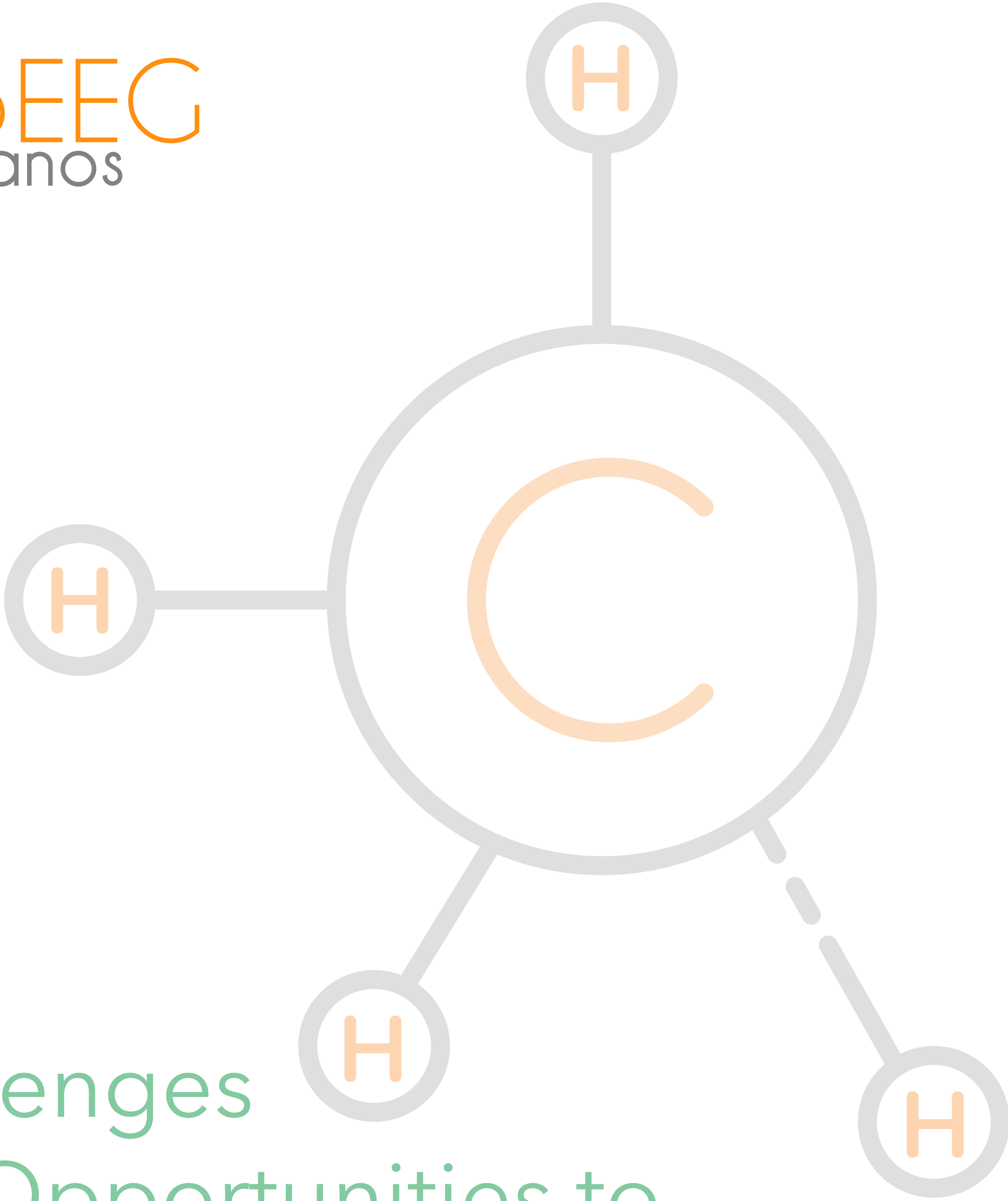
10 SEEG anos



Challenges and Opportunities to **Reduce Methane Emissions** in Brazil

Climate Observatory 20 years

2022

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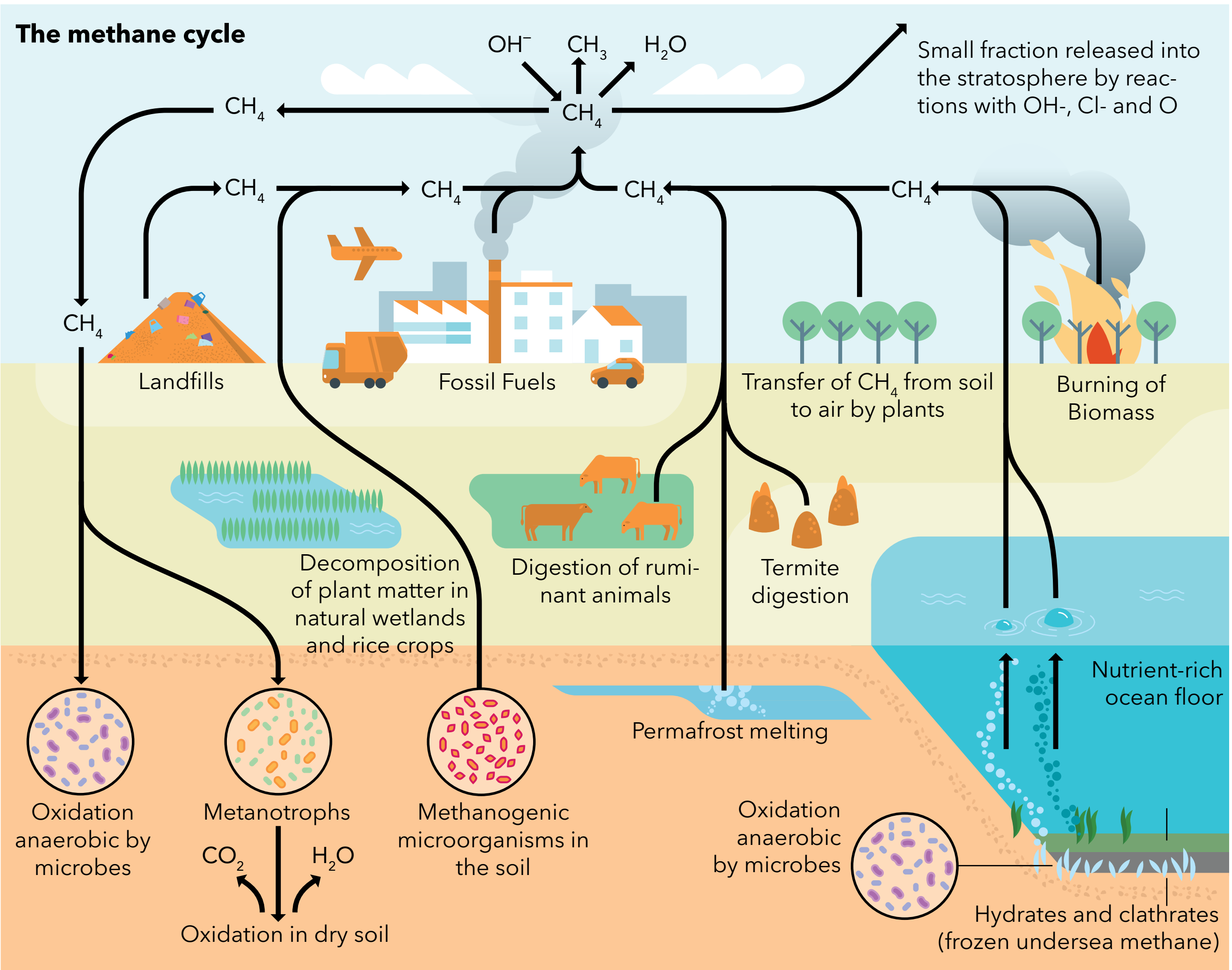
Executive summary

- Methane (CH4) is a powerful greenhouse gas and the second largest contributor to global warming. **Each ton of methane has 28 times more potential to warm the planet in a hundred years than one ton of carbon dioxide** (CO_2), the biggest cause of the climate crisis.
- **The atmospheric concentration of methane has more than doubled since pre-industrial times**. Fortunately, it is much lower than that of CO_2 - it is measured in parts per billion of air rather than parts per million, as is the case with carbon dioxide. Methane also lasts less time in the atmosphere, approximately 12 years, compared to 150 years for CO2. Hence it is classified as a short-lived climate pollutant (SLCP).
- Methane also contributes to the formation of tropospheric ozone (O3), which, like it, is a short-lived but powerful greenhouse gas. So-called surface ozone is also an air pollutant with harmful effects on human health, ecosystems and agriculture.

Figure I. The methane cycle



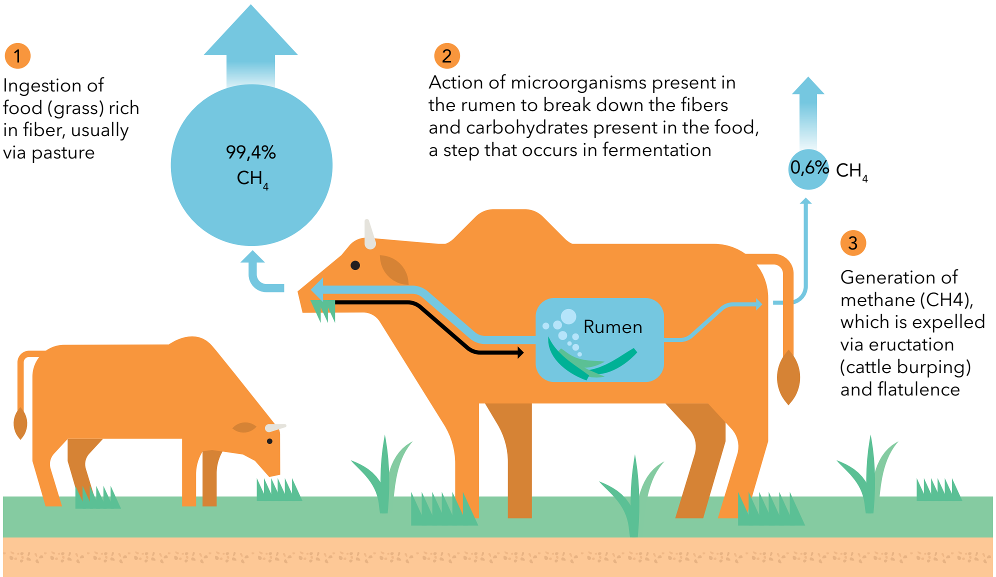
- Global methane emissions reached 364 million tonnes in 2020, representing 10 billion tonnes of CO_2 equivalent, or 16% of global greenhouse gas emissions in CO_2e. **Half of the net increase in global temperature seen today is due to CH_4.**
- This high warming potential and shorter duration in the atmosphere make methane a good target for policies to immediately reduce greenhouse gas emissions that help humanity gain time to make the energy transition to an economy without fossil fuels and, thus keeping alive the Paris Agreement target of limiting the Earth's warming to 1.5°C compared to the pre-industrial era.
- At COP26 in Glasgow, Scotland, over 100 countries signed the Global Methane Pledge, committing **to reduce methane emissions by 30% by 2030 compared to 2020 levels.** This puts pressure on countries and scientists to understand the most important patterns, causes and mitigating factors if this target is to be met.
- **Brazil is the fifth largest emitter of methane in the world.** It alone emits the equivalent of 5.5% of the planet's methane, while the country's share in overall greenhouse gas emissions is 3.3%. Brazilian emissions in 2020 were estimated by the Climate Observatory at 21.7 million tons in 2020, which corresponds to 565 million tons of CO_2 equivalent ($MtCO_2e$) or 26% of the country's total greenhouse gas emissions.
- The member organizations of SEEG, the Climate Observatory's Greenhouse Gas Emissions Estimating System, made the **first estimate of the trajectory of national methane emissions and proposed a target for Brazil.** According to OC calculations, if no policy is adopted, the country will reach 2030 emitting 23.2 million tons, a 7% increase compared to 2020.
- On the other hand, by applying existing best practices and technologies that can be implemented by 2030, 13.75 $MtCH_4$ emissions are achieved in 2030, which represents a 36.4% reduction from the 2020 emissions. This is equivalent to a reduction of 180 $MtCO_2e$ comparing 2020 and 2030.
- Thus, we propose that Brazil adopt **a goal of reducing its methane emissions by 36% by 2030 when compared to 2020**, this being a significant contribution of the country to the Global Commitment to Methane goal of a 30% reduction of methane emissions by 2030.

Methane emissions in Brazil:

Agriculture

- **The agricultural and livestock sector is the largest emitter of methane in Brazil**, responsible for 14.54 million tons in 2020, or 71.8% of emissions.
- Agricultural activity accounts for 91.6% of the sector's emissions (13.32 Mt CH_4), resulting mainly from enteric fermentation of the cattle herd (the "burp" of the ox), followed by the management of animal waste (0.85 Mt CH_4) with 5.8%. Agricultural activity has 2.6%, resulting from the cultivation of irrigated rice (0.37 Mt CH_4) from the burning of sugar cane waste (0.008 Mt CH_4).

Figure II.
Methane emission by enteric fermentation



- Emissions from irrigated rice cultivation have increased by increasing the area cultivated under irrigated production systems and the type of management of flooding of these areas. At the same time, productivity increased by more than 70% between 1990 and 2020.
- To promote the reduction of methane by enteric fermentation with continuous productivity increase and meeting the demand for livestock products, mitigation strategies have been proposed for beef and dairy cattle herds through the adoption of intensive finishing (IT), animal genetic improvement (AMM), rumen fermentation manipulation, and animal diet improvement.
- For the emissions from animal waste management, the mitigation strategy was based on the replacement of less efficient waste treatment systems with more efficient technologies, with lower methane generation by the treatment system and waste conditioning, such as the use of digesters and composting by the cattle and pig herd.
- The proposed strategy for irrigated rice crop emission is based on the best management of pre-planting soil preparation and with irrigation management, without the cultivated areas remaining constantly flooded.
- For the burning of sugarcane residues, the strategy was based on the adoption of the mechanized harvesting practice, which has already reduced emissions from this activity by 80% in the last decades.
- With current management practices and emissions trends in recent years, it is expected that in 2030 the sector's emissions will increase by 5.6%, reaching 15.37 Mt CH_4. **With the adoption of these mitigation strategies for livestock and agricultural activity, up to a 30% reduction in emissions** can be obtained, reaching an achievable emission of 10.17 Mt CH_4.

Waste

- **The waste sector is the second largest emitter of CH_4 in Brazil,** responsible for 15.8% of the emissions in 2020 (3.17MtCH_4).
- The largest contribution (66.6% of total emissions) comes from the final disposal of solid waste. Domestic wastewater treatment is in second place with 26%. Industrial wastewater treatment (6.2%), incineration and/or open burning (1.2%) and the biological treatment of solid waste (0.04%) together account for about 7.5% of the remaining methane emissions from the sector.
- The main mitigation strategies for the waste sector can be achieved with a significant number of low and medium-cost strategies since most technologies are already available for use on an economic scale.
- The solutions with the greatest reduction potential are directed at solid waste through the gradual reduction of organic waste in landfills, recovery or flaring of at least 50% of the biogas generated by landfills, and the eradication of landfills. For wastewater treatment, increasing the utilization rate of biogas from sewage treatment plants also has great potential for cutting emissions.
- The SEEG has estimated that **if no mitigation strategy is adopted, CH_4 emissions in the waste sector are expected to rise 25.8% by 2030**. If measures consistent with the national legislative framework for waste were adopted, a reduction of 6.5% could be achieved, **and the reduction potential of about 36% could be reached with more ambition in the proposed mitigation strategies.**

Land use change and forests

- Land use change, especially slash and burn, represents 9% of the national total of methane emissions, or 2.71 million tons. Another 620 thousand tons come from fires not associated with deforestation, which are not computed in the national inventory.
- **The Amazon leads the emission of CH_4 in this sector,** for being where most deforestation occurs and for containing the largest carbon stocks.
- The SEEG also estimated methane emissions in reservoirs of hydropower plants. The exercise resulted in a CH_4 estimate of 1.55 Mt/year, which is probably an underestimate since it does not consider all the processes that occur within the reservoirs and that can generate emissions.
- Combating deforestation plays a central role in reducing the fires associated with the opening of new areas and, in this context, we proposed a goal of zero deforestation with evidence of illegality by 2028 as a way to reduce methane emissions.
- Considering that part of the burning in crop and pasture areas is a cultural practice, we proposed as a goal only the elimination of burning in natural areas.

Energy

- **The energy sector emitted, in 2020, 572 thousand tons of methane, corresponding to 2.6% of the country's emissions.** Industrial processes and product use represent another 0.2%, bringing the emissions of the two sectors to almost 3% of the national total.
- Two major emission sources stand out: the burning of firewood and the exploration and production of oil and natural gas.
- Firewood is used mainly in households for cooking food, reflecting the lack of access to other energy sources. In the 1970s and 1980s, there was a large reduction in the consumption of firewood (and emissions) with the spread of gas stoves. From the 1990s on, we see the stagnation of firewood consumption and methane emissions at a level close to half of what was observed in the early 1970s.
- Replacing the use of firewood with modern gas or electric stoves reduces methane emissions and increases the users' quality of life. The use of modern wood-burning stoves with controlled burning is also an alternative, which does not generate indoor air pollution. There is also the alternative of using electric stoves, which, combined with a low-carbon electricity matrix, can further reduce emissions.
- Fugitive emissions are the result of intentional and unintentional discharges of gases from the production processes of coal, oil and natural gas. Among them, currently, the highlight are the emissions from oil and natural gas exploration. These emissions were boosted by the discovery of the pre-salt in the 2000s.
- Recently the oil and gas industry globally has announced efforts to control such emissions, one example being the Aiming for Zero Methane Emissions Initiative launched in March 2022. The initiative calls for the elimination of virtually all methane emissions from oil and gas assets operated by signatories by 2030.
- The study's scenario exercise points out that **Brazil can reduce its methane emissions by 32% between 2020 and 2030. And by 2050, a 63% reduction could be achieved.**

Proposal for Reducing Methane Emissions by 2030

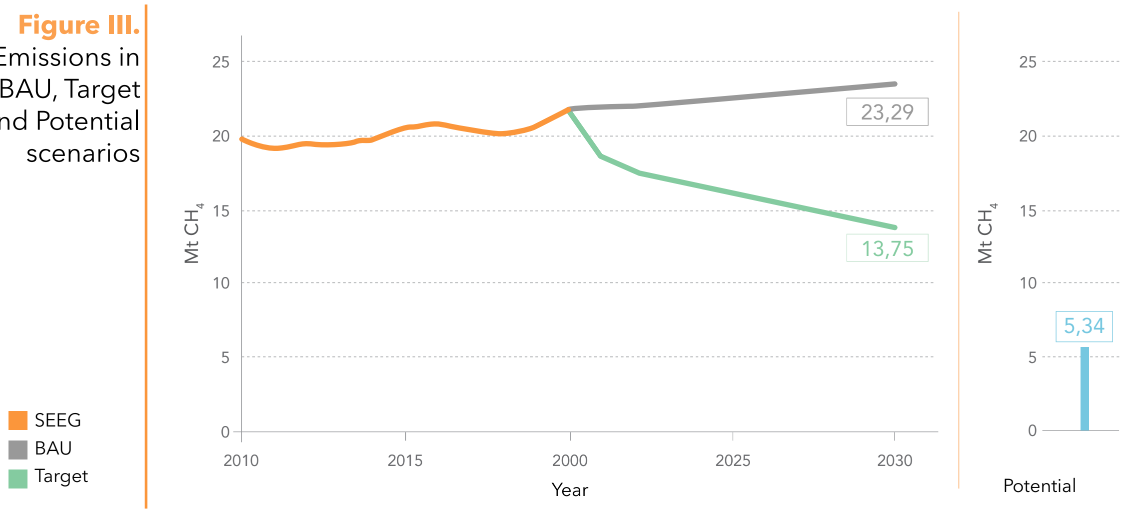
We evaluated three scenarios for methane emissions

(i) The path of methane emissions in Brazil up to 2030 considering current mitigation policies in the country (BAU);

(ii) The potential for reducing methane emissions in Brazil in the long term;

(iii) A proposed emissions reduction target achievable by Brazil by 2030 2030 in a manner compatible with the Global Commitment on Methane target of 30% emissions reduction compared to 2020.

Figure III. Emissions in BAU, Target and Potential scenarios



By aggregating the values from the analyses of each of the four sectors (agriculture and cattle ranching; land use change and forestry; waste treatment; and energy*), we obtain for the **BAU scenario** a 23.3 MtCH4 emission in 2030 with a 7% growth in emissions compared to the 21.7 MtCH4 in 2020 (Figure 33).

As for the **Potential Reduction Scenario**, we have an emission of 5.3 MtCH4, which represents a 75% reduction in emissions compared to 2020. That is, with the known technologies it is not possible to zero the methane emissions. It would be necessary to use compensations with carbon equivalent removal to zero residual emissions.

Finally, applying the best practices and existing technologies that can be implemented until 2030, we obtain the emission of 13.75 MtCH4 in 2030, which represents a reduction of 36.4% in relation to emissions in 2020. This is equivalent to a reduction of 180 MtCO2e comparing 2020 and 2030.

Thus, we propose that Brazil adopt **a goal of reducing its methane emissions by 36% by 2030 when compared to 2020**, this being a significant contribution of the country to the Global Commitment to Methane goal of a 30% reduction of methane emissions by 2030.

To achieve this goal it is necessary, among other practices, to zero illegal deforestation and the fire associated with it, to reduce the use of firewood for cooking, to control fugitive emissions from the oil and gas industry, to recover at least 50% of all methane generated in landfills, to expand methane recovery from animal waste treatment, to achieve 30% intensive finishing of beef cattle, to convert 75% of rice cultivation to advance preparation, and to cut by half the practice of burning sugarcane straw that still exists.

This goal can be achieved through regulatory policies, capacity building and economic incentives in the public and private sectors.

* The Industrial Processes and Product Use sector was not addressed in this exercise due to its relatively low contribution to national methane emissions (0.22% in 2020, according to SEEG data).

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1 Introduction: Understanding Methane Emissions

Methane (CH_4) is a powerful greenhouse gas. Its potential global warming effect over 100 years (GWP-100) is equivalent to 28 times that of carbon dioxide (CO_2), i.e., one ton of methane is equivalent to 28 tCO_2e (GWP-100 equivalent tons of carbon dioxide)[3].

The atmospheric concentration of methane has more than doubled since pre-industrial times (Nisbet et al., 2019). This gas is second only to carbon dioxide in changing the Earth's climate during the industrial era (Myhre et al., 2013). Methane is a short-lived climate pollutant (SLCP) with an atmospheric lifetime of approximately 12 years (Unep, 2021). Methane also contributes to the formation of tropospheric ozone (O_3), which, like it, is a short-lived but potent greenhouse gas. So-called surface ozone is also an air pollutant with harmful effects on people, ecosystems, and crops.

While it is not directly hazardous to human health, it indirectly affects agricultural productivity through ozone and climate change. Recent studies have found that these health consequences and agricultural damage (Shindell et al., 2019) are greater than previously believed. These new studies include the finding that tropospheric ozone may have much larger impacts on public health, particularly deaths from respiratory and cardiovascular disease (Turner et al., 2016). In addition, the understanding of the effect of methane on radiative forcing has recently improved, leading to an upward revision since the Fifth Assessment Report Intergovernmental Panel on Climate Change (IPCC) (Collins et al. 2018; Etminan et al. 2016).

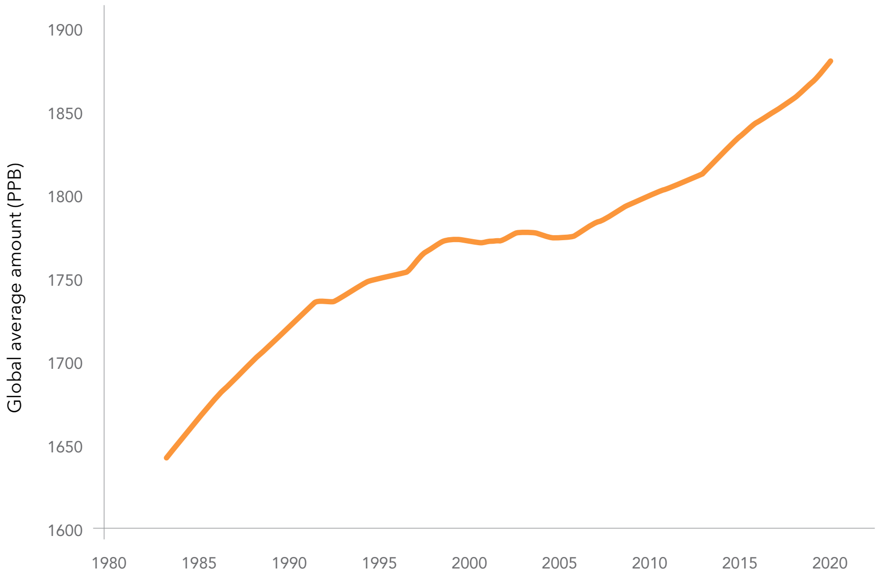
1.1. The evolution of methane concentration in the atmosphere

Observations of atmospheric methane content exhibit a pattern of increase from 1982 until 2000, a period of stabilization between 2000 and 2007, and a further increase from 2007 onwards (Turner et al. 2019).

Large uncertainties are associated with the reasons behind this pattern, but there are indications that the burning of fossil fuels is not responsible for this more recent increase in methane, as the methane isotope content related to these sources does not follow the increase (Lan et al., 2021). Thus, methane sources unrelated to the burning of fossil fuels are suspected to be responsible for the most recent rise. However, it is unclear whether these are natural variations, which are large on annual scales, whether they are caused in part by El Niño, or whether they are caused by a positive feedback mechanism between climate changes that have already been occurring (Turner et al., 2019).

[3] The Global Warming Potential (GWP) is calculated and published in the Assessment Reports (AR) of the IPCC (Intergovernmental Panel on Climate Change). The last assessment report - AR6 considers the average of 28 tCO_2e but presents the specific values for methane of fossil origin (29.8) and non-fossil origin (27.2).

Figure 1.
Global average amount of methane (1984-2019), parts per billion



source: Ed Dlugokencky, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends_ch4/)

At COP26 in Glasgow, Scotland, over one hundred countries signed the Global Methane Pledge[4] and committed to reducing methane emissions by 30% by 2030 (based on 2020 levels). This puts pressure on countries and scientists to understand the most important patterns, causes and mitigating factors if this target is to be met.

1.2 Share of methane in greenhouse gas emissions

Global methane emissions reached 364 million tons in 2020 (Unep, 2021) which represents 10 $GtCO_2e$ (GWP AR5) or 16% of global GHG emissions in CO_2e.

Brazil's methane emissions in 2020, meanwhile, were estimated by the SEEG to be 20.2 million tons in 2020, corresponding to 565 $MtCO_2e$ or 26% of the country's total GHG (greenhouse gas) emissions.

While in total Brazil represents 3.3% of global GHG emissions, in the case of methane the country represents 5.5% of global emissions.

5,5%

of global methane emissions come from Brazil

1.3. What generates methane emissions

There are natural and anthropogenic sources of methane. Among the natural ones are volcanic activity, the decomposition of organic material (especially under anaerobic conditions), the digestion process of herbivorous animals (especially ruminants), and the burning of native vegetation and agricultural areas.

More than half of global methane emissions, however, derive from human activities such as agriculture and cattle ranching (40% of anthropogenic emissions), burning of fossil fuels (35%), and waste management (20%)5.

[4] https://www.globalmethanepledge.org/
[5] UNEP – Global Methane Assessment - pg 6 - https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

1.3.1. Agriculture

Methane is the main gas emitted by the agriculture and cattle ranching sector, and its emission sources can be classified according to the productive activities of livestock and agriculture. In livestock, emissions result from livestock and the way animal waste is managed, with their emissions accounted for by the subsectors enteric fermentation and animal waste management, respectively. In agriculture, emissions occur due to the forms of land use and management of irrigated rice, sugar cane, and herbaceous cotton crops. The rice cultivation subsector accounts for methane emissions from rice production under continuous and intermittent irrigation. For sugarcane and herbaceous cotton, the emission is due to the burning of agricultural waste, measured by the subsector of the same name (MCTI, 2020a).

ENTERIC FERMENTATION

Methane gas is a byproduct of enteric fermentation, a process that occurs in the digestion performed by herbivorous animals (IPCC, 2006), in which the cellulosic carbohydrates present in the cell walls of plants are ingested and decomposed by an anaerobic process by the microorganisms present in the digestive system of these animals. As a result of this process, methane is expelled mainly by eructation (burping), in addition to respiration and through the anus (Martin et al., 2010).

The amount of methane released depends on the type of digestive system of the animals. Ruminant animals, such as cattle, buffalo, goats, sheep and camelids, have a stomach divided into four compartments, including the rumen, an organ capable of digesting the cellulose present in their food. Ruminants are more emitters than non-ruminants, those who do not have the rumen, precisely because they digest the food for longer and extend the enteric fermentation process (IPCC, 2006). About 95% of the methane produced by ruminant animals is emitted via eructation. Of the remaining 5%, approximately 89% is emitted through respiration and 11% through the anus (MCTI, 2020b).

95%

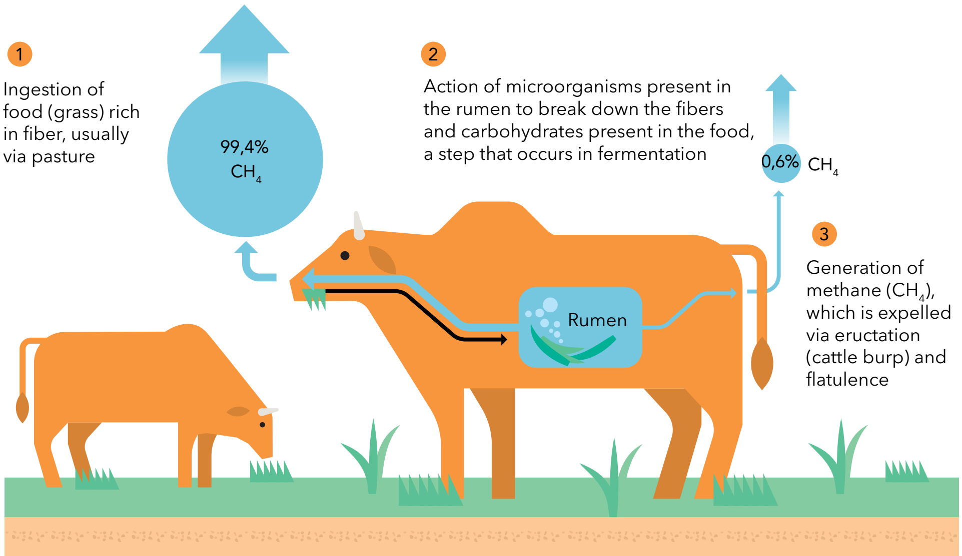
of the methane produced by ruminants is eliminated by eructation ("burping")

The microorganisms present in the rumen ferment the carbohydrates present in cellulose, producing volatile fatty acids (VFA), which ensures more than 70% of the energy needs of the animal. This VFA production results in the production of hydrogen (H2), which is eventually converted into methane by methanogenic microorganisms (Vijn et al., 2020).

Non-ruminant animals, such as horses, mules, donkeys and pigs, are monogastric and methane generation is done in the cecum, part of their digestive system capable of digesting cellulose (MCTI, 2020b).

In addition to the type of animal, variables such as sex, age, weight and its diet, considering the type of food, quantity and quality, also influence methane emissions. For this, only herds under domestic management are accounted for in the calculation of methane emissions from these animal populations (IPCC, 2006).

Figure 2.
Route of methane emission by the animal digestive process in which enteric fermentation occurs.



MANAGEMENT OF ANIMAL WASTE

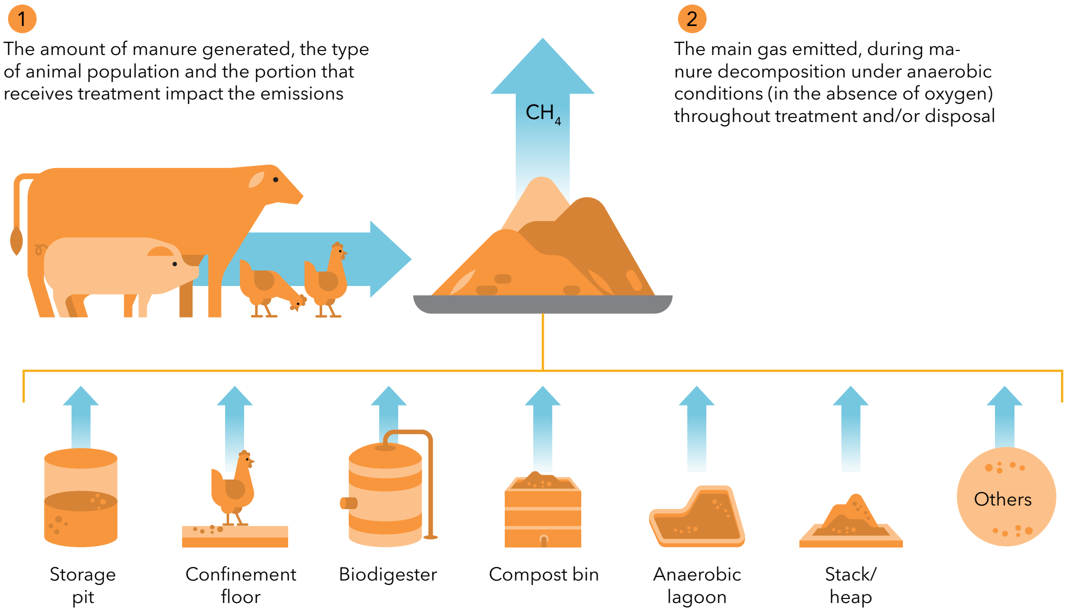
Also in livestock farming, the different types of animal production systems generate methane emissions due to the type of manure management generated throughout the life cycle of livestock (Costa Junior et al., 2013).

Methane is the gas emitted in greater quantity by the management of manure, resulting from the steps of the treatment processes. There is also, to a lesser extent, the emission of nitrous oxide, which occurs directly and indirectly during the treatment and disposal stages. The direct emission of nitrous oxide is associated with the duration of storage and treatment of manure, in which the process of nitrification (oxidation of ammonia into nitrite and then into nitrate) and denitrification (conversion of nitrate into nitrogen gas) occur, along with the nitrogen and carbon content of the manure. Indirect emissions, on the other hand, are due to the treatment time and temperature at which they occur, with nitrogen loss due to its volatilization, largely in the form of ammonia and nitrogen oxides (MCTI, 2020c). The methane emissions generated by manure are associated with the amount produced and the portion that decomposes anaerobically (IPCC, 2006).

Manure management involves the form of collection, storage, type of treatment and possible forms of use by the sector itself. In Brazil, animals are usually kept in pastures and areas such as corrals, sheds and stables, where the waste is deposited and managed to only then be used in agriculture or remain in the pasture itself. The management and treatment of waste can be focused on the solid or liquid part, with the use of anaerobic lagoons, anaerobic digesters, solid storage in open-air piles, storage pits at the site of generation or outside, composting and with the presence or absence of a waste collection bed for poultry (MCTI, 2020c).

In general, the retention period of this manure and the temperature at which they operate influence the amount of methane emitted, with solid management systems emitting less due to their decomposition occurring in a less anaerobic environment, as in the case of manure deposited in pastures (IPCC, 2006).

Figure 3.
Methane emission pathway by the adoption of different types of animal waste management systems.



IRRIGATED RICE FARMING

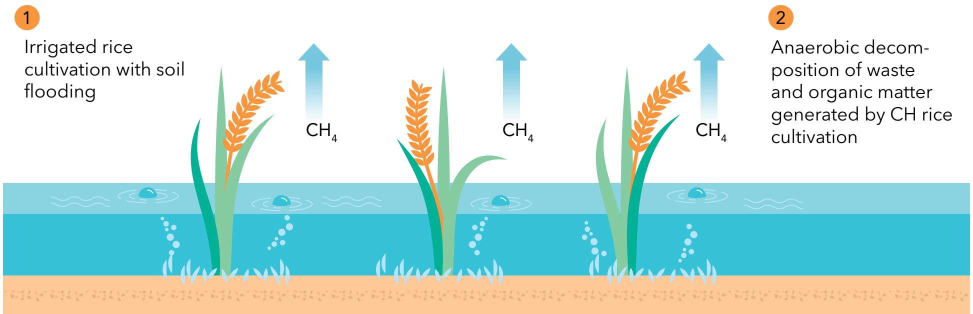
Methane emission in rice production is generated by the anaerobic decomposition of organic matter in irrigated systems where soil flooding occurs. The amount of methane emitted is linked to the size of the cultivated area, as well as the time and type of irrigation, and the way the soil is prepared before cultivation. Rice production also generates nitrous oxide emissions through the conversion of nitrogen present in the soil by microorganisms and the decomposition of its agricultural waste, and only the emission from its waste is accounted for in the Managed Soils subsector (IPCC, 2006).

92%

of rice production in Brazil is by irrigated system

In Brazil, about 92% of rice production is by the irrigated system, representing 77% of the total rice growing area. The rest is produced without flooding the soil, which does not generate methane emissions (Embrapa Rice and Beans, 2022). Out of the different types of irrigation, continuous soil flooding predominates, representing almost all of the irrigated areas. In addition, there is intermittent flooding with single aeration (irrigation followed by soil drying) and with multiple aerations (MCTI, 2020d).

Figure 4.
Pathway of methane emission by irrigated rice cultivation in the flooded system.

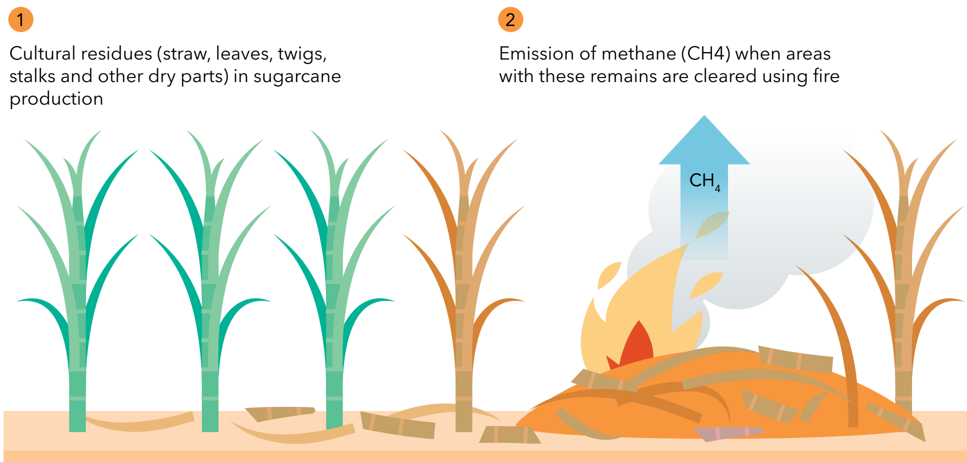


BURNING OF AGRICULTURAL RESIDUES

Agricultural residues are mainly composed of straw, leaves, sticks, stalks and other dry parts of the biomass of the crop produced and with no economic value. Methane emissions are generated from the use of fire as a means of managing this waste, with its burning varying according to the type of crop and the model of agricultural practice used (IPCC, 2006).

The burning of agricultural residues has the purpose of facilitating the cleaning of the field and the harvesting of the crop, in addition to the phytosanitary effect by preventing and combating possible pests and diseases. Despite these facilities, the combustion of this waste is responsible not only for the emission of methane, but also for other gases such as nitrous oxide (N_2O), nitrogen oxides (NOx), and carbon monoxide (CO), in addition to effects on air quality, directly affecting public health. In Brazil, the emissions from sugar cane and cotton crops are accounted for. For sugarcane, the use of fire is mainly associated with areas where manual harvesting still occurs, with burning still being carried out before the harvest. As for herbaceous cotton, burning was performed mainly for pest control, a practice that was extinguished with the modernization that the sector went through in the 1990s (MCTI, 2020e).

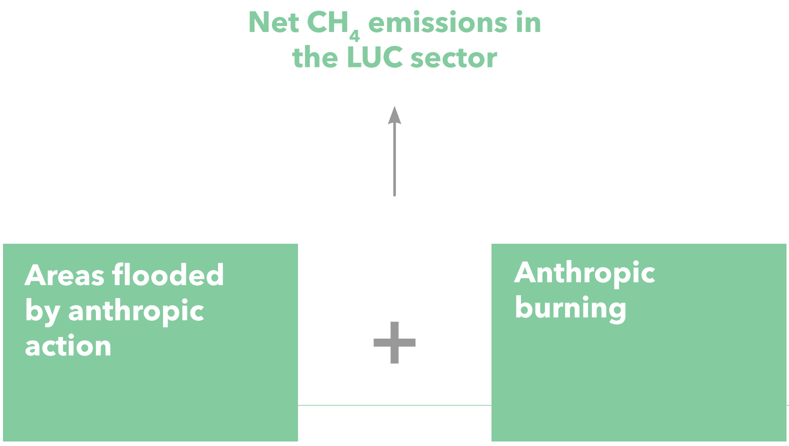
Figure 5.
Methane emission pathway through the practice of burning sugarcane agricultural residues.



1.3.2. Land use change and forests

Methane emissions related to the land use change and forestry sector come from the decomposition of organic matter in anoxic (oxygen-free) environments by methanogenic microbiota found in wetlands, lakes, and reservoirs (Moore & Knowles, 1989), and from the burning of organic matter associated with land use (Koppmann et al., 2005). Wetlands include peatlands and flooded forests and grasslands, and the emissions that occur in these environments are natural sources of methane (Watson et al., 2000); emissions caused by the damming of rivers and the formation of artificial reservoirs are caused by human action (IPCC, 2019). Similarly, fires can be anthropogenic or natural, especially in biomes such as the Cerrado and Pantanal in Brazil. To account for the anthropogenic component of CH_4 emissions, therefore, it would be necessary to quantify net emissions related to anthropogenic activities, discounting those methane emissions that occur naturally both in wetlands and wetlands and in burned areas.

Figure 6. Anthropogenic components of methane emissions in the Land Use Change and Forestry sector.



WETLANDS

The greatest uncertainties in the global atmospheric methane balance are related to wetlands, as emissions in these places have a dynamic that is still poorly understood. Without understanding how the natural dynamics happen, it is hard to understand what part is the consequence of the methane balance of anthropogenic changes in ecosystems. However, it is known that land use changes alter the microbial communities in wetlands and can turn them into methane sources. In general, the drainage of wetlands favors CO2 emissions, while the flooding of previously non-flooded areas promotes CH4 emissions (Pangala et al., 2017).

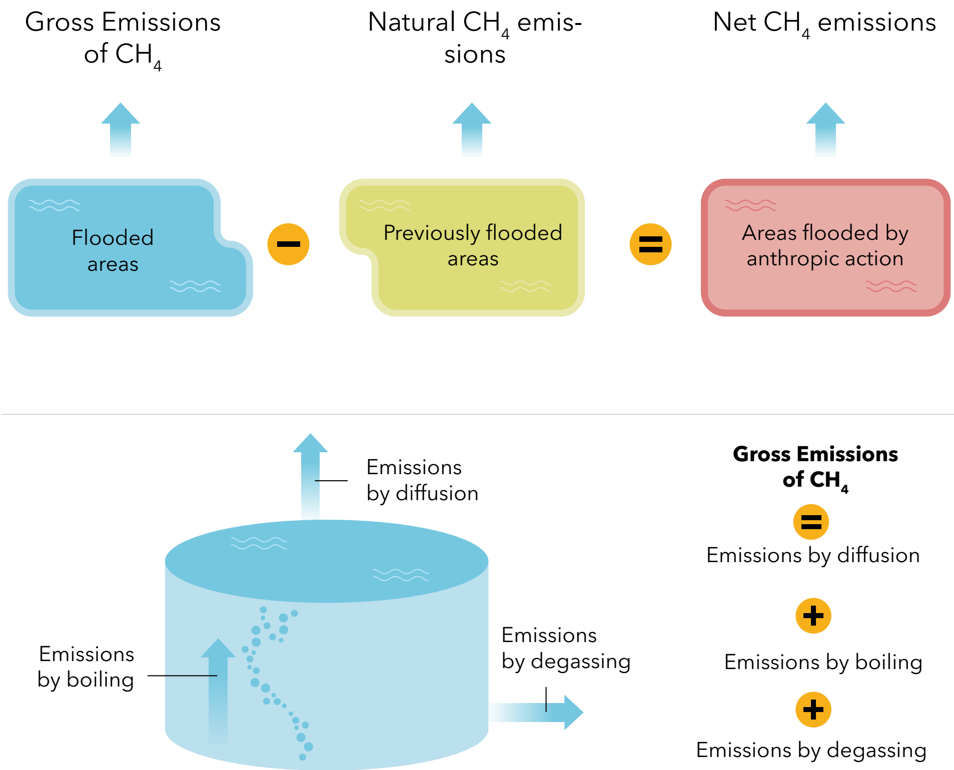
RESERVES

Hydroelectric power plants (HPPs) and their reservoirs can significantly emit carbon dioxide and methane, and some studies have shown that hydropower plants can pollute more than gas, oil, and coal-fired plants (De Faria et al., 2015). Methane emissions occur due to the flooding of large amounts of carbon stock in vegetation and organic matter in the soil, which will decompose in an anoxic environment after the dam is filled.

Methane emissions in hydroelectric reservoirs can occur in three ways (IPCC, 2006):

1. By molecular diffusion through the air-water interface at the lake surface;
2. By boiling, in the form of bubbles that rise from the sediment deposited on the bottom of the reservoir and go directly up the water column;
3. By degassing, which consists of molecular diffusion between air and water in an accelerated manner, caused by the passage of water through the turbines.

Figure 7. Sources of methane in wetlands and accounting for the anthropogenic component of emissions; and mechanisms related to emissions in artificial reservoirs.



However, there is controversy about the role of reservoirs of large hydropower plants (HPPs) for methane emissions (Dos Santos et al., 2017; Fearnside, 2013). Studies comparing diffusion emissions at the surface of reservoirs have concluded that methane emissions at hydropower plants are almost always lower than emissions generated by thermal power plants (Rosa et al., 2004). Fearnside (2013; 2015), on the other hand, discusses that not considering emissions generated by boiling (bubbles produced at the bottom of the reservoir) and especially by the passage of water through the turbines (degassing) can greatly underestimate emissions, which had already been indicated by other studies (Kemenes et al., 2007). In fact, the largest and longest study of methane emissions at a tropical hydroelectric plant, Petit Saut in French Guiana, indicated significant methane emissions, especially from the degassing process in the turbines (Demarty & Bastien, 2011).

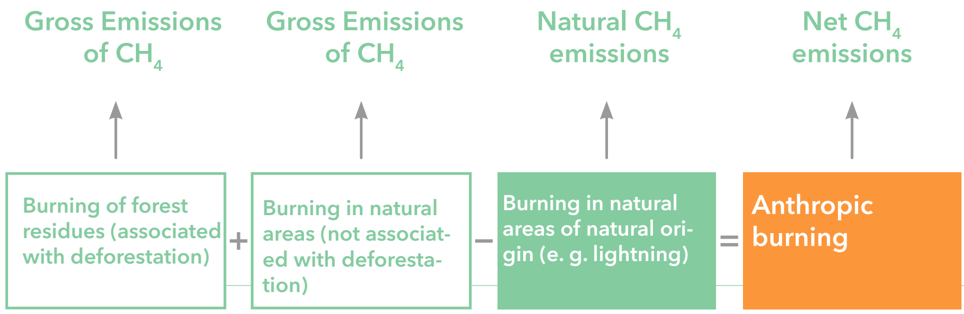
Furthermore, methane remains in the atmosphere on average about one-tenth the time of CO2 (Myhre et al., 2013). Consideration of the appropriate time window for comparing emissions in reservoirs with emissions from the burning of fossil fuels is therefore essential. The longer the time horizon used for comparison, the lower the impact attributed to hydroelectric dams as besides a lower half-life in the atmosphere, methane emissions from reservoirs decay over time (Fearnside, 2016) and after about a decade will stabilize and remain equivalent to the amount of organic matter continuously entering the system (Demarty & Bastien, 2011).

BURNING

Another source of methane emissions related to the land use change and forestry sector is the burning of organic matter. These emissions are more easily calculated and depend on specific emission factors for each type of vegetation and on the local carbon stock. Burning can be of natural origin, as caused by lightning, for example, and the classification of anthropogenic versus natural burning is not so simple, especially in fire-tolerant ecosystems, which evolved with the presence of natural fire (Cerrado and Caatinga). However, it is known that the vast majority of current burning, even in these biomes, is anthropogenic in origin (Schumacher et al., 2022).

In addition, the burning of native vegetation residues after deforestation of an area is also an important source of methane in Brazil and is already currently accounted for in the National Inventory (MCTI, 2020f), as well as in the SEEG.

Figure 8. Burning-related methane sources and accounting for the anthropogenic component of emissions.



1.3.3. Waste

The sector includes methane (CH_4) and other greenhouse gas emissions from sanitation services. Emissions exclusively related to the treatment of solid waste and liquid effluents are considered. In particular, the emission source activities are disaggregated into: final waste disposal in landfills and other types of disposal; the incineration of waste from health services (RSS) and open burning of solid waste; and the treatment and disposal of domestic and industrial liquid effluents.

FINAL DISPOSAL OF WASTE

The final disposal of municipal solid waste produces significant amounts of methane through the decomposition of the degradable organic fraction of the waste under anaerobic conditions. The potential for CH_4 generation from solid waste is estimated from the analysis of the gravimetric composition, the type of management adopted in the final disposal sites - landfills, controlled landfills or sanitary landfills - precipitation rates, temperature, and the amount of material sent to each type of destination.

BIOLOGICAL TREATMENT

Biological treatment consists of the degradation of organic carbon through processes such as composting and anaerobic digestion. Composting is an aerobic process, in which the organic fraction of the waste is converted into CO_2, CH_4 (in the anaerobic sections of the compost) and a small fraction of N_2O. Anaerobic digestion of organic waste accelerates the natural decomposition of organic matter without oxygen, leading to the generation of CH_4.

OPEN BURNING

Incineration is a thermochemical waste treatment process. It consists of the combustion of solid and liquid waste in controlled plants, with a consequent reduction in the volume and hazardous characteristics of the waste.

In this process, CH_4 emissions are not estimated, since the standard emission factor for incinerators is zero. Open burning, defined as the combustion of combustible materials in the open air or in open dumps with emissions being released directly into the atmosphere without passing through a filter stack, is responsible for the emission of CH_4.

DOMESTIC AND INDUSTRIAL LIQUID EFFLUENTS

Domestic effluent has a high content of organic load that, when degraded, can generate significant emissions of CH_4. These emissions differ according to the type of treatment applied, reaching larger quantities with anaerobic treatments. The industrial effluents, on their turn, present different organic material loads, depending on the sector of the industrial process. They can be responsible for emitting significant amounts of CH_4 depending on the conditions under the types of treatment adopted.

1.3.4. Energy

Energy production and consumption generate methane emissions from fuel combustion and fugitive emissions.

When fuels are burned, the chemical energy contained in the fuel is released as heat, which can be put to direct end use (furnaces, heaters, etc.) or converted into electrical or mechanical energy, as occurs in thermal power generation and mobile sources (vehicles). Ideally, in a complete combustion, all the carbon (C) stored in the fuels is oxidized and emitted as carbon dioxide (CO_2). However, what actually happens is incomplete combustion, where other gases, including methane, are emitted in smaller quantities than CO_2.

Fugitive emissions are the result of intentional and unintentional discharges of gases from the production processes of coal, oil and natural gas. They occur in various stages of production processes: extraction, storage, processing, and transportation of fuels.

In the oil and gas industry, fugitive emissions are grouped into three activity types[6]:

1. Extraction and production: venting (intentional release of gas to regulate process pressure), flaring (intentional burning of gas to regulate process pressure), methane flash tanks, glycol dehydration process, CO_2 removal from gas (MEA and DEA columns), pigging in lines (for inspection or cleaning), and fugitive in line components such as connectors, valves, and others, drilling activities, oil spills in pipelines, depressurization and cleaning of tanks and vessels;
2. Refining or processing: UFCC (Fluid Catalytic Cracking Unit) regenerator, hydrogen generation units (UGH), fugitive of line components such as connectors, valves and others, flaring, venting, glycol dehydration process and pigging passages in lines;
3. Transportation: depressurization of lines, leakage of line components such as connectors, valves, flanges, and others, leaks in pipelines, venting, flaring, methane flash in tanks, pigging in lines, and loading of trucks or railcars.

In the geological process of coal formation, which occurs over millions of years, there is the formation of methane gas, which remains trapped with the solid mineral. The gas is released when the coal is exposed to the atmosphere, which occurs during the excavation of the mines for its extraction.

1.3.5. Industrial processes and product use

Industrial activities can generate atmospheric emissions by burning fuels (heat or power generation), by waste disposal (industrial effluent treatment and incineration) and by chemical and/or physical transformation processes of materials. For each one of these processes, the emissions vary according to the product, the inputs that feed the processes, the type of technological route used in production, the industrial plant equipment, and the efficiency levels, among others. The Intergovernmental Panel on Climate Change (IPCC) categorizes as industrial processes and product use (IPUP) exclusively emissions that occur in the chemical or physical transformation of materials. Thus, emissions from fuel combustion are allocated to the "energy sector", and emissions from waste disposal are allocated to the "waste sector". In the IPUP sector, methane emissions are estimated in the production of metals (production of pig iron and steel, production of ferroalloys and production of other non-ferrous metals) and in the chemical industry (production of methanol, ethylene, ethylene oxide, acrylonitrile, dichloroethane, vinyl chloride, calcined petroleum coke and carbon black)[7].

[6] Reference Report "Energy Sector - Fugitive Emissions Sub-Sector - Oil and Natural Gas Category" (MCTI/PETROBRAS, 2020), an integral part of the 4th National Inventory of Greenhouse Gas Emissions and Removals.

[7] SEEG, 2021 - Methodological Note, Industrial Processes and Product Use, available at: https://seeg-br.s3.amazonaws.com/Notas%20 Metodologicas/SEEG_9%20%282021%29/SEEG9_NotaMetodologica_PIUP_2021.10.26.pdf [accessed on March 23, 2022]

1.4. Global Commitment to Methane

30%

of reduction by 2030 compared to 2020 was the commitment adopted in Glasgow in 2021

The Global Commitment to Methane is an initiative that originated in articulation between the USA and the European Community and was announced in September 2021, inviting countries to reduce emissions of this greenhouse gas. In November of the same year, during COP26, a hundred countries joined the agreement, which by September 2022 had 122 signatory countries, including Brazil.

Participants who join the commitment agree to take voluntary actions to contribute to a collective effort to reduce global methane emissions by at least 30 percent by 2030 from 2020 levels, which could prevent 0.2°C of warming of the Earth by 2050.

Participants also committed to using IPCC-compliant inventory best practices, as well as working to continuously improve the accuracy, transparency, consistency, comparability, and completeness of national greenhouse gas inventory reports under the UNFCCC and the Paris Agreement.

The commitment aims to catalyze global action and strengthen support for existing international methane emission reduction initiatives to advance the technical and policy work that will underpin domestic action.

While it does not include country targets, the commitment involves taking comprehensive domestic actions to achieve the global goal, focusing on achieving all feasible reductions in the energy and waste sectors and pursuing agricultural emissions reductions through technological innovation as well as incentives and partnerships with farmers. Every year, starting in 2022, ministerial meetings will be held to assess progress toward the methane agreement target. Although not an obligation, it is expected that signatory countries will express their domestic commitment to the methane emissions reduction agenda as the US and the European Union have done.

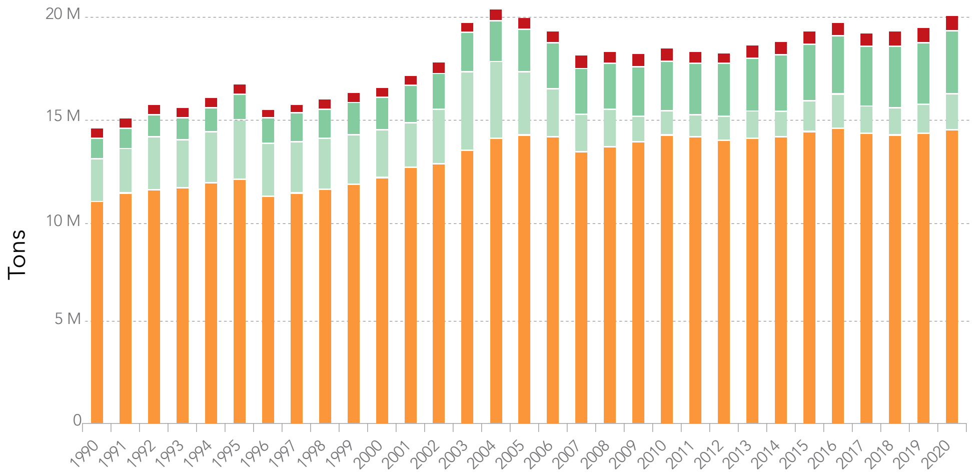
2 Overview of methane emissions

2.1. Overall emissions

Brazilian methane emissions in 2020 were estimated by the SEEG at 20.2 million tons in 2020, corresponding to 565 $MtCO_2e$ or 26% of the country's total greenhouse gas emissions.

Figure 9. Methane Emissions in Brazil by Sector (1990 – 2020)

Agriculture and Cattle Raising
Land Use Change and Forests
Waste
Energy

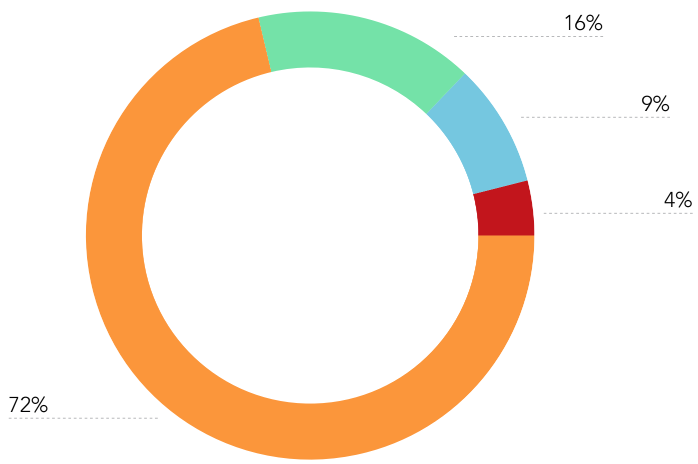


72% of Brazil's methane emissions come from agriculture and cattle raising

After a period of decline between 2004 and 2008 methane emissions have been gradually increasing. The main source of methane in Brazil is agriculture and cattle ranching, with 71.8% of emissions (especially enteric fermentation, waste management and irrigated rice production), followed by waste treatment, with 15.8%, and land use change with 8.7%. Energy and industrial processes contribute 2.8% of emissions.

Figure 10. Methane emissions of Brazil

Agriculture and Cattle Raising
Waste
Land Use Change and Forests
Energy and Industrial Processes



2.2. Cattle Raising

The agricultural and livestock sector is the largest responsible for methane emissions in the country, traditionally occupying the position of annual leader in these emissions and in the cumulative total already emitted. In 2020, methane emissions totaled 14.54 million tons (14.54 Mt CH_4), equivalent to 71.8% of national emissions of the gas and a 1.4% increase over the previous year. It was the second largest emission in the sector, second only to emissions in 2016, when 14.6 million tons were emitted. The historical trend is upward, with small annual swings up and down.

Within the sector, the sources of methane emissions are predominantly from digestion by ruminant animals (enteric fermentation), followed by treatment and disposal of waste generated by these animals (waste management). With much less expressive participation, the other emissions come from irrigated rice cultivation and the burning of agricultural waste from sugar cane cultivation.

Resulting from livestock activity, the subsector that contributed most to methane emissions was enteric fermentation, with a total emission of 13.32 Mt CH_4 (91.6% of emissions in the sector in 2020). Historically, the main source of emissions of this subsector is the beef cattle herd, due to the digestion performed by ruminant animals, popularly known as the "burp" of the ox. In 2020, the Brazilian cattle herd was responsible for the emission of 11.49 Mt CH_4, the highest value in its historical series, with 86.3% of emissions within the enteric fermentation subsector. The second largest emission source, the dairy cattle herd, emitted 1.41 Mt CH_4 (10.6%). Thus, beef and dairy cattle herds together totaled 96.9% of these emissions. The other ruminant animals complete the remaining 3.1%, with a total emission of 0.41 Mt CH_4.

Still resulting from livestock activity, animal waste management was the second largest emitter in 2020, also occupying the same position historically. Besides the emission of nitrous oxide (N_2O), one of the most impacting GHG, the subsector has as its main emitted gas, methane (CH_4), reaching its highest emission in 2020, with a total of 0.85 Mt CH_4 and accounting for 5.8% of the total emissions of the agriculture and cattle ranching sector. The pig herd is the highlight as the main emission source, having emitted 0.39 Mt CH_4, equivalent to 45.6% of the subsector's emissions. Soon after come the beef cattle herd (31.0%) and the dairy cattle herd (17.2%). The participation of poultry emissions is also noteworthy, with 3.5% of participation, while the other animal herds account for less than 3% remaining.

The remaining methane emissions are from agricultural subsectors, which together accounted for 2.6% of total emissions from the agricultural sector in 2020. Rice cultivation emitted a total of 0.37 Mt CH4 (2.5%), resulting from rice production by the irrigated system. Completing the agricultural activity emissions, the burning of agricultural waste accounted for 0.1% of total methane emissions, having as emission sources the burning of waste generated by sugarcane cultivation. This emitted in 2020 approximately 8 thousand tons of methane.

Figure 11 and Table 1 show the evolution of methane emissions in agriculture and cattle ranching and the values of emissions by source from 1990 to 2020, respectively.

Figure 11. Evolution of methane emission in agriculture and cattle ranching and the values of emissions by source from 1990 to 2020

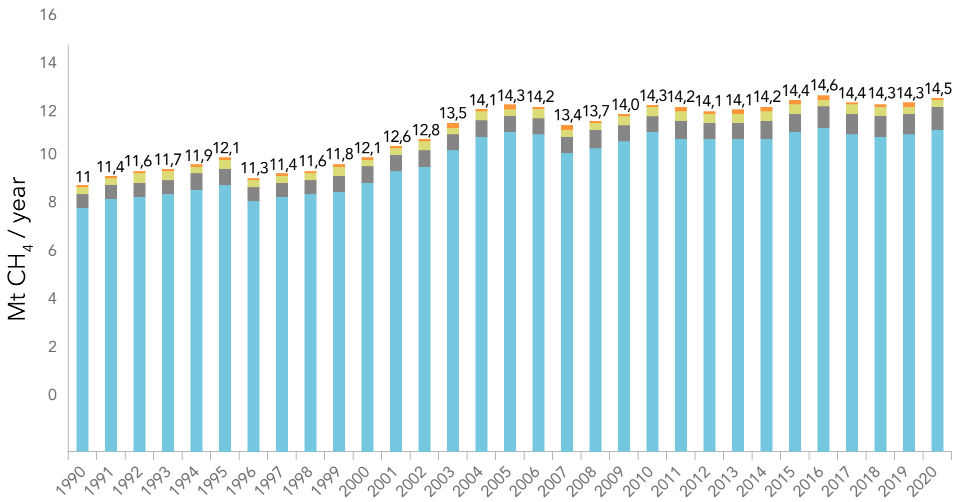
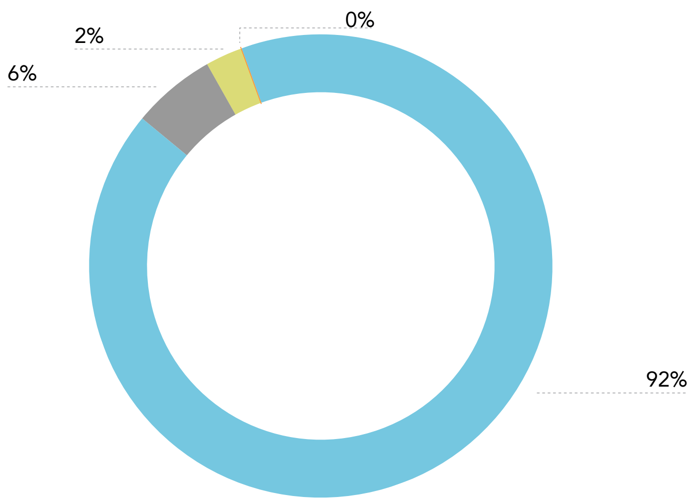


Figure 12. Evolution of methane emission in agriculture and cattle ranching and the values of emissions by source from 1990 to 2020



- Enteric fermentation
- Management of Animal Waste
- Rice Farming
- Burning of agricultural waste

Table 1.
Methane emissions
by subsector and their respective
sources between 1990 and 2020

SOURCES OF ISSUE BY SUBSECTOR	TONS OF METHANE PER YEAR (tCH_4/year)							% OF PARTICIPATION
	1990	1995	2000	2005	2010	2015	2020	2020
Enteric fermentation	**10,095,823**	**11,051,168**	**11,155,863**	**13,158,041**	**13,160,583**	**13,178,198**	**13,320,477**	**91.6%**
Beef cattle	7,917,610	8,718,622	9,155,918	10,941,913	10,771,054	10,947,751	11,496,964	86.3%
Dairy cattle	1,764,259	1,909,699	1,656,211	1,858,068	2,029,910	1,855,869	1,412,479	10.6%
Equine	110,187	115,095	104,973	104,170	99,257	99,923	107,318	0.8%
Sheep	100,073	91,682	73,925	77,940	86,903	92,053	103,143	0.8%
Buffalo	76,840	90,307	60,640	64,550	65,148	75,377	82,637	0.6%
Goat	59,473	56,358	46,734	51,534	46,564	48,104	60,506	0.5%
Swine	33,623	36,062	31,562	34,064	38,957	39,795	41,124	0.3%
Mule	20,329	19,901	13,479	13,887	12,774	11,667	10,749	0.1%
Asinine	13,428	13,442	12,422	11,915	10,016	7,660	5,556	0.0%
Management of Animal Waste	**540,848**	**602,294**	**571,046**	**664,364**	**715,213**	**818,880**	**845,146**	**5.8%**
Swine	268,085	294,486	241,520	264,848	289,282	370,819	385,390	45.6%
Beef cattle	175,656	195,473	207,182	249,333	243,925	248,647	262,244	31.0%
Dairy cattle	62,623	73,627	85,032	109,192	136,724	151,924	145,192	17.2%
Birds	10,974	14,649	16,970	20,118	25,038	26,908	29,918	3.5%
Equine	11,355	11,892	10,805	10,815	10,390	10,497	11,373	1.3%
Sheep	3,403	3,123	2,634	2,834	3,157	3,370	3,874	0.5%
Buffalo	2,424	2,870	1,912	2,038	2,073	2,426	2,672	0.3%
Goat	2,569	2,434	2,034	2,239	2,016	2,090	2,642	0.3%
Mule	2,165	2,144	1,484	1,537	1,422	1,294	1,189	0.1%
Asinine	1,593	1,594	1,474	1,412	1,186	904	653	0.1%
Rice Farming	**331,173**	**412,032**	**368,254**	**385,583**	**385,492**	**425,361**	**370,341**	**2.5%**
Rice	331,173	412,032	368,254	385,583	385,492	425,361	370,341	100.0%
Burning of agricultural waste	**40,430**	**42,389**	**37,471**	**48,662**	**42,927**	**13,728**	**7,723**	**0.1%**
Sugarcane	36,663	42,389	37,471	48,662	42,927	13,728	7,723	100.0%
Cotton	3,767	0	0	0	0	0	0	0.0%
Grand Total	**11,008,274**	**12,107,883**	**12,132,635**	**14,256,650**	**14,304,216**	**14,436,167**	**14,543,687**	**100.0%**

Analyzing the total emissions by source, animal sources are predominant, mainly beef (11.76 Mt CH_4) and dairy cattle (1.56 Mt CH_4), totaling in 2020 the emission of 13.32 Mt CH_4, which corresponds to 91.6% of the total methane emissions in agriculture and cattle raising.

Even the other agriculture and cattle raising sources are far behind cattle production, as seen in the third most emitting source in the sector, pigs, with a total emission of 0.43 Mt CH_4 and a total participation of 2.9%. The fourth source is the emission of agricultural origin, and irrigated rice is responsible for 2.5% of emissions, with 0.37 Mt CH_4. The other sources represent 3%.

Since 1990, methane emissions from the agricultural and livestock sector increased by 32.1%, driven by the expansion of the cattle population in the country. From 1990 to 2020, the cattle herd has grown 48.3%, from 147.1 million to 218.2 million heads (IBGE, 2022a). For the same period, total methane emissions from this herd increased by 34.2%, from 9.92 Mt CH_4 to 13.32 Mt CH_4. The difference between the percentages indicates that, despite the increase in emissions to the growth of the herd, there was a gain in efficiency in the sector.

From the reported emission sources, the average emission per head of beef cattle in the country has been decreasing, starting from 63.2 kg CH_4 in 1990 and reaching 58.2 kg CH_4 in 2020. For dairy cattle, the average emission per head oscillated between 95.8 kg CH_4 and 96.3 kg CH_4 for the same period. This shows the potential for reduction in the intensity of emissions that the sector can further explore through the adoption, maintenance and expansion of practices and technologies that seek to reduce methane emissions in cattle ranching, conciliating the search for greater productivity for the meat and milk chain.

In 2020, the emission from the beef carcass produced was 1.50 kg CH_4/kg carcass, 37.5% less than in 2000, when the emission was 2.40 kg CH_4/kg carcass. For the same period, milk production was a record 35.4 billion liters, resulting in an emission intensity of 0.04 kg CH_4/liter of milk, less than half that of 2000, with 0.09 kg CH_4/liter of milk and a milk production 44.2% lower than 2020.

12%

was the increase in methane emission per rice production since 1990

From the agricultural activity, rice grown under irrigated systems is the most emitting source. From 1990 to 2020, the emission of methane had an increase of 11.8%, from 0.33 Mt CH_4 to 0.37 Mt CH_4. This relationship can be seen when we see, in parallel, the increase of 18.1% in the cultivated area for the same period, from 1.1 million hectares in 1990, to 1.3 million hectares in 2020, even with the tendency of reduction of the total area in the country in recent years, with the maximum area until then, 1.51 million hectares in 2011. In contrast to the increase in emissions, productivity has been growing over time, with greater efficiency, going from 4.6 tons per hectare in 1990, to 7.8 tons per hectare in 2020, that is, a 70.2% increase in productivity (Embrapa Rice and Beans, 2022).

Concerning the burning of sugarcane residues, the positive impact of regulations and good practice actions for the management and harvest, such as Federal Decree 2661/1998, which provides for the gradual reduction of the use of fire as a means of managing sugarcane, is evident. There were also initiatives at the state level, such as in the state of São Paulo, the largest sugarcane producer and with the largest area. For cottonseed, the burning of its residues stopped occurring still in the 1990s, being eliminated already in 1995, resulting from the total mechanization process of the sector and the use of pesticides as a means of eliminating the residues generated (MCTI, 2020d).

Thus, from 1990 to 2020, emissions from the burning of sugarcane and cotton residues were reduced by 80.9%, from 0.04 Mt CH4 to approximately 0.008 Mt CH_4. At the same time, cotton production was a record in 2020, reaching 7.1 million tons, four times what the sector had in 1990. Sugarcane more than doubled its production, going from 4.3 million to 10 million tons, an increase of 134.4%, while its harvested area almost tripled, reaching 757.1 million hectares in 2020 (IBGE, 2022b).

Figure 13 and Table 2 show the evolution of methane emissions by agriculture and cattle ranching sources and their emission values from 1990 to 2020, respectively.

Figure 13.
Evolution of methane emission by agriculture and cattle ranching sources and their emission values from 1990 to 2020

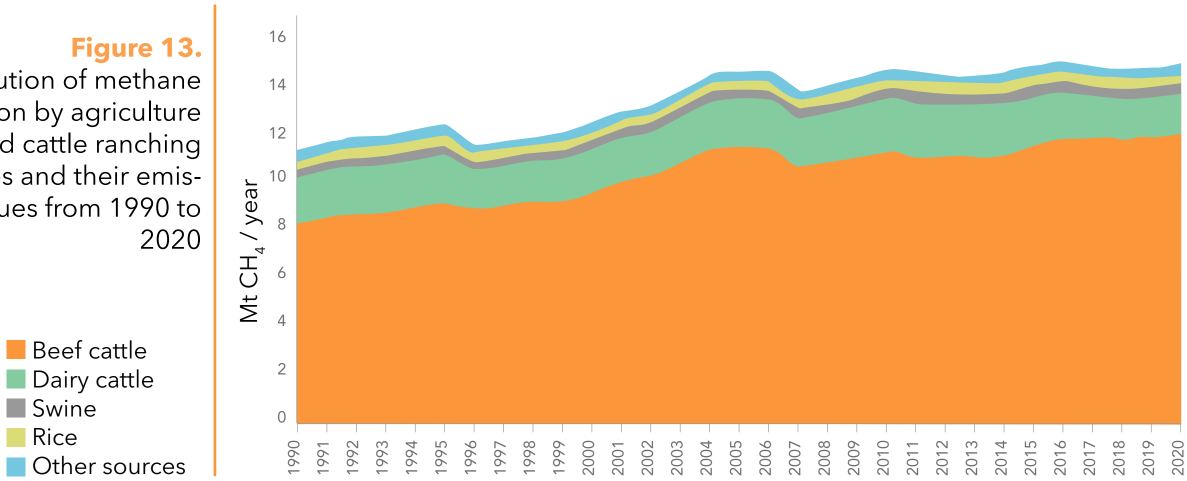


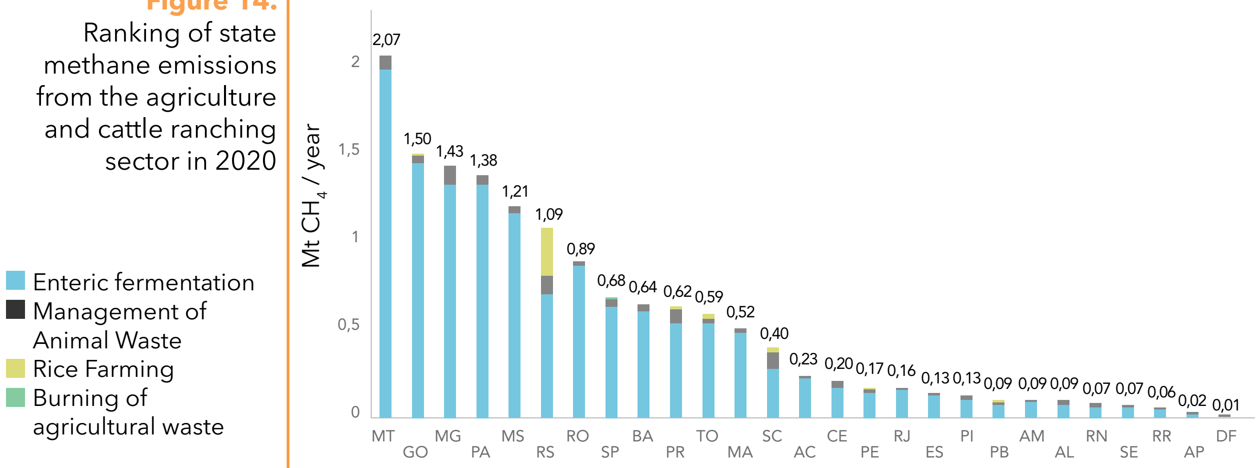
Table 2.
Methane emissions (CH_4) by sources between 1990 and 2020

SOURCES OF EMISSION	TONS OF METHANE PER YEAR (tCH_4/year)							% OF PARTICIPATION
	1990	1995	2000	2005	2010	2015	2020	2020
Beef cattle	8,093,267	8,914,095	9,363,100	11,191,246	11,014,979	11,196,398	11,759,208	80.9%
Dairy cattle	1,826,882	1,983,326	1,741,243	1,967,259	2,166,634	2,007,793	1,557,671	10.7%
Swine	301,708	330,548	273,082	298,912	328,239	410,615	426,514	2.9%
Rice	331,173	412,032	368,254	385,583	385,492	425,361	370,341	2.5%
Equine	121,542	126,986	115,778	114,985	109,647	110,421	118,691	0.8%
Sheep	103,476	94,805	76,558	80,774	90,060	95,423	107,017	0.7%
Buffalo	79,265	93,178	62,552	66,587	67,221	77,803	85,309	0.6%
Goat	62,042	58,793	48,768	53,773	48,580	50,194	63,148	0.4%
Birds	10,974	14,649	16,970	20,118	25,038	26,908	29,918	0.2%
Mule	22,494	22,045	14,963	15,423	14,196	12,961	11,937	0.1%
Sugarcane	36,663	42,389	37,471	48,662	42,927	13,728	7,723	0.1%
Asinine	15,021	15,036	13,895	13,327	11,202	8,564	6,209	0.0%
Cotton	3,767	0	0	0	0	0	0	0.0%
Grand Total	**11,008,274**	**12,107,883**	**12,132,635**	**14,256,650**	**14,304,216**	**14,436,167**	**14,543,687**	**100.0%**

At the state level, the largest source of emission is always livestock activity. The largest emitter is Mato Grosso, with 2.07 Mt CH4 in 2020, accounting for 14.2% of national emissions from agriculture and cattle ranching. Since 2003 the state has held this position, justified by having the largest cattle herd, with more than 32 million head in 2020. Close behind are Goiás (10.3%) and Minas Gerais (9.8%), emitting a total of 1.50 and 1.43 Mt CH_4, respectively. These three states together represented more than 34.4% of the emissions.

Also notable are Pará (9.5%), Mato Grosso do Sul (8.3%) and Rio Grande do Sul (7.5%), with irrigated rice cultivation being the second most emitting source for the latter, a state with the largest rice harvested area. Figure 14 shows the total emission of each state in 2020.

Figure 14. Ranking of state methane emissions from the agriculture and cattle ranching sector in 2020



2.3. Land use change and forests

WETLANDS

Methane emissions in wetlands worldwide are estimated to be between **55 and 150 million tons (Mt)** per year (Watson et al., 2000). However, there are large uncertainties associated and only an understanding of natural methane cycles in wetlands will allow the generation of better estimates of emissions caused by anthropogenic activities.

Several pieces of research have been conducted to understand the natural dynamics of methane emissions in wetlands and the anthropogenic consequences of these dynamics. In Brazil, these studies occur mainly in the Amazon, which is a major global source of methane, with important emissions coming from flooded soil, floodplain trees (Pangala et al., 2017), but also from trees on terra firme (Gauci et al., 2021). However, Basso et al. (2018) did not identify significant changes in methane emissions for the period 2010 to 2018, which would leave Amazon out of the prime suspects for the observed increase from 2007.

Uncertainties related to methane emissions in wetlands are compounded by the lack of agreement (by about 30% of estimated global totals) between top-down methods of quantifying emissions (e.g. satellite imagery) and bottom-up methods (local quantification with flow measurements). Methodological advances are still needed to narrow these gaps and more accurately determine emission models across scales (Winton et al., 2017; Saunois et al., 2020). Mapping wetlands and floodplains, as well as peatlands, at high resolutions and capturing the different vegetational types, are also needed for improved estimates (Saunois et al., 2020). Indeed, tropical wetlands show a large seasonal and regional variation in atmospheric CH_4 signatures, which should be better understood to improve global and regional models, as studies are currently still scarce (Winton et al., 2017; Teh et al., 2017; France et al., 2022).

THE RESERVOIR ISSUE

The patterns and dynamics of methane emissions in artificial reservoirs are highly variable and the results are highly dependent on the method used for measurement (Fearnside, 2016; Brandão et al., 2019). Some factors are responsible for the variability of emissions in reservoirs (Steinhurst et al., 2012), among them: temperature, water time in the reservoir, water volume and depth, type of flooded vegetation, geographic location, and age since flooding.

Even considering all these factors, most measured methane fluxes remain highly variable (Hertwich, 2013). These large temporal and spatial variations challenge the reliability of global emission factors or even of specific climate regions. Thus, the most current guidelines suggest studying and generating domestic emission factors for countries that choose to report their methane emissions (IPCC, 2019).

The only review of studies ever conducted on large-scale tropical hydropower plants was done by Demarty and Bastien (2011), which included ten Brazilian plants. The study draws attention to the fact that there is no methodological consensus for estimating emissions in reservoirs, and that therefore the comparison between analyses is fraught with uncertainty. In the table below, we present the major surveys done by the study concerning hydropower plants in Brazil, and include the Petit Saut plant in French Guiana, because it is the longest and most complete tropical reservoir study ever done (Abril et al., 2005; Table 3).

Emissions from the three compartments within the reservoir (by diffusion, boiling, and degassing) must be considered (Demarty & Bastien, 2011). However, only three studies considered emissions from degassing: Fearnside et al. (2002) at Tucuruí (estimated, but not directly measured), Kemenes et al. (2007) at Balbina and Abril et al. (2005) at Petit Saut. For the other plants with energy densities and diffusion emissions comparable to the Petit Saut and Balbina diffusion emissions (Três Marias, Barra Bonita, Serra da Mesa, and Samuel), the degassing emissions were estimated by Demarty and Bastien (2011) considering the proportions obtained in these studies over the total measured diffusion emissions.

Table 3.
Characteristics of hydroelectric plants and their reservoirs surveyed by the study of Demarty and Bastien (2011), including plants in Brazil and Petit Saut in French Guiana. In bold are the reservoirs whose studies considered emissions from degassing in their calculations and estimates. In italics are the reservoirs with energy density and diffusion emissions comparable to the most comprehensive studies (Balbina and Petit Saut), for which the authors applied the ratio "emissions by degassing/diffusion emissions" obtained in Balbina and Petit Saut.

PLANT	YEAR	AGE AT THE TIME OF THE STUDY	RIVER/STATE	AREA (km²)	VOLUME (m³)	ANNUAL EMISSIONS OF CH_4	ENERGY DENSITY (MW/km)	EMISSION FACTOR (Kg CO_2e/ MWh)*
Três Marias	*1962*	*36*	*São Francisco (MG)*	*1155*	*$1.42x10^7$*	*74508*	*0.34*	*875.56*
Barra Bonita	*1963*	*35*	*Tietê (SP)*	*334.31*	*$2x10^5$*	*2379*	*0.42*	*422.12*
Tucuruí	**1984**	**5**	**Tocantins (PA)**	**2875**	**$6.04x10^6$**	**97001**	**2.91**	**115.37**
Samuel	*1987*	*11*	*Jamari (RO)*	*560*	*$3.48x10^5$*	*21224*	*0.39*	*560.88*
Balbina	**1989**	**16**	**Uatuma (AM)**	**2360**	**$3.88x10^5$**	**97000**	**0.11**	**2222.00**
Itaipu	1991	7	Paraná (PR)	1350	$1x10^7$	5880	9.33	1.51
Segredo	1992	6	Iguaçu (PR)	82	NA	263	15.37	1.21
Xingó	1994	4	São Francisco (SE)	60	$1.32x10^7$	878	50	1.13
Miranda	1998	1	Araguari (MG)	70	NA	2847	5.83	45.42
Serra da Mesa	*1998*	*1*	*Tocantins (GO)*	*1784*	*NA*	*16637*	*0.71*	*61.57*
Petit Saut	**1994**	**10**	**Sinnamary (French Guiana)**	**310**	**$4.5x10^5$**	**11427**	**0.37**	**510.50**

*Emissions in CO_2 and adapted from the article and calculated considering only the emissions in CH_4

Note that the emission factors resulting from the study are highly variable, from 61.57 to 2,222 Kg CO_2e/MWh. Using these factors based on the energy generated (MWh) in reservoirs of HPPs would generate values with discrepancies of up to 40 times between the most and least conservative. For this reason, and due to the high uncertainty associated with these studies, we present in this document the exercise proposed by the IPCC at the Tier 1 level (described below), so that we report more conservative values for methane emissions by hydroelectric power plant reservoirs.

IPCC GUIDELINES

The IPCC Wetlands guidelines (2006), which encompassed both natural wetlands and reservoirs, carried default factors at Tier 1, generated by taking the median of estimates obtained from a literature review. These median factors used to exclude extremely high estimated emission data, are criticized by Fearnside (2015), who indicates that the mean would be better suited to capture the reality of these emissions, in addition to charging the review conducted, which excluded much of the studies conducted in tropical regions. In any case, the IPCC (2006) still makes the caveat that the variability of the estimates is extremely high in all the processes considered (diffusion, boiling, and degassing) and the adoption of default emission factors will result in a high degree of uncertainty.

The refinement of the guidelines in 2019 brought the novelty of specific factors for macroclimatic regions, but still uses median estimates and indicates emissions only by diffusion in Tier 1, where the activity data needed for the calculation is the surface area of the reservoir.

At Tier 2, the IPCC currently suggests adopting country-specific boil-off emissions, and only at Tier 3, it suggests including emissions from turbine degassing and considering reservoir depth and age. Reporting of emissions at more detailed tiers (Tiers 2 and 3) remains optional, although diffusion emissions from the reservoir surface are the most conservative (Fearnside, 2013).

Finally, in the new guidelines (IPCC, 2019), it is also suggested that countries calculate the indicative anthropogenic component of emissions, which would consider only the flooded area that was not a water body or natural wetland unmanaged before filling. In this case, mapping these elements is necessary.

For the present paper, we did the exercise of calculating the emissions in Tier 1 considering the area of the reservoirs, obtained through the mapping performed by the MapBiomas initiative and applying the factors brought by the IPCC (2019). The only considerations, in the use of the factors, are to classify the macroclimatic region of the reservoir, which varies, in the tropical zone, between wet and dry, based on the cumulative annual precipitation of 1,000 mm; and the classification of the age of the reservoir (greater or less than 20 years). The reservoir surface map was thus cross-referenced with the average accumulated precipitation isohyets (CPRM/Brazilian Geological Survey) to define the total area of reservoirs in tropical wet and tropical dry zones. Table 4 presents the information and the calculation performed by us for this exercise, which results in total CH4 emissions of 1.55 Mt/year.

Table 4.
Calculation of methane emissions by reservoirs at Tier 1 level, based on the method and factors from IPCC (2019). The activity data for this exercise is the reservoir surface area in each climate zone. We used for this exercise the reservoir surface mapping done by the MapBiomas Água initiative, and classified the climate zone of each reservoir according to the isohyets of average annual cumulative precipitation in Brazil (CPRM/Brazilian Geological Service)

AGE OF THE RESERVOIR	AREA (HECTARE)	EMISSION FACTOR	EMISSION DOWNSTREAM OF THE TURBINE (PROPORTION)*	TROPHIC STATE*	CLIMATE ZONE	CH_4 EMISSIONS (Mt/year)
< 20 years	2,902,371	141.1	0.09	1	6 (tropical humid)	0.45
< 20 years	417,724	283.7	0.09	1	5 (tropical dry)	0.13
> 20 years	2,902,371	251.6	0.09	1	6 (tropical humid)	0.80
> 20 years	417,724	392.3	0.09	1	5 (tropical dry)	0.18
					Total	**1.55**

*Parameters with default values for IPCC Tier 1 (2019).

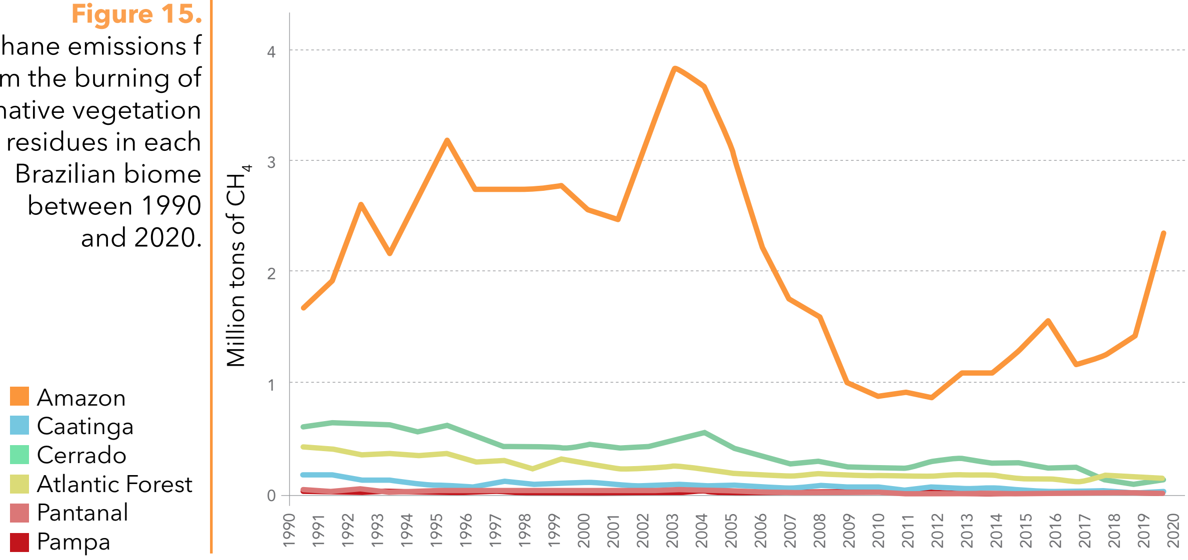
BURNING

The emission from the burning of organic matter is immediate and there are already methane emission factors related to burning detailed by vegetation type. These specific factors are brought by IPCC (2006) and used in the National Inventory (MCTI, 2020f).

Burning associated with deforestation

The emissions associated with deforestation are calculated based on the method used in the Fourth National Inventory (MCTI, 2020), where the biomass of firewood and logs obtained by state (SIDRA/IBGE platform) is removed from the emissions from deforested areas. The remaining dry biomass is considered to be burned, generating methane and nitrous oxide emissions. This is already accounted for in the SEEG collections, and is identified as "forest waste". In terms of emissions from deforestation residue burning, the Amazon has always led the CH4 emission patterns, since that is where most of the deforestation occurs in the country, as well as containing the largest carbon stocks (Fig. 15). In 2020, the steep increase in deforestation in the Amazon was accompanied by higher emissions from the burning of forest residues in that biome.

Figure 15. Methane emissions f rom the burning of native vegetation residues in each Brazilian biome between 1990 and 2020.



Burning not associated with deforestation

Initiatives that bring in the mapping of burned areas/fire scars allow the detailing of these emissions. This mapping is usually done with the use of satellite images (specific Modis products or spectral indices from optical satellites). The MapBiomas Fogo initiative aims to generate a time series of burned areas for Brazil at a resolution of 30 m since 1985, which represents the possibility of generating high-detail estimates of methane emissions from fire (MapBiomas Fogo, available at https://mapbiomas.org/).

For this calculation, we considered all annual scars generated by MapBiomas Fogo in natural areas (forest, savanna, grasslands, and wetlands) and anthropic areas (pasture and agricultural areas). In the case of pasture, it is a common practice to clear the land with fire for pasture renewal, and this class presents the highest proportion of the average annual burned area (Table 5, Figure 16). A precaution was taken to avoid recounting anthropic areas burned soon after deforestation: the annual deforestation area generated by the Land Use Change and Forestry sector in the SEEG method was discounted from the annual fire scars, so that only pasture and agricultural fires not associated with the deforestation process were accounted for.

The Fourth National Communication brings combustion factors only for native classes, but we sought emission and combustion factors for grassland and agricultural areas from IPCC (2006). For fires not associated with deforestation in Amazonian forests, fire frequency was considered, as this biome is highly sensitive to fire and suffers an increase in tree mortality in areas burned repeatedly. Thus, the map of carbon stock in necromass (combustible material) in the forests is updated at each burning event. This method has already been calculated in SEEG 9, and is reported as NCI (not accounted for in the inventory) emissions.

In total, we calculated emissions from the burning of 531,810,842 ha accumulated over the whole period, in areas of native vegetation (forest, savanna, grasslands, and wetlands) and anthropogenic areas (pasture and agriculture). Annually, in Brazil, the classes with the largest burned area are the savanna formation and pasture (Figure 13). However, in the total accumulated in the period, fires in grasslands stand out with almost one-third of all fires accounted for (Table 5). Altogether, however, the native areas represent 65% of all burned areas in the country in the analyzed period, against 35% of anthropic areas, of which the largest part (92%) is pasture. However, we emphasize that emissions are not directly proportional to the burning areas, as fuel stocks, as well as combustion factors, vary according to the type of vegetation.

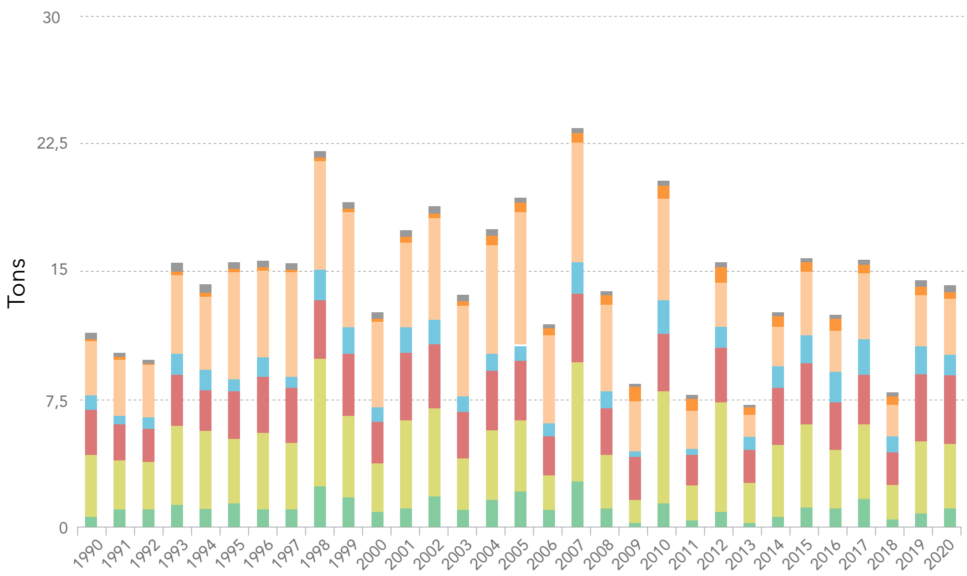
65%

of all the area burned in the country since 1985 was native vegetation

Table 5.
Burned areas considered and not considered in this exercise, for fires not associated with deforestation, obtained from the MapBiomas Fogo initiative platform (https://mapbiomas.org/), as well as the emission and combustion factors associated with each class, according to MCTI (2020f) and IPCC (2006)

CLASS MAPBIOMAS	ACCUMULATED BURNED AREA (HECTARE)	AVERAGE BURNED AREA PER YEAR (HECTARE)	PROPORTION OF BURNT AREA	CONSIDERED IN THE CALCULATION?
Forest	43,952,083	1,220,891	8.24%	yes
Savanna	153,107,093	4,252,975	28.70%	yes
Field	108,332,093	3,009,225	20.31%	yes
Wetlands	42,453,187	1,179,255	7.96%	yes
Pasture	169,328,738	4,703,576	31.74%	yes
Agriculture	14,637,648	406,601	2.74%	yes
Other classes	1,634,097	45,392	0.31%	no

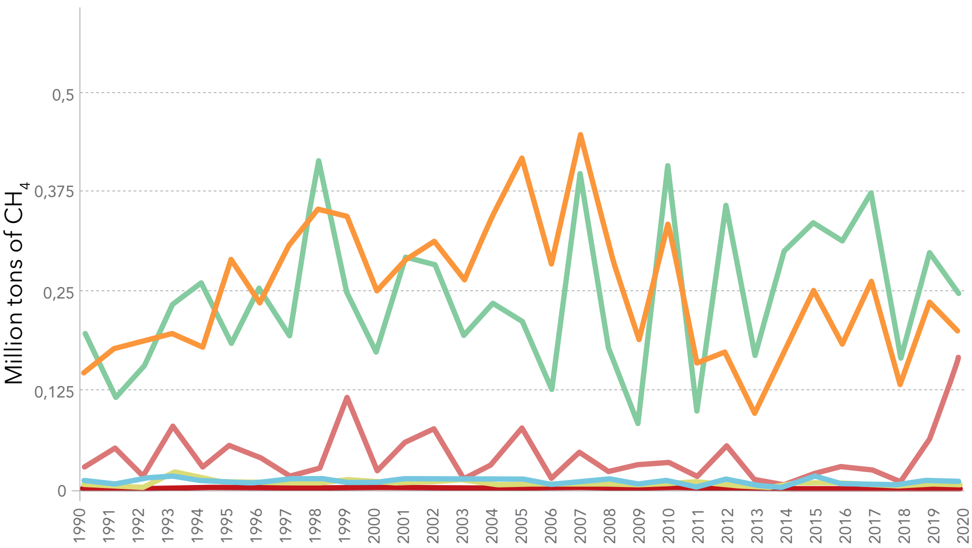
Figure 16.
Burnt area in Brazil in each class between 1990 and 2020, according to MapBiomas Fogo



Forest Formation
Savanna formation
Grassland formation
Wetlands
Pasture
Agriculture
Others

Emissions from fires not associated with deforestation occur mainly in native areas, which are on average responsible for 87% of the number of annual fires in the country (Table 5). The Amazon and Cerrado biomes are the biomes that burn the most, but a significant increase was observed in the Pantanal in 2020, at which point it almost reached the emissions of the Amazon (Figure 17).

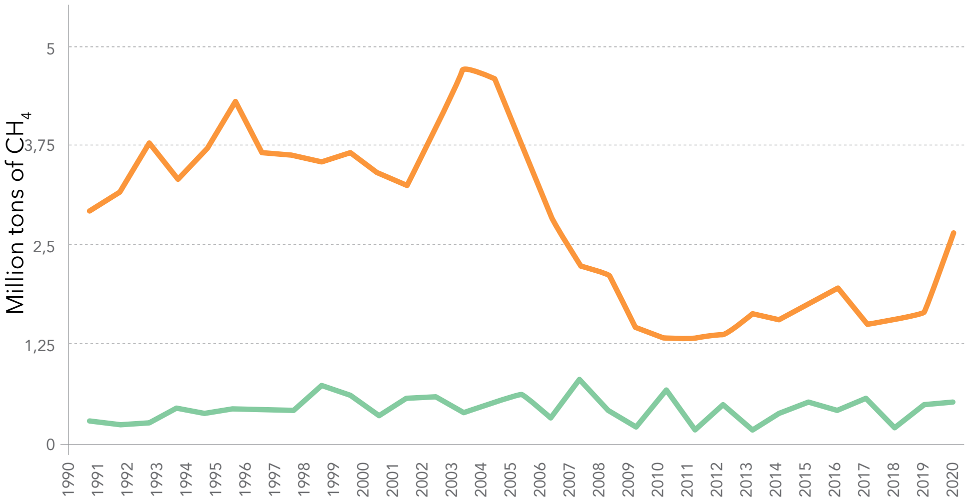
Figure 17.
Methane emissions by burning in native vegetation (forest, savanna, grasslands and wetlands formations) and in anthropic use classes (pasture and agricultural area) in each Brazilian biome from 1990 to 2020, according to the burned area classified by the MapBiomas Fogo initiative.



Amazon
Caatinga
Cerrado
Atlantic Forest
Pantanal
Pampa

Overall, the emissions from fires associated with deforestation exceed the emissions not associated with deforestation (Figure 18), even considering that the areas burned are larger than the areas deforested each year. This is because the biomass that burns in natural areas is always necromass, which is available as fuel at the moment the fire comes out. In newly deforested areas, the entire present stock is burned, except for a portion in firewood and logs previously removed. This difference explains the greater effect of burning associated with deforestation on methane emissions.

Figure 18. Methane emissions associated and not associated with deforestation in Brazil, in the period between 1990 and 2020

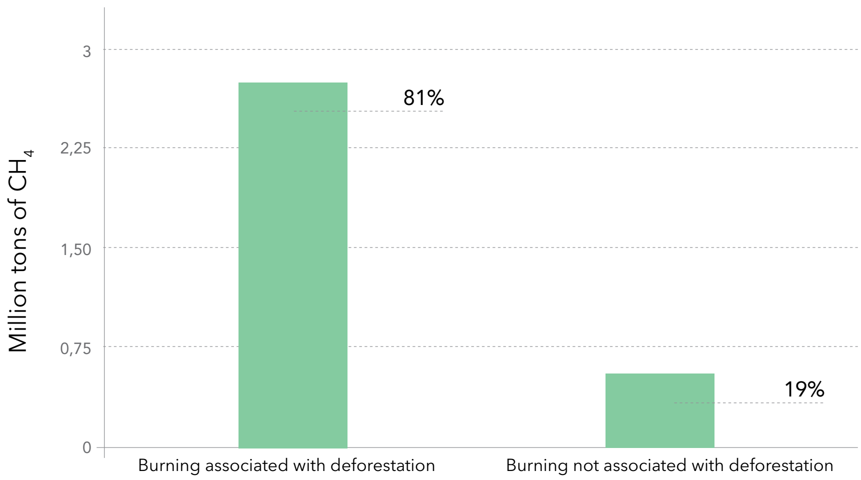


Associated with deforestation
Not associated with deforestation

GENERAL OVERVIEW MUT SECTOR

In general, for 2020, emissions from fires associated with deforestation represent the majority (81%) of the emissions accounting for with 2.71 million tons of CH_4. Burning not associated with deforestation emitted 620 thousand tons of CH_4 (19%) (Figure 19).

Figure 19. Profile of methane emissions estimated for 2020 in the Land Use Change and Forestry sector, regarding deforestation-associated burning and non-deforestation-associated burning in Brazil



2.4. Waste treatment

In 2020, methane emissions totaled 3.17 million tons (3.17 Mt CH_4), an increase of 1.8% over the previous year. The waste sector shows a continuous growth profile in its historical series: in 1990, the emissions were 0.95 million tons of CH_4, reaching 2.47 million tons in 2010 and 3.17 million tons in 2020.

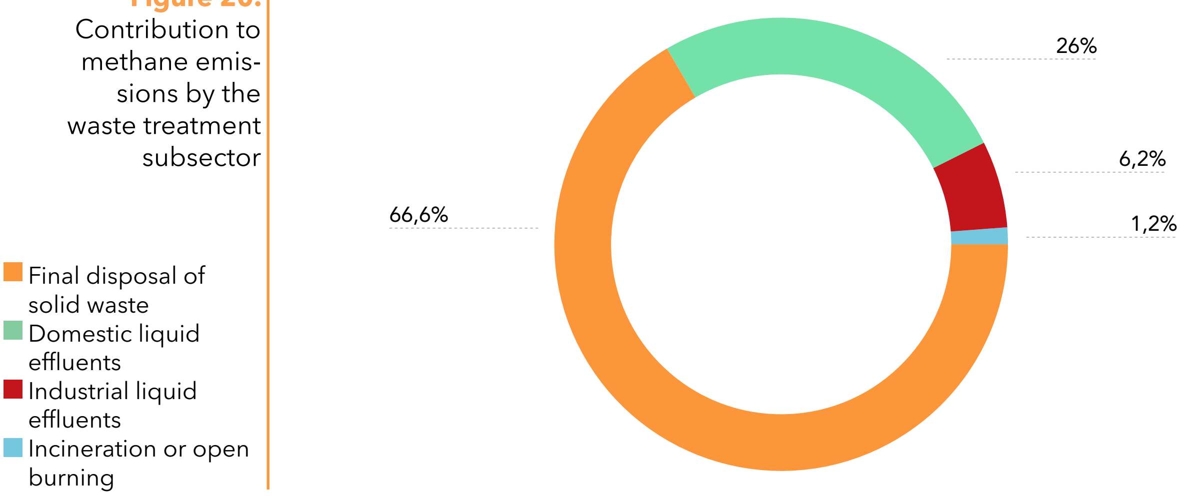
The sector was responsible for 15.8% of the national CH_4 emissions, presenting as the predominant emission source the final disposal of municipal solid waste, which accounted for 2.11 Mt (million tons) of CH_4, followed by emissions from the treatment of domestic wastewater, which accounted for 0.82 Mt CH_4, as can be seen in Table 6 and Figure 20.

Table 6. Methane emission by type of treatment of solid waste and liquid effluents in 2020

SUBSECTOR	tCH_4 IN 2020	CONTRIBUTION (%)
Final Disposal of Solid Waste	2,114,384	66.6
Incineration or open burning	38,091	1.2
Biological Treatment of Solid Waste	1,252	0.04
Domestic Liquid Effluent	825,072	25.99
Industrial Liquid Effluents	196,019	6.17
TOTAL	**3,174,817**	**100.00**

Source: SEEG data, 2021

Figure 20. Contribution to methane emissions by the waste treatment subsector



Historically, the sector's emissions are marked by sharp growth, with slight stabilization in recent years. This behavior is mainly related to the increase in population and, consequently, in the amount of waste generated, as well as to the advance in access to sanitation services, as can be seen in the figure below.

Figure 21.
Methane emission profile in waste treatment for the period 1990 to 2020

Solid waste
Liquid effluent treatment

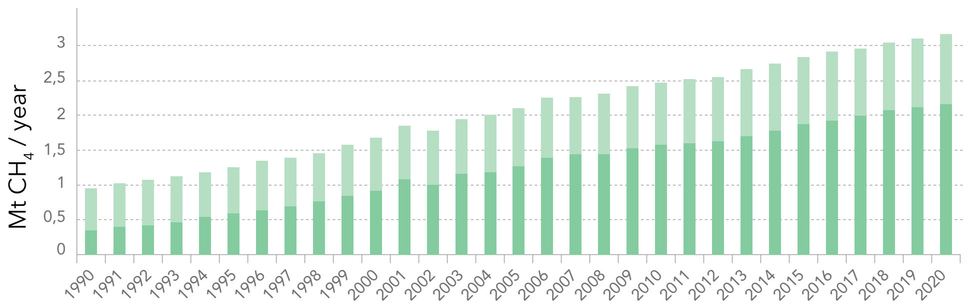
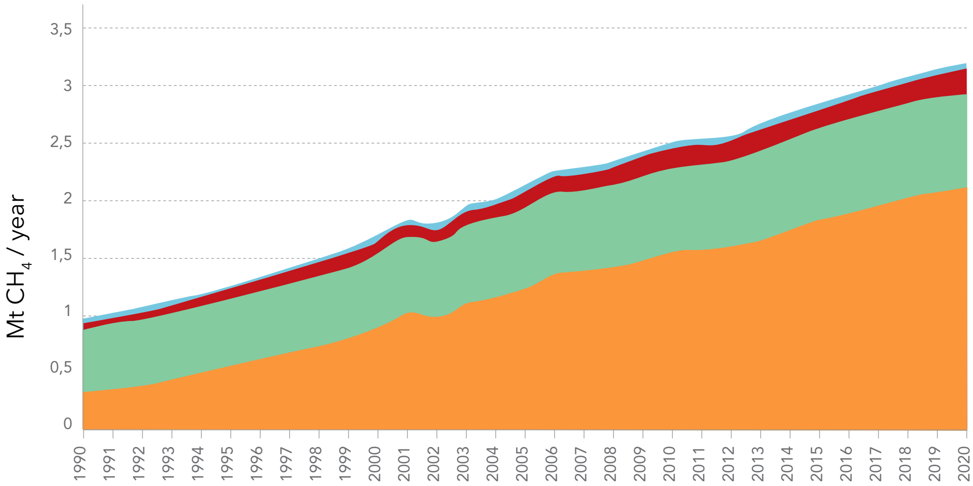


Table 7 describes CH_4 emissions by emission source activity in the waste sector for the period 1990 to 2020. Note that at the beginning of the historical series, methane emissions came mainly from domestic wastewater treatment. Over the years, with the advance of the implementation of landfills and the increase in solid waste collection rates, the final disposal started to stand out. Currently, sanitary landfills, especially those located in metropolitan regions and that receive a large amount of waste, are the main contributors to methane emissions in the sector. Figure 22 shows the evolution of methane emissions by source for the waste sector from 1990 to 2020, respectively.

Table 7.
Breakdown of emissions from the waste sector

EMISSION SOURCES BY SECTOR	TONS OF METHANE PER YEAR (tCH_4/year)						
	1990	1995	2000	2005	2010	2015	2020
Final Disposal of Solid Waste	**331,987**	**544,465**	**878,655**	**1,235,791**	**1,544,809**	**1,831,450**	**2,114,384**
STP sludge	1,375	4,030	5,697	7,113	8,357	9,637	10,640
Health Service Waste	0	353	420	425	387	395	434
Municipal Solid Waste	330,613	540,083	872,538	1,228,253	1,536,065	1,821,419	2,103,310
Incineration or open burning	**18,990**	**23,999**	**35,491**	**40,247**	**35,251**	**42,169**	**38,091**
Emissions from Open Pit Burning	18,990	23,999	35,491	40,247	35,251	42,169	38,091
Biological Treatment of Solid Waste	1,165	1,937	3,040	540	206	1,133	1,252
Municipal Solid Waste	1,165	1,937	3,040	540	206	1,133	1,252
Domestic Liquid Effluent	**541,628**	**593,371**	**648,660**	**701,641**	**725,993**	**795,981**	**825,072**
Domestic Sewage	541,628	593,371	648,660	701,641	725,993	795,981	825,072
Industrial Liquid Effluents	**61,311**	**83,452**	**101,014**	**133,271**	**161,930**	**180,488**	**196,019**
Poultry Meat Production	1,403	2,458	4,043	6,860	10,619	13,148	13,786
Beef Production	9,899	14,046	16,219	28,295	33,360	35,185	37,357
Pork Production	2,590	4,454	5,593	9,711	14,954	16,678	21,749
Cellulose Production	9,018	11,389	12,762	16,522	20,991	25,485	31,052
Beer Production	3,706	11,000	15,400	10,388	711	794	981
Raw Milk Production	27,099	33,401	43,100	57,400	76,401	86,000	88,149
Pasteurized Milk Production	7,596	6,704	3,898	4,095	4,894	3,197	2,945
Grand Total	**955,082**	**1,247,224**	**1,666,860**	**2,111,489**	**2,468,189**	**2,851,220**	**3,174,817**

Figure 22. Evolution of emissions in the waste sector by source

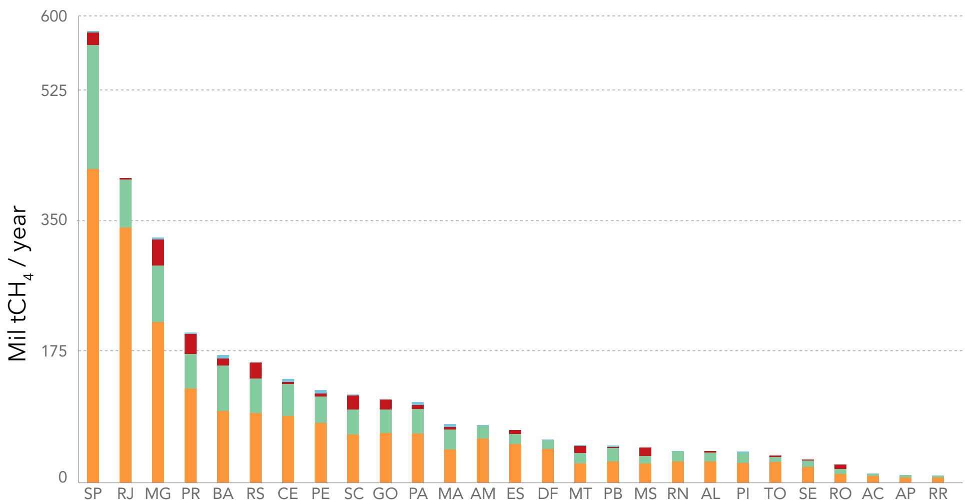


- Final disposal of solid waste
- Domestic liquid effluents
- Industrial liquid effluents
- Incineration or open burning

As observed at the national level, in the States the main sources of methane are also the final disposal of solid waste and the treatment of domestic liquid effluents. However, some States, such as Minas Gerais, Santa Catarina, Mato Grosso do Sul and Mato Grosso also present significant contributions from the industrial liquid effluents subsector, as they concentrate pulp, milk or meat production activities.

In general, the states with the highest population rates are also those that contribute the most to methane emissions. In 2020, the largest emitter was the State of São Paulo, with the emission of 603.14 thousand tons of CH_4, corresponding to 19% of the sector's emissions, followed by Rio de Janeiro, with the emission of 407.55 thousand tons of CH_4, corresponding to 13% of the national waste emissions, in 2020. Close behind are Minas Gerais (10%) and Paraná (6%), contributing with a total of 328.04 and 201.35 thousand tons of CH_4, respectively. Figure 23 shows the total emission of each state in 2020.

Figure 23. Evolution of emissions in the waste sector by source



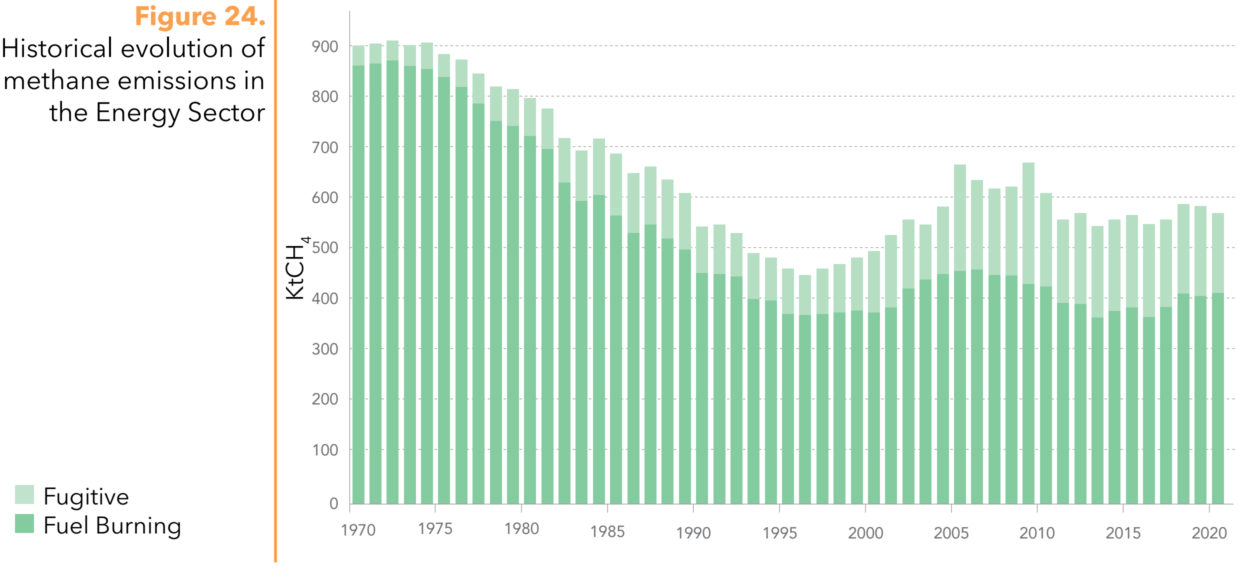
- Final disposal of solid waste
- Domestic liquid effluents
- Industrial liquid effluents
- Incineration or open burning
- Biological treatment of solid waste

2.5. Energy

It is estimated that approximately 572,000 tons of methane were emitted in the energy sector in 2020, corresponding to 2.6% of the total anthropic emissions of the gas by Brazil in the year. Out of these emissions, 414,000 occurred from fuel burning and 158,000 were fugitive emissions (Figure 24).

Historically, among the methane emissions from the sector, which started from a level near 900,000 tons in the early 1970s, emissions from fuel burning predominated, with a drop from 1970 to the mid-1990s and relative stability since then. Fugitive emissions, on the other hand, gradually increased throughout the historical series until 2009, decreasing since then. Between 1995 and 2000, we observed the period of lowest emissions in the historical series, below 500,000 tons per year.

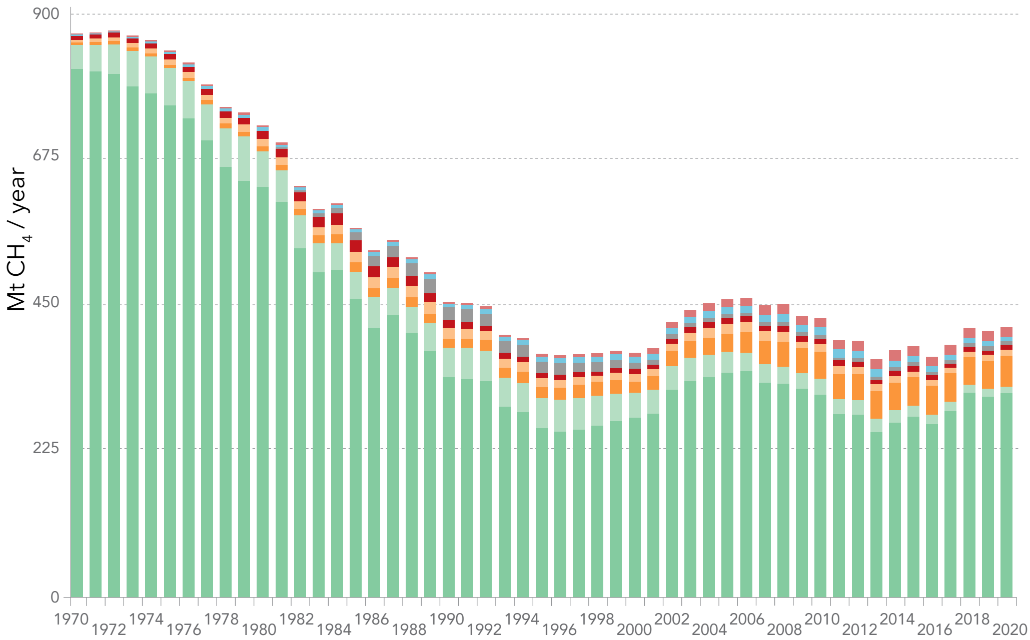
Figure 24.
Historical evolution of methane emissions in the Energy Sector



In more detail, we observe that two major emission sources stand out: the burning of firewood and the exploration and production of oil and natural gas.

In the burning of fuels, firewood is responsible for the vast majority of emissions, see Figure 25. This fuel was and is used mainly in homes for cooking food, according to the data from the National Energy Balance, which portrays the lack of access to other more efficient energy sources. In the 1970s and 1980s, we had a large reduction in the consumption of firewood with the spread of gas stoves. Consequently, emissions declined. In the 1990s, we see the stagnation of firewood consumption and methane emissions at a level close to half of what was observed in the early 1970s.

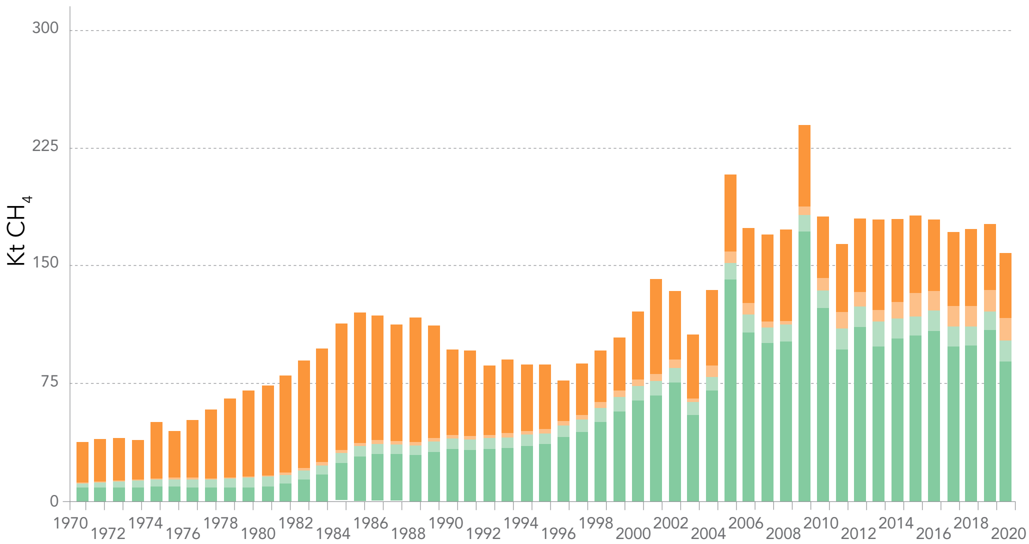
Figure 25. Historical evolution of methane emissions from fuel combustion



Among the fugitive emissions, the highlight is the emissions from oil and natural gas exploration (Figure 26). Unlike emissions from fuel combustion, the overall dynamics of fugitive emissions has been growing in the historical series. Before the 1990s, fugitive emissions were predominantly those associated with coal production. In the 1980s, methane emissions from the production of this fuel almost reached 100,000 tons per year, but subsequently decreased, reaching 42,000 tons in 2020 as a result of the decrease in domestic coal production.

Practically non-existent in the 1970s and boosted by the Pre-Salt discovery in the 2000s, oil and natural gas exploration caused an increase in methane emissions until 2009 and, from then on, started to oscillate around the 100,000 tons level. In 2020, emissions were at a level of 73,000 tons.

Figure 26. Historical evolution of fugitive methane emissions



For this document, methane estimates were revised to the latest version of the SEEG (9th edition), in which fugitive emissions from oil and gas exploration were calculated from simplified emission factors and extrapolated from activity data, taking as basis emissions published up to the 3rd National Inventory. This analysis considers methane emissions reported in the 4th National Inventory, in the case of fugitive emissions associated with oil and natural gas.

2.6. Industrial processes and product use

0,22%

was the share of the IPPU sector in the total national methane emissions in 2020

In 2020, methane emissions from the Industrial Processes and Product Use (IPPU) sector were estimated at 44,000 tons, which represented about 0.22% of Brazil's total methane emissions in the year, according to data from SEEG collection 9. Thus, we have that methane emissions from IPPU are much less significant compared to other emission sources in the country. Thus, no analysis or proposals regarding methane emissions by IPPU are presented in this document. was the share of the IPPU sector in the total national methane emissions in 2020

3 Measures to reduce Brazil's emissions

3.1. Cattle Raising

The mitigation of methane emissions in the agricultural and Cattle Raising sector comprises different handling practices and technologies. Among the various benefits of mitigating methane, there is the great opportunity associated with the continuous meeting of the growing demand for agricultural products, driven by the search for increased productivity, along with the promotion of adaptation of production systems to the effects of climate emergency, contributing to more sustainable, low-carbon and continuous long-term activities.

Several of these management practices and technologies are already known and applicable, and it is increasingly necessary that their adoption, expansion, and maintenance are encouraged for all production models and scales. The following are the main methane mitigation routes.

3.1.1 Livestock Waste Treatment (LWT)

Livestock Waste Treatment (LWT) is part of the management of animal waste, which includes the collection, storage, treatment and potential agricultural uses of the by-products generated. It is methane, as well as nitrous oxide, mitigation strategy, with the adoption of technologies and systems that reduce the conversion of organic matter into methane, such as biodigestion and composting. Thus, they enable the treatment and environmentally appropriate disposal of animal waste (MCTI, 2020c).

The adoption and consolidation of the use of LWT contribute to the sanitation and environmental regularity of rural properties with livestock activity, with greater protection of soil and water bodies, besides enabling economic gains with the possibility of using energy and organic inputs generated by the byproducts of the treatment routes used, when economically feasible (Mapa, 2012).

The treatment route via biodigestion consists of the decomposition of organic matter by microorganisms present in the waste, through anaerobic digestion, generating biogas as one of its products. Biomethane can be extracted from biogas, used for the reuse of energy by generating electricity and heat, and can also be burned if there is no such reuse (flares). Digestate, another by-product of biogas, can be used in agricultural production as a biofertilizer, as it contains essential nutrients such as NPK. Thus, the reduction of methane emission is guaranteed when the treatment of waste is performed by replacing the use of anaerobic lagoon and manure lagoon technologies, the most common in the country, for technologies such as biodigestion and composting (Mapa, 2019, 2021).

Another methane mitigation strategy is the use of composting, a technique based on a biological treatment by controlling the mixture between manure and organic matter added as a carbon source (wood shavings, sawdust and straw), and you can use the resulting biomass as an agricultural input due to the high concentration of nutrients. Thus, biomass with low methane emissions is generated, avoiding the emissions that would result from the anaerobic decomposition of the waste if it were left untreated, and it can be a product easily transportable by farms as it is in a solid state (Mapa, 2019).

In its first cycle, the ABC Plan had as a domestic goal the incentive for the adoption and expansion of animal waste treatment, with the use of biogas and organic compounds generated in its process. For this, it was foreseen for the year 2020 the treatment of 4.4 million m³ of animal waste, with the potential to mitigate 6.9 Mt CO_2e (Mapa, 2012).

In its cycle launched in 2021, the new ABC+ Plan reformulated LWT, which is now called animal production waste management (APWM). It also incorporated other residues from livestock, resulting from animal husbandry. Examples of these residues are cleaning water mixtures, food leftovers, poultry litter, carcass and dead animal remains, physiological residues and other residues that require previous treatment. In addition, the APWM continues to promote the use of by-products obtained from these treatment processes, such as bioenergy and biofertilizers.

Thus, the goal is that by 2030 MRPA is responsible for the treatment of 208.4 million m³ of animal waste, with a mitigation potential of 277.80 Mt CO_2e. This expected volume is based on the assumption that 27% of the total waste generated by animal production systems will be treated via biodigestion and composting (Mapa, 2021).

Following the methodology adopted by the Fourth National Inventory (MCTI, 2020c), methane emission reduction can be obtained to the extent that the animal waste management systems employed for the different animal productions are replaced by other more efficient systems. Thus, the mitigation potential is associated with the amount of waste treated by systems that result in lower methane emissions, such as the use of digesters replacing anaerobic lagoons or the use of composting in place of handling waste in solid storage.

3.1.2 Intensive Pasture Termination (IPT)

Intensive Pasture Termination is one of the new technologies included in the new cycle of the ABC+ Plan, seeking not only the mitigation of emissions, especially methane, but also contributing to the adaptation of the animal production system, through more efficient use of pastures.

The mitigation promoted by IPT is based on intensified feed management, which makes available a greater amount of energy consumed by beef cattle in the rearing and fattening phases of their slaughter cycle. Thus, the animals can be slaughtered earlier, with a shorter fattening time to reach the ideal weight for slaughter, along with changes promoted in their digestive system by the type and quality of food sources provided. The greater availability of feed avoids the "rebound effect" in cattle, so the mass gain increases continuously. This can be achieved mainly through the addition of grains, flours, feed additives, and by-products in the confinement, semi-confinement, and pasture supplementation systems (Mapa, 2021).

More intensive animal husbandry systems contribute to higher productivity, for example by improving the quality of the pastures already used and introducing semi-confinement and confinement rotation systems. This intensification means a reduction in emissions intensity per carcass produced, due to the shorter lifespan of cattle, and can reduce methane emissions per kilo of meat produced by up to 30%, even with a possible increase in daily methane emissions (Berndt et al., 2013).

An example of this was the results of Cardoso et al. (2016), in a study where intensification of beef cattle production through pastures using fertilizers, forage legumes, supplements, and concentrates, based on an average production pattern based on pastures with low input use, has been shown to reduce the area required for the production of 1 kg carcass, with an increase in carcass production of about 51% per herd, in addition to reducing emissions by about 49.6%, from 58.3 kg CO_2e/kg carcass to as low as 29.4 kg CO_2e/kg carcass.

16,2 $MtCO_2e$

is the reduction potential by 2030 of the intensive termination technique.

The ABC+ Plan aims to increase the average number of cattle slaughtered through IPT to 500,000 per year by 2030, which equates to 5 million cattle slaughtered. Over the decade, slaughtering this herd through the use of IPT has the potential to reduce around 16.25 Mt CO_2e, based on a possible average reduction value of 11.40 kg CO_2e/kg carcass. The monitoring of the target is based on the number of cattle up to 36 months old slaughtered and the number of farms using IPT (Mapa, 2021). At present, there is no official data on the monitoring of the number of animals slaughtered in confinement, semi-confinement, and pasture supplementation systems.

Based on the same study by Cardoso et al. (2016), on which the ABC+ Plan is based, it can be estimated that the methane reduction associated with the use of IPT is about 42.3% for each kilo of methane per kilo of bovine carcass slaughtered (kg CH_4/kg carcass). This value was determined from the average difference in methane emissions from less intensive to more intensive production scenarios. The less intensive scenarios consider production systems characterized by cattle production on pasture, from degraded pastures to pastures with legume use and pastures improved with nitrogen fertilization through the use of Guinea grass (*Panicum maximum*). The more intensive scenario is defined by feed use and confinement in the 75 days before the end of fattening, with pre-feeding also on pasture fertilized with Guinea grass.

3.1.3. Animal genetic improvement (MGA)

Reducing methane emissions in animal husbandry can also be achieved through genetic improvement by encouraging the selection of traits associated with lower methane emissions per animal in crossing. In this way, a continuous increase in productivity can be ensured, which is accompanied by a reduction in the emission intensity of products such as meat and milk, as well as more sustainable production systems through more efficient and better-adapted animals (Pickering et al., 2015; Pinto, 2019).

With the help of MGA, better indicators for the productivity of the animals are to be achieved with lower emission intensity by either emitting fewer emissions and/or increasing production, such as the shorter period of their reproduction, resistance to disease, younger age at weaning, faster slaughter due to more efficient mass gain, longer lactation or longer production time, as in the case of dairy cows.

Genetic variation affecting methane yield from animal production takes into account the reduction of enteric fermentation and the stability of how this process occurs. Although these traits are already known, the magnitude of methane reduction potential through a selection of these traits is not always fully known or easily determined, depending on the other traits and variables associated with what these traits are involved in, in addition to specific techniques and equipment for direct measurement. This measurement limitation can be circumvented by selecting traits indirectly related to productivity via animal performance metrics such as dry matter consumption, milk production, and mass gain (Pickering et al., 2015; Congio et al., 2021).

In Brazil, a joint study by CNA (Confederation of Agriculture and Livestock) and Cepea (Center for Advanced Studies in Applied Economics) of Esalq/USP was conducted in 2018 to evaluate cattle productivity gains in the states of Acre, Bahia, Maranhão, Pará, and Tocantins after investments in genetic improvements and feeding. A 14.8% increase in productivity was observed, from 4.87 arrobas per hectare (@/ha) between 2007 and 2012 to 5.59 @/ha in the period between 2013 and 2017, in addition to an increase in the reproduction rate of the herd by 23%.

Another study prepared by Cepea (2015) analyzed full-cycle (breeding, rearing, and fattening) farms that invested in genetics, which had a net margin of R$1,926 per hectare, while the other typical farms in the region without investment in genetics had a value of R$32.42 per hectare. This shows the economic and environmental benefits of how genetic investments can positively impact livestock production, even more so when the focus is on reducing greenhouse gas emissions.

The potential to reduce methane emissions associated with the use of MGA can vary greatly depending on the trait selected for the animal.

as well as the methane emissions metric selected to evaluate mitigation, which may be based on emissions per animal product (milk and meat). Therefore, we used as a basis of reduction in methane emissions through MGA for dairy cattle of 37.6%, using the intensity of methane emissions from milk production (g CH_4/kg milk) according to Congio et al. (2021). For cattle, on the other hand, the 10.8% reduction percentage is based on the methane emission intensity per meat production (g CH_4/kg meat), according to Maciel et al. (2019).

3.1.4. Improvement and manipulation of animal diet

About 2 to 12% of the gross energy consumed by ruminants is lost through conversion to methane. These fluctuations in methane production are related to the degree of digestibility of the food that makes up the animal diet and the amount of fermented carbohydrate and hydrogen gas (H_2) present in the rumen that is used as an energy source by the methanogenic archaea, resulting in the production of methane during the enteric fermentation process. Thus, methane emission is indicative of energy loss in the agricultural and livestock production system (Machado et al., 2011). This energy loss due to enteric fermentation in the rumen is related to factors related to the genetic traits of the animal, as well as variables related to the quantity and quality of food available for consumption, types of carbohydrates, digestibility of food, and other resources used for their diet (Sene et al., 2019).

Therefore, any methane reduction strategy through the improvement and manipulation of the animal diet must balance the reduction of methane from enteric fermentation with the continuous increase of productivity, mainly through improvements in pasture conditions and diet composition offered to animals (Machado et al., 2011).

According to Mapbiomas (2022), the country's total grazing area was 154.7 million hectares in 2020, 52% of which was in some state of deterioration. This grazing area is the main source of energy in cattle feed, with methane emissions mainly influenced by the low proportion of non-fibrous carbohydrates and the higher proportion of fiber and lignin in the forage offered. The type and quality of the grasses used, as well as the productivity of these pastures, affect the energy efficiency of the diets practiced, especially during dry periods (Sene et al., 2019).

To promote sustainable intensification of animal husbandry with a reduction in methane emission intensity from animal production, it is, therefore, necessary to apply best practices in grazing and feed management.

In addition to better pasture management, other feeding strategies can be used to ensure ruminant performance with productivity increases and methane reductions.

The other forms of methane reduction through feeding are related to changing rumen conditions at the time of enteric fermentation and complement the strategies of considering pasture as a forage source (low energy, high fiber feed). Therefore, possible strategies for feeding ruminants include increasing protein intake in the diet, adding lipids (such as soybean cake, linseed oil, palm oil. and cottonseed), increasing feeding levels, and using protein-energy supplements through concentrates (such as corn, cottonseed, soybean meal, soybean hulls) (Congio et al., 2021).

52%
of the pasture lands of the country are degraded to a certain degree

This is supplemented by the provision of concentrated feed when seeking to ensure that the nutritional demand is met when it cannot be met by the pasture, particularly during drier periods or when animal performance is to be increased. Thus, the performance of the animals is improved through higher fodder intake, better digestibility, and better nutrient uptake, reducing the age of slaughter and contributing to more quantity and quality in carcass production and consequently reducing methane emissions from the product (Anjos, 2019; Sene et al., 2019).

The estimated methane reduction potential for livestock feeding improvements for cattle and dairy cattle only is based on the methane emissions estimated by Congio et al. (2021). Considering the intensity of methane emission from animal products such as milk (g CH_4/kg milk) and from mass gain (g CH_4/kg mass gained), it is possible to obtain the average of the values presented for feeding strategies that take into account the adoption of practices such as pasture management with continuous and rotational stocking when feeding forages with increased protein, using cottonseed-based concentrates, increasing lipids in the diet, and increasing dietary content. From these practices, an average methane reduction value of 31.6% and 13.9% was obtained for cattle and dairy cattle, respectively.

3.1.5. Manipulation of rumen fermentation

Another strategy to reduce methane emissions is the manipulation of rumen fermentation, whereby the reduction is achieved by interfering with rumen activity. It should be based on reducing the production of H_2 already produced and on changing the activity of the methanogenic (archaea) microorganisms by inhibiting or reducing their population in the rumen. This is intended to balance the reduction in methane emissions from enteric fermentation while increasing the productivity of products such as meat and milk, reducing emissions intensity per product unit or area (Machado et al., 2011).

One way to manipulate the rumen is through the use of additives, a strategy aimed at increasing feed efficiency and reducing methane formation in ruminants, contributing to better utilization and absorption of the food administered. The effect of its use is mainly due to the modification of the rumen ecosystem, with the inhibition of the process carried out by archaea, which contributes to the optimization of animal metabolism, better conversion of food into energy, and the use of its nutrients.

Among the different types of additives, the most commonly used are ionophores, yeasts, organic acids, natural extracts, the addition of lipids and others that are consumed with food (Anjos, 2019).

Ionophores are drug additives with antimicrobial activity that manipulate enteric fermentation by altering the growth or elimination (defaunation) of H_2-producing microorganisms, being able to reduce methane production by up to 25% and feed consumption by 4% while maintaining animal performance (Machado et al., 2011). Only a few types of ionophores are approved and their use is not sustained over long periods as they are not a viable methane reduction strategy in the long term precisely because of the drug-additive nature and the ability of the rumen ecosystem to adapt to its effects. Therefore, several other natural inhibitors have come to the fore (Anjos, 2019).

Yeasts are fungi that serve to improve the digestion of the dry matter ingested from the feed, especially fiber (Anjos, 2019). Natural extracts are an alternative to chemical additives, derived from compounds that protect plants from fungi, bacteria, insects, and even herbivores. The use of additives containing tannins, saponins, and essential oils stands out (Machado et al., 2011).

From national studies considering the effects produced by direct manipulation of rumen activity through diets, supplementation, and the use of additives to reduce and suppress H_2 generation, as well as changes in methanogenic microorganisms in beef cattle, an average emission factor of 37.7 kg CH_4/head/year was obtained, about 37.4% less than the average emission from cattle by enteric fermentation reported in the last national inventory, which indicates the potential that these methane mitigation strategies have if properly applied, despite the use of resources such as additives in pasture-based production systems being challenging (Berndt et al., 2013; MCTI, 2020b).

To estimate the methane reduction potential through the strategy of manipulating rumen fermentation, the method developed by Arndt et al. (2021) was used, resulting in a 35% reduction in daily methane emissions (g CH_4/day).

35%

is the potential for reducing methane emissions by manipulating rumen fermentation

3.1.6. Management methods in irrigated rice farming

The reduction of methane emissions in irrigated rice farming is based on the introduction of better management methods and land use, especially in Rio Grande do Sul, Brazil's top rice producer (Embrapa Arroz e Feijão, 2022; Irga, 2022).

There are different types of soil tillage systems in the state of Rio Grande do Sul, such as the conventional tillage system, the advanced tillage system, and others. In the advanced tillage system, more soil conservationist practices are used, such as minimum tillage and mainly no-tillage, before rice sowing.

From 1990 to 2016, the area cultivated with advanced tillage system increased from 14.1% to 64.1%, resulting in reduced methane emissions, because, while in the conventional system soil turning operations occur before rice sowing and the permanence of vegetable organic matter that will be decomposed anaerobically because it is produced under a continuous irrigation system, in the advance tillage system operations take place in periods when the soil is drained, promoting the aerobic decomposition of these residues and, therefore, reducing methane emissions.

This advanced tillage helps reduce planting delays and productivity losses by starting soon after harvest, resulting in emission gains and productivity gains (MCTI, 2020d). Changing the type of tillage results in a potential methane reduction of about 22% (MCTI, 2020d).

This change in tillage is also confirmed by Zschornack (2011), who measured emissions of 537.38 kg CH_4/ha, 391.24 kg CH^4/ha, and 372.46 kg Ch_4/ha for an irrigated rice area with conventional tillage, minimal tillage, and no-tillage, respectively. These values correspond to a reduction in emissions of 27.2% with minimal tillage and 30.7% with no tillage compared to conventional tillage. Thus, with advanced tillage techniques, it is possible to reduce methane emissions per hectare by 28.9% without reducing the productivity of rice crops.

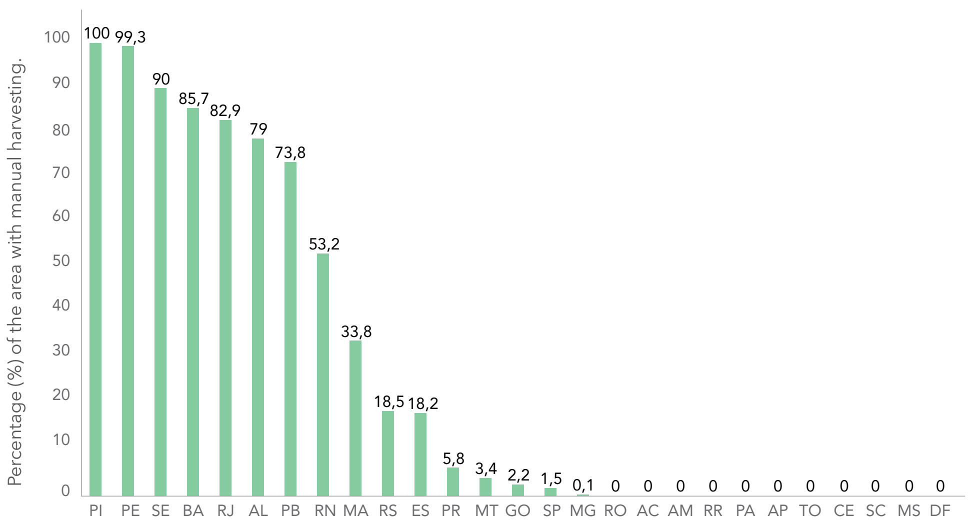
Another management practice that can reduce methane emissions is water management in irrigated production systems. By draining the water line of continuously flooded soils in the irrigation regime, it is possible to reduce emissions without loss of productivity. According to Zschornack (2011) and Camargo (2015), methane emission rates for intermittent irrigation systems were lower than those for continuous irrigation systems, at 40.8% and 47.8%, respectively.

3.1.7. Reducing the burning of agricultural sugarcane residues

The reduction in methane emissions from agricultural sugarcane residue burning is related to the expansion of mechanized harvesting areas, which replaces manual harvesting. Burning of sugarcane residues is still a pre-harvest practice to facilitate field cleaning and the harvesting process. The use of mechanized harvesting can completely eliminate the emissions associated with this phase of agricultural production, in addition to secondary benefits such as reducing the risk of fire and improving air quality and the safety of those who carry out the harvest in the cultivated areas (MCTI, 2020e).

In this way, the potential for reducing emissions can reach rates close to 100% concerning the reduction in the use of fire, with reductions in methane emissions accompanied by increased area for mechanized harvesting. Conab (2021) surveys in states where harvesting is still done by hand. Figure 27 shows the percentage of manual harvesting in cultivated areas in 2020.

Figure 27. Percentage of sugarcane area with manual harvesting



Source: CONAB (2021)

To achieve universal mechanized harvesting, some regulations set targets for its use and prohibit the practice of using fire, in addition to joint public and private initiatives, as in the case of the Environmental Protocol in the state of São Paulo. Aiming at promoting the sustainable development of the sugarcane sector in the state, the Protocol went beyond the current regulations (State Law No. 10,547/2000, amended by State Law No. 11,241/2002) by setting its target to reduce advanced sugarcane burning to what was already provided by state regulations, in which it was expected to achieve 70% of the sugarcane area without the use of fire by 2011, while the regulations for the same year provided for 50% of the area (IEA, 2012). Other states have also passed laws to control and prevent burning, such as Mato Grosso do Sul (State Law No. 3,357/2007), Minas Gerais (Joint Resolution SEMAD/IEF No. 2,988/2020), and Goiás (State Law No. 15,834/2006).

3.1.8. Other ways to reduce methane in agricultural production

In addition to the reduction methods already mentioned, some solutions are not yet widely used or are in the research and development stage. In addition to the reduction potential that can be achieved within the activities of the farm, the reduction potential arising from the different links and actors of the agro-industrial system of the sector can also be considered, taking into account not only the stages of production but also the stages related to inputs, processing, distribution, and consumption.

An example of this is vaccination against methanogenic microorganisms, which are responsible for methane production in the rumen. It is a practice that needs further study to ensure the desired effects (Machado et al., 2011; Subharat et al., 2015). Other forms of methane mitigation are associated with reducing food loss and waste, in addition to associated changes in dietary habits and food consumption (Unep and Climate and Clean Air Coalition, 2021).

Finally, another strategy with the potential to reduce methane emissions, despite variations in its capacity, is the use of algae in animal feed, mainly for cattle and dairy cattle. Several results indicate the reduction of methane production by using small doses when feeding ruminants, which shows the possibility of evaluating the methane reduction potential of different algae species.

3.2. Land use change and forests

In the area of land use change and forests, combating slash-and-burn is the most important measure to reduce methane emissions from combustion associated or not with deforestation. First, tackling deforestation plays a central role in reducing the burns associated with developing new areas. In addition, fire is used in agriculture and livestock and as an aid in deforestation, which is a cultural habit in most parts of Brazil. Fire moratoriums and campaigns to reduce the use of fire in agriculture and livestock, accompanied by effective enforcement, are important strategies to reduce emissions associated with these events.

Together, the prevention and suppression of forest fires in natural areas that are largely anthropogenic in origin (Schumacher et al., 2020) is a priority action. Training and funding for brigades to fight forest fires, both from the fire department and from federal agencies such as PrevFogo/Ibama, will have an impact on fighting these fires effectively. In addition, the role of these agencies in fire prevention includes the installation and maintenance of firebreaks near natural areas, such as Conservation Units, in addition to prescribed burning to reduce combustible material. These are tools currently used in some areas of the Cerrado biome to mitigate the occurrence and extent of fire events in areas with native vegetation.

In the case of methane emissions from reservoirs, we propose to review and pause the design and installation of new hydroelectric power plants. Although current Brazilian legislation requires the removal of vegetation before backfilling dams, significant amounts of organic matter remain in the soil, which can lead to significant emissions in reservoirs of hydroelectric power plants (Fearnside, 2016).

The three most promising strategies for limiting the share of hydroelectric power plants in national methane emissions are therefore known to be the following: (1) Limiting the nutrient content of reservoirs by removing vegetation before filling (de Faria et al., 2015; Fearnside, 2016) and by designing reservoirs away from or upstream from significant exogenous nutrient sources (e.g. agricultural land) (Deemer et al., 2016); (2) designing run-of-river reservoirs that flood as little area as possible, and (3) designing shallower turbines that do not move deep water where methane concentrations are higher (IPCC, 2019). However, these measures must be taken before installation, in the design phase of the plants and their reservoirs.

For plants already installed, the time since flooding will make a big difference in decreasing methane emissions at a rate not yet understood.

3.3. Waste treatment

Brazil has an important legal framework for waste management that contributes to the sector's potential to reduce greenhouse gas emissions, such as Law No. 12,035/2010 (which establishes the National Policy on Solid Waste) and Law No. 11,448/2007 (which establishes national guidelines for basic sanitation). These policies include sustainable waste management and promote practices to reduce the generation, reuse, recycle, and use of the energy of biogas produced in landfills and wastewater treatment plants.

There are also instruments such as the National Plan on Solid Waste (Planares)[8] and the National Sanitation Plan (Plansab)[9].

[8] Planares – https://bit.ly/3cQHz0c
[9] Plansab – https://bit.ly/3TM7qqH

It is also worth mentioning the new law No. 14,026/2020[10], which amends the Legal Framework for Basic Sanitation and has as one of its main objectives the promotion of universal access and the effective provision of basic sanitation, to guarantee 99% of the population access to drinking water and to 90% the collection and treatment of wastewater by 31 December 2033. In addition, the framework also provides instruments for greater private sector involvement in this sector. However, the climate issue is not mentioned in the document.

The production of biogas and biomethane in Brazil has the greatest potential for the recovery of CH_4 from the treatment and final disposal of municipal and agricultural solid waste and liquid effluents (domestic and industrial). According to EPE[11], the theoretical potential to produce 4.9 billion Nm³ (standard cubic meters) of biogas in 2019 was observed. However, translating the theoretical potential into an absolute value is a complex task that depends on several factors, especially related to the universalization of sanitation, such as the population served, the percentage served by anaerobic treatment systems, and the biogas production factor. According to Probiogás[12], only 4% of the biogas produced is currently used, as a high percentage of the population still does not have access to adequate sanitation facilities.

The National Association and Union of Private Concessionaires of Water and Sewage Services (Abicon/Sindicon) produced a document called Legislative Agenda of Private Sanitation Operators[13] presenting proposals to facilitate the implementation of the new regulatory framework of basic sanitation from the perspective of the private sector. This material highlights the importance of Draft Bill 6559/2013, which provides for rules on the exploitation of biogas since it can be an instrument to encourage the appropriate use of biogas generated in landfills and wastewater treatment plants. Currently, the sanitation service providers discard the use of the methane generated, especially considering the production costs versus the expectations of recovering these costs (Abcon Sindcon, 2022).

Recently, in March 2022, the National Program to Reduce Methane from Organic Waste – Methane Zero was launched, which aims to use solid waste to produce renewable and economically viable energy. Proper treatment of urban and rural waste produces biomethane[14], a gaseous biofuel that has various uses such as electricity generation, the use in vehicles, and the possible feeding into natural gas grids (MMA, 2022).

The launching document of the Zero Methane program[15] foresees specific credit and financing lines, aiming at the development of the following actions (MMA,2022):

A. *installation of biodigesters, especially in rural areas;*

B. *installation of a system to purify biogas and produce and compress biomethane;*

C. *creation of green points and corridors to supply biomethane-powered heavy vehicles such as buses, trucks, and farm implements, which will help reduce greenhouse gases and improve air quality;*

D. *introduction of technologies that allow the use of sustainable fuels and low greenhouse gas emissions in Otto or Diesel cycle internal combustion engines, in compliance with the standards set by the competent bodies.*

E. *use or development of vehicle technology*

F. *tax breaks for infrastructure related to biogas and biomethane projects*

Based on the total waste generation per day in Brazil, the program estimates the theoretical capacity to use 120 million m³ of biomethane per day, a capacity larger than that of the Brazil-Bolivia natural gas pipeline (MMA, 2022). However, it should be noted that the use of biomethane depends on the distribution routes and the presence of pipelines at strategic points in the country.

[10] Law No. 14,026/2020 – https://bit.ly/3evV4Da
[11] EPE VII Biogas Forum - https://bit.ly/3TLgRXt
[12] Probiogás (2015) – https://bit.ly/3qcWZyT
[13] Abcon Sindcon – https://bit.ly/3qcGC5o
[14] According to ANP Resolution No. 685/2017, biomethane is purified biogas that has a mandatory minimum composition of 90% methane (CH_4).
[15] MMA – https://bit.ly/3AU9WCL

The lack of a physical structure hinders the distribution of this fuel and reduces its utilization potential. The maximum exploitation of the potential to reduce CH_4 emissions through the use of biogas and biomethane depends on factors such as the widespread collection and treatment of wastewater and disposal of solid waste, federal and state government support to ensure that municipalities have sufficient funds to achieve the goals of the PNRS, as well as broad access to the available technologies for SUW management and unlimited support measures.

In general, the most relevant reduction measures relate to the implementation of sectoral policies and programs (e.g. National Plan on Solid Waste, Legal Framework for Basic Sanitation, Zero Methane National Program) and also to the measures previously established in the Climate Observatory's Proposal for Brazil's 2nd Nationally Determined Contribution under the Paris Agreement.

The main mitigation strategies for the waste sector can be achieved with a significant number of low- and medium-cost strategies since most technologies are already available at a level that allows their deployment at an economic scale. Solutions such as separating and treating organic waste through composting and anaerobic digestion, converting it into compost and bioenergy; increasing biogas recovery at Wastewater Treatment Plants (WWTPs); and using biogas generated at landfills have the potential to reduce methane emissions in the waste sector by 30-35% by 2030 (CCAC, 2021). For these solutions to be feasible, the sector's budgetary investment must be increased to reach at least 1% of the country's GDP to guarantee the waste sector an average of R$20 billion per year (CEBDS, 2020).

Among the already-known solutions with the greatest reduction potential, the following stand out in this context:

- **Solid waste:**
  - Gradually reduce the disposal of organic waste in landfills until this practice is eliminated;
  - Expand and promote energy recovery and landfill gas burning;
  - Diversify solid waste treatment routes, expanding biological treatment of solid waste;
  - Reduce waste generation rates in major centers.
- **Liquid effluent treatment:**
  - Use for secondary/tertiary anaerobic treatment with biogas recovery and use;
  - Evaluate measures for more effective and sustainable treatment of water and domestic wastewater to minimize greenhouse gas emissions.

These strategic actions and mechanisms that can enable more sustainable waste management have been detailed in the SEEG Soluções initiative, a process through which the Climate Observatory proposed to map and compile mitigation and adaptation actions at the local level, to promote sustainable development with emission reductions and instrumentalize and engaging the key stakeholders to meet this challenge. Measures to reduce Brazil's emissions

3.4. Energy sector

As discussed in section 2.1.5, the burning of firewood for home cooking is one of the largest sources of methane emissions in the energy sector. Overcoming this use of firewood - which points to the lack of access to more efficient energy sources and the resulting social vulnerability - is therefore also a way to reduce emissions. Over time, replacing firewood with gas stoves - fueled by liquefied petroleum gas (LPG) or natural gas (NG) - has resulted in significant reductions in greenhouse gas emissions. This substitution led to an immediate improvement in the quality of life for people who had to collect firewood for cooking and, in addition, were exposed to the air pollution in their homes caused by the burning of this biomass.

At first glance, the case that substituting biofuels with fossil fuels leads to lower greenhouse gas emissions may seem counterintuitive, since carbon dioxide (CO_2) emissions from the combustion of biofuels should not be included in the total emissions balance as the biomass absorbed the same amount of CO_2 from the atmosphere during its growth. It happens that burning firewood for cooking in poor conditions is very inefficient and emits more than twice as much greenhouse gases (CO_2, CH_4, and nitrous oxide (N_2O) expressed in carbon dioxide equivalent (CO_2e)) than LPG and NG, as shown in the table below, the last column of which gives the amount of greenhouse gas emissions per useful energy output provided by the fuels. The "r" column gives the efficiency of the stoves for each fuel type according to the Useul Energy Balance.

Table 8.
Emission factors for direct residential heating

	KGCO_2/TJ	kgCH_4/TJ	kgN_2O/TJ	kgCO_2e/TJ	r	kgCO_2e/useful TJ
Dry natural gas	56.100	1.0	1.00	56,393.0	50%	112.786
LPG	63.100	1.1	1.00	63,395.8	50%	126.792
Firewood	-	932.0	9.06	28,496.9	10%	284.969

Source: prepared based on the SEEG and the Useful Energy Balance

Another way to improve home cooking, independent of the use of fossil fuels, is to use modern, controlled-burning wood-burning stoves[16]. These stoves are designed to burn wood efficiently and not cause indoor air pollution. In addition, it must be ensured that the fuel used has a certified origin and is not associated with deforestation. There is also the alternative of using electric stoves, which, combined with a low-carbon electricity mix, can further reduce greenhouse gas emissions.

In general, and beyond using energy to cook food, Increasing energy efficiency across all fuel consumption segments is also a way to reduce methane emissions by reducing actual fuel combustion.

16 The Climate and Clean Air Coalition and the Drawdown Project are committed to the solution: <https://www.ccacoalition.org/en/content/short-lived-climate-pollutant-solutions&sa=D&source=docs&ust=1648228341939753&usg=AOvVaw1HsDFK6OXa5uYz q9wg6-oa>, acesso em 16 de março de 2022; e <https://drawdown.org/solutions/improved-clean-cookstoves&sa=D&source=docs&u st=1648228341959655&usg=AOvVaw1y3SzGkohDWgyh1bfbl4t8>, acesso em 16 de março de 2022.

As discussed in section 2.1.5, fugitive emissions from the oil and natural gas industry are another important source of methane emissions in the energy sector. Recently, this industry has announced global efforts to control such emissions, one example being the Aiming for Zero Methane Emissions Initiative, launched in March 2022 by the Oil & Gas Climate Initiative in light of the Global Methane Pledge. The initiative calls for the elimination of virtually all methane emissions from oil and gas facilities operated by signatories by 2030, with each party being responsible for determining how it will achieve that goal. Brazil's Petrobras is among the signatory companies with a target to reduce its emissions intensity by 40% by 2025 compared to 2015 levels.

To point the way toward reducing methane emissions, to meet the Global Methane Pledge, the following actions contribute to reducing emissions from the main sources of methane in the energy sector:

- Replacing traditional (or precarious) wood-burning stoves with modern wood-burning stoves, which are more efficient;
- Replacing the use of firewood with LPG in households;
- Replacing the use of fuel with electric energy in residences;
- Reducing the intensity of fugitive methane emissions in oil and gas exploration and production;
- Reducing mineral coal exploration;
- Adopting energy efficiency measures in industry, reducing the burning of fuels.

4 Goal for the reduction of methane emissions

This chapter sought to assess (i) the path of methane emissions in Brazil by 2030 considering current mitigation policies in the country (BAU); (ii) the potential for reducing methane emissions in Brazil in the long term; and (iii) a proposal for an emission reduction target achievable by Brazil within the 2030 horizon, compatible with the global target of reducing emissions by 30%.

First, we present the analysis for each sector and, in the end, the aggregated values for all of Brazil.

4.1. Cattle Raising

For the projection of methane emissions from the agricultural and livestock sector from 2021 to 2030, the same methodology as in the Fourth National Inventory (MCTI, 2020a) was used and the projection of activity data necessary for the calculation of emissions from the subsectors of animal waste management, enteric fermentation, rice cultivation, and burning of agricultural residues was carried out.

For the subsector of animal waste management, the data of the entire cattle and milking cow herd populations were projected, based on the trend of increase of these herds presented by the projections made for the Brazilian agribusiness until 2029, according to Fiesp (2020). For the herd of confined cattle, data from Annualpec (2021) of beef cattle in a confinement system in 2020 were used, and the projection by Barbosa et al. (2015) was used for the number of heads of cattle in confinement until the year 2030.

For the total pig population, the projection data of pork production (in tons) up to 2030 according to MAPA (2021b) were used. For the herd of reproductive pigs, the data were split annually up to 2030 according to the percentage of this herd in the total herd. Subsequently, the pig herd was divided into industrial and subsistence herds according to the methodology of the Fourth Inventory.

For the other livestock, such as horses, buffaloes, goats, sheep, donkeys, mules, all chickens, chickens, quails, and roosters, chickens and chicks, the values were projected based on the growth and downward trend shown between 2010 and 2020.

For the enteric fermentation subsector, we used the same data that was intended for animal waste management, except for data from pig herds, total chickens, chickens, quails and roosters, chickens and chicks. Data from the projections made were also used

For the irrigated rice subsector, the Mapa projection (2021b) of the harvested area and rice production data (irrigated and non-irrigated) through 2030 was used. Thereafter, 2020 irrigated rice area and production data provided by Embrapa Arroz e Feijão (2021) were used.

For the burning of the agricultural residues subsector, both harvested area and sugar cane production based on Mapa's (2021b) projection up to 2030 were used. The average annual change from 2011 to 2021 was used for the projection of the area with a manual harvest.

After projecting all the necessary data on livestock and agricultural activities, methane emissions can be calculated for three different mitigation scenarios: the emissions scenario taking into account the already planned emission reduction policies and measures (BAU), the scenario with the proposed target of a 30% reduction in emissions from the sector by 2030 compared to 2020 (Target), and finally the theoretical reduction potential (Potential) scenario.

For each scenario, the mitigation strategies were applied to the respective methane emission sources and activities, using the mitigation potential according to the assumptions and adoption rates of these practices and mitigation technologies.

It is worth noting that for the enteric fermentation subsector, emission mitigation strategies of intensive pasture termination (IPT), animal genetic improvement (MGA), and animal nutrition improvement and manipulation had the calculation based on the application of potential methane reduction per unit of animal product (carcass and milk) based on assumptions about adoption rates of management practices and related technologies. For the rumen fermentation manipulation mitigation strategy, its mitigation potential was estimated by multiplying the emission factor of each animal herd category by the reduction potential assumed for that mitigation pathway. In the end, the mitigation value of each strategy was summed to compare it with the BAU emissions scenario.

For the subsector of animal waste management, irrigation rice cultivation, and burning of agricultural residues, the estimated mitigation potential resulted from changing emission factors and calculation parameters that represented the premises and adoption rates expected for each scenario evaluated.

Table 09 shows the assumptions used to calculate the estimates for each subsector for the projected scenarios (BAU, Target and Potential), considering the adoption rates for the deployment of methane reduction processes and technologies and the sources and emitting activities for which the reductions were considered according to the strategy covered.

Table 9.
Considerations for calculating the mitigation potential of each mitigation strategy adopted for the BAU, Target, and Potential emissions scenarios.

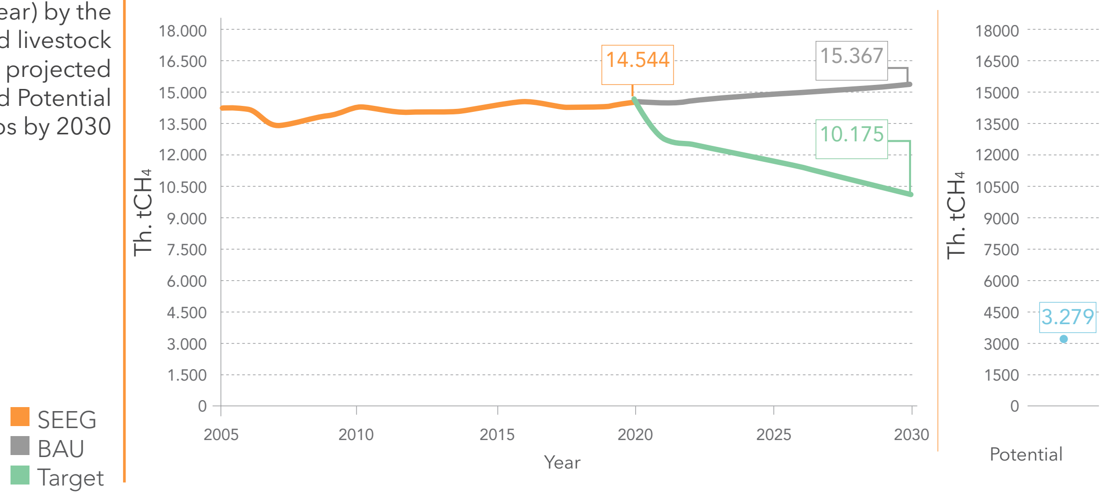
SUBSECTOR	MITIGATION STRATEGY	BAU	TARGET	POTENTIAL
Management of Animal Waste	Livestock Waste Treatment (LWT)	**Industrial Pigs:** Increase the share of the Biodigester in the Liquid/Slurry portion (with natural crust cover) by 27% and complete conversion (100%) of the Anaerobic Lagoon system to Biodigester	**Industrial Pigs:** Increase the share of Biodigester in the Liquid/Slurry portion (with natural crust cover) by 45% and complete conversion (100%) of the Anaerobic Lagoon system to Biodigester **Beef cattle (confined):** Increase the share of the Dry Lot system to an average treatment share of 92% when replacing the Solid Storage system **Dairy cattle (high production):** Increase the share of Biodigester system to an average treatment share of 11.5% when replacing the Anaerobic Lagoon system **Dairy cattle (low production):** Total conversion (100%) of the Solid Storage system for Confinement Composting (Dry Lot) in Animals	**Industrial Pigs:** Increase the share of Biodigester in relation to Liquid/ Slurry (with natural crust cover) by 100% and complete conversion (100%) of the Anaerobic Lagoon system to Biodigester **Beef cattle (confined):** Replace 100% of the Solid Storage system for Confinement Floor (Dry Lot) **Dairy cattle (high production):** Pasture System remains the same and replaces 100% of the Anaerobic Lagoon system for Biodigester **Dairy cattle (low production):** Total conversion (100%) of the Solid Storage system for Composting
Enteric fermentation	Termination	Slaughter of 5 million heads until 2030 (annual average of 500,000 heads per year until 2030) (Source: ABC+ Plan)	Around 30% of animals slaughtered through IPT by 2030 (slaughter of 91.3 million heads by 2030)	Reach 100% of cattle slaughtered through IPT by 2030 (slaughter of 304.4 million heads by 2030)
	Animal Genetic Improvement (MGA)	-	**Beef and Dairy Cattle:** 3% annual increase in beef and dairy cattle production generated by MGA	**Beef and Dairy Cattle:** 10% annual increase in beef and dairy cattle production generated by MGA
	Manipulation of Rumen Fermentation	-	**Beef (confined) and Dairy (high production) Cattle:** 4.5% increase in beef and dairy cattle production generated by Manipulation of Rumen Fermentation	**Beef (confined) and Dairy (high production) Cattle:** 10% annual increase in beef and dairy cattle production generated by Manipulation of Rumen Fermentation
	Improvement and Manipulation of Animal Diet	-	**Beef and Dairy Cattle:** 6.5% annual increase in beef and dairy cattle a on better diet	**Beef and Dairy Cattle:** 10% annual increase in beef and dairy cattle a on better diet
Irrigated Rice Farming	Management Practices in Irrigated Rice Farming	-	**Rio Grande do Sul (RS):** Conversion of 75% of the state's productive area (conventional tillage and others) to advanced tillage **RS and Other States:** Annual adoption of 2% irrigation management	**Rio Grande do Sul (RS):** Conversion of 100% of the conventional tillage area and others to advance tillage **RS and Other States:** Annual adoption of 2% irrigation management
Burning of agricultural waste	Reducing the Burning of Agricultural Sugarcane Residues	-	Reduction of 50% of manual harvesting for each state (increase to 50% of mechanized harvesting)	Reduction of 100% of manual harvesting for each state (increase to 100% of mechanized harvesting)

Considering the BAU emissions scenario, it is estimated that there would be a 5.66% increase in methane emissions in 2030 compared to 2020, reaching the value of 15.37 Mt CH_4. For the proposed scenario of a 30% reduction target in the sector's emissions by 2030 compared to 2020 (Target), the accumulated mitigation value was 34.23 Mt CH_4 over the ten-year period was calculated, reaching 10.17 Mt CH_4 emissions in 2030. For the emissions scenario considering the theoretical reduction potential (Potential) a 77.45% reduction of methane emissions in 2030 was estimated compared to 2020, besides presenting the accumulated mitigation value of 86.97 Mt CH_4 over the ten-year period, reaching the hypothetical emission of 3.28 Mt CH_4. Table 10 and Figure 28 show the estimated and projected emission values for each subsector for these scenarios and the total values for the agriculture and livestock sector, respectively.

Table 10.
Projections of methane emissions (thousand tCH_4/year) for the agricultural and livestock sector by 2030.

Th. CH_4	MANAGEMENT OF ANIMAL WASTE		ENTERIC FERMENTATION		IRRIGATED RICE FARMING		BURNING OF AGRICULTURAL RESIDUES		TOTAL	
YEAR	BAU	TARGET	BAU	TARGET	BAU	TARGET	BAU	TARGET	BAU	TARGET
2020	845.15	845.15	13,320.48	13,320.48	370.34	370.34	7.72	7.72	14,543.69	14,543.69
2021	804.63	787.54	13,347.15	11,636.79	353.86	349.17	8.69	8.69	14,514.33	12,782.20
2022	803.42	770.97	13,462.13	11,412.99	325.65	317.06	8.62	8.34	14,599.82	12,509.35
2023	804.41	756.06	13,578.79	11,184.37	307.89	295.75	8.60	7.96	14,699.69	12,244.13
2024	804.18	739.45	13,695.39	10,949.20	291.64	276.36	8.59	7.54	14,799.81	11,972.56
2025	804.70	723.01	13,812.25	10,707.79	271.32	253.61	8.59	7.09	14,896.86	11,691.51
2026	803.51	704.42	13,928.96	10,459.75	250.26	230.74	8.60	6.61	14,991.33	11,401.53
2027	801.95	684.94	14,045.72	10,205.27	230.54	209.65	8.61	6.09	15,086.82	11,105.95
2028	799.25	663.88	14,162.40	9,944.21	210.87	189.13	8.63	5.55	15,181.15	10,802.76
2029	796.38	642.10	14,279.24	9,676.82	190.42	168.44	8.66	4.96	15,274.70	10,492.32
2030	792.81	619.14	14,396.19	9,403.05	169.61	147.97	8.69	4.35	15,367.30	10,174.50
Potential	923.72		33,127.97		164.20		19.11		34,235.00	

Figure 28.
Methane emissions (thousand tCH_4/year) by the agriculture and livestock sector for the projected BAU, Target, and Potential scenarios by 2030



4.2. Land use change and forests

2028
was Brazil's proposed date to reach zero illegal deforestation

The NDC proposed by the Climate Observatory in 2021 proposed a reduction in gross emissions in the MUT sector to bring deforestation to zero by 2030, while allowing a constant level of emissions associated with other types of land use change (OC, 2021). At the same time, at COP26 in Glasgow in 2021, the Minister of Environment promised that Brazil would reach zero illegal deforestation by 2028. In this context, two projected scenarios of methane emissions from fires associated with deforestation were prepared. The first scenario is the maximum reduction potential considering that methane emissions caused by fires associated with deforestation will decrease exponentially until they reach zero in 2030.

The second, more conservative scenario is our proposed target. It expects that the proportion of these emissions with signs of illegality will fall to zero by 2028, while the proportion without signs of illegality will remain constant compared to 2020. These signs include the lack of permits for vegetation suppression, the overlap with legally protected areas (Conservation Units and Indigenous Lands), protected areas within rural lands (Legal Reserve and Permanent Preservation Area), areas under embargo, and areas of the Sustainable Forest Management Plan (PMFS) (MapBiomas, 2021).

The average proportion of deforested areas showing signs of illegality by biome for the period 2019-2021 was calculated by the MapBiomas Alerta initiative and is presented in Table 11. These targets were then compared to a business-as-usual (BAU) scenario, in which deforestation continues at the same rate as in 2020 (Table 11).

For emissions from fires not associated with deforestation, we prepared an initial scenario that represents the maximum reduction potential, which consists of abandoning the practice of restoring pasture lands and crops using fire, in addition to eliminating anthropogenic burning in natural areas. Considering that fire can occur naturally in some biomes such as Cerrado and Pantanal, we defined a proportion of fire that must be due to natural causes in these two biomes since they occur during the rainy season. Knowing that these are rare events, we defined the seasons when a fire occurs less intensely in the two biomes based on the area of fire scars mapped by the MapBiomas Fogo initiative (Figure 29). Thus, the periods of non-anthropic fires were determined to be from November to April in the Cerrado and from January to May in the Pantanal.

Over the entire period from 1985 to 2020, this corresponds to an estimated proportion of natural fires of 0.03% in the Pantanal and 0.07% in the Cerrado (Table 11). It is a fact that some of these fires may still be anthropogenic, but in the absence of a more precise way of classifying natural fires in these biomes, we have chosen to be conservative and classify more fire events as natural to accommodate a greater proportion of events in 2030.

The second scenario proposed for fires not associated with deforestation is more conservative and, in addition to considering the percentage considered natural in the Cerrado and Pantanal, it consists in considering the non-elimination of the practice of using fire to clear and restore already open areas (Target). This calculation was based on the proportion of burned areas not associated with deforestation in classes of pasture and agricultural land in each biome, according to MapBiomas Fogo (Table 11). Finally, a business-as-usual (BAU) scenario is also presented, in which fires not associated with deforestation will persist at the same rate as those observed in 2020 (Table 11).

Figure 29. Monthly distribution of burned areas in the Cerrado and Pantanal biomes for the total period 1985 to 2020, according to MapBiomas Fogo, used to define the natural burning periods during the rainy season: from November to April for the Cerrado and from January to May in Pantanal.

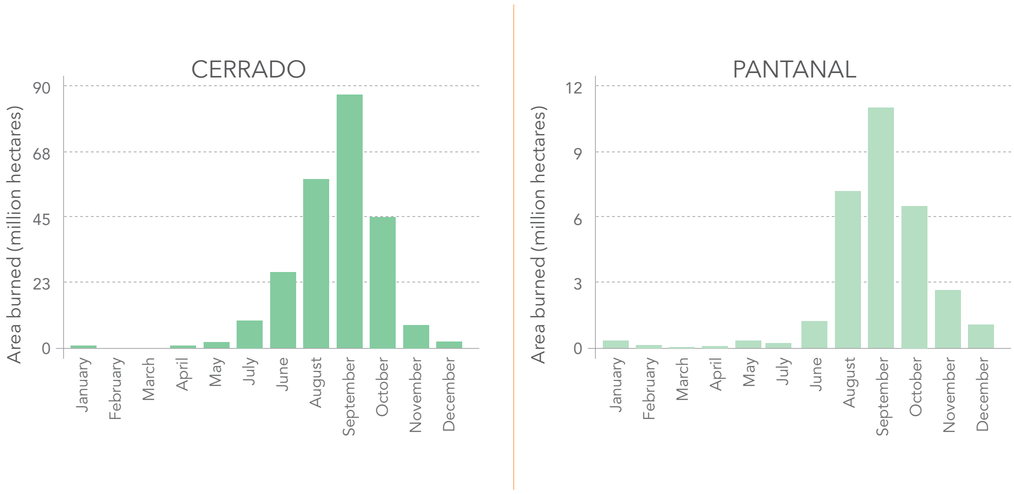


Table 11.
Data used to calculate future scenarios of fires associated and not associated with deforestation. The percentage of deforestation where there are signs of illegality is the average of the three years reported by the MapBiomas Alerta Annual Deforestation Report (MapBiomas, 2021). The percentage of fires considered natural and fires in agricultural and livestock areas were calculated based on the monthly areas of fire scars by biome obtained from MapBiomas Fogo

BIOME	FIRES ASSOCIATED WITH DEFORESTATION	FIRES NOT ASSOCIATED WITH DEFORESTATION	
	SHARE OF DEFORESTATION WITH SIGNS OF ILLEGALITY (2019-2021)	SHARE OF FIRES CONSIDERED NATURAL (2016-2020)	SHARE OF FIRES IN AGRICULTURAL LAND (1990-2020).
Amazon	99%	-	-61%
Caatinga	99%	-	10%
Cerrado	99%	0.07%	8%
Atlantic Forest	89%	-	38%
Pampa	100%	-	35%
Pantanal	99%	0.03%	6%

Table 12.
Description of the proposed scenarios for
the Land Use Change and Forests and their criteria.

SUBSECTOR	BAU	TARGET	POTENTIAL
Fires associated with deforestation	Deforestation at the same rate as in 2020	Zero deforestation with signs of illegality by 2028 Deforestation with no signs of illegality at the same level as in 2020	Zero deforestation by 2030
Fires not associated with deforestation	Area burned at the same rate as in 2020	Elimination of anthropogenic fires in areas covered by native vegetation Non-elimination of the use of fire as a land restoration practice on pasture and agricultural lands	Elimination of anthropogenic fires in areas covered by native vegetation Elimination of the use of fire as a land restoration practice on pasture and agricultural lands

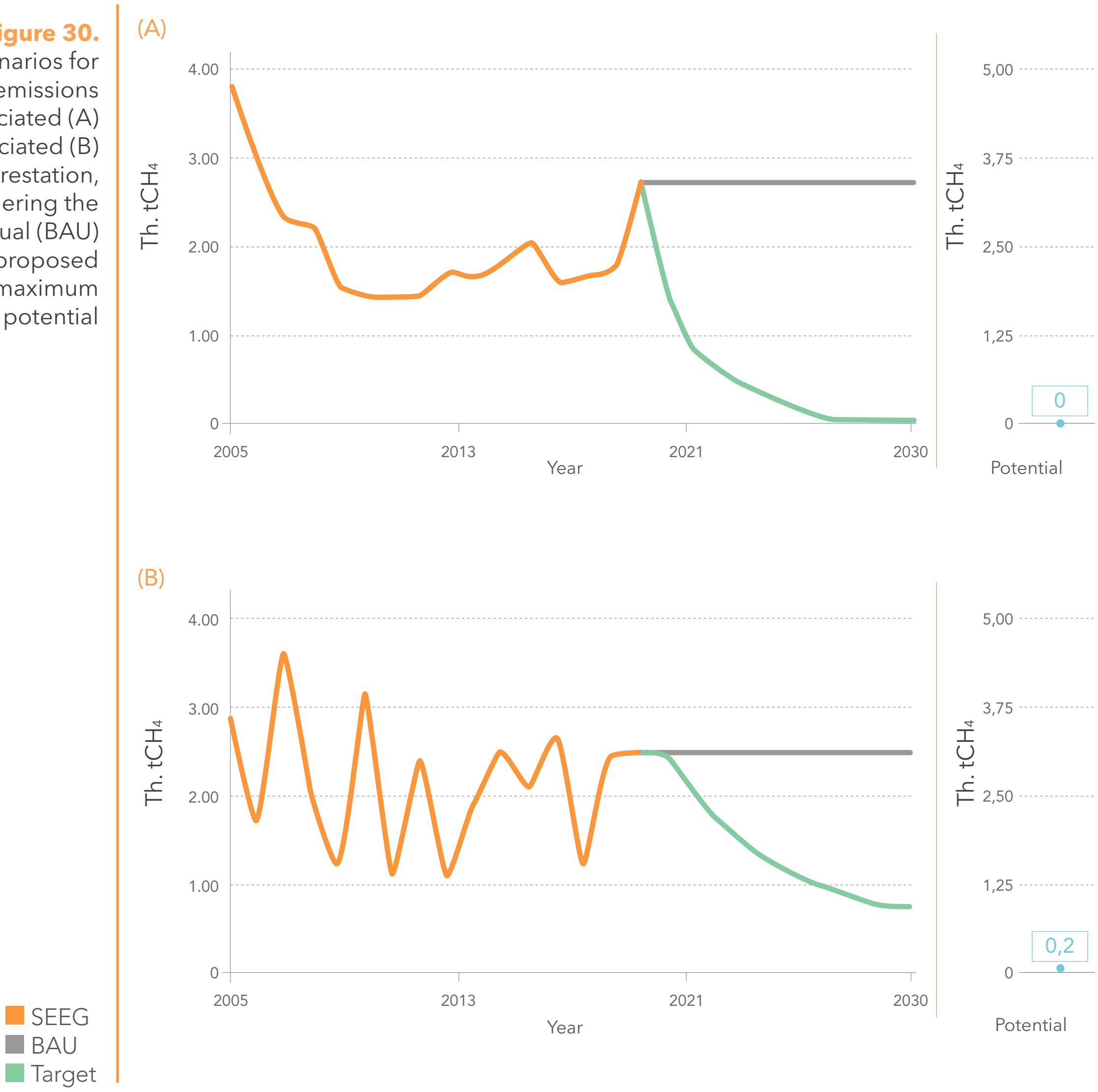


Figure 30. Pathway scenarios for gross methane emissions from fires associated (A) and not associated (B) with deforestation, considering the business-as-usual (BAU) scenario, proposed targets, and maximum reduction potential

The Target scenario in terms of fires associated with deforestation means reaching 29 thousand tonnes of CH_4 by 2028, versus an estimate of 2.7 million tonnes of CH_4 according to the BAU scenario (Figure 30A; Table 13). The potential for fires associated with deforestation is zero, considering the elimination of all types of deforestation by 2030, with or without signs of illegality.

For fires not associated with deforestation, the potential scenario is zero anthropogenic fires by 2030, considering the occurrence of a small fraction of fires considered to be of natural origin in the Cerrado and Pantanal, leading to 23 thousand tons of CH_4 in 2030. The projected target that also considers the occurrence of fires in agricultural areas would reach 190 thousand tons of CH_4 by 2030, compared to 623 thousand tons of CH_4 in the BAU scenario (Figure 30B; Table 13).

Overall, the target for the sector considering both categories (fires associated and not associated with deforestation) is 219,000 tons of methane, compared to a projection of 3.33 million tons by 2030 (Figure 31).

Figure 31. Consolidated projections of methane emissions from the Land Use Change and Forests sector, taking into account the overall estimates (fires associated and not associated with deforestation), including the historical scenario from 2005 to 2020 (SEEG), the business-as-usual scenario (BAU), and the target by 2030 and the maximum reduction potential

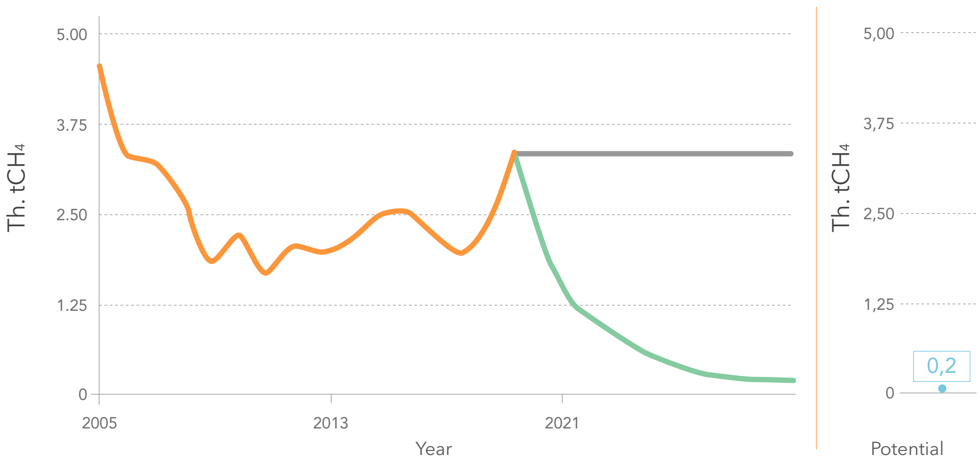


Table 13. Gross methane emissions (in millions of tons) pathway considered in the projected scenarios (BAU and Target) for fires associated and not associated with deforestation, including the maximum reduction potential for 2030

Th. CH_4	FIRES ASSOCIATED WITH DEFORESTATION		FIRES NOT ASSOCIATED WITH DEFORESTATION		TOTAL	
YEAR	BAU	TARGET	BAU	TARGET	BAU	TARGET
2020	2.71	2.71	0.62	0.63	3.34	3.34
2021	2.71	1.48	0.62	0.62	3.34	2.10
2022	2.71	0.81	0.62	0.52	3.34	1.32
2023	2.71	0.57	0.62	0.43	3.34	1.01
2024	2.71	0.39	0.62	0.37	3.34	0.76
2025	2.71	0.25	0.62	0.31	3.34	0.56
2026	2.71	0.14	0.62	0.27	3.34	0.41
2027	2.71	0.05	0.62	0.24	3.34	0.29
2028	2.71	0.03	0.62	0.22	3.34	0.24
2029	2.71	0.03	0.62	0.20	3.34	0.22
2030	2.71	0.03	0.62	0.19	3.34	0.22
Potential	0		0.02		0.02	

4.3. Waste

For the projection of methane emissions from the waste sector from 2021 to 2030, assumptions based on Planares, Plansab, and the NDC proposed by the OC were adopted. In this context, three sectoral scenarios for CH_4 emissions are presented. The first is the business-as-usual (BAU) reference scenario, which considers the linear projection based on historical emissions. This approach culminated in an emissions growth rate of 25.8% by 2030 compared to 2020.

6,5%

Is the reduction in emissions from waste by 2030 in the Target scenario.

The second scenario, called the Target scenario, considers the alignment of the waste sector with public policy targets and additional mitigation measures according to the time horizons presented in Planares to reach the target of a 30% reduction in CH4 emissions. The Target scenario projections can achieve a 6.5% reduction in emissions from the sector by 2030 compared to 2020. Finally, the Potential scenario considers a more ambitious proposal to reduce emissions than the Target scenario, as it brings forward the Planares targets from 2040 to 2030, and incorporates measures presented in the study "Options for Mitigation of GHG Emissions in Key Sectors of Brazil" prepared by the Ministry of Science and Technology and other references. The projections of the waste sector's reduction potential under a more ambitious perspective can achieve a reduction of 35.95% of the sector's emissions by 2030 compared to 2020. No increase in CH4 emissions from the sector is expected for the Target and Potential scenarios. Table 14 shows the assumptions and considerations used to estimate each projection.

Table 14.
Assumptions used for the waste sector

BAU	TARGET	POTENTIAL
Linear growth trend in waste generation - an overall growth rate of 14% for 2020-2025 and 12% for 2025-2030.	1.5% increase in generation for 2020-2025 and 1.2% for 2025-2030; Divert at least 8.1% of all organic waste from landfills by 2030; Recover or incinerate at least 50% of biogas generated from landfills; Divert 12.5% of the dry fraction by 2030; Eliminate all landfills by 2024.	Maintain current generation rates resulting from the implementation of non-generation and generation reduction policies; Divert at least 14% of all organic waste from landfills by 2030; Recover or incinerate 75% of biogas generated from landfills; Recycle 20% of all household paper by 2030; Eliminate all landfills by 2024; Increase the share of biogas use in WWTPs (potential reduction of about 200 thousand tons of CH_4).

Table 15 contains the projections of methane emissions up to 2030 for each scenario with proposed reductions.

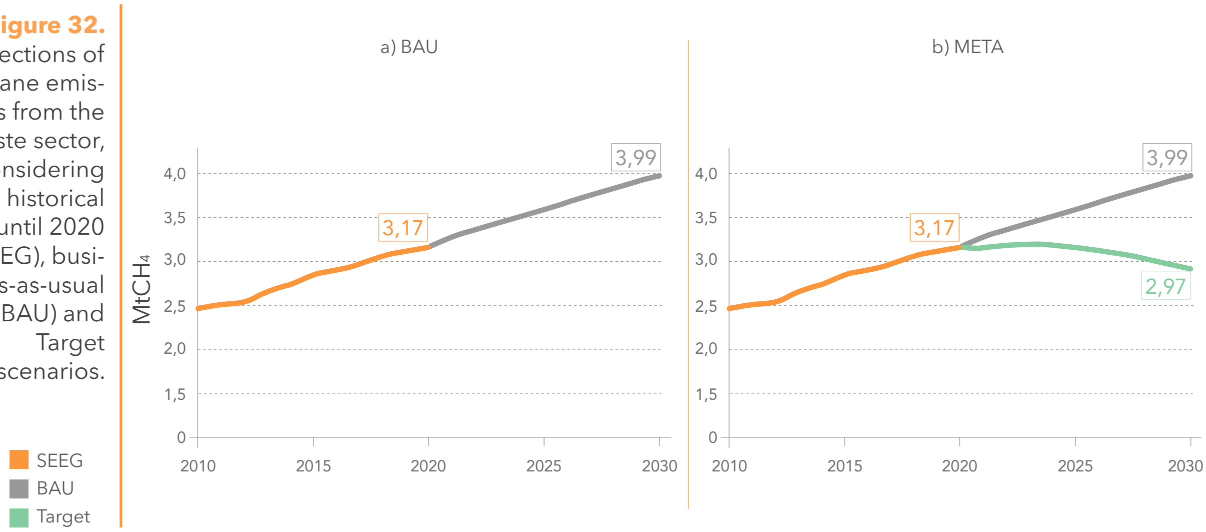
Table 15.
Projections of methane emissions by scenario for the waste sector

Th. tCH_4	SOLID WASTE		LIQUID EFFLUENT TREATMENT		TOTAL	
YEAR	BAU	TARGET	BAU	TARGET	BAU	TARGET
2020	2,154	2,154	1,021	1,021	3,175	3,175
2021	2,237	2,094	1,061	1,061	3,298	3,158
2022	2,290	2,087	1,085	1,085	3,375	3,176
2023	2,342	2,074	1,110	1,110	3,452	3,188
2024	2,394	2,053	1,135	1,135	3,529	3,191
2025	2,447	2,020	1,160	1,160	3,607	3,183
2026	2,499	1,974	1,185	1,185	3,684	3,162
2027	2,551	1,917	1,210	1,210	3,761	3,130
2028	2,604	1,849	1,234	1,234	3,838	3,086
2029	2,656	1,770	1,259	1,259	3,916	3,032
2030	2,709	1,682	1,284	1,284	3,993	2,969
Potential	961		1,072		2,033	

In 2030, the BAU scenario presented an increase of 0.82 $MtCH_4$, equivalent to about 25.8% in relation to the 2020 emissions. In contrast, the projections for the Target show a reduction of 0.20 $MtCH_4$ for the same period, i.e., the assumptions suggested in Table 14 for the Target scenario can achieve a 6.5% reduction in emissions from the waste sector in relation to emissions in 2020.

The emissions projection for the Meta scenario indicates that the main mitigation strategies for the waste sector can deliver results, even if they cannot reach the 30% reduction target, with a significant number of low- and medium-cost strategies, since most technologies are already available at a level that allows their use on an economic scale. In addition, the most relevant mitigation measures are in dialogue with the implementation of sectoral policies and programs, indicating the importance of the execution of these plans, not only from a perspective of improving the quality of life and the environment but also from the climate perspective. Figure 32 shows the projections of methane emissions by 2030, considering the assumptions in Table 14 and the emissions in Table 15.

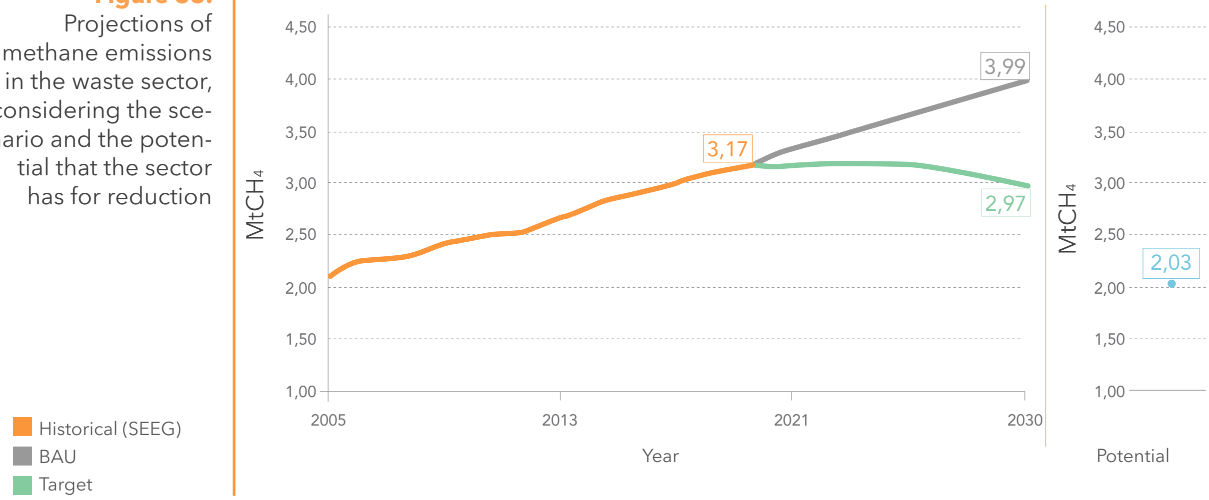
Figure 32. Projections of methane emissions from the waste sector, considering the historical until 2020 (SEEG), business-as-usual (BAU) and Target scenarios.



The emissions estimates for the Potential scenario are more ambitious, projecting a more significant CH_4 reduction potential for the waste sector. The assumptions used were presented in Table 14.

The assumptions adopted for the Potential scenario continue to converge with the sectorial plans but in a slightly more ambitious way. Besides that, the maximum recovery potential or collection efficiency of 75%[17] of all biogas generated in landfills is also considered, besides the expansion of biogas use in WWTPs (potential reduction of about 200 thousand tons of CH_4). No increase in emissions is foreseen in the sector to reach this potential. Figure 33 shows the projections of methane emissions by 2030, considering the assumptions in Table 14 and the emissions in Table 15 and the maximum potential of reduction that the sector presents.

Figure 33. Projections of methane emissions in the waste sector, considering the scenario and the potential that the sector has for reduction



4.4. Energy sector

To point the way to reducing methane emissions in the energy sector, aiming at meeting the Global Commitment on Methane, a projection exercise of emissions was carried out with the application of mitigation measures mentioned in chapter 3.

To this end, methane emissions were firstly projected based on the energy projections of the Decennial Energy Plan 2031, resulting in 597 thousand tons estimated for 2030, constituting a 4% increase in emissions relative to the 572 thousand tons estimated for 2020. In Figure 34, this scenario is called BAU.

[17] In landfills the amount of biogas produced depends on the technology employed and you should consider the efficiency of the system, the USEPA (United States Environmental Protection Agency) recommends 75% efficiency. The efficiency of Biogas production systems generally ranges between 50% and 75%. Biogas Toolkit - https://bit.ly/3eMa5Rk

A second scenario was built, considering the mitigation actions to be implemented by 2030, as shown in Table 16. This scenario resulted in methane emissions estimated at 391,000 tons, a level 32% lower than the emissions estimated for 2020, thus being in line with the objective of the methane agreement. Figure 31 shows the projected methane emissions trajectories, the second scenario being called the Target.

Besides the BAU and Meta scenarios, an emissions projection exercise was also carried out with a more ambitious, long-term goal, called Potential, in which measures that maximize emissions reduction were envisioned. For this exercise, the year 2050 was considered, and the actions are listed in Table 16. As a result, methane emissions from the energy sector could reach the level of 210,000 tons.

Table 16.
Assumptions adopted for the energy sector scenarios

BAU
• Based on the Decennial Energy Plan 2031
TARGET
• Total replacement of the use of firewood in urban areas by PLG by 2030. It was considered that 38% of firewood consumption is in urban areas, according to the EPE Technical Note[3]. • A 30% reduction in the projected wood consumption in rural areas by 2030, could be achieved through the application of modern wood-burning stoves, which are more efficient. • A 10% reduction in the projected fuel consumption in the industry by 2030, could be achieved by energy efficiency measures. • Reduction in the intensity of fugitive methane emissions in oil and gas exploration and production for the entire operation in Brazil by 2025, in line with the Petrobras goal[4]. • Halving the intensity of fugitive methane emissions in oil and gas exploration and production for the entire operation in Brazil between 2025 and 2030, approaching the emissions elimination target of the Aiming for Zero Methane Emissions Initiative.
POTENTIAL
• Total electrification of residential energy consumption; • Oil and natural gas production peaking in 2030 and then declining; • Total control of fugitive emissions from oil and natural gas exploration and production; • Elimination of coal mining; • Continued reduction in the emission intensity of transportation; • Emission intensity of electricity generation peaking in 2035 and then declining; • Continued reduction in the emission intensity of "others in the energy sector".

[3] Technical Note EPE DEA 016/2021, Consumo de Lenha e Carvão Vegetal, Setor Residencial Brasil, available at: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-578/Nota%20T%C3%A9cnica%20Consumo%20 de%20lenhaCV%20-%20Residencial%20final%202021.pdf

[4] Petrobras Climate Change Booklet (2022), available at: https://api.mziq.com/mzfilemanager/v2/d/25fdf098-34f5-4608-b7fa-17d60b2de47d/d7092e4e-9830-c6b1-ff36-62247b97a17a?origin=1

Figure 34.
Estimates and projections of methane emissions in the Energy Sector

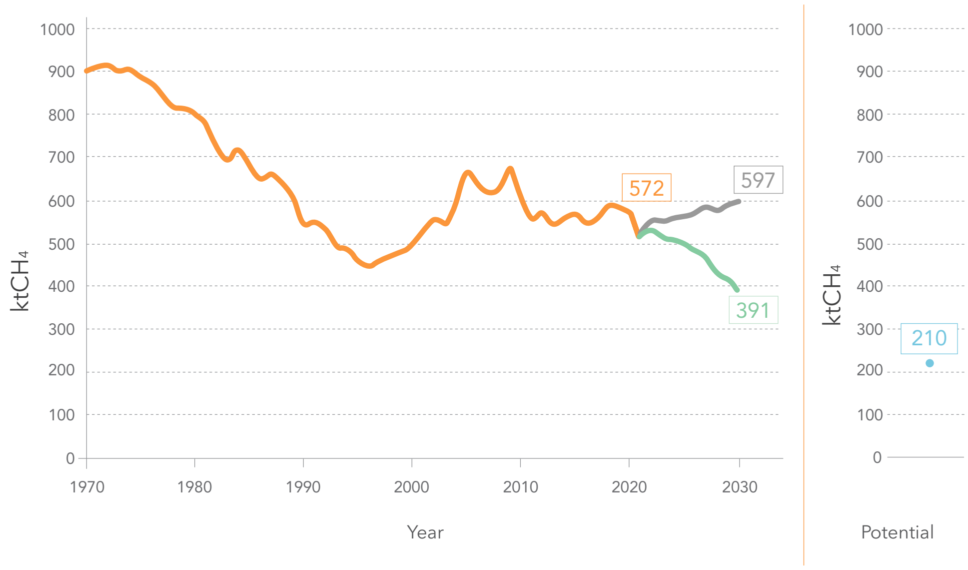


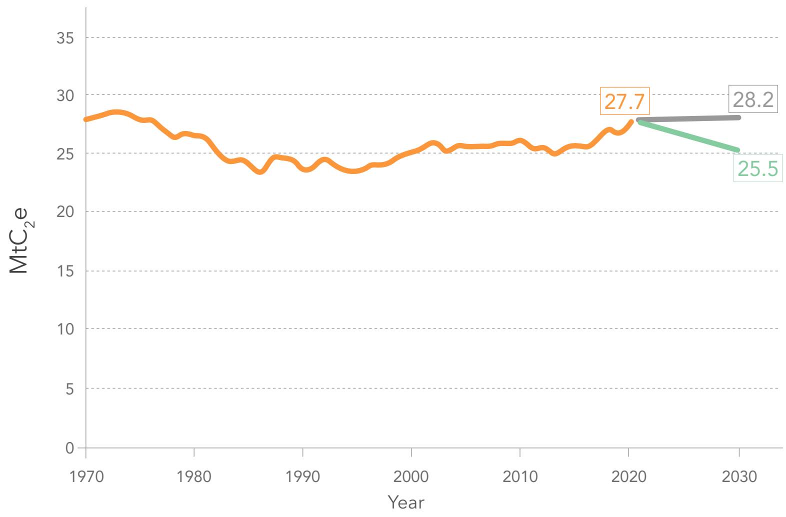
Table 17 shows projected emissions for this year, broken down according to the main emission sources in the Energy Sector.

Table 17.
Projections of methane emissions from the Energy Sector

[$ktCH_4$]	Residential fuel consumption		Fugitive emissions from O&G		Fugitive emissions from coal		Industrial fuel consumption		Transportation		Consumption of firewood in agriculture and livestock		Consumption of sugarcane bagasse in the production of alcohol		Electricity generation		Others		Total	
YEAR	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**	**BAU**	**TARGET**
2020	**286**	**286**	**116**	**116**	**42**	**42**	**34**	**34**	**28**	**28**	**23**	**23**	**18**	**18**	**11**	**11**	**14**	**14**	**572**	**572**
2021	277	266	91	91	30	30	34	33	29	29	23	23	17	17	14	14	13	14	528	517
2022	271	247	113	113	38	38	34	34	30	30	23	23	17	17	13	13	14	15	553	529
2023	264	227	116	116	37	37	35	34	30	30	23	23	18	18	14	14	14	15	552	514
2024	258	207	127	127	37	37	36	35	31	31	24	24	19	19	14	14	15	15	560	508
2025	252	188	133	133	37	37	37	35	32	32	24	24	19	19	14	14	15	16	563	498
2026	246	168	144	133	38	38	38	36	32	32	24	24	20	20	15	15	15	16	572	482
2027	239	149	159	135	38	38	39	36	33	33	24	24	20	20	16	16	16	16	585	467
2028	234	129	172	132	20	20	40	37	34	34	24	24	21	21	17	17	16	16	577	430
2029	228	110	177	123	30	30	41	37	35	35	25	25	21	21	17	17	17	17	590	413
2030	222	90	181	111	36	36	42	38	36	36	25	25	22	22	18	18	17	17	597	391
Potential	0		21		0		52		23		29		34		27		25		210	

To illustrate the fact that the substitution of firewood (a biofuel) for LPG (a fossil fuel) leads to the reduction of total GHG emissions, Figure 35 presents the total residential GHG emissions in the above-mentioned scenarios. In other words, the reduction in methane emissions from the reduction of firewood consumption in the scenario of compliance with the Methane Pledge is not offset by the increase in CO_2 and methane emissions from the increase in LPG consumption. Although it seems counterintuitive, what happens is a net reduction in total GHG emissions.

Figure 35.
Estimates and projections of residential GHG emissions



4.5. Aggregate target of all sectors

This chapter evaluates three emission scenarios:

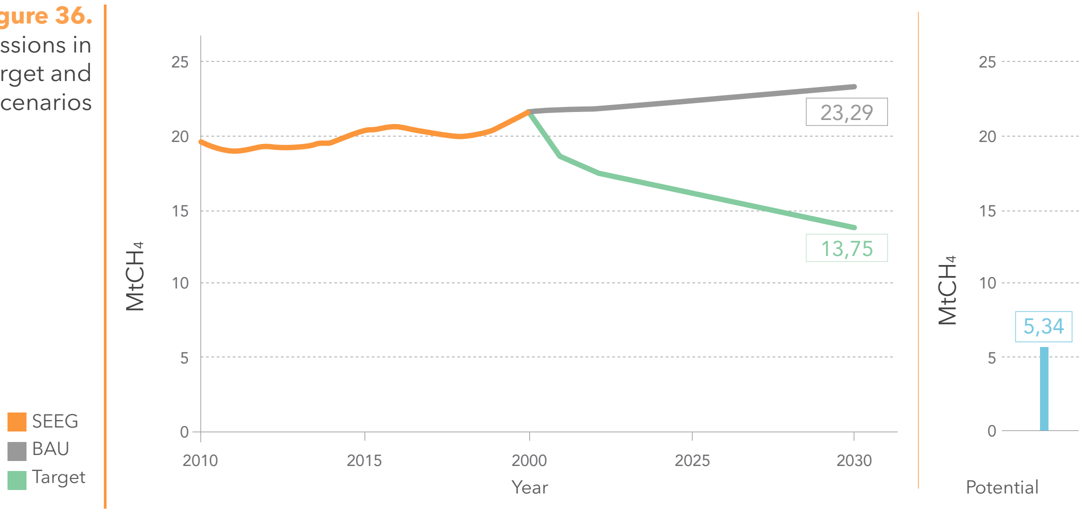
(i) The **path of methane emissions** in Brazil up to 2030 considering current mitigation policies in the country **(BAU)**;
(ii) The **potential for reducing methane emissions** in Brazil in the long term;
(iii) A proposed **emissions reduction target** achievable by Brazil by 2030 in a manner compatible with the Global Methane Pledge target of 30% emissions reduction compared to 2020.

Table 18.
Historical emissions and scenarios for methane emission (2010-2030)

DATA	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
HISTORICAL	19,599,168	18,935,614	19,222,716	19,256,707	19,585,739	20,310,330	20,621,256	20,195,150	19,919,774	20,395,919	21,625,465

SCENARIO		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
POTENTIAL		14,553,968	13,353,415	12,240,817	11,196,655	10,199,243	9,190,272	8,204,361	7,227,583	6,251,805	5,335,604
TARGET		18,561,507	17,538,323	16,951,029	16,427,276	15,933,798	15,456,602	14,992,851	14,562,884	14,162,283	13,753,223
BAU		21,675,170	21,863,043	22,038,598	22,224,019	22,401,881	22,582,389	22,768,177	22,931,879	23,115,429	23,291,684

Figure 36.
Emissions in BAU, Target and Potential scenarios



By aggregating the values from the analysis of each of the 4 sectors (agriculture and cattle ranching; land use change and forestry; waste treatment; and energy[18]), we obtain for the BAU scenario a 23.3 $MtCH_4$ emission in 2030 with a 7% growth in emissions compared to the 21.7 $MtCH_4$ in 2020 (Figure 33).

As for the **Potential Reduction Scenario**, we have an emission of 5.3 $MtCH_4$, which represents a 75% reduction in emissions compared to 2020. That is, with the known technologies it is not possible to zero the methane emissions. It would be necessary to use compensations with carbon equivalent removal to zero residual emissions.

Finally, applying the best practices and existing technologies that can be implemented until 2030, we obtain the emission of 13.75 $MtCH_4$ in 2030, which represents a reduction of 36.4% in relation to emissions in 2020. This is equivalent to a reduction of 180 $MtCO_2e$ comparing 2020 and 2030.

Thus, we propose that Brazil adopt **a goal of reducing its methane emissions by 36% by 2030 when compared to 2020**, this being a significant contribution of the country to the Global Methane Pledge goal of a 30% reduction of methane emissions by 2030.

36%

is the reduction target in methane emissions proposed by the OC for 2030

5 Final Considerations

Methane accounts for about 16% of global greenhouse gas emissions when converted to CO_2e (UNEP, 2021). As it is a short-lived gas in the atmosphere (less than 20 years of decay time), any effort to reduce its emissions can have a faster impact on global temperature, increasing the window of time available for humanity to meet the Paris Agreement goal of stabilizing global warming to 1.5°C above the pre-industrial average.

In 2021 Brazil joined the Global Methane Pledge along with 122 other countries that are committed to seeking a 30% reduction in global methane emissions by 2030, compared to 2020.

Brazil is the fifth largest emitter of methane in the world after China, the US, Russia, and India, with its main source of emissions being livestock (particularly enteric fermentation), followed by waste treatment, and burning.

75%

is the potential reduction by 2030 using all known technologies at scale

We evaluated the emissions pathway under current policy conditions, which result in a 7% increase in emissions from 2020 to 2030. We also evaluated the hypothetical emissions reduction potential if all known technologies and best practices were fully applied, and concluded that emissions could be reduced by 75% compared to 2020 levels. Finally, we identified the opportunity to reduce emissions by 36.4% by 2030 compared to 2020 levels by applying existing technologies and best practices.

Brazil can contribute to the transition to a low methane emissions world with an ambitious and achievable target: Reduce methane emissions by 36% by 2030 compared to 2020 levels.

To achieve this goal it is necessary, among other practices, to zero illegal deforestation and the fire associated with it, to reduce the use of firewood for cooking, to control fugitive emissions from the oil and gas industry, to recover at least 50% of all methane generated in landfills, to expand methane recovery from animal waste treatment, to achieve 30% intensive finishing of beef cattle, to convert 75% of rice cultivation to advanced preparation, and to cut by half the practice of burning sugarcane straw that still exists.

This goal can be achieved through regulatory policies, capacity building and economic incentives in the public and private sectors.

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