POTENTIAL MITIGATION OF GREENHOUSE GAS EMISSIONS IN LIVESTOCK

Minerva Foods Case Study

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This project was developed by Minerva Foods in partnership with Embrapa, FGV and Unicamp, to calculate the balance of greenhouse gases on supplier properties.

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SUMMARY

OVERVIEW

According to the report of the Intergovernmental Panel on Climate Change (IPCC - AR6) the increase in the concentration of greenhouse gases (GHG) in the atmosphere, as a result of human activities, has caused the average temperature of the planet to rise and has led to a series of problems for all of humanity. In light of this situation, the responsibility for the reduction of emissions in sectors such as energy, industry, agriculture and livestock have become evident, as well as the need for active participation by government entities and society as a whole towards this common purpose. When evaluating the net balance of GHG emissions by country for 2018, Brazil accounts for 3% of total net emissions, despite being one of the top 10 global emitters. Meanwhile, 51.2% of global emissions come from China, the United States, India and the European Union. According to the Brazilian Greenhouse Gas Emissions Estimating System - SEEG (2022), the national contribution by sector for greenhouse gas emissions are agriculture and livestock (25%), energy (18%), land use change and forestry (49%), industrial processes (4%), and waste treatment (4%). The agricultural sector in Brazil is responsible for a considerable portion of GHG emissions, primarily due to methane from enteric fermentation in ruminants. At the same time, it is one of the sectors most affected by the adversities of climate change, including: extreme temperatures, altered rainfall, increased frequency of flooding, and desertification. These adversities threaten agricultural production and food supply, and cause other social and economic problems. It is essential to develop sustainable agriculture that produces food for humanity while simultaneously conserving the environment and mitigating and adapting to the effects of climate change. There is a huge potential for Brazil to sustainably increase its agricultural and livestock production. There are real examples of rural producers that produce, conserve and contribute to the benefit of the environment. It is essential to tell their story, evidenced by facts and data in order to engage and stimulate sustainable production. With this in mind, a partnership, together with Embrapa, the Getúlio Vargas Foundation, Unicamp and Minerva Foods, was established to develop a project to update and adapt the GHG Protocol for Agriculture, a methodology for calculating GHG inventories. The project aims to calculate the emissions and removals of rural properties in Brazil that operate cattle grazing and/or confinement in a credible and transparent way. This report, developed by Minerva Foods, demonstrates the results of the GHG balance of 23 cattle suppliers of Minerva Foods operations. The objective is to provide a better understanding of emissions and removals, in order to improve agricultural and livestock production processes and identify unique opportunities for rural producers that adopt increasingly sustainable and regenerative production technologies..

01 INTRODUCTION

According to the latest report of the Intergovernmental Panel on Climate Change (IPCC - AR6), the increase in the concentration of Greenhouse Gases (GHG) in the atmosphere as a result of human activities has increased the average temperature of the planet and triggered a number of issues for humankind. The report also describes alarming climate change risks with devastating impacts if urgent climate change mitigation and adaptation measures are not adopted in the various sectors of the global economy. Given this outlook, the responsibility of reducing emissions from sectors such as energy, industry and, especially for Brazil, agriculture and livestock, as well as Land Use and Land Use Change, becomes evident, in addition to the active participation of government entities and society as a whole towards this common objective.

In 2019, according to Tubiello et al (2021), emissions from global agrifood systems were estimated to be around 16.5 billion metric tons

($GtCO_2e\ yr^{-1}$), corresponding to 31% of total anthropogenic emissions. Of these, 7.2 Gt $CO_2e\ yr^{-1}$ are a result of agricultural and livestock production processes and energy use within the rural properties and 3.5 Gt $CO_2e\ yr^{-1}$ stem from emissions arising from land use change and deforestation.

These estimates further reveal significant variations among countries in terms of total emissions, as well as the composition of on-farm contributions, land-use change, and pre- and post- cessation components, with China being the largest emitter (1,9 Gt $CO_2e\ yr^{-1}$), followed by India, Brazil, Indonesia and the US (1,2 a 1,3 Gt $CO_2e\ yr^{-1}$). Brazil accounts for 3% of global emissions, with emissions stemming mainly from agriculture and land-use change, while China, the United States, India, and the European Union together account for 51.2% of global emissions.

According to the Brazilian Greenhouse Gas Emissions Estimating System - SEEG (2022), in 2021 the sectoral distribution of Greenhouse Gas (GHG) emissions in Brazil was composed as follows:

- Land use change and forestry 49%,
- Agriculture 25%,
- Energy 18%,
- Industrial operations 4%, and
- Waste treatment 4%.

Therefore, according to this paradigm, land-use change, forestry, and agriculture are the main sectors responsible for GHG emissions in Brazil. Within agriculture, the main source of emissions is enteric fermentation of ruminants, accounting for 64.6% of all emissions by the sector.

Simultaneously, agriculture is one of the sectors most affected by the adversities of climate change, including: extreme temperature risks, shifts in rainfall patterns, increased frequency of flooding, and desertification. These adversities can threaten food production and supply, as well as cause other social and economic problems.

Sustainable agriculture production that produces food for humanity and conserves the environment, mitigating the impacts of climate change and adapting to its effects, is of utmost importance. There is a huge potential for Brazil to sustainably increase its agricultural and livestock production. This has become evident by the real-life examples of rural producers that have been able to produce, conserve and contribute to the benefit of the environment. It is essential that their story be heard, substantiated with facts and data in order to engage and stimulate sustainable production.

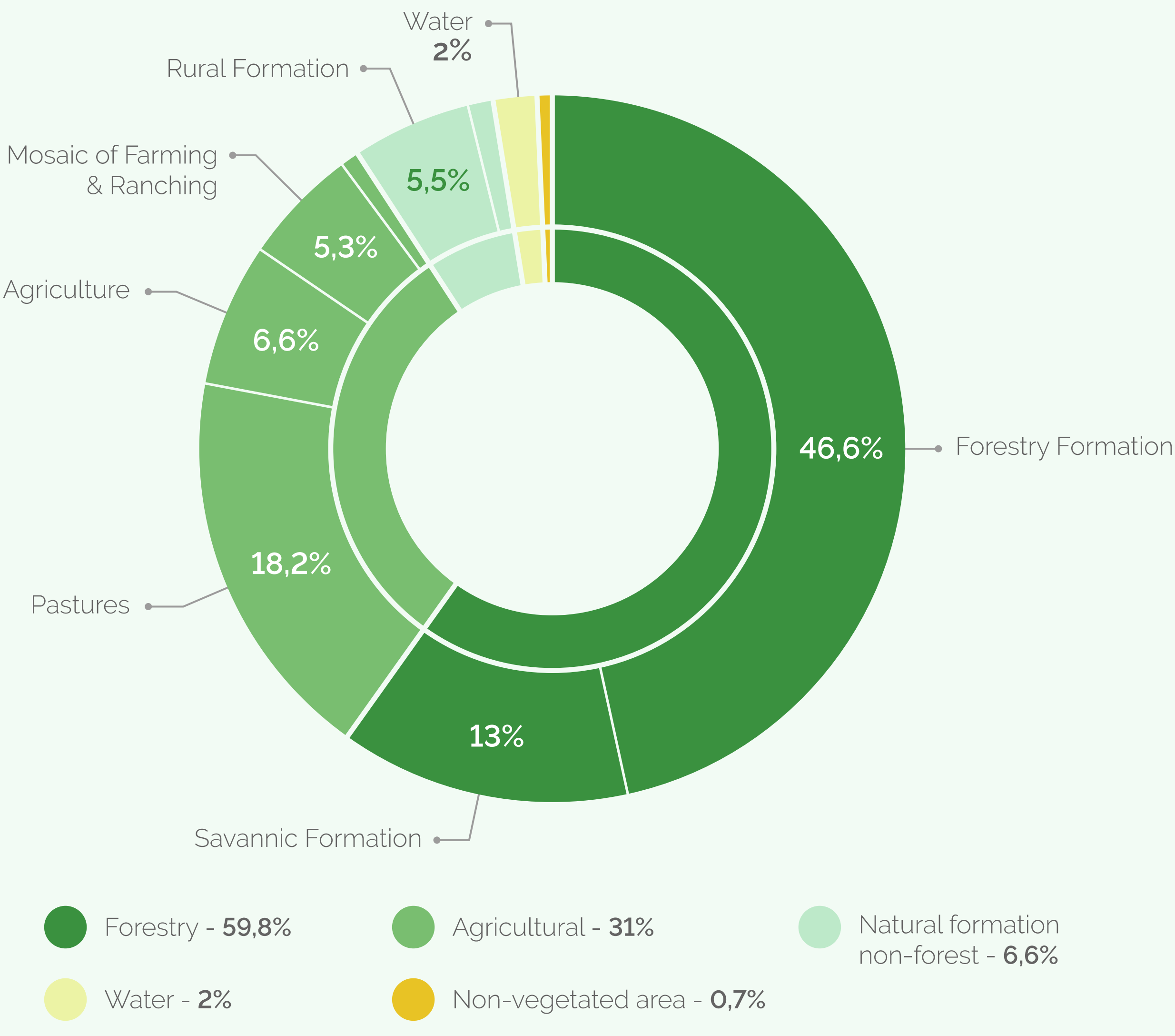
Even in the absence of a legally binding regulatory scenario in Brazil, the beef supply chain is generally aware of both the risks and opportunities of taking action on climate change. Among the opportunities, participation in carbon markets and changes in the cost structure of operations that result in reduced emissions and increased productivity are especially noteworthy. Regarding risks, attention is drawn to corporate image or reputation and uncertainties about changes in the regulatory environment (Campos and Fischamann, 2014).

This was the reason behind the partnership between Embrapa, Fundação Getúlio Vargas, Unicamp, and Minerva Foods for the development of a Measurement, Reporting and Verification (MRV) protocol, which required the adaptation and updating of the GHG Protocol for Agriculture, a carbon accounting tool that allows the calculation of GHG emissions and removals from rural properties, including the diversity of production systems such as agricultural production, reforestation, beef cattle (including feedlots) and dairy, as well as emissions from electrical use, inputs and waste. This report features the GHG balance results of 23 of Minerva Foods supply farms, with the aim of better understanding emissions and removals, to improve agricultural production processes, and identify differentiated opportunities for ranchers that adopt more sustainable production technologies.

02 AGRICULTURE AND THE ENVIRONMENT: A CONVERGING AGENDA

The Brazilian territory is composed of 8.51 million km², equivalent to 851 million hectares, of which 59.8% are made up of forests and 31% of agricultural. The share represented by Brazilin agribusiness corresponds to 263.1 million hectares divided into pasture, agriculture, forestry and a mosaic of farming and ranching.

GRAPH 1 – Land cover and use in Brazil in 2020



Source: MapBiomas, 2022.

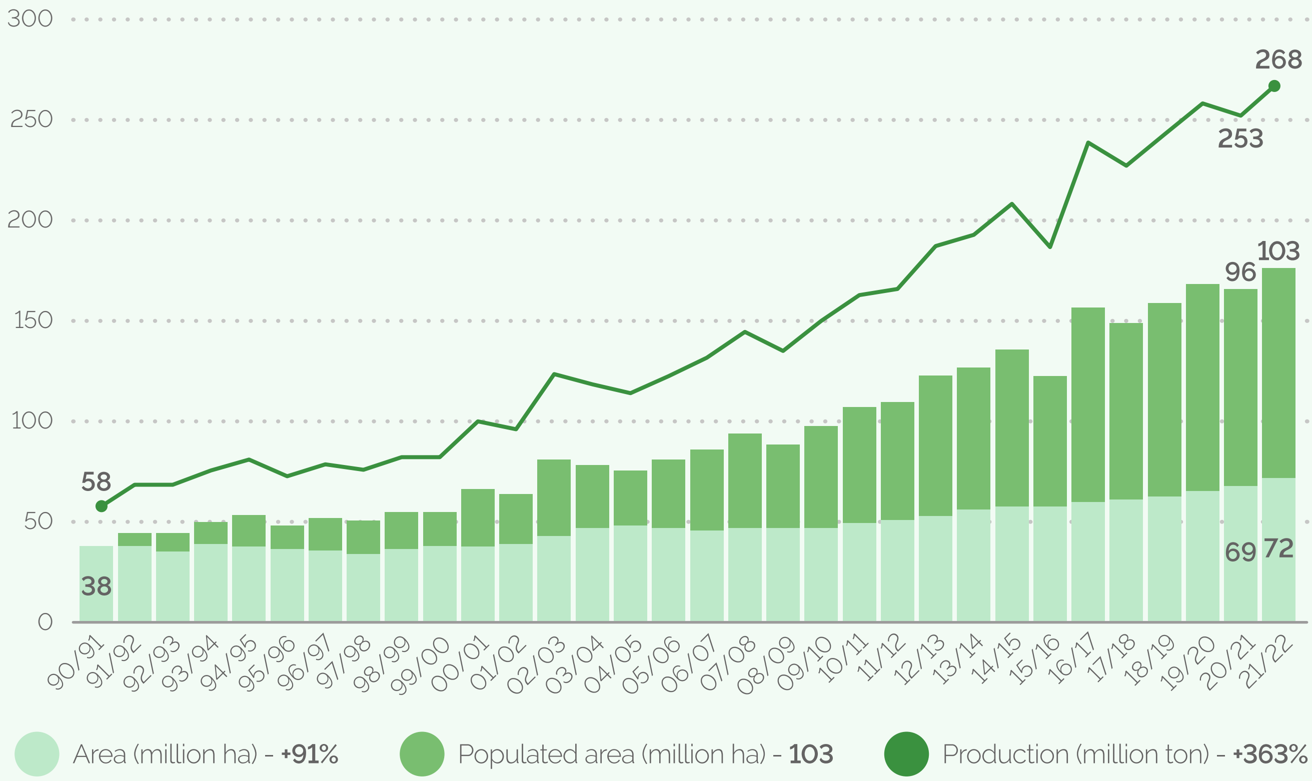
Historically, Brazilian agriculture has been known for its expansion over natural vegetation. In recent years, however, this territorial expansion has been replaced by the vertical intensification of production. For Lopes (2017), the Brazilian agricultural model, which is strongly based on science, knowledge and technology, has promoted a strong transformation of food production in the tropics, but there are still challenges to be faced, such as increasing the efficiency of soil and water use and continuously reducing the negative impact on the environment as a strategy to maintain a leading role in meeting the demands of national and international markets.

In this sense, even taking into account the natural limitations of tropical soil fertility, which requires a systematic compensation and replacement of nutrients to ensure sustainable crop production, the joint work of rural producers, academic research, partnerships between the public and private sectors, and public policies for the development of the country's agricultural sector, through fiscal incentives and investments, make Brazil a world player in agricultural production and exports. The income generated by exports is important for the country's economy, increasing the Gross Domestic Product (GDP) and maintaining a positive balance of payments.

The adoption of a more modern technologies and the climatic conditions have allowed agribusiness to achieve successive productivity gains over the years. If we compare the 1990/1991 harvest with the expected 2021/2022 harvest, we can see that while grain production increased by 363%, from 58 million tons to 268 million tons, the area under cultivation increased at a much lower rate, from 38 million hectares to 72 million hectares.

In other words, an increase of 103 million hectares would have been necessary if cultivation areas had continued to grow at the same rate. Thus, the successive productivity gains have had a land saving effect of 103 million hectares in grains alone.

GRAPH 2 – Brazilian Grain Production: 1990/91 to 2021/22* Crop



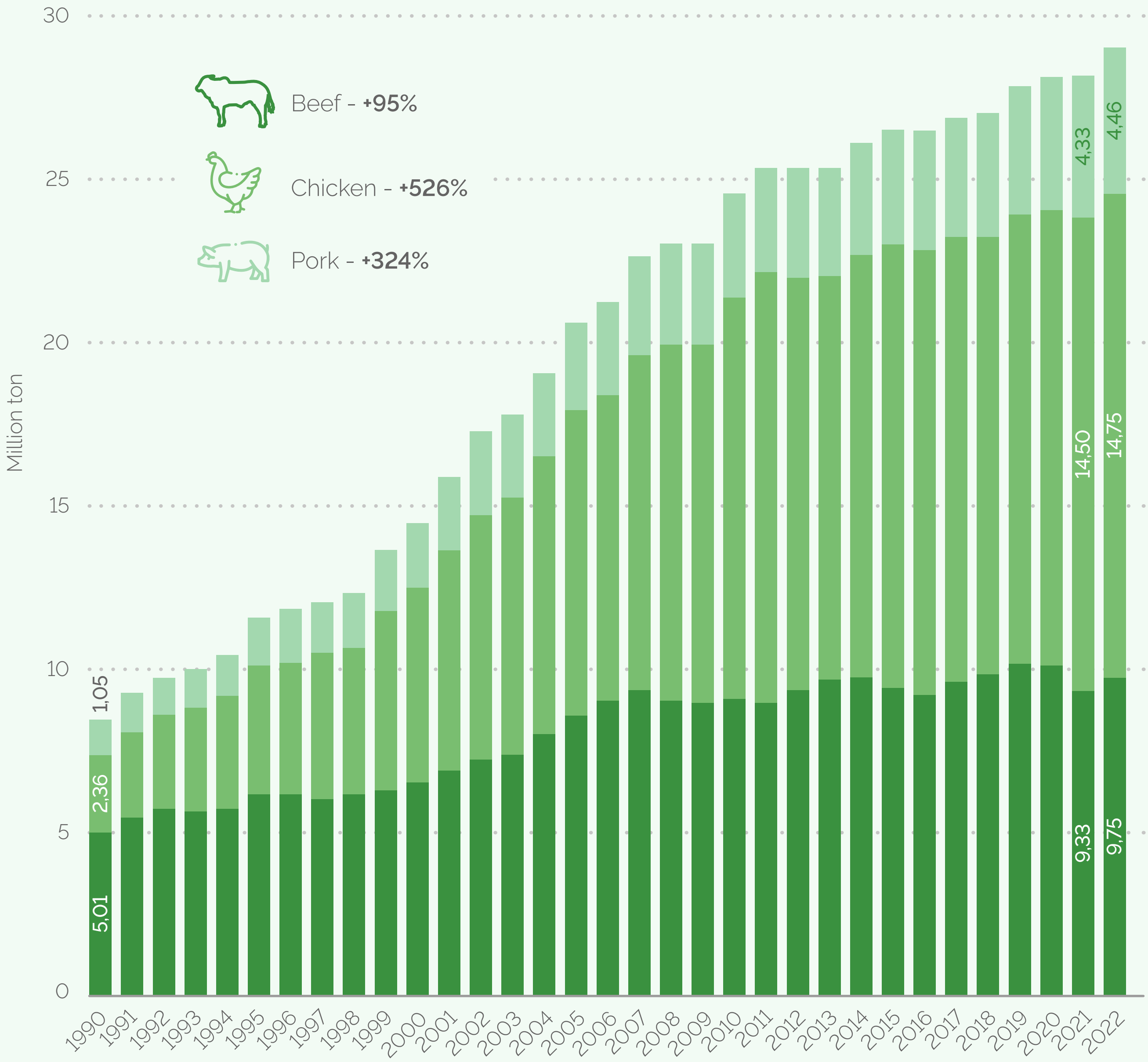
Source: Conab.

Note: *4th Survey - Harvest 21/22 - January/2022.

A similar trend can be observed in livestock production. Since 1990, pork production has tripled, from 1.05 million to 4.46 million tons. Chicken production has increased even more, from 2.36 to 14.75 million tons.

Even in beef production, where the animal cycle tends to be longer, production increased to 9.75 million tons compared to 5.01 million tons in 1990.

GRAPH 3 – Brazilian Meat Production

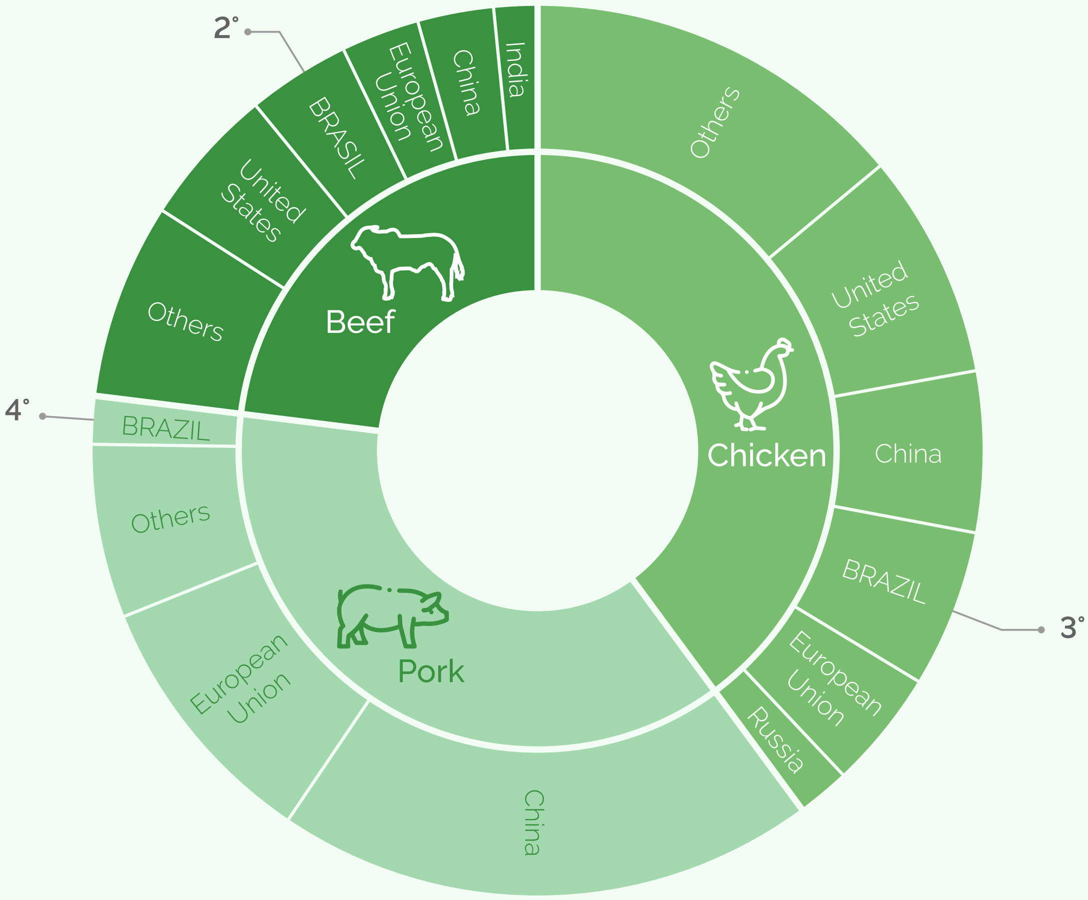


SOURCE: USDA.

Note: *Estimates for 2022.

The advancement of animal protein production has made Brazil a global player in this segment. Currently, the country accounts for 16.2% of the world's production of beef, 14.5% of chicken, and 4.0% of pork, placing it among the top five producers of all these proteins.

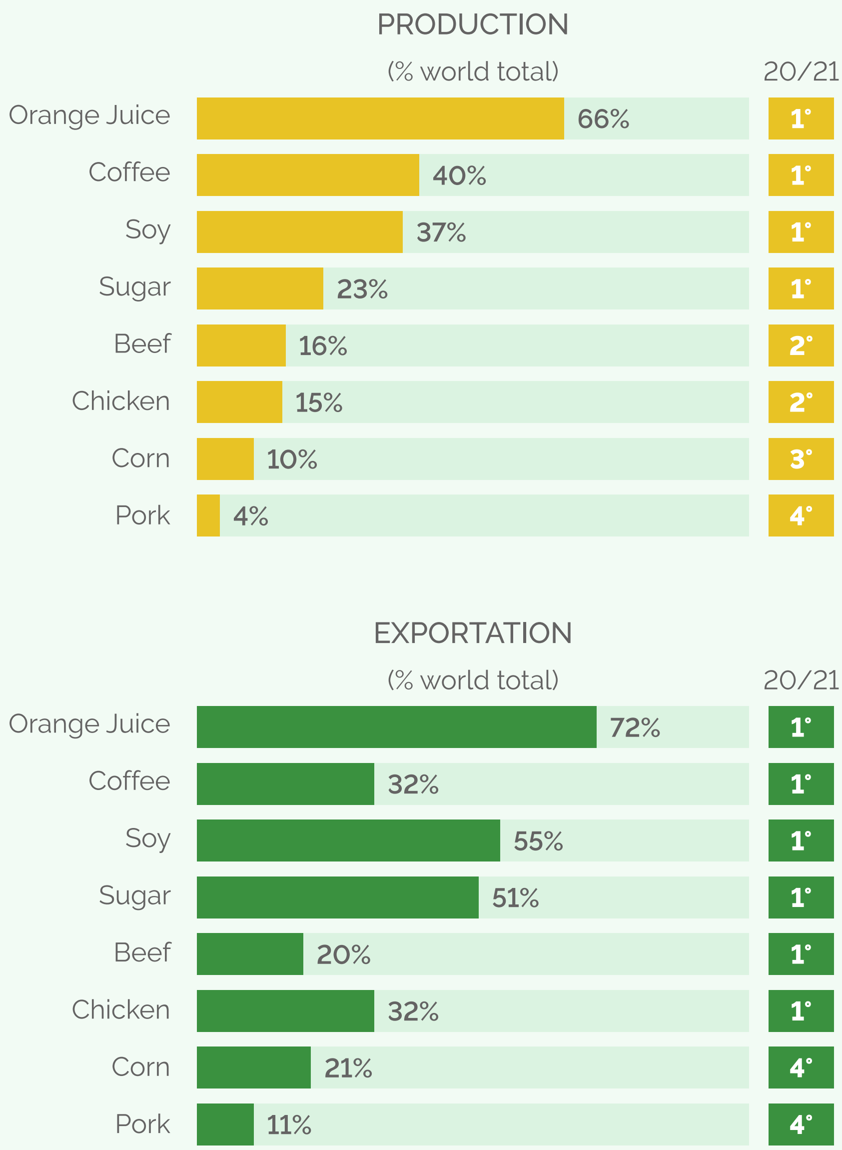
GRAPH 4 – World's Leading Animal Protein Producers in 2021



Source: USDA, 2022.

Technological advances, combined with the availability of arable land, favorable climatic conditions and skilled labor, have allowed Brazil to expand its agricultural production and distinguish itself from the rest of the world. Beyond animal protein, Brazil is a world leader in meat production, sugar, coffee, orange juice, corn, soybeans and cotton.

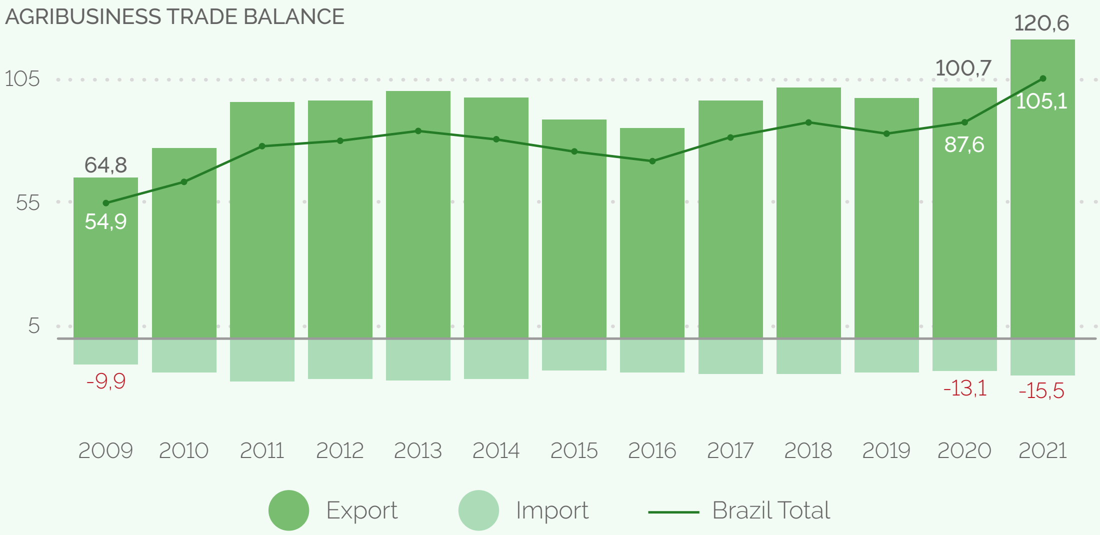
GRAPH 5 – Brazilian Position in the World Ranking in 2021

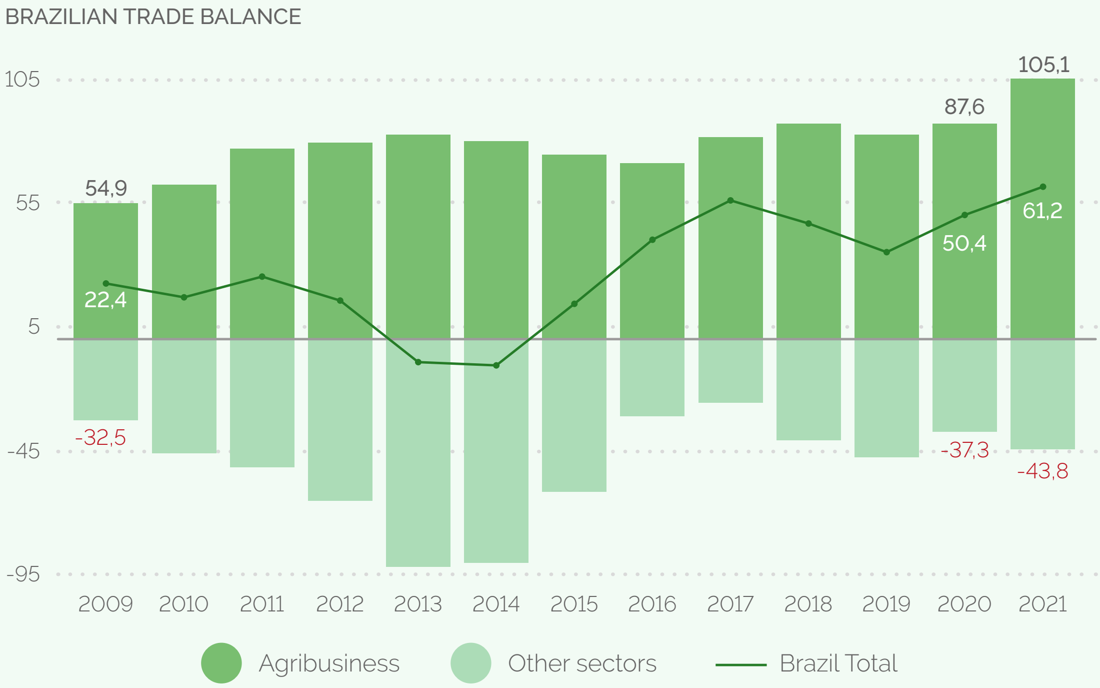


Source: USDA, 2022.

As a result of this performance, the agricultural and livestock sector in Brazil has grown in economic importance in recent years. In terms of foreign trade, agribusiness has contributed to the trade surplus year after year. In 2021, the trade balance of other economic sectors was negative, in the order of US$43.8 billion, while the balance of agribusiness was positive, in the order of US$105.1 billion, an overall result that guaranteed Brazil a trade surplus of US$61.2 billion. This same pattern can be observed, year over year, since 2015.

GRAPH 6 – Brazilian Foreign Trade Performance (US$ Billion)





Source: MAPA e MDIC, 2022.

The figures demonstrate the importance of agribusiness to the Brazilian economy. In 2021, the sector accounted for 43% of exports1, 24% of gross domestic product2 (GDP) and 20% of jobs[1],

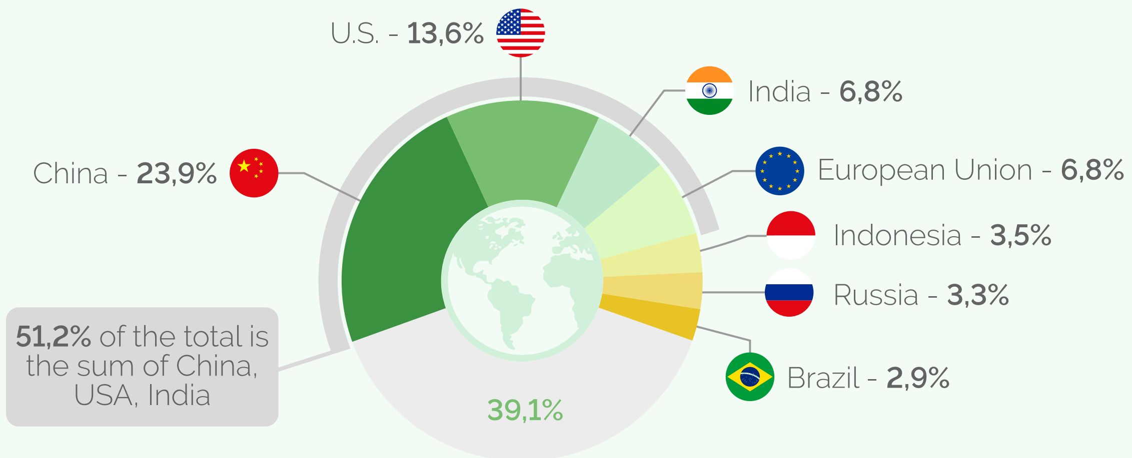
1 Source: MAPA, 2022.

24% of gross domestic product[2] (GDP) and 20% of jobs[3] created in the country. In the same year, the Gross Value of Production (GVP) of agriculture and livestock reached R$ 1.15 trillion, an amount 10.4% higher than in 2020. Crops accounted for 68% of this total, while livestock accounted for the remaining 32%.

One of the major challenges facing the sector is its vulnerability to environmental impacts and climate change. This is particularly true in Brazil, where agriculture faces a two-front conflict: on the one hand, the sector is responsible for 26.7% of national emissions[4], mainly methane, and on the other, it is among the sectors most affected by climate change, being highly dependent on meteorological phenomena such as thermal and hydric cycles. Changing weather patterns can be destructive to agricultural production (Assad, et al., 2019).

Brazil currently accounts for 3% of global net greenhouse gas emissions. Nevertheless, the country is among the top 10 emitters worldwide. However, there is a difference in the Brazilian contribution to global emissions. While 73.2% of global emissions come from the energy sector, 73.0% of national emissions come from the Agriculture, Forestry and Other Land Use (AFOLU) sector. The AFOLU sector generates GHG emissions through a variety of activities, including land-use changes that alter soil composition, methane generated during the digestive processes of ruminant livestock, and nutrient management for agricultural practices.

GRAPH 7 - Share of Net Greenhouse Gas Emissions Balance by Country in 2018 (Share of CO2e)



Source: Emissions in 2018: Climate Watch (except U.S. and Russia); Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S.); National Report on greenhouse gas emissions (Russia). Prepared by: FGV's Bioeconomy Observatory

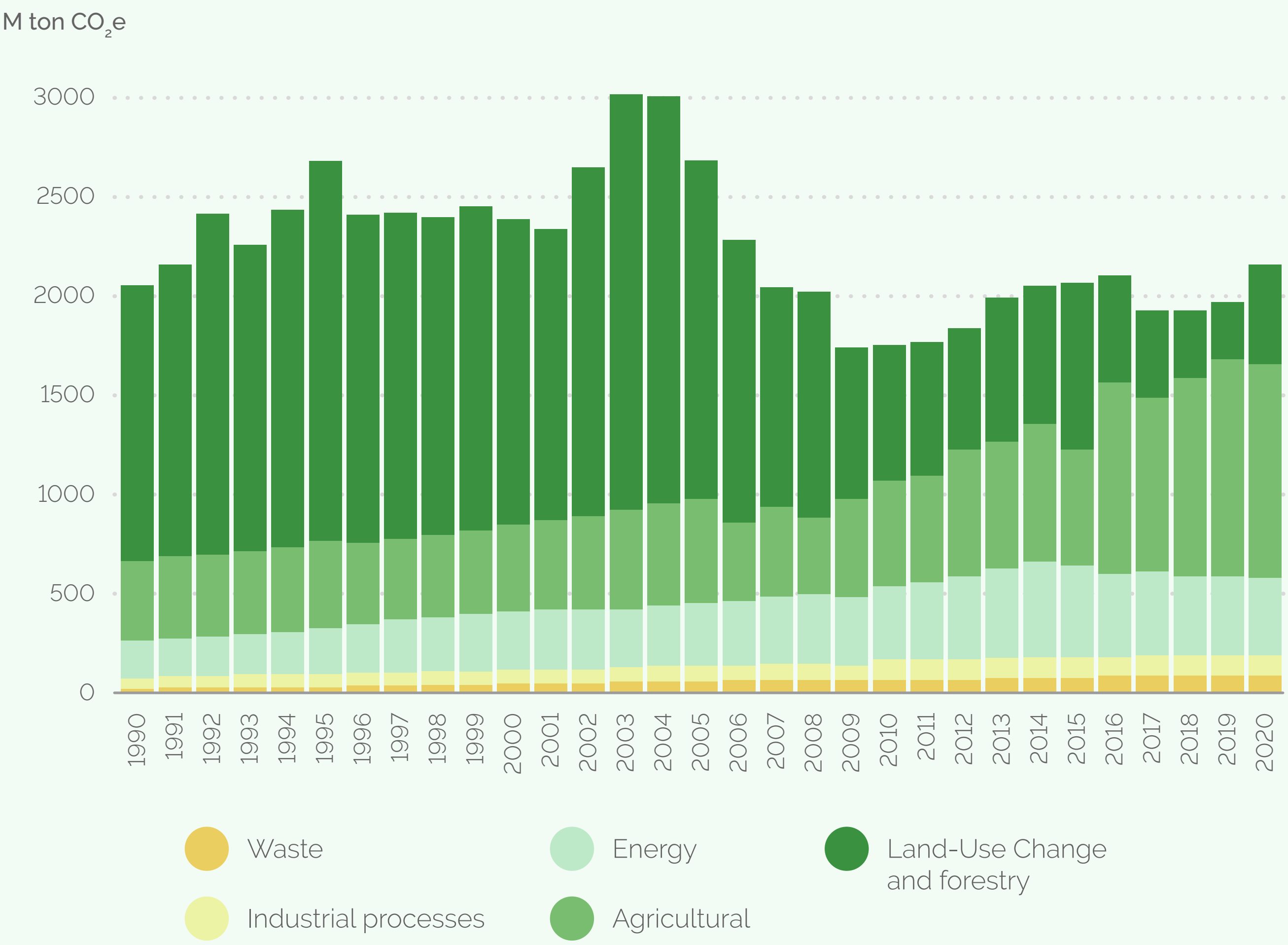
2 Source: CEPEA/USP and CNA, 2022.

3 Source: IPEA, 2022.

4 Note: The data presented is based on emissions calculated for 2020, which are the most recent to date. Source: SEEG, 2022.

Emissions generated in Brazil are around 2.16 billion tons of CO_2e[5], of which 26.7% (around 577.0 million tons of CO_2e) come from agriculture and ranching. Emissions have been stable over the years and rank second in the emissions ranking, after land-use change and forestry category.

GRAPH 8 – Total Brazilian Emissions by Category

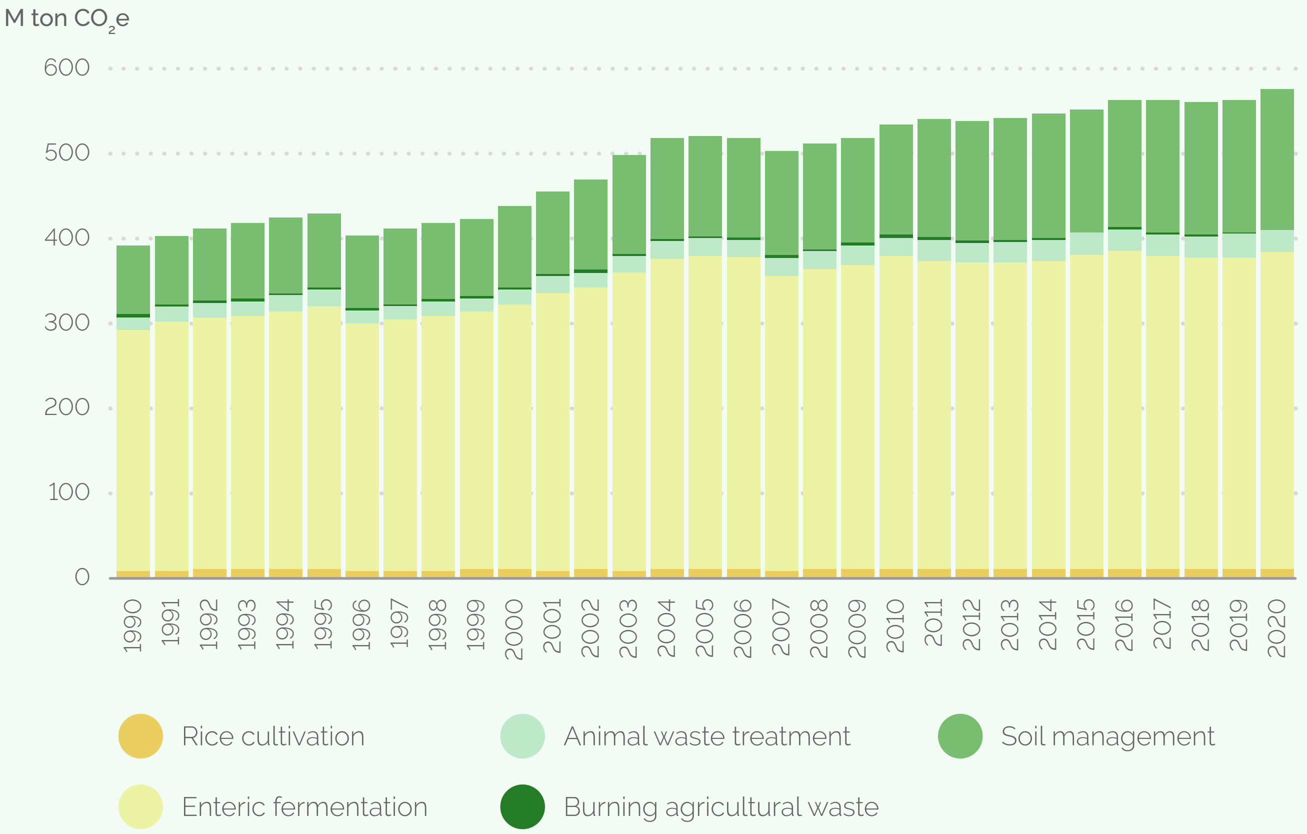


Source: SEEG, 2022.

The emission sources from agriculture are spread across rice cultivation, enteric fermentation, animal waste management, burning of agricultural waste, and soil management. Enteric fermentation is the largest contributor to emissions in this category, accounting for 64.6% of the total in 2020. Soil management, the second largest source, accounts for 28.8%. Combined, these two categories represent more than 90% of agricultural emissions.

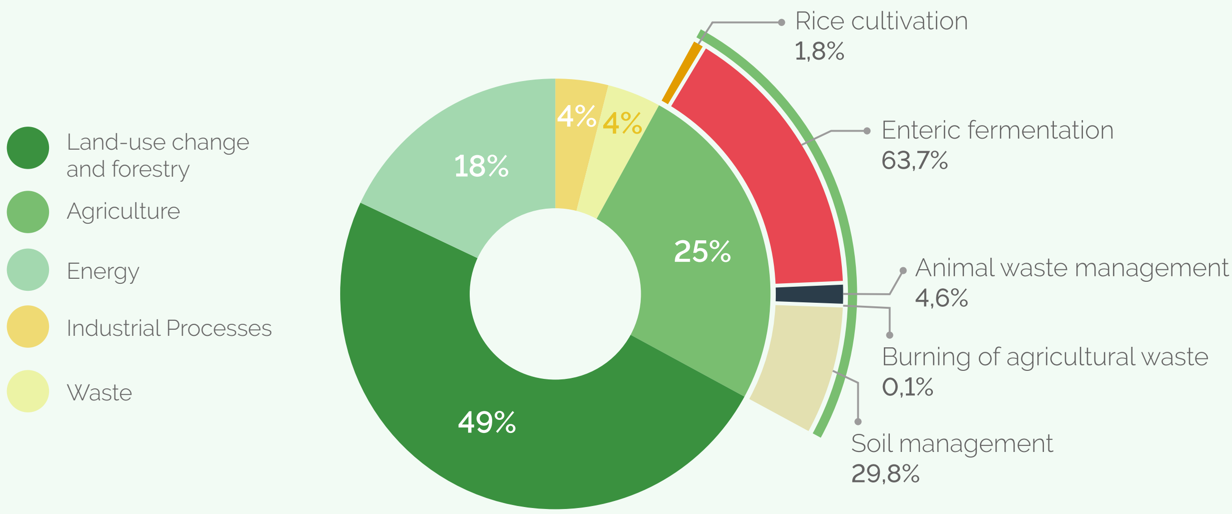
5 Note: The data presented refer to emissions calculated for the year 2020, which are the most current to date. Source: SEEG, 2022.

GRAPH 9 – Total Emissions from Brazilian Agriculture by Category



Source: SEEG, 2022.

GRAPH 10 – Distribution of Total Emissions in Brazil and Brizilian Agriculture by Category in 2021



Source: SEEG, 2022.

Enteric fermentation, a natural digestive process that occurs in ruminants such as cattle, and waste management are processes associated with livestock production. The former releases methane gas, while animal waste releases nitrous oxide in addition to methane. These processes account for around 70% of emissions from livestock.

Although agriculture is responsible for about a quarter of Brazil's total emissions, it has significant potential to contribute to reducing greenhouse gas emissions through proper management and the adoption of good practices on agricultural land.

In an effort to promote an increasingly productive sector while reducing its emissions, the Low Carbon Emission Agriculture Plan (ABC Plan) was developed. Launched in 2010 by the Ministry of Agriculture, Livestock and Supply, the program aims to promote the adoption of sustainable agricultural production technologies and identifies ways to achieve low carbon emission agriculture.

The ABC Plan identifies climate change adaptation measures as part of a set of public policies for coping with climate change. The strategy is to invest in more efficient agriculture by promoting the adoption of diversified systems and the sustainable use of biodiversity and water resource. This includes support for the restructuring process, reorganization of production, ensuring income generation, and research (genetic resources and improvement, water resources, customizing production systems, identifying vulnerabilities and modeling). Preliminary results indicate that the ABC Plan mitigated between 100 and 154 million tons of CO_2e[6] over 8 years (from 2010 to 2018) (Manzatto et al., 2020). Among the proposals of the ABC Plan is the adoption of sustainable production systems through consolidated technologies to increase productivity and reduce GHG emissions of production systems. Some of these include the restoration of degraded pastures, integrated Crop-Livestock-Forest systems, no-till farming and forest plantations.

2.1 AVAILABLE TECHNOLOGIES AIMED AT AGRICULTURAL SUSTAINABILITY

Sustainable agriculture and ranching have 3 main objectives:

1. Efficient use of natural resources and environmental protection.
2. Feasibility, profitability and economic sustainability.
3. Responsibility and social justice.

Adopting appropriate productive practices can contribute to the sustainable development of the territory. There are opportunities to improve the performance of production systems by reducing costs, increasing productivity, better control and efficiency in the use of available resources, diversifying markets, improving the quality of the soil and the productive ecosystem, among others.

The effects of climate change, together with the diversity of biomes, the socioeconomic conditions of farmers, and productivity gains aimed at increasing production and reducing costs, underscore the importance of increasing the adoption of sustainable production sys-

6 Note: https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/plano-abc

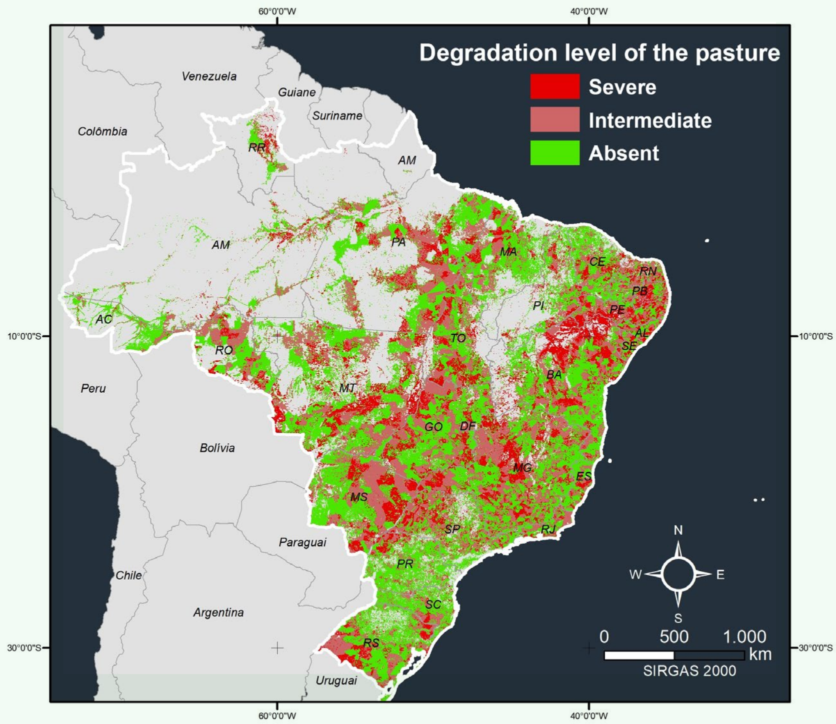
tems by farmers in response to domestic and international market demands, especially in livestock (Manzatto e Skorupa, 2019).

Since the 1960s, Brazil has undergone an intense process of agricultural modernization. This has been driven by advances in science, technology and innovation, assertive public policies and the efforts of rural entrepreneurs. Efforts aimed at restoring degraded pastures, reforestation and planted forests, integrated production systems, no-till farming, biological fixation of nitrogen and treatment of residues are practices that have been adopted and supported as state programs. The use of these solutions is essential for the sustainability and continuity of the Brazilian agricultural sector, as they not only increase productivity, but also reduce greenhouse gas emissions and the need to develop new land for production, known as the "land saving effect".

2.1.1 Restoring Degraded Pastures

Most of Brazil's arable land, about 160.9 million hectares, is occupied by pastures. One of the greatest threats to the territorial occupation of Brazilian agribusiness is the degradation of these areas. According to LAPIG (2021), while about 45.9% of the total pasture area (73.9 Mha) shows no signs of degradation, 39.4% (63.4 Mha) exhibit an intermediate level of degradation, and the remaining 16.0% (25.7 Mha) suffer severe degradation. Degraded pastures can be characterized as systems featuring low tech and inadequate management, such as lack of maintenance fertilization and livestock overcrowding. The precariousness of this management leads to widespread degradation and poor yields, resulting in low productive performance (Strassburg et al., 2014).

FIGURE 1 – Map of Brazilian Pasture Quality by Level of Degradation



Source: Lapig, 2022.

The likelihood of durability and sustainable maintenance in a system where pastures are at a certain level of degradation is marginal. Pasture recovery is a viable practice, both technically and economically. According to Oliveira et al. (2005), if recovery practices were applied to every hectare of degraded pasture, it would be possible to double the average stocking rate in Brazil from about 1 to approximately 2 AU/ha (AU = Animal Unit, 450 kg live weight), effectively making it possible to double the national herd without cutting down a single tree.

Under this scenario, there is a significant opportunity to reduce the impacts of cattle ranching, primarily through restoration techniques on degraded rangelands and integrated production systems. These techniques offer a combination of increased productivity and GHG mitigation potential, while also contributing to reduced deforestation to expand cattle ranching.

2.1.2 Forests: planted and native

The cultivation of planted forests on rural properties has four basic objectives:

- Implement a long-term source of income;
- Increase the supply of wood for industrial purposes (pulp and paper, furniture and wood panels), energy (charcoal and firewood), civil construction and other uses;
- Reduce the pressure on native forests to meet the demand for wood; and
- Help mitigate the effects of climate change by removing CO_2 from the atmosphere.

In addition to the climate change mitigation benefits of forests, native forests also provide benefits related to the permanent water regime, in which vegetation retains rainwater. Therefore, forest conservation is essential for:

- Preserving springs;
- Regulating the flow of water sources that supply cities and towns;
- Regulating the climate;
- Regulating temperature and soil quality;
- Protecting slopes and hillsides.

One of the objectives of the established ABC Plan is to promote efforts towards reducing forest deforestation resulting from the advances in agricultural.

2.1.3 Integrated Systems

Integrated systems, also known as Integrated Crop-Livestock-Forestry (ICLF), are one of the most important practices for mitigating and adapting to climate change. ICLF combines agricultural, livestock, and forestry production systems and can be done in intercropping, in succession, or in rotation, creating mutual benefits for all its components (BALBINO, 2011; OLIVEIRA, 2018). As a result of this integration, the technology also aims to increase agricultural and livestock productivity. Furthermore, ICLF has the potential to reduce GHG emissions through the recovery of degraded areas, thus reducing the pressure to open up new areas (CORDEIRO, 2015; FIGUEIREDO, 2017).

Unlike conventional agriculture, the management practiced in the ICLF system promotes long-term improvements in soil quality through crop diversification, permanent vegetative cover, and reduced tillage (MORAES, 2014; SALTON 2014). This management can promote an increase in soil organic carbon and offset N_2O and CH_4 emissions (CONCEIÇÃO, 2017).

2.1.4 No-till System (NT)

The no-tillage system (NT) is a conservationist system with specific practices to increase productivity, so that the presence of mulch protects the soil from erosive effects of rain and wind, thus avoiding pollution and degradation of rivers and springs due to the load of fertilizers and chemical products (HERNANI & SALTON, 1998). The main features of this system are:

- No soil disturbance,
- Crop rotation and
- Permanent soil cover from crops or crop remains.

NT has the function of integrating a set of interdependent techniques that support the improvement of the environment, the quality of human life, as well as socio-economic concerns and the sustainability of agricultural activities (HERNANI & SALTON, 1998).

Today, Brazil is one of the countries with the largest no-till farming areas in the world, with 33[7] million hectares under no-till cultivation. Studies indicate that productivity gains are as much as 30% over conventional systems, and as much as 50% during the rainy season.

2.1.5 Biological Nitrogen Fixation (BNF)

Biological nitrogen fixation (BNF) is the use of legumes as green manure or as a crop rotation. It is a biological process in which microorganisms convert atmospheric nitrogen (which cannot be used by plants) into ammonia in the soil, which can then be absorbed by the commercial crop.

BNF is the primary pathway for nitrogen fixation in the biosphere and, aside from photosynthesis, the most important biological process for plants and fundamental to life on Earth.

Some studies have shown that BNF is an important mechanism to increase the positive nitrogen (N) balance in agricultural systems. This is because the inadequate or excessive use of nitrogen fertilizers in agriculture is of concern, both economically and environmentally. Nitrogen fertilizers, in addition to being a source of N_2O emissions, represent a high cost, since it is linked to the cost of oil, whose derivatives are used in the production of these fertilizers. In Brazil, approximately 70% of the total nitrogen fertilizer used is imported. Therefore, BNF presents itself as an alternative to the use of nitrogen fertilizers for some crops, helping to reduce, totally or partially, the quantity of fertilizers applied to legumes, grasses and other species.

Benefits of BNF are:

- Reducing the use of nitrogen fertilizers, thus reducing import costs and national dependence on fertilizers;
- Increased productivity;
- Reduction of environmental impacts

2.1.6 Environmental and legal compliance in rural properties

The Legal Reserve (LR) and the Areas of Permanent Preservation (APP) provide environmental benefits necessary for sustainability.

The Legal Reserve (RL) is an area of native vegetation on rural property that must be maintained and conserved in accordance with legal requirements. The Forestry Code (Law 12.651 of 2012) defines the area allocated to the RL on each property according to its territorial location:

7 Source: Federação Brasileira do Sistema Plantio Direto, 2022.

- 80% for rural properties located in forest areas in the Brazilian Legal Amazon (BLA);
- 35% for rural properties located in areas of the Cerrado (savannah) in the BLA;
- 20% for rural properties located in areas of Campos Gerais in any region of the country;
- 20% for rural properties located in areas of forest or other forms of native vegetation in all other regions of the country.

The conservation of LR is of paramount importance for the protection of native fauna and flora, the maintenance of biodiversity, and the sustainable use of natural resources. Therefore, sustainable economic use of natural resources can take place in LR areas.

APPs, on the other hand, are legally defined areas, which may or may not be covered by native vegetation, designed to protect watercourses, the landscape and biodiversity. APPs must be established along rivers or other waterways, starting from their highest elevation and within a buffer zone whose minimum width on each bank depends on the width of the body of water. The Forestry Code (Law 12.651 of 2012) stipulates that APPs may be established in, among other places, springs, lakes and natural ponds, watersheds, hilltops, motes, mountains, hills, slopes, edges of mesas or plateaus, sandbanks, and at altitudes above 1800 meters. Any rural property with an APP that has been cleared of its native vegetation for agricultural or economic activities must promote the restoration of these areas by legal mandate.

2.2 SUSTAINABILITY IN BEEF PRODUCTION

Sustainability of agricultural and livestock production depends directly on the conservation of soil, water resources, forests and other forms of native vegetation on rural lands. Failure to comply with environmental legislation and legislation governing agricultural activities puts the producer at risk of fines, loss of funding, loss of business opportunities and, above all, being forced to pay for the damage caused by the loss of biodiversity and the changes in the climate regime.

The Agricultural Sector Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture (MAPA, 2010) provides guidance to farmers on sustainable agricultural management that promotes environmental, economic and social improvements.

Many guidelines are provided that address the agricultural production system to be used, soil and input management, preservation of native vegetation, animal management, waste handling, and reduction of GHG emissions, among others. The Sector Plan also contains significant recommendations for the livestock sector, such as the adequate handling of waste and effluents generated by animal husbandry, which is an important factor for the environmental sustainability of rural properties. The proper treatment of these effluents and wastes contributes to the reduction of methane emissions and enables

The producers to gain new sources of revenue, either through the production of organic compost or by energy production through the use of biogas.

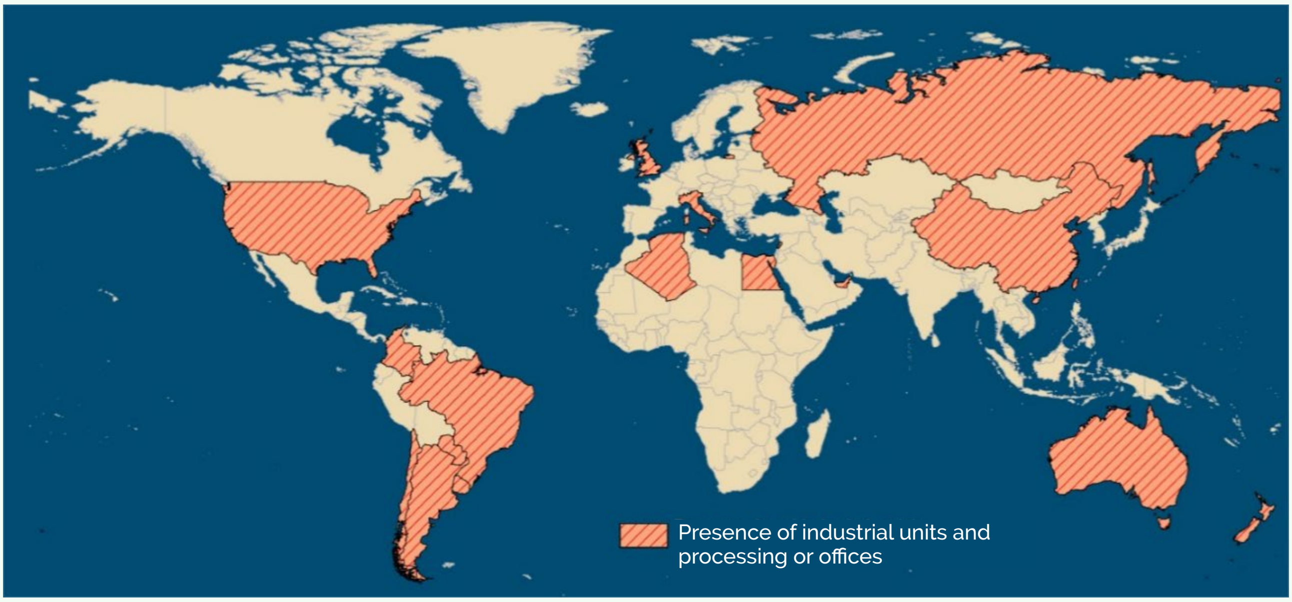
Many issues arise in managing the day-to-day operations of a livestock operation. In addition to managing the operation "inside the gate," the rancher faces concerns "outside the gate" that influence his decision making. These concerns are driven by the demands of the beef consumer market, such as phytosanitary issues, animal welfare and cattle traceability.

The journey towards sustainable meat production must be accompanied by a maturing relationship with the environment, which is becoming increasingly requested by the markets, especially with regard to climate issues, product traceability and the fight against deforestation. Products destined for the market must be guided by a vision of sustainability that unites commitment to the planet, commitment to the well-being of society, product quality and respect for life. This is the goal of Minerva Foods, a company that has distinguished itself both for its ability to face the challenges of the sector and for its achievements, thanks to its strategic initiatives to combat climate change and protect ecosystems, with an emphasis on the environmental efficiency of its operations and the fight against illegal deforestation throughout the supply chain..

03 MINERVA FOODS

Minerva Foods is the leading beef exporter in South America as well as operating in the processed foods segment, marketing its products in over 100 countries. In addition to Brazil, Minerva has operations in Paraguay, Argentina, Uruguay and Colombia. It also has facilities in Australia specializing in sheep production. In total, Minerva employs more than 20,000 people, making it possible to provide beef, lamb and their derivatives across five continents, through its 32 industrial units, 11 international offices and 14 distribution centers.

FIGURE 2 – Map of Minerva Foods industrial and processing units, and branch offices



Minerva Foods has an extensive base of cattle suppliers and a network of offices and operations that connect growing markets, such as Asia, with beef production centers in South America. At the end of 2020, the company recorded net revenues of R$19.4 billion, of which 68% came from exports. In 2021, it recorded net sales of R$ 26.9 billion, an increase of 39%.

Furthermore, Minerva has established its practices in its Animal Welfare Policy, which stipulates a strict zero-tolerance policy for the abuse, neglect or mistreatment of animals, striving to implement best management practices, training of personnel and constant monitoring at all stages of production.

With investments in tracking technologies, control of deforested areas and monitoring of protected areas and indigenous territories, the company has under its umbrella some 9,000 suppliers in the Amazon region, covering a radius of more than 9 million hectares. Among several other initiatives, Minerva Foods is also the first company in the industry to take significant action to evaluate the chain of indirect suppliers in the Amazon. In 2020, the company went beyond the Amazon and extended its geographic monitoring of suppliers to the Cerrado, a biome suffering from alarming rates of deforestation that has already lost 50% of its original size. The concern for the preservation of the Cerrado is also a direct reflection of the pressure from investors and multinationals seeking supply chains that have a lower impact and a greater commitment to the environment.

According to its most recent Sustainability Report (2021), the company is committed to achieving zero illegal deforestation throughout its supply chain in South America by 2030, through initiatives such as geographic monitoring of suppliers in Latin America and the development and implementation of an indirect supplier monitoring program for all countries of operation in South America. Through this monitoring it is possible to determine if the rural property is involved with deforestation, burning, occupation of legally areas, in addition to socio-economic compliance.

In view of the global threat of climate change, the company has integrated the value of sustainability as one of its pillars for continued growth and market positioning. Minerva Foods is committed to becoming carbon neutral in Scopes 1, 2 and 3 by 2035. In response, the Renove program was created in 2021 to support the reduction of emissions in the supply chain.

Recently, Minerva also announced its new sustainability strategy with a commitment to be carbon neutral and achieve zero net emissions by 2035, 15 years ahead of the Paris Agreement. The Company will invest in projects that will help reduce emissions throughout the production chain by the announced date. Its first commitment is to ensure an end to illegal deforestation throughout the South American supply chain.

3.1 GHG PROTOCOL TOOL FOR AGRICULTURE AND RANCHING: PARTNERSHIP BETWEEN EMBRAPA, FGV AND MINERVA FOODs

The World Resources Institute (WRI), a research organization, in partnership with the World Business Council for Sustainable Development (WBCSD), a consortium of companies with a global presence, developed the GHG Protocol methodology, which provides the necessary guidelines for calculating and accounting for GHG emissions and removals from economic activities in various sectors, enabling the development of emission reduction targets and changing the production paradigm to meet these targets.

In 2012, WRI Brazil, in partnership with Embrapa and Unicamp, developed a project to create and adapt the guidelines for calculating agricultural emissions to tropical conditions, in order to better measure and manage agricultural emissions in line with Brazilian realities.

The project became known as the **Agricultural GHG Protocol**.

In the period between 2012 and 2013, the project developed two technical resources: the Brazilian Agricultural Guidelines and the Agricultural GHG Protocol Calculation Tool.

Together, these features make it possible to:

- Identify opportunities to reduce agricultural GHG emissions;
- Track progress toward reduction goals;
- Communicate results to investors and end consumers; and
- Respond to national and international demands for lower carbon products.

Minerva Foods partnered with Embrapa and the Getúlio Vargas Foundation to update the latest version of the Agricultural GHG Protocol with the latest emission factors published in Brazil's Fourth National Communication to the United Nations Framework Convention on Climate Change (UNFCCC).

This made it possible to account for GHG emissions from cattle grazing in pastures and feedlots in a way that is more consistent with the reality of suppliers to Minerva Foods in Brazil. It is worth noting that this updated version did not change the content (inputs and outputs of the calculation), but rather updated the emission factors.

Accordingly, the sources of emissions considered by the GHG Protocol for Agriculture and Livestock are:

- Organic Fertilization;
- Limestone application;
- Application of synthetic nitrogen fertilizer;
- Urea application;
- Electricity consumption;
- Rice cultivation;
- Enteric fermentation;
- Emissions from secondary sources (atmospheric deposition and leaching or surface runoff);
- Waste management;
- Land use and land use change;
- Mechanized operations;
- Burning of plant residues;
- Decomposition of crop residues..

According to the GHG Protocol guidelines, the reporting of GHG emissions is classified according to the degree of responsibility or control of the inventory-taker organization vis-à-vis the source of the emissions direct sources (sources that belong to or are controlled by the inventory-taker organization) and indirect sources (sources that belong to or are controlled by another organization, but result from the activities of the inventory-taker organization). This structure is represented by Scopes 1, 2 and 3, as defined below::

Scope 1: These are direct emissions from sources owned or controlled by the inventory-taking organization.

Scope 2: Indirect emissions from the use of electrical and thermal energy consumed by the inventory-taker organization. This category includes GHG emissions associated with the consumption of electrical energy purchased by the organization.

Scope 3: All other indirect emissions not reported under Scope 2. Scope 3 emissions are a consequence of the company's activities but occur at sources not owned or controlled by the reporting organization, generally related to its value chain.

In addition to the emissions reported within the Scopes, biogenic emissions, carbon sequestration, net emissions and other gases are also reported.

Biogenic Emissions: CO_2 emissions resulting from the combustion of biomass (biological material composed of carbon, hydrogen and oxygen). Biomass burning results in emissions that are considered climate neutral because CO_2 is produced through a short biological cycle (rather than a geological cycle, as is the case with fossil CO_2). Burning of native vegetation as a result of land use change (i.e. deforestation) should be reported in scope 1 or 3 as it is not considered climate neutral.

Biogenic Removals: Biological carbon fixation is a process of photosynthesis that temporarily reduces the concentration of CO_2 in the atmosphere. Thus, the increase in carbon in plant tissue should be accounted for as biogenic removal of CO_2. Examples: planted vegetation (commercial forestry), increased soil carbon stocks, green manure, land-use changes that increase carbon stocks, etc.

Land use and land cover change: Land use transition to stabilization. For example, area degraded to pasture, agriculture, or sugar cane. Includes carbon in soil and biomass (e.g. native vegetation and other uses).

Net emissions represent the difference between total emissions and carbon sequestration (Equation 1). If net emissions are positive, the property is considered a GHG emitter; if net emissions are negative, the property is considered a GHG mitigator. In this report, 23 cattle suppliers to Minerva Foods were analyzed.

Scope 1 Emissions
+
Scope 2 emissions
±
Biogenic emission or removal
±
Land use change
=
Net Emissions

04 RESULTS OF THE GHG PROTOCOL - AGRICULTURE AND LIVESTOCK

To participate in the study, cattle suppliers to the Minerva Foods processing units were selected, prioritizing the geographic diversity of cattle purchasing operations and also the different animal finishing strategies. As a result, 23 partner suppliers were selected, located in 3 of the 5 major regions of Brazil.

. **FIGURE 3 – Municipal geographical distribution of the properties participating in the study**

The 23 suppliers operate in the states of Mato Grosso (MT), Goiás (GO), Minas Gerais (MG) and Rondônia (RO). They cover three different regions (Midwest, Southeast and North) and include at least one Minerva slaughter unit, strategically located to meet market demand while respecting animal welfare criteria. It should be emphasized that the properties studied are cattle ranches from which Minerva Foods directly purchases cattle, so no GHG emissions from indirect suppliers were studied.

Of the total gross value of agricultural production in Brazil in 2021 (R$ 1,129.2 billion), these 5 states account for 39.5%, about R$ 445.8 billion (MAPA, 2021). These states also contain 47% of the national herd, about 102.4 million head of cattle (IBGE, Pesquisa da Pecuária Municipal, 2020).

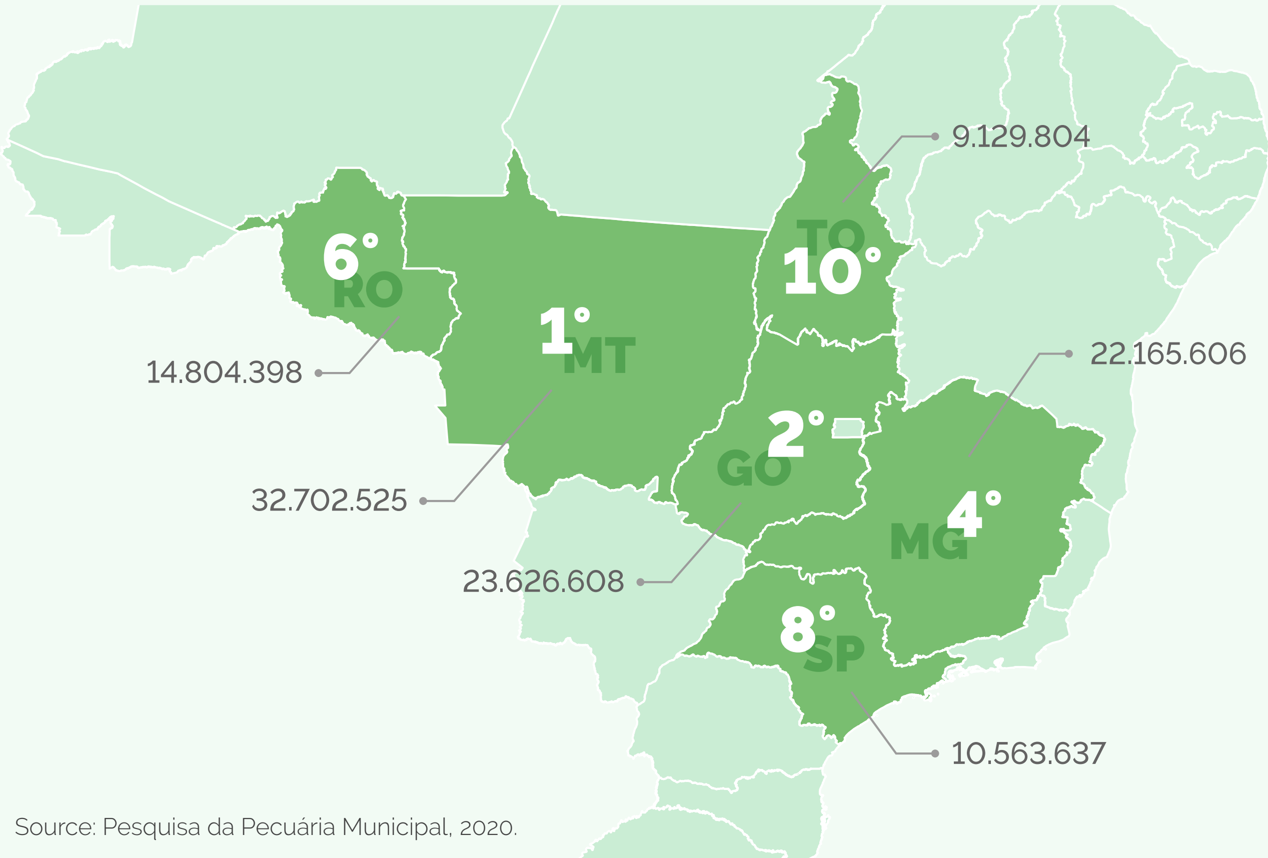
Minerva Foods has two meat packing units in the state of Mato Grosso, located in the cities of Mirassol D'Oeste and Paranatinga. It is currently the state with the largest cattle herd in Brazil (IBGE, Pesquisa da Pecuária Municipal, 2020), followed by the state of Goiás, which also has a meat packing facility in the city of Palmeiras de Goiás.

According to data from the Image Processing and Geoprocessing Laboratory (Lapig/UFG), in 2020 the State of MT had a total area of 19.7 million hectares of mapped pastures, representing 21.87% of the state's area and 12.3% of the country's pastures. As for Goiás, this area amounted to 13.8 million hectares, representing 39.58% of the state, corresponding to 8.4% of the country's pastures.

Another state where Minerva Foods has a processing plant is Minas Gerais, in the municipality of Janaúba. In this state, pastures cover 19.9 Mha, or 33.98% of the state's territory and 12.4% of Brazil's pastures. The state has the 4th largest cattle herd in Brazil. In the state of São Paulo, the meat processing units are located in the cities of Barretos and José Bonifácio, in the microregion of São José do Rio Preto, which is home to the second largest cattle herd in the state of São Paulo. The state of São Paulo itself boasts the fourth largest cattle herd in Brazil.

Minerva Foods also has strategically located units in the municipalities of Rolim de Moura, in Rondônia, and Araguaína, in Tocantins, whose state herds are the 6th and 10th largest in Brazil..

FIGURE 4 – States with Minerva slaughter units and corresponding number of cattle (no. of head) for 2020



Source: Pesquisa da Pecuária Municipal, 2020.

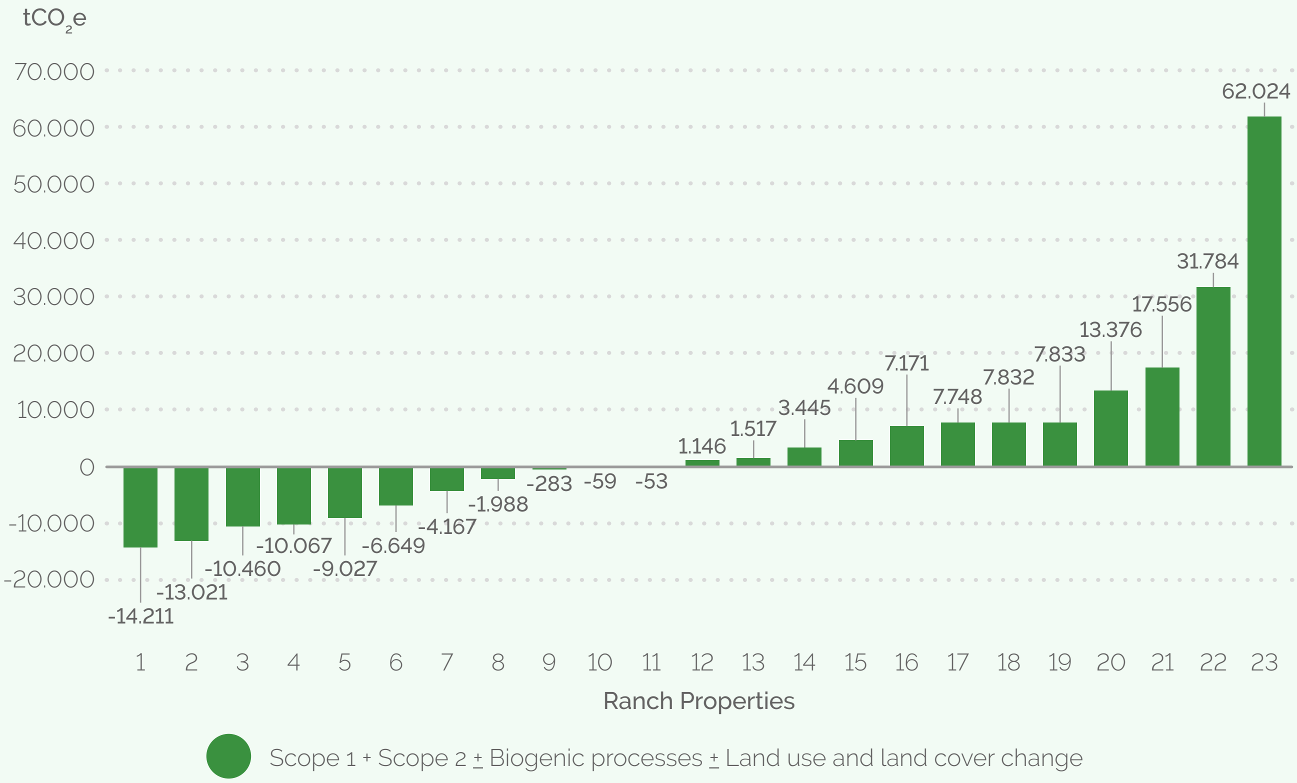
The ranches included in the study supply the units in José Bonifácio/SP, Rolim de Moura/RO, Palmeiras de Goiás/GO, Mirassol do Oeste/MT. These properties differ from each other in that they use different management techniques for the herd, and different types of finishing (pasture or feedlot). These ranches were responsible for supplying 12.6% of the volume of heads processed in Brazil for the 20/21 crop year - the period covered by the GHG Protocol.

4.1. BALANCE OF GREENHOUSE GAS EMISSIONS FOR THE 20/21 PERIOD

The results show that of the 23 properties analyzed, 11 have a negative carbon footprint, meaning they remove more carbon equivalent than they emit. In other words, these ranches are not only offsetting their own emissions, but also helping to mitigate carbon emissions.

The properties analyzed have different characteristics. These include cropland, pasture availability and condition, livestock numbers, management techniques, and fertilization. The results presented in **Graph 11** show the aggregate effect of all these practices and techniques on GHG emissions.

GRAPH 11 – Greenhouse Gas Emissions Balance for the properties analyzed

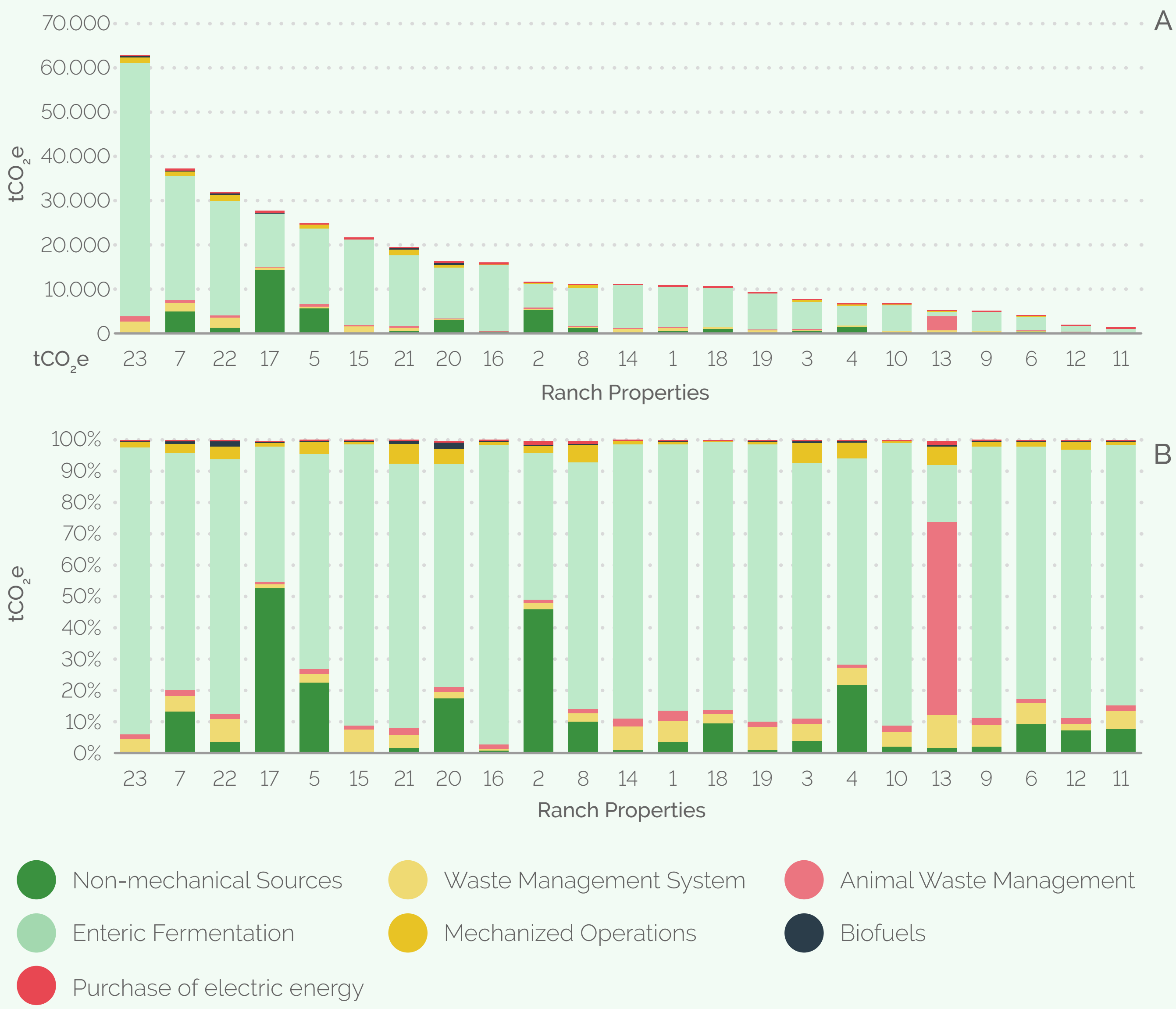


The results obtained take into account factors such as input application, land use transition, cattle herd size, animal waste management, and energy and fuel consumption in the operations carried out during the 20/21 crop year. These factors can vary from year to year within the same rural property. For example, input use may be related to pasture recovery, an operation that may not be repeated every year. According to Oliveira et al. (2005), a pasture, once recovered and properly managed, can last for decades without the need for further intervention.

The properties with the highest net emissions are those with cattle confinement systems, and as a result, their respective GHG mitigating production systems cannot offset the emissions from enteric fermentation, the popular "burping" of cattle, which represents a critical point in the consolidation of sustainable ranching. **Graph 12 A and B** below shows the dynamics of emission sources for each property.

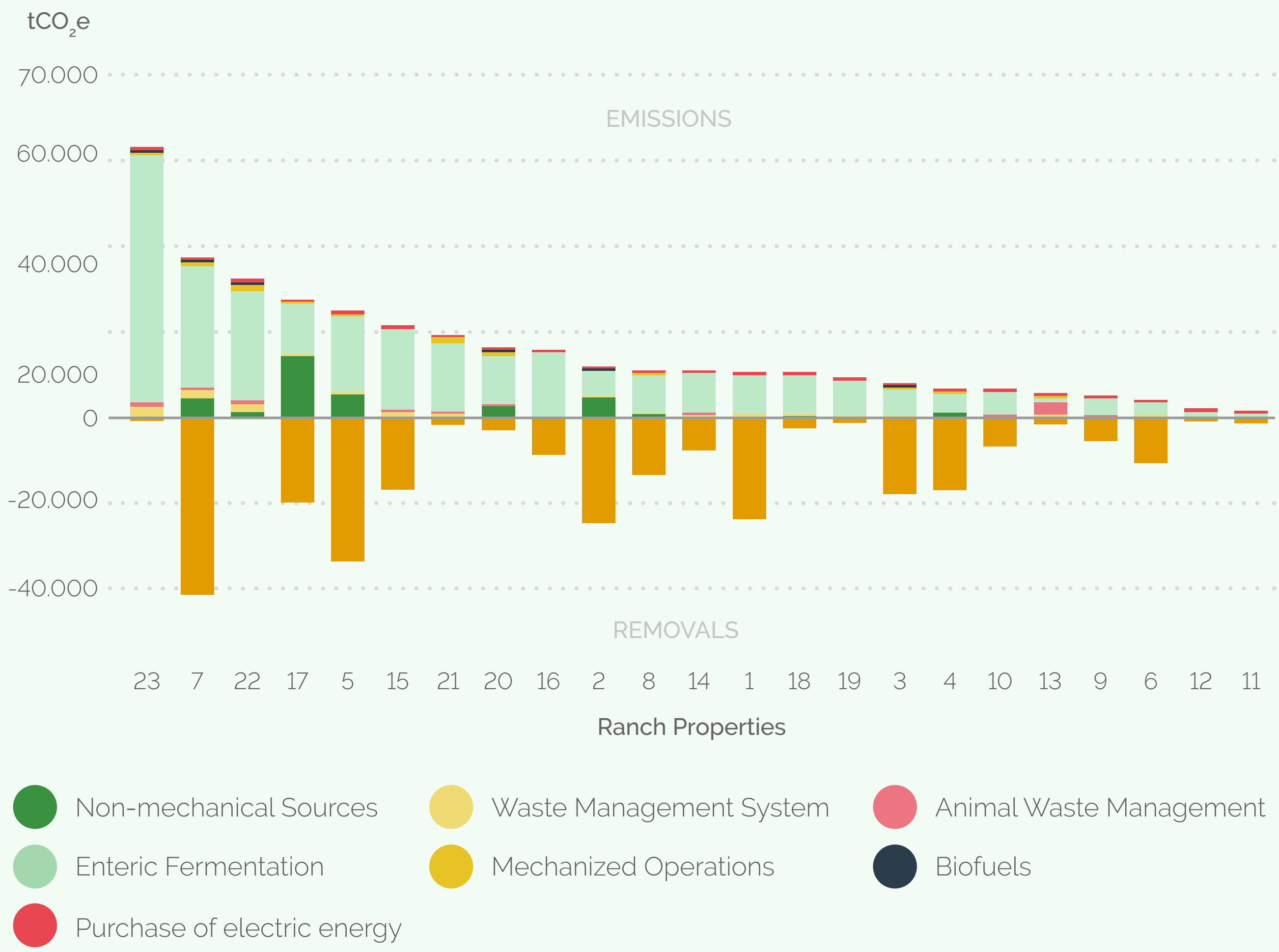
Graph 12 A presents the absolute contribution of each source to the total emissions. It can be seen that the order of the properties that emit the most differs from the one shown in **Graph 11**, regarding the balance of emissions. For example, Ranch 7 has a negative carbon balance of 4,167 t CO_2e. In other words, this ranch emits 30,774.1 metric tons of CO_2e, mostly from enteric fermentation, and removes 36,312.5 metric tons of CO_2e from the atmosphere through land-use change practices, resulting in a negative balance. The main source of emissions on this ranch is enteric fermentation, a characteristic also found on the other ranches. This is due to the fact that the balance takes into account everything that has been emitted by the ranch, as well as all the removals, which are primarily the result of changes in land use. As discussed previously, technologies such as pasture recovery or conversion of degraded pastures to integrated systems have the potential to remove carbon from the atmosphere. **Graph 12 B** shows the relative contribution of each source to total emissions. Enteric fermentation is the largest contributor of emissions sources in the analysis and is also the primary source of emissions from the national herd.

GRAPH 12 – Absolute (A) and Relative (B) Contribution of Greenhouse Gas Emission Sources for the Properties Analyzed

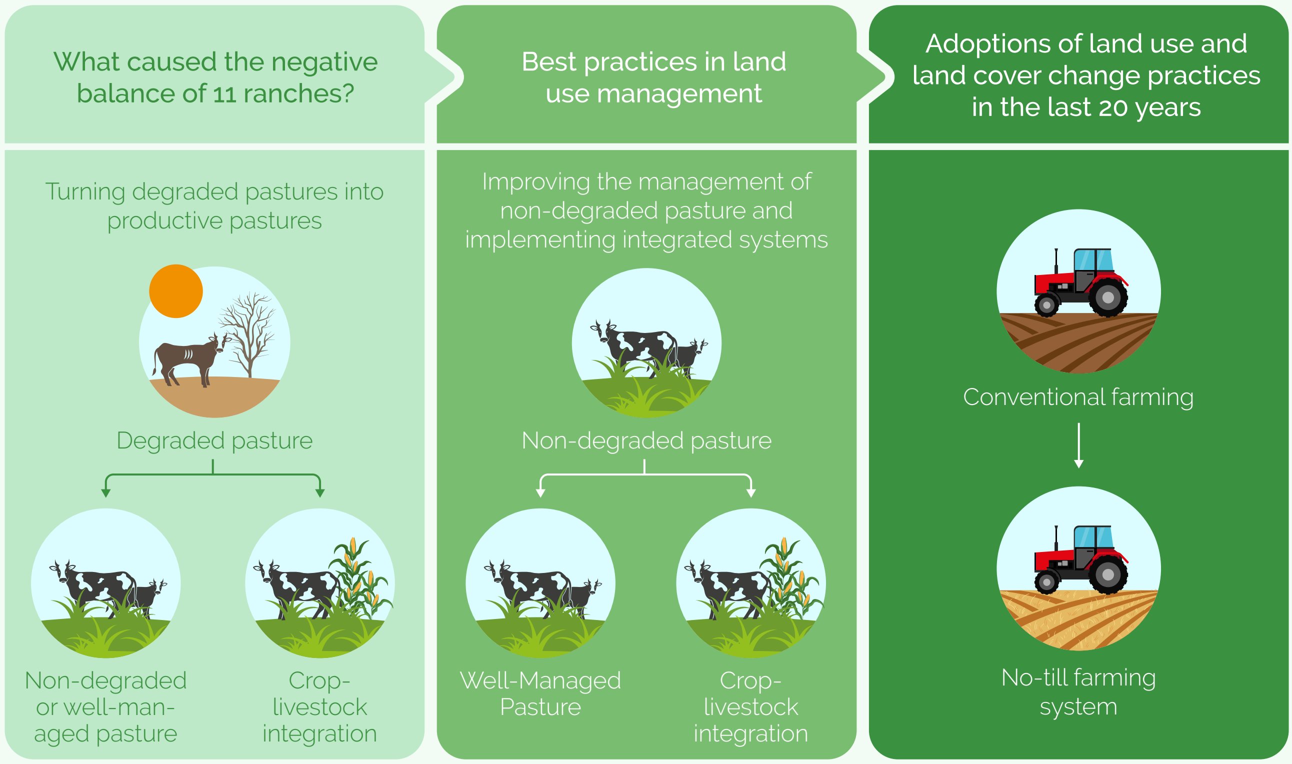


Graph 13 illustrates the main sources of GHG removals for each property. Using the example of ranch 7, it can be seen that although the emissions of this ranch reached 36,965.1 t CO_2e, the removals amounted to 41,132.5 t CO_2e. This result was achieved due to the conversion of pasture land into Crop-Livestock Integration areas. The amount of CO_2e removed from the atmosphere was therefore greater than the amount emitted.

GRAPH 13 – Sources of Greenhouse Gas Emissions and Removals for the Properties Analyzed



Nevertheless, the in-gate activities identified for negative carbon balance properties can be attributed to the best land use management practices of the last 20 years. We have identified properties where pasture recovery is in progress, establishing pastures that are always well managed through renovation or the adoption of integrated systems, in addition to the adoption of no-till farming.



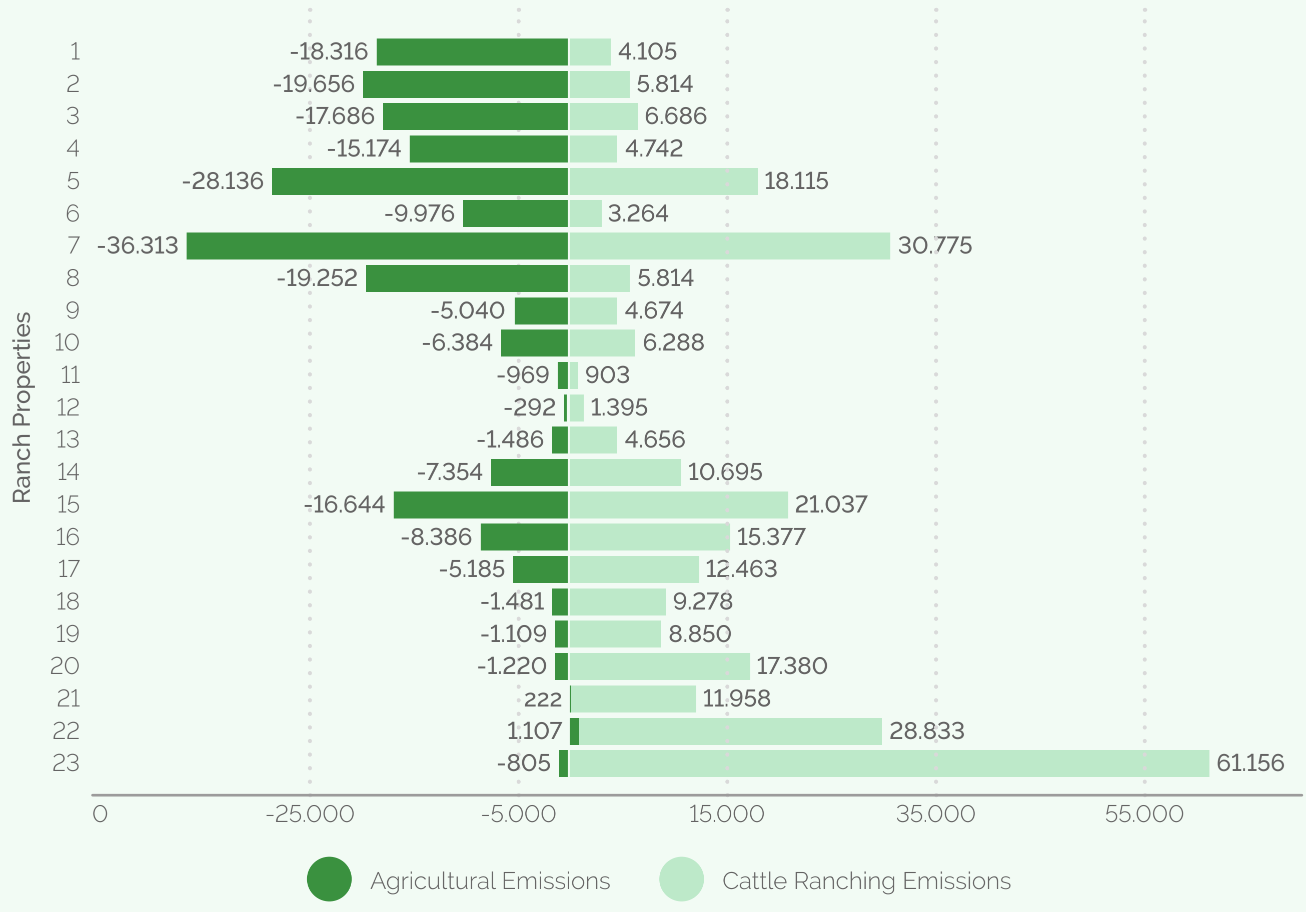
If we separate the in-gate activities, i.e., agriculture and ranching, we can see from **Graph 14** that for most properties, agriculture removes and ranching emits. What determines whether the emissions balance is negative is how much more is removed by agriculture through land use change than is emitted from ranching. Because of their root systems, grasslands and agriculture sequester large amounts of carbon in the soil and store a significant amount of carbon as biomass (Jansson et al., 2010).

This is because Brazilian agriculture currently has access to several technologies that promote soil carbon storage and increase productivity, in addition to representing advances in the search for a more sustainable system. Forestry integrated systems, direct seeding and biological nitrogen fixation are examples of these strategies.

Through the use of these techniques on the property, the producer begins to contribute to the reduction of GHG emissions or even achieves a negative balance, i.e., the amount of GHG stored on the property is greater than the amount emitted. In addition, the use of these technologies is part of the implementation of Good Agricultural Practices[8] and enables the producer to develop more effective ways to increase profitability throughout the production process, avoiding waste.

8 A set of standards and techniques to guide the entire process of food production, processing and transport, with the aim of increasing agricultural productivity and reducing potential harm to human health, ag workers and the environment.

GRAPH 14 – GHG Emissions by Source (Agriculture and Cattle Ranching) for the Properties Analyzed



Good agricultural practices are also a way of reducing emissions from cattle. In this case, as methane emissions from cattle are mainly due to the enteric fermentation process, the strategy is to adopt practices that offset these emissions, such as improving the quality of pastures by increasing the amount of carbon in the soil, which can also contribute to live weight gain and reduce the time it takes for the animal to be ready for slaughter, as well as more efficient waste management. **Graph 15** shows emissions per thousand head of cattle from the 23 partner suppliers of Minerva Foods, as well as the average for Brazil. Only one property registered emissions above the national average.

To calculate the average emissions for Brazil, it was necessary to determine the total value of emissions generated by the Brazilian herd, by state and by animal category[9], and to measure those emissions against the total size of the herd.

9 This effort was necessary because the emission factors used to calculate greenhouse gas emissions vary depending on the location and age of the animal. The detailed calculation is presented in the Appendix.

This breakdown allows for a more reliable calculation of the emissions of the national herd in a given year. Based on this information, it is possible to define the "Brazilian average" of Brazilian herd emissions. This average is given by:

$$\mu_{Br} = \frac{\sum_{uf,T}\left(EF_{uf,T} \times \left(\frac{N_T}{10^6}\right)\right) + \sum_{uf,T}\frac{\left(EFM_{uf,T} \times N_T\right)}{10^6}}{\sum_T\left(N_T\right)} \quad (1)$$

Rearranging:

$$\mu_{Br} = \frac{\sum_{uf,T}\left(\frac{(EF_{uf,T} \times N_T) + \left(EFM_{uf,T} \times N_T\right)}{10^3}\right)}{\sum_T\left(N_T\right)}$$

In which:

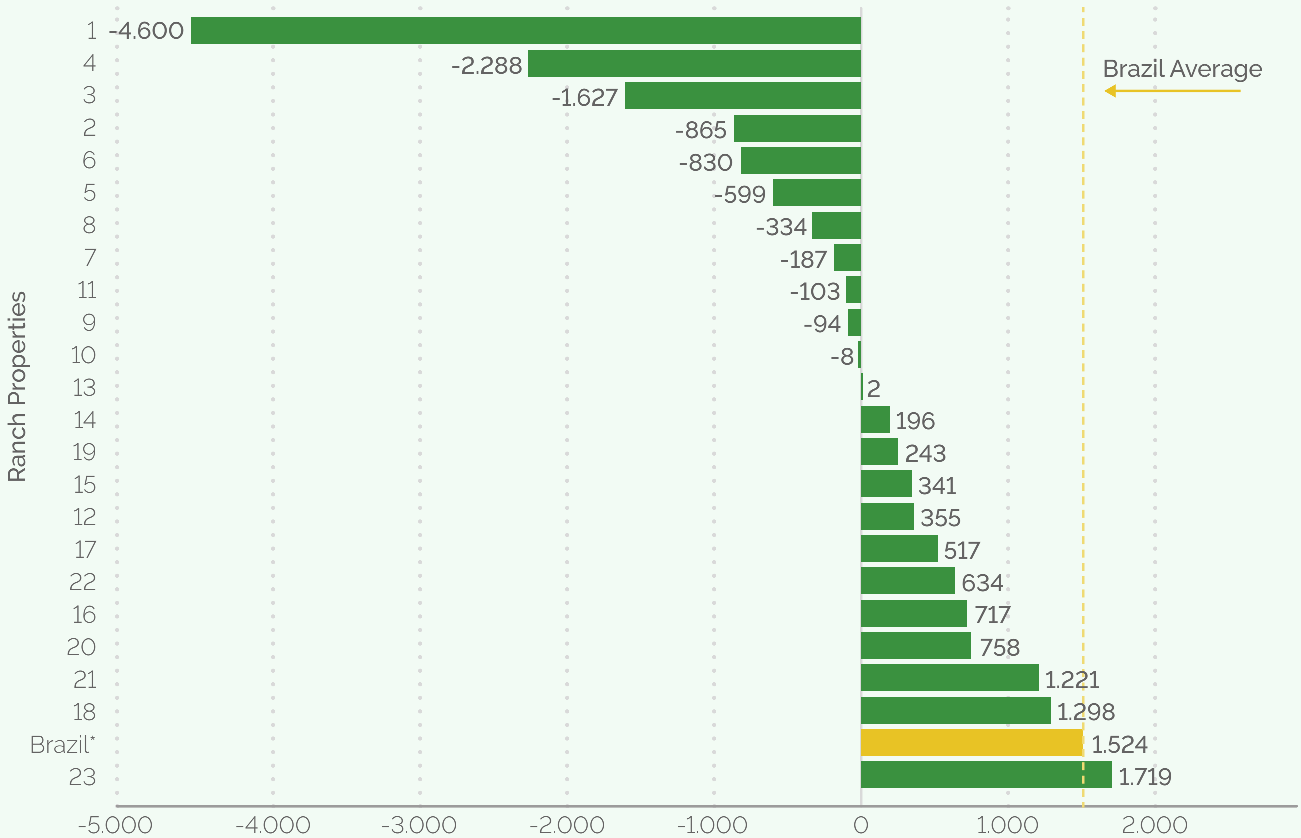
μ_{Br} = Average Brazilian emissions from cattle ranching, thousand head of cattle/year

$EF_{uf,T} \times \left(\frac{N_T}{10^6}\right)$ = Methane emissions from enteric fermentation, Gg CH_4/year

$\frac{\left(EFM_{uf,T} \times N_T\right)}{10^6}$ = CH_4 emissions from animal waste management by animal type, Gg CH_4/yr

N_T = Number of heads by animal type *T*

GRAPH 15 – Livestock Emissions per Thousand Heads of Cattle for Ranches Analyzed



Source: MCTI - Fourth national inventory of anthropogenic greenhouse gas emissions and removals,2020.

The national average for Brazil therefore corresponds to all national cattle emissions, as determined by herd size. Therefore, on average, Brazil emits 1,524 tons of CO_2e per thousand head of cattle. Of all the properties analyzed, only Ranch 23 emits more than the national average. The total amount of emissions from this property is 1,725 tons of CO_2e per thousand head of cattle. A decisive factor is the volume of animals in the herd, calculated for the analysis of the GHG emissions, which, even when added to a carbon removal strategy, is still large enough to render this production system an emitter. Most of the emissions of this property, about 92%, come from the enteric fermentation of cattle.

It is important to note that the GHG Protocol tool calculates emissions at a specific point in time, in this case for emissions that occur in a crop year. Therefore, the tool does not take into account the dynamics of the life cycle of methane, a gas with a short atmospheric lifespan. In other words, the tool considers only the methane emitted during the specific analysis period and does not represent the emissions removed from the atmosphere through the ac-

tual biogenic cycle[10] of the gas. Nevertheless, the tool takes into account all the removals that occur in the same period as the emissions analyzed, resulting in the balance of emissions and removals of the property.

An interesting observation is that of the 23 properties, 11 report negative emissions, in other words, for every thousand head of cattle on each of these ranches, CO_2e is removed rather than emitted. This is possible due to the existence of carbon mitigation practices that offset the herd's emissions. In addition, there are 3 properties in which the carbon removal is higher than the average observed in Brazil, i.e., more than 1,524 tons of CO_2e per thousand head of cattle. This means that these properties, in addition to removing the equivalent of their net GHG emissions, contribute to offsetting the average emissions of at least another thousand head of cattle. These resources enable producers to include reporting and mitigation of GHG emissions in their annual production strategies and planning.

We can therefore see the importance of determining the balance of GHG emissions of the analyzed properties, their respective sources of emission and removal within the boundaries of the property. We can also see the importance of the efforts made by the analyzed properties to use low-emission techniques and/or to remove carbon from the atmosphere. A number of them are able to offset their own emissions and contribute to the offsetting of emissions from other activities, not generated within their own operations, originating from outside their boundaries.

On a global scale, where the effects of climate change are already having a devastating impact, there is a greater focus on methane, and in particular on that emitted by Brazilian livestock. The emphasis of this work is to highlight the performance of these suppliers to Minerva Foods, which already stand out for their superior performance compared to the national average.

10 The biogenic methane cycle begins when plants capture carbon dioxide from the atmosphere through photosynthesis. These plants then serve as a food source for grazing animals. During the ruminant's digestive process, the ingested carbon is converted to methane gas, which is then released into the atmosphere by cattle. The methane remains in the atmosphere for 12 years before breaking down into carbon dioxide (CO_2) and water vapor (H_2O). The resulting CO_2 is recycled and returned to the cycle through photosynthesis. Thus, biogenic methane is derived from carbon dioxide (CO_2) in the atmosphere (PINTO et al., 2022).

05 CONCLUDING REMARKS

The Brazilian agribusiness is an economically representative sector, due to its agricultural aptitude, which places it in a globally prominent position in terms of food production, conferring to the country a key role in global food security. Ensuring food security has become a key issue for countries with different levels of economic development, whereby the agricultural sector plays a strategic role in improving the availability of these commodities.

The Brazilian agricultural sector is in a position to contribute to this agenda, as it has developed over the years and has shown that it is capable of expanding agricultural production without increasing the conversion of native vegetation and greenhouse gas emissions at the same rate. This achievement is a reflection of the availability of arable land, skilled labor and sustainable tropical techniques.

In addition to enhancing sustainability and productivity, these techniques, such as the restoration of degraded pastures, integrated production systems, no-till farming, and biological nitrogen fixation, make these systems more resilient to the effects of climate change. These practices also promote "land -saving effect," where production can be increased without opening up native vegetation to agricultural production.

These measures to reduce GHG emissions from agricultural activities have been stimulated at the federal level by plans aimed at sustainable agriculture, such as the Sector Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture, the ABC+ Plan, which aims to reduce carbon equivalent emissions in agriculture by 1.1 billion tons by 2030 and facilitates some aspects of this process by offering loans through the ABC Program, characterized by the financing of investments that contribute to the reduction of environmental impacts caused by agricultural and livestock activities.

It is important to understand the need for policies and incentives targeted at the rural producer. These policies should facilitate access to rural credit, technology transfer, and the expansion of technical assistance so that the producer is progressively able to increase agricultural productivity while reducing greenhouse gas emissions from their property.

With the current global discussions on food security, climate change and the reduction of greenhouse gas emissions, such initiatives are relevant. It is essential to expand food production in an increasingly sustainable manner. In this respect, the GHG Protocol for Agriculture and Livestock is a step forward, as it allows the producer to measure the emissions and removals generated by activities carried out within the boundaries of the operation, thus supporting decision-making. The tool uses methodologies and emission factors specific to the Brazilian reality, based on scientific studies, as a means of accounting for the emissions generated and evaluating the maintenance and/or implementation of mitigation technologies.

This type of control at the rural property level is effective in addressing issues raised

at the global level that have a direct impact on Brazilian agriculture. On the one hand, there is an expected increase in the demand for food due to the growing world population, which is expected to reach 9.7 billion people by 2050[11], and on the other hand, an increase in consumer and external market demands, which are already more rigorous and seek assurances of sustainable agricultural practices. These demands include global debates on carbon taxation at the border and carbon trading markets.

Therefore, the adoption of low-carbon technologies allows rural producers to respond to new patterns of global demand. This study demonstrates the adoption of these technologies by ranches located in three different regions of the country (North, Midwest, and Southeast) covering three different biomes (Cerrado, Atlantic Forest, and Amazon). The results indicate that despite the different soil and vegetation characteristics, the lasting effects of these technologies remain. For example, GHG emissions per thousand head of cattle were below the national average in 22 of the 23 cattle ranches analyzed. The fact that only one farm failed to achieve a lower GHG emission rate per livestock unit does not necessarily mean that there isn't some future emission reduction technology available for its production system. Climate targets and the growing demand for meat are driving the scientific search for technologies and innovations to reduce methane production in livestock without compromising productivity. This performance, as well as its monitoring, can benefit both producers and society. It can contribute to the protection of the environment, respond to the demands of consumers and prove to be suitable for this external market..

11 Source: https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

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APPENDIX

01 CALCULATION METHODOLOGY FOR THE AVERAGE EMISSIONS OF THE BRAZILIAN HERD PER THOUSAND HEAD

The following is the methodology used to calculate the average emissions of the Brazilian herd for each thousand head of cattle.

This average is determined by:

$$\mu_{Br} = \frac{\sum_{uf,T}\left(EF_{uf,T} \times \left(\frac{N_T}{10^6}\right)\right) + \sum_{uf,T}\frac{\left(EFM_{uf,T} \times N_T\right)}{10^6}}{\sum_T (N_T)} \quad (1)$$

Restructuring:

$$\mu_{Br} = \frac{\sum_{uf,T}\left(\frac{(EF_{uf,T} \times N_T) + \left(EFM_{uf,T} \times N_T\right)}{10^3}\right)}{\sum_T (N_T)}$$

Where:

μ_{Br} = Average Brazilian emissions from cattle ranching, thousand head of cattle/year

$EF_{uf,T} \times \left(\frac{N_T}{10^6}\right)$ = Methane emissions from enteric fermentation, Gg CH_4/year

$\frac{\left(EFM_{uf,T} \times N_T\right)}{10^6}$ = CH_4 emissions from animal waste management by animal type, Gg CH_4/year

N_T = Number of heads by animal type *T*

The first step to calculate the total emissions from the Brazilian herd was to first determine the emissions generated by **enteric fermentation**[12]:

12 Calculations were based on the methodology described in Volume 4, Chapter 10 of the IPCC Guidelines (2006 IPCC Guidelines for National Greenhouse Gas Inventories; IPCC, 2006; V.4, C.10, Livestock)

$$EmissõesFE = EF_{uf,T} \times \left(\frac{N_T}{10^6}\right) \qquad (2)$$

Where:

Emissions = Methane emissions from enteric fermentation, Gg CH_4/year

EF_T = Emission factor defined by animal category, Kg CH_4/head/year

N_T = Number of heads by animal category *T*

EMISSIONS FROM ANIMAL WASTE MANAGEMENT

CH_4 emissions

It was also necessary to determine the emissions from the **handling of animal waste**[13]. The equations take into account the animal population, percentage of use of each type of treatment, and climatic conditions. The equations used are:

$$Emissões\ CH_4 = \sum_{uf,T} \frac{\left(EFM_{uf,T} \times N_T\right)}{10^6} \qquad (3)$$

$$EFM_{uf,T} = \left(VS_{uf,T} \times 365\right) \times \left[B_{0,T} \times 0{,}67 \times \sum_S \frac{MCF_S}{100} \times MS_{uf,S,T}\right] \qquad (4)$$

Where:

Equation (3)

CH_4 emissions = CH_4 emissions from manure management by animal category, Gg CH_4/yr

EFM_T = emission factor defined by animal category, Kg CH4/head/year

N_T = number of heads per animal category *T*

Equation (4)

$VS_{uf,T}$ = Daily Volatile Solids excreted for T-category animals (Kg/*MS*/animal/day)

365 = Basis for calculating annual SV production (days/year)

$B_{o,T}$ = Maximum methane production capacity for manure produced by the animal category, m^3/CH_4/kg of VS excreted

0,67 = Conversion factor from m^3 CH_4 to Kg CH_4

13 Calculations were based on the methodology described in Volume 4, Chapter 10, of the IPCC Guidelines (2006 IPCC Guidelines for National Greenhouse Gas Inventories; IPCC, 2006; V.4, C.10, Livestock)

MCF_S = Methane conversion factors for each manure management system S by climate region K *(uf)* (%)

$MS_{uf,S,T}$ = Fraction of livestock category T manure handled using manure management system S in climate region K *(uf)*

Volatile Solids

$$VS_{uf,T} = \left[GE_{uf,T} \times \left(1 - \frac{DE\%}{100}\right) + \left(UE_{uf,T} \times GE_{uf,T}\right)\right] \times \left[\left(\frac{1 - ASH_{uf,T}}{18{,}45}\right)\right] \quad (5)$$

where:

$VS_{uf,T}$ = volatile solid excretion per day of dry matter (DM), kg SV/day

$GE_{uf,T}$ = gross energy intake, MJ/day

%DE = digestibility of feed in percentage (%)

(UE x GE) = urinary energy expressed as fraction of *GE*

$ASH_{uf,T}$ = the ash content of manure calculated as a fraction of *MS*

18,45 = conversion factor for dietary *GE* per kg of MS (MJ/kg). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock

N_2O Emissions

Methodology used to calculate nitrous oxide emissions from livestock manure handling is the same as that used to calculate methane emissions. The quantification of direct N_2O emissions from manure handling ($N_2O_{D(MM)}$) was done by multiplying the total N excretion (Nex_T) for each species/category of the herd (T), the total number of heads per category (N_T), which occurs in each type of manure management system ($MS_{T,S}$) by a specific emission factor for the type of management system used ($EF_{3,S}$), as shown below:

$$N_2O_{D(MM)} = \left[\sum_S \left[\sum_T \left(N_T \times Nex_T \times MS_{T,S}\right)\right] \times EF_{3,S}\right] \times \frac{44}{28} \quad (6)$$

$$Nex_T = Nrate_T \times \frac{TAM}{1000} \times 365 \quad (7)$$

$$N_2O_{G(MM)} = \left(N_{volatilization-MMS} \times EF_4\right) \times \frac{44}{28} \quad (8)$$

$$N_{volatilization-MMS} = \sum_S \left[\sum_T \left[\left(N_T \times Nex_T \times MS_{T,S}\right) \times \left(\frac{FRAC_{GasMS}}{100}\right)_{T,S}\right]\right] \quad (9)$$

Animal *N* excretion (Nex_T) was estimated using Equation 6, which requires data on daily *N* excretion rate ($Nrate_T$) and live weight *(TAM)* for each herd category considered in the Inventory.

During manure management, *N* losses by volatilization can occur, and the volatilized *N* can be deposited elsewhere, generating N_2O, emissions, or indirect emissions. The calculation of indirect emissions ($N_2O_{G(MM)}$) was performed by Equation 8, following Tier 1. It was necessary to estimate the amount of *N* volatilized ($N_{volatilization\text{-}MMS}$), calculated by Equation 9, using default values for the fraction of *N* in the managed manure that was volatilized ($Frac_{GasMS}$) for each type of handling for each herd category.

MAKEUP OF THE NATIONAL HERD

In order to determine the methane and nitrous oxide emissions from enteric fermentation and animal waste management it is necessary to classify the cattle population. The cattle population can be divided into beef cattle - pasture and confined - and dairy cattle. The main database used is the ANUALPEC, 2021 for beef cattle herd, confined cattle and dairy cattle.

A mapping was made between the categories of beef cattle of ANUALPEC (T_A) and the categories of the IV National Inventory (*T*). This mapping is important to maintain the consistency of the results of this study with other publications in the area, such as the IV National Inventory. Therefore, for the beef herd, we used the *T*-categories consisting of the following animals: bulls, under 1 year old, between 1-2 years old, females over 2 years old, males over 2 years old. Once this mapping had been carried out, the shares of each animal category in the state's 2020 ANUALPEC cattle herd were established. These shares were applied to the total ANUALPEC cattle herd. Thus, we have the beef herd defined by animal category (*T*).

The next step was to determine the confined cattle herd. This data was obtained directly from the ANUALPEC database. Thus, we have the confined cattle herd defined by animal category (*T*) where *T = {conf}*.

For the dairy cattle herd, information from the IBGE's Pesquisa Pecuária Municipal (Municipal Livestock Survey) was combined with data from ANUALPEC. The first step was to identify the total number of dairy cows (heads) and milk production (thousand liters) at the municipal level. In line with the methodology of the IV national inventory, a threshold of 2,000 liters/head/year was established to determine the classification between high or low milk production. Therefore, productivity greater than or equal to the threshold is classified as high production. At the end of this step, using the PPM-IBGE data, it was possible to define the dairy cattle herd by animal category (T), where *T = {alta, baixa}*. The following step determined the state parcels by category in the PPM-IBGE database. These plots were used for the disaggregation of the dairy cattle herd data from ANUALPEC. Thus, the dairy cattle herd is defined by animal category (T) where *T = {alta, baixa}*.

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