Local Governments for Sustainability

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GOVERNMENT OF THE STATE
SECRETARIAT FOR THE ENVIRONMENT AND CLIMATE CHANGE

Ceará's Greenhouse Gas Emissions Inventory

2018 - 2023

2025

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Ceará's Greenhouse Gas Emissions Inventory

2018 - 2023

November, 2025

LIST OF ACRONYMS

AECIPP	*Association of Companies of the Pecém Industrial and Port Complex*
ABRACAL	*Brazilian Association of Agricultural Limestone Producers*
ARCE	*Regulatory Agency of the State of Ceará*
AFOLU	Agriculture, Forestry, and Other Land Use
ANP	*National Agency of Petroleum, Natural Gas and Biofuels*
ANAC	*National Civil Aviation Agency*
ANDA	*National Association for Fertilizer Distribution*
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)
ASMOC	*West Caucaia Municipal Landfill*
BEN	*National Energy Balance*
CAGECE	*Ceará Water and Sewage Company*
CEGÁS	*Ceará Gas Company*
CGIRS	*Integrated Solid Waste Management Consortium*
C40 Cities	Climate Leadership Group
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP 29	29th Conference of the Parties – UNFCCC
COVID-19	Coronavirus Disease 2019
DETRAN	*State Department of Traffic of Ceará*
DNIT	National Department of Transportation Infrastructure
ENEL	*Electric utility company operating in Ceará*
EPA	United States Environmental Protection Agency
EPE	*Energy Research Company*
ETE	*Effluent Treatment Plant*
F-GASES	Fluorinated gases
FIEC	*Federation of Industries of the State of Ceará*
GHG	Greenhouse gases
LPG	Liquefied Petroleum Gas
CNG	Compressed Natural Gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IBGE	*Brazilian Institute of Geography and Statistics*
IMU	*Urban Mobility Index*
IPCC	Intergovernmental Panel on Climate Change
IPECE	*Ceará Institute for Economic Research and Strategy*
IPPU	Industrial Processes and Product Use
MCTI	*Ministry of Science, Technology, and Innovation*
MMA	*Ministry of the Environment and Climate Change*
MT	*Ministry of Transport*
$MtCO_2e$	Millions of tons of carbon dioxide equivalent
N_2O	Nitrous oxide
NDC	Nationally Determined Contributions
UN	United Nations
PBMC	*Brazilian Panel on Climate Change*
PFC	Perfluorocarbons
GDP	Gross Domestic Product
RSS	*Healthcare Waste*
SAAEs	*Autonomous Water and Sewage Services*
SEBRAE	*Brazilian Micro and Small Business Support Service*

SEEG	*Greenhouse Gas Emissions and Removals Estimation System*
SEMA	*Secretariat for the Environment and Climate Change*
SEINFRA	*Secretariat of Infrastructure*
SF_6	Sulfur Hexafluoride
SIDRA	*IBGE Automatic Recovery System*
SIN	*National Interconnected System*
SNIS	*National Sanitation Information System*
SINISA	*National Basic Sanitation Information System*
SISAR	*Integrated Rural Sanitation System*
tCO_2e	Ton(s) of carbon dioxide equivalent
UNICA	*Brazilian Sugarcane Industry Association*
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
GVA	Gross Value Added
WRI	World Resources Institute

*Some acronyms in this list originate from Brazilian institutions, programs, or policies and therefore derive from Portuguese names. To preserve accuracy and traceability, these acronyms are presented in their original form, followed by their English translation in italics.

GLOSSARY

AR5	Fifth assessment report of the IPCC on climate change.
C	Chemical element that forms the basis of gas emissions such as CO_2 and CH_4.
CH_4	Potent greenhouse gas, primarily emitted from agricultural activities and waste decomposition.
CO_2	The main greenhouse gas emitted from the combustion of fossil fuels.
CO_2e	Unit expressing the impact of different GHGs relative to CO_2.
COP 29	UN international conference for global climate negotiations.
F-GASES	Synthetic industrial gases with high GWP, such as HFCs and PFCs.
GHG	Gases that intensify global warming by trapping heat in the atmosphere.
GWP	Index measuring a gas's warming potential relative to CO_2.
HFC	Gases used in refrigeration and other applications, with high global warming potential.
$MtCO_2e$	Unit of measurement for large-scale GHG emissions.
N_2O	Greenhouse gas emitted mainly through fertilizer use.
NDC	Emission reduction commitments made by countries under the Paris Agreement.
PFC	Industrial gases with high GWP, commonly used in metallurgical processes.
SF_6	Gas with extremely high GWP, used primarily in electrical insulation equipment.
tCO_2e	Standard unit for measuring greenhouse gas emissions.

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ABOUT ICLEI

ICLEI – Local Governments for Sustainability is a global network of more than 2.500 local and regional governments committed to sustainable urban development. Established in 1990, ICLEI is active in more than 130 countries, where it influences sustainability policies and drives local action toward sustainable, zero-carbon, nature-based, equitable, resilient, and circular urban development.

ICLEI's network and team of experts collaborate to provide local governments with access to knowledge, partnerships, and training to support systemic change. As the designated focal point for the Local Governments and Municipal Authorities Constituency (LGMA) at the Conferences of the Parties (COPs) on Climate, Biodiversity, and Desertification, ICLEI provides local governments with a voice at international negotiations and coordinates the implementation of international agreements at the local level.

Operating in Latin America since 1994, ICLEI South America connects its 157 members across eight countries to this global movement, supported by three regional offices in Brazil, Colombia, and Argentina. ICLEI South America promotes four key strategies with its member governments in the region: (a) Access to information on international agreements; (b) Visibility and positioning in international negotiations; (c) Opportunities for technical exchange and experience-sharing; and (d) Access to innovative methodologies and solutions from ICLEI's global portfolio.

Through these initiatives, ICLEI South America strengthens local governments' capacity to develop and implement public policies, contributing to making their cities more resilient, sustainable, and aligned with global climate commitments.

FOREWORD

The climate crisis is urgent! It is an unquestionable reality of our time and requires firm, coordinated, and evidence-based action. The state of Ceará, historically marked by environmental challenges such as water scarcity and climate vulnerability, has taken a leading role in addressing climate change by promoting integrated, innovative public policies committed to sustainable development.

It is in this spirit of responsibility and vision for the future that we present to the people of Ceará the Greenhouse Gas Emissions Inventory, a technical document that systematically, transparently, rigorously, and collaboratively organizes data on greenhouse gas emissions and removals across our territory from 2018 to 2023.

The inventory is more than a report: it is a strategic tool for building more effective climate policies, enabling us to identify the main sources of emissions, establish reduction targets, and monitor progress in the transition to a low-carbon economy. The methodology adopted — the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC) — ensures the credibility, reliability, and international comparability of the data, thereby strengthening our state's climate governance.

This document complies with the provisions of the State Policy on Climate Change (Law No. 16,146/2016) and the commitments made by the Government of the State of Ceará to national and international climate agendas, including the Race to Zero initiative and the Under2 Coalition, under the United Nations Framework Convention on Climate Change (UNFCCC).

Facing a challenging scenario, particularly in the northeastern semi-arid region, which is already experiencing the impacts of global warming, Ceará has made concrete progress in sustainable solutions: strengthening renewable energy capacity, protecting biodiversity, restoring ecosystems such as the Caatinga, protecting coastal and marine zones, promoting low-carbon agriculture, and investing in sustainable technological innovation. These are decisive steps toward building a greener, fairer, and more resilient future.

The launch of this inventory represents an important milestone in our commitment to climate action. May it serve as a solid foundation for evidence-based decision-making, for the development of public policies, and for engaging the entire society of Ceará in this collective mission to preserve our planet and ensure quality of life for future generations.

Vilma Maria Freire dos Anjos
Secretary of Environment and Climate Change
Government of the State of Ceará

PREFACE

It is with great satisfaction that we present Ceará's Greenhouse Gas Emissions Inventory, a strategic milestone for strengthening climate governance and consolidating public policies aimed at addressing the climate crisis.

Ceará has distinguished itself nationally as a leader in the sustainability agenda. This inventory represents a decisive step, providing the technical and scientific foundation to guide state planning towards carbon-neutral and resilient development, in line with ICLEI's strategic pathways and Brazil's Nationally Determined Contributions (NDCs), as well as the National Plan on Climate Change developed by the Ministry of the Environment and Climate Change (MMA, in the Brazilian acronym), which establishes strategic actions to mitigate greenhouse gas emissions and adapt to climate impacts in Brazil by 2035.

The inventory was developed following the internationally recognized methodology of the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC), designed by ICLEI in partnership with other world-renowned institutions. This approach ensures data comparability, transparency, and consistency, allowing Ceará to align with global best practices in climate planning. In this context, particularly ahead of COP 30 in Brazil, the robustness and transparency of this inventory are of heightened significance. To ensure data accuracy, calculations and analyses were performed using the WayCarbon Ecosystem platform as a technical support tool.

For a region like the semi-arid Northeast, which is particularly vulnerable and already experiencing significant climate impacts, this inventory is truly indispensable. It guides local efforts to reduce emissions, advances the energy transition, highlights the unique value of the Caatinga biome, and promotes low-carbon agricultural practices.

ICLEI – Local Governments for Sustainability is honored to support the Government of Ceará in this crucial endeavor. We are confident that these results will be instrumental in accelerating the decarbonization of the state economy, attracting sustainable investments, and ultimately enhancing the quality of life for current and future generations.

May this inventory inspire ongoing collective action, establishing Ceará's role as a national and international benchmark in the fight against climate change.

Rodrigo Perpétuo
Executive Secretary
ICLEI – Local Governments for Sustainability

EXECUTIVE SUMMARY

This **Greenhouse Gas (GHG) Emissions Inventory** presents an analysis of GHG emissions in the state of Ceará for the period 2018–2023. Beyond serving as a monitoring tool, this inventory is a strategic instrument for guiding **policies and actions aimed at reducing emissions and supporting climate adaptation**. It serves as a baseline for climate planning, enabling the identification of emission sources, the establishment of reduction targets, and the monitoring of progress toward more sustainable and low-carbon development.

The methodology employed to prepare this inventory is the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), developed by ICLEI, the World Resources Institute (WRI), and the C40 Cities Climate Leadership Group. This approach ensures the consistency and comparability of data for community, city, and state-level inventories, while enabling international comparison. The GPC is based on three scopes: a) direct emissions from activities within state boundaries (**Scope 1**); b) indirect emissions from electricity consumption from the national grid (**Scope 2**); and c) other indirect emissions occurring outside state boundaries but resulting from local activities (**Scope 3**).

Six sectors were evaluated: **Stationary Energy**, which includes energy production and consumption; **Transportation**, covering fuel combustion by vehicles; **Waste**, including solid waste and wastewater treatment; **Industrial Processes and Product Use (IPPU)**, addressing industrial processes and the use of fluorinated gases; **Agriculture, Forestry, and Other Land Use (AFOLU)**, considering GHG flows associated with land use and management; and Other Indirect Emissions, for activities not addressed in the other sectors. Estimates for the Land-Use Change sub-sector of AFOLU were derived from the SEEG (*Sistema de Estimativas de Emissões de Gases de Efeito Estufa*) database.

Main results of the Greenhouse Gas Emissions Inventory

Total net emissions in Ceará, considering the inventoried sectors, showed **a 24.11% increase in net emissions** between 2018 and 2023. Starting from 28.17 MtCO$_2$e in 2018, net emissions reached 34.96 MtCO$_2$e in 2023. A slight decline was observed in 2020, possibly associated with the impacts of the COVID-19 pandemic on economic activities, followed by a resumption of growth.

The sectors contributing most significantly to the state's emissions profile were:

- **AFOLU:** the largest source of emissions in 2023, driven primarily by deforestation and livestock farming. A significant increase of 166% underscores the urgent need for more sustainable land use policies.

- **IPPU:** the second largest source of emissions, with a 13.3% increase in emissions since 2018. Steel and cement production are the primary contributors.

- **Transportation:** the third largest source, demonstrating 8.2% growth. Road transportation and the consumption of fossil fuels (gasoline and diesel) are the main emission drivers.

- **Stationary Energy:** despite a substantial decrease of -72.5%, this sector remains dependent on fossil fuels and is sensitive to fluctuations in the energy matrix; periods of elevated emissions correspond to coal consumption in thermoelectric plants.

- **Waste:** emissions increased by 18.6% during the analyzed period. Waste disposal facilities are the largest contributors, while wastewater, incineration, and open burning also contribute.

Based on this analysis, **recommendations and opportunities for improvement** include encouraging reforestation and the recovery of degraded areas; expanding renewable energy generation and reducing dependence on fossil fuels; transitioning to more efficient and cleaner modes of transportation; promoting industrial energy efficiency; expanding separate waste collection and recycling programs; and universalizing access to basic sanitation services.

While the completion of this Greenhouse Gas Emissions Inventory represents a significant milestone, it is also a starting point for the next steps in Ceará's climate compliance. To move forward effectively, it is essential to:

- **Support public climate policies**
- **Advance state climate compliance**
- **Define and monitor established goals**
- **Promote reporting and transparency**
- **Strengthen institutional capacity and technical expertise**

In summary, this document constitutes a critical step in supporting Ceará's development, providing a comprehensive profile of the state's emissions and outlining pathways toward a more sustainable and resilient future.

1

INTRODUCTION

Accounting for greenhouse gas (GHG) emissions is a core component of implementing a state-level climate agenda. Comprehensive information on emissions sources and trends is obtained through GHG Emissions Inventories, which provide the evidence base needed for informed and effective decision-making.

A GHG Emissions Inventory is a strategic instrument that aims to quantify, characterize, and monitor the emissions of an institution or community. By defining system boundaries, identifying and accounting for emission sources and sinks, the inventory enables a comprehensive understanding of the emissions profile resulting from the activities of the various sectors that comprise the territory. This understanding supports the state government in identifying the primary mitigation measures necessary to reduce GHG emissions.

This report presents the results of Ceará's first Greenhouse Gas Emissions Inventory, the methodology employed, the assumptions adopted, and the data sources. Its structure is organized as follows:

• **Chapter 1 – Introduction:** contextualizes the inventory and outlines how the report is structured.

• **Chapter 2 – Science and Climate Policy**: introduces the concepts of climate change, the greenhouse effect, their impacts, and key international and national milestones.

• **Chapter 3 – Methodology**: presents the adopted methodology, what is included in the inventory, and the accounting principles and standards used in its preparation.

• **Chapter 4 – Inventory Boundaries**: delineates the limits of the inventory, characterizing the state's territory, the sectors to be analyzed, and presents the emission sources and input data.

• **Chapter 5 – Inventory Results:** presents the overall results of Ceará's GHG Emissions Inventory.

• **Chapter 6 – Analysis of Results by Sector**: presents the results of Ceará's GHG Emissions Inventory for each sector and sub-sector.

• **Chapter 7 – Comparison of Emissions with Brazil and Other States:** compares the emissions results with national data and emissions from states in the northeast and southeast regions, evaluating emissions intensity per capita and per Gross Domestic Product (GDP).

• **Chapter 8 – Evolution of Emissions and Compliance with Nationally Determined Contribution (NDC)**: presents the historical emissions trajectory based on the National Inventory, advances achieved with Ceará's GHG Emissions Inventory, and compares results with the targets established by Brazil's NDC.

• **Chapter 9 – Final Considerations**: synthesizes the key findings and discusses possible actions and mitigation opportunities to be developed.

• **Bibliographical References**: documents the sources used to compile this inventory.

• **Appendices**: present the calculation methodologies and emission factors employed.

The detailed results of this inventory, based on data collected and analyzed, are presented in the following sections.

2 SCIENCE AND CLIMATE POLICY

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC, 2022) as a statistically significant change in the climate system, characterized by variations in its mean state or variability, sustained over extended periods of several decades or longer. According to the United Nations Framework Convention on Climate Change (UNFCCC, 2022), such changes result from both natural climate variability and anthropogenic activities that modify the composition of the global atmosphere.

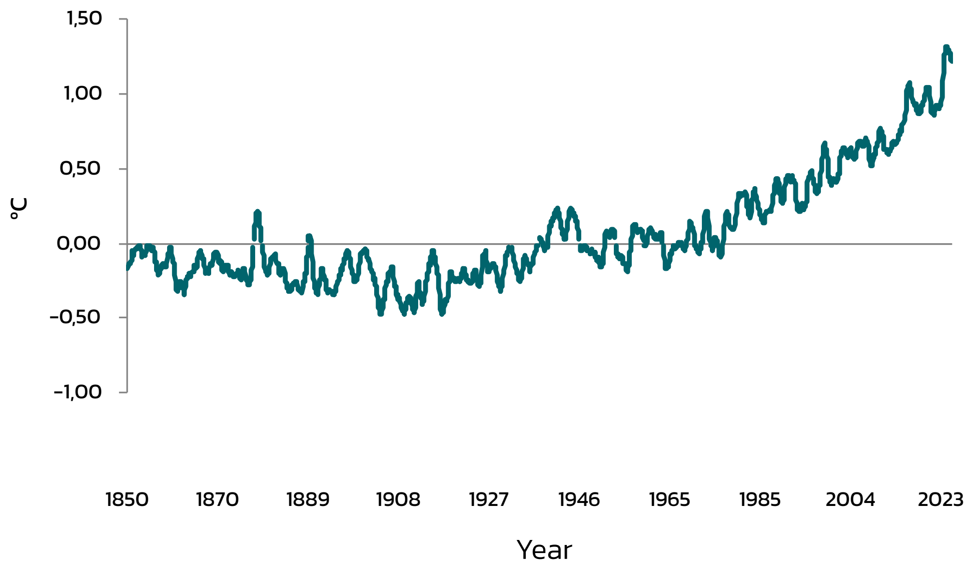
Scientific evidence demonstrates that the current climate system changes are predominantly induced by anthropogenic activities, notably the burning of fossil fuels, land-use changes, and intensive agricultural practices. Recent estimates indicate that more than 97% of peer-reviewed scientific literature converges on this conclusion (IPCC, 2022; WMO, 2023).

Observable indicators of these changes include a sustained increase in global mean temperatures (NOAA, 2023), the accelerated retreat of ice sheets and glaciers, alterations in precipitation and atmospheric circulation patterns, as well as changes in ocean salinity and temperature. These changes have directly contributed to the increased frequency, intensity, and duration of extreme weather events such as heat waves, prolonged droughts, floods, and tropical cyclones (IPCC, 2022; C3S, 2024).

According to a consolidated analysis of data from six international databases by the World Meteorological Organization (WMO, 2025), 2024 ranks as the warmest year on record, with a global mean temperature of 1.55°C above the 1850–1900 baseline. While this value carries a margin of uncertainty of ±0.13°C, it suggests that, for the first time, we may have experienced a calendar year with a global mean temperature exceeding 1.5°C above pre-industrial levels.

Figure 1 illustrates the increase in global mean temperature from 1850 to 2025.

Figure 1. Evolution of global mean temperature (1850-2025).

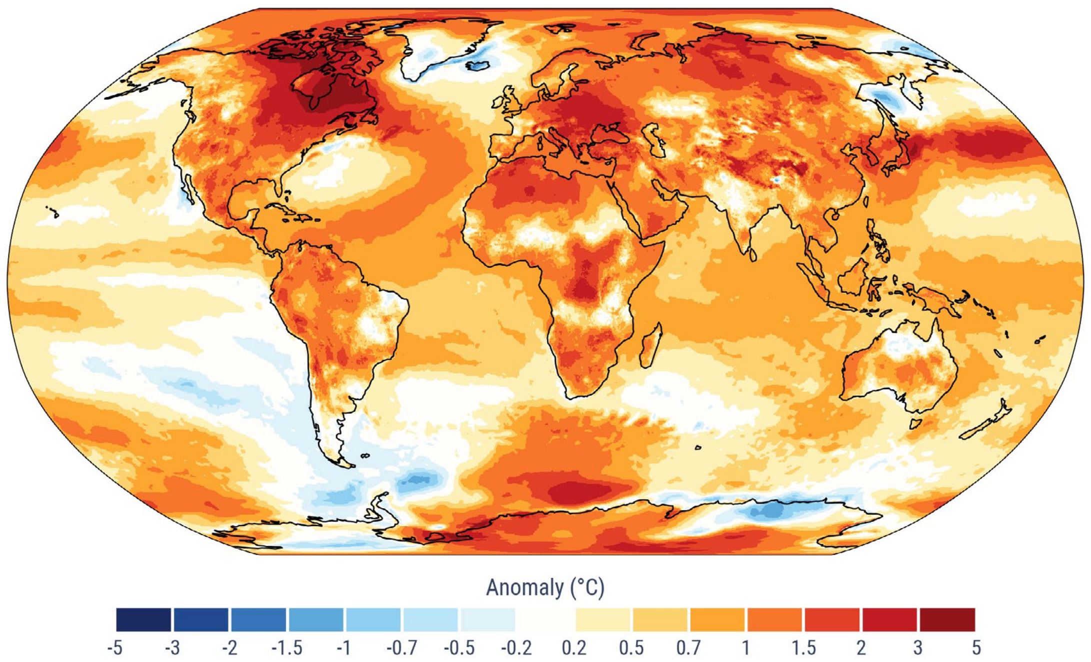


Source: NOAA, 2025.

This temperature anomaly reflects a rate of warming unprecedented in the Holocene (the current geological epoch, spanning approximately 11,700 years), driven by a significant increase in greenhouse gas (GHG) concentration. The accumulation of these gases intensifies radiative forcing and creates an energy imbalance in the climate system, thereby exacerbating the impacts of global warming.

These findings unequivocally reinforce the urgent need to advance strategies in emissions mitigation and climate change adaptation. **Figure 2** illustrates the temperature anomalies recorded in 2024, highlighting the alarming trends observed in this global scenario.

Figure 2. Surface air temperature anomalies in 2024 relative to the 1991–2020 reference period average.



Source: C3S, 2024.

2.1. The Greenhouse Effect Phenomenon

The greenhouse effect is a natural phenomenon essential to the planet's thermal balance, responsible for maintaining the Earth's mean temperature at around 15°C, a fundamental condition for the existence of life as we know it. Without the natural greenhouse effect, the mean surface temperature would be below 0°C, making the planet inhospitable (IPCC, 2007; Denchak, 2019).

According to the IPCC Sixth Assessment Report (2023), the atmosphere plays a crucial role in regulating the planet's energy balance. Approximately 71% of incident solar radiation penetrates the Earth's atmosphere, while roughly 29% is reflected back to space. This reflection phenomenon, known as albedo, results largely from interaction with clouds, but also from the surface reflectance of the Earth. The solar radiation that successfully penetrates the atmosphere is absorbed by the Earth's surface, the oceans, and the atmosphere itself, triggering processes such as surface warming, evaporation, cloud formation, precipitation, winds, and ocean currents (IPCC, 2021).

The natural greenhouse effect occurs when greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), and water vapor, efficiently absorb infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This radiation is re-emitted in all directions, including back toward the Earth's surface, thereby trapping heat in the surface-troposphere system and maintaining the planet at a temperature significantly warmer than it would be in the absence of these gases. This "atmospheric radiance" is directly correlated with the temperature at which it is emitted. Since tropospheric temperature decreases with altitude, the majority of infrared radiation released into space originates from altitudes with an average temperature of -19°C, which is in radiative equilibrium with net solar radiation, while the Earth's surface maintains a mean temperature of 15°C (IPCC, 2021).

However, the increase in greenhouse gas concentrations resulting from human activities intensifies this natural effect, generating what is known as the "enhanced greenhouse effect." This increase in GHG concentration raises the infrared opacity of the atmosphere, causing radiation emitted into space to originate from greater altitudes and correspondingly lower temperatures. This creates radiative forcing, i.e., an energy imbalance in the climate system that can only be balanced by additional warming of the surface and troposphere. This intensified warming is the main cause of the increase in global mean temperatures and the climate changes currently documented (IPCC, 2023).

This increase results from the continuous rise in atmospheric GHG concentrations, driven primarily by the combustion of fossil fuels (coal, oil, and natural gas), agricultural activities, industrial processes, and deforestation. In Brazil, for example, deforestation is the main source of emissions, given that forests function as carbon sinks; however, when cleared or burned, they release substantial volumes of CO_2 into the atmosphere (WWF, n.d.).

2.2. Impacts of Climate Change and International Milestones

Climate change presents one of the most significant threats to human society and ecosystems, generating impacts across various environmental, economic, and public health spheres (IPCC, 2022). The intensification of global warming and persistent observed trends have led to sea level rise, increased frequency of extreme weather events such as floods, droughts, and storms, the proliferation of tropical diseases, and biodiversity loss.

The Paris Agreement, established during COP21 in December 2015, represents a milestone in international climate governance. As the first universal, legally binding agreement on climate change, it establishes a new model of cooperation among nations. Its fundamental objective is to limit global warming to well below 2°C relative to pre-industrial levels, with a preferred target of 1.5°C.

This agreement innovates by adopting a "bottom-up" methodology, where each nation determines its own emission reduction targets through Nationally Determined Contributions (NDCs), in contrast to previous frameworks that imposed standardized targets. This flexibility allows countries at different stages of development to contribute more realistically and effectively to the global mitigation effort.

Brazil has set ambitious targets for 2035, demonstrating its commitment to the international climate agenda. The main targets include a substantial reduction in GHG emissions of 59 to 67% below 2005 levels. Additionally, the country aims to achieve carbon neutrality by 2050 and eliminate illegal deforestation by 2030 (MMA, 2024).

These commitments are particularly relevant considering Brazil's strategic role in preserving tropical forests, generating renewable energy, and advancing sustainable agricultural practices. To achieve these goals, the country needs to implement a series of integrated public policies involving various sectors of the economy and different levels of government, while engaging the private sector and civil society.

It is observed that natural systems in all regions of the planet and in the oceans are being impacted, mainly as a consequence of rising global mean temperatures (IPCC, 2021). In Brazil, it is noteworthy that temperature increases result in significant climate variability, affecting hydrological cycles and the frequency of extreme phenomena. As a result, measures to reduce greenhouse gas emissions and adapt to climate change are becoming increasingly imperative.

In this context, the active participation of cities and states in reducing carbon emissions, complying with the Paris Agreement, and fostering sustainable urban development has become increasingly relevant. Subnational governments play a strategic role in implementing adaptation and mitigation programs, which generate numerous co-benefits for communities in terms of poverty reduction, employment generation, improved service provision, and enhanced quality of life.

These governments are crucial in implementing public policies like preserving green areas, promoting sustainable mobility, and energy efficiency. Furthermore, they serve as a critical link in fostering community awareness and engagement with the climate agenda. Therefore, effective coordination among different levels of government and its practical application in urban areas is essential for Brazil to achieve its internationally established goals and strengthen national climate resilience.

National Policy on Climate Change (PNMC - Brazilian acronym), Climate Plan, and Brazilian NDC

The PNMC, established by Law No. 12,187/2009, is the main legal framework for climate action in Brazil. Its primary objective is to guide measures to mitigate GHG emissions and adapt to climate impacts. To achieve this, the PNMC provides for instruments such as sectoral plans, emissions inventories, and the development of national action plans.

The **National Plan on Climate Change**, commonly referred to as the "Climate Plan" (Plano Clima in Portuguese), is the main medium - and long-term planning instrument established by the PNMC. Its purpose is to define cross-sectoral and sectoral strategies to guide emissions reduction and climate adaptation targets by 2035. Brazil launched an initial version of the plan in 2008, establishing targets for 2020 (MMA, 2025a).

Currently, the Federal Government (MMA, 2025b) is developing an updated version of the Plan, which provides for enhanced integration among federal, state, and municipal policies, as well as engagement from the private sector and organized civil society. Among its guidelines, the following are noteworthy:

- **Definition of intermediate sectoral targets**, prioritizing the commitment to climate neutrality by 2050;
- **A national strategy encompassing seven Sectoral Mitigation Plans**, including Agriculture and Livestock, Cities, Energy, and others, which must contain high-impact actions, structural measures, and progressive targets extending to 2035;
- **A national strategy comprising 16 sectoral adaptation plans**, divided into themes such as biodiversity, health, food security, risk and disaster management, and others;
- **Strengthening of monitoring, reporting, and verification (MRV) systems**, allowing for greater transparency in tracking the evolution of GHG emissions; and
- **Coordination with sustainable development policies** in order to align economic growth, social inclusion, and emissions reduction.

This planning process was coordinated with the updating of Brazil's NDC targets, which established a **reduction in net GHG emissions of 59% – 67% by 2035**, compared to 2005 levels. Previously established targets — a **48% reduction by 2025 and 53% by 2030** — were maintained, reaffirming the commitment to achieve net-zero emissions by 2050. In absolute terms, the NDC projects that Brazil's emissions in 2035 should range between **850 million and 1.05 billion tons of CO_2 equivalent**, requiring an accelerated energy transition, reduction of illegal deforestation, and expanded use of low-carbon technologies in various sectors (MMA, 2025c).

The alignment among the PNMC, Climate Plan, and NDC is based on dialogue and cooperation among the federal, state, and municipal governments, where coordinated action will be decisive in guiding the trajectory of GHG emissions reduction, ensuring transparency in meeting targets, and expanding climate ambition in future cycles (MMA, 2025c).

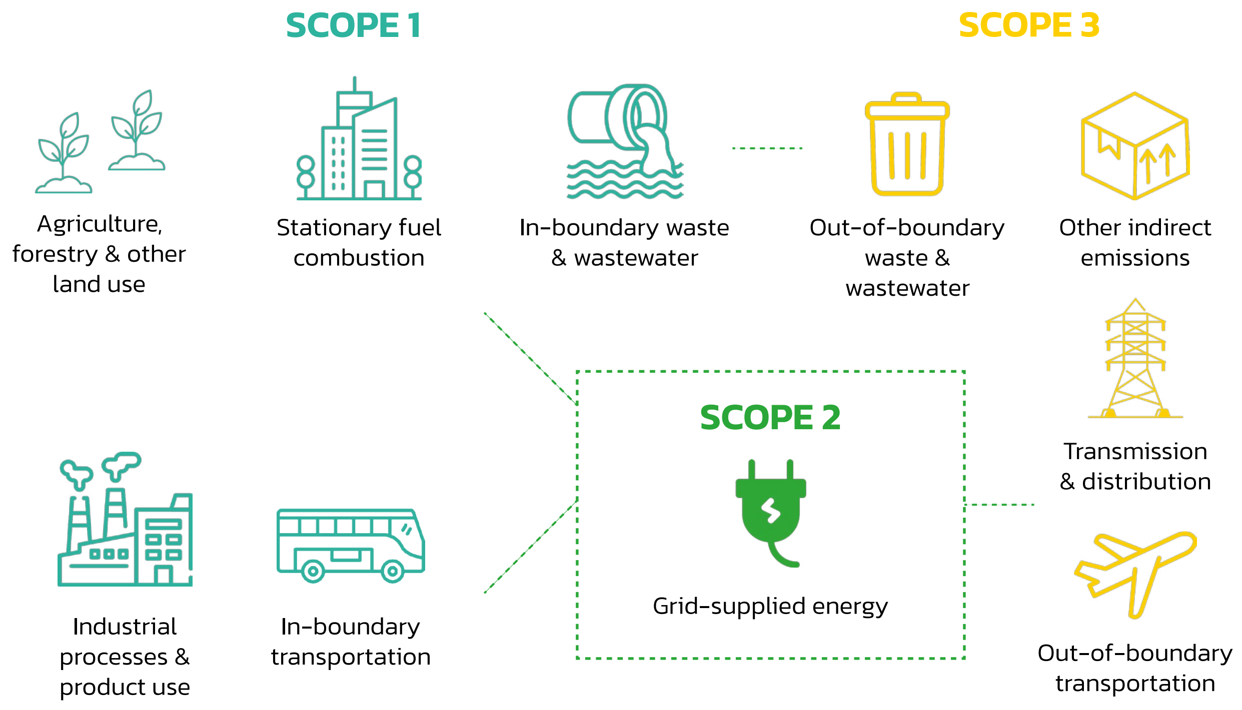
METHODOLOGY

Greenhouse Gas Emissions Inventories are essential tools for climate management at all levels of government. For the development of Ceará's GHG Emissions Inventory, the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) was adopted. This protocol, developed in 2014 by ICLEI – Local Governments for Sustainability, the World Resources Institute (WRI), and the C40 Cities Climate Leadership Group, is internationally recognized for its robust and standardized structure.

The GPC's main objective is to enable the aggregation of data and ensure its reliability for community, city and regional inventories, as well as to facilitate comparative analyses among different local governments. By establishing clear requirements and providing detailed guidelines for GHG calculations and reporting, the GPC ensures accuracy and international comparability, positioning Ceará at the forefront of climate action and enabling its participation in global networks and initiatives that require standardized emissions reporting.

In inventories prepared according to the GPC methodology, emissions are classified into three main categories, based on the geographic location of the activities generating those emissions, as illustrated in **Figure 3** and described in **Box 1**.

Figure 3. Delimitation of the scopes considered in the GPC method.



Source: WRI; C40; ICLEI, 2014.

Box 1. Delimitation of scopes in the GPC method.

Scope 1	Direct GHG emissions from sources located within state boundaries.
Scope 2	Indirect GHG emissions resulting from the use of electricity supplied by the national grid within the state's boundaries, such as Brazil's National Interconnected System (SIN, in the Brazilian acronym).
Scope 3	Indirect GHG emissions occuring outside state boundaries as a result of activities that take place within its boundaries. These emissions originate from sources located outside state boundaries, but result from activities under the direct responsibility of the state administration.

Source: Adapted from WRI; C40; ICLEI, 2014.

In addition to the breakdown into scopes, the GPC also provides for the allocation of emissions by sectors and sub-sectors, as shown in **Box 2**, with the objective of ensuring that all activities are identified and categorized consistently. To this end, the GPC determines six primary sectors in which emitting activities are allocated:

Box 2. Description of emission sectors.

Sector 1	**Stationary Energy**	This sector includes emissions generated from the production, transformation, distribution, and consumption of various forms of energy. It also includes fugitive emissions, i.e., those resulting from the intentional or accidental release of GHGs during the extraction, processing, transformation, and distribution of fossil fuels, such as emissions from natural gas leaks and methane emissions from coal mining, and emissions during oil extraction and refining. The *GPC* identifies the main sources as: residential buildings; commercial and institutional buildings; manufacturing and construction industries; energy production facilities; agriculture, forestry, and fishing; unspecified sources; fugitive emissions from coal mining, processing, storage, and transportation; and fugitive emissions from oil and natural gas leaks.
Sector 2	**Transportation**	This sector includes emissions generated by fuel combustion across various transportation modes within the state, as well as energy consumption by electric vehicles, where applicable. Emission sources are segregated by transportation mode: on-road, rail, waterborne, aviation, and *off-road* . The following are assessed: consumption of gasoline, ethanol, diesel, aviation gasoline, and aviation kerosene; consumption of Compressed Natural Gas (CNG); fuel consumption for domestic transportation; and diesel consumption in public transportation systems.

Source: ICLEI – Local Governments for Sustainability, 2025.

Box 2. Description of emission sectors.

Sector 3	**Waste**	This sector includes emissions related exclusively to the treatment of solid waste and wastewater. Emissions of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) from the degradation of organic matter and other compounds across different waste treatment pathways are quantified. Emission sources are segregated into: solid waste disposal, biological treatment, incineration, and wastewater treatment and disposal.
Sector 4	**Industrial Processes and Product Use *(IPPU)***	This sector quantifies emissions from industrial processes, the use of GHGs in products, and non-energy applications of fossil fuels. The main emission sources are associated with manufacturing industries (chemical or physical transformations), such as iron, steel, and cement production. Additionally, the use of GHGs (such as hydrofluorocarbons - HFCs) in products such as refrigerators, foam insulation, or aerosol containers is also accounted for.
Sector 5	**Agriculture, Forestry, and Other Land Use *(AFOLU)***	This sector encompasses GHG flows from land use and management that influence a variety of ecosystem processes, including photosynthesis, respiration, decomposition, nitrification/denitrification, enteric fermentation, biomass combustion, and others. All these processes involve physical (combustion, leaching, and runoff) and biological (activity of microorganisms, plants, and animals) transformations of carbon and nitrogen. This sector quantifies emissions of CO_2, CH_4 and N_2O. For the AFOLU sector, emission sources are segregated into: livestock, land use, aggregate emissions, and other non-CO_2 emissions.
	Other indirect emissions	This sector includes emissions generated by activities that occur outside the state's borders but are related to activities that occur within its boundaries and not covered in other sectors. Estimates account for activities that cause indirect emissions, such as the rate of wastewater generated in the state but discharged beyond its boundaries, emissions from the consumption of inputs for civil construction, and others. It should be noted that, according to the GPC, quantification of these emissions is not mandatory.

Source: ICLEI – Local Governments for Sustainability, 2025.

For a better understanding of how the different sectors of activity are linked to the emission scopes in the inventory, **Box 3** below presents the allocation of each sector within Scopes 1, 2, and 3. This categorization is essential for identifying the source of emissions (direct or indirect) and effectively targeting mitigation strategies.

Box 3. Sectors and scopes of the GHG Inventory.

Sector	Scope 1	Scope 2	Scope 3
Stationary Energy	x	x	x
Transportation	x	x	x
Waste	x		x
IPPU	x		
AFOLU	x		
Other Scope 3 emissions			x

Source: WRI; C40; ICLEI, 2014.

Furthermore, for an accurate interpretation of the data, it is necessary to differentiate between gross emissions and net emissions. **Gross emissions** correspond to the total greenhouse gases released into the atmosphere from human activities, without considering the compensation provided by carbon sinks. **Net emissions**, however, result from the balance between gross emissions and GHG removals, which occur, for example, through carbon sequestration in forests and other vegetation, more accurately reflecting the net impact of anthropogenic activities on the climate. This difference is expressed in the equation below:

NET EMISSIONS = GROSS EMISSIONS – CARBON REMOVALS

Finally, it is also necessary to define the boundaries of the system under analysis. This step involves specifying the geographic boundary and identifying emission source activities by sector, aspects that are detailed in the following sections.

Different methodologies for preparing GHG emissions inventories

The preparation of GHG emissions inventories can follow different methodologies, depending on the scale of analysis and the purpose of the assessment. In Brazil, the **National Inventory of Anthropogenic GHG Emissions and Removals adopts the IPCC (Intergovernmental Panel on Climate Change) Guidelines** as its primary reference.

The **National Inventory** focuses primarily on measuring GHG emissions at the national scale, breaking down activities into key sectors defined by the IPCC: energy, industrial processes and product use, agriculture, land-use change and forestry, and waste. The primary objective is international reporting, ensuring transparency, comparability, and compliance with internationally established commitments, supporting national communications and tracking of emissions over time.

The **GPC (Global Protocol for Community-Scale Greenhouse Gas Emission Inventories)** methodology, on the other hand, was designed for local-scale inventories in cities and regions, seeking to support climate management at the subnational and urban levels. This method, also based on calculation approaches presented in the IPCC guidelines, disaggregates emissions into five primary sectors and three scopes, which determine whether emissions are direct or indirect.

The GPC is designed to facilitate decision-making processes in the implementation of local public policies. It is important to note that the different methodologies are complementary, adopting best practices and standardized methods for measuring GHG emissions. The National Inventory enables assessment of the country's performance against internationally established climate targets, while the GPC provides tools for action at the subnational level, where most emissions and mitigation opportunities are concentrated.

3.1. Engagement and Training of Strategic Actors

The preparation of a Greenhouse Gas Emissions Inventory for a territory as large as the State of Ceará requires, in addition to technical work, an engagement process and capacity-building for the various actors involved. Recognizing this premise, Ceará's GHG Emissions Inventory Work Plan established the creation of a strategic Working Group (WG), composed of state managers and technical staff, to build awareness and capacity.

The main objective of forming the WG is to promote knowledge and autonomy among state managers and technical staff in the development of Ceará's GHG Emissions Inventory. This WG was fundamental both for supporting data collection and for reviewing and validating the information and products generated by the inventory.

The Working Group included members from the Secretariat for the Environment and Climate Change (SEMA, in the Brazilian acronym) and other state agencies, with the aim of optimizing communication and collaboration in data collection and validation.

3.1.1. Awareness and Technical Training Session

As part of the engagement strategy, an in-person awareness and training session on GHG Emissions Inventory preparation was held on April 3, 2025, at the Cocó Ecological Park Amphitheater in Fortaleza. This activity, developed by ICLEI South America, was directed at the Working Group and other interested technical staff.

The training program addressed a series of essential topics for understanding the climate context and inventory methodologies, including:

• **Climate Change**: Foundational knowledge on the greenhouse effect, GHGs, emission source activities, and the impacts of climate change.

• **Legal and Institutional Framework**: Discussion of the Paris Agreement and Brazil's Nationally Determined Contributions (NDCs), providing context for climate targets.

• **Inventory Preparation Methodologies**: Presentation of the methodologies of the IPCC (Intergovernmental Panel on Climate Change) and the GPC (Global Protocol for Community-Scale Greenhouse Gas Emission Inventories), which guide inventory development.

• **Sectoral Issues**: In-depth analysis of the Stationary Energy, Transportation, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry, and Other Land Use (AFOLU) sectors, identifying their main emission sources.

• **Calculation and Data Collection**: Guidance on simplified calculation methodologies, activity data, emission factors, and global warming potential, as well as strategies for effective data collection from institutions holding the necessary information. The use of the WayCarbon Ecosystem platform as a support tool for data calculation and processing was emphasized.

3.2. Calculation Tool

This inventory was prepared using the WayCarbon Ecosystem platform, a software system developed by WayCarbon, a partner organization of ICLEI, which is methodologically robust and employs best-practice references to establish calculation methods and select the most appropriate emission factors for each activity.

Additionally, given the scarcity of state-specific data, the estimates presented in the GHG Emissions and Removals System (SEEG — *Sistema de Estimativas de Emissões de Gases de Efeito Estufa*), a renowned initiative of the Climate Observatory, were also used as a reference.

Finally, some GHG emissions information was obtained directly from partner organizations, with emission inventories and databases that are publicly disclosed.

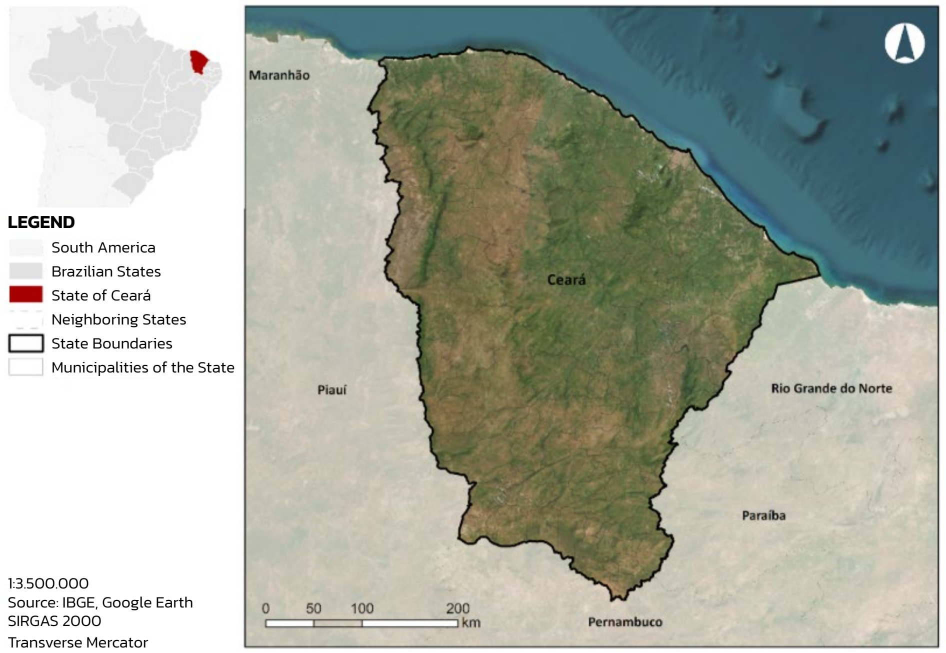
INVENTORY BOUNDARIES

4.1. Characterization of the State of Ceará

The State of Ceará is located in Brazil's Northeast region, bordering Pernambuco to the south, Rio Grande do Norte and Paraíba to the east, Piauí to the west, and the Atlantic Ocean to the north. With a territorial area of 148,894.4 km² (IBGE, 2024a), the state comprises 184 municipalities, with Fortaleza as the capital.

According to the 2022 census, Ceará's population was 8,794,957 (IBGE, 2022), with a population density of approximately 59.07 inhabitants/km², making it the 3rd most populous state in the Northeast, and the 8th in Brazil (IBGE, 2022). This density is higher than that of other Northeastern states such as Piauí (12.99 inhabitants/km²) and Bahia (25.04 inhabitants/km²), but lower than Pernambuco (92.37 inhabitants/km²) (IBGE, 2022). **Figure 4** shows a map of the state.

Figure 4. Location of the State of Ceará



Source: ICLEI – Local Governments for Sustainability, 2025.

In 2021, Ceará's Gross Domestic Product (GDP) was approximately BRL 194.9 billion, and the per capita monthly household income was BRL 881. In terms of 2021 gross GDP, Ceará ranked 3rd in the Northeast, behind Bahia (BRL 352.6 billion) and Pernambuco (BRL 220.8 billion) (IBGE, 2021). Regarding per capita monthly household income, the state also ranked 3rd in the region, ahead of Rio Grande do Norte (BRL 1,109.00) and Sergipe (BRL 929.00) (IBGE, 2024b).

Ceará's economy is predominantly supported by the Services sector, which represented 75.2% of the state's Gross Value Added (GVA) in 2022, followed by Industry (19%) and Agriculture and Livestock (5.8%). In 2024 all sectors grew, with Agriculture and Livestock standing out (+25.2%), driven by good harvests and expansion of livestock. Industry grew by 10.7%, with emphasis on the textile, footwear and construction segments, while Services expanded by 4.3%, maintaining its role as the base of the state economy (IPECE, 2025).

In 2022, Ceará had 1.65 million formal jobs, an increase of 8% compared to the previous year, and 199,000 registered establishments, with a slight contraction in the number of establishments. The sectors that employed the most were Public Administration, Retail Trade and Education (SEBRAE, 2022).

Ceará is divided into 12 river basins, with notable rivers including the Acaraú, Banabuiú, Jaguaribe and Salgado — the Jaguaribe River being the most important and extensive, about 652 km long. The state also contains significant lagoons such as Almécegas, Catú, Cauípe, Jijoca and Uruaú. Precipitation is irregular, with two defined seasons: a rainy season, concentrated in the first half of the year, and a dry season in the second half, when rainfall is scarce (FUNCEME, 2024) and there is a higher incidence of wildfires in the state. The predominant climate is Hot Semi-Arid Tropical (IPECE, 2014) and the main biome is Caatinga (IBGE, n.d.).

In 2023, land cover in Ceará was predominantly natural areas, which accounted for 69.77% of the territory, totaling 10.39 million hectares. Areas under anthropic use corresponded to 30.16%, or 4.49 million hectares, below the average observed in other states in the region such as Rio Grande do Norte (49%), Bahia (46%) and Pernambuco (45%) (MapBiomas, 2023). **Box 4** provides the characterization and the inventory boundaries of the state.

Box 4. Information on Ceará..

Inventory characterization and boundaries	
State name	Ceará
Capital	Fortaleza
Country	Brazil
Area	148.894,4 km²
Geographical boundaries	Pernambuco, Rio Grande do Norte, Paraíba and Piauí
Population	8.794.957 people (2022)
GDP per capita	R$ 21.090,11
Climate	Predominantly Hot Semi-Arid Tropical
Predominant biome	Caatinga

Source: IBGE, 2023, 2024b.

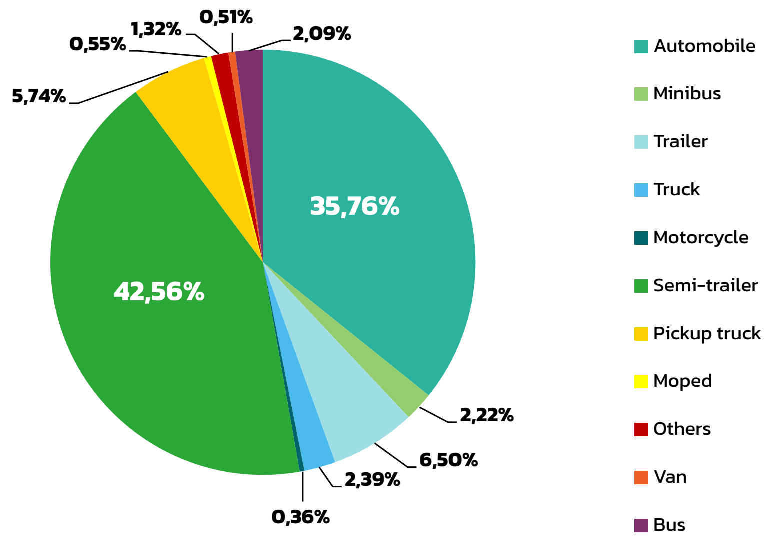
As part of defining the inventory boundaries, the following sections characterize the State of Ceará according to the sectors recommended by the GPC: Stationary Energy, Transportation, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry, and Other Land Use (AFOLU).

4.1.1. Transportation

According to Ceará's State Traffic Department (DETRAN-CE, in the Brazilian acronym), by September 2023 the state had a total fleet of 3,735,255 vehicles. Motorcycles were the most numerous, representing 42.56% of the total, followed by passenger cars with 35.76%. Pickups and scooters accounted for 6.50% and 5.74%, respectively. SUVs represented 2.39% of the fleet, while trucks made up 2.22% (DETRAN-CE, 2023).

The predominance of motorcycles and passenger cars in Ceará's fleet (**Figure 5**) indicates the relevance of on-road transportation to the state's emissions profile, a trend that is later confirmed by the inventory results.

Figure 5. Fleet by type in Ceará.



Source: ICLEI adapted from Detran-CE, 2023.

According to the National Agency of Petroleum, Natural Gas and Biofuels (ANP, 2025), in 2023 Ceará presented a diversified energy consumption profile, with a notable intensive use of fossil fuels in the transportation sector. Gasoline C led fuel consumption among transportation fuels, with 1.53 billion liters used exclusively in road transportation. Hydrated ethanol, also used solely in road transportation, totaled 147 million liters, indicating a still relevant presence of biofuels in Ceará's vehicle fleet.

Diesel oil was another significant input, with total consumption of approximately 1.14 billion liters, of which 89.96% was allocated to the road transportation sector, and the remaining 10.04% distributed among other sectors. In the aviation sector, aviation kerosene consumption reached 219.2 million liters, while aviation gasoline amounted to only 427,872 liters, both exclusively for air transportation (ANP, 2025).

Additionally, Compressed Natural Gas (CNG) recorded consumption of 38.56 million m^3 in 2023, reinforcing its growing importance as a lower-emission energy alternative in urban road transportation, particularly in taxi fleets and light cargo vehicles (CEGÁS, 2025).

Thus, Ceará's Transportation sector had a significant impact on GHG emissions, due to the predominant use of fossil fuels such as gasoline and diesel, which accounted for 46% and 34% of the fuel matrix, respectively. The state's vehicle fleet, composed mainly of motorcycles and passenger cars, further intensifies this impact. Despite the presence of biofuels such as ethanol, their use remains limited compared to the total volume of fuels consumed.

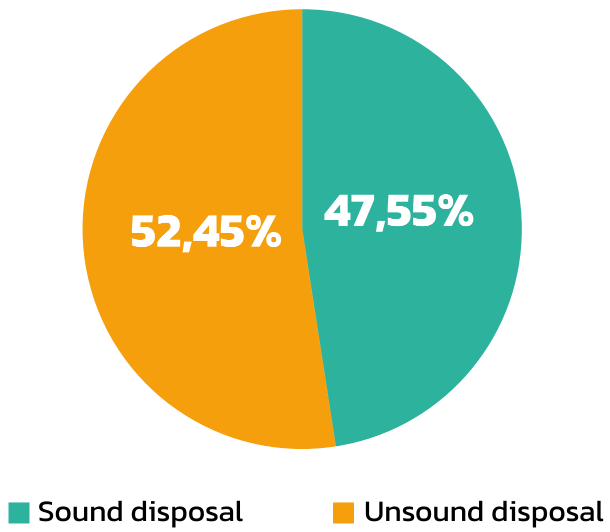
4.1.2. Waste

• Urban Solid Waste

Based on the National Sanitation Information System (SNIS, 2025b), in 2023 Ceará sent a total of 3,748,274.80 tonnes of solid waste to final disposal units. Of this volume, 1,782,294.70 tonnes (47.55%) went to environmentally sound disposal units, i.e., sanitary landfills. Unsound disposal, such as open dumps and controlled landfills, totaled 1,965,980.10 tons (52.45%), highlighting challenges in the state's waste management. According to SNIS, in 2022 there were 148 uncontrolled disposal sites and six environmentally sound disposal units in operation in Ceará.

Final waste disposal is shown in **Figure 6** below.

Figure 6. Final waste disposal in Ceará.



Source: ICLEI adapted from SINISA, 2025.

1 NBR 8849/1985, which regulated controlled landfills, was canceled, given that this technique does not ensure environmental preservation, especially due to the absence of adequate soil waterproofing, which can result in groundwater contamination. However, according to SNIS data, controlled landfills are still used in some locations in the territory. For this reason, they were considered and accounted for in this study.

In 2023, Ceará had 83.78% of its population covered by regular household solid waste collection services, totaling 7,442,575 inhabitants. This coverage refers to collection performed directly or indirectly with a minimum frequency of once per week. However, separate collection in the state was substantially lower, reaching only 5.96% of the population, equivalent to 529,552 inhabitants (SINISA, 2025b).

Compared to national figures for the same period, Ceará's regular household waste collection coverage is slightly below the national average of 86%. The disparity is more pronounced for separate collection of recyclable materials: nationally 35% of the population had access to this service, while in Ceará less than 6% did.

Within the Northeast region, coverage rates were even lower than the national average: regular household waste collection reached 75% of the population, while separate collection covered only 5%. In this context, Ceará's separate collection performance (5.96%) places the state slightly above the regional average, but still far from national levels.

As a result, the great majority (94.04%) of Ceará's population lacks access to regular separate collection services. Although the state aligns with regional averages, the low coverage indicates a major challenge for separation and proper destination of recyclable materials, especially compared to higher national rates (SINISA, 2025b).

• Sanitary Sewage

According to SINISA (2025a), in 2023 33.07% of Ceará's population had access to a sewage collection network, which corresponds to 2,824,984 inhabitants. Consequently, 66.93% of the population still lack access to sewer networks or use individual solutions to treat their wastewater. The public sewer network covered 6,669.3 km of extension, indicating a system still under expansion.

Regarding treatment, approximately 109 million m³ of sewage were collected during that year, of which about 100 million m³ were effectively treated, resulting in a sewage treatment rate of 92.11% of collected volume (SINISA, 2025a).

In a regional and national comparison: Ceará's percentage of population served by sewage collection in 2023 was close to the Northeast macro-region average (33.79%), but considerably below the national average (59.70%) (SINISA, 2025a).

It is important to note that the limited coverage (only one-third of the population served) implies a smaller volume of sewage to be treated. This is reflected in the SINISA (2025a) data: while the Northeast treats 80.97% of collected sewage, surpassing the national average of 78.68%, this performance must be interpreted with caution. Systems with lower coverage tend to show higher treatment rates, as they operate at smaller scales and with less operational complexity than areas with more extensive networks.

Concerning municipal solid waste, the high share of final disposal in landfills and the low selective collection coverage (5.96%), which results in low recovery rates for recyclables and organic fractions, favor methane emissions. As for sanitation, although 92.11% of collected sewage was treated, only 33.07% of the population has access to the sewer network, which has environmental and social impacts beyond climate change considerations. Overall, due to this scenario, the Waste sector contributed significantly to Ceará's GHG emissions in 2023.

4.1.3. Stationary energy

• Energy generation

According to the National Energy Balance (BEN, 2024), in 2023 wind energy was the main source of electricity generation in Ceará, representing 71% of the state's electricity matrix, followed by solar energy (25%).

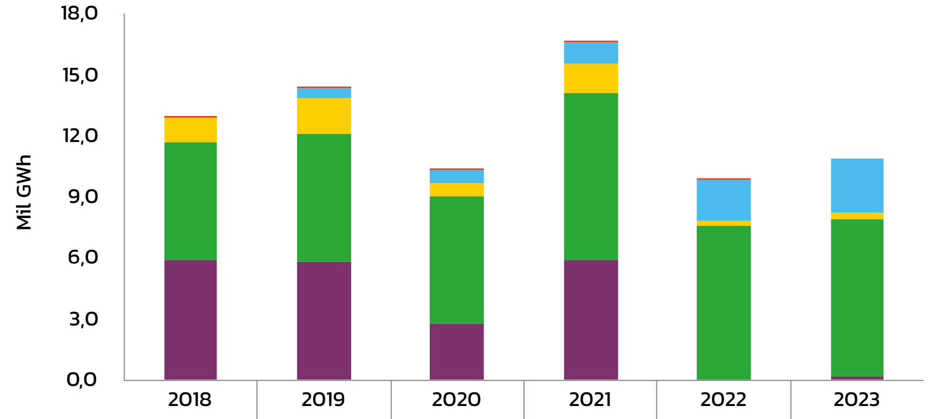
Regionally, wind energy also led electricity generation in the Northeast, accounting for 55% of the total, followed by hydropower (22%) and solar (11%). At the national level, electricity generation remains dominated by hydropower, corresponding to 57% of the Brazilian matrix, while wind and solar comprised 13% and 7%, respectively (BEN, 2024).

Figure 7 shows GWh generation in Ceará by source for the inventory period. As noted, wind generation is the primary contributor to the state matrix, highlighting the role of renewables in Ceará's grid. Another noteworthy aspect is the significant increase in the state's generation in 2021, with a 60% increase compared to the previous year (BEN, 2024).

It should be noted that the period also saw electricity generation from coal-fired thermoelectric plants, which played a significant role until 2021. However, this contribution became practically negligible in subsequent years, falling from 5,880 GWh in 2021 to just 12 GWh in 2022 and 169 GWh in 2023.

This behavior is strongly connected to the Brazilian context, where in 2022 there was a marked reduction in electricity generation from fossil sources in favor of renewable sources. This trend was driven both by favorable climatic conditions for hydropower and by the increased participation of wind and solar sources. Notably, wind generation surpassed thermal generation at the national level for the first time. These factors resulted in an approximate 68% reduction in global emissions associated with electricity generation in Brazil (IEMA, 2023).

Figure 7. Energy generation by source (2018-2023).



	2018	2019	2020	2021	2022	2023
Hydroelectric	1	4	4	4	4	0
Solar	66	469	624	1037	2033	2706
Other fossil fuels	1164	1842	674	1400	209	285
Wind	5828	6279	6247	8287	7614	7776
Steam coal	5898	5802	2796	5880	12	169

Source: ICLEI adapted from BEN, 2024.

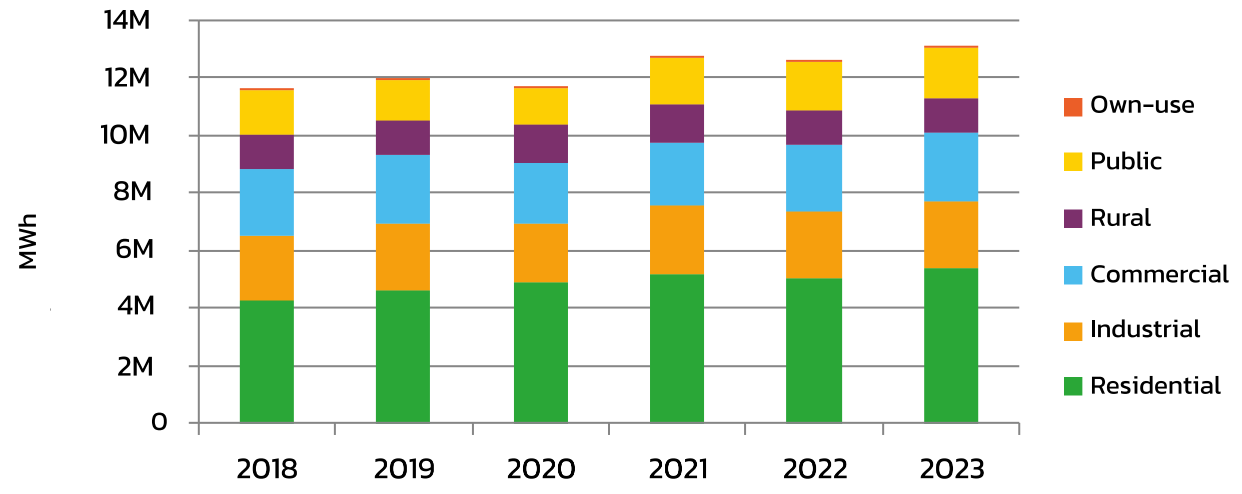
• Electricity consumption

In 2023, total electricity consumption in Ceará reached 13,027,256 MWh over the year. The residential sector accounted for the largest share (approximately 41.5% of the total), followed by the commercial (18%), industrial (17.8%) and public (13.3%) sectors. The rural and own-use[2] sectors had smaller shares, with 9.3% and 0.2%, respectively (IPECE, 2023).

According to IPECE (2023), between 2018 and 2023 total consumption ranged from 11,575,659 MWh to 13,027,256 MWh, while the number of electricity consumers grew from 3,543,521 to 4,406,218 — an increase of about 24%. This consumption growth occurred unevenly over the period: increases between 2018 and 2019, a slight decline in 2020 and recovery from 2021 onward. Despite year-to-year fluctuations, the proportional participation of the different consumption sectors remained relatively stable (**Figure 8**).

2 Includes the electricity consumption of utility facilities. Some utilities also report power plant self-consumption under this category (EPE, 2019).

Figure 8. Electricity consumption by sector and year in Ceará.



Source: ICLEI adapted from IPECE, 2023.

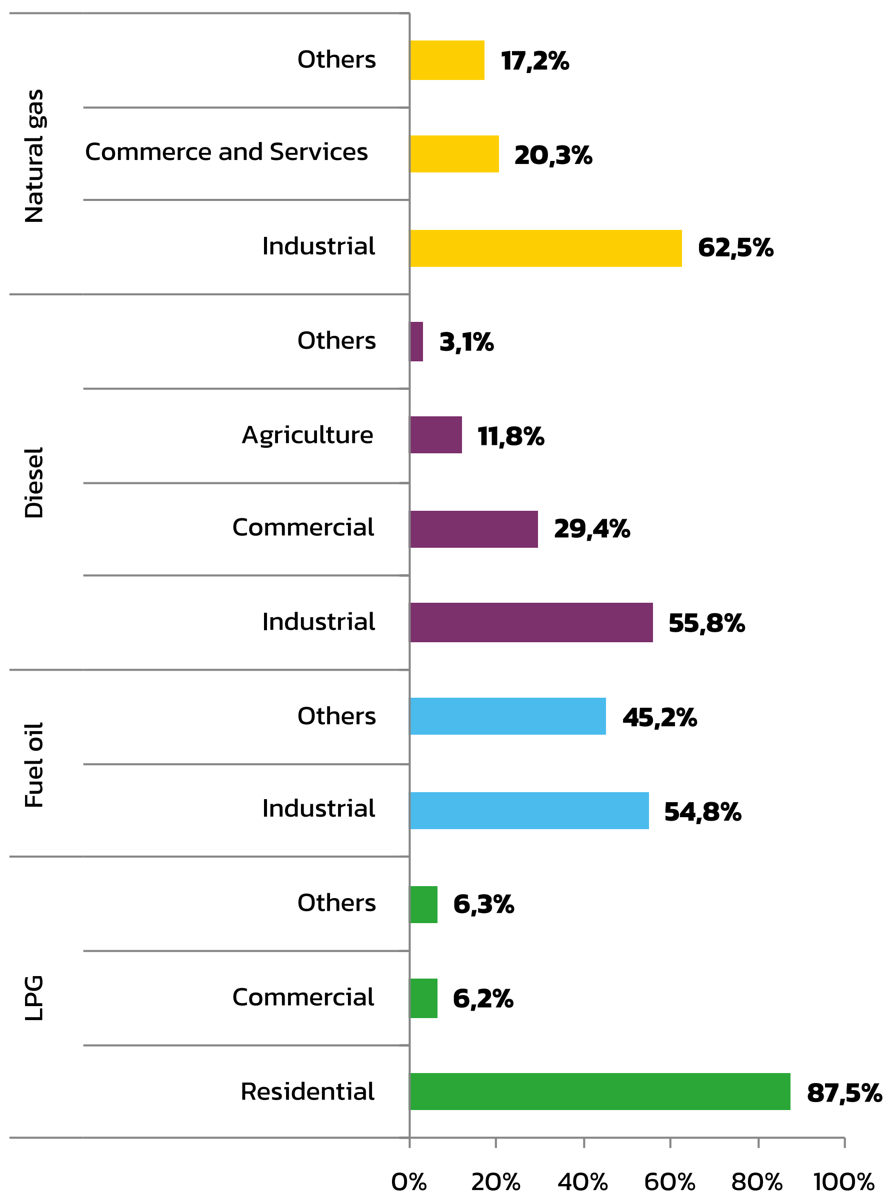
• Fossil fuel consumption

Fuel oil consumption in Ceará amounted to 2.14 million liters, of which 54.76% was used by industry and 45.24% by other unspecified sectors. Liquefied Petroleum Gas (LPG) consumption was 289.4 million kg, most of which was directed to the residential sector (87.5%). The remainder was distributed across the commercial (6.2%), industrial (6.15%), agricultural (0.14%) and public (0.01%) sectors (ANP, 2023).

Regarding diesel oil, total consumption in 2023 reached approximately 1.14 billion liters. Of this volume, 90.39% was used in the transportation sector. The industrial and commercial sectors accounted for 5.13% and 2.70%, respectively. Other applications — agriculture (1.08%), public sector (0.19%) and other uses (0.09%) — together totaled 1.36% of total consumption (ANP, 2023).

For natural gas, total consumption in the state reached approximately 21.15 million m³ in 2023, with the industrial sector predominant, consuming 13.22 million m³ (62.5%). Next were the commercial and services sectors (4.28 million m³; 20.3%), residential (2.40 million m³; 11.4%) and cogeneration (1.24 million m³; 5.9%) (CEGÁS, 2025). **Figure 9** shows the consumption of these fuels by their main uses in stationary sources in 2023.

Figure 9. Fossil fuel consumption by main uses in stationary sources.



Source: ICLEI adapted from ANP, 2023 and CEGÁS, 2025.

4.1.4. Agriculture, Forestry, and Other Land Uses

• Land use and land cover

According to MapBiomas, in 2023 Ceará's land cover was predominantly natural vegetation, with 67.75% of the area classified as forest. Shrub and herbaceous vegetation had low representation, covering only 0.28% of the territory. Water bodies covered 1.44% of the state territory, remaining a modest fraction of the landscape.

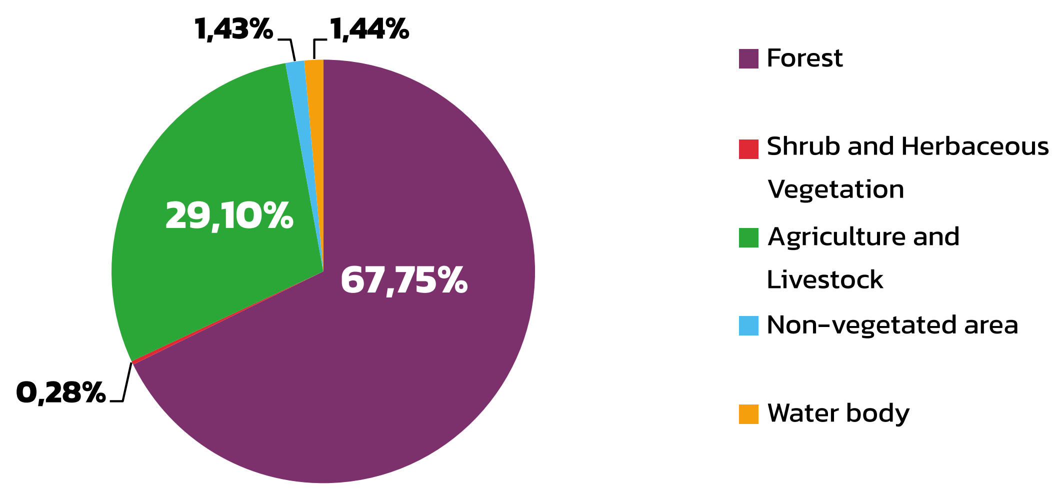
Agricultural and livestock activities accounted for 29.10% of Ceará's land cover. Of this total, pastures occupied the largest share (64.12%), followed by agricultural areas (13.58%) and mosaics of uses (22.30%). No forestry was recorded in the state during this period (MapBiomas Project, 2023).

Non-vegetated areas represented 1.43% of the surface, mainly composed of urbanized areas (68.80%), beaches (25.32%), mining (1.34%) and other unspecified non-vegetated areas (4.54%) (MapBiomas Project, 2023).

At the national level in the same year, land cover was also predominantly natural areas, with forest vegetation covering 61.47% of the national territory. Agricultural activities corresponded to approximately 30% of the country's area. Shrub and herbaceous vegetation represented 5.72%, while water bodies occupied 2.15% of the national surface. Non-vegetated areas totaled 0.66% nationally, of which around 65% were classified as urbanized areas (MapBiomas Project, 2023).

Regionally, land use distribution varies among Northeastern states. In Bahia, 50% of the territory was forested and 45% used for agriculture. In Pernambuco, forest cover represented 53% and agricultural activities 44%. In Piauí, forest vegetation predominated more markedly, covering 79% of the state, while agricultural activities occupied 18% (MapBiomas Project, 2023). **Figure 10** shows land cover and land use in Ceará for 2023.

Figure 10. Land cover and use in Ceará in 2023.

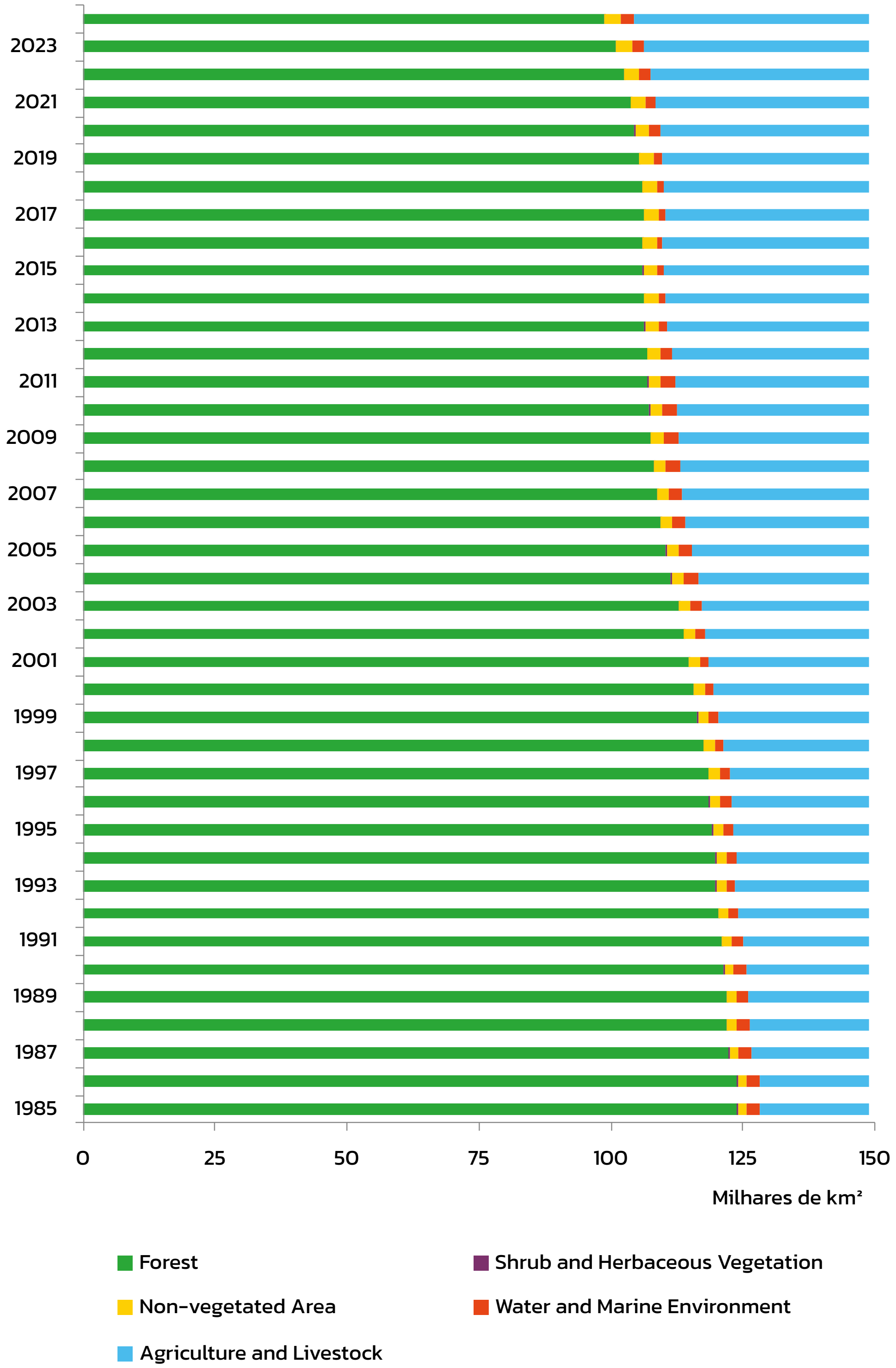


Source: ICLEI adapted from MapBiomas Project, 2023.

Thus, Ceará exhibits a proportion of vegetative cover higher than the Brazilian average and higher than other Northeastern states such as Bahia and Pernambuco, which have more than ten percentage points more land under agricultural use.

However, it is important to highlight that historically there has been a significant reduction in state areas classified as forest, which have been converted to other uses. **Figure 11** presents the evolution of areas by classification type from 1985 to 2024, showing a strong expansion of areas destined for agricultural activities at the expense of savanna forest formations characteristic of the Caatinga (MapBiomas Project, 2023).

Figure 11. Change in land use and occupation from 1985 to 2024.



Source: ICLEI adapted from MapBiomas Project, 2023.

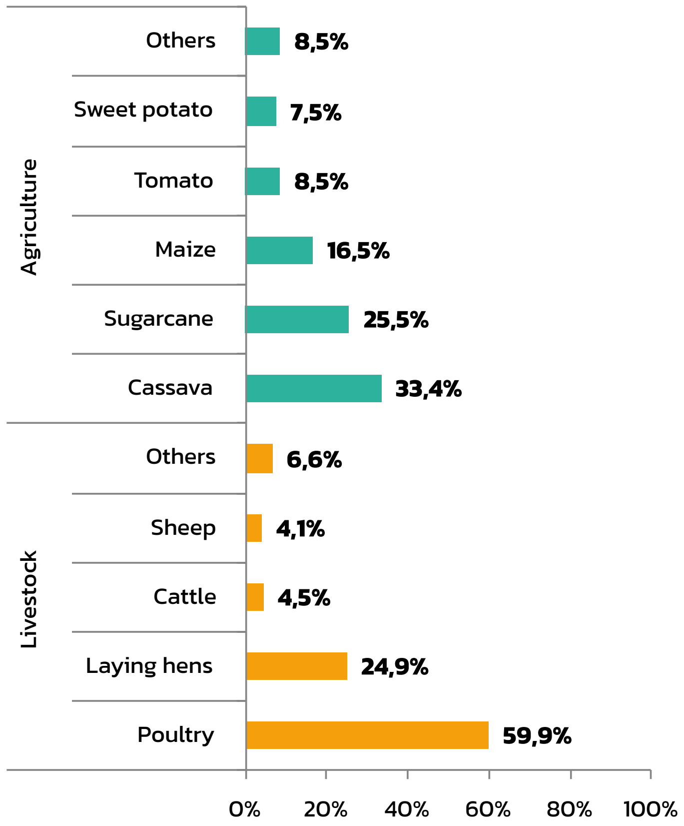
• Agriculture and livestock

According to IBGE's Municipal Agricultural Production survey (SIDRA, 2023b), in 2023 Ceará's agricultural production was dominated by cassava (33.39%), sugarcane (25.52%) and maize (16.52%). Other notable crops included tomato (8.48%) and sweet potato (7.50%). Smaller shares were recorded for beans (3.12%), melon (3.02%), rice and soy (both 0.88%), sorghum (0.21%), onion (0.11%) and cotton (0.27%). Crops such as pineapple, peanuts, castor beans, and tobacco accounted for less than 0.1% of total production.

Regarding livestock, the Municipal Livestock Survey (SIDRA, 2023a) shows the poultry sector as the most representative, with poultry making up 59.90% of the total livestock, of which 24.93% were laying hens. The cattle herd accounted for 4.45% of the total, of which 1.12% were dairy cows. Sheep and goat herds were also relevant, representing 4.08% and 1.86%, respectively. Pigs accounted for 2.05% of the herd, including 0.35% sows. Other animals such as equines (0.22%) and quails (1.03%) comprised the remainder of Ceará's livestock (SIDRA, 2023a).

Figure 12 shows the main crops and herds in Ceará in 2023.

Figure 12. Main agricultural and livestock production in 2023 in Ceará.



Source: ICLEI adapted from SIDRA, 2023a, 2023b.

A comparison of agricultural data for Brazil and the Northeast region in 2023 reveals differences in production structure and the prominence of certain crops and livestock. National agricultural production totaled approximately 1.19 billion tonnes, while the Northeast accounted for around 104.5 million tonnes, about 8.8% of national production. Sugarcane was the main crop nationally (66%) and in the Northeast (57%) (SIDRA, 2023b).

Regarding livestock, the Northeast's herd numbered approximately 281 million head, about 14.7% of the national herd (1.92 billion). Although bovine numbers are substantial — 35.3 million in the Northeast (13% of the national total) — the region stands out for goat and sheep farming, representing 96% and 71% of Brazil's goat and sheep herds, respectively. Poultry accounts for 74% of the region's animal production, following the national trend (82% of total). The Northeast also concentrates more than 20% of Brazil's quail production, reinforcing its specialization in small-scale poultry farming (SIDRA, 2023a).

Thus, Ceará's agriculture — marked by intensive cultivation of cassava, sugarcane and maize, and predominance of poultry — has a significant impact on the state's GHG emissions, which is addressed in Section 4.3.

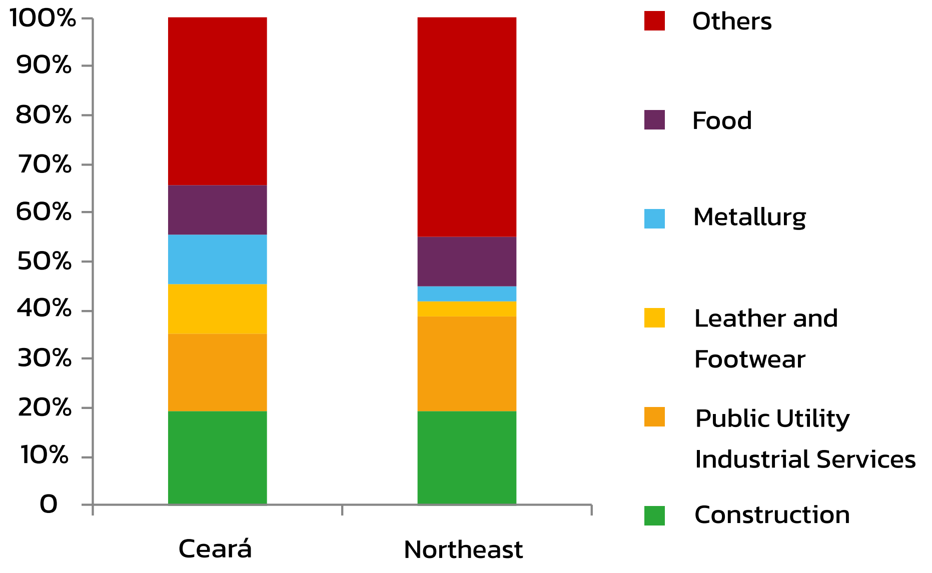
4.1.5. Productive sectors

Based on CNI data (2025), Ceará has a medium-sized industrial park, with an industrial GDP of BRL 35.2 billion, equivalent to 1.5% of national industry and 19% of the state's GDP. Ceará's industry employs 356,800 workers and includes around 17.8 thousand establishments, representing 3% of the national total. The sector is predominantly composed of micro and small enterprises (94%), although large industries concentrate 43.7% of employment, indicating a heterogeneous productive profile (CNI, 2025).

The main industrial segments in the state are Construction (19.1%), Utilities and Public Services for Industry (16%), Leather and Footwear (10.3%), Metallurgy (10.1%) and Food (10%), which together account for almost half of the industrial structure. Metallurgy, in particular, has gained prominence over the last decade, increasing its share by 8.8 percentage points between 2012 and 2022, driven by the expansion of the Pecém Complex and export-oriented industry (CNI, 2025).

Figure 13 presents the main industries in Ceará and in the Northeast region.

Figure 13. Comparison of Ceará and Northeast industrial profile in 2022.



Source: ICLEI adapted from CNI, 2025.

Regionally and nationally, the state accounts for 11% of the Northeast's industrial GDP, but only 1.5% of Brazil's total. The industry's share in the state's GDP (19%) is below the Northeast average (20.8%) and substantially lower than Brazil's (26.3%), indicating a more service-oriented economy (CNI, 2025).

In terms of exports, Ceará stands out for its industrial export basket: 80.6% of the state's exports are industrialized products, mainly metallurgical goods (52.5%). However, the state accounts for only 0.8% of Brazil's industrialized exports, reflecting a small relative weight nationally (CNI, 2025).

Ceará's industrial profile, while more diversified and developed compared to other Northeastern states, still presents GHG emission challenges. The predominance of sectors such as construction, food, leather and footwear, metallurgy and utilities indicates a medium energy intensity profile, with emissions associated with electricity consumption, use of fossil fuels in industrial processes, and generation of waste and wastewater. Therefore, Ceará's industrial trajectory requires strategies focused on technological modernization, energy efficiency and decarbonization of production processes.

4.2. Period covered by the Inventory

The GPC method recommends that inventories cover a minimum of 12 consecutive months, ideally aligned to a calendar or fiscal year, consistent with the periods commonly used by organizations. For Ceará's GHG Emissions Inventory, the present analysis accounts for emissions for the period 2018 to 2023.

4.3. Data collection

Data collection is a fundamental step in developing any GHG inventory and, for this Ceará Inventory Report, reflects a continuous effort to compile information. The team from the Coordinator for Sustainable Development of the Secretariat for the Environment and Climate Change of Ceará (CODES-SEMA), with technical support from ICLEI, carried out the data gathering according to the sectors and sub-sectors proposed by the GPC, and sent official letters to data-holding institutions. **Box 5** provides a general description of the sectors, their respective emission sources and the types of data providers.

Box 5. Sectors and sub-sectors included in Ceará's GHG Inventory.

Sector	Sub-sector	Source of emissions	Data providers
I. Stationary Energy	I.1. Residential buildings; I.2. Commercial and institutional buildings; I.3. Manufacturing and construction industries; I.4. Energy industry; I.5. Agricultural, forestry, and fishing activities.	Emissions from the combustion of fossil fuels (natural gas, diesel oil, and liquefied petroleum gas – LPG) in buildings and facilities, as well as emissions associated with electricity consumption and coal combustion in thermoelectric power plants.	ANP CEGÁS ENEL - CE EPE SEMA AECIPP SEINFRA - CE PECÉM Complex
II. Transportation	II.1. On-road transportation; II.2. Aviation; II.3. Water-borne transportation.	Emissions from combustion in mobile sources such as automobiles and others.	ANP ARCE DNIT - CE ANAC DETRAN - CE
III. Waste	III.1. Solid waste disposal in landfills and other types of disposal; III.2. Incineration and open burning; III.3. Domestic wastewater treatment (population without sewage collection, volume of wastewater treated by treatment type).	Emissions from municipal solid waste disposal and wastewater treatment.	SNIS/SINISA Marquise Ambiental CAGECE SAAEs SISAR Fortaleza ASMOC/CGIRS
IV. Industrial Processes and Product Use *(IPPU)*	IV.1. Industrial processes.	Emissions related to manufacturing industries, especially cement and steel production.	FIEC AECIPP Other industries in the region

Source: ICLEI – Local Governments for Sustainability, 2025.

For data collection, SEMA, with ICLEI's support, sent official requests to data-holding institutions seeking information on emitting activities in Ceará between 2018 and 2023. Where public data were available, these were collected from sources such as IBGE for agriculture and livestock, SNIS/SINISA for solid waste, UNICA for sugarcane and ethanol production, and the estimates from the Greenhouse Gas Emissions and Removals Estimation System (SEEG, in the Brazilian acronym) and MapBiomas for land-use changes.

The WayCarbon Ecosystem platform was used to prepare and calculate emissions estimates. This tool includes a database of emission factors according to IPCC guidance and allows the input and processing of activity data, facilitating visualization of results by sector, scope and year, enabling identification of reduction opportunities and monitoring the effectiveness of mitigation actions. The parameterization of the platform and the use of available activity data in WayCarbon Ecosystem enabled the preparation of the graphs and analyses contained in this report.

It should be emphasized that this consolidated report was prepared from the best set of information available at the state level, considering data collected and validated with the responsible institutions. Nevertheless, ongoing updates to databases and improvements in monitoring systems may, in the future, refine and complement the analyses presented here.

Sector-specific data limitations are detailed throughout Chapter 6, where the gaps that we hope to address in subsequent project stages are indicated, along with recommendations.

4.3.1. Limitations and Recommendations

The data collection process for emissions inventories, particularly at a comprehensive state scale, may present significant challenges.

Experience in preparing GHG inventories and the progress of this project itself indicate that some limitations are recurrent:

• **Availability and information flow:** The absence or delay in data provision by some institutions is a common obstacle, especially when an inventory is being prepared for the first time for certain activity data that were not routinely monitored. The need to redesign communication flows, often due to changes in institutional focal points, can also cause delays and require additional effort from the team;

• **Alternative data sources and uncertainty:** In the absence of primary, specific data, it is necessary to resort to alternative sources such as universities, national public datasets (e.g., ANP, IBGE, EPE-BEN, SEEG) or regional sources, or use mathematical resources (interpolation and extrapolation) to estimate emissions. While essential to ensure inventory completeness, these alternatives may introduce a level of uncertainty into the final estimates;

• **Absence of local georeferenced data** on land cover and land use transition matrices;

• **Lack of information on fossil fuel and biomass consumption** beyond the data provided by ANP.

To mitigate these challenges and improve future editions of the inventory, some recommendations are essential:

• **Strengthening institutional communication and cooperation:** It is crucial that data be made available in a systematic manner, avoiding concentration on individuals. Active participation of relevant state secretariats and agencies, together with periodic alignment meetings, is needed.

• **Documentation and transparency:** Detailed documentation of all activities performed, data sources used and assumptions made is essential for transparency and traceability of the inventory, allowing future revisions and replication.

• **Continuous improvement:** The difficulties encountered in obtaining data serve as points of attention for improvements. For the next editions of Ceará's GHG Emissions Inventory, continuous improvement in the quality and completeness of data sources is sought. Proactivity in seeking more detailed state information is a constant objective to ensure the robustness and enhancement of the data.

4.4. Greenhouse Gases

According to the GPC, inventories should cover the different types of GHGs reported under the Kyoto Protocol report, the six main ones being: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Each GHG has an associated Global Warming Potential (GWP), a relative coefficient which measures how much each gas contributes to global warming relative to the same mass of CO_2 (conventionally assigned a GWP of 1). Thus, GWP is expressed in terms of CO_2 equivalence (CO_2e).

GWP values may be updated over time as new scientific evidence emerges. These updates are reported in IPCC assessment reports. **Table 1** shows the GWP values used in the present GHG Emissions Inventory, taken from the IPCC Fifth Assessment Report (AR5, 2013).

The gases listed are those most studied and recognized as relevant to emissions inventories, directly associated with the main anthropogenic activities present in the territory. Other greenhouse gases exist but were not included in this analysis because they are not significant in the activities surveyed across Ceará.

Table 1. Global Warming Potential (GWP) of Greenhouse Gases

Greenhouse Gas (GHG)	*GWP*
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	265
Nitrogen trifluoride (NF_3)[3]	16.100
Sulfur Hexafluoride (SF_6)	23.500
Hydrofluorocarbons (HFCs)	116 – 12.400
Perfluorocarbons (PFCs)	6.300 – 17.400

The main GHGs and their generating activities are summarized in **Box 6**:

Box 6. Main GHGs and their generating activities.

CO_2	Generated by the combustion of fossil fuels (such as coal, oil, natural gas, and their derivatives) by mobile and stationary sources, in industrial processes, through the use of dolomitic limestone and urea fertilizers, and through deforestation of native forests;
CH_4	Generated by fossil fuel combustion from mobile and stationary sources, by decomposition of organic matter in anaerobic processes in wastewater and solid waste treatment, by enteric fermentation of animals, and animal waste management;
N_2O	Generated by fossil fuel combustion from mobile and stationary sources, in wastewater treatment processes and through the use of nitrogen fertilizers.

Source: ICLEI – Local Governments for Sustainability, 2025.

3 Although NF3 is listed among the reference gases, it was not considered in this inventory because it does not present significant sources of emission in the anthropogenic activities identified in Ceará.

4.5. Calculation Method

Emission factors used for each source type were gathered from national databases, such as the 4th National Inventory (MCTI, 2021), and, when not available, from international databases such as IPCC reports. In simplified form, emissions and removals can be estimated using the following general formula:

$$E_{i,g,y} = DA_{i,y} * FE_{i,g,y} * GWP_g$$

Where:

- ***I*** **–** Index denoting an individual source or sink activity;
- ***G*** **–** Index denoting the type of GHG;
- ***Y*** **–** Reference year of the report;
- $E_{i,g,y}$ **–** Emissions or removals of GHG g attributable to source or sink i during year y, in tCO2e;
- $DA_{i,y}$ **–** Consolidated activity data for source or sink i during year y;
- $FE_{i,g,y}$ **–** Emission or removal factor for GHG g attributable to source or sink i during year y, in t GHG g/u;
- GWP_g **–** Global warming potential of GHG g, in tCO2e / t GHG g.

Ceará's GHG Emissions Inventory was developed with the support of the WayCarbon Ecosystem software, which contains a database of emission factors for each source type. Collected data were entered and processed in this tool, previously parameterized by the technical team, allowing adjustment of measurement units and visualization of results in different ways: disaggregated by sector or sub-sector, by scope, by year of emission, among others. Fuel consumptions such as gasoline and diesel also considered the variation in the percentage of biofuels in their compositions.

INVENTORY RESULTS

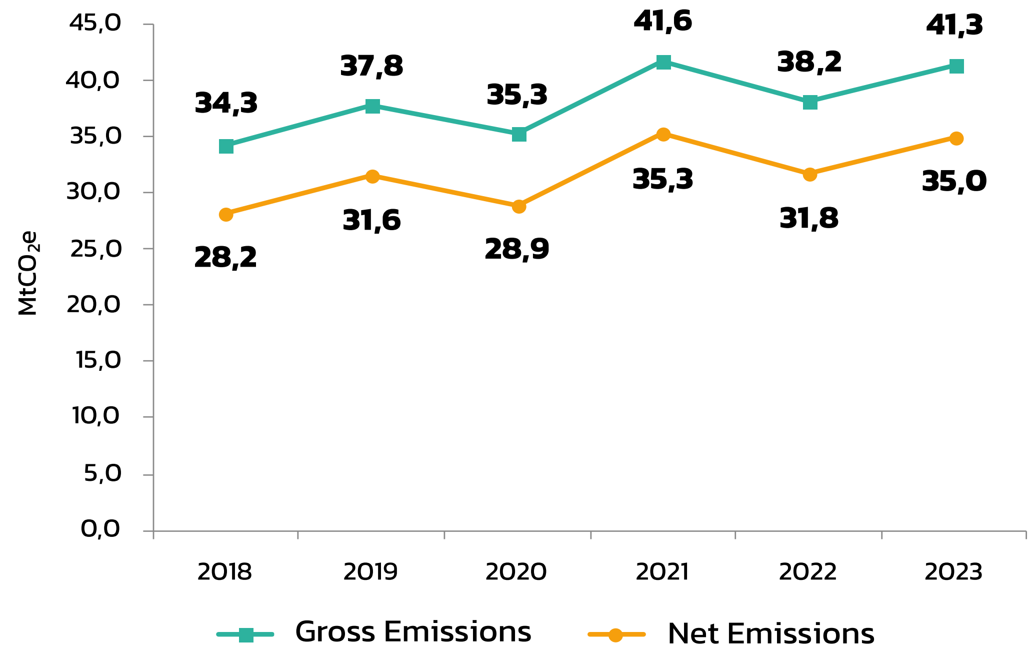
This chapter presents the results of Ceará's Greenhouse Gas Emissions Inventory for the period from 2018 to 2023. The information presented herein is the outcome of a comprehensive evaluation based on collected activity data and consolidated emission estimates in accordance with the GPC method, providing a solid foundation for understanding Ceará's GHG emissions profile.

To recap, gross emissions represent the total volume of GHGs released by human activities, while net emissions correspond to the balance between these emissions and carbon removals carried out by natural sinks such as forests, according to the following equation:

NET EMISSIONS = GROSS EMISSIONS – CARBON REMOVALS

During the analyzed period (2018–2023), the State of Ceará recorded a significant increase of 20.4% in gross emissions and 24.1% in net emissions, as shown in **Figure 14**, which illustrates interannual variations and highlights the upward trend observed over the period, particularly in 2021 and 2023.

Figure 14. GHG emissions evolution in the State of Ceará (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

Over the historical series, Ceará's gross emissions increased from 34.32 $MtCO_2e$ in 2018 to 41.32 $MtCO_2e$ in 2023, after oscillations marked by a 7% decrease in 2020 and a sharp 18% increase in 2021. This behavior is closely linked to reductions in fuel consumption in the energy sector and decreases in deforestation during the first year of the COVID-19 pandemic — factors that will be explored in later sectoral analyses. Net emissions followed a similar trend: rising from 28.17 $MtCO_2e$ in 2018 to 34.97 $MtCO_2e$ in 2023. In this interval, the lowest value occurred in 2020 and the highest in 2021, also reflecting the pandemic's influence on economic and productive dynamics.

Table 2 details the annual evolution of gross and net emissions in Ceará during the period analyzed.

Table 2. Annual evolution of gross and net emissions in Ceará (2018–2023).

Year	Millions of tons of CO_2e ($MtCO_2e$)	
	Gross Emissions ($MtCO_2e$)	Net Emissions ($MtCO_2e$)
2018	34,32	28,17
2019	37,83	31,58
2020	35,27	28,95
2021	41,64	35,26
2022	38,19	31,82
2023	41,32	34,97

Source: ICLEI – Local Governments for Sustainability, 2025.

5.1. Inventory results by scope

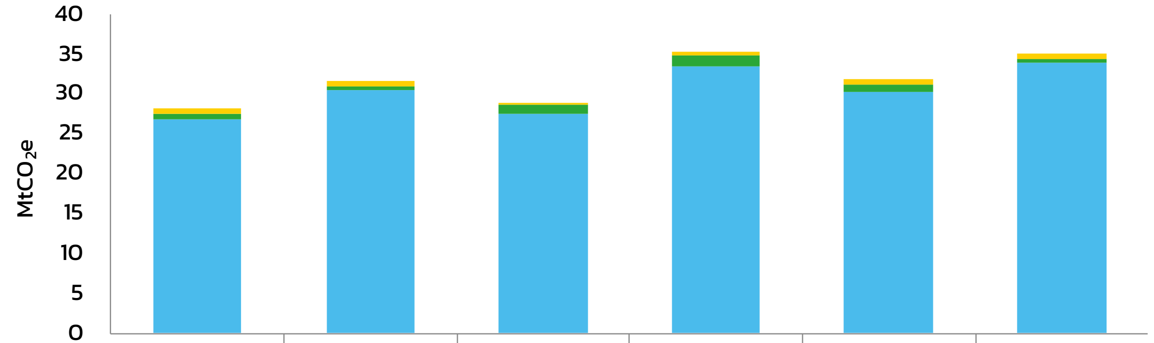
Ceará's net GHG emissions totaled 190.7 million tCO_2e, considering the sum of annual contributions from 2018 to 2023, with an annual average of 31.8 million tCO_2e and an accumulated increase of 24% over the period.

When analyzing these emissions by GPC scopes — which distinguish whether emissions are direct or indirect and their territoriality — a predominance of Scope 1 emissions becomes evident. Scope 1 includes direct emissions originating from sources located within the territory, such as fossil fuel combustion, industrial processes, and agriculture and livestock. This scope accounted for 96% of total emissions, with a 27% increase over the period (from 26.8 million tCO_2e in 2018 to 34.0 million tCO_2e in 2023). This growth is strongly associated with increases in emissions from the Stationary Energy, IPPU, and AFOLU sectors.

Scope 2, referring to indirect emissions associated with the consumption of purchased electricity, displayed an irregular pattern and low participation in the total, accounting for 3% of emissions. While it peaked in 2020 and 2021 (1.1 and 1.5 million tCO_2e, respectively), it closed 2023 at 392 thousand tCO_2e.

Finally, Scope 3, which includes other indirect emissions (such as aviation and electricity transmission and distribution losses), accounted for only 2% of the total, with a decreasing trend (–8%) between 2018 and 2023. **Figure 15** shows the behavior of emissions by scope for the period analyzed.

Figure 15. GHG emissions by scope in Ceará (2018–2023).



	2018	2019	2020	2021	2022	2023
Total	28.174.491	31.578.488	28.946.713	35.262.335	31.819.172	34.966.225
Scope 3	606.862	673.314	320.602	377.299	574.371	557.401
Scope 2	725.437	438.725	1.101.590	1.509.744	943.151	392.312
Scope 1	26.842.192	30.466.449	27.524.521	33.375.292	30.301.651	34.016.511

Source: ICLEI – Local Governments for Sustainability, 2025.

5.2. Main emitting activities

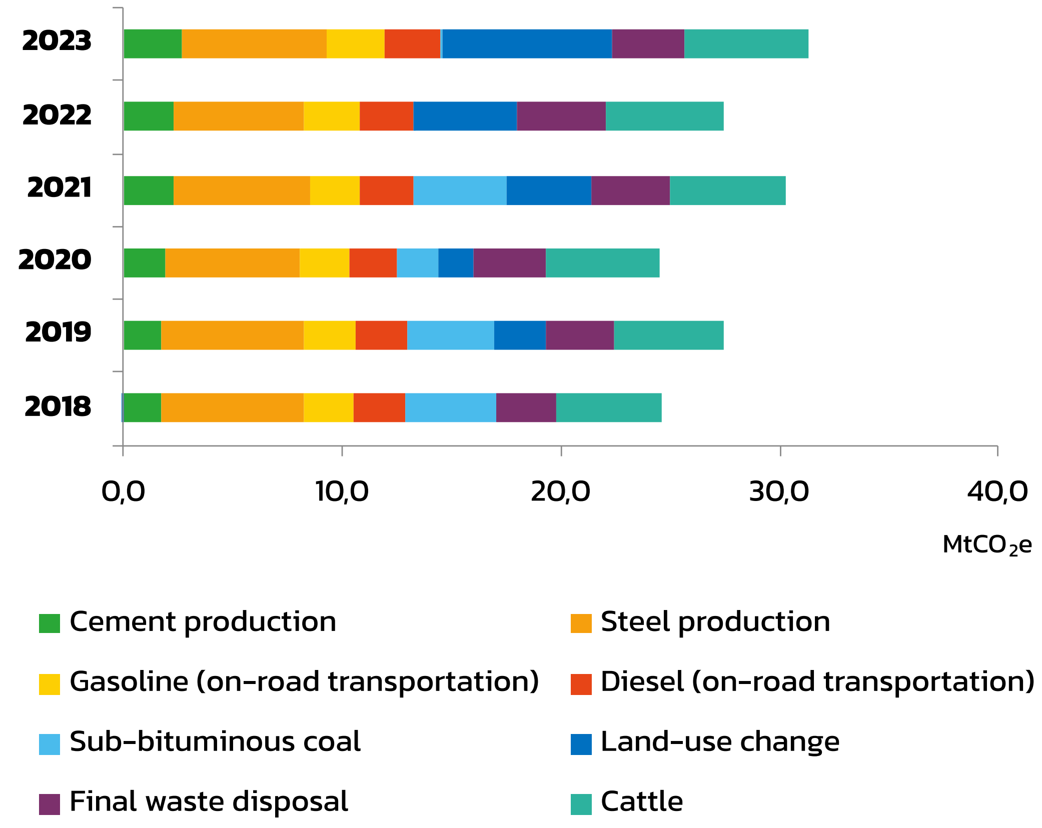
To identify the activities that most contributed to Ceará's GHG emissions, this section applies the sectoral logic defined by the GPC, providing insights to guide decision-makers in prioritizing strategic actions across the territory. Within this context, the eight main emitting sources were identified. Consistently across the years, steel production, cattle raising, and solid waste management stand out as major contributors.

Beginning in 2021, increasing emissions associated with land-use change — primarily driven by deforestation — became more prominent, making land-use change the state's leading emitting activity in 2023.

Coal consumption, which had been a relevant emitting activity until 2021, experienced a 97% reduction in emissions in subsequent years due to the discontinuation of coal use for electricity generation in state thermoelectric plants, resulting from the expansion of renewable energy such as wind and solar.

Other activities, including cement production and diesel and gasoline consumption in road transportation, also represent significant contributions to GHG emissions. **Figure 16** illustrates the main emitting activities and their respective contributions from 2018 to 2023.

Figure 16. Main emitting activities in Ceará (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

SECTORAL ANALYSIS OF RESULTS

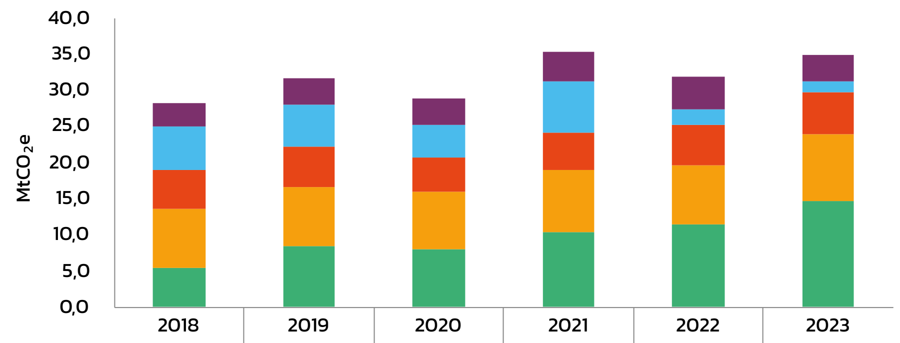
This chapter deepens the analysis of Ceará's Greenhouse Gas Emissions Inventory by examining emissions by sector of activity for the period 2018–2023. Understanding the emissions profile of each sector is essential for strategically targeting public policies and mitigation actions, promoting a more sustainable development pathway aligned with the state's climate commitments.

For this assessment, the following sectors were considered according to the GPC: Transportation, Stationary Energy, Agriculture, Forestry, and Other Land Use (AFOLU), Waste, and Industrial Processes, and Product Use (IPPU).

The evolution of Ceará's net emissions over time, disaggregated by sector for each year of the historical series, is shown in **Figure 17**.

The sectors behaved quite differently over the analyzed period. Emissions associated with AFOLU displayed a very pronounced increase — 166% between 2018 and 2023 — driven by intensified agricultural activities and land conversion. The IPPU, Waste, and Transportation sectors exhibited fluctuations but showed a slight upward trend overall. Meanwhile, Stationary Energy recorded a substantial decrease of 73%, mainly due to the drastic reduction in coal use at thermoelectric plants.

Figure 17. Net emissions profile by sector (2018 – 2023).

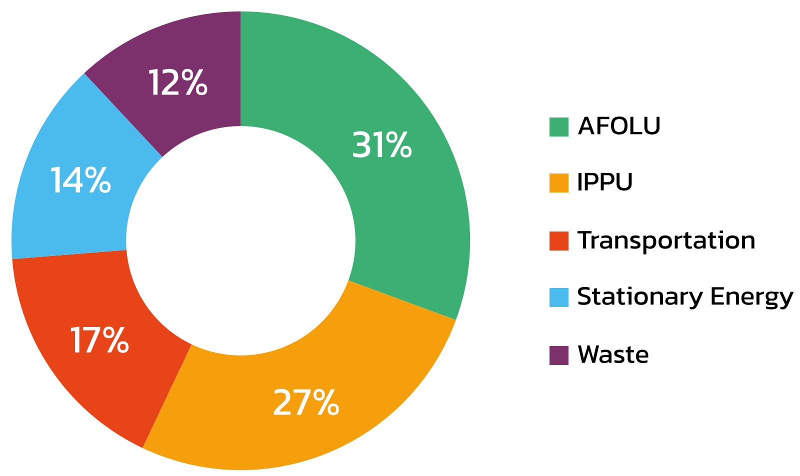


	2018	2019	2020	2021	2022	2023
TOTAL	28.174.491	31.578.488	28.946.713	35.262.335	31.819.172	34.966.225
Waste	3.069.735	3.479.050	3.707.967	3.989.581	4.400.024	3.641.929
Stationary Energy	6.119.250	5.873.022	4.436.153	7.161.241	2.116.186	1.680.216
Transportation	5.260.287	5.487.044	4.752.568	5.144.805	5.573.066	5.693.026
IPPU	8.226.320	8.196.340	8.064.990	8.490.740	8.276.110	9.321.895
AFOLU	5.498.900	8.543.033	7.985.035	10.475.969	11.453.787	14.629.157

Source: ICLEI – Local Governments for Sustainability, 2025.

The state-level profile, considering the average contribution of each sector, is shown in **Figure 18**. When averaging contributions from 2018 to 2023, AFOLU emerges as the state's main emitting sector, followed by IPPU, Transport, Stationary Energy, and Waste as the lowest contributor.

Figure 18. Average net emissions profile in Ceará (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

The following sections present an in-depth analysis of each sector, detailing their main emission sources, trends, and overall impact on the state's GHG balance.

6.1. AFOLU sector

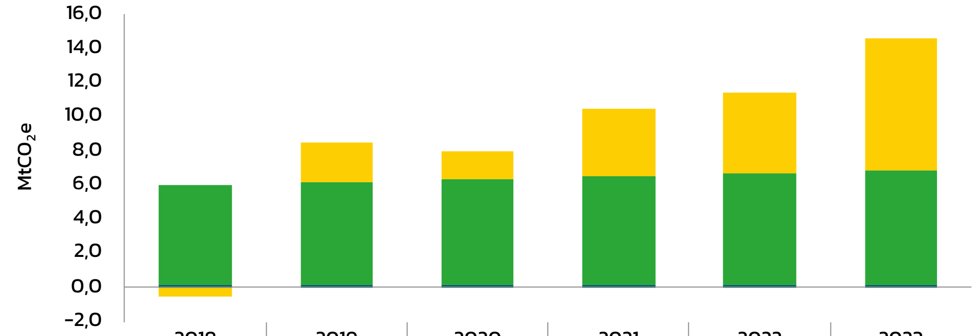
The AFOLU (Agriculture, Forestry, and Other Land Use) sector plays a central role in Ceará's GHG balance, as it encompasses both emission sources and carbon removal processes. Activities in this sector include livestock raising, crop cultivation, land-use and land-cover change, and the maintenance and restoration of vegetated areas. Under the GPC, emissions from this sector are considered Scope 1 only.

During data collection for Ceará's inventory, it was not possible to obtain georeferenced land-use information based on datasets provided by SEMA. Given this limitation, emissions and removals associated with land-use change were based on SEEG data, which provides detailed descriptions of emitting and removing activities within the state.

The historical series shows significant growth, with emissions increasing from 5.5 $MtCO_2e$ in 2018 to 14.62 $MtCO_2e$ in 2023, a 166% rise over the period.

Figure 19 illustrates emissions by sub-sector, highlighting the main drivers of this dynamic.

Figure 19. Net emissions in the AFOLU sector by sub-sector (2018–2023).



	2018	2019	2020	2021	2022	2023
AFOLU	5.498.900	8.543.033	7.985.035	10.475.969	11.453.787	14.629.157
Land use	-497.414	2.363.495	1.595.959	3.959.037	4.744.022	7.727.433
Livestock	5.865.656	6.057.009	6.253.305	6.390.467	6.578.152	6.775.947
Aggregate and other non-CO_2 emissions	130.657	122.529	135.771	126.465	131.613	125.777

Source: ICLEI – Local Governments for Sustainability, 2025.

The livestock sub-sector was the largest contributor, totaling 37.92 $MtCO_2e$ (65% of AFOLU emissions) across the full period. From 2018 to 2023, emissions increased 16%, due to enteric fermentation and animal waste management, reflecting the gradual expansion of livestock activity.

Land-use change accumulated 19.89 $MtCO_2e$ in total over the period, and showed the most dramatic increase, shifting from a net removal of –497,414 tCO_2e in 2018 to emissions of 7.73 $MtCO_2e$ in 2023. This 1,654% increase was largely driven by conversion of savanna forest areas to agricultural and livestock uses, highlighting the pressure on ecosystems and the limitation of the carbon removal capacity of original vegetation.

Aggregated and other non-CO_2 emissions decreased slightly (–4%) over the period, totaling 772,812 tCO_2e. This sub-sector includes various sources, such as agricultural soil management and waste burning, which remained relatively stable in the period.

6.1.1. Land Use

The Land Use sub-sector is one of the main determinants of Ceará's net emissions profile. It includes both emissions from activities that release carbon (such as deforestation) and carbon removals through sinks (such as protected areas maintenance and secondary vegetation regeneration). **Table 3** presents the detailed emissions and removals for this sub-sector based on SEEG data.

Table 3. Emissions and removals from the land use sub-sector

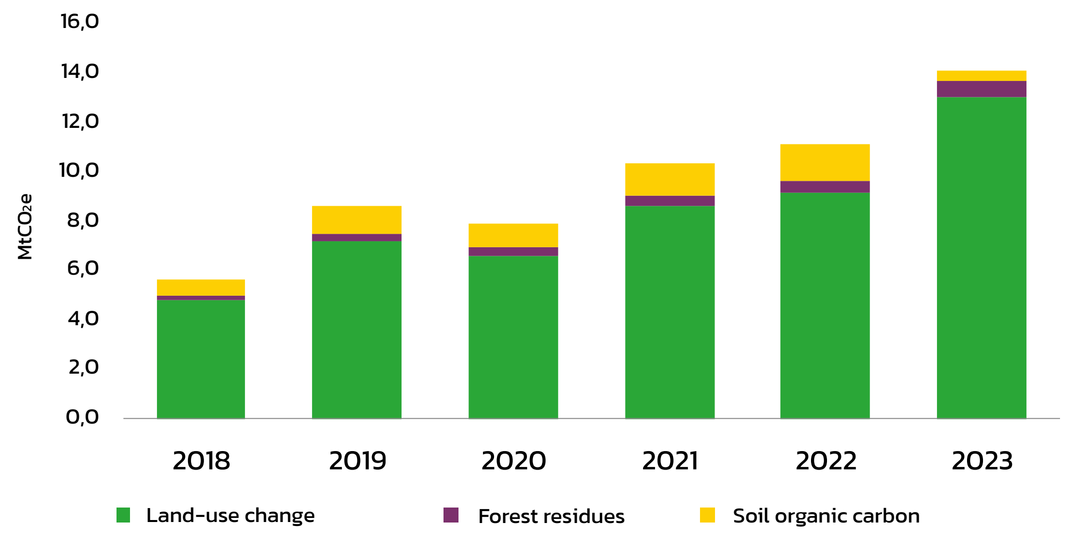
Component	2018 (tCO_2e)	2019 (tCO_2e)	2020 (tCO_2e)	2021 (tCO_2e)	2022 (tCO_2e)	2023 (tCO_2e)
Land-use changes	4.793.881	7.164.730	6.620.802	8.623.466	9.172.228	13.034.832
Forest residues	199.280	327.354	300.326	411.973	442.284	631.033
Organic carbon in soil	657.253	1.123.546	1.002.316	1.306.134	1.504.285	419.044
Removal due to land-use change	-24.729	-21.434	-14.562	-11.690	-6.393	-8.264
Removal in protected areas	-307.207	-307.327	-306.026	-306.486	-304.985	-304.130
Removal by secondary vegetation	-5.815.892	-5.923.374	-6.006.897	-6.064.360	-6.063.397	-6.045.082

Source: ICLEI – Local Governments for Sustainability, 2025.

Emissions from land-use change — particularly deforestation — remain one of the most impactful components. They rose from 4.79 $MtCO_2e$ in 2018 to 13.03 $MtCO_2e$ in 2023, an increase of 172%, primarily associated with conversion of natural areas to agricultural and livestock use and areas without vegetation, which may be related to the expansion of wind farms in the state. Notably, 97% of emissions in this category stem from the transition to agricultural and livestock uses.

Emissions arising from forest residues and soil organic carbon/ organic carbon in the soil also contributed, totaling, respectively, 2.31 $MtCO_2e$ for forest residues (a 217% increase) and 6.01 $MtCO_2e$ for soil organic carbon, although the latter showed a 36% decrease over the period, as reflected in **Figure 20**.

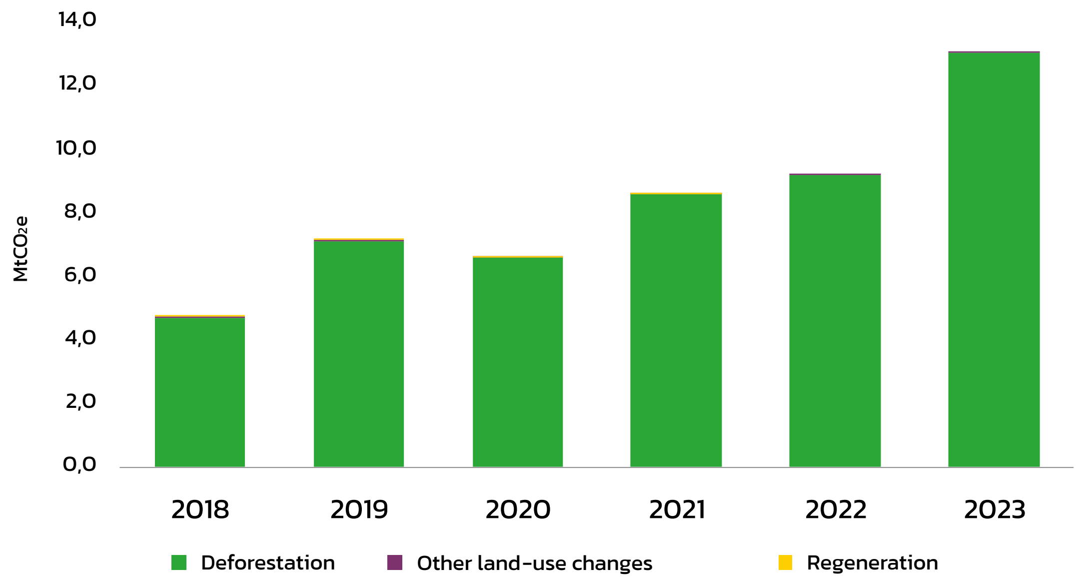
Figure 20. Emissions and removals from land-use change activities (2018-2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

This dynamic highlights the central role of deforestation in increasing sub-sector emissions, underscoring the urgency of public policies to curb vegetation loss and strengthen ecosystem conservation and restoration initiatives. **Figure 21** shows the main emitting activities within the Land-Use Change sub-sector.

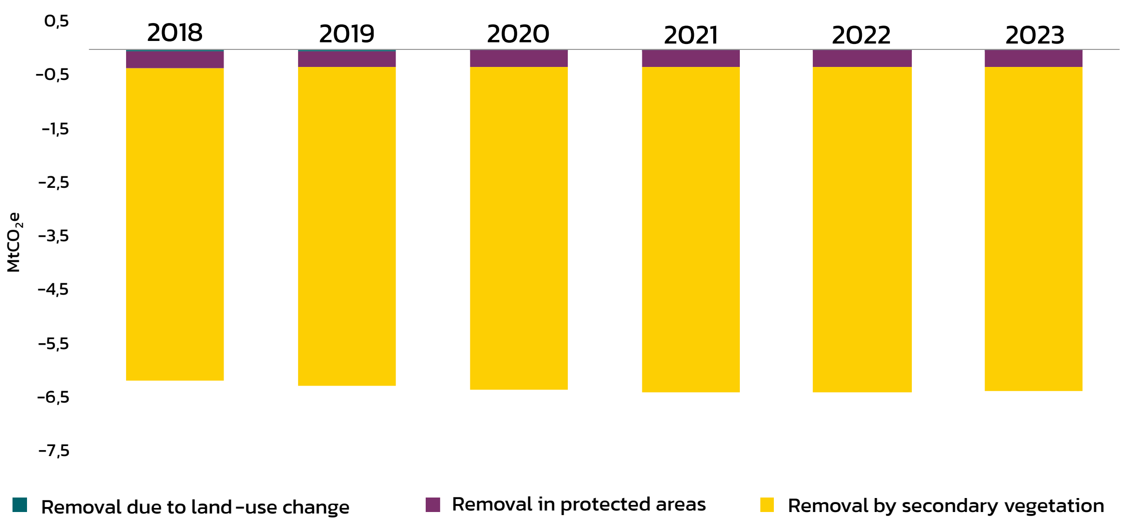
Figure 21. Emissions from land-use change activities (2018-2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

Conversely, carbon sinks played an important role in partially offsetting these emissions. Removal by secondary vegetation was the main sink, totaling −35.92 MtCO_2e over the period, with a slight increase (4%) in sequestration capacity between 2018 and 2023. Removal in protected areas remained relatively stable, averaging −0.306 MtCO_2e per year, while removal due to land-use change was comparatively small (total −0.087 MtCO_2e), as shown in **Figure 22**.

Figure 22. Removals from land-use activities (2018-2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

The net balance of the sub-sector shows a strong reversal over the period: from a net sink of −0.497 MtCO_2e in 2018 to a net emission of 7.73 MtCO_2e in 2023 — an increase of 1,654%. This evolution demonstrates that despite increased sink activity, gross emissions from land-use change far outpaced removals, reinforcing the urgent need for more effective conservation and restoration measures.

6.1.2. Livestock

Emissions from the Livestock sub-sector are mainly generated by enteric fermentation (ruminant digestion) and animal waste (manure) management. **Table 4** presents emissions by livestock type.

Table 4. Emissions by type of livestock.

Livestock	2018 (tCO_2e)	2019 (tCO_2e)	2020 (tCO_2e)	2021 (tCO_2e)	2022 (tCO_2e)	2023 (tCO_2e)
Other herds	328.633	335.809	349.810	355.797	365.412	372.109
Sheep	680.245	698.409	722.392	733.720	746.868	746.153
Cattle	4.856.779	5.022.791	5.181.103	5.300.950	5.465.873	5.657.684

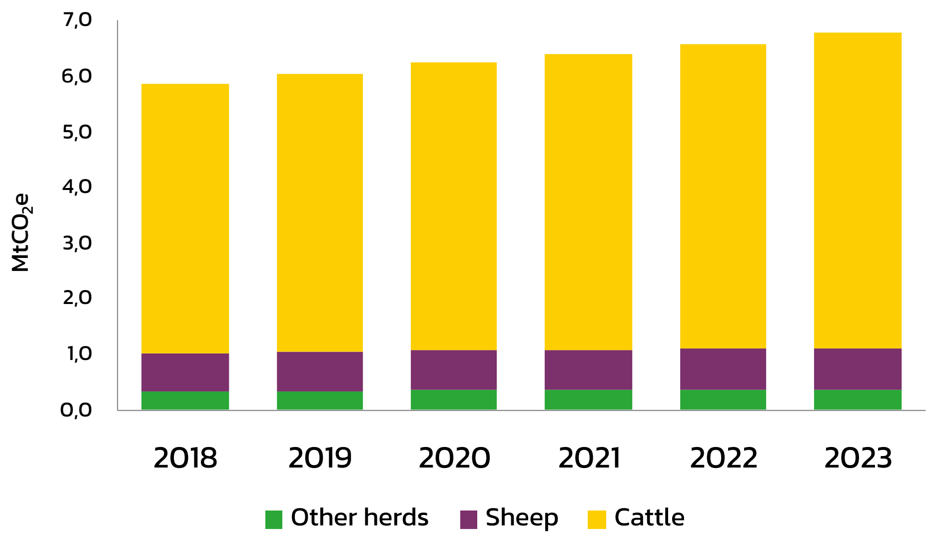
Source: ICLEI – Local Governments for Sustainability, 2025.

Cattle are clearly the largest contributors within the livestock sub-sector. Cattle emissions increased 16% over the period, from 4.86 MtCO_2e in 2018 to 5.66 MtCO_2e in 2023, reflecting the prominence of bovine livestock in the state's emission profile.

Sheep showed a 10% increase across the period, reinforcing its weight in the regional agricultural matrix, while the "Other herds" category (including poultry, goats, equines, swine and buffalo) rose 13% from 2018 to 2023.

Figure 23 illustrates the evolution of emissions by herd type in the AFOLU sector.

Figure 23. Emissions by livestock type (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

6.1.3. Aggregate and other non-CO_2 emissions

This sub-sector groups several smaller AFOLU emission sources that collectively contribute to the sector's overall emissions. **Table 5** details emissions by activity type.

Table 5. Emissions by activity type.

Aggregate and other non-CO_2 emissions	2018 (tCO_2e)	2019 (tCO_2e)	2020 (tCO_2e)	2021 (tCO_2e)	2022 (tCO_2e)	2023 (tCO_2e)
Rice	46.111	37.044	37.178	39.747	39.379	38.610
Agricultural waste	75.958	76.522	89.208	77.632	80.150	74.375
Dolomitic limestone	–	–	143	191	542	429
Other crops	8.589	8.963	9.241	8.895	11.541	12.363

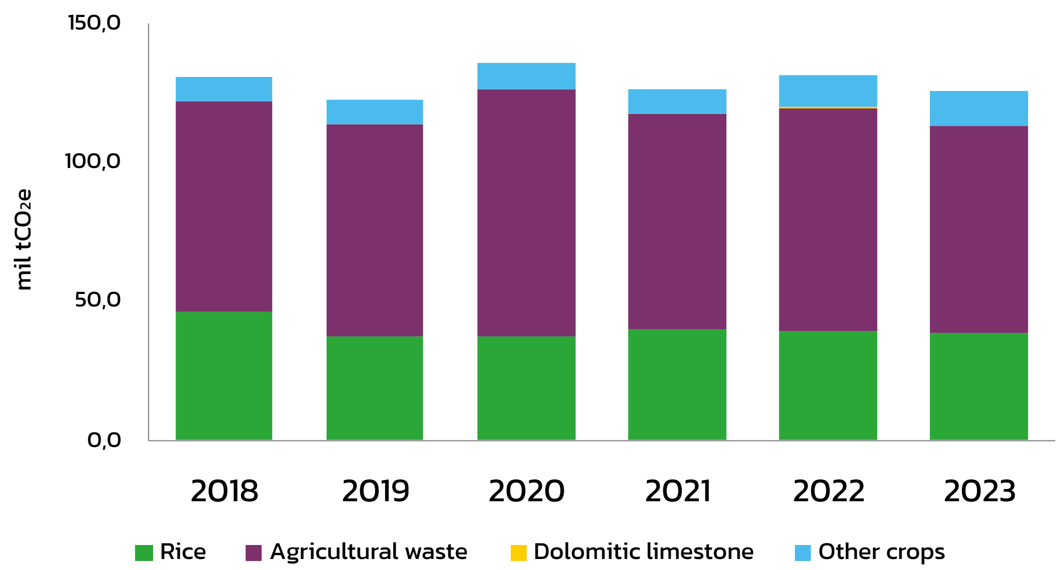
Source: ICLEI – Local Governments for Sustainability, 2025.

Within this sub-sector, Agricultural Waste stands out as the main source, totaling 473,845 tCO_2e across 2018–2023, although they registered a slight 2% decrease over the period. Rice cultivation appears as the second largest contributor, totaling 238,069 tCO_2e, but with a more significant drop of 16%, indicating a contraction in this activity.

"Other crops" (generic grains, cassava, soy, and sorghum) increased 44%, from 8,589 tCO_2e in 2018 to 12,363 tCO_2e in 2023, totaling 59,592 tCO_2e in the period — reflecting gradual diversification among agricultural emission sources. Dolomitic limestone application, not reported in 2018–2019, began to be recorded from 2020 onward, totaling 1,305 tCO_2e accumulated, indicating agricultural practices that add to non-CO_2 emissions.

Overall, the aggregated non-CO_2 sub-sector saw a 4% reduction in total emissions between 2018 and 2023, ending the period at 125,777 tCO_2e, showing relative stability despite category-level variations. **Figure 24** illustrates emissions by activity type.

Figure 24. Emissions by activity type (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

6.2. IPPU Sector

The Industrial Processes and Product Use (IPPU) sector accounts for GHG emissions resulting from the physical and chemical transformations of materials in industrial processes and from fluorinated gas use in products. This sector reflects the carbon footprint associated with manufacturing activities and specific product applications. For this inventory, data were obtained for steel and cement production only.

Globally, iron and steel production is a major industrial source of GHGs, responsible for approximately 7–9% of energy-related CO_2 emissions. Emissions are mainly due to coal and coke use in blast furnaces (about 90% of sector emissions originate from integrated coal-based processes), with average factors between 1.8 and 2.2 tCO_2/t of steel. More efficient routes, such as Electric Arc Furnaces (EAF), have much lower intensity, between 0.3 and 0.7 tCO_2/t (Kim et al., 2022).

Similarly, cement production contributes significantly to industrial emissions, responsible for roughly 7–8% of global CO_2 emissions. Emissions derive from both the chemical process of clinker calcination and fossil fuel combustion in kilns, with estimates indicating 60% of emissions from calcination and 40% from energy use (Chen et al., 2022).

According to the National Emissions Registry System (SIRENE, in the Brazilian acronym), mineral and metallurgical industries accounted for 84% of emissions within the IPPU sector (SIRENE, 2025). Thus, even though the current inventory does not cover all industrial sub-sectors, the most emission-intensive activities are represented.

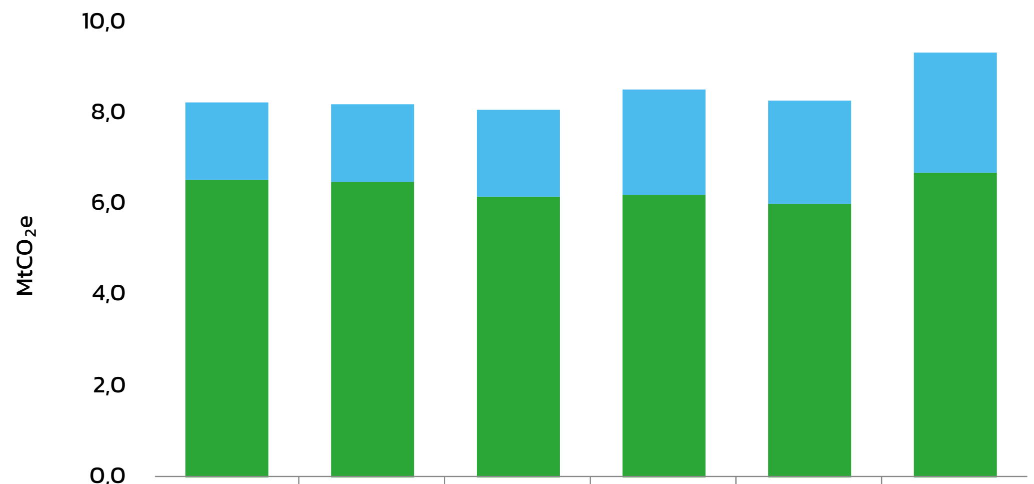
Under GPC rules, IPPU emissions are accounted as Scope 1. The sector showed a 13.3% increase in emissions between 2018 (8.2 $MtCO_2e$) and 2023 (9.3 $MtCO_2e$), indicating growth in Ceará's industrial output.

Steel production stands out as the main contributor in the IPPU sector, representing 75% of sectoral emissions in the period. Steel emissions varied from 6.5 $MtCO_2e$ in 2018 to 6.67 $MtCO_2e$ in 2023 — a moderate growth of 2.4%. Despite increased production, local mitigation measures in the production process have gradually reduced the emissions intensity (tCO_2e per tonne of steel), signaling progress toward decarbonization.

On the other hand, cement production, responsible for 25% of sector emissions, increased markedly by 55%, from 1.7 $MtCO_2e$ in 2018 to 2.6 $MtCO_2e$ in 2023, reflecting an expansion in construction activity and infrastructure development in the state.

Figure 25 details the evolution of GHG emissions by production type, highlighting changes in the sector over the period.

Figure 25. Emissions by industrial production type (2018–2023).



	2018	2019	2020	2021	2022	2023
Cement	1.706.320	1.726.340	1.914.990	2.280.740	2.266.110	2.644.353
Steel	6.520.000	6.470.000	6.150.000	6.210.000	6.010.000	6.677.542

Source: ICLEI – Local Governments for Sustainability, 2025.

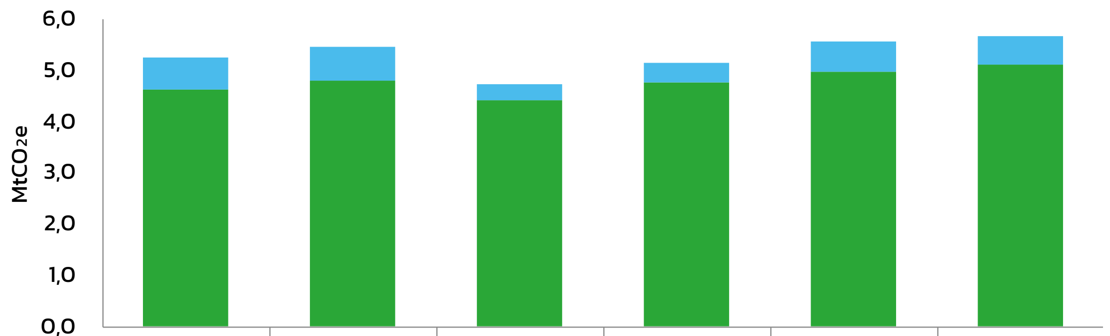
6.3. Transportation Sector

Emissions from the Transportation sector come from the consumption of gasoline, ethanol, diesel oil, aviation gasoline, and aviation kerosene across different transportation modes operating within the state. Emissions were calculated based on fuel commercialization data.

Across the historical series, the sector showed an 8.23% increase, rising from 5,260,287 tCO_2e in 2018 to 5,693,026 tCO_2e in 2023. This trajectory reflects the intensification of transport activity in the state, with fluctuations driven by multiple factors, including mobility restrictions in 2020, the economic impacts of the pandemic, and the subsequent economic recovery.

Figure 26 presents total sectoral emissions disaggregated by GPC scopes. Scope 1 accounts for 90% of emissions, representing fossil fuel combustion occurring within the state. The remaining emissions fall under Scope 3, corresponding to aviation activities — classified as indirect because these emissions do not occur fully within Ceará's inventory boundaries. Although discussions on fleet electrification and energy transition are growing nationally, electric vehicle penetration in Ceará remains limited; therefore, no Scope 2 emissions were observed in the Transportation sector.

Figure 26. Transportation sector emissions by scope (2018–2023).



	2018	2019	2020	2021	2022	2023
Total	5.260.287	5.487.044	4.752.568	5.144.805	5.573.066	5.693.026
Scope 3	606.831	673.280	320.569	377.231	574.347	557.372
Scope 1	4.653.456	4.813.764	4.431.999	4.767.574	4.998.719	5.135.654

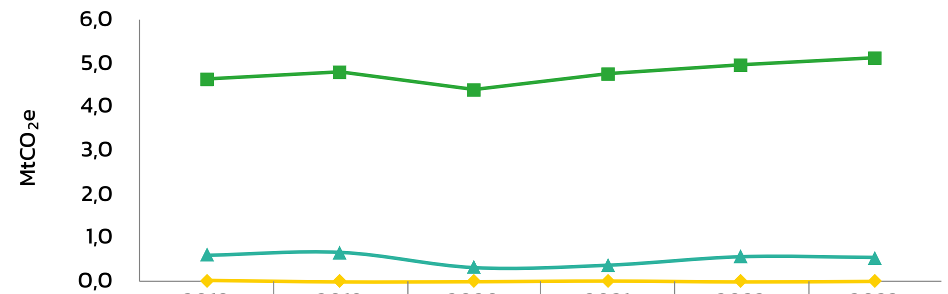
Source: ICLEI – Local Governments for Sustainability, 2025.

The following subsections analyze emissions by transportation mode and by fuel type, highlighting the main drivers within the sector.

6.3.1. Emissions by transportation mode

The distribution of emissions by transportation mode demonstrates the predominance of on-road transportation, responsible for 90% of sectoral emissions. Road emissions increased from 4,640,433 tCO_2e in 2018 to 5,125,219 tCO_2e in 2023, a 10.5% increase, as shown in Figure 27. This rise is driven by fleet expansion and increasing demand for passenger and freight mobility.

Figure 27. Transportation sector emissions by sub-sector (2018–2023).



	2018	2019	2020	2021	2022	2023
Total	5.260.287	5.487.044	4.752.568	5.144.805	5.573.066	5.693.026
Water-borne transportation	13.023	9.023	9.571	11.333	9.017	10.435
Aviation	606.831	673.280	320.569	377.231	574.347	557.372
On-road transportation	4.640.433	4.804.742	4.422.428	4.756.241	4.989.702	5.125.219

Source: ICLEI – Local Governments for Sustainability, 2025.

Aviation, responsible for 9.7% of transportation emissions, showed notable fluctuations, falling from 606,831 tCO_2e in 2018 to 557,372 tCO_2e in 2023, an 8.15% decrease. The sharpest reduction occurred in 2020 due to flight restrictions and reduced demand during the COVID-19 pandemic.

Water-borne transportation, with only 0.2% of emissions, dropped from 13,023 tCO_2e in 2018 to 10,435 tCO_2e in 2023, a reduction of 19.88% — possibly due to shifts in operational demand or efficiency improvements.

6.3.2. Emissions by fuel type

Combustion of fossil fuels remains the main source of Transportation sector emissions. Analysis by fuel type shows that gasoline and diesel are the largest contributors, reflecting their dominance in the state's vehicle fleet, as shown in **Table 6**.

Table 6. Emissions by fuel type.

Fuel	2018 (tCO_2e)	2019 (tCO_2e)	2020 (tCO_2e)	2021 (tCO_2e)	2022 (tCO_2e)	2023 (tCO_2e)
Gasoline	2.304.765	2.400.942	2.215.520	2.298.805	2.480.114	2.599.942
Diesel	2.238.869	2.238.418	2.083.468	2.332.888	2.418.301	2.452.184
Aviation kerosene	605.688	672.472	320.000	376.354	573.543	556.401
Others	110.964	175.212	133.581	136.758	101.108	84.498

Source: ICLEI – Local Governments for Sustainability, 2025.

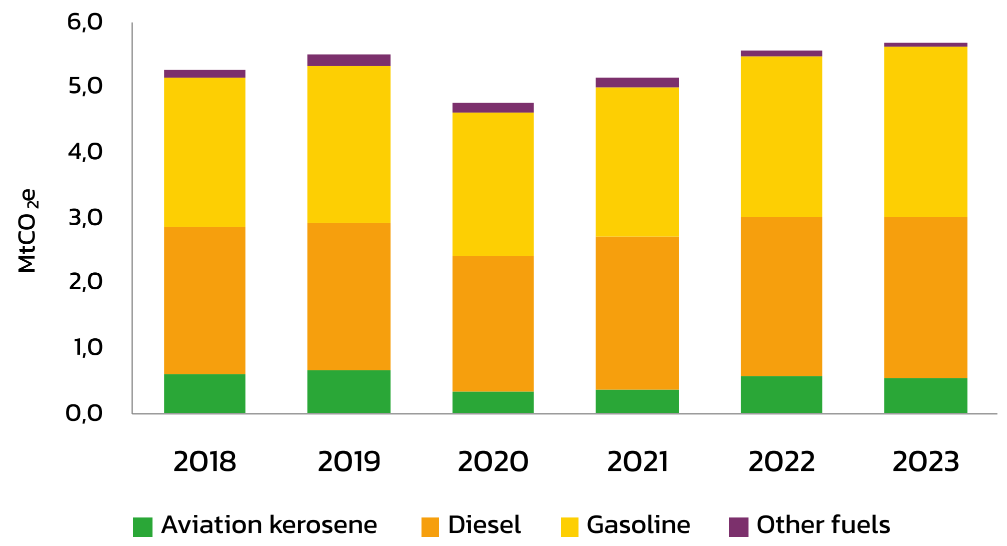
Gasoline and diesel account for the vast majority of emissions in the Transportation sector: gasoline contributes 45% of road transportation emissions and diesel 43%. Both fuels show emission growth over the period, reflecting fleet expansion and increased freight and passenger mobility.

Aviation kerosene ranks third but was sharply affected in 2020, mirroring the contraction of aviation activity. Although there was a rebound, emissions remained below pre-pandemic levels.

The "Other" category — which includes Compressed Natural Gas (CNG), hydrated ethanol, and aviation gasoline — showed a 23.85% reduction, as illustrated in **Figure 28**.

It is important to highlight that CO_2 emissions from hydrated ethanol, anhydrous ethanol (present in blended gasoline), and biodiesel (present in Brazilian diesel) are considered biogenic and therefore carbon-neutral in GHG accounting. Their use, therefore, represents an important mitigation measure in Brazil's transportation energy matrix.

Figure 28. Transportation sector emissions by fuel type (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

6.4. Stationary Energy Sector

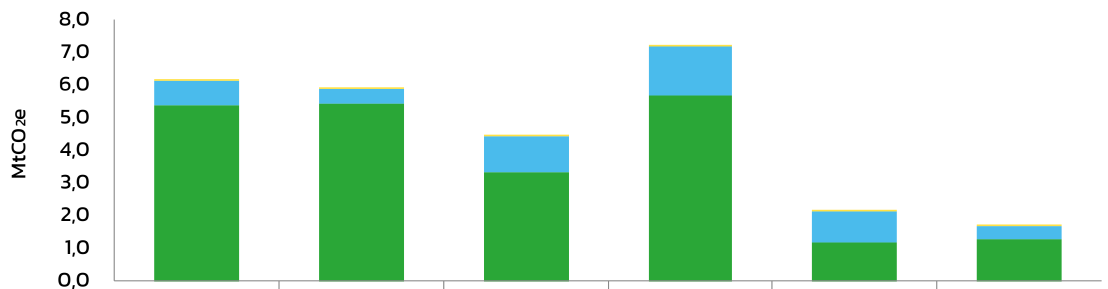
The Stationary Energy sector is a major contributor to GHG emissions due to fossil fuel combustion for steam or electricity generation, electricity consumption in buildings, and technical losses in transmission and distribution systems. Emissions are grouped across several sub-sectors, including residential buildings, manufacturing and construction industries, commercial and institutional buildings, and others.

From 2018 to 2023, the sector registered a sharp 72.5% reduction, falling from 6.1 $MtCO_2e$ in 2018 to 1.7 $MtCO_2e$ in 2023. This steep decline is closely tied to the reduction in coal consumption in thermoelectric plants, reflecting major changes in Ceará's and Brazil's energy matrix during the period.

At the beginning of the historical series, emissions were predominantly Scope 1 (direct emissions within state boundaries). From 2020 onward, Scope 2 emissions, which refer to indirect emissions from electricity consumption, became more relevant, representing on average 28% of emissions between 2020 and 2023.

In 2023, Scope 1 emissions decreased significantly, leaving Scope 2 emissions as an important share of the total, even though they also declined. Scope 3 emissions correspond exclusively to electricity transmission and distribution losses and remained consistent in their relative share. Figure 29 shows the evolution of emissions by scope.

Figure 29. Stationary Energy sector emissions by scope (2018-2023).



	2018	2019	2020	2021	2022	2023
Total	6.119.250	5.873.022	4.436.153	7.161.241	2.116.186	1.680.216
Scope 3	31	34	33	68	24	29
Scope 2	725.437	438.725	1.101.590	1.509.744	943.151	392.312
Scope 1	5.393.781	5.434.262	3.334.530	5.651.429	1.173.011	1.287.875

Source: ICLEI – Local Governments for Sustainability, 2025.

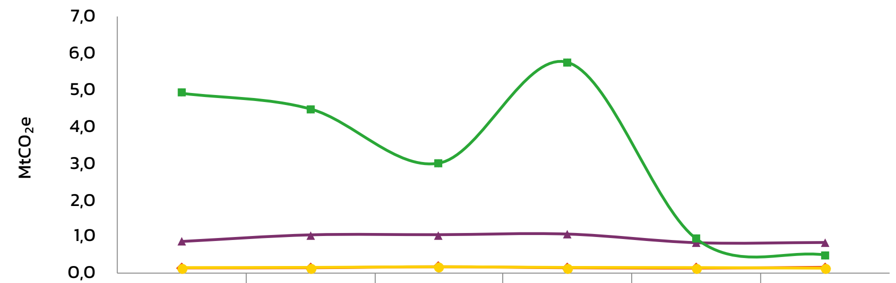
Analyzing emissions by GPC sub-sector allows identification of segments contributing most to emissions and their respective reduction trajectories. The Energy Industries sub-sector stands out due to both the magnitude and the drastic reduction of emissions.

In 2018, this sub-sector accounted for 4.9 $MtCO_2e$, reaching a peak of 5.8 $MtCO_2e$ in 2021. However, in 2022 and 2023, emissions fell sharply to 0.95 $MtCO_2e$ and 0.52 $MtCO_2e$, respectively — representing a 90% reduction relative to the highest-emission year. This shift illustrates a transformation in Ceará's electricity generation matrix, marked by reduced coal use and increased adoption of wind power, in line with national trends in electricity decarbonization (IEMA, 2023).

Residential buildings were the second-largest source, with an annual average above 961,084 tCO_2e, experiencing a slight 3.06% reduction in the period. The manufacturing and construction industry also contributed but saw an 11.1% drop in emissions. Conversely, commercial and institutional buildings recorded a 5.4% increase, possibly reflecting expanded activity in these segments.

The analysis of emissions by sub-sector allows us to identify the energy consumption and production segments that contribute most to emissions in the state. **Figure 30** illustrates the evolution of these emissions.

Figure 30. Stationary Energy sector emissions by sub-sector (2018-2023).



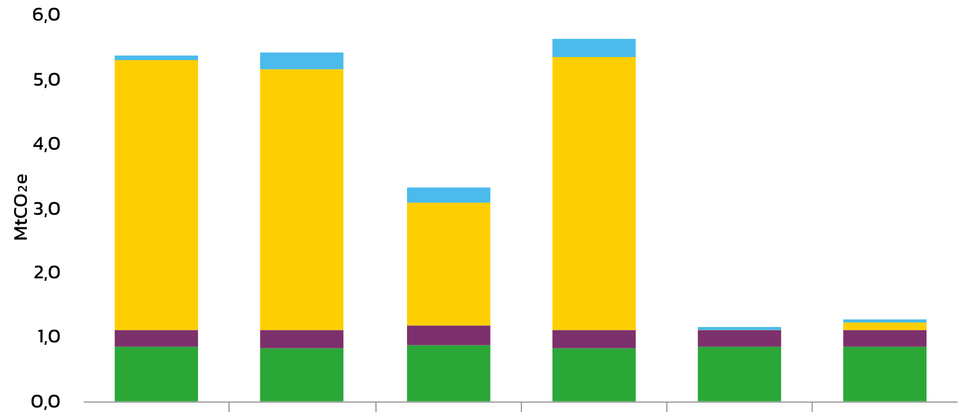
	2018	2019	2020	2021	2022	2023
Total	6.119.250	5.873.022	4.436.153	7.161.241	2.116.186	1.680.216
Commercial and institutional buildings	156.685	158.956	172.969	159.154	153.499	165.174
Residential buildings	880.682	1.052.513	1.057.096	1.073.118	848.691	854.403
Manufacturing and construction industries	159.294	166.038	185.009	165.326	159.999	141.533
Energy industry	4.922.589	4.495.514	3.021.079	5.763.643	953.997	519.107

Source: ICLEI – Local Governments for Sustainability, 2025.

6.4.1. Emissions by Fuel Type

Disaggregating emissions by fuel type provides a more granular understanding of sources within the Stationary Energy sector. **Figure 31** illustrates these results.

Figure 31. Stationary Energy sector emissions by main fuel types (2018-2023).



	2018	2019	2020	2021	2022	2023
Others	83.885	267.111	235.642	279.014	54.523	50.804
Mineral coal	4.197.120	4.056.755	1.919.456	4.253.831	10.823	126.765
Diesel	262.726	267.632	305.333	272.467	257.616	245.315
LPG	850.050	842.765	874.099	846.116	850.050	864.990

Source: ICLEI – Local Governments for Sustainability, 2025.

As mentioned, coal was the principal fuel responsible for emissions over the period. However, it also showed the most significant decline, with a 96.9% reduction between 2018 and 2023.

Coal was used in two thermoelectric plants in Ceará and was a major component of the state's energy matrix during years of high electricity generation. A notable example was 2021, when Ceará recorded significant increases in electricity production. In 2024, the state signed a Memorandum of Understanding to convert the Pecém I Thermoelectric Plant (UTE Pecém I), located in the Pecém Industrial and Port Complex (CIPP, in the Brazilian acronym), from coal to natural gas.

Liquefied Petroleum Gas (LPG) was the second-largest source, with stable emissions and a slight 1.76% increase, used mainly in residential buildings for cooking. Diesel, the third-largest contributor, is primarily used in manufacturing/construction industries and commercial/institutional buildings. Natural gas also had relevant contributions between 2019 and 2021, especially in residential buildings.

6.4.2. Emissions from electricity consumption

Electricity consumption emissions — classified as indirect emissions — represent an important component of the Stationary Energy sector. Estimation depends on two primary variables: electricity consumption in the state, and the emission factor of the National Interconnected System (SIN, in the Brazilian acronym).

Electricity consumption in Ceará increased 19% between 2018 and 2023. Residential buildings were the largest consumers (40% of demand), followed by industry (20%), commerce (18%), and rural areas (10%).

Emission factors are widely used in analyses that require average GHG emissions associated with the SIN in Brazil. These monthly factors, published by the Ministry of Science, Technology and Innovation (MCTI, 2025), estimate the average CO_2 emitted per unit of electricity generated nationwide. They account for emissions from the entire fleet of operating power plants, not only marginal plants activated during times of peak demand. This method provides a comprehensive metric for Brazil's grid carbon intensity, and serves as an useful tool for studies, inventories, and policies aimed at emissions management in the energy sector.

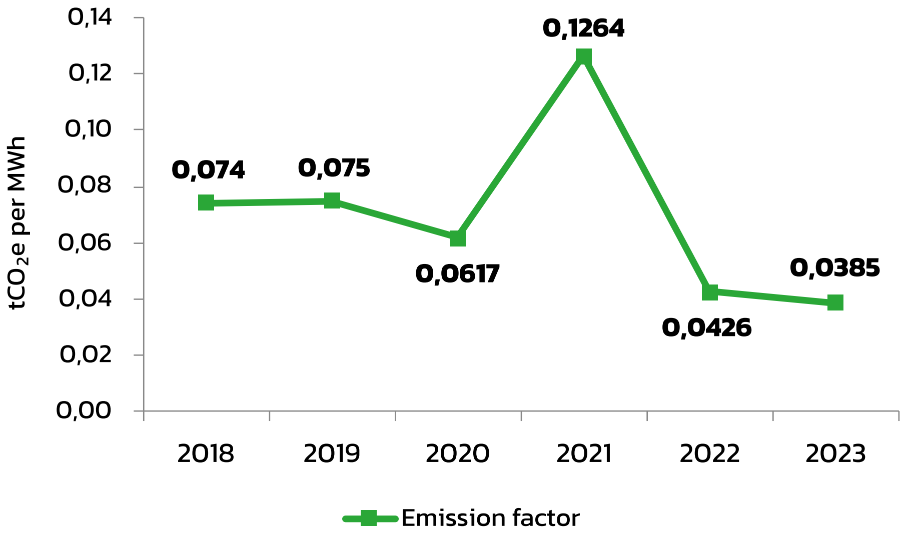
The so-called average factor represents an average of GHG emissions per unit of energy consumed or fuel used in a given sector or activity (MCTI, 2021a). It is important to note that this average factor is influenced by climatic variations, such as the absence of rainfall or extreme precipitation events. These climatic variations can directly affect energy generation, mainly because the Brazilian energy matrix depends significantly on water sources, such as hydroelectric power.

During periods of prolonged drought, hydroelectric plants may operate at reduced capacity, resulting in lower energy generation. In this scenario, there is often greater demand for other sources, such as the activation of thermoelectric plants. As these plants use fossil fuels, the emission factor tends to increase, reflecting a more carbon-intensive matrix.

The SIN's emission factor is sensitive to climate variability. Dry periods reduce hydropower generation, increasing reliance on thermoelectric plants and raising emission factors.

Between 2020 and 2021, fossil-fuel participation in power generation rose from 15% to 20% (IEMA, 2022), leading to a temporary increase in average emission factors, as seen in **Figure 32**. In 2022, the scenario was reversed, with a greater share of renewable sources and, as a result, reduced emission factors.

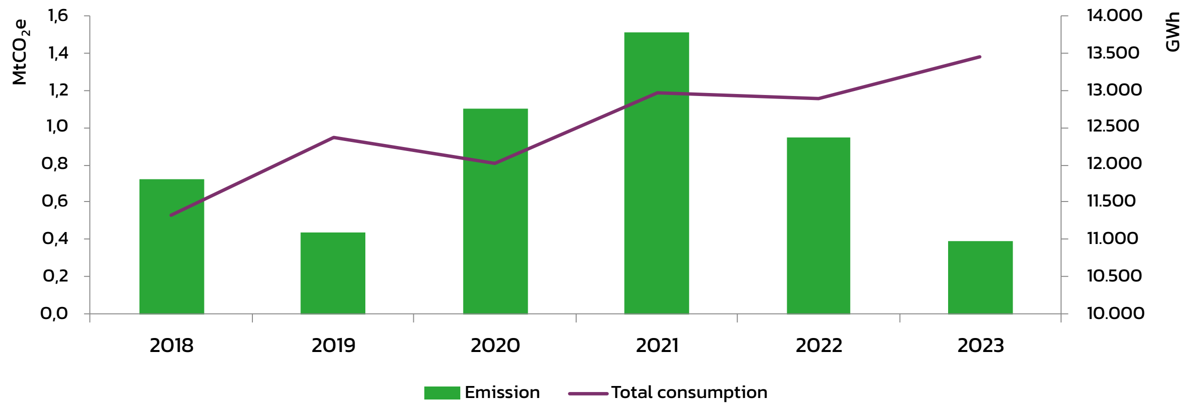
Figure 32. CO_2 emissions factor for the Stationary Energy sector (2018–2023).



Source: ICLEI based on MCTI, 2025

These two drivers combined influence emissions behavior in the analyzed period, which was marked by significant variations. In 2018, emissions from electricity consumption totaled 0.725 $MtCO_2e$. In 2021, emissions peaked at 1.5 $MtCO_2e$, an increase of 108%, driven by both higher demand and a significantly higher emission factor. From 2022 onward, the sharp decline in emission factors led to lower emissions, reaching 0.39 $MtCO_2e$. This evolution can be seen in **Figure 33**.

Figure 33. Evolution of emissions and electricity consumption in Ceará (2018-2023).



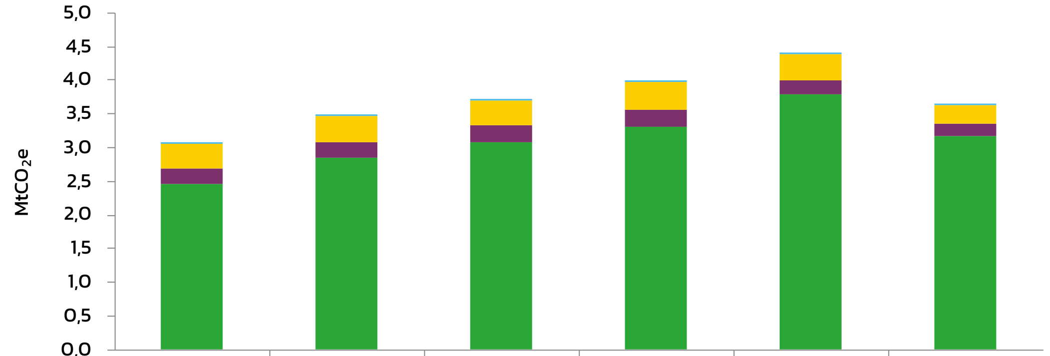
Source: ICLEI – Local Governments for Sustainability, 2025.

6.5. Waste Sector

The Waste sector includes emissions generated by the treatment of solid waste and wastewater, comprising activities such as the final disposal of solid waste in environmentally sound (sanitary landfills) and unsound disposal sites (controlled landfills and open dumps), the incineration of healthcare waste (HCW) or open burning, as well as the treatment of domestic and industrial wastewater. Analysis of this sector is crucial for identifying mitigation opportunities, especially considering the high methane generation potential.

Only activities occurring within the inventory boundary were included in the Waste sector — i.e., those resulting in direct emissions, classified as Scope 1. The sector's trajectory shows a 19% increase in emissions, rising from 3.06 $MtCO_2e$ in 2018 to 3.64 $MtCO_2e$ in 2023. **Figure 34** presents the annual contribution of each sub-sector and their respective evolutions.

Figure 34. Waste sector emissions by sub-sector (2018–2023).



	2018	2019	2020	2021	2022	2023
Total	3.069.735	3.479.050	3.707.967	3.989.580	4.400.024	3.641.929
Industrial wastewater treatment	6.818	6.923	6.544	3.766	6.062	7.047
Domestic wastewater treatment	374.060	383.066	376.169	419.839	389.550	283.466
Incineration or open burning	231.787	235.237	247.717	250.182	200.689	185.997
Solid waste final disposal	2.457.070	2.853.823	3.077.536	3.315.792	3.803.723	3.165.419

Source: ICLEI – Local Governments for Sustainability, 2025.

The solid waste disposal sub-sector is the main emission source, responsible for 18.67 $MtCO_2e$ over the period, showing a growing trend. Domestic wastewater treatment contributed 2.26 $MtCO_2e$, with a 24% decrease over the period. Incineration or open burning accounted for 1.3 $MtCO_2e$, while industrial wastewater treatment presented the smallest contribution. These sub-sectoral dynamics are analyzed in the following sections.

It is important to note that biological treatment—such as composting or anaerobic digestion — is also a source of emissions and a relevant alternative for sustainable solid waste management. However, these practices remain incipient in the state and were therefore not considered in the current inventory.

6.5.1. Solid waste final disposal

The final disposal of domestic and public waste collected in Ceará is the most impactful category in the Waste sector, accounting for 84% of sectoral emissions. These emissions are generated mainly through anaerobic decomposition of organic matter in disposal units — both environmentally sound (sanitary landfills) and unsound disposal (controlled landfills and open dumps) — resulting in methane (CH_4) emissions.

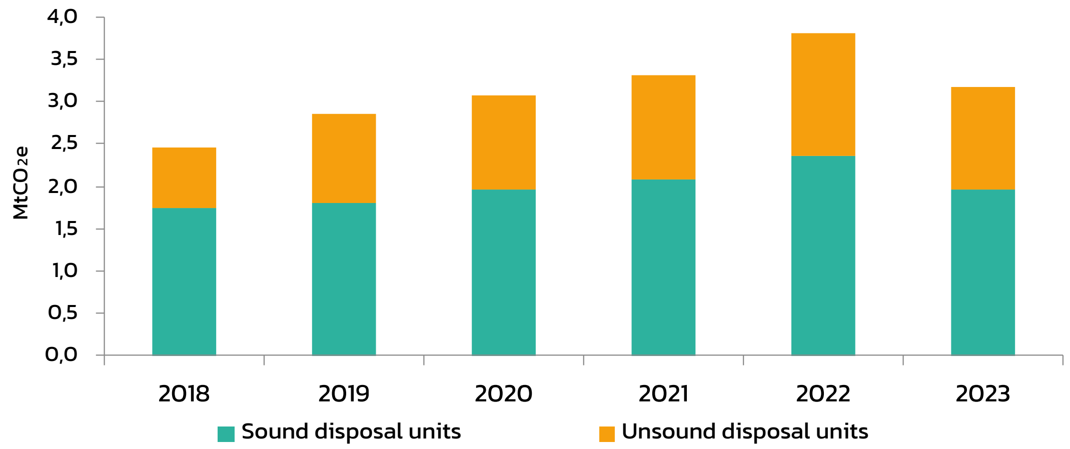
Emissions were estimated following IPCC guidelines, based on the quantity of waste collected, gravimetric composition, and type of disposal, which determines the amount of degradable organic carbon disposed in the ground. Emissions increased 29% between 2018 and 2023, with steady growth until 2022 (peaking at 3.99 $MtCO_2e$), followed by a slight reduction in 2023. This pattern reflects variations in the total volume of waste sent to final disposal: years with higher emissions coincide with years of higher waste generation and collection.

Another important aspect is the type of disposal adopted. In Ceará, around 52% of collected waste is sent to environmentally unsound final disposal sites. This is relevant not only from an emissions accounting perspective but also in terms of compliance with the National Solid Waste Policy — which mandates the closure of open dumps — and due to the significant socio-environmental impacts associated with unsound disposal, including risks to human health, soil contamination, and pollution of surface and groundwater.

A key mitigation measure implemented in the state is the energy use of landfill biogas, particularly at the Metropolitan Sanitary Landfill, home to GNR Fortaleza — a partnership between Marquise Ambiental and MDC Energia — which captures and upgrades methane into biomethane in the Caucaia unit, contributing to local energy supply (ABREMA, 2025).

Figure 35 presents emissions by disposal type. On average, environmentally sound disposal accounted for 64% of emissions, while unsound disposal accounted for 36%, highlighting the need for progress in sustainable waste management and broader implementation of mitigation measures by the state of Ceará.

Figure 35. Emissions by type of waste disposal



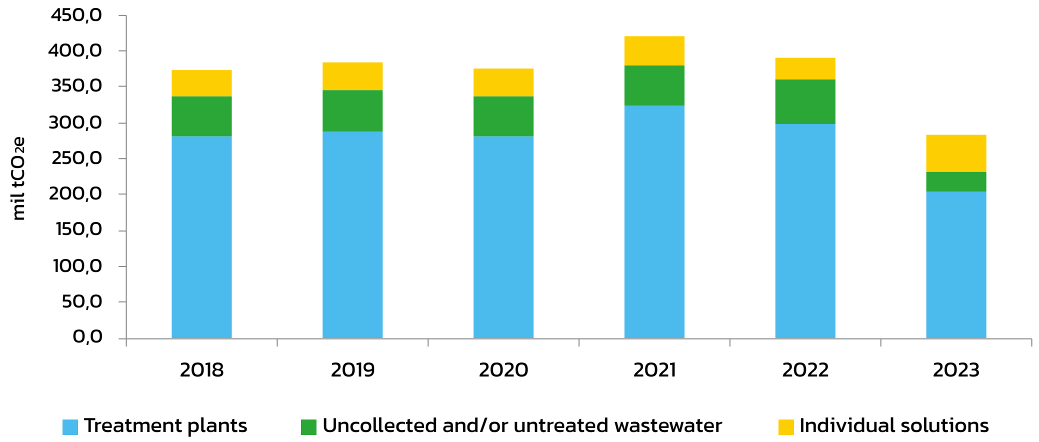
Source: ICLEI – Local Governments for Sustainability, 2025.

6.5.2. Domestic wastewater treatment

Regarding wastewater, emissions are strongly linked to the type of treatment used at wastewater treatment plants (WWTPs, or ETPs in the Brazilian acronym), the proportion of the population served by collection systems, and the portion not covered by sanitation services.

Emissions from domestic wastewater treatment decreased 23.73% between 2018 and 2023. After relative stability and a peak in 2021, emissions fell substantially in 2023 — 27% below the previous year — as shown in **Figure 36**.

Figure 36. Domestic wastewater treatment emissions (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

Throughout the series, emissions from wastewater collected and treated in WWTPs were the most relevant, accounting for an average of 75% of sub-sector emissions. These emissions are associated with 276 sanitation systems operating in 79 municipalities.

During the analyzed years, 40–50% of the population lacked access to domestic wastewater collection services, demonstrating that untreated wastewater remains a significant emission source. This underscores the need for substantial progress toward universal sanitation services, as set out in Brazil's Legal Framework for Sanitation and other relevant policies. Incorporating mitigation measures in wastewater treatment is also critical.

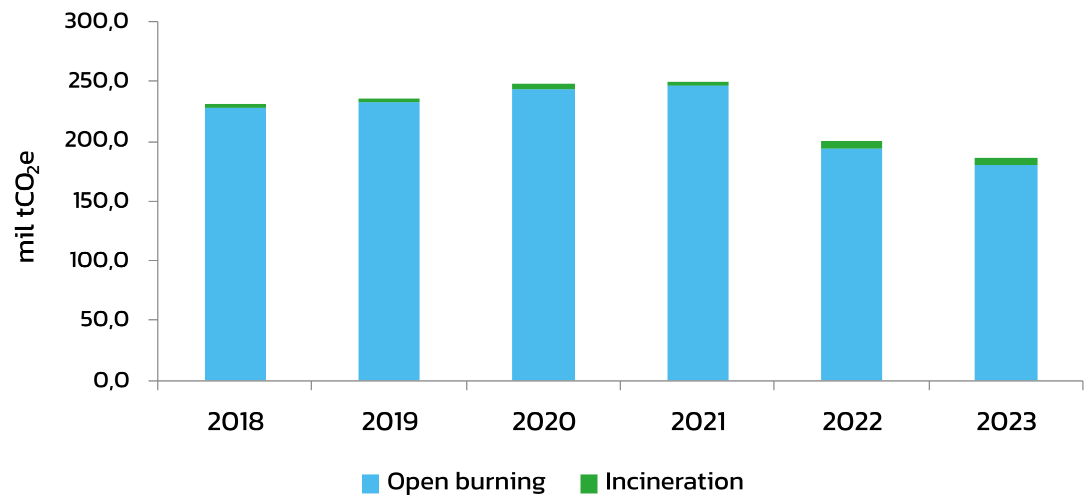
6.5.3. Open burning or HCW incineration

The Waste Incineration or Open Burning sub-sector includes emissions generated from controlled or uncontrolled burning of solid waste. For this inventory, it covers specifically the incineration of healthcare waste (HCW), as incineration is not commonly used for household or public waste in Brazil. It also includes uncontrolled burning of municipal solid waste, a practice often associated with gaps in collection services, where part of the population resorts to burning waste on their own property — an environmentally unsound practice that contributes significantly to GHG emissions and air pollution.

Emissions in this sub-sector decreased 20% between 2018 and 2023, with open burning accounting for 97% of emissions, as shown in **Figure 37**.

Open burning is an inappropriate practice that contributes directly to GHG emissions and worsens air pollution. According to the Continuous National Household Sample Survey, 16.4% of Ceará's population resorted to burning waste on their property in 2018. By 2023, this figure had fallen to 12.4%, that sanitation systems are being expanded, with a greater number of inhabitants having access to solid waste collection services.

Figure 37. Emissions from incineration and open burning (2018–2023).



Source: ICLEI – Local Governments for Sustainability, 2025.

6.5.4. Industrial wastewater treatment

Industrial wastewater treatment is the smallest contributor within the Waste sector. This sub-sector accounts for emissions from industries with high potential for organic matter generation in their effluents. In Ceará, emissions were quantified for meat processing activities (beef, pork and poultry) and dairy production (raw and pasteurized).

The sub-sector recorded a 3% increase in emissions, from 6,800 tCO_2e in 2018 to 7,000 tCO_2e in 2023.

7

COMPARISON OF EMISSIONS WITH BRAZIL AND OTHER STATES

Understanding Ceará's GHG emissions becomes even more relevant when they are examined in a comparative context with other Brazilian states. This approach helps situate the state's climate performance in relation to different economic, territorial, and productive realities, highlighting both regional progress and the challenges faced in addressing climate change.

Between 2018 and 2023, Ceará recorded 190.7 $MtCO_2e$, with an annual average of 31.8 $MtCO_2e$ and a 24.11% increase in net emissions during the period. This growth reflects, above all, the expansion of the AFOLU sector, which increased its emissions by 166%, driven by the intensification of agricultural and livestock activities and the conversion of vegetated areas. Comparing Ceará with other Northeastern states and with the industrial hubs of the Southeast makes it possible to assess the relative weight of the state's emissions across different scales and productive contexts.

At the regional level, Ceará reported higher emissions than Piauí (140.6 $MtCO_2e$) and Pernambuco (126.0 $MtCO_2e$), yet remained below Bahia (483.1 $MtCO_2e$), the state with the largest productive base and territorial area in the Northeast. In all cases, emissions from land-use change and agriculture dominate; however, Ceará stands out for the significant participation of the energy and industrial sectors, reflecting its growing economic diversification.

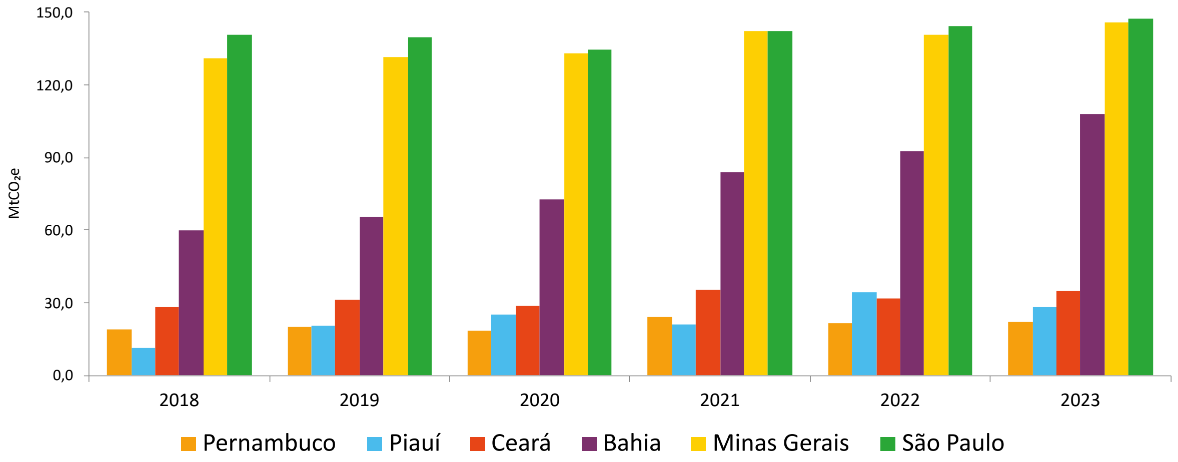
While Bahia and Piauí exhibited strong dependence on emissions associated with land-use change, Ceará presents a more balanced profile, with a higher relative share from the energy sector (27%) and waste sector (17%). These categories are directly linked to urbanization and infrastructure expansion. This characteristic places Ceará in an intermediate position between predominantly agricultural economies and those that are more industrialized.

Compared to the major states of the Southeast, Ceará's emissions are significantly lower than those of São Paulo (849.5 $MtCO_2e$) and Minas Gerais (824.4 $MtCO_2e$). In terms of trends, both states showed relatively stable behavior, with a slight reduction in 2020 due to the pandemic's economic impacts, but an accumulated increase of approximately 8% between 2018 and 2023.

In São Paulo, this increase was driven mainly by the energy and agriculture sectors, while in Minas Gerais, the country's leading steel-producing state, moderate growth was observed in emissions associated with industrial processes and land use.

In Ceará's case, 38.0 $MtCO_2e$ of total emissions recorded between 2018 and 2023 originated from steel production, demonstrating the importance of this sector to the state's industrial and climate profile. Thus, although the sectoral profiles of Minas Gerais and São Paulo are more industrialized and energy-intensive, Ceará faces similar challenges in reducing the carbon intensity of its productive activities, especially within steel and industrial value chains. **Figure 38** presents a comparison of emissions across Brazilian states.

Figure 38. Comparison of emissions across Brazilian states (2018-2023).



Source: ICLEI - Local Governments for Sustainability, 2025; SEEG, 2024

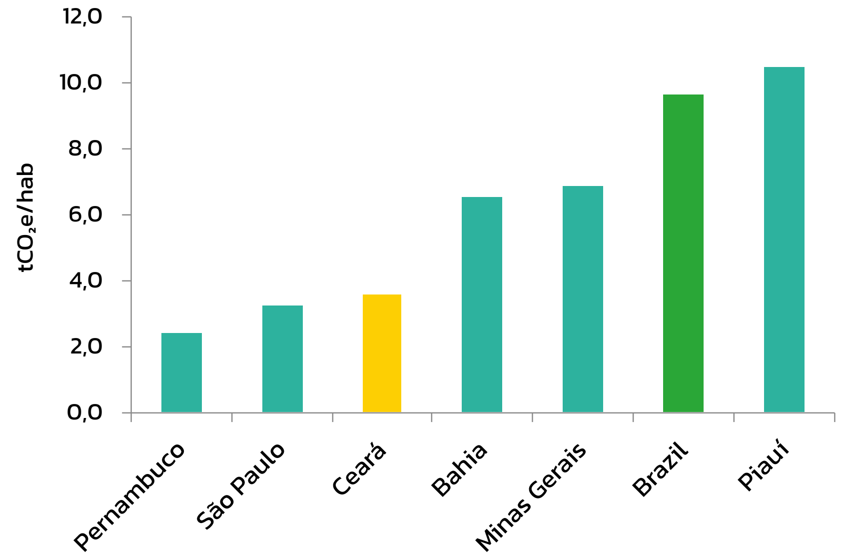
Using data from SEEG (2024), this inventory, and the Demographic Census (IBGE, 2023a), it is possible to compare per capita emission intensities for the year 2022.

Ceará reported an average of 3.58 tCO_2e per inhabitant, below the national average (9.63 tCO_2e/capita) and similar to São Paulo (3.26 tCO_2e/capita), reflecting an economy that is less carbon-intensive and predominantly service-oriented.

In contrast, states such as Bahia (6.55 tCO_2e/capita) and Minas Gerais (6.84 tCO_2e/capita) reported higher values, associated with the greater presence of industrial and agricultural activities. Piauí (10.49 tCO_2e/capita) stood out with the highest value among the states analyzed, strongly influenced by emissions from land-use change. Pernambuco (2.38 tCO_2e/capita) reported the lowest indicator, possibly due to its high population density and a productive structure less dependent on direct-emission activities (**Figure 39**).

Overall, Ceará ranks among the states with the lowest per capita emissions, reflecting an increasingly urban and service-based economy, as well as progress in diversifying its energy matrix and improving waste management.

Figure 39. Per capita emissions in Brazil, Ceará, and selected states in 2022.



Source: ICLEI - Local Governments for Sustainability, 2025; SEEG, 2024; IBGE, 2023a.

In terms of emissions intensity per million reais of GDP (IBGE, 2025), comparing Ceará with other Brazilian states reveals significant differences in the carbon intensity of economic activity. In 2021, Ceará reported an average intensity of 0.18 tCO_2e per million reais of GDP, below the national average of 0.22 tCO_2e/million BRL (SEEG, 2024). This reflects a productive structure that is less emissions-intensive and largely service-based.

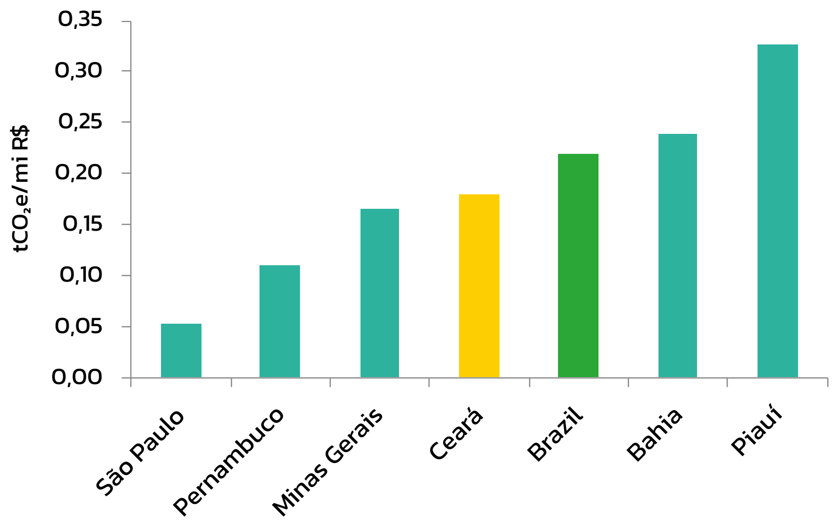
In contrast, Northeastern states such as Bahia (0.24 tCO_2e/million BRL) and Piauí (0.33 tCO_2e/million BRL) show higher intensities, influenced by the greater relative contribution of agriculture and land-use change in their economies. Pernambuco (0.11 tCO_2e/million BRL) stands out positively with the lowest indicator among states analyzed, possibly due to its productive structure being more concentrated in services and having fewer energy-intensive industrial sectors.

Among Southeastern states, São Paulo (0.05 tCO_2e/million BRL) confirms its position as the most emission-efficient economy, reflecting its high economic density and sectoral diversification.

Minas Gerais (0.17 tCO_2e/million BRL) presents an intermediate profile, associated with the strong presence of manufacturing and basic industries, especially steel production (**Figure 40**).

In summary, Ceará demonstrates a favorable performance in the relationship between emissions and GDP, signaling gains in productive efficiency and opportunities to consolidate a low-carbon economy compared to other states in the Northeast and Southeast.

Figure 40. Emissions per GDP in Brazil, Ceará, and selected states in 2021.



Source: ICLEI - Local Governments for Sustainability, 2025; SEEG, 2024; IBGE, 2025.

Specifically for Ceará, emissions intensity per GDP varied between 2018 and 2021, reflecting fluctuations in economic growth and total GHG emissions. In 2018, the indicator was 0.1807 tCO_2e/thousand R$, rising to 0.1930 tCO_2e/thousand R$ in 2019 (+6.8%), indicating a relative increase in emissions compared with the state GDP. In 2020, the value dropped to 0.1734 tCO_2e/thousand R$ (–10.2%), possibly associated with the economic slowdown caused by the COVID-19 pandemic. By 2021, the intensity rose again to 0.1809 tCO_2e/thousand R$ (+4.3%), accompanying the recovery of productive activities.

EVOLUTION OF EMISSIONS AND COMPLIANCE WITH THE NDC

Brazil's NDC highlights that dialogue and cooperation between the federal government and the states will be decisive in guiding the national trajectory of emission reductions. In this sense, achieving the proposed reduction target of 57% to 67% below 2005 levels will only be possible through coordinated and proactive action across sectors.

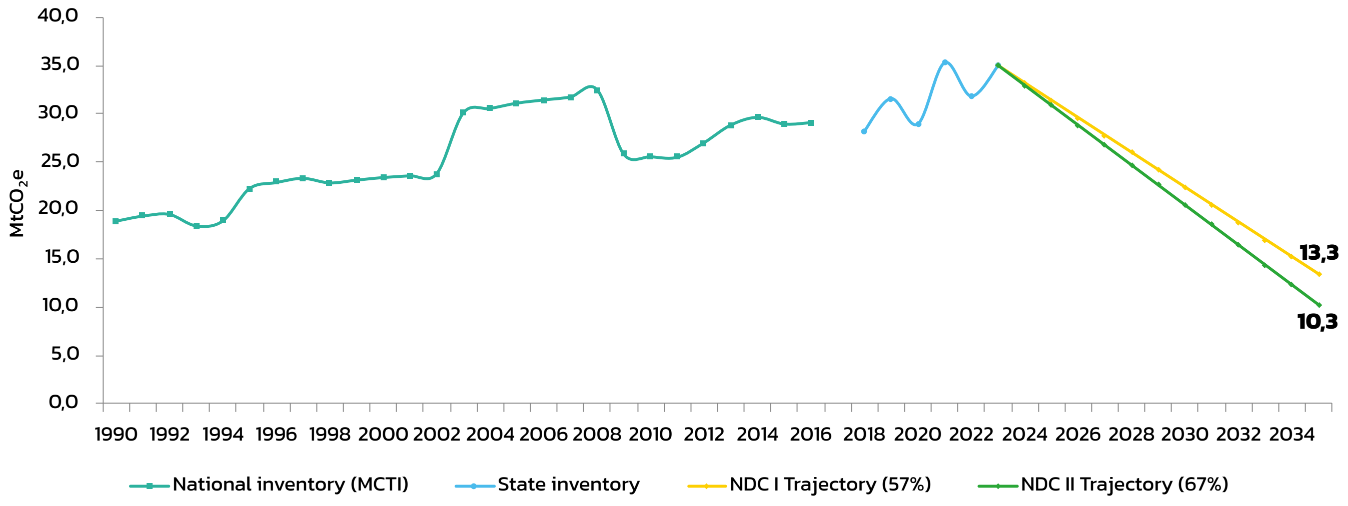
This chapter presents Ceará's emissions trajectory in relation to the Brazilian NDC, as shown in Figure 41. The analysis is based on the results of Ceará's Greenhouse Gas Emissions Inventory for the 2018–2023 period, combined with data from the national inventory prepared by the Ministry of Science, Technology and Innovation (MCTI, in the Brazilian acronym), covering 1990–2016.

Between 1990 and 2016, Ceará's emissions increased by 53%, with peak levels recorded between 2003 and 2008 — the first period in which the state surpassed 30 $MtCO_2e$ in annual emissions. The current inventory shows that emissions continued to grow from 2018 to 2023, with peaks in 2021 and 2023 (35.2 $MtCO_2e$ and 34.96 $MtCO_2e$, respectively).

To effectively contribute to Brazil's NDC, Ceará will need to reduce emissions by 62% to 71%, based on its estimated 2023 emissions of 34.9 $MtCO_2e$, reaching a level between 13.3 $MtCO_2e$ and 10.3 $MtCO_2e$ by 2035.

Figure 41 compares the National Inventory and Ceará's GHG Emissions Inventory with the Brazilian NDC targets.

Figure 41. Comparison of inventories with Brazil's NDC targets.



Source: ICLEI – Local Governments for Sustainability, 2025.

Within this context, no large-scale mitigation measures were implemented in Ceará during the period analyzed, and the state experienced a marked increase in GHG emissions from 1990 to 2023. Meeting Brazil's NDC will require the state to adopt more ambitious climate action, particularly in advancing the energy transition, implementing low-carbon agriculture, controlling deforestation, and a range of additional measures that are briefly discussed in the following sections.

9

FINAL CONSIDERATIONS

This Greenhouse Gas Emissions Inventory Report represents an essential diagnostic tool for understanding Ceará's climate profile. More than a compilation of data, it serves as a strategic instrument to inform and guide public policy and support concrete actions in Ceará's transition toward a more resilient, equitable, and carbon-neutral future.

A detailed analysis of emitting sectors provides clarity on the state's main challenges and the most promising opportunities for mitigation, while also aligning Ceará with national and international commitments — particularly with ICLEI's Five Pathways.

9.1. Overall Emissions Profile

Considering all sectors, Ceará's net emissions increased by 24.11% between 2018 and 2023. Starting at 28.17 $MtCO_2e$ in 2018, net emissions reached 34.96 $MtCO_2e$ in 2023. A slight decline occurred in 2020, likely linked to reduced economic activity during the COVID-19 pandemic, but emissions resumed their upward trend thereafter, with peaks in 2021 and 2023.

The sectors that contributed most significantly to Ceará's emissions profile were:

• **AFOLU (Agriculture, Forestry, and Other Land Use)**: AFOLU was the largest source, with 14.63 $MtCO_2e$ in 2023. Most emissions stem from land-use change, particularly the conversion of natural areas for agricultural purposes, deforestation, and also livestock emissions. The 166.04% increase in this sector signals the urgent need for sustainable land-use policies and agricultural practices.

• **IPPU (Industrial Processes and Product Use)**: Emissions reached 9.32 $MtCO_2e$ in 2023, an increase of 13.32% compared to 2018, making it the second-largest source. Steel production is the dominant emissions source, followed by cement production, reflecting the strong expansion of construction activities in the state.

• **Transportation**: Total emissions were 5.69 $MtCO_2e$ in 2023. The predominance of on-road transportation and the heavy reliance on fossil fuels remain the primary drivers, despite a relatively modest 8.23% increase over the period.

• **Stationary Energy**: Contributing 1.68 $MtCO_2e$ in 2023, this sector saw a sharp 72.54% reduction during the 2018-2023 period due mainly to decreased coal use in thermoelectric generation. Despite the decline, fossil fuels still play an important role in the state, according to variations in the energy matrix, to which this sector is very sensitive.

• **Waste**: Emissions reached 3.64 $MtCO_2e$ in 2023, up 18.64% since 2018. Final waste disposal (to both environmentally sound and unsound units) is the main source, driven by methane emissions from organic waste decomposition. Wastewater treatment, incineration, and open burning also contribute substantially.

9.2. Recommendations and Mitigation Opportunities

To support Brazil's NDC, Ceará will need to reduce its emissions by 21.06 to 24.71 $MtCO_2e$ by 2035. Achieving this will require increasingly ambitious measures guided by sustainable, low-carbon development. Below are key recommendations and opportunities for each sector, aligned with ICLEI's Five Pathways: Zero Carbon, Nature-Based, Resilient, Equitable, and Circular.

AFOLU Sector (Agriculture, Forestry, and Other Land Use)

• **Strengthen monitoring and enforcement to combat deforestation**: Implement robust, georeferenced monitoring systems and enforcement mechanisms to reduce the illegal conversion of natural areas, especially for agricultural expansion.

• **Promote reforestation and the restoration of degraded areas**: Support ecological restoration programs, including the planting of native species and the stimulation of natural regeneration. These actions increase carbon sequestration and contribute to biodiversity conservation.

• **Adopt low-carbon agricultural practices**: Encourage the implementation of systems such as Crop-Livestock-Forest Integration (ILPF, in the Brazilian acronym), integrated pest management, and the proper management of agricultural residues.

• **Reduce emissions from livestock**: Promote genetic improvement, optimized animal nutrition, and methane capture from manure to mitigate emissions from enteric fermentation and waste management.

• **Support sustainable family farming**: Provide technical assistance and access to resources so smallholders can adopt low-carbon practices and adapt to climate change, enhancing their resilience.

• **Advance land tenure regularization**: Strengthen land regularization to promote legal and environmental security, encouraging conservation and the sustainable use of land.

Stationary Energy Sector

• **Promote a more sustainable and diversified energy matrix by investing in renewable sources** such as wind, solar, biomass, hydrogen, and biogas/biomethane.

• **Improve energy efficiency in buildings**: Implement incentive programs for upgrading lighting and air conditioning systems and equipment in public and private buildings, reducing overall energy demand.

• **Reduce dependence on fossil fuels**: Encourage the replacement of fuels such as LPG and diesel in stationary applications with cleaner alternatives. This transition can be strengthened through a review of state regulations and legislation aimed at phasing out or reducing tax incentives for non-renewable sources while expanding incentives for renewable energy. Ceará has strong technical and territorial potential for solar and wind energy, making it essential to accelerate the energy transition and align the state's fiscal and energy policy with decarbonization and climate-neutrality goals.

Transportation Sector

• **Encourage the use of biofuels:** Promote policies that increase the participation of ethanol and biodiesel in the transportation fuel mix.

• **Shift toward cleaner and more efficient transportation modes:** Invest in infrastructure for mass transit systems (such as Light Rail Vehicles/LRTs and Bus Rapid Transit/BRTs) and promote the use of electric and hybrid vehicles for both public and private fleets.

• **Improve logistics efficiency:** Implement urban and freight logistics solutions that optimize routes, reduce empty trips, and promote intermodal transportation to decrease fuel consumption.

• **Advance sustainable and inclusive mobility:** Ensure that clean transportation solutions are accessible to all segments of the population, improving air quality and public health while reducing vulnerability to fossil-fuel price fluctuations.

IPPU Sector (Industrial Processes and Product Use)

• **Enhance industrial energy efficiency:** Implement energy audit programs and offer incentives for modernizing equipment and industrial processes, reducing energy consumption and associated emissions.

• **Encourage the substitution of inputs and processes:** Promote research and development for low-carbon materials (e.g., low-carbon cement) and the adoption of cleaner technologies in industry.

• **Strengthen dialogue with local actors and companies**: Facilitate multi-stakeholder engagement focused on promoting sustainable, low-carbon industrial development.

• **Support innovation:** Foster a favorable environment for innovation and investment in sustainable industries, creating green jobs and strengthening the local economy.

Waste Sector

• **Expand separate collection and recycling:** Invest in infrastructure and awareness programs to significantly increase source-separated collection and recycling rates, diverting materials from sound and unsound final disposal sites.

• **Implement composting and anaerobic digestion:** Promote the treatment of organic waste through composting and biodigestion, converting it into fertilizers and biogas (with energy-generation potential) and reducing methane emissions.

• **Expand biogas-to-energy systems at environmentally sound disposal facilities:** Scale up biogas recovery and utilization in facilities where technical and economic feasibility is demonstrated.

• **Achieve universal access to sanitation services:** Invest in the expansion and improvement of sewage collection and wastewater treatment infrastructure, ensuring adequate services for the entire population and reducing methane emissions from wastewater.

• **Eliminate environmentally unsound disposal sites:** Continue efforts to eradicate inadequate disposal, replacing them with environmentally sound waste management systems.

• **Strengthen community engagement:** Engage the population and waste pickers in waste management solutions, ensuring social and economic inclusion.

9.3. Next Steps and the Way Forward

The completion of Ceará's GHG Inventory is a significant milestone and, more importantly, it represents the starting point for a structured path toward state climate compliance. To advance strategically, the next steps include:

• **Supporting Climate Public Policies:** The inventory will serve as a key tool to inform and strengthen the development of state-level public policies aimed at emission mitigation, the transition to a zero-carbon development model, and enhanced territorial resilience.

• **Building Statewide Climate Compliance:** Preparing the inventory is the first step in Ceará's journey toward climate compliance. Based on the data and insights generated, the state's next steps include developing the Climate Risk and Vulnerability Assessment and the State Climate Action Plan, which will define long, - medium - and short-term mitigation and adaptation strategies.

• **Setting and Monitoring Targets:** The inventory will provide the basis for establishing realistic emission-reduction targets and for monitoring the state's progress toward its climate commitments, aligned with Brazil's Nationally Determined Contributions (NDCs).

• **Reporting and Transparency:** Promote accessible and transparent dissemination of the inventory results to civil society, the private sector, and academia, fostering engagement from all actors in implementing effective climate actions. This will strategically include reporting through the CDP-ICLEI Track platform, ensuring international visibility and recognition of Ceará's climate efforts and progress.

• **Institutional Strengthening and Capacity Building:** The continuous inventory process will strengthen the technical capacity of state teams and improve data-collection workflows, consolidating Ceará as a reference in climate-information management.

Finally, by adopting an integrated and ambitious approach, Ceará can fulfill its climate commitments aligned with national and international agreements, while transforming challenges into opportunities for greener, fairer, and more prosperous economic and social development. The transition to a zero-carbon economy is a powerful driver of innovation, competitiveness, and improved quality of life for all residents of Ceará. This document is a fundamental step in supporting the state's development, detailing Ceará's emissions profile and outlining possible pathways toward a more sustainable and climate-resilient future.

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APPENDIX A. Calculation Method and Emission Factors

This Appendix presents considerations on the calculation methods and emission factors (EF) used in the preparation of Ceará's GHG Emissions Inventory. The WayCarbon Ecosystem platform was used to support all calculations and emissions estimates.

The inventory preparation process consisted of a parameterization stage, in which the ICLEI technical team, with support from the state of Ceará and the tool itself, created parameters for all emission source activities in the territory.

In this parameterization process, scopes, technologies and activity classifications are defined, and the most appropriate emission factors are selected to estimate the emissions associated with activity in the GPC sectors.

After defining the parameters, the respective activity data were entered into the tool. Once the data were entered, GHG emission estimates were automatically generated, enabling visualization of results by sector, scope, category, and other relevant classifications.

The tool also includes an audit component that allows the review of all adopted calculation methods, the emission factors applied and their respective references — which, in general, are standard values defined by the IPCC or obtained from the National Inventory of Anthropogenic Emissions and Removals, prepared by the Ministry of Science, Technology and Innovation (MCTI, in the Brazilian acronym).

To access all calculation methods and the respective emission factors adopted in the state of Ceará, refer to the following appendix file: **https://docs.google.com/spreadsheets/d/1x0aEhLKV8vfFh44vJmPrq1yXWQE-28IJ/edit?gid=780603508#gid=780603508**.

The calculation methods related to land-use change are available in the sectoral methodological notes of SEEG (2023a; 2023b).

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