - ABNT NBR ISO 14064: 2007". Despite that, it is essential to note that Brazil reached 2020 without complying with the PNMC, including regressing in the treatment Against emissions established in the NDC because there are no active implementation plans. It was not enough to classify it as "insufficient" to fulfil the Paris Agreement's goal of stabilising global warming to well below 2ºC in this century concerning the pre-industrial era, with efforts to limit it to 1.5ºC (SEEG, 2020).

CONCLUSIONS

Espirito Santo's inventory does not discriminate between the gases involved (e. g., CH_4, N2O, HFC, SF6), showing all values in terms of CO_2eq. Therefore, CO_2 emissions are likely to be overestimated, but they are the safest information available. The total emissions of Espírito Santo are well below the average of the other states that make up the Southeast region of Brazil, which is the most developed region of the country.

In Minas Gerais, the Agriculture, Forestry and Other Land Use sector was the largest emitter of greenhouse gases, with 51.4%, mainly due to agriculture and cattle-raising. In second place is the Energy Sector, with 36.9%, due to the burning of fossil fuels in industry and transport. CO_2 contributed 60.6%, CH_4 28.0%, and N2O 10.8% in terms of greenhouse gases.

The weight of the energy sector in greenhouse gas emissions is closely associated with the use of transport and, therefore, loses considerable relevance when only stationary sources are considered. The efforts to survey bibliographic data on CO_2 emissions in Brazil, made available by government agencies and other national and international institutions, reveal a gap to be filled when the intention is to build proposals for the implementation of projects of CCS. The data provided are mostly aggregated by large sectors of activity or by units of the federation and presented in different patterns, making it challenging to locate and quantify.

The implementation of CCS projects requires systematised and georeferenced data considering the CO_2 emitting sources. Therefore, there is an urgent need to collect data from a bottom-up perspective from this study specifically. It will allow us to identify the sectors where and how CO_2 emissions occur, at the most disaggregated level possible, enabling the identification of the sectors of most significant interest for carbon dioxide storage, with an emission amount of CO_2 in southern and south-eastern regions around 420 Mt/year (SEEG, 2020).

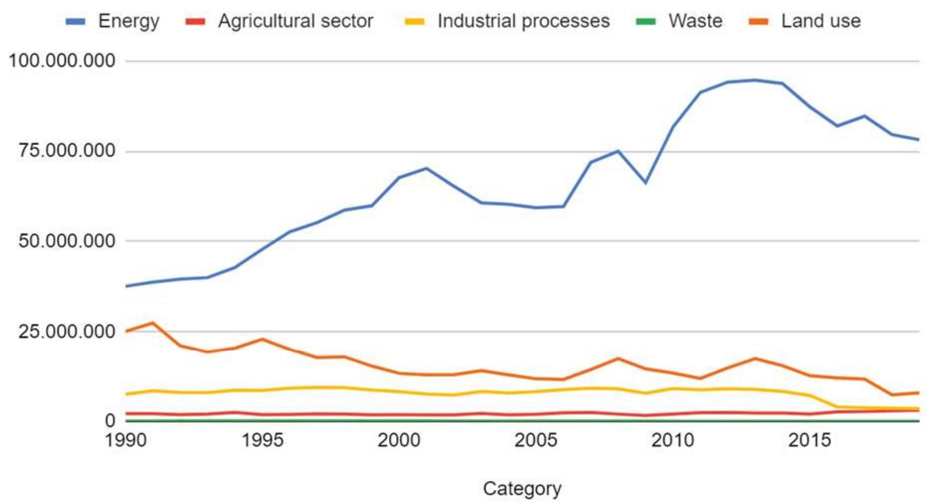

Figure 3. Total emissions in São Paulo (tCO_2). Source: SEEG, 2020.

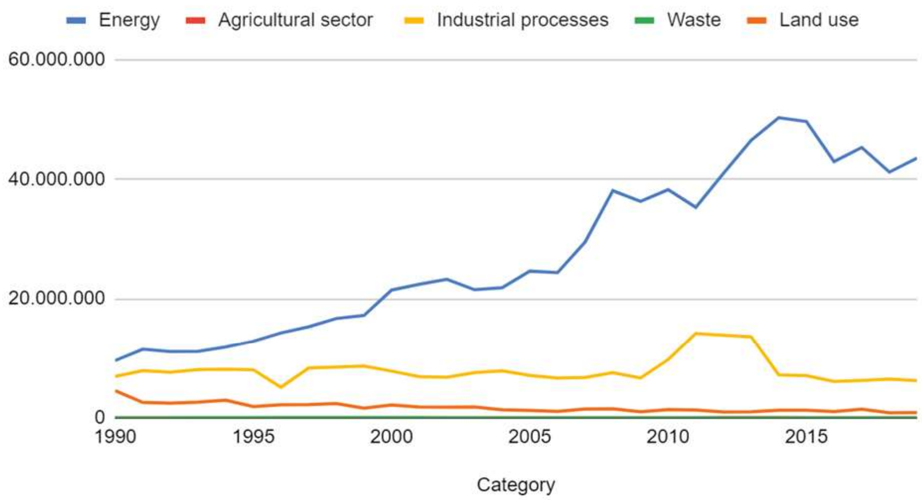

Figure 4. Total emissions in Rio de Janeiro (tCO2). Source: SEEG, 2020

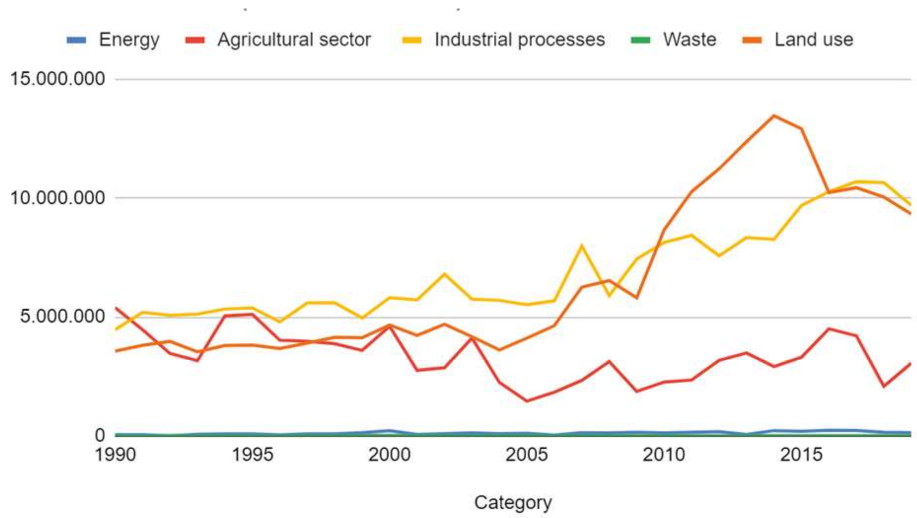

Figure 5. Total emissions in Espirito Santo (tCO_2). Source: SEEG, 2020.

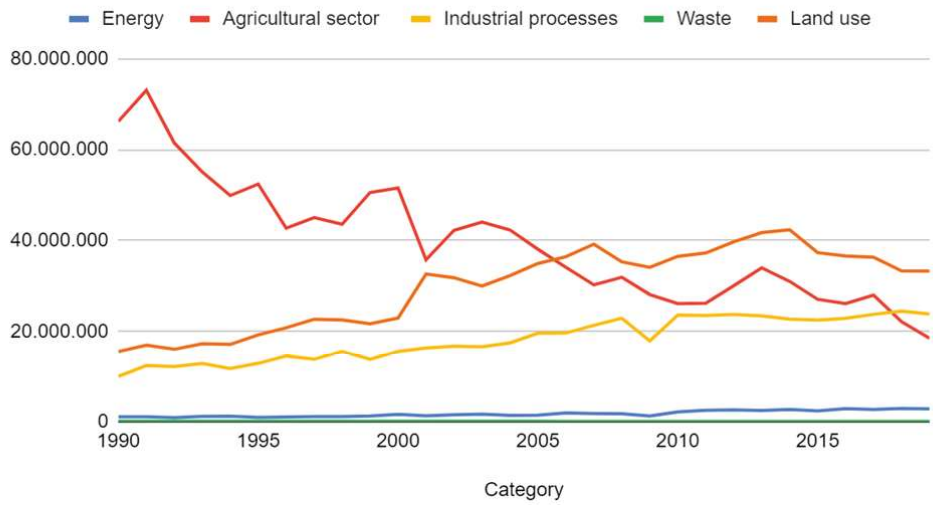

Figure 6. Total emissions in Minas Gerais (tCO2). Source: SEEG, 2020

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