Atlas of Energy Efficency Brazil | 2024

Indicators Report

epe

MINISTÉRIO DE MINAS E ENERGIA

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Public Value | EPE 20 years

The Brazilian Energy Research Office (EPE), founded in 2004 and part of Brazil's Ministry of Mines and Energy (MME), plays a key role in supporting energy sector planning through its research and studies. One of its standout initiatives is the Atlas of Energy Efficiency in Brazil, a report published regularly since 2014 that tracks progress in energy efficiency across the country using detailed indicators.

Together with the Methodological Manual for the Atlas of Energy Efficiency, this publication aims to provide transparency and close information gaps about Brazil's energy efficiency advancements, focusing particularly on the residential, industrial, and transportation sectors.

This report features a special chapter...

which provides a detailed analysis of the ferroalloys and silicon metal sector in Brazil, the result of a collaboration between EPE and the Brazilian Association of Ferroalloy and Silicon Metal Producers (ABRAFE). It presents a nationwide overview of this sector, with a particular focus on energy consumption for the industrial production of ferroalloys in Brazil.

ABRAFE

The ABRAFE team that contributed to the preparation of this report was:

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Objective

Purpose

The main purpose of this report is to track the Brazilian energy efficiency advances through an indicators analysis. In 2014 the first Energy Efficiency Indicators Report was published, with data up until 2012. Since then, this report is being updated, and in 2020 it started to be called as "Atlas of Energy Efficiency Brazil – Indicators Report". This document complements and updates, in a synthetic way, the first reports, with data up until 2023.

2014

2017

2020

Special Chapter

Energy Efficiency Benchmarking: Brazil in the Global Scenario

2021

Special Chapters

- Cement Sector in Brazil and in the World
- Covid-19 effects

2022

Special Chapter

Road freight transport and the comparison of the Brazilian case with selected countries

2023

Special Chapter

- Steel sector

Special Chapter

- Residential Sector

2024

Special Chapter

- Industry sector of Ferroalloys and Silicon metal

Definitions

ODEX

The ODEX is an indicator that measures the energy efficiency progress. It can be combined by sector (industrial, residential, services and transport) or for the whole economy. The ODEX is being used by the European Union in the ODYSSEE database program to track efficiency gains (Enerdata, 2020).

The ODEX by sector (e.g. industry) is based on specific consumption indexes by subsector (cement, ceramics, textiles, etc.) and weighted by its share on the total energy consumption. The specific consumption by subsector can be expressed in different units to provide the best energy efficiency proxy, such as consumption per household, consumption per physical production or consumption per transport activity (measured in units such as passenger-kilometre and tonne-kilometre).

For this report, 2005 was taken as the base year (value = 100), essentially due to the data availability for most sectors from that year onwards. A decrease in the ODEX from 100 in 2005 to 80 in any given year, for example, represents a 20% gain in energy efficiency over the analyzed period. In other hand, if the ODEX increases from 100 to 120, means that the energy efficiency declined over the years.

In the case of the global ODEX, the same method is applied with weighted factors, based on the share of each sector on the total final energy consumption, in relation to the total final energy considered for all the evaluated sectors.

For this report purposes, the industrial, residential and transport sectors were considered. Other sectors (energy, services and agriculture) were not included due to the data unavailability in the appropriate format for the indicator calculation.

The Methodological Manual of the Atlas of Energy Efficiency in Brazil provides detailed information about the data and indicators used to prepare this report, including the ODEX. It can be accessed by clicking on Methodological Manual

This edition of the Atlas of Energy Efficiency includes changes to historical data compared to previous editions. These updates are justified by the revision of historical data series used in the calculation of the ODEX for the transport sector.

Energy Intensity

Energy intensity refers to the amount of energy required to produce one final product or service. It is the ratio between an energy indicator (ton oil equivalent [toe], Joule, calorie, Btu, among others) and an activity indicator (U$, R$, m^2, ton-kilometers, passenger-kilometers, among others).

Hypothetical examples:

- Industrial Energy intensity: 100 toe/U$ ppp 2010
- Energy intensity of residential building: 0.5 toe/m^2
- Energy intensity of commercial building: 200 KJ/m^2
- Energy intensity in the transport sector: 1,000 toe/tkm

The energy intensity of an economy corresponds to the ratio of Internal Energy Supply divided by the Gross Domestic Product (GDP) of the country. This indicator is typically used to measure a country's energy efficiency. However, it's important to notice that this ratio does not necessarily express energy efficiency. It means that a country with low energy intensity may still be inefficient from an energy perspective. For example, consider the case of a small country with an economy based on the service sector. This country may have lower energy intensity than another large nation with an economy based in industrial production. However, the second country may efficiently use more energy in its industries compared to the first, which utilizes energy for developing a trade and service-based economy.

Thus, the energy intensity should not be analyzed alone. Efficiency gains are only one component of this analysis, which must also consider the **structure** (structural effect) of a country's economy (involvement of intensive-energy industries, developed services sector, etc.) and **activity** changes (activity effect), which are influenced by the country’s size (implying in higher transport sector demand, for example).

In this report, the indicator will be established in two ways: from the perspective of total energy supply (TES), identified as Primary Intensity (i), and from the perspective of final energy consumption, denoted as Final Intensity (ii).

I. Total Energy Supply (thousand toe)/GDP (M$[2010])
II. Final Energy Consumption (thousand toe)/GDP (M$[2010])

Final Consumption

This is all the energy that reaches consumption sector for energy and non-energy purposes (raw material, for example). The sources used as input or raw material for transformation into other energy products are not included in this concept. These activities are ranged, according to the Brazilian Energy Balance, as Transformation Centers (examples: water used to generate electricity or oil that will be transformed into gasoline, diesel oil, etc.).

In general, the sectors in this report are ranged according to the Brazilian Energy Balance, except for some intensive-energy sectors, to depict better the energy efficiency progress in Brazil.

Final consumption can be calculated in the following ways:

- **Final consumption =** primary final consumption (+) secondary final consumption, or;
- **Final consumption =** non-energy final consumption (+) final energy consumption

Where:

- **Primary final consumption** is the consumption of primary energy, i.e., consumption from sources coming directly from nature. Examples: natural gas, mineral coal, solar, wind, hydro and sugar cane products, among others
- **Secondary final consumption** is the consumption of secondary energy, i.e., consumption from sources coming from different transformation centers, for a different economy sectors destination. Examples: electricity, gasoline, diesel oil, ethanol, among others.
- **Non-energy final consumption** corresponds to the consumption of sources that, although they have energy content, are used as raw materials for other purposes. Example: use of naphtha for the thermoplastics manufacture.
- **Final energy consumption** is the use of sources by sectors of the economy as energy.

INOVA-E

The INOVA-E digital platform was developed to provide information about innovation in energy in Brazil accessible to a wide range of audiences. In its investment module, the strategic information available on the platform has been arranged into a single database, presenting a relevant overview for understanding the country's investment trends in energy RD&D. This unprecedented overview provided by INOVA-E attempt to support EPE, MME, MCTI, among other government parties, private and civil society organizations, formulating and promoting public policies aimed on Brazilian energy transition. In its most recent update, the platform's RD&D investment module underwent several methodological improvements, which resulted in the expansion of mapped investments and the inclusion of projects in the investment history.

Public investment in R&D - Public investment in R&D are calculated based on expenditure on reimbursable and non-reimbursable R&D projects carried out by public institutions that promote innovation in Brazil. The statistics presented on this platform include the following federal bodies: BNDES, CNEN, CNPq, FINEP; and the state of São Paulo: FAPESP.

Publicly oriented investment in R&D - Publicly oriented investment refers to private investment driven by public policies, being compulsory for companies in the energy sector. These are resources that fall under public programs whose purpose is to induce companies to invest in RD&D. The statistics presented on this platform include R&D projects regulated by the ANEEL and ANP agencies.

For more details, visit:

Energy innovation investments in Brazil overviewing

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Transport Sector

Activity

Activity in the transports sector is internationally represented by the indicators passenger-kilometer and ton-kilometer transported. Passenger-kilometer is a unit that relates the relative work to the passenger displacement over one-kilometer displacement. Similarly, ton-kilometer is the unit that represents the relative work to the displacement of a ton of cargo over one kilometer distance. It is also called as transport momentum.

Intensity of use

Ratio between transport activity and distance traveled. It is expressed in ton-kilometer/kilometer or Passenger-kilometer/kilometer.

Fuel Economy

Ratio of the distance traveled by passengers or cargo and the fuel consumption in volume and expressed as a measure of range.

Usually in kilometers/Liter.

Fuel Consumption

It is the spent fuel amount (volume) to travel a given distance, usually 100 km. It is expressed in Liters/100km.

Energy Efficiency

Ratio of estimated activity (t.km or p.km) to total energy demand (in units with Joule [J], Watt [W] or ton oil equivalent [toe]).

Transport Sector

Light Duty Vehicles (by size)[1]

Automobile

Motor vehicle for passenger transportation, with capacity up to eight people (excluding the driver);

Light Commercial Vehicle

- **Utility Vehicle** – vehicle for freight transportation with GCVW less than 3,500 kg;
- **Medium Duty Passenger Vehicle** – mixed vehicle for passenger transport;
- **SUV** – Mixed vehicle characterized by its versatility of use, even off road.

Heavy Duty Vehicles[2]

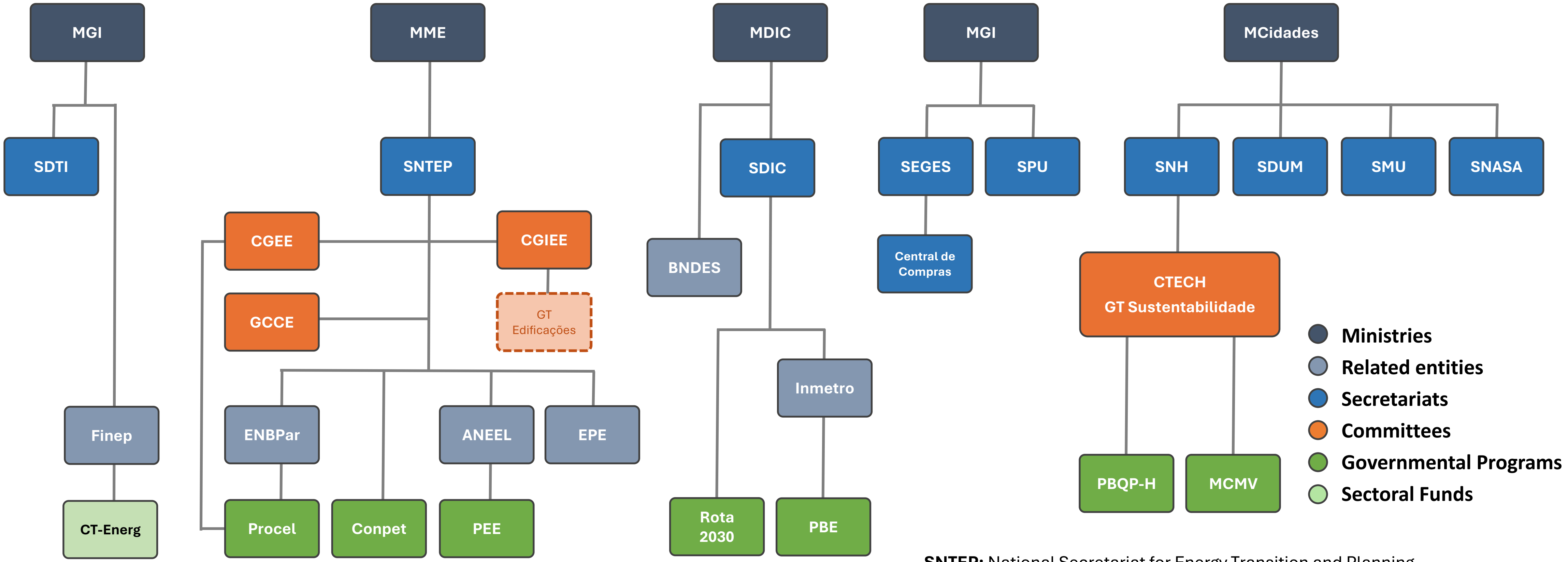
Trucks

- **Semi-light** – 3.5 t. < GCVW < 6 t.
- **Light** – 6 t. ≤ GCVW < 10 t.
- **Medium** – 10 t. ≤ GCVW < 15 t.
- **Semi-heavy** – GCVW ≥ 15 t. e MTC ≤ 45 t.
- **Heavy** – GCVW ≥ 15 t. e MTC > 45 t.

[1]Código Nacional de Trânsito (BRASIL, 1997)
[2]Anfavea (2023)
GCVW – Gross combined vehicle weight; MTC – Maximum Traction Capacity;
PBT – Total Gross Weight; CMT – Maximum Traction Capacity

Introduction

Governança institucional da eficiência energética no Brasil



SNTEP: National Secretariat for Energy Transition and Planning
SDIC: Secretariat for Industrial Development, Innovation, Trading and Services
SPU: Secretariat for the Coordination and Governance of Federal Assets
SNH: National Housing Secretariat
SDUM: National Secretariat for Urban and Metropolitan Development
SMU: National Secretariat for Urban Mobility
SNASA: National Secretariat for Environmental Sanitation

Energy Efficiency Policies Timeline...

1981
Ordinance MIC/GM46
CONSERVE Programme
Industry and imported energy sources substitution

1982
Decree 87079
PME: Energy Mobilization Programme

1984
PBE | INMETRO
PROGRAMA BRASILEIRO DE ETIQUETAGEM

1985
IO[1] 1.877
Establishes PROCEL

1990
Decree 99656
CICE – Internal Commission for Energy Conservation
(withdraw by Decree 10473/2020)

1991
Federal Decree 07/18/1991
Establishes CONPET

1993
Federal Decree 12/08/1993
Efficiency seal

1997
Law 9478
National Energy Policy Council (CNPE) and ANP

2000
Law 9991
PEE ANEEL: Investments in R&D and energy efficiency
ANEEL AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA

2001
Law 10.295[2]
Energy Efficiency Law
(MEPS - Minimum Energy Performance Standards)

Decree 4.059 and republished by **Decree 9.864/2019**
CGIEE/ Buildings Technical Group

2002
Procel Industry

2003
Procel EDIFICA
Procel SANEAR

2004
Law 10.847
Decree 5.184
Establishes EPE

2005
Conpet Seal

2007
PNE 2030

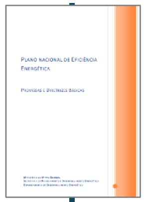
Notes: (1) IO = Interministerial Ordinance
(2) Three-phase electric motors, compact fluorescent lamps, refrigerators and freezers, gas stoves and ovens, air conditioners, gas water heaters, sodium-vapor and metal-halide lamps, incandescent lamps, distribution transformers, ceiling fans.

... over the years to the present day

2009
- Vehicle and Commercial Building Labeling
- **Decree 6996 (withdraw)**
  Decree 11158/2022 (in force)
  Tax reduction (IPI) for products with energy efficiency levels A and B

2010
- Residential Label

2011
- **Ordinance MME 594**
  NEEP: Energy efficiency targets



2014
- **NI[1] 02 MPOG**
  Requirements for Federal Public Buildings and Procurement
- **Procel Seal for Non-residential Buildings**

2016
- **ProEESA:** Energy Efficiency in Water Supply Systems Project
- **Law 13280**
  Reallocation of resources from PEE to Procel
- Nationally determined contribution (NDC)

2017
- **Law 13576**
  National Biofuels Policy (RenovaBio)
- Aliança Programme (industry)

2018
- **Decree 9557**
  Rota 2030 Programme (transport)

2019
- Brasil Mais Produtivo – Eficiência Energética Programme (B+P EE) (industry)

2020
- **Procel Seal for Residential Buildings**
- Energy Efficiency Networks for Industry and Public Buildings

2021
- **Decree 10791**
  Establishes ENBPAr
- PotencializEE Programme (industry)

2022
- FGEnergia
  Guarantee Fund for Energy Efficiency (BNDES and PROCEL resources)

2023
- Energy Efficiency Website (MME)

2024
- CGIEE
  Res. CGIEE nº 01/2024
  Regulatory Agenda CGIEE 2024-2026

Notes: (1) NI = Normative Instruction

Political Integration Viewing

ENDORSEMENT SEAL
Rewards the most efficient products

PROCEL Seal
1985

ENCE
Comparative label that rates energy performance

ENERGY EFFICIENCY LAW
Regulates minimum energy performance standards (MEPS) and the establishment of energy efficiency requirements for buildings

Minimum Energy Standards
Law Nº 10,295/ 2001

Energy Efficiency

Brazilian Labeling Programme
INMETRO (1984)

Implementam as políticas e desenvolvem o mercado

Energy Efficiency Programmes
PEE/ANEEL
PAR PROCEL

Research, Development and Innovation Programme (PDI)
ANEEL

Law nº 9,991/2000 delivers the rules about the investments in RD&D (currently PDI) and EE for the electric utilities. Currently 0.5% of the utilities' Net Operating Revenue (NOR).
After Law No. 13,280/2016, which amends Law No. 9,991/2000, 20% of the EE resources are destined for Procel and 80% for the PEE/ANEEL.

Share of renewables in the Energy Mix

Historically, Brazil is known as a country with a high percentage of renewable energy sources in its internal supply, when compared worldwide. In the last 20 years, the renewables energies share in Brazilian matrix has remained stable, over 40%, which is big challenge for the country. Recently, between 2011 and 2014, there was a reduction in the renewable energies share due a decrease in hydraulic supply, associated with less rainfall. Since 2015, renewable sources recovered the growth trajectory because of the expansion of sugarcane derivatives, wind and biodiesel supply, reaching 49.1% in 2023 also associated with the favorable hydrological situation.

Figure 1: Share of renewables in the Total Energy Supply (TES): international comparison

Source: EPE (2024b)

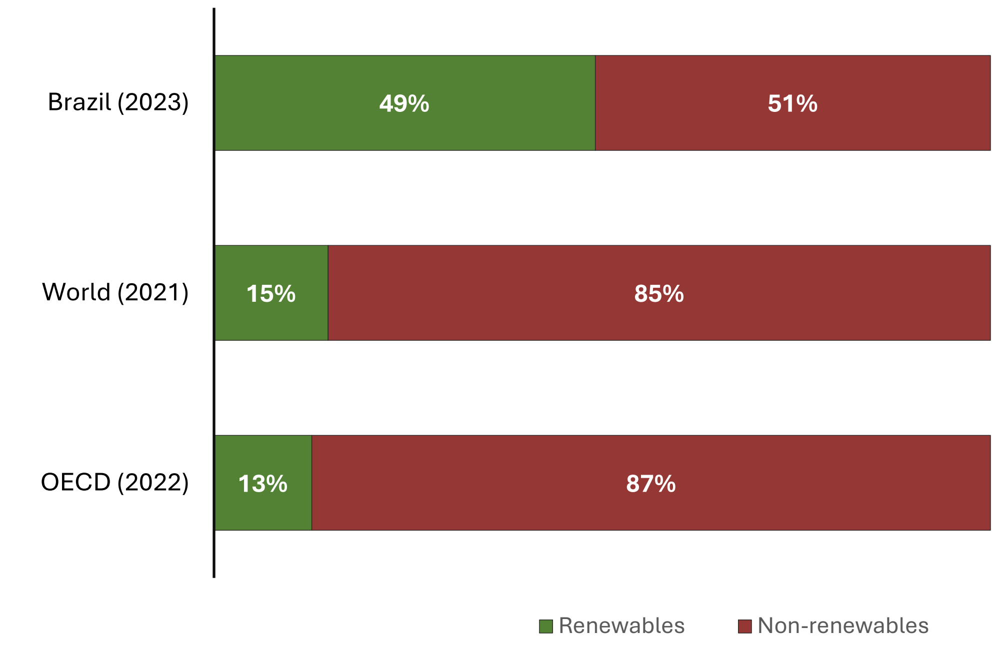
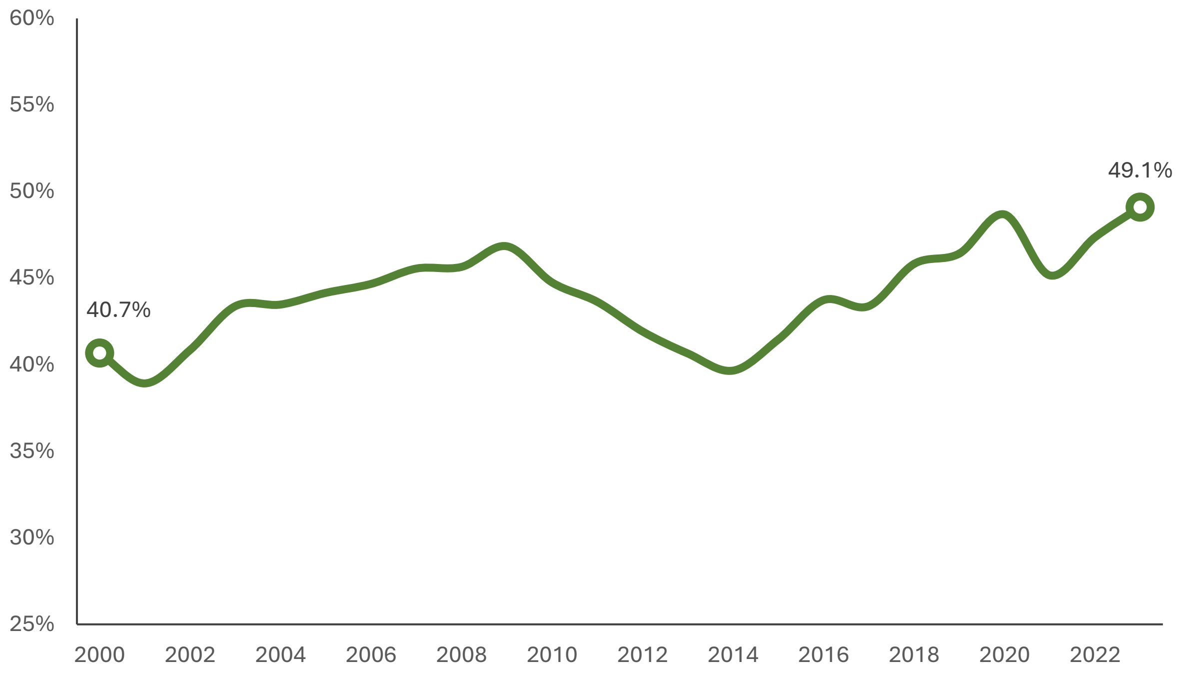


Figure 2: Evolution of the renewable sources' share in the Total Energy Supply (TES)

Source: EPE (2024b)

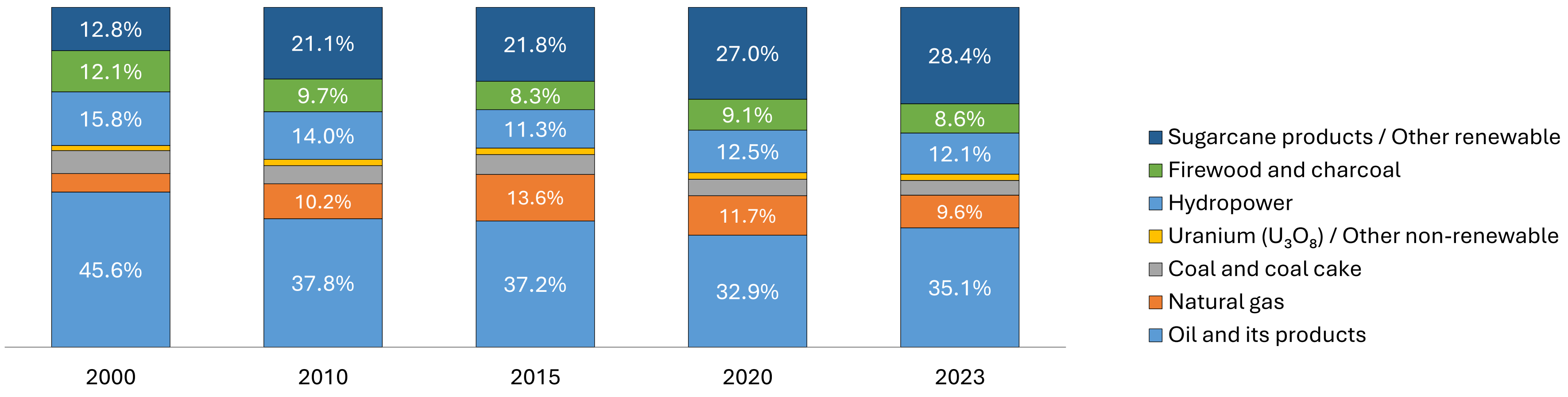


Evolution of Total Energy Supply (TES) by source

In the field of non-renewable energies, oil and its derivatives are still the largest share. However, natural gas has been the spotlight, with its share rising from 5.4% in 2000 to 9.6% in 2023 due to its use in basic thermoelectric plants and the extension of the pipeline network, which has made it possible to use it in industries as well as in residential, commercial and public buildings.

Figure 3: Total Energy Supply (TES) by source in selected years

Source: EPE (2024a)



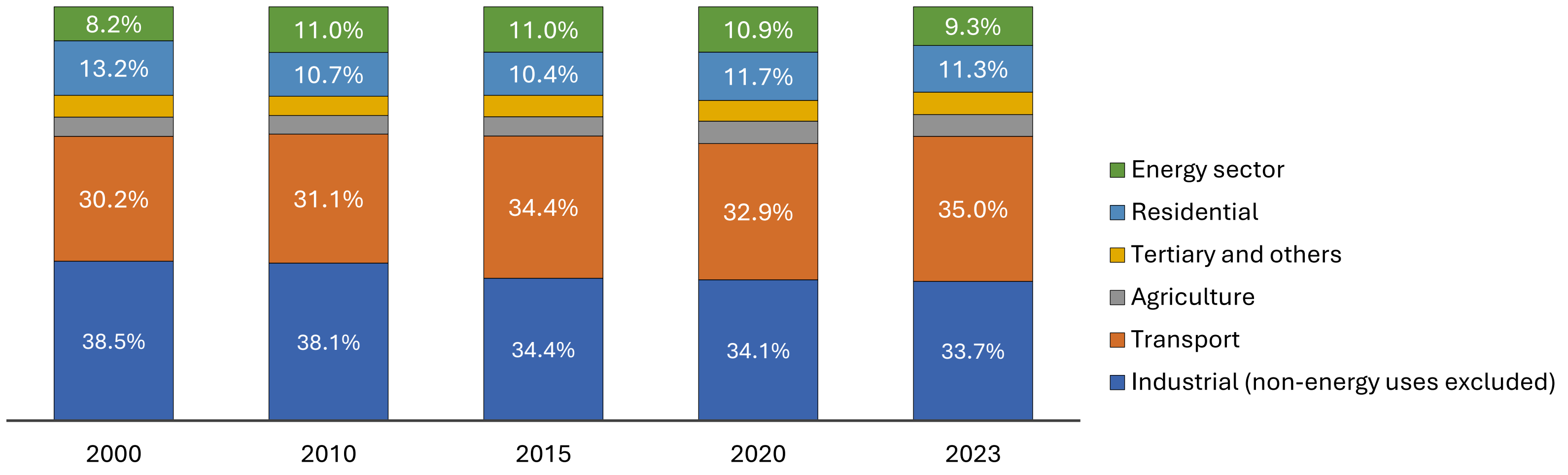
Renewable sources grew in a fast pace due to sugar-alcohol sector expansion and other renewable sources strong insets, such as wind, bleach and biodiesel. Wind power has shown increasing participation in the energy matrix, reaching 2.6% of the TES in 2023. Bleach, directly associated with the cellulose industry, contributed 3.4% of TES in 2023. Biodiesel has been favored because of the policies of adding this fuel to fossil diesel. In 2023, the percentage of addition (by volume) was set at 12% starting from April of that year. The annual average volume of biofuel addition reached 11.54% in the composition of total diesel oil in 2023.

Evolution of energy consumption by sector

The main noted movement in this period was the decrease in the industry share, in contrast to the growth of the transportation sector, which reached a 35% share in 2023. The transport sector grew up in an average rate of 3.2% per year (2000-2023), and more sharply between 2000 and 2015, with a road sector growing share. In 2020, the sector was impacted by the COVID-19 pandemic due to mobility restrictions, resuming its recovery trajectory in subsequent years and accounting for 36% of the increase in national energy demand in 2023.

Figure 4: Energy consumption by sector in selected years

Source: EPE (2024a)



In industry, **the most prominent segments** were pulp and paper (3.5% per year), sugar (2.5% per year) and cement (2.5% per year). It should be noted that pulp and sugar production are energy-intensive and use the co-products bleach and sugarcane bagasse, respectively, which are renewable.

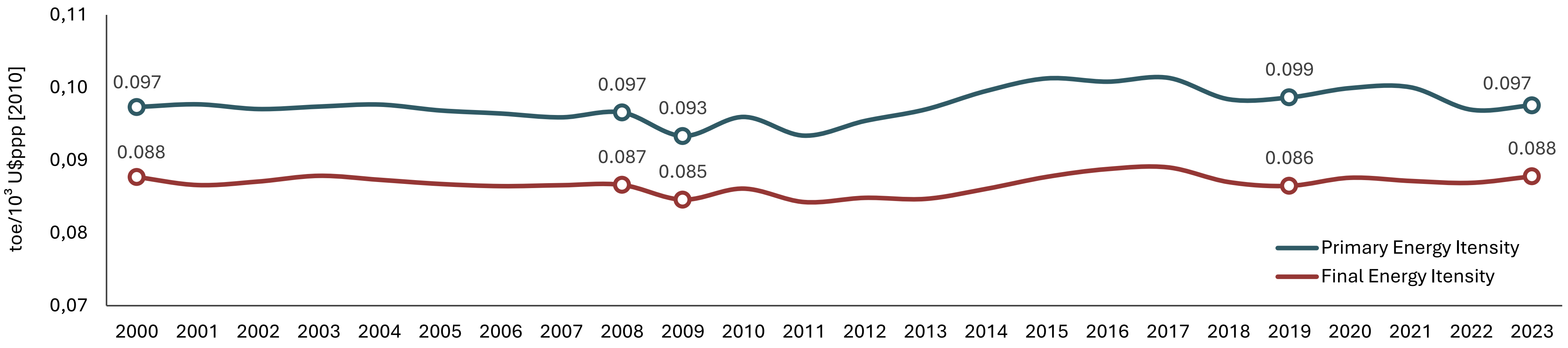
The Sugar segment experienced a 20.7% increase in energy consumption, while the Chemical segment reduced by 7.8% and Ferroalloys by 7.3%. The energy sector is driven by oil and ethanol production, which grew at annual rates of 4.5% and 4.7% during the period. However, ethanol production decreased by 0.5% between 2020 and 2023.

Energy Intensity

From 2000 to 2008, primary energy intensity remained stable at around 0.097 toe/10^3U$ppp[2010]. Likewise, the final intensity stabilized at around 0.087 toe/10^3U$ppp[2010]. In 2009, the effects of the international crisis on industry contributed to a reduction in primary energy intensity to 0.093 toe/10^3U$ppp[2010]. More inefficient units with higher intensities were shut down.

Figure 5: Evolution of energy intensity in Brazil

Source: EPE (2024b)



Between 2010 and 2023, the primary and final intensities grew up on rates of 0.13% and 0.15% per year, respectively, reflecting OIE growth over the GDP growth. Between 2014 and 2023, primary energy intensity fell at a rate of 0.22% per year. Final consumption intensity, over the same period, grew at a rate of 0.22% per year. The upward trend in energy intensity may be associated with the growth in the production of low value-added energy-intensive products production growth, related to other manufactured products.

Note: Clarifications about Energy Intensity available at Definitions

Brasil is investing in Energy Efficiency

Competitive sectors such as industry depend on energy efficiency in their production processes and regular working days. Without it, many businesses could become unviable. Technological changes is one of the main sources of wealth creation and long-term economic growth.

According to the INOVA-E platform[1], between 2013 and 2023, Brazil invested almost R$ 6 billion in researches, development and demonstration (RD&D), in energy efficiency projects from public or publicly oriented investments[2]. From this amount, more than a half came from the BNDES (National Development Bank), while ANEEL (National Electricity Agency) and Finep (Financing Agency for Studies and Projects) accounted for 14% and 16% respectively.

Figure 6: Evolution of RD&D investments in Energy Efficiency

Source: EPE (2024c)

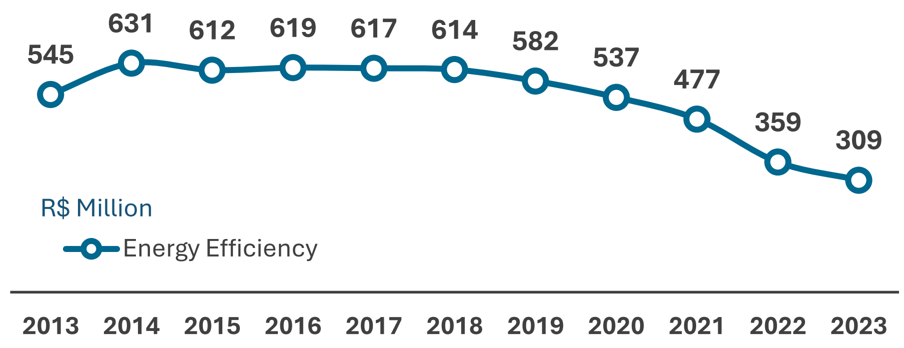
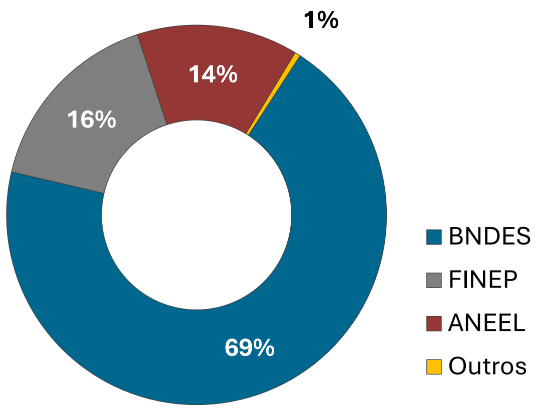


Figure 7: Source of resources (%) for Energy Efficiency RD&D investments

Source: EPE (2024c)



The previous version of the Atlas presented lower values in the curve of R&D investments in Energy Efficiency, totaling nearly 5 billion reais throughout the historical series up to 2022.

Methodological improvements in the INOVA-E platform allowed for the revision of historical financing values, as presented in this version.

inova e BRASIL

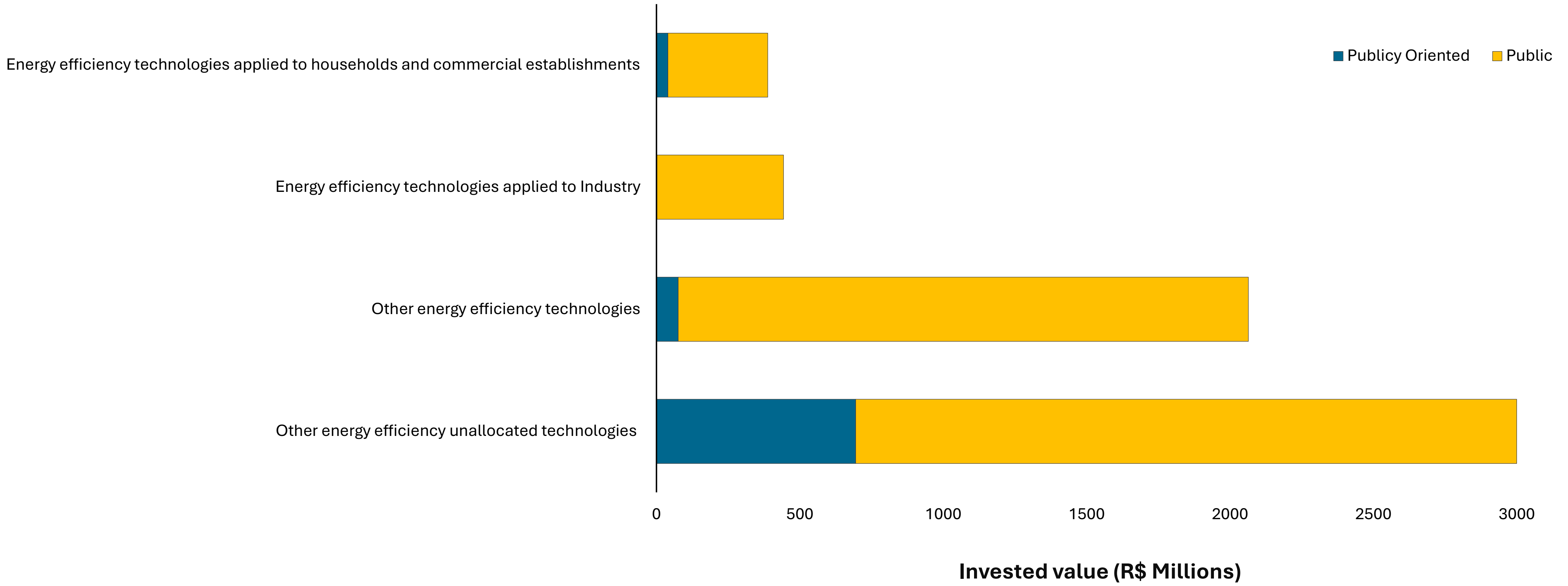
Data from INOVA-E shows an average annual investment of around R$ 536 million over the eleven-year time series, considering public and publicly oriented resources in R&D projects in Brazil.

Note: For more Information on INOVA-E and the meaning of the expressions "public investments" or "publicly oriented" go to Definitions.

RD&D Energy Efficiency Investments

Figure 8: Nature and modality of investments, in millions of reais - 2013 to 2023

Source: EPE (2024c)



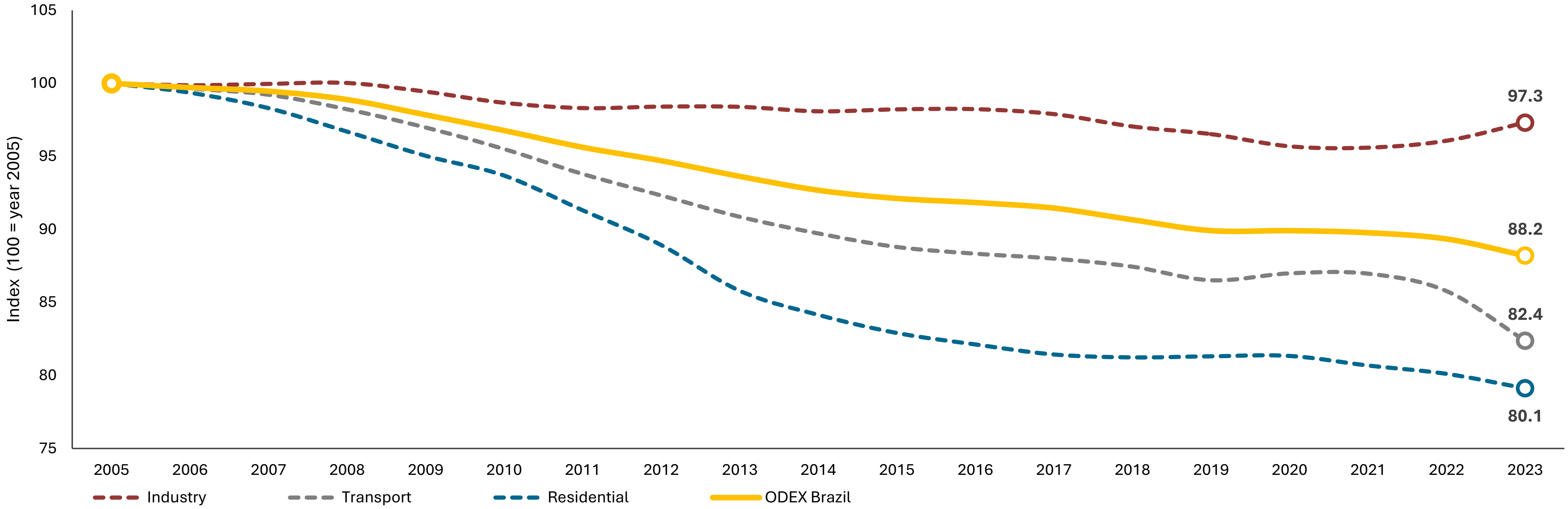
Note: The investments presented in the figure were adapted from the Inova-e tool, which adopts the classification of the International Energy Agency (IEA). As a change compared to the previous version of this Atlas, the categories 'Other energy efficiency technologies' and 'Other unallocated energy efficiency' were aggregated into 'Unallocated energy efficiency'.

ODEX

In this report, 2005 was set as the base year (100), covering the industrial, residential and transport sectors, and Brazil as a whole. During the term, all the analyzed sectors showed efficiency gains, with emphasis to the residential and transport sectors, the biggest gains, with 20.9% and 17.6% efficiency gains in the period, respectively. The ODEX calculated for 2023 shows that the country will be around 11.8% more energy efficient than it was in 2005.

Figure 9: ODEX Brazil

Source: Compiled by EPE



Note: Clarifications on changes in ODEX data history are available at Definitons

Buildings

Evolution in Buildings' consumption: residential, commercial and public sector

The main source of energy used in buildings is electricity[1]. In 2023, households used 48% electricity, 21% LPG and 26% firewood, while commercial and public buildings mostly use electricity with a 73% share.

Figure 10: Total energy demand in buildings

Source: EPE (2024a)

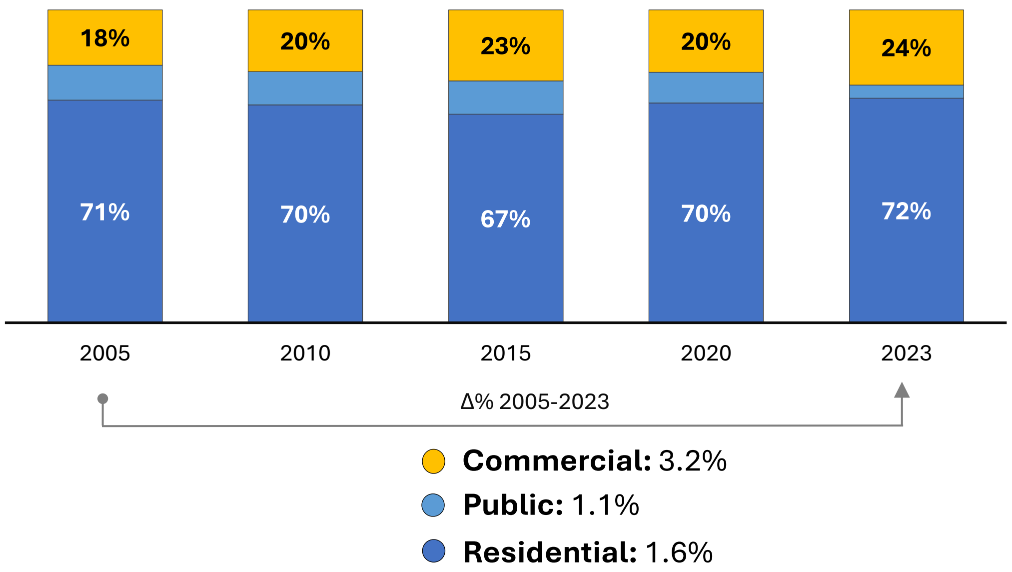
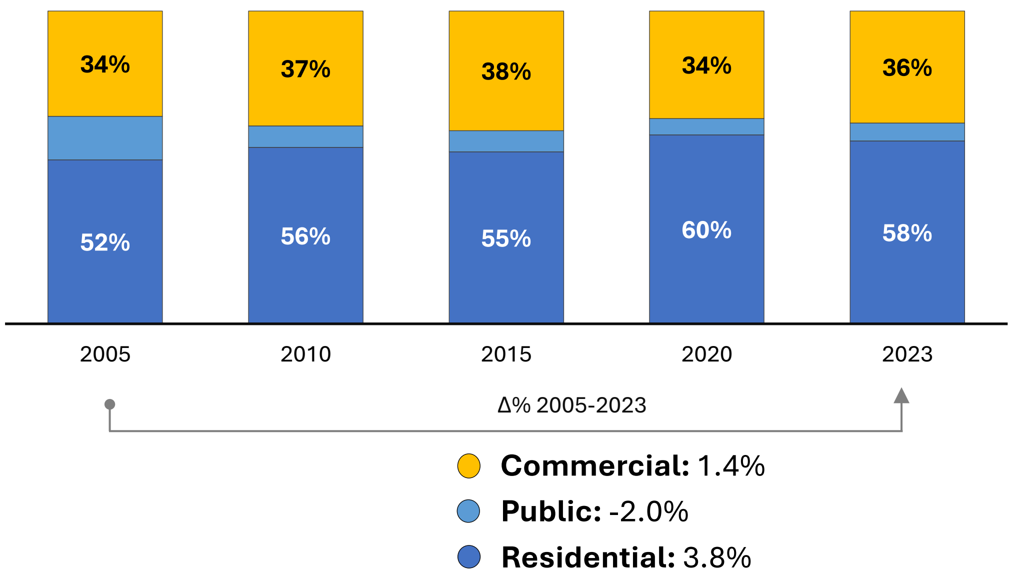


Figure 11: Electricity demand in buildings



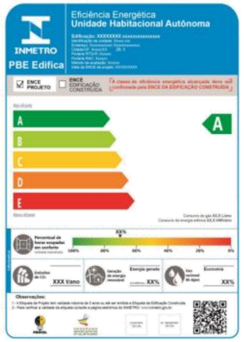
In 2023, buildings consumed 290 TWh, which represents 47% of the country's electricity. Considering the attendance of buildings in electricity consumption, this sector can be considered to have the biggest potential for electrical efficiency.

Note:

[1] According to the historical series, electricity has been the main source since 2008.

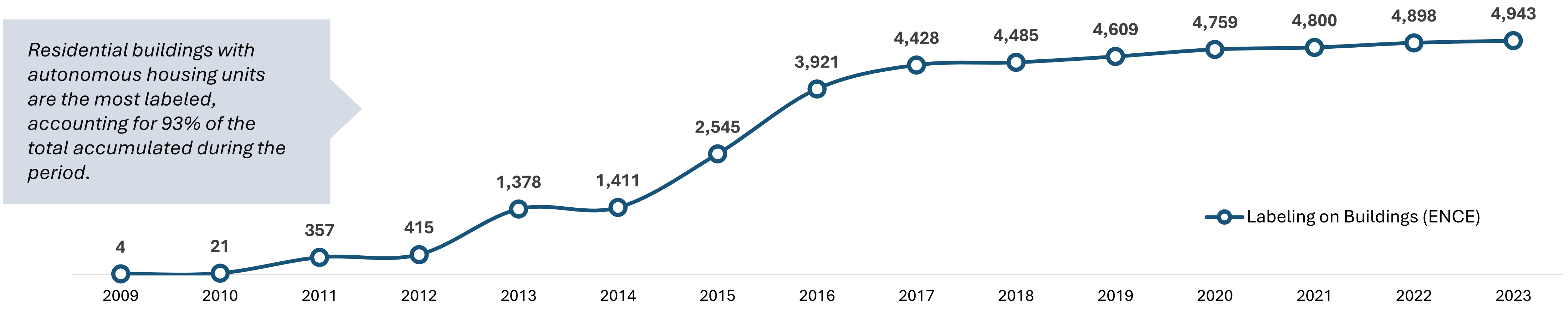
[2] The public sector accounted for in buildings does not include Public Lighting and Sanitation.

Building Labeling Evolution – Brazilian Labeling Programme (PBE Edifica)



The Building Labeling classifies energy efficiency into values ranging from A (most efficient) to E (least efficient). It covers Commercial, Service, and Public Buildings, as well as Residential ones. There are two types of labels that can be applied: to the project and the constructed building. Another complementary policy is the Procel Seal for Buildings, established in November 2014, which encourages and rewards Buildings with Label A. These policies are voluntary adherence instruments.

Figure 12: Evolution of the National Energy Efficiency Label for Buildings - ENCE (number of issued labels)
Source: INMETRO (2023)



Building labeling is a voluntary adherence instrument, similar to the Procel Seal for Buildings, which aims to stimulate the market towards the acquisition and use of more efficient properties. In the 10 years of the Procel Seal's existence, a total of 54 seals were issued for projects and constructions. Given the importance of the building sector in Brazil, accounting for around 50% of electricity consumption, these policies hold significant relevance for energy efficiency and environmental comfort.

Note: PBE is the Brazilian Labeling Program.
PBE Edificações: https://pbeedifica.com.br/

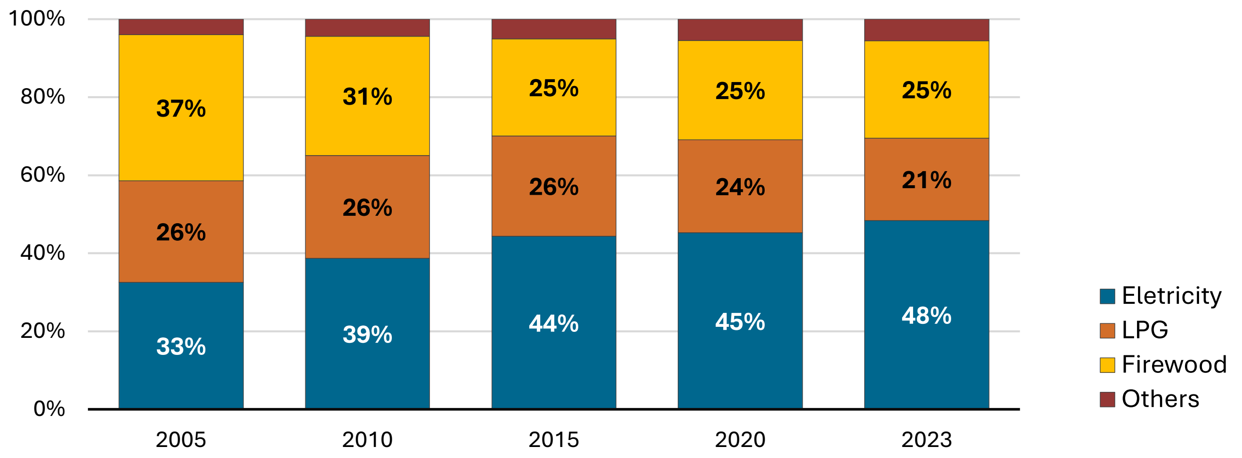
Residential Sector

Evolution of energy consumption in Households by source

Electricity is still widely most used energy source in Brazilian households, with an increase in its energy share of 15.9 percentage points (p.p.) between 2005 and 2023. It is broadly used in homes and can be used for air conditioning, food conserving, cooking and preparing, water heating, lighting, laundry, entertainment, communications, personal beauty and in electrical and electronic equipment.

Figure 13: Evolution of energy consumption in Households by source

Source: EPE (2024a)



Liquefied Petroleum Gas (LPG) keeps up as an intermediate share (21% in 2023), and its main use is associated with food cooking.

Natural Gas (NG) is included in Other category (see the Figure) and is used for food cooking and water heating, mainly in urban country areas with distribution grid.

Solar thermal energy is also included in Other category and is used for water heating.

There is a reduction in the firewood use for cooking from 2005 to 2015, due to the improvement in families' economic conditions. Since 2015, the energy share of firewood is remaining around 25%.

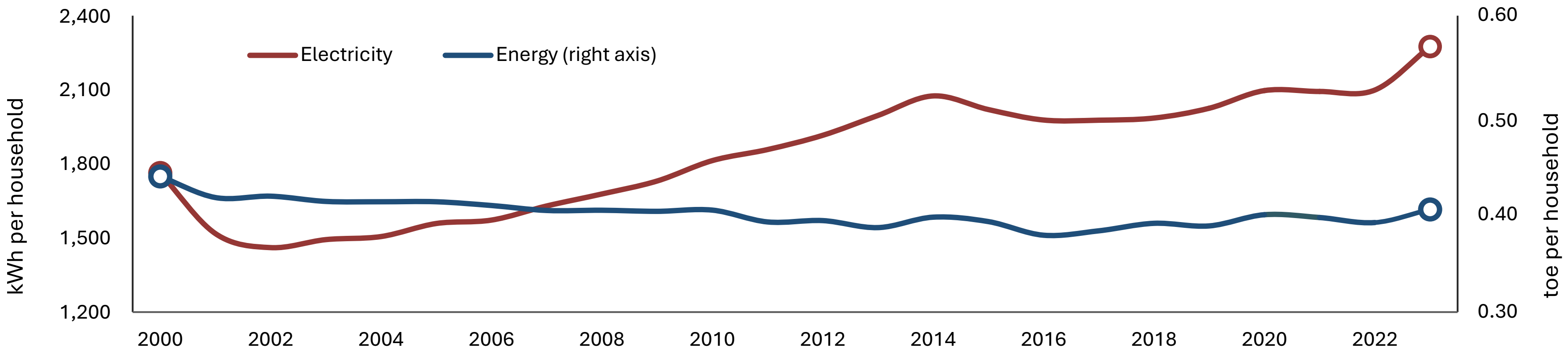
Note: Notation "p.p." refers to percentage points.

Evolution of electricity and energy consumption in households

While energy consumption per household decreased by 7.6% (a drop of 0.3% per year) from 2000 to 2023, electricity demand per household grew by 29% (an increase of 1.1% per year) over the same period. Electricity demand experienced a sharp decline in 2001 due to rationing, which encouraged behavioral changes and the implementation of energy efficiency measures in Brazilian households. The significant increase in electricity consumption in 2023 can be explained by the more intense use of fans and air conditioning devices due to the heat wave caused by the arrival of El Niño in the final months of the year.

Figure 14: Evolution of electricity and energy consumption in households

Source: Compiled by EPE



Electricity demand per household increased from 2000 to 2023 due to the economic progress of families, the expansion of credit for purchasing appliances, government policies for expanding the general grid—especially in rural areas—and housing programs combined with incentives to reduce Brazil's housing deficit. Meanwhile, total energy consumption per household showed an average annual reduction of 0.3% per year over the period. This was due to the decreased share of less energy-efficient sources (traditional biomass—firewood and charcoal) and their subsequent replacement by more modern sources (LPG, natural gas, and electricity). It is also important to note that energy consumption per household includes solar thermal energy for water heating, which has been increasing significantly since 2005.

Effects of energy efficiency policies on households

Energy efficiency policies can include minimum energy efficiency indexes (or maximum consumption indexes), comparative labeling (compulsory or voluntary) and endorsement seals.

These initiatives have been introduced in the country since 1984, with the establishment of the Brazilian Labeling Programme (PBE), headed by INMETRO, which began to produce comparative labels for equipment's energy performance, providing consumer education and stimulating more efficient products manufacture from industry.

In 1993, the PROCEL (for electrical equipment) and CONPET (for products that use derived fuels from oil and natural gas) seals were created to emphasize the most energy-efficient devices.

There are complementary actions aimed at reducing energy demand in homes, including performance standards (ABNT NBR N0 15.220 and N0 15.575), labeling standards (PBE Edifica) and endorsement seals (Procel Edifica) for buildings, as well as encouraging the use of alternative energy generation systems in social housing (HIS).

It is estimated that the average annual consumption per **air conditioner** reduced about 15.3% between 2005 and 2022 (-1.0% per year), because of the minimum energy efficiency index, regulations initiated by MME/MCT/MDIC IO nº 364/2007 and revised the IO nº 323/2011 and by the IO nº 2/2018.

In the case of **refrigerators**, it is estimated that the average annual consumption per appliance reduced about 11.5% between 2005 and 2022 (-0.7% per year), because of the minimum energy efficiency index regulations initiated in 2007 by IO MME/MCTI/MDIC nº 362/2007, which was revised by the IO nº 326/2011 and by the IO nº 01/2018.

Following on the new policies from Law N0 10,295 of 2001, known as the Energy Efficiency Law, it is important that the regulations about minimum energy efficiency ratings be extended to other household appliances, prioritizing those with the highest average consumption per appliance.

IO = Interministerial Ordinance

Solar Heating Systems (SHS) ingress in houses

The conversion of solar energy into thermal energy is based on the absorption of solar radiation and its transfer, in the form of heat, to an element that will provide a specific energy service.

Solar water heating systems (SAS) are composed of solar collectors and a thermal reservoir, where heated water is stored. SAS have complementary heating equipment, which can use electricity or gas and are activated during periods of low solar intensity, such as at night or on cloudy days. The collectors and reservoirs are standardized by the Brazilian Labeling Program (PBE), coordinated by INMETRO.

For consumers, the use of SAS can reduce total energy expenses. For the electricity sector, their use can decrease grid consumption, peak demand during critical periods, and technical losses in the system, helping to postpone new investments in generation, transmission, and distribution. Finally, from an environmental perspective, the use of SAS can contribute to reducing greenhouse gas (GHG) emissions.

Residential solar thermal energy is primarily used for water heating in showers and swimming pools, which can be located within homes or in recreational areas of buildings. It is estimated that the energy consumption avoided in residential households across the country amounted to 856,000 toe (tons of oil equivalent) in 2023 due to the use of SAS.

Figure 15: Solar Heating Systems (SHS) ingress

Source: Compiled by EPE

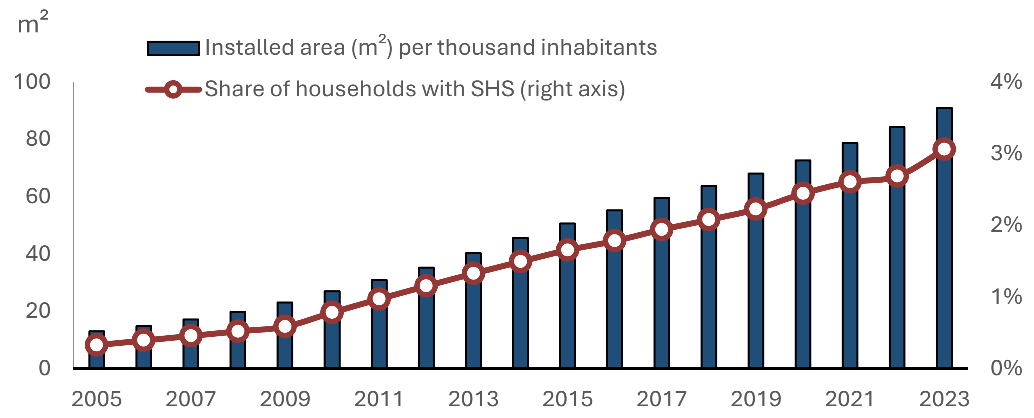
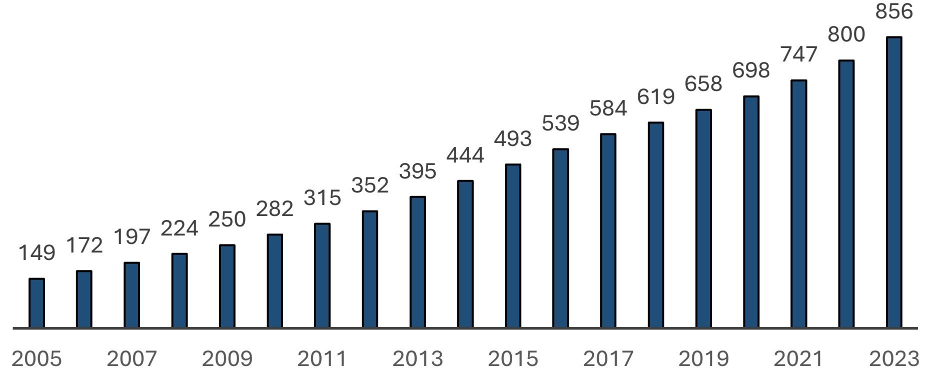


Figure 16: Avoided Residential Energy Consumption (thousand toe)

Source: Compiled by EPE



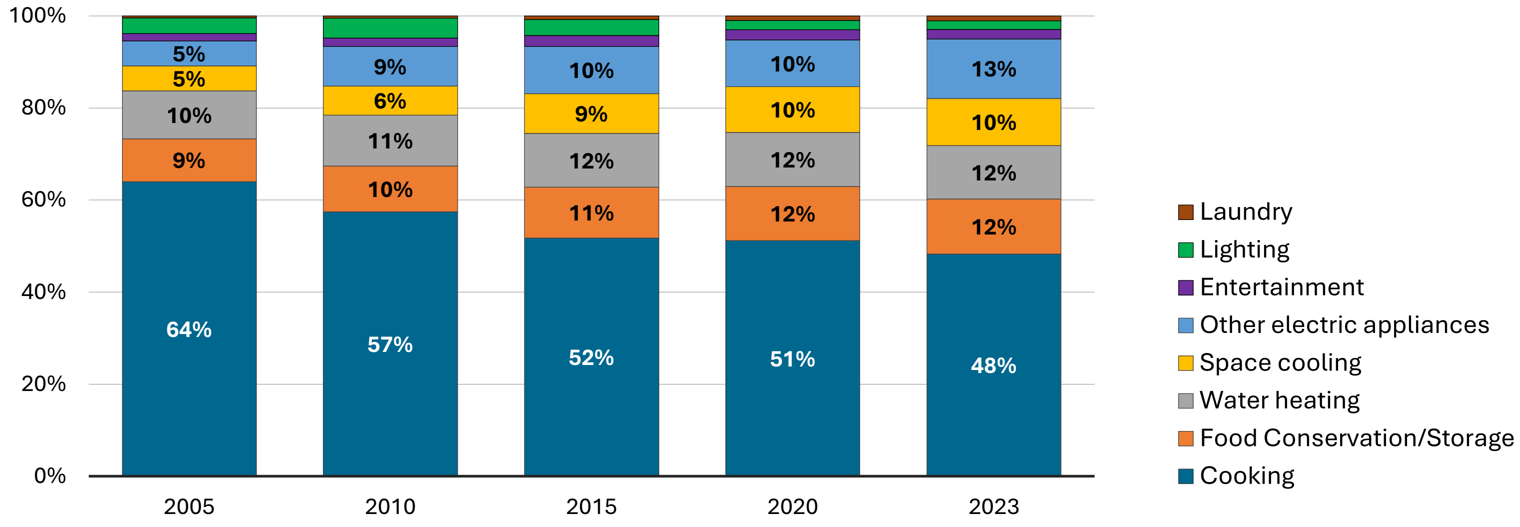
Energy share evolution of the final consumption in the residential buildings

The main final energy use in Brazilian homes is cooking, followed by food preserving and water heating. The reduction in the energy share of food cooking between 2005 and 2023 can be explained by the energy transition process of the most economic disadvantaged families, which have been replacing the consumption of traditional biomass by modern and efficient fuels, as they economically progress. Lighting, on the other hand, has been losing share over time due to the increasingly use of efficient light bulbs, especially compact fluorescent and LED technology.

The increase in the electrical and electronic equipment share can be explained by the increase in the families' possessions and resources, which follow a technological and habits transition.

Figure 17: Evolution of the energy share of end uses in the residential energy demand

Source: Compiled by EPE



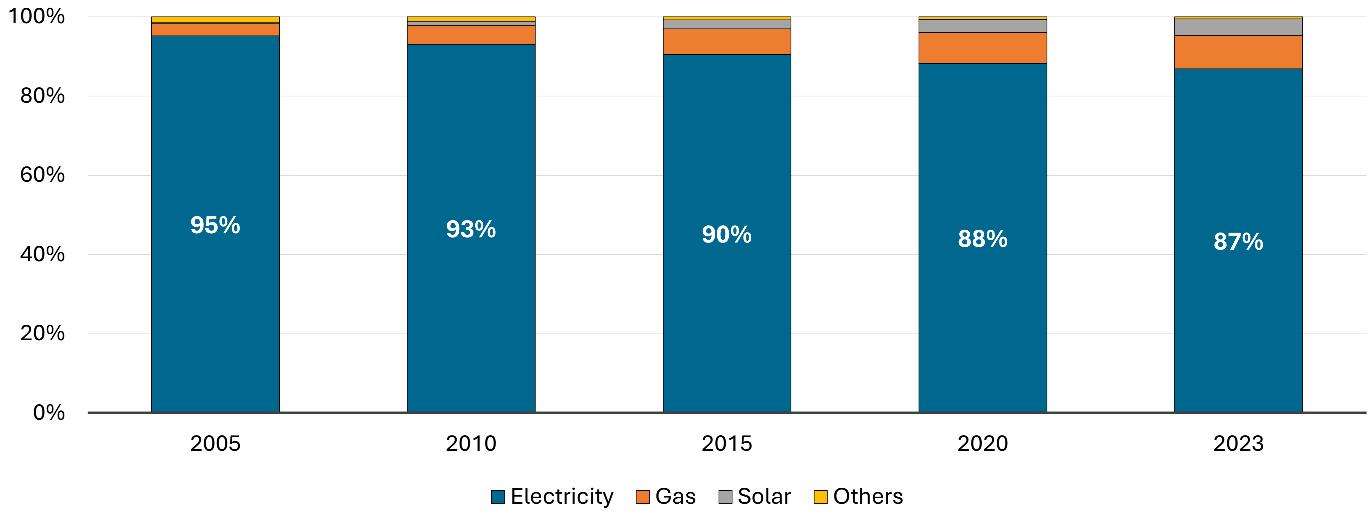
Conditioning air has become more popular due to the increased use of equipment's by families, as they are able to afford them, replacing fans and air circulators, which are relatively cheaper and use less energy. This may also happen due to the increase of warmer days average occurrence over the years.

Heating water houses percentage evolution by energy source

Electricity is the biggest energy source used by Brazilian households to heat water, because of the electric showers. It is estimated that the country has an average of 0.71 electric showers per house and the percentage of households using electricity to heat water reached 86.9% in the same year. In addition, the households with solar thermal energy for water heating reached 4.1% of all heating water households in 2023.

Figure 18: Evolution of the share of households that heat water by energy source

Source: Compiled by EPE



Water gas heaters, which can be tankless or storage tank, are alternatives to electric showers, especially in urban areas with gas distribution grid. It is estimated that around 8.4% of households are using gas to heat water.

This equipment is standardized by the Brazilian Labeling Programme (PBE), coordinated by INMETRO. There are also regulations for minimum energy performance standards for gas heaters, which started with the MME/MCT/MDIC Interministerial Ordinance No. 298/2008 and was reviewed in 2011 by the Interministerial Ordinance No. 324.

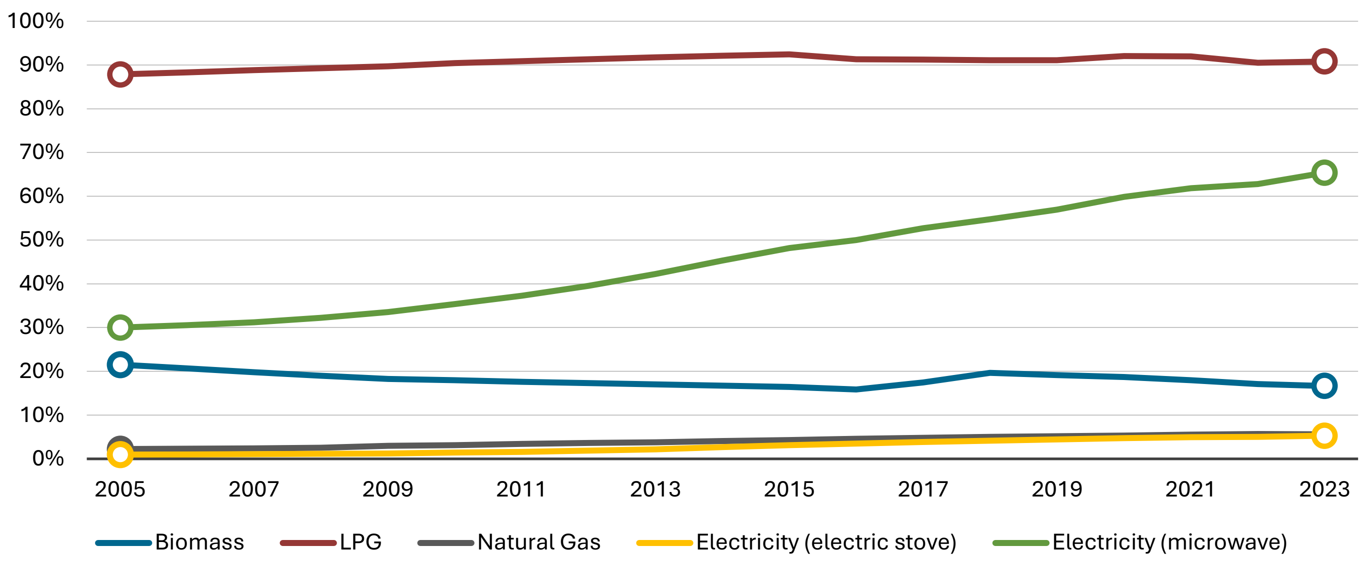
There are very warm weather Brazilian regions, such as the North and Northeast. This may contribute to the low percentage of households that heat water for bathing, as illustrated by the Survey of Ownership and Habits of Use of Equipment - PPH 2019 (PROCEL/ELETROBRAS). The EPE calculations, using the data collected in this survey, estimate that around 35% of Brazilian households did not heat water for bathing in the country in 2019. This number of houses is much higher in the North (94%) and Northeast (88%).

Percentage evolution of households cooking food by energy source

LPG has a large grid in Brazil, reaching 91% of national households in 2023. The use of natural gas is still small (5.6% of national households), basically restricted to urban areas in cities with distribution infrastructure.

Figure 19: Percentage evolution of households that cook food by source in relation to the total number of national households

Source: Compiled by EPE



The electricity use in food cooking has been growing over time, mainly due to the increase in microwave ownership (65% in 2023).

With the technology evolution and the cost reduction, people are more likely to buy these type of electrical appliances for domestic use, because it is practical, and brings satisfactory results. It includes ***microwaves, electric ovens and hobs, sandwich makers, grills, toasters, electric fryers, electric pans, among other devices.***

The traditional biomass (firewood and charcoal) share for food cooking in the country's houses felt down between 2005 and 2015 because of the economic progress in most of the disadvantaged Brazilian families. However, it had a growth from 2015 to 2020 due to the economic worsening scenario, with a further reduction in the following years until 2023.

Electricity - ending use, ownership and average annual consumption by equipment

Figure 20: Residential electricity consumption by end use

Source: Compiled by EPE

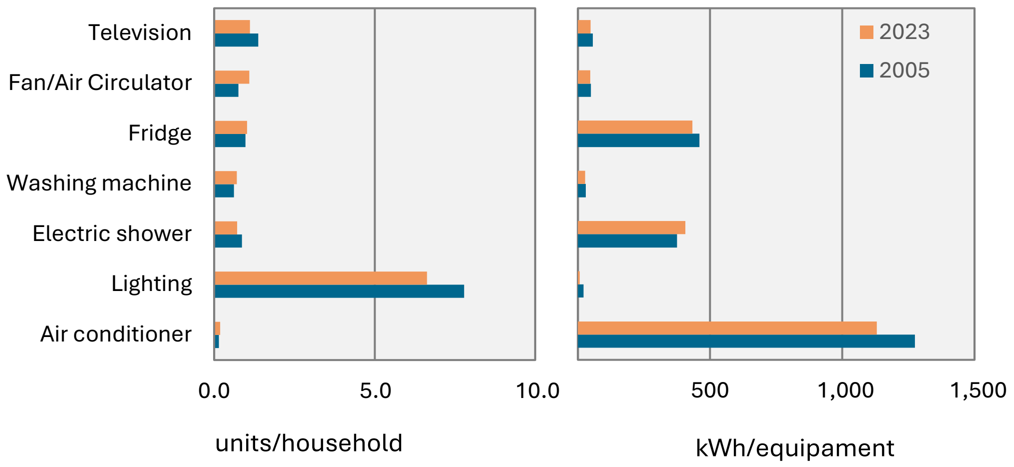
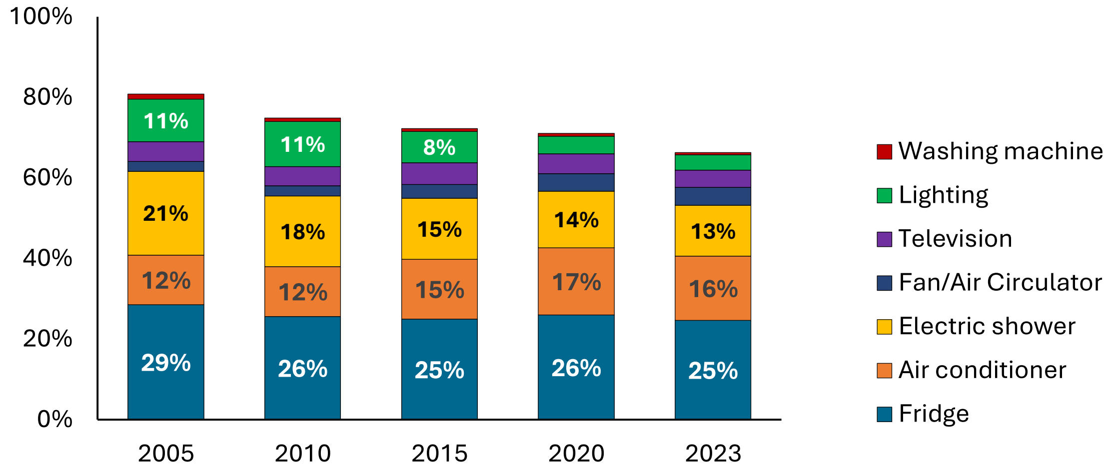


Figure 21: Electricity consumption share by equipment type

Source: Compiled by EPE



Food preservation is the highest end use consumption per household in the country, because of the refrigerators which are turned on practically in every Brazilian home, 24 hours a day, every day, all year long. It means a highly significant specific consumption.

Despite the air conditioners decrease of 0.18 appliances/house in 2023, it has the highest average consumption per appliance, that results in being the ranking second-place among the most electro-intensive appliances in 2023 (around 16% of total residential consumption in the year). Fans and air circulators have slightly more than 1 appliance/household, making them a lower-cost solution for conditioning the air.

The number of electric showers felt between 2005 and 2023. Although the average annual consumption per device has increased due to the acquisition of higher-power showers, the share of this equipment in annual residential electricity consumption has significantly decreased since 2005, reaching 13% in 2023.

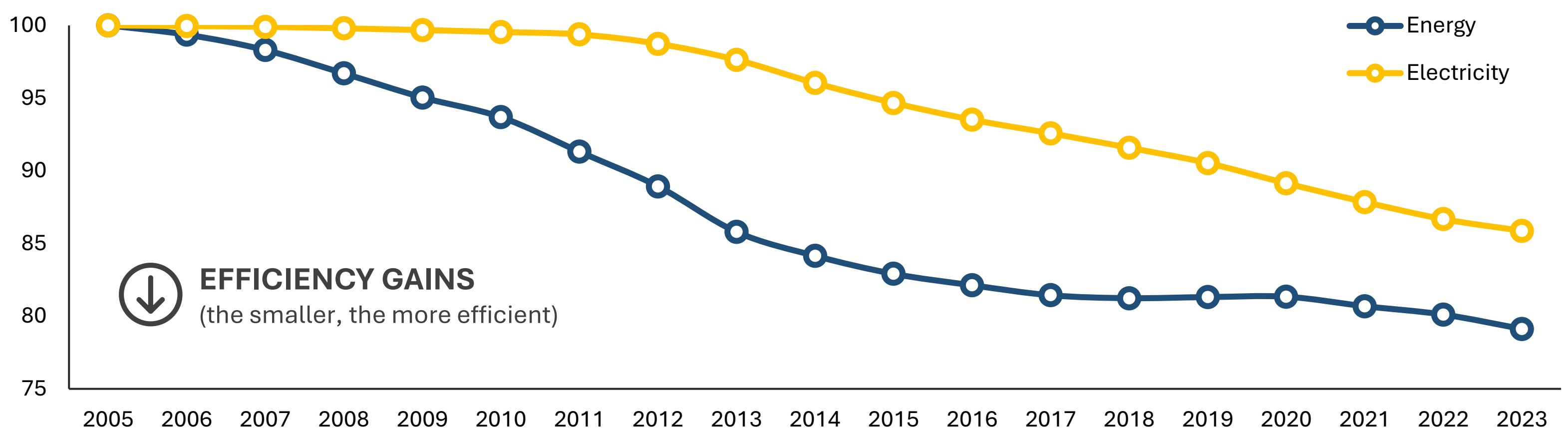
The insertion of more efficient equipment, replacing older equipment, tends to reduce the average consumption of the existing stock in the country.

Residencial ODEX

ODEX is an index that analyzes the energy efficiency improvements over a period of time. For households, this measure brings the consumption trend of the different end uses (in the case of energy), or the main electrical equipment (in the case of electricity), weighted by their total consumption.

Figure 22: Residential ODEX evolution calculated for total energy and electricity

Source: Compiled by EPE



Energy efficiency trends in the Brazilian residential sector between 2005 and 2023.

While the ODEX calculated for electricity fell by 14.1% (0.8% p.y.) between 2005 and 2023, the ODEX for energy fell by 20.9% (1.2% p.y.). In recent years, the indicator decrease has been higher for electricity, suggesting the importance of this source in the country's residential energy conservation.

For electricity, there is a noted reduction in the average specific consumption of the national stock of equipment, driven by the initial purchase or replacement of obsolete devices or those nearing the end of their useful life with more efficient appliances. On the other hand, when considering other energy sources, it is possible to observe that there was a stabilization of the ODEX between 2017 and 2020, which can be explained by a slight increase in the use of biomass for cooking due to heightened budget constraints and the increased share of LPG in household expenses, particularly for low-income families.

Note. The Residential ODEX methodology has been updated to isolate the ownership effect and specific equipment consumption and, consequently, to highlight energy efficiency gains by equipment. The facilities considered in the calculation of the electrical ODEX are light bulbs, fridges, washing machines, TVs, electric showers, air conditioning and fans. In the energy ODEX, in addition to the electrical equipment energy consumption considered, different energy sources consumption are considered for heating water and cooking food.

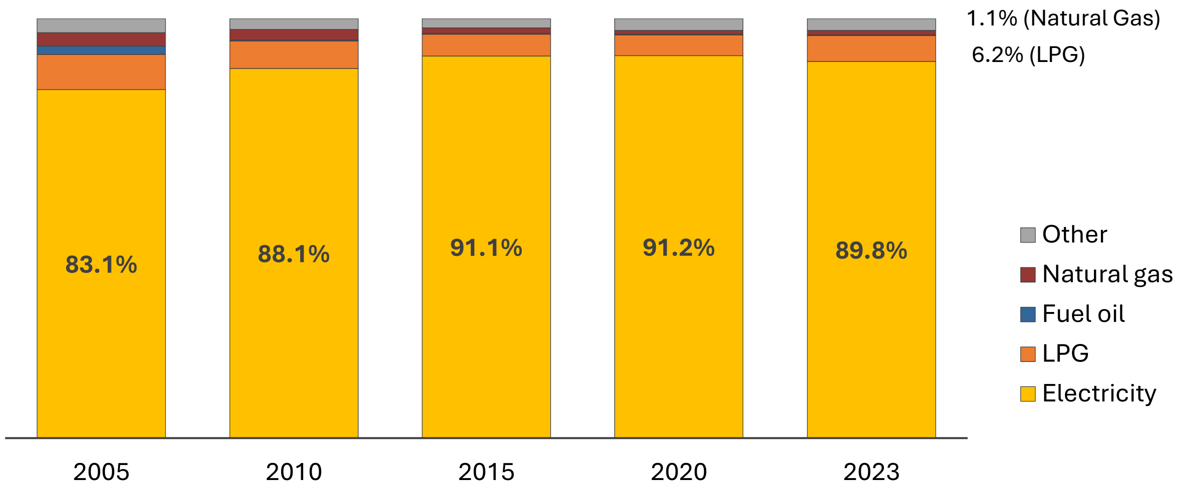
Services Sector
(commercial and public services)

Overview: final energy consumption evolution by source in the services sector[1]

Electricity remains the final energy consumption main source in the services sector with a 90% share, along with LPG (6.2%) and natural gas (1.1%). It must be noticed that the final consumption data does not include the use of natural gas to generate electricity, according to the National Energy Balance (BEN) methodology.

Figure 23: Final energy consumption by source in services sector

Source: EPE (2024a)



The importance of electricity in the sector's final consumption may be associated with a lot of factors such as electricity availability, the increase in the electrical equipment ownership in facilities, the processes and equipment automation, the replacement of equipment that uses LPG and natural gas by electricity appliances, such as ovens and stoves, among other factors.

Electricity is the main source in this sector and showed an average annual growth of 3% during the period (2005-2023). Electricity from photovoltaic solar sources grew by 13.1% and stands for 1.3% of the energy consumption in the services sector.

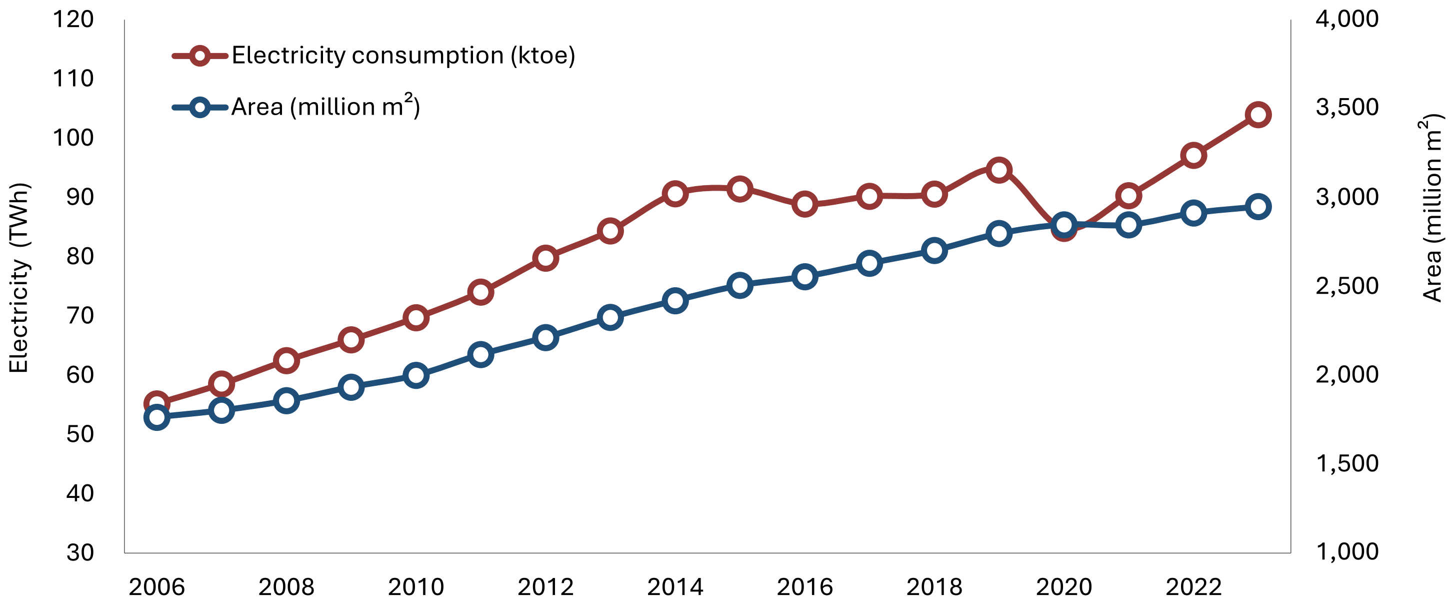
[1] Commercial and public sectors according to the classification of the National Energy Balance.

Analysis: Commercial Sector

In 2023, electricity consumption in the commercial sector increased by 7% compared to the previous year, while the built area saw an increase of 1.2%. Analyzing the period from 2006 to 2023, there was a steady increase in the area of commercial establishments with an average annual growth rate of 3.1%, while during the same period, electricity consumption in the sector showed an average annual increase of 3.8%. Data from ABRAVA's economic bulletin (December 2023) indicate a 10% growth in 2023 for central equipment (refrigeration ton – RT) and a 14% increase in revenue for the entire sector compared to 2022, largely driven by the resumption of services and higher average temperatures.

Figure 24: Electricity consumption evolution and commercial sector area

Source: Compiled by EPE



Electricity consumption grew by 7.1% in 2023 compared to the previous year. This increase is partly justified by higher temperatures and the growth rate in revenue, according to ABRAVA (December 2023).

In 2023, the GDP of the Civil Construction sector declined by 0.5% (IBGE). The contraction may be linked to interest rates and the conclusion of small renovations initiated during the COVID-19 pandemic (CBIC).

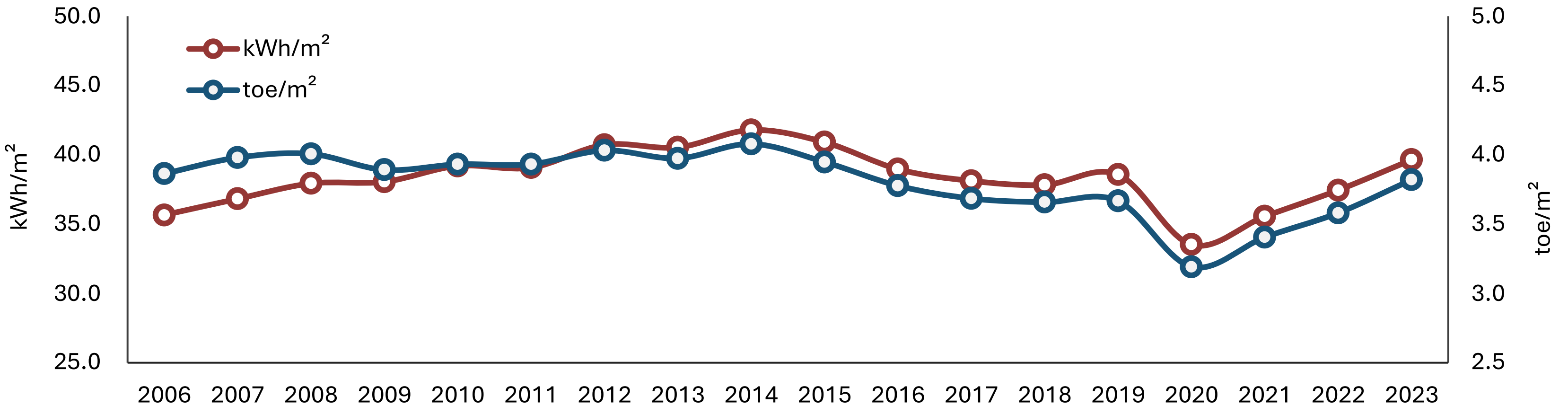
Sectorial Indexes: commercial and public buildings consumption evolution per area

Energy consumption per square meter in commercial and public buildings grew up between 2006 and 2014, mainly due to the electrical equipment ownership and using increase. However, from 2014 onwards, the indicator showed stability until 2019, culminating in a vertiginous drop in Covid-19 pandemic year, with a partial recovery in 2021 and 2022. It is important to note that both indicators are under the effect of energy efficiency, as ongoing efficiency policies mitigate consumption growth. However, there are other effects that validate the trajectories illustrated, such as:

- The Aneel Resolution 414/2010 implementation, which reclassified part of the condominium buildings electricity consumption, previously accounted for in the residential sector, to the commercial sector.
- The climatic effect that intensifies/enables the operation of environmental conditioning equipment: air conditioners, fans, among others.
- The recent years water, economic and health crises.

Figure 25: Specific consumption[1] per square meter

Source: Compiled by EPE



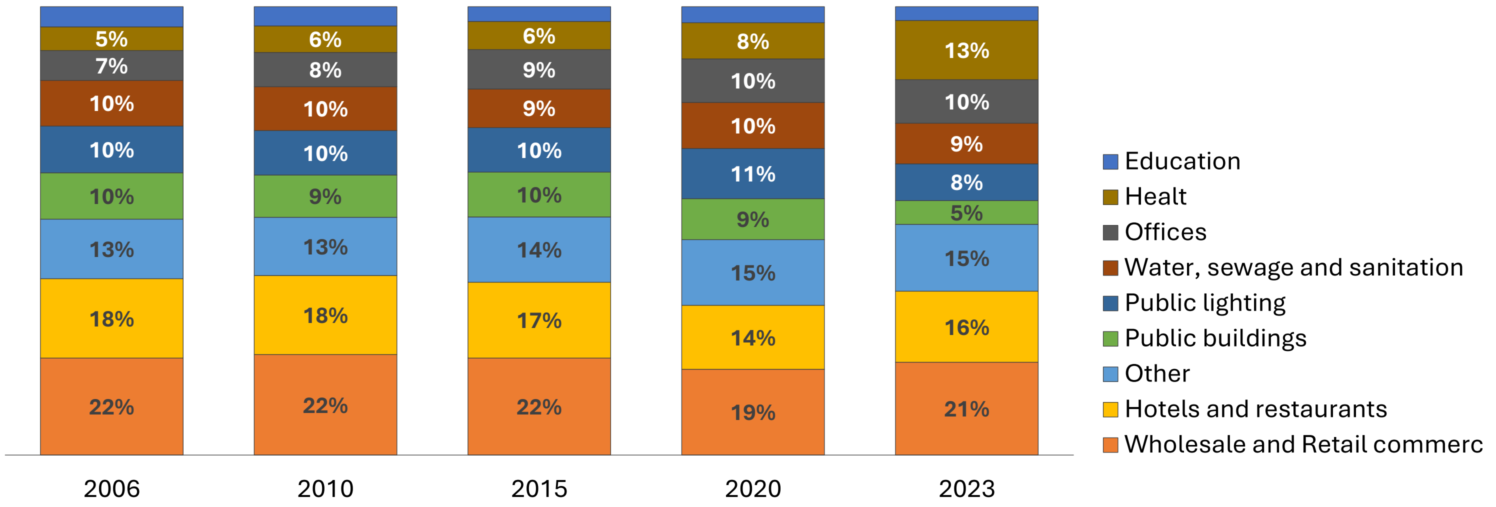
Data	Δ% 23/22
Electricity Consumption	7%
Energy Consumption	8%
Area (millions m²)	1%

[1] Does not include consumption in the following segments: public lighting, water, sewage and sanitation.
Consumption in toe considers all energy sources

Energy Consumption in services segment by sector 2006-2023

During the period from 2006 to 2023, the healthcare segment recorded the highest growth rate, with 8% per year, compared to other segments. Meanwhile, the Wholesale and Retail Trade segment holds the largest share of consumption, accounting for 21% of the total. Adding the hotel/restaurant and healthcare segments to this, the share rises to half of the total consumption.

Figure 26: Final energy consumption in services segment by sector
Source: Compiled by EPE from EPE (2015)



Share in Energy Consumption	
Wholesale and Retail commerce	21%
Hotels and restaurants	16%
Health	13%
Main sectors (total)	50%

The services sector is diverse, with distinct characteristics and usage profiles. However, the distribution of energy consumption by segment during the period shows a certain homogeneity. Two segments stand out: public buildings with a reduction in energy consumption and healthcare with an increase. Energy consumption in 2023, compared to the previous year, shows a 7% increase.

[1] Others category includes condominiums, public places (theaters, clubs, museums, churches, galleries, etc.) and information (cinemas, radio, TV, telephony, etc.).

E-commerce share in traditional retail trade sector

The evolution of e-commerce's share in traditional retail reached 8.6% in 2023. Part of the reduction in energy consumption in retail is corroborated by the increase in online sales. The share of e-commerce revenue reached 9.5% in 2023.

Figure 27: Profile of online buyers (revenue share)
Source: ABComm (2024)

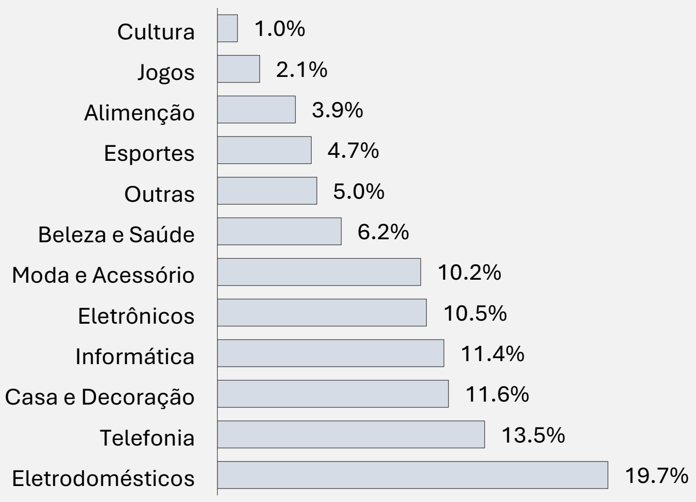


Figure 28: E-Commerce geographical region profile
Source: ABComm (2024)

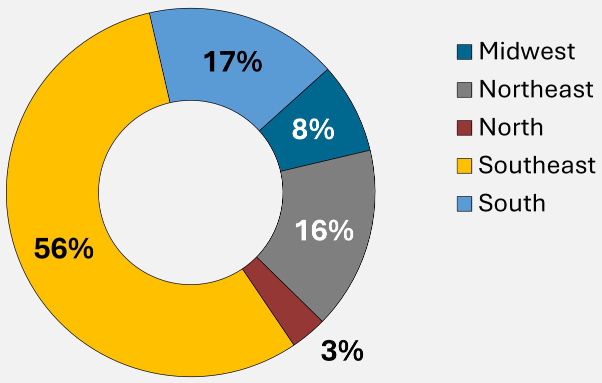


Figure 29: E-commerce in Traditional Retail Share – 2010 - 2023
Source: ABComm (2024)

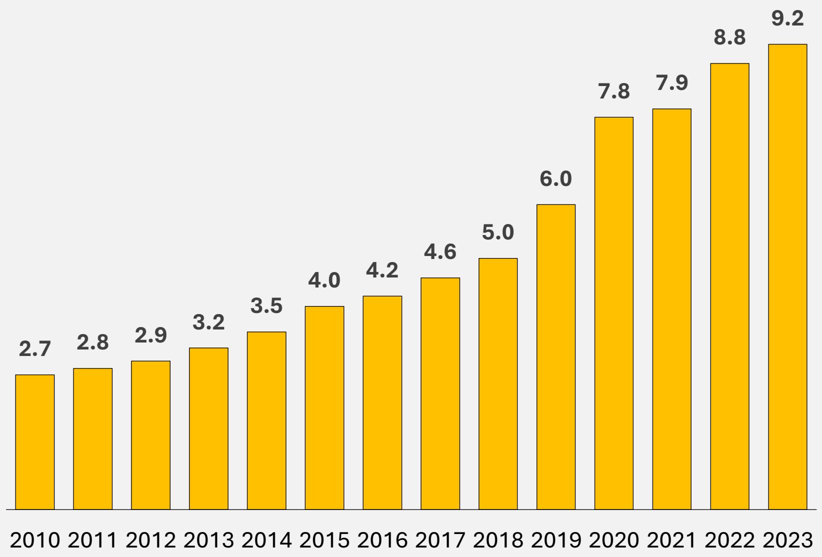
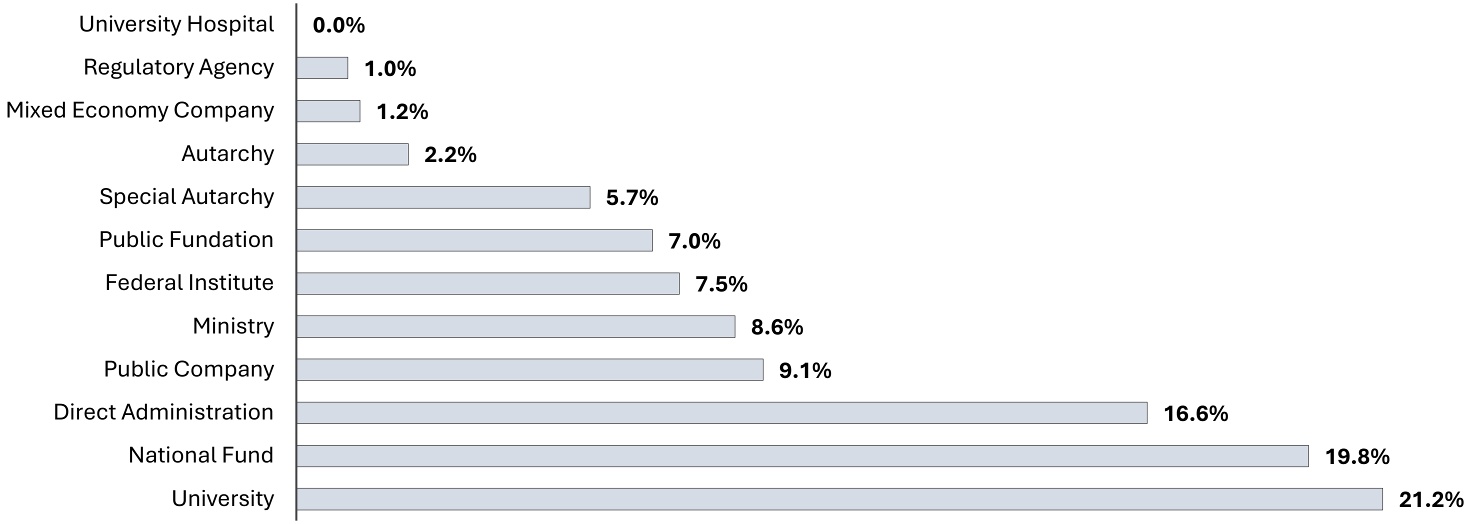


Figure 29 shows the increasing growth of the participation of online e-commerce, led by the Southeast region with a 56% share in sales. In Figure 28, it is observed that home appliances and telephony have the highest participation in online sales.

Electricity spends profile in the federal public administration

It is possible to analyze the electricity expenditure profile in the federal public administration through the Administrative Cost Panel. Currently, the panel provides information on expenditure, and Figure 30 shows the distribution by agency. In the absence of electricity consumption data, this information helps to see the biggest expenses to drive policies and prioritize actions for energy efficiency.

Figure 30: Distribution of Electricity Spending – 2023
Source: MGISP (2023)



In 2023, it was observed that approximately 60% of electricity expenses were concentrated in three segments: Universities (21%), National Fund[1] (20%), and Direct Administration (17%). By analyzing the profile of electricity expenditures, it is possible to identify the segments with the greatest potential for efficiency improvements.

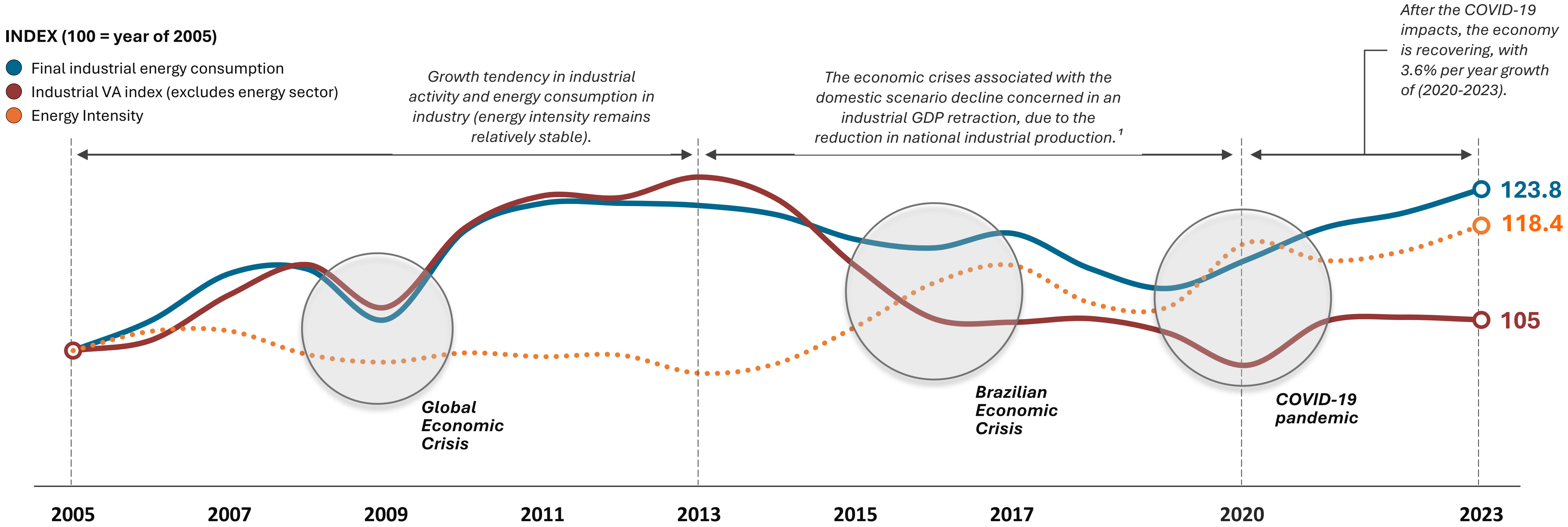
[1] National funds include, for example: the National Health Fund, the Education Development Fund, the Indian Fund, the Arts Fund, the Anti-Drugs Fund, the Culture Fund, the Civil Aviation Fund, etc.

Industrial Sector

Energy consumption and aggregated value evolution in Brazilian industry

Figure 31: Energy Consumption and Aggregated Value by Industries in Brazil (Index 2000 = 100)

Source: Compiled by EPE, from EPE (2024a) and IBGE (2023a)



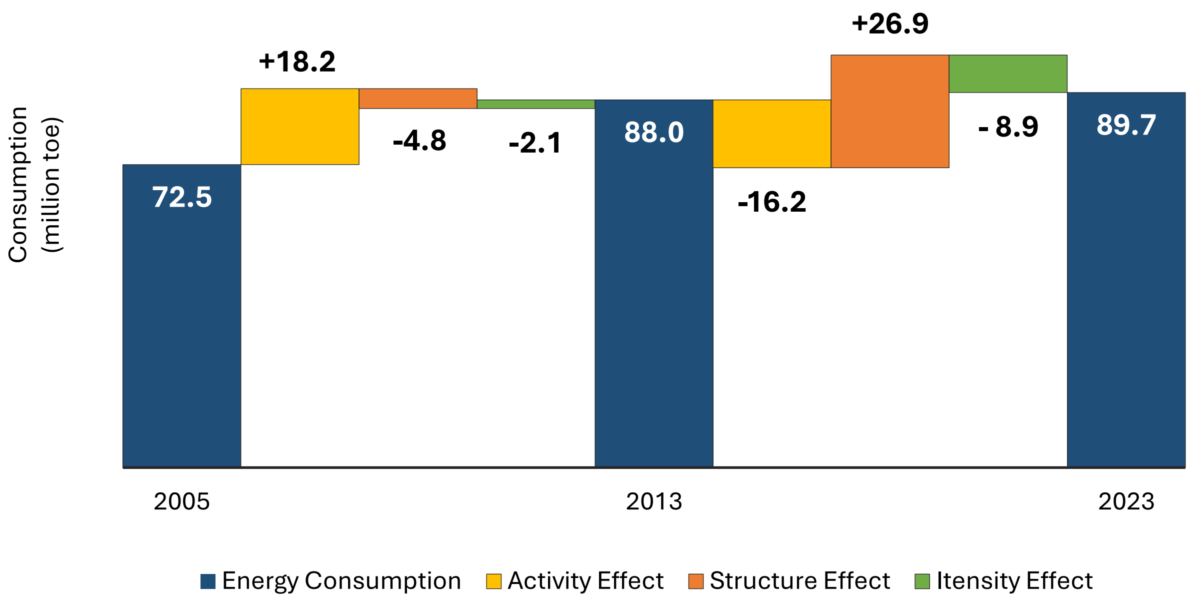
The decoupling observed since 2015 between the energy consumption curves and the added value results in an **increase in energy intensity**, which is **not necessarily related to the energy efficiency of industrial plants** but rather to other effects, such as the greater participation of energy-intensive segments in recent years.

[1] National industrial production with some exceptions

Energy consumption effects sectioning: what is behind the increase in industrial energy intensity?

Figure 32: Breakdown of changes in industrial energy consumption

Source: Compiled by EPE from EPE (2024a) and IBGE (2023a)



The three main effects that compose the industrial consumption variation are: added value (changes in the activity level), the industrial segments relative share (i.e. the structure of industry) and each segment intensity (the ratio between energy consumption and added value for each segment).

Between 2005 and 2013, there was a significant **increase in industrial activity**, associated with a reduction in the structural effect and intensity effect. The industries that grew the most during this period were cement, sugar, pulp and paper, and mining.

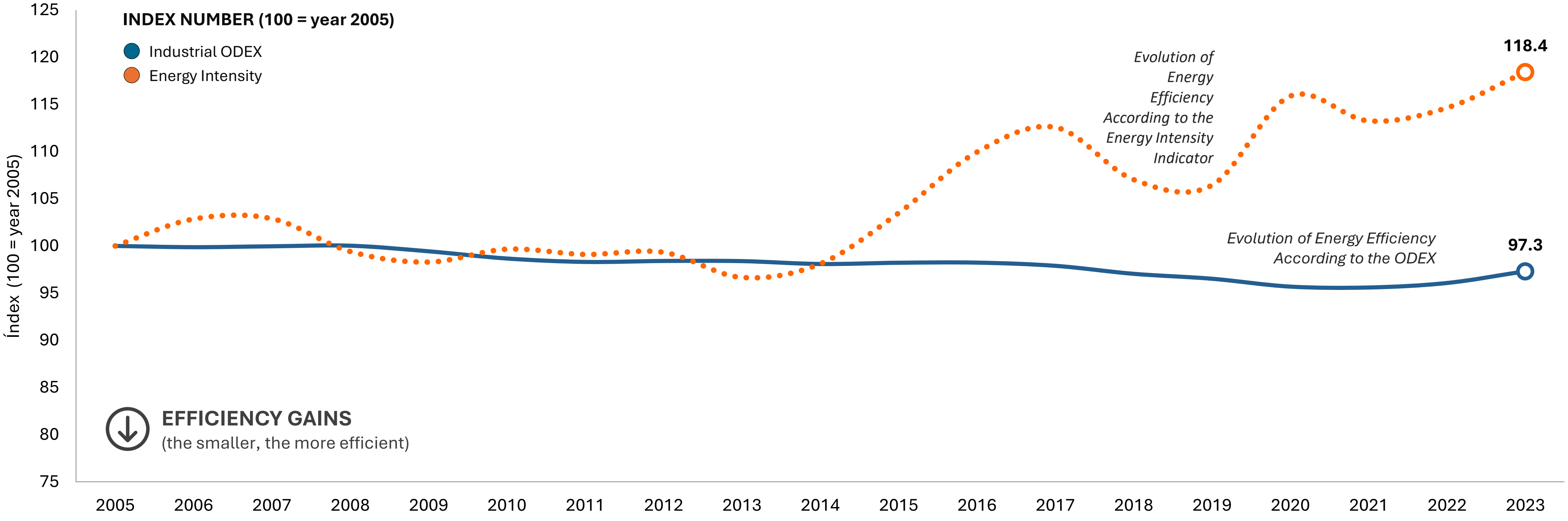
Between 2013 and 2023, there was a **decline in economic activity**, with a drop in the value-added of mining, other industries, and the chemical industry, as well as in the physical production of cement and steel. The **change in industrial structure** was marked by an increase in the participation of energy-intensive segments above the industry average, such as pulp and paper, ferroalloys, and sugar.

>> More details about this split in the section Definitions

In the first period, almost all segments grew, with little structural variation within the industry. In the second period, however, the trend reversed due to a reduction in economic activity and its impact on industrial activity, causing a change in the energy consumption structure of the Brazilian industry.

[1] Decomposition of the variation in industrial energy consumption into activity, structure and intensity effects, according to the LMDI I method ("logarithmic mean Divisia index method I") with additive decomposition (Ang & Liu, 2001).

The ODEX indicator is an alternative to energy intensity...



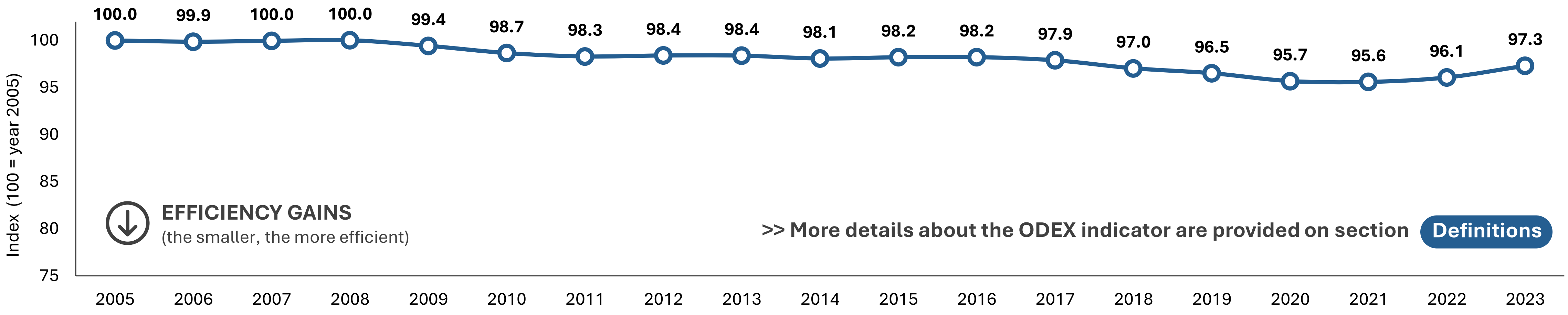
The industrial ODEX is based on unit consumption indices by segment (cement, ceramics, textiles, etc.) weighted by their share of the sector's total energy consumption. Unit consumption can be expressed in different units to provide the best 'proxy' for evaluating energy efficiency, such as energy consumption per unit of physical production or per unit of added value. This approach allows mitigating the structural effect among industry segments, unlike what occurs with energy intensity.

Energy consumption ODEX in the industrial sector

For the calculation of the ODEX, the variation in specific consumption based on physical production was considered for the segments of steel, pulp and paper, cement, and sugar, **which together represent about 60% of energy consumption in the industry.** For the segments of other food products, textiles, chemicals, ceramics, ferroalloys, other metallurgy, mining, and other industries, the calculation is based on the variation in energy intensity. In both cases, the variations are weighted by the share of each segment in the sector's final energy consumption.

Figure 33: Industrial ODEX

Source: Compiled by EPE



Although the industrial ODEX remained relatively stable throughout the entire period, a relative increase in this indicator was observed in the years 2022 and 2023, largely due to the internal structural effect of some energy-intensive segments.

[1] For more details about the ODEX calculation, access: Atlas of Energy Efficiency Methodological Manual

Particularities of some segments contributed to the increase in the industrial ODEX

Throughout 2023, there was a sharper **reduction in the production of electric steel mills** (about a 12% drop) compared to the production of crude steel in integrated steel plants (about a 5% drop). The steel industry's "mix" in 2023, compared to the previous year, increased its specific consumption, contributing to the rise in the industry's ODEX, **which does not mean that technological routes individually became less efficient.**

In the cement sector, an effort by the industry to reduce greenhouse gas (GHG) emissions has been observed, including the use of alternative fuels such as tires, industrial waste, urban solid waste, and "other renewable sources" like charcoal, wood, agricultural residues, biodiesel, and other biomasses. These actions have sometimes led to an increase in the specific energy consumption of the sector, as was observed in 2023. **In other words, reducing emissions was prioritized over improving the global energy efficiency of the sector.**

In the Non-Ferrous Metals and Other Metallurgy sector, primary aluminum production grew by 26% in 2023, largely due to the **resumption of operations at Alumar**[1]. The production of primary aluminum is highly energy-intensive and accounts for a significant portion of the group's electricity consumption. However, in terms of added value (VA), its contribution is low compared to other products. The combination of these factors contributed to the increase in the ODEX for this segment in 2023.

> Segments that feature differentiated technological routes and products are influenced by the internal structural effect. For example, the specific consumption for recycled paper production is much lower than the specific consumption for pulp production. Similarly, crude steel production from scrap (electric steel mills) requires less energy per ton of steel compared to integrated steel plants.

[1] More details are available at:
Boletim Trimestral do Consumo de Eletricidade – Ano IV – Número 16 – 4º trimestre de 2023

Timeline: Energy efficiency policies and programs

Main energy efficiency policy Highlights linked to industrial sector

Source: EPE.

1984

Labeling Brazilian Programme
[INMETRO/MDIC]

- Three-phase electric induction engines up to 250CV
- Pumps and motor pumps up to 25CV

1985

PROCEL[2]
[ENBPar/MME]

1991

CONPET
[MME]

2000

Law Nº 9.991 | EE Programme, R&D and Procel
[ANEEL]

- R$93 million in 42 PEE/ANEEL industry projects (2009-2018), saving 135 MWh/year
- Priority Project Calling No. 2/2015: replacement of electric engines
- R$492 million from P&D/ANEEL in efficiency

2001

Law Nº 10.295 | Minimum Energy Performance Standards
[MME/MCTIC/MDIC]

- Three-phase electric induction engines up to 500 hp
- Technical Group of refurbished engines

2011

NEEP
National Energy Efficiency Plan
[MME]

2016

Law n° 13.280/2016 changed Law 9.991/2000, allocating 20% of energy efficiency resources to Procel

2020

RedEE Indústria
[MME/ GIZ/ Ahk São Paulo]

2021

PotencializEE
Transformative Investments for Industrial Energy Efficiency Programme
[MME/GIZ]

2022

FGEnergia
Guarantee Fund for Energy Efficiency
[BNDES and PROCEL]

1st PAR	2nd PAR	3rd PAR	4th PAR
▪ Alliance Programme ▪ More Productive Brazil EE Programme ▪ Structuring through indicators and standardizing	▪ Alliance 2.0 Programme ▪ Digital EE ▪ Compressed Air Systems EE Programme ▪ Methodology for Thermal and Motor Systems ▪ Study on motor systems ▪ Evaluation of the Lamotriz network ▪ Impact of motor repair on efficiency	▪ Application of solar thermal systems ▪ Engine repair communication plan ▪ Engine repair laboratory	▪ Promoting energy management ▪ Malmquist Index and Data Envelopment Analysis ▪ Regulatory impact analysis (RIA) for compulsory certification of distribution transformers ▪ RIA for improving the motor repair service ▪ Implementation of the Lamotriz Network Business Plan ▪ Computer tool for analyzing pumping systems

[1] Non-exhaustive list
[2] Law No. 13,280/2016 amended Law 9,991/2000, allocating 20% of energy efficiency resources to Procel.

The Industry profile

The oil products use is losing share due to the reduction in the fuel oil using in all segments, and the petroleum coke lower share in the cement industry. Coal is also losing share due to the steel sector usage reduction. Even though, it is used more in the ferroalloys sector. Bleach (black liquor) is gaining share, in line with the pulp industry, which uses this co-product in its processes.

Figure 34: Industry share by segment

Source: EPE (2024a)

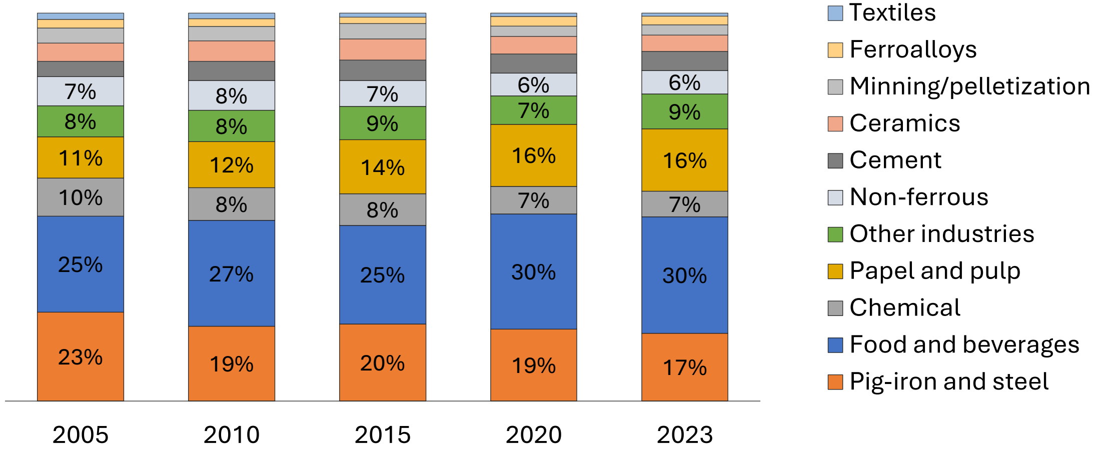
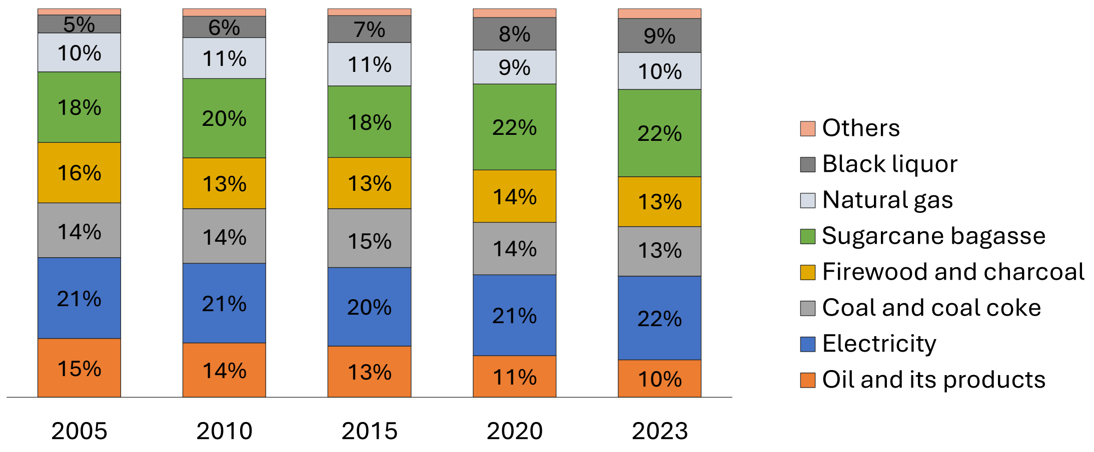


Figure 35: Industrial energy mix

Source: EPE (2024a)



In 2023, the food and beverage, pig iron and steel, and pulp and paper industries were the most representative in terms of energy consumption. Electricity is the most important source and is earning a slight share.

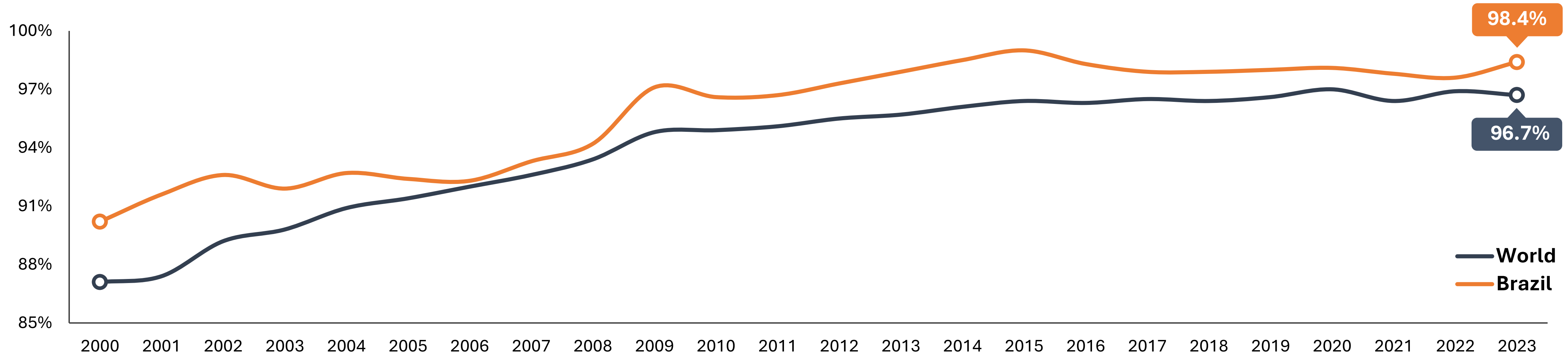
Overview
of industry selected branches

Steel industry: spread of contínuos casting

Liquid steel can be solidified by conventional casting[1] or by continuous casting. Continuous casting can be considered one of the radical innovations in the steel industry worldwide, as it now allows a high semi-finished/liquid steel yield (around 98%), is more compact and gives better quality to the final product.

Figure 36: Diffusion rate of continuous casting in the steel industry, Brazil and worldwide (percentage)

Source: Worldsteel (2009, 2019, 2021, 2023, 2024)



The worldwide diffusion of continuous casting went from 87.1% (in 2000) to 94.9% (in 2010) and 96.7% (in 2023). During this period, the relative importance of continuous casting in Brazil was higher than the world average.

[1] Using ingot moulds, a mould that has the function of receiving metal or metal alloy in a liquid, hot state, to provide a certain piece after the curing time, when the material solidifies

Cement: specific consumption and clinker content

The cement industry in Brazil has a modern and efficient industrial park, which is constantly being updated. More than 99% of production is carried out in dry kilns (the most efficient), around 40% of the industrial park is less than 15 years old and more than 70% of its kilns are equipped with 4 to 6-stage preheater towers and pre-calciners (EPE, 2021). Modern grate coolers equip 80% of Brazilian kilns and approximately 50% of raw material mills are vertical, which are considered to have the lowest electricity consumption.

Figure 37: Consumo energético específico na indústria de cimento

Source: Compiled by EPE from EPE (2024a).

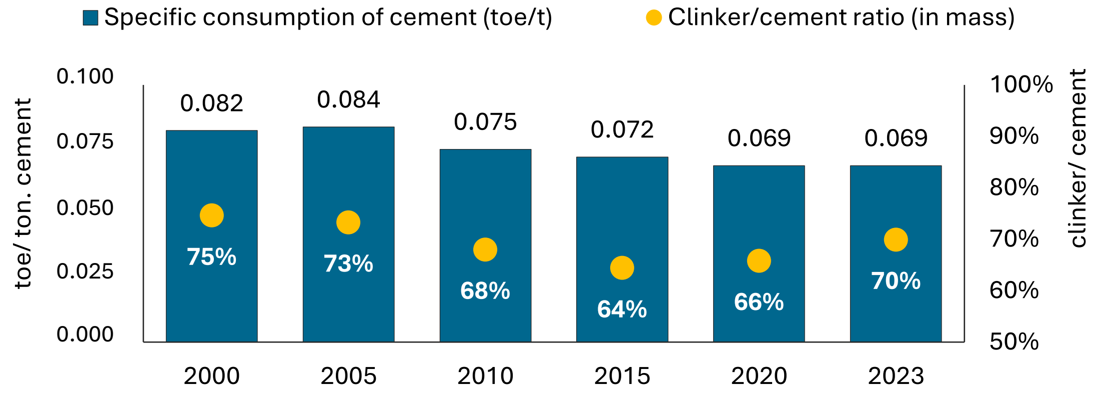
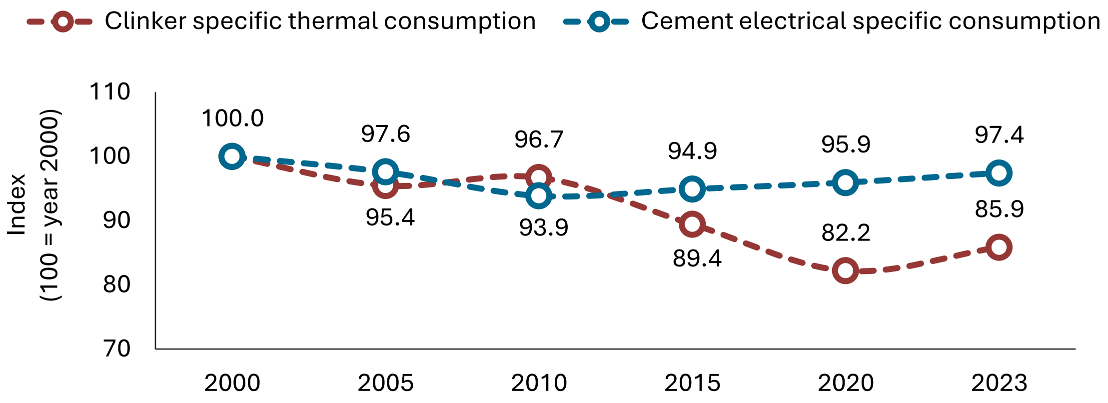


Figure 38: Índice de variação do consumo específico de cimento (clínquer e cimento)

Source: Compiled by EPE from EPE (2024a).



Regulation advances, cement chemistry researches, new cements development, among other things, would enable progress to make the cement additions incorporation, replacing clinker, which currently stands at 32%, reducing greenhouse gas emissions associated with calcination and energy use.

The Figure 38 shows the specific thermal and electrical consumption for clinker and cement production, respectively. Electricity is consumed mainly in cement production (grinding) and fuel in clinker production (kiln).

The specific thermal consumption of clinker fell by 14% over the entire scenario, while the specific electrical consumption of cement fell by 3%.

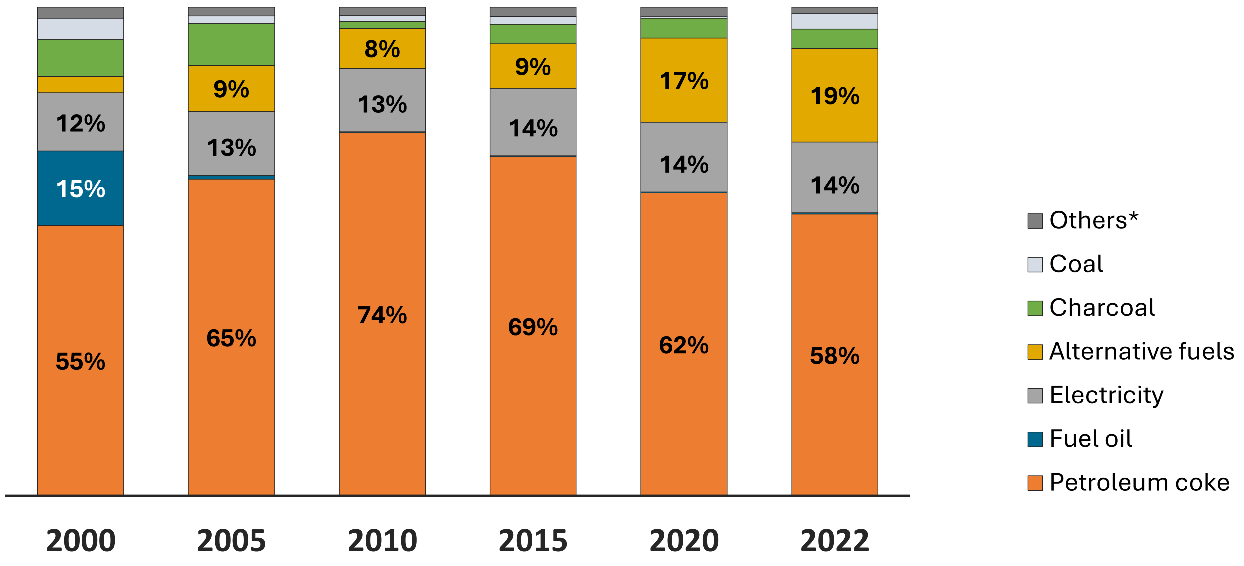
[1] EPE (2021) used data from the Cement Technology Roadmap, available at: roadmap-tecnologico-do-cimento-brasil.pdf

Cement: energy matrix and co-processing

The cement industry's energy matrix has changed over time. During the oil crises there was a momentary migration from fuel oil to coal (mineral and vegetable). In the 2000s, the sector switched to imported petroleum coke instead of fuel oil. Currently, petroleum coke is the main source, due to its low price and guaranteed supply.

Figure 39: Final energy consumption by source in the cement industry

Source: EPE (2024a).



Since the 2000s, a new energy revolution becomes more important: alternative fuels, characterized by the wasting co-processing and the biomass use.

Co-processing has several environmental benefits, as it provides an appropriate destination for waste and reduces GHG emissions (since most of this waste has a lower emission factor than traditional fossil fuels).

This energy transition has demanded - and will demand even more - investment from the sector in adapting the production process, as well as improvements in monitoring and control (EPE, 2021).

The share of alternative fuels has been gaining prominence as a substitute for petroleum coke, reaching 23% of consumption in 2023.

Note: "Others" includes natural gas, firewood, diesel oil and LPG

Pulp and paper: profiling and recycling

Pulp production is increasing in a faster pace than paper production, with large pulp-only mills and an increase in exports, because of the great Brazilian product competitiveness. In 2020, domestic pulp production was already double that of paper production. Since pulp production is more energy-intensive than paper production, this affects the evolution of the sector's specific consumption.

Figure 40: Pulp/paper production ratio in Brazil

Source: Compiled by EPE.

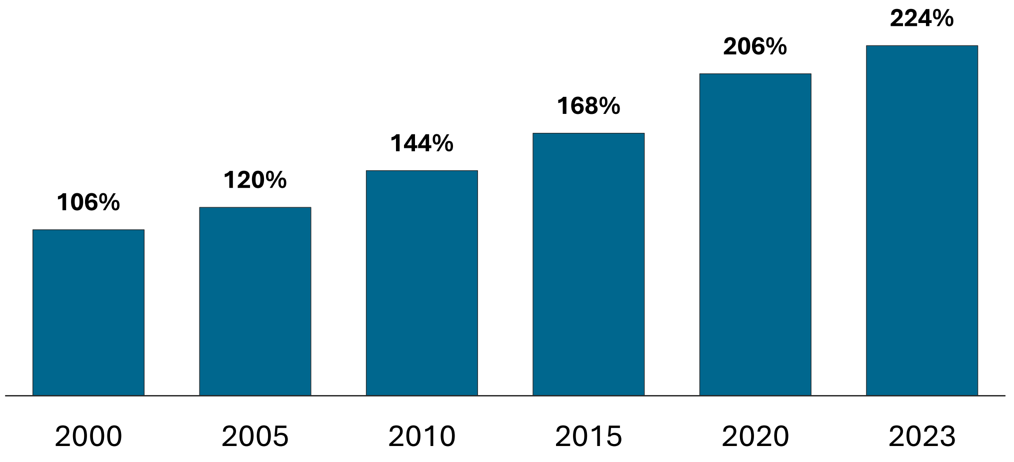
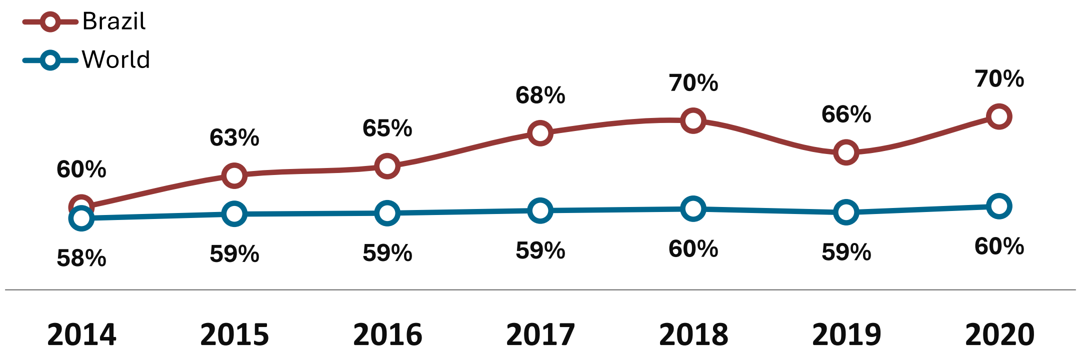


Figure 41: Paper recycling rates in Brazil and worldwide

Source: Compiled by EPE, from ICFPA (2023), ANAP (2020 e 2021) and Ibá (2024).



Paper recycling is an important sustainability measurement. Replacing the paper produced from pulp with paper scraps is a circular economy action that avoids energy consumption and other impacts of pulp production.

The sector has a positive track record in reverse logistics, having reached the 70% recycling rate milestone in 2020, above the global average of 60%. The recycling rate for packaging is even higher, reaching 80%.

However, it is important to know that recycling paper can switch the product characteristics and quality, and it can't always be used for the same application, and it depends on a logistics grid for collecting paper scraps, which goes beyond the confines of the factory.

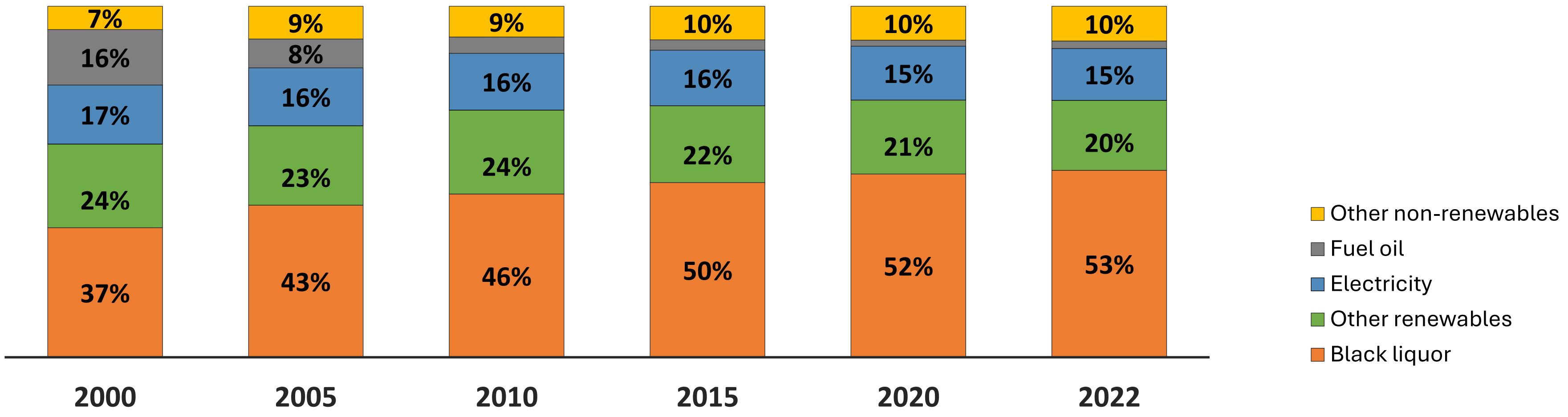
Note: Calculated based on the collection of scraps relative to the apparent paper consumption. The paper recycling rate in Brazil stands at 58.1%, according to the Ibá 2024 Annual Report, available at: Ibá 2024 Annual Report

Pulp and paper: energy matrix and renewability

The national pulp and paper sector's energy matrix has a high level of renewability, reaching 88%. The sector uses by-products of the pulp production process, bleach (black liquor) and wood waste, for cogeneration. Natural gas began to be used in the 1980s, and its share, since the 2000s, has been relatively stable at 7%, mainly in boilers. Fuel oil, on the other hand, has significantly reduced its share from 16% in 2000 to 2% today, used to start boilers, in lime kilns and in the fuel oil boilers of a few plants (EPE, 2018).

Figure 42: Final energy consumption by source in the pulp and paper industry

Source: EPE (2024a).



In 2023, 92% of the segment's energy consumption was supplied by energy generated by the companies themselves (Ibá, 2024), predominantly from renewable sources such as black liquor.

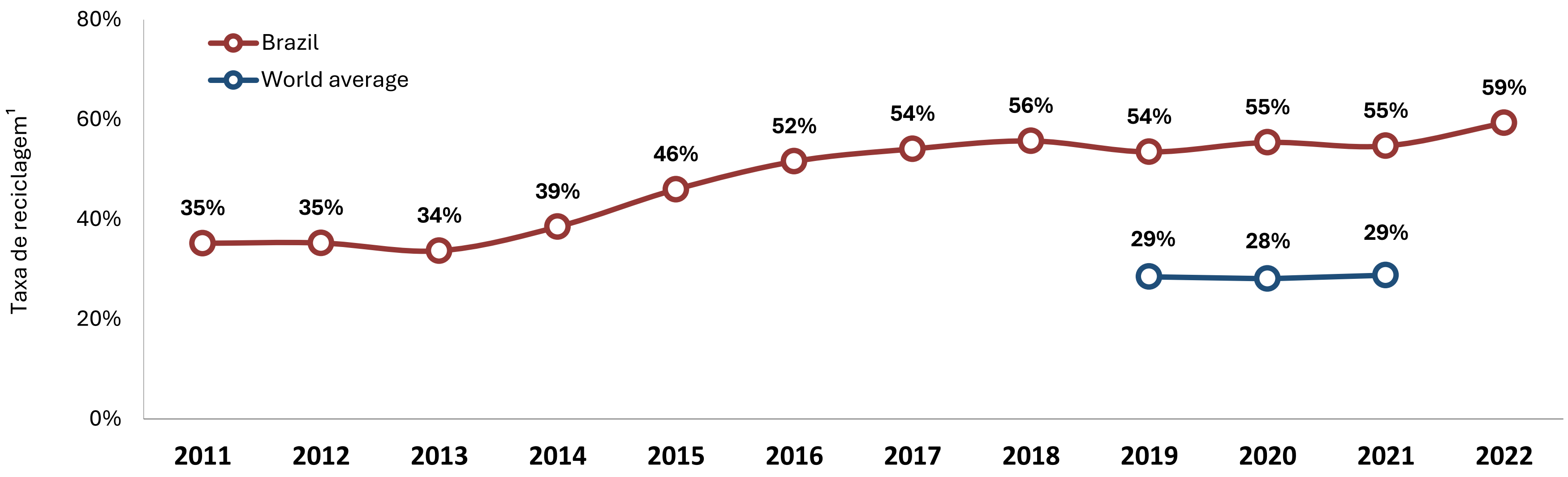
[1] Assuming that the electricity consumed in the sector is 100% renewable.

Aluminum: scrap recovery rate evolution

In 2023, with a consumption of 32.3 billion aluminum cans, equivalent to over 150 cans per person per year, Brazil achieved an aluminum recycling rate of 57%, remaining above the global average.

Figure 43: Evolução da taxa de recuperação de sucata de alumínio

Source: Compiled by EPE, from ABAL (2024).



Recycling is a strategy to make the economy run with a lot of socio-environmental benefits. The electricity consumption of secondary (recycled) aluminum is lower than the primary aluminum, which is electro-intensive. According to the World Economic Forum (2021), the consumption of recycled aluminum is in around 5% of the consumption of primary aluminum. This fact is also supported for Brazil, as pointed out by the EPE (2017) study.

[1] Using molds, a tool designed to receive metal or alloy in a liquid, hot state, to form a specific piece after the curing time, when the material solidifies.

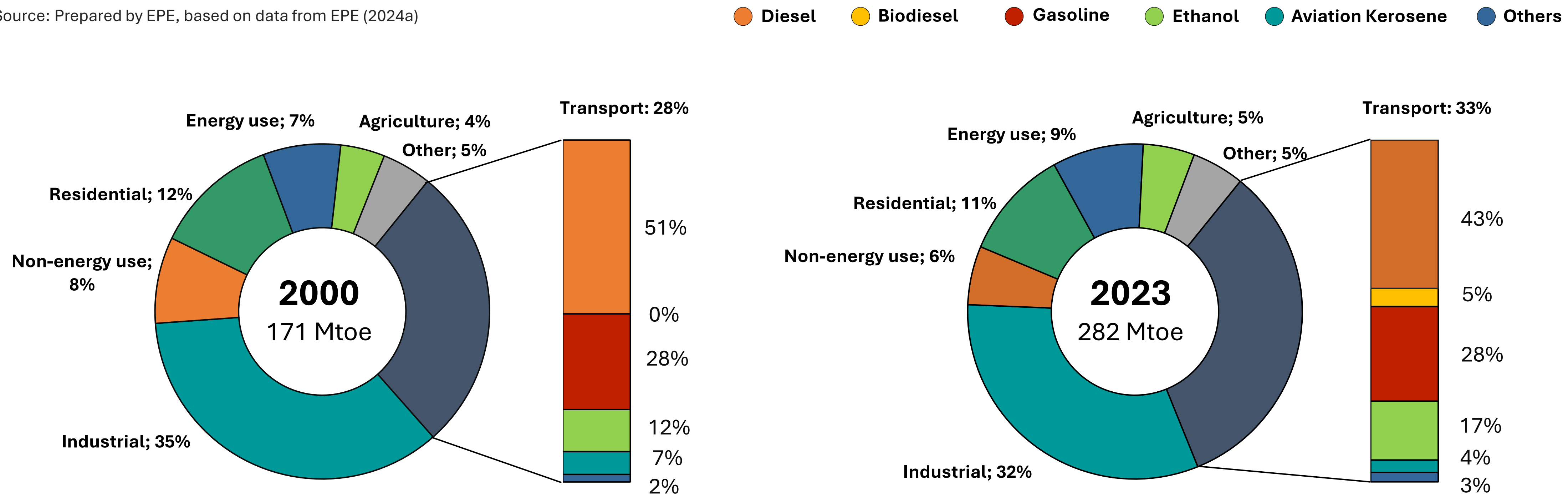
Transport Sector

Energy consumption in the transport sector

In 2023, national energy consumption increased by 4.0% compared to 2022, a rate higher than the increase in GDP, of 2.9%. The energy demand of the transport sector grew by 4.4% in 2023, accounting for 36% of the increase in final energy consumption. Highlight for the activity in passenger transport, which was once again above that recorded in 2019, before the pandemic, increasing by 15%, with an increase of only 6.1% in energy expenditure. Freight transport activity also grew significantly (3.5%), efficiently, with an increase in energy expenditure of only 2.1%. In the case of freight transport, the increase in energy consumption has been at record highs every year since 2016, being 25% above the level of activity in 2019.

Figure 44: Final consumption of the transport sector in Brazil

Source: Prepared by EPE, based on data from EPE (2024a)



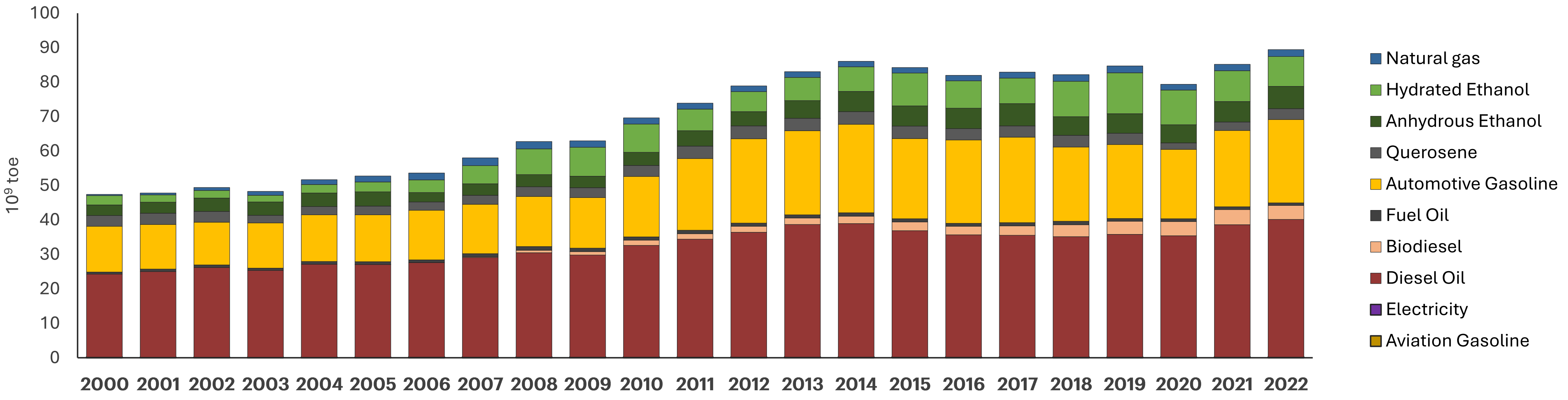
Transport Sector’s energy consumption share evolution

The increase in the sector's energy demand in 2023 was due not only to the growth in freight transport, but also to passenger transport. Particular emphasis is on the increase in demand for diesel oil and gasoline, encouraged by the increase in the consumption of goods, the increase in agricultural and industrial production, and the full recovery of the population's mobility after the pandemic. The registered growth rate, 4.4%, was above the GDP expansion, especially due to the mobility of the population.

The activity of the metro-rail and bus sectors has not yet recovered from the pandemic. However, the activity of individual transport more than compensated these sectors, promoting the increase in energy demand for the Otto cycle. With regard to the air transport activity, there was a recovery to pre-pandemic levels at the end of 2023 (but not on average for the year), with an increase in efficiency, since the consumption of aviation kerosene remained 7% below the level recorded in 2019.

Figure 45: Consumption of the transport sector by energy source (10^6 toe)

Source: EPE (2024a)

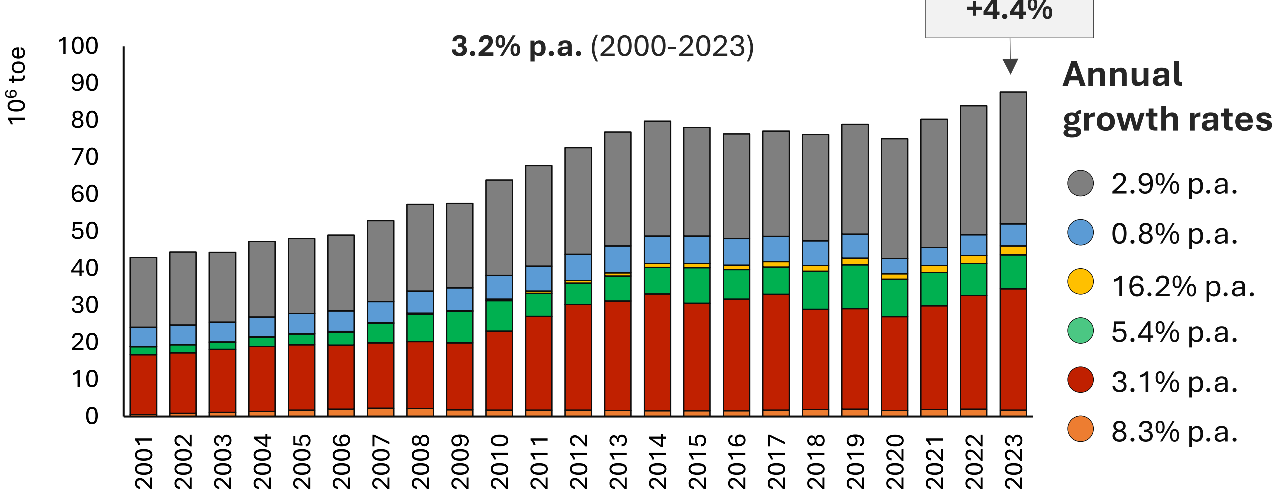


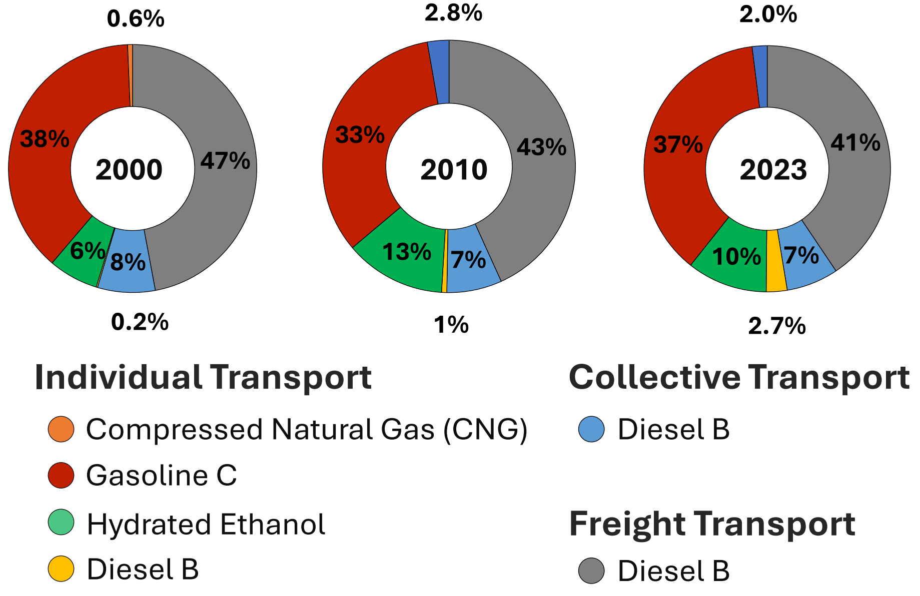
Road transport energy consumption evolution

Between 2000 and 2023, the demand for road passenger transport increased by 113% (3.3% p.a.), and that for cargo transport grew by 94% (2.9% p.a.). The highlights for the year 2023 were the increase in demand for the Otto cycle (+5.7%), with growth in demand for gasoline C (+6.6%) and hydrous ethanol (+6.9%). There was also an increase in the demand for diesel fuel for light vehicles (+10.2%), due to the record sales of SUVs and light commercial vehicles running on diesel, as well as diesel for buses (+6.5%). The volume of diesel oil for freight transportation also registered a new record (+2.2%), due to the increase in agricultural production, the recovery of industry, trade and retail, and the record exports.

Figure 46: Energy consumption by mode and source

Source: Prepared by EPE.





The Otto cycle stands out, which reached an absolute all-time high in 2023 (7.8% above the pre-pandemic record, set in 2019). Which had been in line with the previous record recorded in 2014. On the other hand, diesel demand for public transport by bus is 20% below its record set in 2014.

Passenger Transport

In 2023, passenger transport in Brazil was one of the least energy-efficient times per passenger-kilometer. Despite gains in technical efficiency (of equipment) of new cars, subways and especially aircraft, public transport lost users, who migrated to cars or motorcycles, reducing the systemic efficiency of the sector.

Figure 47: Energy intensity by mode [toe/(10^6 p.km)]

Source: Prepared by EPE

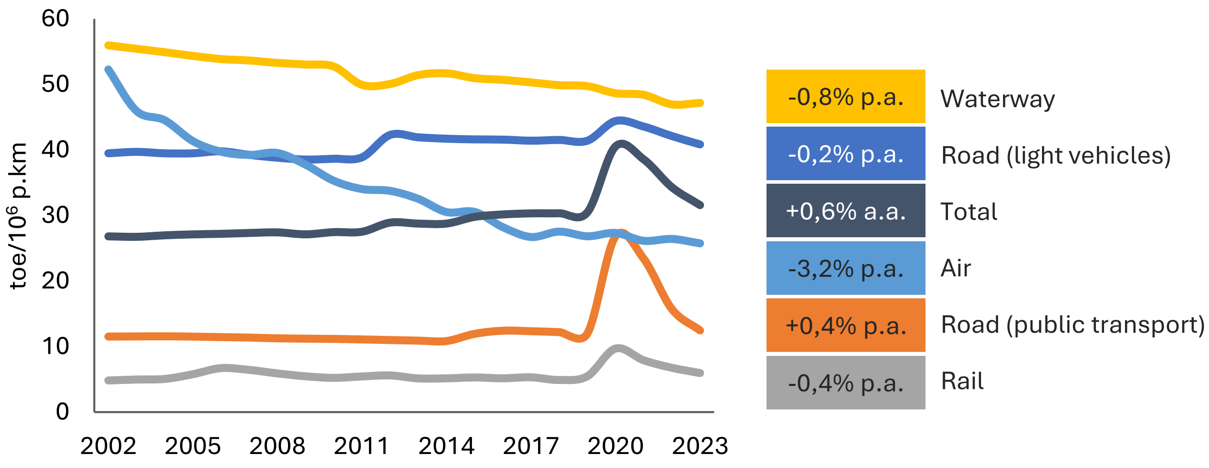
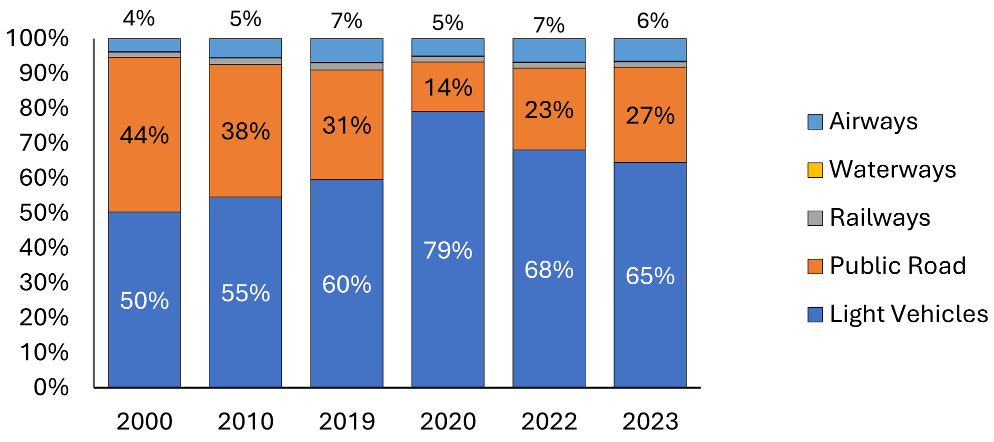


Figure 48: Activity by mode [p.km]

Source: Prepared by EPE



The passenger transport activity exceeded pre-pandemic levels in 2023, being the result of the influence of several factors, namely:

- ↓ maintenance of some degree of teleworking in some cities
- ↑ reduction of unemployment and increase in income mass
- ↑ increase in the fleet of cars and motorcycles
- ↑ reduction in fuel prices recorded throughout 2023
- ↓ number of passengers on buses, trains, subways and aircraft below the levels recorded in 2019
- ↓ International flights at levels lower than in previous years, especially due to the exchange rate, which discouraged trips abroad

Note: the unit "p.km" refers to passenger-kilometers.

Individual passenger transport

Figure 49: Car fleet and specific consumption from 2000 to 2023
Source: Prepared by EPE.

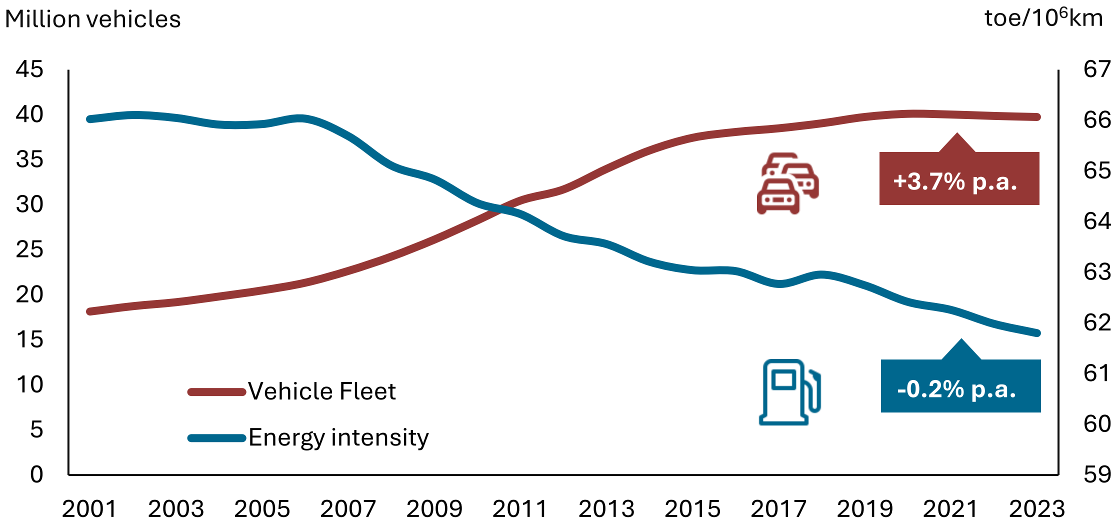
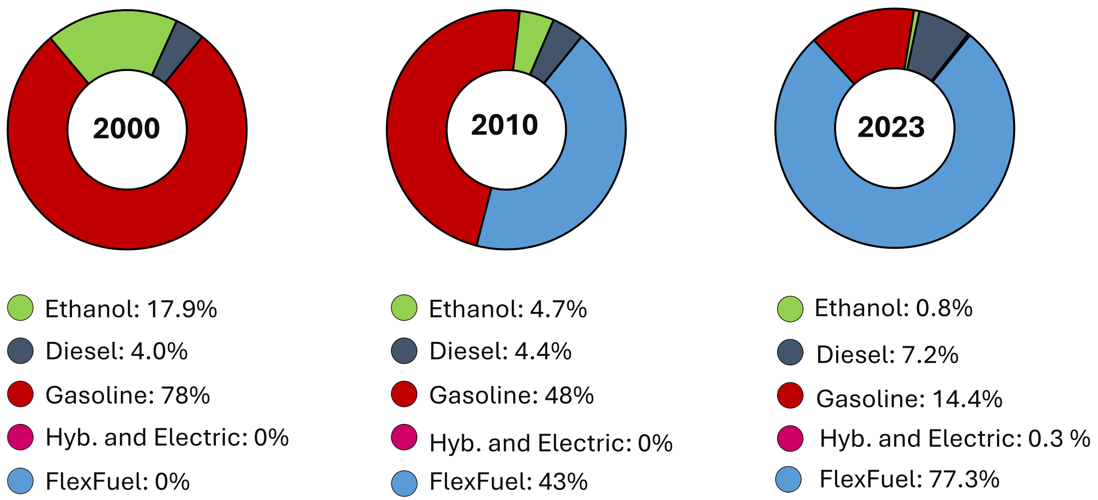


Figure 50: Light vehicle fleet by type of motorization in selected years
Source: Prepared by EPE.



Car sales followed the growth of Brazilian per capita income throughout the 2000s. In the last 3 years, a stabilization of light car sales was observed at around 2 million units.

The history of government initiatives such as the Brazilian Vehicle Labeling Program (PBVE), Inovar Auto and Rota 2030, promoted the improvement of the energy efficiency of new vehicles, and the rapid advance of the participation of flexfuel vehicles in the fleet.

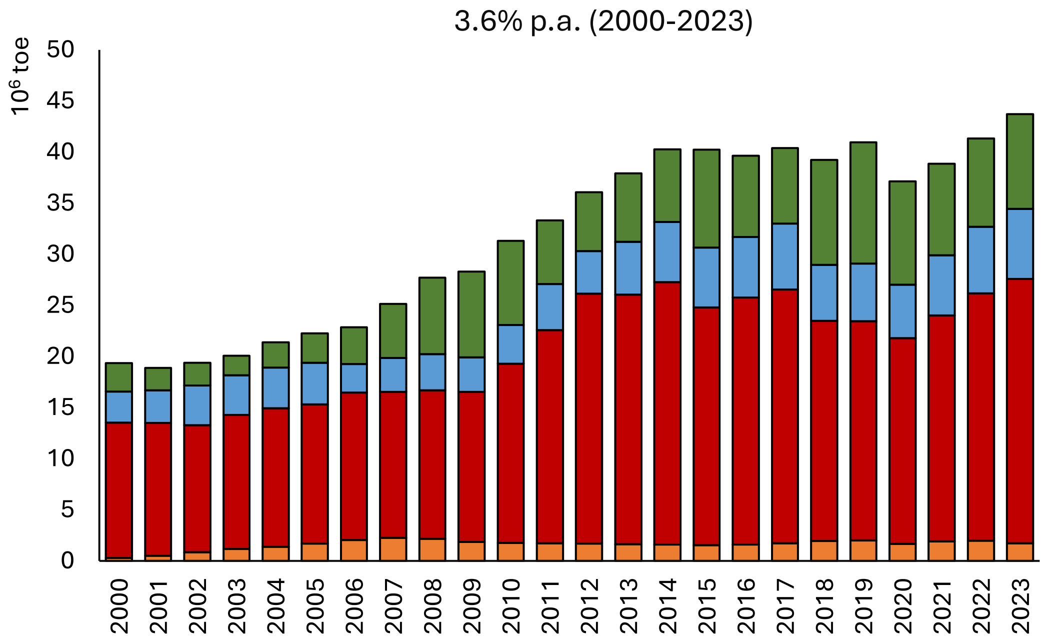
This advance reduces the average efficiency gains of the fleet, as they have slightly lower efficiency than dedicated analogues. The increase in the licensing of light sports commercial vehicles (SUVs) and light diesel commercial vehicles has also increased the specific consumption of the fleet, since they are less efficient vehicles, especially due to their considerable weight.

Of note is the percentage growth in licensing and in the fleet of electrified cars and light commercial vehicles, whose fleet increased by 74% in 2023, reaching 220 thousand units, representing 0.6% of the total fleet.

Otto cycle and individual road transport

Figure 51: Energy consumption by source

Source: Prepared by EPE.

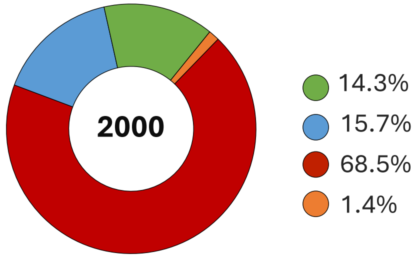


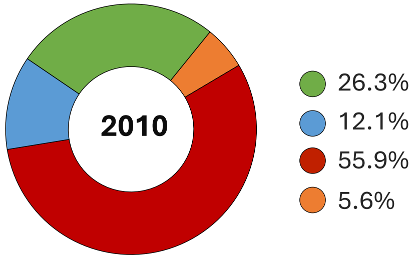
2019/20
-9.3%

2020/21
+4.6%

2021/22
+6.4%

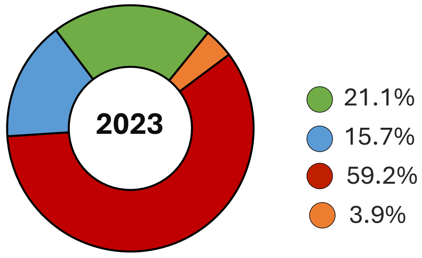
2022/23
+5.7%





Annual growth rates 2000-2023

- Hydrous Ethanol: 5.4% p.a.
- Anhydrous Ethanol : 3.6% p.a.
- Gasoline A: 2.9% p.a.
- Compressed Natural Gas (CNG): 8.3% p.a.



In 2023, demand for Otto cycle fuels grew at a significant rate of 5.7%, above the average growth between 2000 and 2023, of 3.6% p.a. The return to face-to-face work of some companies that were still in a hybrid and remote regime put pressure on the demand for mobility. The greater number of employed people and the greater mass of income also stimulated the demand for both trips to work and leisure trips. The reduction in the number of international flights also stimulated more domestic road trips. The increase in the fleet of light vehicles due to the record sale of motorcycles and the resumption of car sales, as well as the availability of transportation by apps, reduced the demand for public transport, with an increase in the demand for Otto cycle fuels.

Freight Transport

In 2023, freight transport set a new record in terms of energy efficiency, reducing its energy consumption per transport activity by another 1.3%, with emphasis on road and waterway transport.

With regard to water transport, 2023 was a record in terms of port handling, due to the increase in exports, which registered an 8% growth in tons handled. This increase in port handling was made possible by investments and the optimization of management between vessels and ports, allowing to reduce the energy intensity of this sector.

For the other modes, the performance of exports of iron ore, soybeans, sugar, corn and soybean meal, which reached historical records, contributed to the transportation of these products both by rail and road. In this context, there was a need for the entry of many new heavy trucks. Much more efficient than the existing fleet, improving the energy efficiency of road freight transport. However, this increased the participation of the road mode in the freight transport mix. Limiting the systemic efficiency gains that could have been achieved if this cargo had been moved by railroads or waterways.

Figure 52: Energy intensity by mode [toe/(10^6 t.km)]

Source: Prepared by EPE

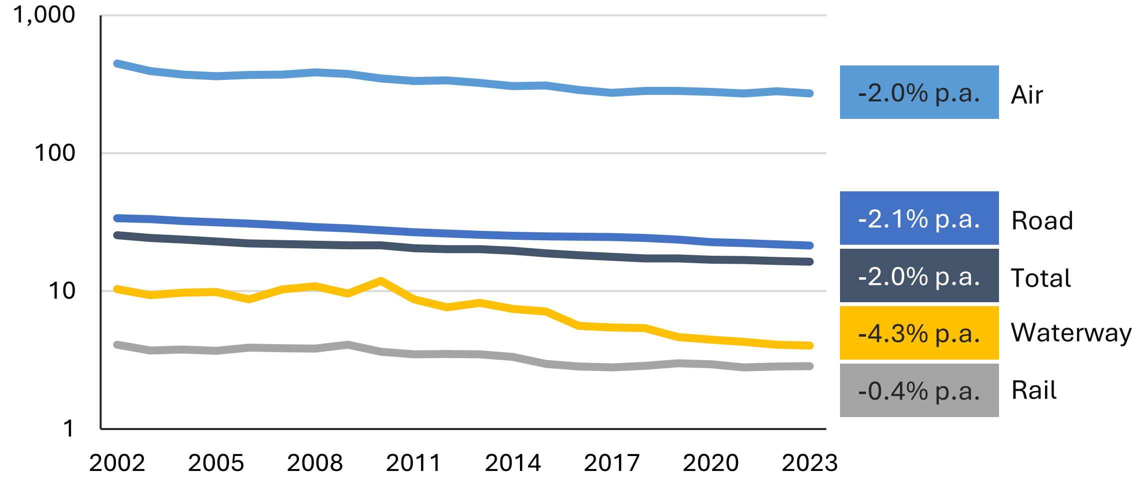
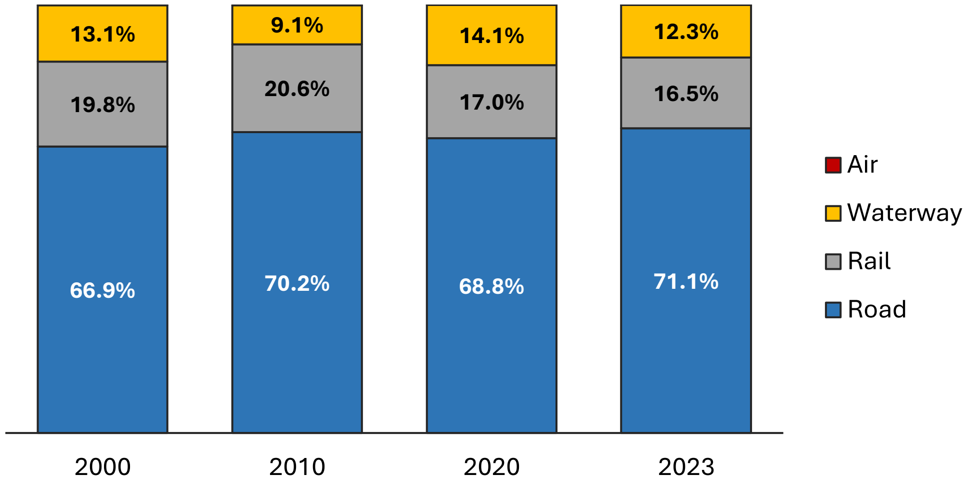


Figure 53: Activity by mode [t.km]

Source: Prepared by EPE



Road freight transport

Figure 54: Truck fleet by category (million units)

Source: Prepared by EPE

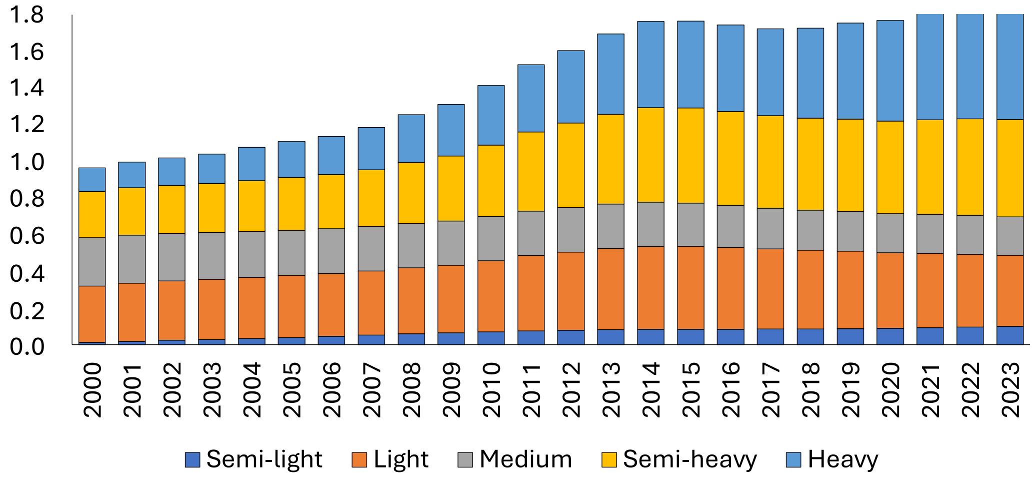
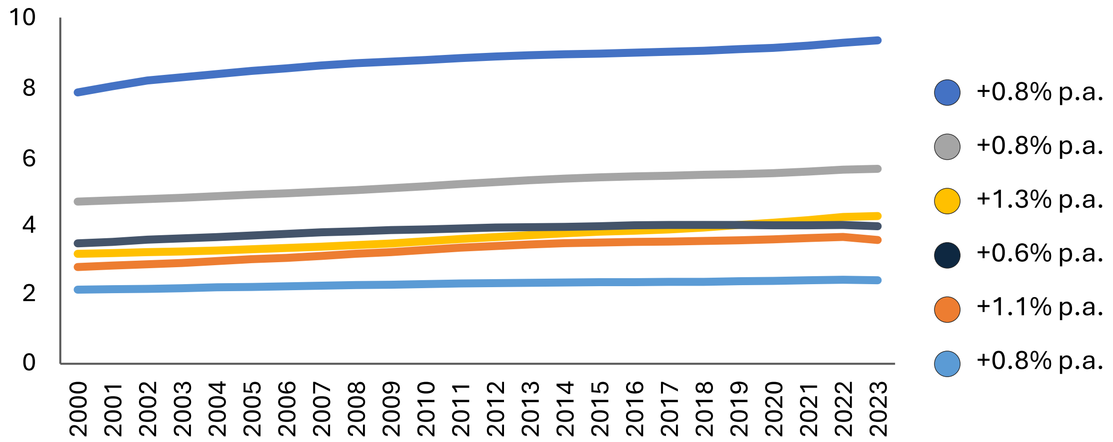


Figure 55: Average energy efficiency of new vehicles sold (with load) [km/L]

Source: Prepared by EPE



Domestic truck licensing in 2023 was 37% below the record recorded in 2011 and 15% below the value reached in 2022. It is important to highlight that the licensing of semi-heavy and heavy trucks, with 82 thousand units, was 38% above the average value recorded between 2000 and 2019. Although the estimate is that the circulating fleet grew 1.3%, the activity of road freight transport increased 4.1%.

Economic activity, especially due to the good performance of the agricultural sector, mining, civil construction, and e-commerce, has leveraged the heavy truck market. In this context, an increase in the average payload transported by truck is projected.

On the other hand, the estimate is that the intensity of fleet use will have been reduced by 0.6 percentage points in 2023. This was caused both by the increase in the fleet, as well as by the increase in the use of waterway and rail modes for long-distance transport, particularly for grains.

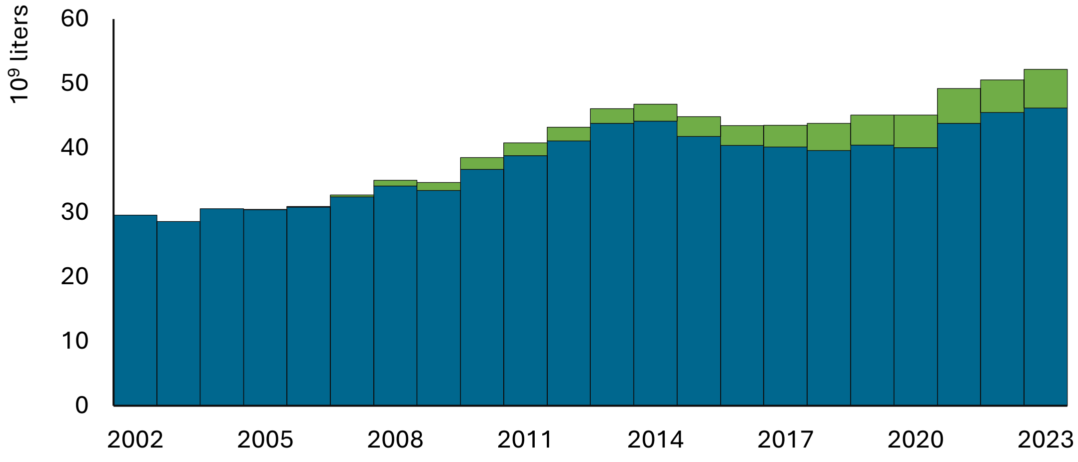
In 2023, the new Phase P8 of the Vehicle Emissions Control Programme (Proconve) began. This program encourages the adoption of more efficient engines to meet the new emission limits. In terms of the indicator (km/L), there was a worsening of 0.6% for heavy trucks and 0.5% for semi-heavy trucks.

Note: The Vehicle Emissions Control Programme (Proconve) was set up to reduce the levels of pollutant emissions from motor vehicles. Phase P8 applies to new heavy-duty vehicles sold from 1 January 2023, and stipulates new maximum emission limits for exhaust gases, particulates and noise, equivalent to the European Euro VI standard.

Diesel and biodiesel consumption

Figure 56: Road diesel and biodiesel consumption (billion liters)

Source: Prepared by EPE



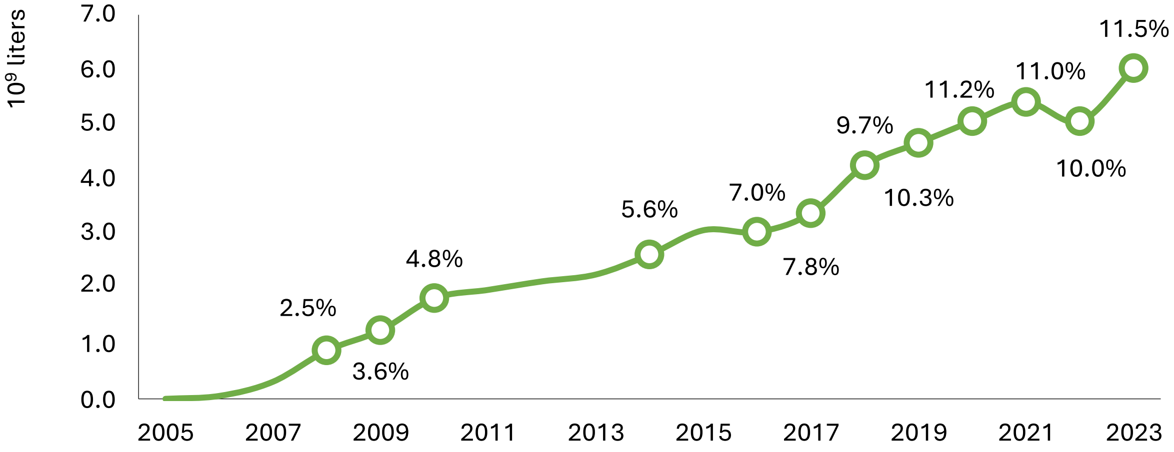
The year 2023 registered a record demand for diesel oil B for transportation, with consumption of 41 billion liters by trucks and 2.4 billion liters for passenger transportation by light commercial vehicles.

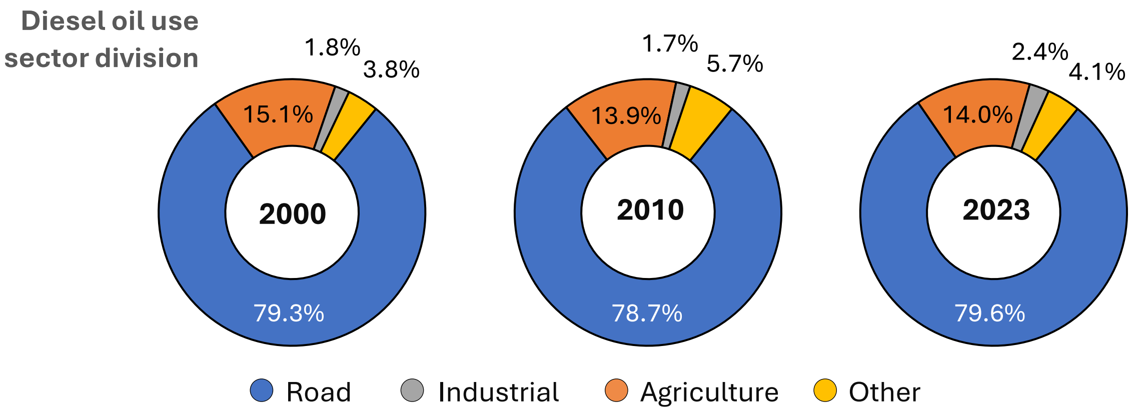
The increase in total road diesel oil demand in 2023 was 1.7 billion liters (+3.3%). Of this increase, trucks were responsible for the consumption of 946 million liters (78% of demand), buses for 442 million, and light commercial vehicles for passenger transport for 268 million.

It is important to note that the mandatory percentage of biodiesel blending in diesel oil increased to 12% as of April 2023, expanding biodiesel production by 19%. In this sense, the increase in the mandatory allowed the additional demand for diesel oil B to be supplied by 970 million liters of biodiesel, mitigating the increase in demand for fossil diesel to only 1.5%.

Figure 57: Evolution of road biodiesel consumption and average addition percentages

Source: Prepared by EPE





Additional remarks on the Transport Sector

The transport sector is the largest consumer of energy in the country, closely followed by the industrial sector. The main reason for the high energy intensity of transport is the profile of the transport matrix, which is extremely dependent on the road mode. In 2023, freight transportation grew by 3.5%, due to the increase in economic activity and the greater use of trucks, leading to an increase in the demand for diesel fuel. Energy demand has also grown, despite advances in the energy efficiency of each mode.

In 2023, passenger transport activity exceeded pre-pandemic levels, growing by 15%. The number of passengers on buses, trains, subways and aircraft was still below the levels recorded in 2019, with the migration of users from public transport to individual transport. In this sense, there was an increase in the fleet of cars and motorcycles. Although individual motorized transport is more efficient compared to other years, the loss of public transport users has reduced the systemic efficiency of the sector and increased the energy demand of passenger transport. The increase in the licensing of light sports commercial vehicles (SUVs) and light diesel commercial vehicles also increased the specific consumption of the fleet.

For another year, there was a record break, with the demand for Otto cycle fuels growing at a significant rate of 5.7%. In 2023, the demand for hydrous ethanol increased by 7% (the same value recorded by gasoline C), allowing hydrous ethanol to supply 21% of the energy demand of individual road transport. When the share of anhydrous ethanol is also considered, the total of fuel ethanol met 37% of the total demand.

In 2023, exports and port handling, at levels higher than historical, increased the demand for transportation activity. Freight transport set a new record in terms of energy efficiency, reducing its energy consumption per transport activity by a further 1.3%. Rail and waterway transport expanded, but the highlight was road transport by trucks. Despite the higher efficiency in part of semi-heavy and heavy-duty trucks sold, the additional demand for diesel in this segment represented approximately 1 billion liters.

The demand for road diesel oil increased by 1.7 billion liters in 2023. This increase coincided with the entry of the new mandatory biodiesel addition percentage of 12% in April, resulting in an annual share of 11.5%. Biodiesel has allowed almost 1 billion liters of the total increase in road diesel oil to be supplied by renewable fuel. The expansion of biodiesel supply in 2023 was 19%.

Special chapter on the ferroalloys and silicon metal industry

1. Analysis of the ferroalloys and silicon metal sector

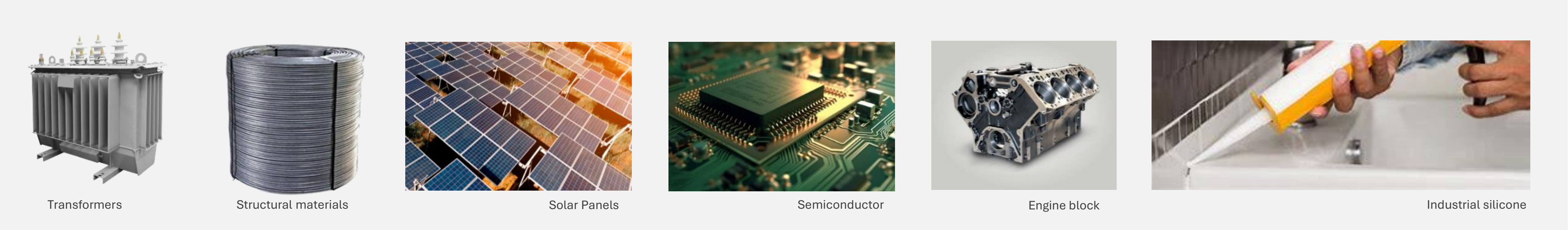
1.1. Overview

Ferroalloys are metallic materials composed of iron and some other chemical element, such as manganese, silicon, chromium, and nickel. They are used in metallurgical production to confer desirable properties to metals. They are mainly intended for the production of different types of steel[1], contributing as an important input to the improvement of the quality of steel products by adding specific characteristics according to the alloyed element.

Silicon metal is a semimetal, usually classified in the group of ferroalloys due to its similarity in industrial processing, obtained by the carbothermic reduction of silicon (quartz) sources in electric furnaces, but with different applications. The Si-metallic metallurgical grade, through refinement and purification processes can give rise to the Si-metallic chemical grade, solar grade and electronic grade.

Figure S1: Examples of applications of ferroalloys and silicon metal in economic sectors

Source: Abrafe (2024)



The Brazilian industrial sector of ferroalloys and metallic silicon contributes to the decarbonization of the metallurgical chain and obtaining new strategic materials for the energy transition, driven by the growing demand for increasingly specialized metals, as well as for the components necessary for the manufacture of solar panels and batteries.

[1] Types of steel, such as: stainless steel, tool steel, micro alloyed steels (ABNT NBR 8643 Iron and steel products).

1.1.1. Types of alloys and applications

Ferrosilicon (FeSi): it is a ferroalloy of iron and silicon, usually with silicon contents between 15% and 90%. Ferrosilicon is widely used in the steel industry to deoxidize steel and improve its mechanical and magnetic properties.

Ferro-Nickel (FeNi): ferroalloys with a nickel content between 15% and 80%. Most stainless steel contains about 8 to 10% nickel, and is mainly used in the production of stainless steel.

Iron-Chromium (FeCr): ferroalloy of iron and chromium in different proportions, essential in the production of specified stainless steels with higher corrosion resistance and hardness.

Ferro-Manganese (FeMn): ferroalloy iron and manganese, mainly used in steelmaking to improve its hardening properties and strength.

Ferro-Niobium (FeNb): ferroalloy with a niobium content of 60 to 70%, the main source of niobium in the manufacture of High Strength and Low Alloy Steels, applied in high-tech projects such as electric vehicle batteries, magnetic resonance equipment, airplane turbines, particle accelerators, rockets and space probes.

Iron-Silicon-Manganese (FeSiMn): ferroalloy mainly used in the steel industry as a deoxidizer and in the specification of mechanical properties of steel. Its composition increases wear resistance, hardness and ductility, making it essential for the production of structural and high-strength steels, in addition to contributing to the purity and metallurgical quality of special steels.

Iron-Silicon-Chromium (FeSiCr): ferroalloy mainly used in the production of stainless steels and corrosion-resistant alloys. Its main function is to introduce chromium and silicon into the steel, elements that increase resistance to corrosion and oxidation at high temperatures, as well as contributing to the hardness and stability of the material.

Silicon Metal: Silicon metal is usually classified in the group of ferroalloys due to the similarity in the production process, being obtained by the carbothermic reduction of silicon (quartz) sources in electric submerged arc furnaces. Depending on its specification, degree of purity, and application, silicon is classified as metallurgical, chemical, solar, or electronic grade. Some of its main applications are as follows:

- **Aluminum Metallurgy:** silicon source for forming alloys with aluminum, applied in various industrial segments.
- **Chemical industry:** production of silicones. The milled silicon reacts with methyl chloride in a fluidized bed reactor to obtain silanes, which are later derived for the production of silicones or ultra-purified silicon for the electronics or photovoltaic industry.
- **Energy:** silicon is the crucial element in the production of photovoltaic solar cells.
- **Electronics Industry:** used in the production of semiconductors and electronic devices, being essential in the manufacture of chips and integrated circuits.

1.2.1. Applications in the Use of Ferroalloys and Silicon Metal

Ferroalloys and silicon metal have several applications, some of which stand out, such as:

Structural materials: ferroalloys are essential in the manufacture of steel, used in beams, pillars and other structures. Silicon metal is the main alloying element for aluminum alloys, present in door and window frames. In addition, metallic silicon is the main raw material for the manufacture of silicones, present in sealants and adhesives for finishes in civil works. Silica fume or silica fume, a by-product of the manufacture of ferrosilicon and silicon metal, is used as an additive for concrete, contributing to the improvement of its physical and mechanical properties.

Automotive: ferroalloys play a key role in the production of high-strength, durable, and safe steels. They are used, for example, to deoxidize steel and improve its mechanical properties, ensuring the safety and reliability of vehicles. Aluminum, high-silicon castings, such as engine blocks and lightweight structural parts, contribute to reducing fuel consumption.

Electronic devices: silicon also stands out in electronic devices such as smartphones, tablets and computers. It is the main material used in the manufacture of semiconductors, essential components for the operation of these devices.

Renewable energy equipment: silicon metal plays a crucial role in the manufacture of photovoltaic solar cells. These cells are essential for the production of solar energy, a clean and sustainable source of electricity. Silicon is used in the composition of solar panels, where it converts sunlight into electrical energy.

Food industry: equipment used in food production and processing, such as machinery, ovens, tanks, pipes, refrigerators, and kitchen containers, stainless steels, produced from iron-chromium and iron-nickel, are widely used due to their corrosion resistance and ease of cleaning.

Cosmetics and hygiene materials: silicones are present in the most innovative skin care products, such as creams, shampoos and deodorants.

Hospital supplies: iron-chromium and iron-nickel are present in stainless steel surgical instruments. Silicones, which are produced from metallic silicon, are present in hospital equipment, surgical prostheses, and even medications, such as dimethicone, a medical silicone indicated for the relief of excess gas in the stomach or intestine.

1.2. Production process

The production of ferroalloys and silicon metal is a highly energy-intensive process, essential for several industries, such as steel and electronics. This process uses electric reduction furnaces, which operate at high temperatures to convert metal oxides into iron-containing alloys or silicon metal, by means of chemical reduction reactions.

Production begins with the mixture of raw materials, such as ores of the desired metal and a source of carbon, which can be of mineral or vegetable origin. This mixture is subjected to high temperatures in electric furnaces, where the use of electricity is intensive. Efficiency in energy consumption is a critical variable, enabling large-scale production and contributing to the reduction of production costs.

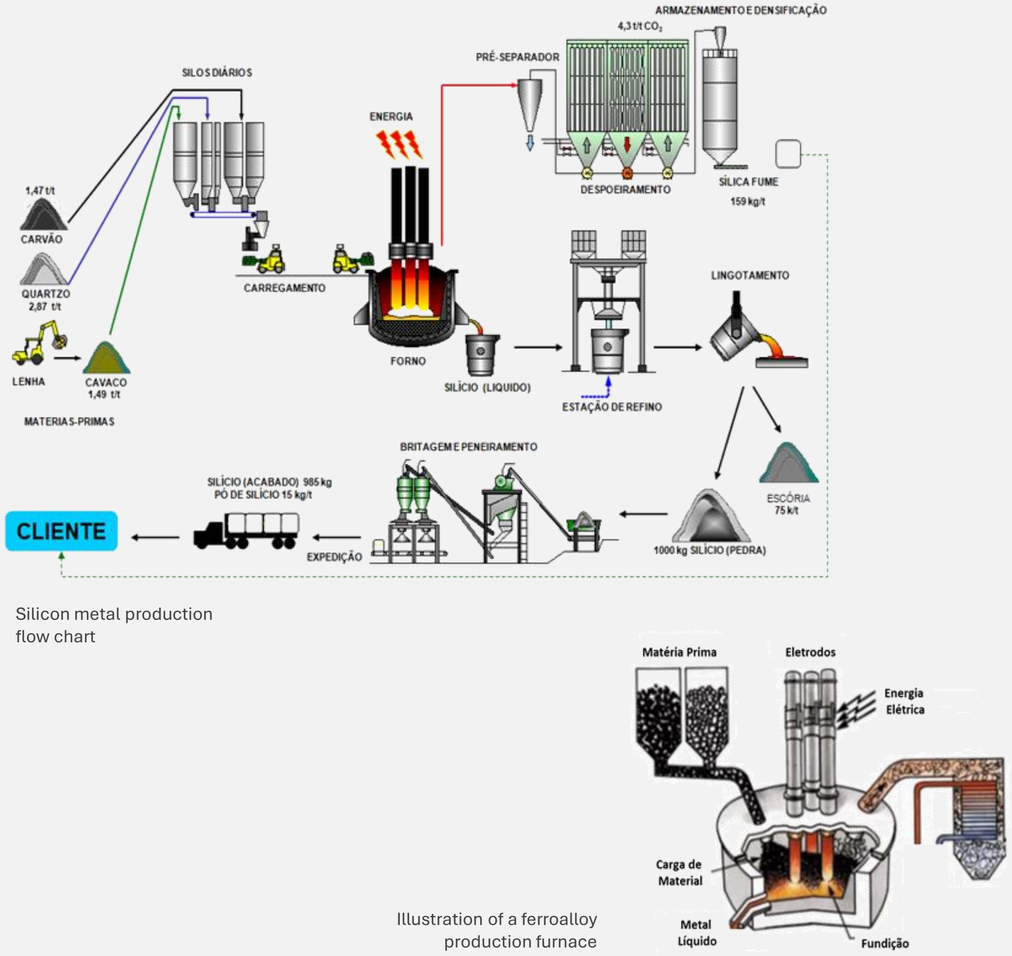
In electric arc furnaces, the passage of electric current between the electrodes generates heat, melting the charge and promoting the reduction reaction in the presence of carbon, which transforms metal oxides into ferroalloys or metallic silicon. During operation, the gases generated are captured and undergo particulate matter removal processes, contributing to the sustainability of the process.

In the case of ferroalloys, the desired properties – such as the proportion of iron and alloying elements (nickel, chromium, manganese, silicon, among others) – determine the type of furnace, the inputs and the operational parameters applied. Production requires strict quality and process control, ensuring that ferroalloys or silicon metal meet the required specifications.

The Brazilian ferroalloys and silicon metal industry has evolved towards technologies that increase energy efficiency and sustainability, such as the use of biomass and other renewable energy sources, replacing fossil fuels. These advances are particularly relevant in the context of the energy transition, putting Brazil in a competitive position to meet the low carbon emission requirements demanded by the global market.

Figure S2: Flowchart of the Production Process for Ferroalloys and Metallurgical Silicon

Source: Abrafe (2024)



Silicon metal production flow chart

Illustration of a ferroalloy production furnace

1.2.1. Production Costs

The production of ferroalloys involves several cost factors that directly affect competitiveness in the international market, among which the following stand out:

Electrical Energy: The production of ferroalloys is highly electro-intensive, requiring a large amount of electricity to feed the reduction furnaces, which presents itself as a comparative advantage for Brazil in relation to the world average and OECD countries, due to the high degree of renewability of the national electricity matrix.

Reducers: Essential in the reduction process, reducers, such as charcoal, coal, coke and other carbonaceous materials, are used to remove oxygen from metal oxides. Brazil has an advantage in the use of renewable charcoal, but it depends on imported coke and coal, which raises costs. On the other hand, countries such as China and South Africa, with abundant access to coal, are able to significantly reduce the cost of production.

Electrodes: Fundamental to the melting-reducing process, carbon electrodes are used to conduct electric current to the furnace, being consumed during the process. The cost of electrodes can vary depending on factors such as global demand and the price of raw materials (petroleum coke, pitch, and anthracite). Brazil imports a large part of these raw materials or even the electrodes, which can increase production costs, especially at times of high global demand, as has been observed in recent years. In comparison, countries that produce electrodes or have greater access to the material, such as China, may have a competitive advantage in this regard.

Raw Materials (ore): The cost of raw materials, such as quartz, iron ores, chromium, nickel, and manganese, varies depending on the location of the mines and the logistics of transportation. In Brazil, ore is abundantly available, which is an advantage, but the distance between mines and production centers and the deficiency of modal infrastructure can increase logistics costs.

Environmental and Regulatory Costs: The costs associated with actions to mitigate greenhouse gas (GHG) emissions can be mitigated in the Brazilian case, due to the sustainable alternatives that the country has, such as the use of charcoal in industry to replace fossil sources that are traditionally used in most ferroalloy-producing countries.

Workforce: In Brazil, the cost of labor is moderate compared to other ferroalloy-producing countries, which makes this cost factor less relevant than the others.

1.3. Brazil's competitiveness in the International Ferroalloys Market

Brazil

It has strong competitive potential, especially due to its renewable energy and the use of charcoal in the production of ferroalloys. However, the reliance on imported reducers such as coke and electrodes.

China

One of the largest producers of ferroalloys and has a significant competitive advantage due to its inexpensive access to coal, electrodes, and power. Despite increasing environmental pressure, the cost of production in China is still lower than in many other countries.

South Africa

It has abundant access to coal, which helps reduce production costs. However, infrastructure problems and political challenges can compromise competitiveness in times of crisis.

United States

It has relatively competitive energy costs compared to other developed countries, thanks to abundant access to natural gas and low-cost energy resources. However, the cost of reducers and electrodes is still high, which may reduce competitiveness compared to regions such as Brazil, China, and South Africa.

Europe

It faces significantly higher energy costs due to reliance on imported energy sources and environmental policies. Additionally, the costs of reducers and electrodes are high, making the production of ferroalloys in the region less competitive compared to other areas of the world.

Brazil's competitiveness in the ferroalloys market is mainly determined by access to sustainable energy resources such as charcoal and the abundance of mineral resources, but faces challenges with the import of electrodes and energy costs, in addition to the need to import reducers.

1.3. Brazil's competitiveness in the International Ferroalloys Market

The global ferroalloys market reached US$ 53.4 billion in 2023 and is expected to reach around US$ 91.8 billion by 2032, which would represent an average growth of 6.2% p.a. Among the main factors for this, the following stand out:

- expansion of the global steel industry, particularly in the rapidly developing economies of Asia-Pacific
- the growing need for high-strength, low-alloy steels in various industries
- technological advances in production processes and
- the rapid process of urbanization and industrialization in these regions increases the need for steel and, consequently, ferroalloys.

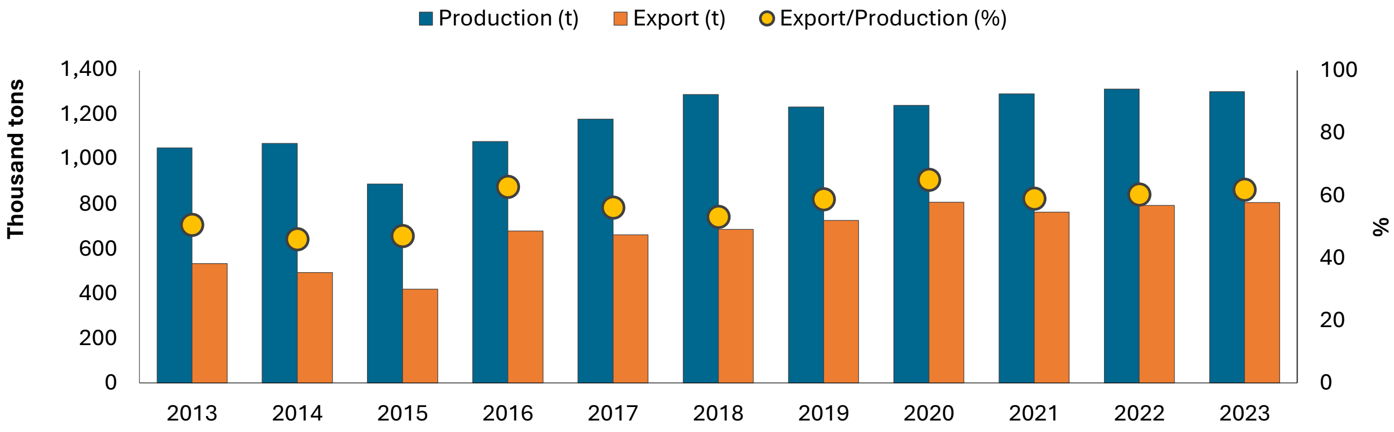
In Brazil, the sector's revenue reached R$ 35.4 billion in 2022, of which R$ 26.1 billion in exports (73.7% of total revenue).

The sector's exports, when associated with import substitution[1] contributed with the equivalent of 11% of the Brazilian trade balance in 2022.

The national production of ferroalloys and silicon metal has surpassed the mark of 1 million tons per year since 2018, reaching 1.30 million in 2022.

Figure S3: Production and Export Values of ferroalloys and silicon metal (thousand tons)

Source: Abrafe (2024)



Despite the challenges faced, characterized by the high level of insecurity that compromised the recovery capacity of post-pandemic economies, combined with the Russia/Ukraine international conflicts, Brazil stood out in the increase in production and exports of ferroalloys and silicon metal, maintaining the expectation of continued growth in the sector.

[1] Import substitution refers to the national production of the sector, meeting the need for imports of ferroalloys and metallic silicon for domestic consumption. It is calculated by the total revenue of the ferroalloys and silicon metal sector over the balance of trade in Brazil.

1.4. National overview

1.4.1. History of the ferroalloys segment in Brazil

The ferroalloys and silicon metal sector in Brazil has its origins in the 18th century, but gained significant momentum in the early 20th century with some milestones:

In 1906...

... a small laboratory at the School of Mines in Ouro Preto, Minas Gerais, produced iron manganese using a rudimentary furnace.

During World War I, the laboratory was expanded and started to produce ferromanganese for the workshops of the railway network, due to the shortage of imported materials. However, experiments in electric furnaces were interrupted in 1919, leading to the decommissioning of the School of Mines Plant.

In the 1930s, small companies linked to hydroelectric installations emerged, such as the Companhia Brasileira de Carbideto de Cálcio (CBCC), founded in 1912, the Companhia Nickel do Brasil, created in 1932, Elquisa-Eletroquímica Brasileira SA, founded in 1934, and the Companhia Nacional de Ferroligas, established in 1940.

These companies were instrumental in the development of the sector, which initially faced challenges such as the low availability of electricity and a small domestic market. **The Companhia Siderúrgica Nacional, created in the same period, was a milestone for the growth of the sector.**

In the 1970s and late 1980s, the sector experienced a great development, driven by large hydroelectric projects and expansion of the steel industry. In the 1970s, with incentives from SUDENE, some ferrosilicon and silicon metal companies settled in the northern region of Minas Gerais, such as LIASA, Minas Ligas, Inonibrás and Eletrosilex.

At the end of the 1980s, the implementation of the Tucuruí hydroelectric plant and the Grande Carajás Project made it possible to produce metallic silicon in the northern region with Camargo Corrêa Metais (CCM). During this period, Brazil became the 4th largest producer in the world and the 3rd largest exporter of ferroalloys.

From the 1990s onwards, there was an increase in electricity prices, the opening of the Brazilian market, currency stabilization and devaluation of the dollar, which made the sector undergo significant restructuring. Many units were deactivated and the remaining ones had to adapt to the new quality and productivity requirements.

The sector was also affected by the rationing of electricity suffered in 2001, when production suffered a significant reduction. Since 2013, the sector has been restructuring and resuming its growth and, more recently, there has been a significant expansion in the production of ferronickel and ferroniobium in Brazil.

The production of ferronickel has grown, especially to serve the stainless steel industry, while ferro-niobium has consolidated Brazil as one of the world's leading producers. Currently, Brazil has a production capacity of about 1.3 million tons per year, has about 100 furnaces in operation, occupies the 6th position among world producers and is able and mature to evolve and meet future demands.

1.4.2. Production and Export

The production of the Ferroalloys and silicon metal sector in Brazil was around 1 million tons over the years 2005 to 2023, with a slight drop in 2014, due to the water crisis that occurred that year, followed by stable growth in the following years. Exports reached their highest peak in 2020, with a volume of 810 thousand tons, which was equivalent to 66% of national production that year.

In recent years, exports have stabilized between 500 and 600 thousand tons, and the proportion between the total exported and produced varied between 50% and 66% over the period 2005 – 2023, evidencing the sector's export predominance.

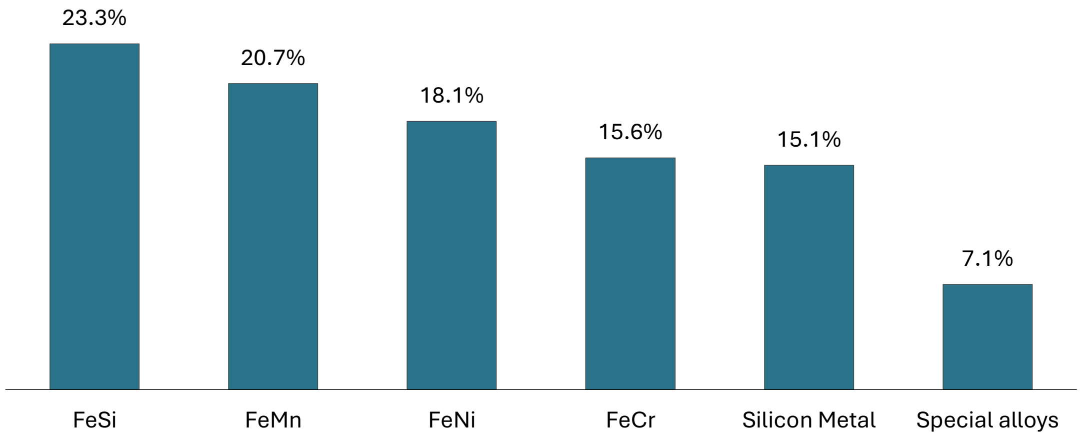
In 2023, production reached a volume of 1.29 million tons, of which:

- 23.3% silicon-based ferroalloys
- 20.6% manganê-based ferroalloys
- 18.1% nickel-based ferroalloys
- 15.6% chromium-based ferroalloys
- 15.1% silicon metal, and
- 7.1% of special ferroalloys.

The sector exported 796 thousand tons in 2023, that is, 62% of production.

Figure S4: Share of each type of alloy and silicon metal in production in 2023

Source: Abrafe (2024)



> The Brazilian trade balance registered a record balance of US$ 98.8 billion in 2023 (approximately R$ 493 billion), according to data from the Secretariat of Foreign Trade (Secex) of the Ministry of Development, Industry, Commerce and Services (MDIC). Exports from the ferroalloys and silicon metal sector, added to import substitution[1], contributed with R$ 27.4 billion, representing 5.5% of the Brazilian trade balance in 2023.

[1] Import substitution refers to the national production of the sector, meeting the need for imports of ferroalloys and metallic silicon for domestic consumption. It is calculated by the total revenue of the ferroalloys and silicon metal sector over the balance of trade in Brazil.

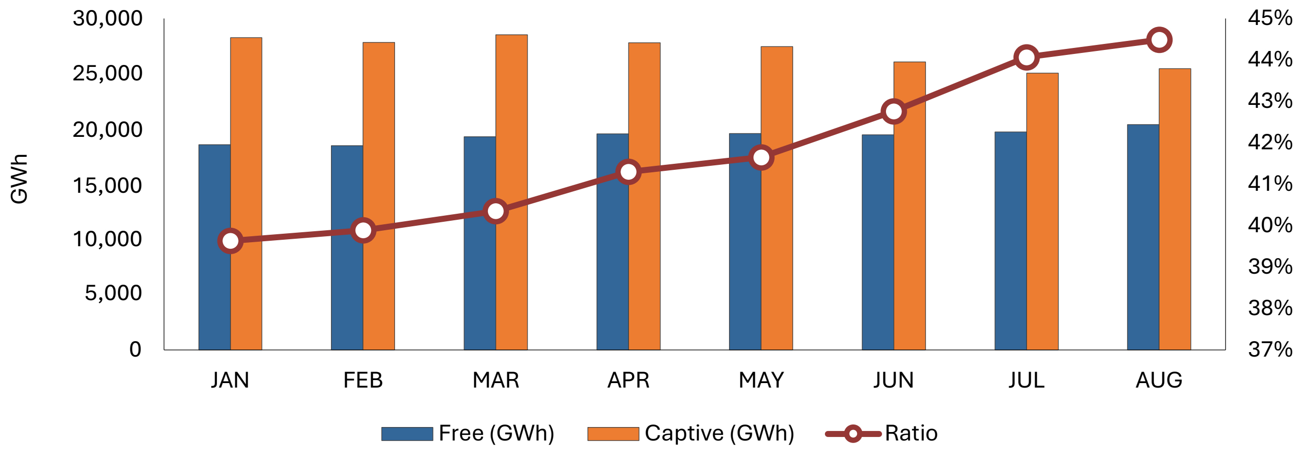
1.4.3. Electricity consumption

The ferroalloys and silicon metal sector is considered to be strongly electro-intensive, with electricity being a significant part of its operation. In 2023, the total consumption of this sector reached a significant level (9,609.8 GWh), representing the use of 82% of the installed capacity of industrial plants. This amount of consumption also corresponds to approximately 4.5% of the entire free energy market in Brazil.

The free energy market has played an increasingly important role in recent years and accounted for 41% of all electricity consumption in the country in 2024[1]. This demonstrates a growing adherence of industries to the migration to the free market, in search of better tariff conditions and greater predictability in energy costs, a crucial factor for the competitiveness of electro-intensive sectors.

Figure S5: Free and captive electricity consumption (GWh) from January to August 2024 (left axis) and ratio [Free Consumption]/[Captive Consumption] (right axis)

Source: Data from SIMPLES (EPE, 2024d).



This interdependence between the production of ferroalloys and silicon metal and the electricity market reflects the ongoing challenge of balancing growing demand with renewable and cost-effective energy sources, ensuring the economic viability of an industry that is essential to various economic sectors.

[1] Amount calculated until August 2024 and available on the Electricity Consumption Panel, accessible at Dashboard Resenha

1.4.4. Job Creation and Human Development

The ferroalloys and silicon metal sector has stood out not only for its industrial relevance, but also for its significant contribution to job creation and human development in the regions where it operates. Since 2020, the sector has recorded continuous growth in job creation, reaching its highest peak in 2023, with the generation of 62,135 jobs, of which 13,808 are direct jobs and 48,327 are indirect jobs. This expansion of the workforce reflects the positive impact that the sector has on the local and national economy.

In addition to job creation, the sector plays a crucial role in regional development, especially in municipalities in the interior of the states where its factories are installed. With a presence in 23 municipalities in 8 Brazilian states, the sector has contributed significantly to the increase in the Human Development Index (HDI) of these locations. According to data from IBGE and IPS Brasil, the municipalities that house factories in the sector have an HDI 5% higher compared to neighboring municipalities with a similar population, with emphasis on the HDI related to Education, which is 4 p.p. higher[1].

Figure S6: HDI Comparison 2010

Source: IBGE – Atlas Brasil (2024)

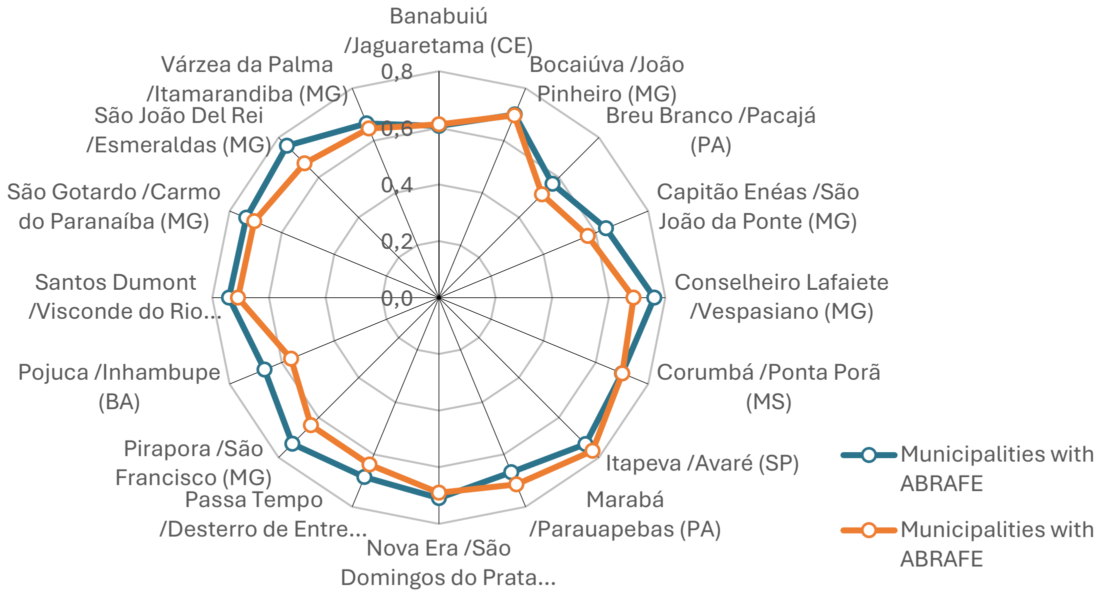


Figure S7: Comparative HDI 2000 - 2010

Source: IBGE – Atlas Brasil (2024)

[1] 4 p.p. refers to 4 percentage points higher.

When compared to the average HDI of Brazil, these municipalities also present superior results, which highlights the role of the sector in advancing the living conditions of local populations. The Social Progress Index (SPI), which evaluates quality of life in a multidimensional way, confirms this trend.

When analyzing the most recent data, it can be seen that the municipalities operating in the ferroalloys and metallic silicon sector have an IPS evaluation on average 6% higher than other locations, with a significant highlight in the opportunities index, which is 10% higher.

These numbers demonstrate that the sector not only generates jobs and moves the economy, but also drives concrete improvements in living conditions and opportunities offered to the populations of the regions where it is present, contributing directly to human and social development.

Figure S8: IPS 2024 Comparison

Source: IPS Brasil (2024)

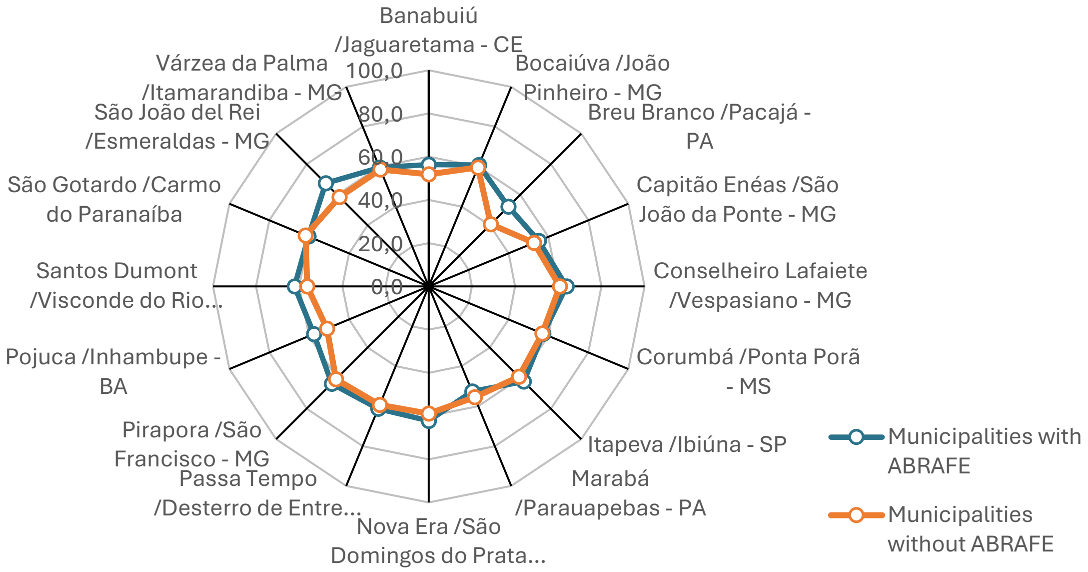
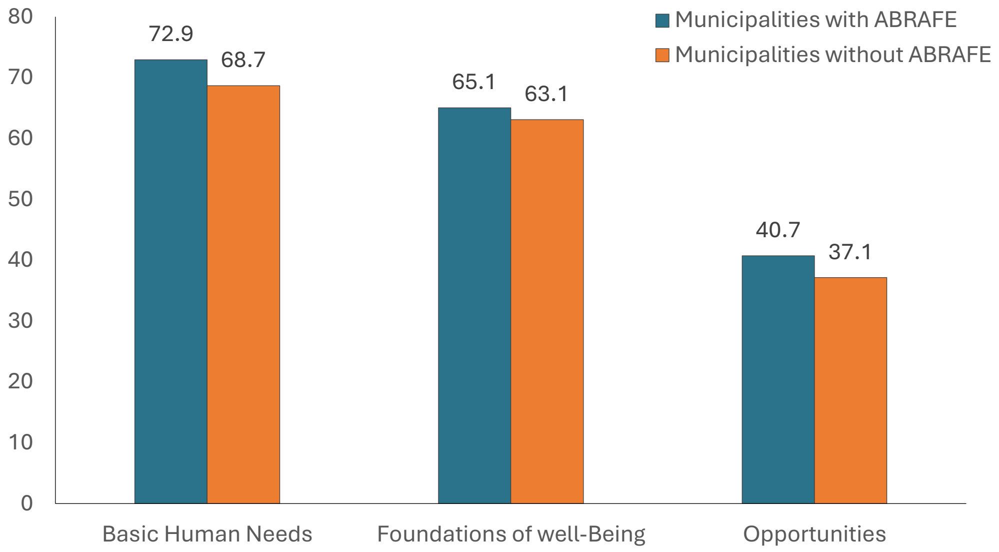


Figure S9: Dimensions of IPS Brazil 2024

Source: IPS Brasil (2024)

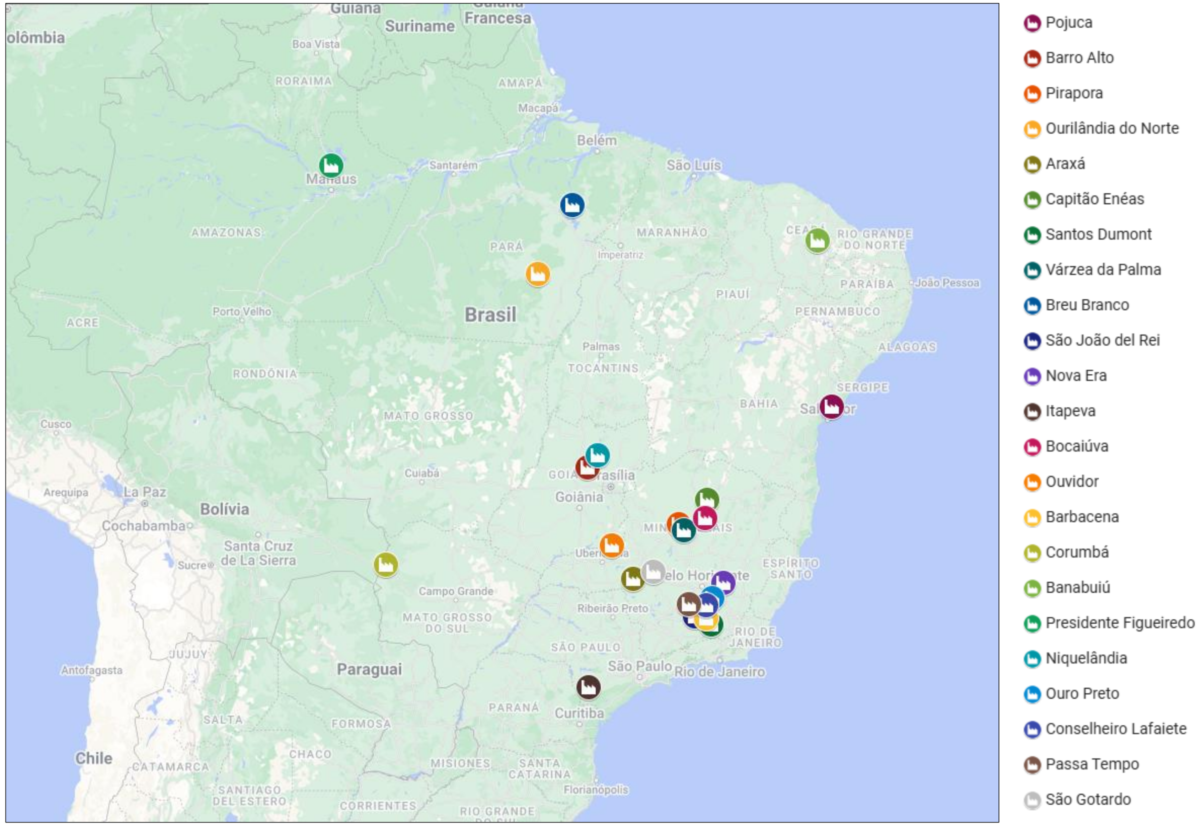


1.4.5. Main companies and locations

The main ferroalloy producing companies in Brazil are concentrated in the center-south of the country, especially in the state of Minas Gerais, where more than half of the companies listed below are located.

Figure S10: Geographical location of the main ferroalloy companies in Brazil

Source: Abrafe (2024)[1]



[1] Map of locations available at https://www.google.com/maps/d/u/0/edit?mid=1lwMFDtVLzwBwrw3hbO3gKdgwlkOmrlM&usp=sharing

Table S1: Highlights of the main ferroalloy companies in Brazil
Source: Abrafe (2024)

Company	State	Key highlights
BOZEL	MG	Largest producer of Calcium Silicon in the West, being also a producer of other ferroalloys in numerous granulometries
DOW	PA e MG	2 silicon metal production units, one in the State of Pará (CCM) and the other in Minas Gerais (CBCC)
ELETROLIGAS	MG	Production of High Carbon Ferro-Manganese and Ferro-Silicon-Manganese
FERBASA	BA	Mining, metallurgy, forest resources and renewable energy. The only integrated producer of ferro-chromium in the Americas
FERLIG	MG	It currently produces 12-16% FeSiMn, with a capacity of 2,000 tons per month
FERMAR	PA	Ferro-manganese using three electric reduction furnaces, two of 12.5 MVA and one of 10.5 MVA
Granha Ligas	MG e MS	It produces manganese ferroalloys and is positioned among the largest national producers
Inonibrás	MG	Production of ferrosilicon and inoculants focused on metal refining processes in steel and cast-iron foundries
LIASA	MG	Silicon metal production
LIBRA LIGAS	CE	Ferrosilicon 75% and inoculants
Maringá Ferro-Liga	PR	Silico-manganese iron and high carbon manganese iron, through five electric reduction furnaces
MINASLIGAS	MG	Ferro silicon, Silicon Metal and Microsilica
Nova Era Silicon S.A.	MG	Ferro silicon to serve the domestic and international market
RIMA Industrial	MG	Production and marketing of silicon and magnesium-based alloys
CBMM	MG	World leader in the production and marketing of niobium products
Mineração Taboca	AM	One of the main producers of tin and niobium in Brazil
Anglo American	MG e GO	Iron and nickel ore mining and ferronickel production
CMOC	GO	Operates niobate and phosphate mines, ferro-niobium alloy production
Vale-Onça Puma	PA	Nickel ore reduction and smelting process and ferronickel production
Nexus Ligas	MG	Produces different manganese alloys

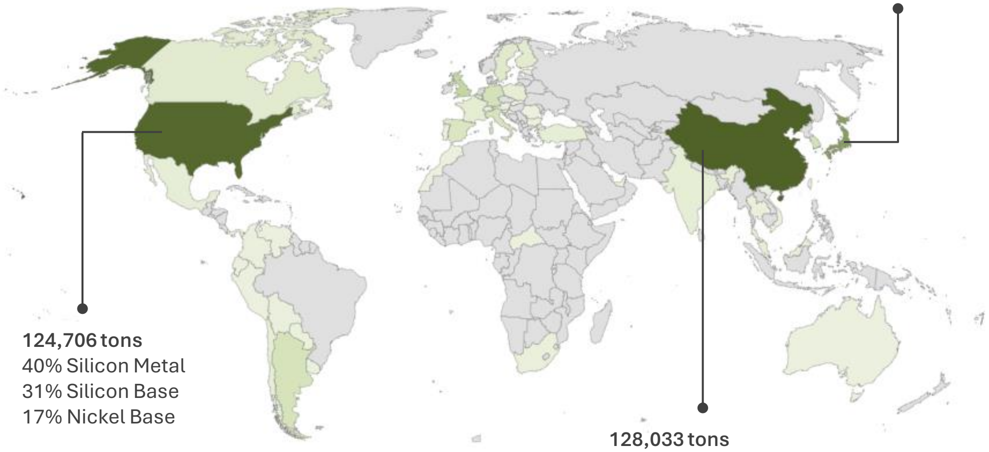
1.4.6. Destination of ferroalloys and silicon metal exports in 2023

In 2023, ferroalloy exports were mainly destined for China (15.8%), the United States (15.45%) and Japan (11.9%). The countries of the European Union were in fourth place, followed by the United Kingdom. However, about 40% of exports were destined for other countries, such as Australia, India, South Africa, Turkey, Mexico, Canada and practically all of South America's neighbors.

Table S2: Destination of Brazilian exports by type of alloy

Source: Abrafe (2024)

Types of alloys (t)	China	USA	Japan	EU[1]	UK	Other	Total
Manganese Base	-	911	-	3,235	-	47,511	51,657
Silicon Base	13,973	39,102	70,488	15,756	194	81,604	221,118
Chromium Base	20,565	7,243	1,806	7,373	54	13,282	50,323
Nickel Base	56,385	21,599	1,130	23,111	27,699	82,171	212,095
Special (FeNb)	36,534	6,058	5,406	17,658	50	23,533	89,239
Silicon Metal	576	49,793	16,966	10,386	31,843	74,299	183,863
Total	**128,033**	**124,706**	**95,797**	**77,519**	**59,841**	**322,400**	**808,295**
Share (%)	**15.8%**	**15.4%**	**11.9%**	**9.6%**	**7.4%**	**39.9%**	**100%**



Among the types of alloys exported by Brazil, Silicon-based and Nickel-based alloys and Silicon Metallic alloys account for more than ¾ of the total tons and have export shares of 27.4%, 26.2% and 22.7%, respectively.

[1] Entry into continental Europe from the port of Rotterdam in the Netherlands

1.5. Technological developments

Some technological advancements are benefiting the ferroalloys industry through innovations such as:

Energy-efficient furnaces and automation in material handling, which optimize production costs and improve the environmental footprint.

Digitalization and the application of practices associated with Industry 4.0 that enable real-time monitoring and

Predictive maintenance, increasing operational efficiency.

In Brazil, one of the notable technological developments is the technology of self-baking electrodes for the production of silicon metal. This innovation provides better energy use and reduced production costs, standing out as a significant advance in the industry. The growing demand for higher value-added steels requires lower and lower levels of impurity, since purer raw materials drive the improvement of ferroalloy refining techniques.

At the same time, the growing trend of applying more sustainable practices associated with compliance with environmental regulations in the production processes, such as the use of silica fume and the development of self-reducing briquettes. Thus, the main technologies are the following:

- Electric Reduction Furnace Control Technologies
- Self Baking Electrodes for Silicon Metal Manufacturing
- Silica fume
- Self-reducing briquettes
- Improvement of Ferroalloys and Silicon Refining Techniques.

1.5.1. Electric Reduction Furnace Control Technologies

In recent decades, the design and operation of electric furnaces has undergone significant advancements, with the industry moving toward greater power and maximizing operational efficiency. This drive for greater efficiency, coupled with more challenging operating conditions and greater ore variability, has required the evolution of furnace instrumentation and control systems to ensure safe and efficient operation.

Control systems that seek the best adjustment of electrical yield combined with the control of mass balance to optimize metallurgical yield are widely used. An important aspect in optimizing the operational efficiency of furnaces is the integration and coordination of upstream and downstream equipment with furnace operation. Recent advances in instrumentation are noted, some of which are still under development, that will continue to shape the next generation of metallurgical furnace operations. Emerging technologies promise even more improvements in the accuracy, reliability, and efficiency of control systems.

Figure S11: Example of an electric reduction furnace (left) and a control room (right)

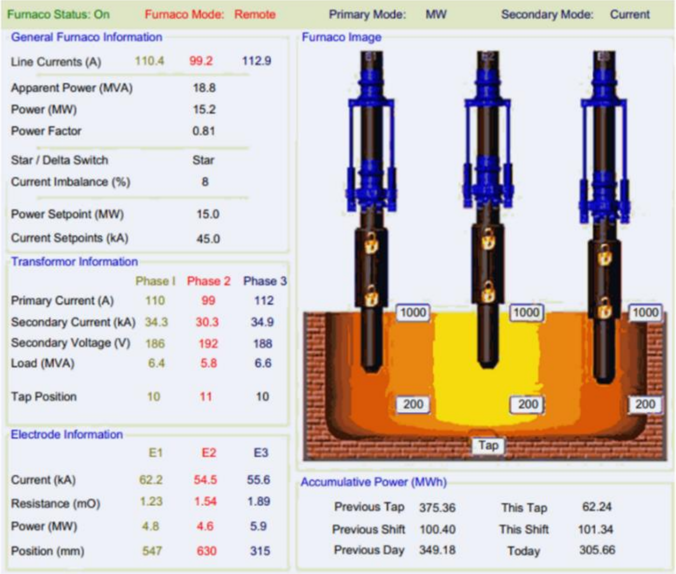
Source: Abrafe (2024)

(Electric Reduction Oven)

(Control room)

Figure S12: Furnace Control Supervisory System Screen

Source: Abrafe (2024)



(Furnace Control Supervisory System)

1.5.2. Self Baking Electrodes for Silicon Metal Manufacturing

Ferroalloys are produced in electric reduction furnaces and use carbon electrodes to conduct electrical energy to the reaction zone. Self-baking electrodes, known as Soederberg electrodes, are usually used.

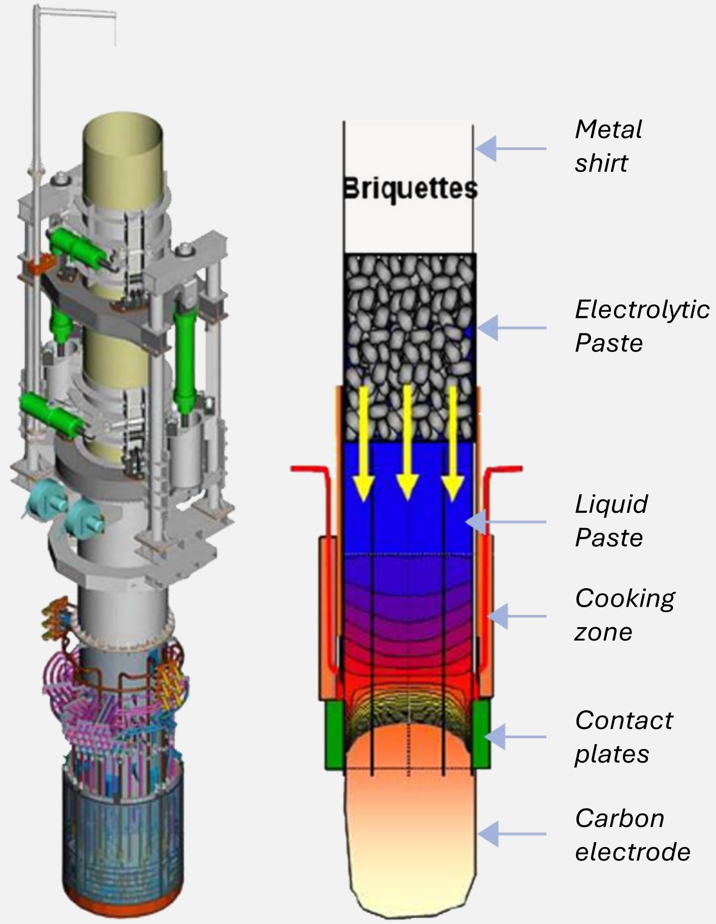
Soederberg self-baking electrodes are widely used in the ferroalloy industry due to their efficiency and cost-effectiveness. Composed of a cylindrical steel jacket, which is continuously fed at the top of the electric furnace by electrolyte paste made of calcined coke and pitch, they constitute an electrode column. The steel jacket works as a form, providing mechanical sustainability and conducting the electrical energy that generates heat for the process. As the electrode is consumed, the slurry is heated by the heat of the process itself, undergoes softening and carbonization, turning into solid carbon and the jacket melts, incorporating iron into the alloy being produced. From then on, the electrode, now formed by solid carbon, conducts electricity to the reaction zone, withstanding the highest temperatures.

The main advantage of Soederberg electrodes is cost reduction, as they eliminate the need for pre-baking. In addition, they allow for continuous operation, providing a constant supply of electrodes and avoiding interruptions in production. Its adaptability to different furnace sizes and production demands is also a strength. However, the use of these electrodes requires strict control of the quality of the paste and operating conditions, as well as proper management of pollutant emissions released during the firing process.

These electrodes are essential for submerged arc furnaces (SAF) in ferroalloy production, due to their ability to be continuously fed and self-cooked, which makes them ideal for large-scale operations in the ferroalloys industry. However, due to the incorporation of iron by the use of steel jackets, Soederberg electrodes are not suitable for the manufacture of metallic silicon, which traditionally uses pre-fired electrodes.

In Brazil, there was an improvement in the design of shirts with the use of new materials, such as aluminum combined with stainless steel, making it possible to take full advantage of the technology in the production of metallic silicon, bringing a competitive advantage without prejudice to the specifications of the alloys produced.

Figure S13: Representation of a self-baking electrode
Source: Abrafe (2024)



1.5.3. Silica fume

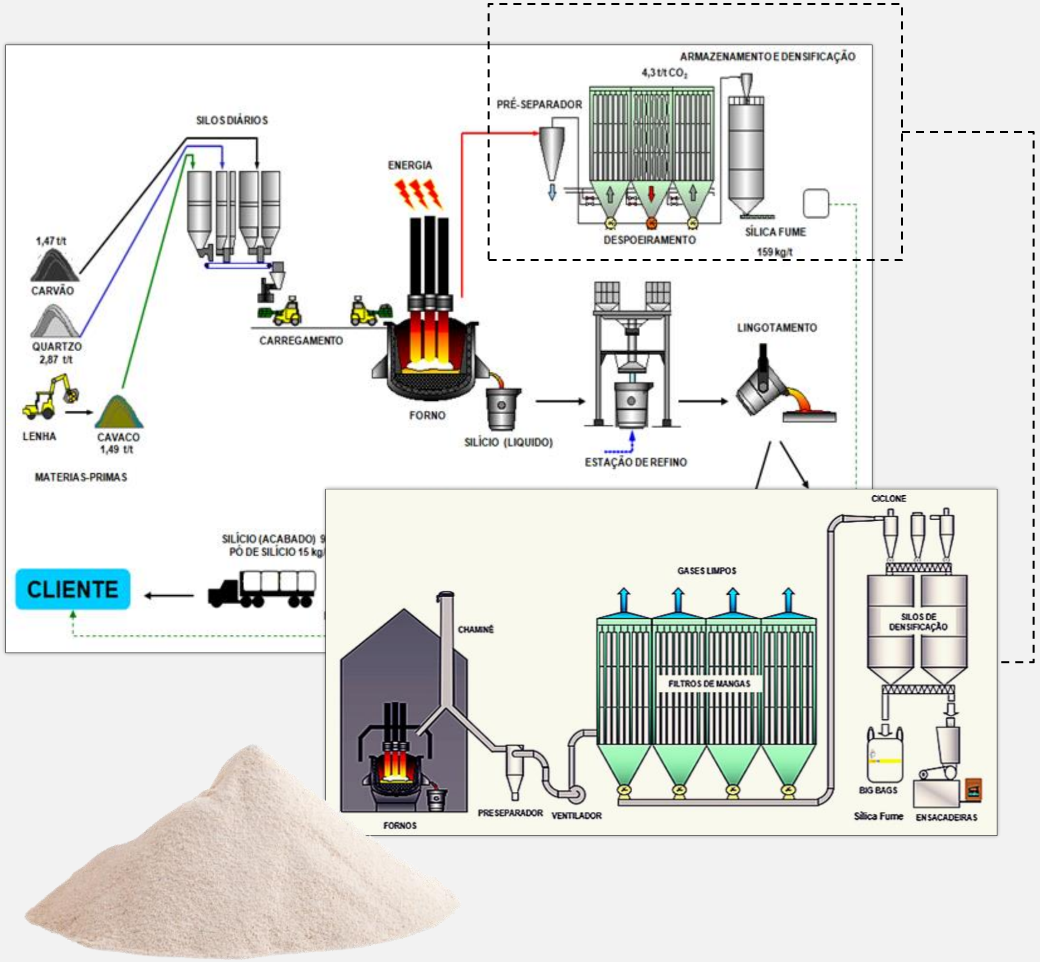
The ferroalloys sector has invested heavily in pollution control systems, especially in bag filter units for the recovery of particulates from gaseous effluents from reduction furnaces. Fume silica, also known as "microsilica", is a byproduct resulting from the manufacture of ferro silicon or silicon metal. When the SiO-rich gas escapes from the furnace through the exhaust system, it is rapidly oxidized (SiO_2), forming silica fume, consisting of nearly spherical solid particles of SiO_2, with an average size of only ~0.15 millimeters. Previously discarded in the environment, fume silica is now transformed into a technological product with high added value, widely used in civil construction.

Silica fume increases the strength, fluidity and useful life of concrete, being used as a high-intensity amorphous pozzolanic addition in concrete or mortar. This transformation provides several benefits, such as reducing the permeability of the concrete, reducing exudation, improving flow properties, and increasing compressive and flexural strengths. Therefore, its use is especially indicated for reinforced concrete structures in highly aggressive environments, offering greater protection against the attack of salts and saline waters and, consequently, reducing the maintenance costs of reinforced concrete parts.

In addition, silica fume is applied in the refractory industry, improving the fluidity of refractory casting materials and increasing the resistance to temperature and thermal shock. The sector continues to invest in research and development to find new applications for silica fume, both in the construction and refractory industry and in the ceramics and fertilizer industries. Thus, the transformation of silica fume from a discarded by-product into a valuable technological product reflects a significant advance towards sustainability in the ferroalloys and silicon metal industry.

Figure S14: Schematic representation of the production of fume silica

Source: Abrafe (2024)

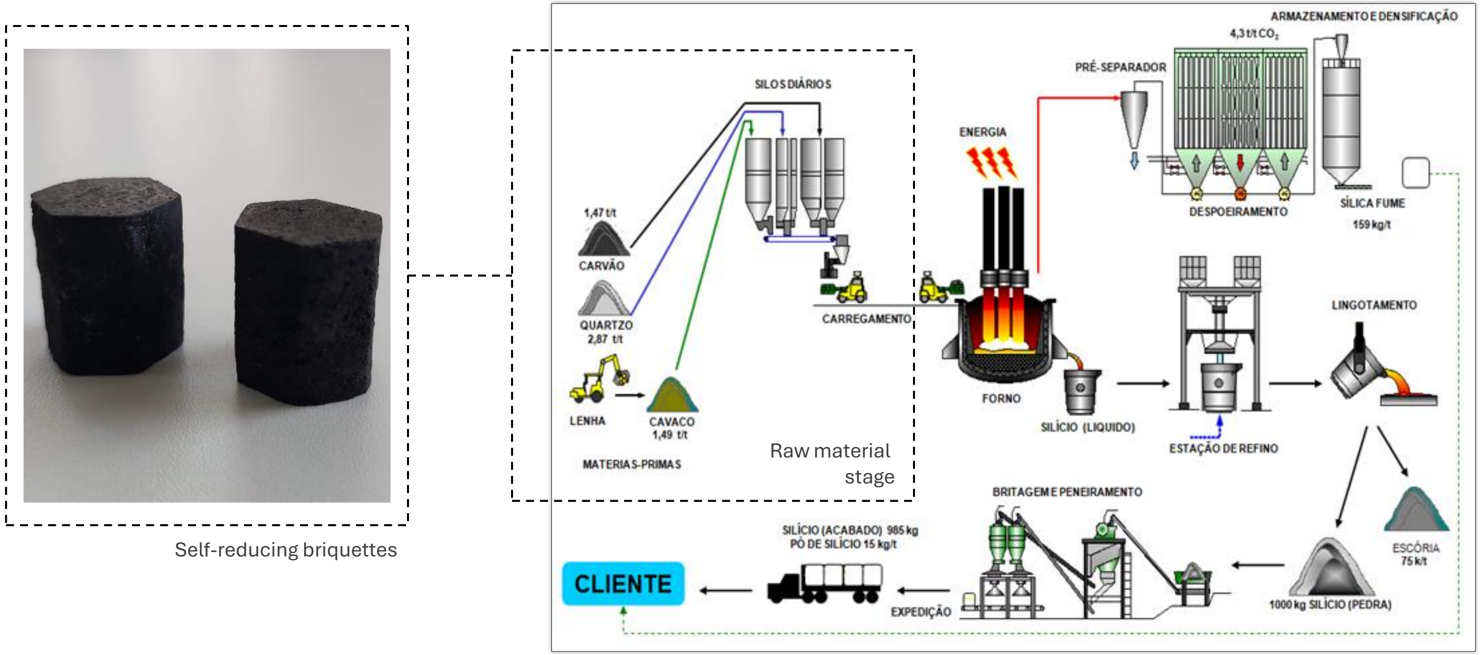


1.5.4. Self-reducing briquettes

Recently, the ferroalloys and silicon metal industry has been investing in the development of new applications for waste recycling and energy use, including self-reducing silica and carbon briquettes, combined in the proportion of silicon carbide formation, advancing a step in the manufacturing process of silicon alloys and improving the energy efficiency of the process.

Figure S15: Schematic representation of the function of self-reducing briquettes in the production process of silicon metal

Source: Abrafe (2024)



The use of self-reducing silica and carbon briquettes can replace initial steps in the production process of raw material necessary for the production of metallic silicon, constituting an alternative to increase the efficiency of the process of an industrial plant.

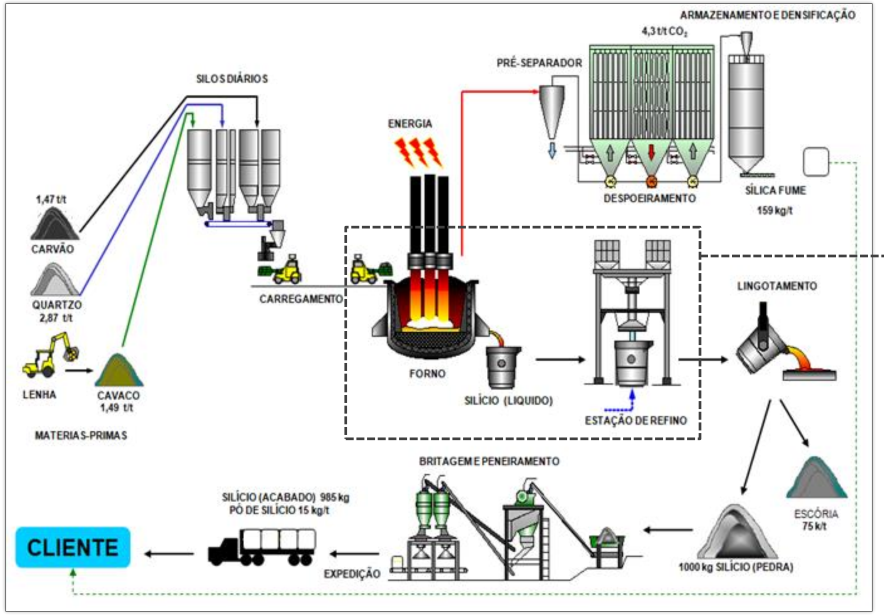
1.5.5. Improvement of Ferroalloys and Silicon Metal Refining Techniques

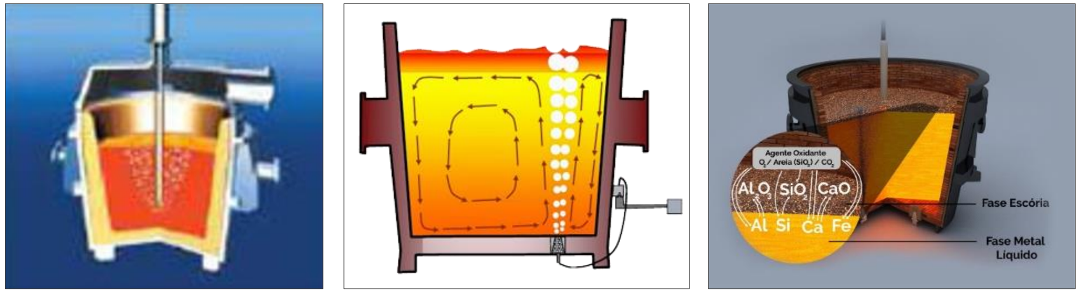
High efficiency of removal of the studied impurities that are harmful in obtaining steel are achieved with the continuous improvement of the control of raw materials and evolution of refining techniques. The determination and knowledge of the physicochemical properties of slag such as density, viscosity, interfacial properties and thermodynamic properties play a fundamental role in refining control. Thermodynamic models play a crucial role in the development of the refining process by determining the control parameters such as blowing time, oxygen flow and enrichment, and the composition of the synthetic slag.

The thermodynamic equilibrium between the metal and the slag is used to predict the behavior of the impurities and adjust the refining process to obtain alloys with low aluminum and calcium contents. The other non-refinable elements in the oxidizing process are monitored and controlled through strict control of the entry of the raw materials, being under controlled conditions. This technological development has resulted in a significant improvement in the quality of the alloys produced, which are essential to meet the requirements of the modern steel industry that demands increasingly pure materials.

Figure S16: Schematic representation of the refining techniques of ferroalloys and silicon metal

Source: Abrafe (2024)





Oxygen injection through the top of the bath (liquid metal)

Injection of gases via plug (porous), at the bottom of the pan

Illustration of the Reactions

1.6. New technologies and perspectives of the ferroalloys and silicon metal industry

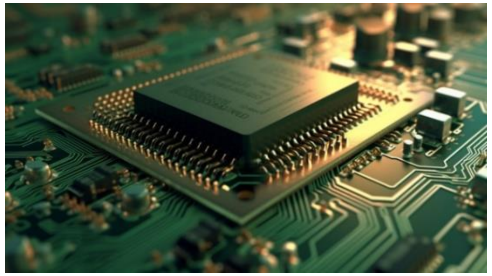
The ferroalloys and silicon metal industry evolves driven by substantial market growth and industry expansion globally. Emerging economies invest heavily in construction and infrastructure, increasing demand for steel and its associated ferroalloys, while new applications for silicon are present in the evolution of the chemical and electronics industry.

Among the changes seen in the world market, the demand for customized products in order to meet the specific requirements of advanced technology sectors such as aerospace and defense, and the participation of large and small companies focused on research and development of high-quality sustainable products stand out.

One of the fundamental prerequisites increasingly reinforced for operating in the segment has been the compliance with environmental regulations, which implies significant investments in cleaner production technologies and investment in pollution control systems, generating opportunities for innovation, such as the use and development of new applications for the fume silica obtained from the filtration of furnace effluent gases.

Figure S17: Examples of applications of new technologies in the ferroalloys and silicon metal industry

Source: Abrafe (2024)



Applications in the electronics industry for High-tech sectors

Sustainable product research and development

Use of ferroalloys in high-specification materials

Cleaner Production Technologies and Pollution Control Systems

> Advances in the use of biogenic coal stand out as examples of the application of technological innovation in the promotion of sustainability and operational efficiency in the ferroalloys and silicon metal segment.

1.6.1. Energy sources for the production of ferroalloys

1.6.1.1 Reducers (Carbon Source)

The production of ferroalloys, which are essential for many industries, relies heavily on carbon sources. These energy sources not only provide the heat needed for metallurgical reactions, but also act as reducing agents, removing oxygen from metal ores. The main sources of carbon used are charcoal and coal, each with its own specific characteristics, advantages, and challenges.

- Charcoal is widely used in the production of ferroalloys due to its specific properties and environmental advantages.
- It is produced from the carbonization of wood, in a process that involves controlled burning in special furnaces. Carbonizing wood removes hydrogen and oxygen, resulting in a carbon-rich material.
- Mineral coal is another important source of carbon in the production of ferroalloys. It is extracted from mines and has different varieties, such as anthracite, bituminous and sub-bituminous, each with specific properties.
- Mineral coal has a higher content of impurities compared to charcoal, which can affect the quality of the ferroalloys produced.
- Coal mining involves underground or open-pit extraction, followed by beneficiation processes to remove impurities and improve fuel quality.
- Coal is widely available in other countries and, in many cases, cheaper than charcoal, making it a viable option for many industries, particularly abroad.
- The use of coal is associated with environmental impacts, particularly with regard to the emission of greenhouse gases and pollutants.
- The high content of impurities can reduce the efficiency and quality of the final product.
- In Brazil, charcoal is mostly produced from planted eucalyptus forests, a practice that helps with environmental sustainability. Eucalyptus grows rapidly and is a renewable source of carbon.
- Charcoal has fewer impurities compared to coal, which results in better reactivity and efficiency in the production of ferroalloys.
- Because it is produced from planted forests, charcoal is a renewable source of energy, contributing to the reduction of greenhouse gas emissions.

1.6.1.2 Sustainable Charcoal Production

Brazil is the world's largest producer of charcoal (6.7 million tons in 2023) from planted eucalyptus forests, and has been consolidating its global leadership with technological advances in furnace design, process control, and sustainability that are presented through the following main aspects:

Evolution in the Design of the Ovens

From the old handmade "hot tail" ovens to the large rectangular ovens with mechanized operation, the design of the ovens has undergone significant changes.

Currently, continuous reactors such as rotary furnaces and vertical retorts increase process efficiency, allowing for uniform and optimized carbonization.

Advanced Operational Control

Automation and the use of sensors continuously monitor the steps of the carbonization process, controlling the temperature and internal atmosphere of the furnaces.

This more precise control results in higher quality coal and reduces process variability, optimizing raw material yield and reducing losses.

Flaring of Waste Gases

Modern gas-burning technology makes it possible to capture and burn methane, which has an environmental impact 28 times greater than CO_2.

In addition to reducing greenhouse gas emissions, burning these gases takes advantage of their calorific value, saving energy and, in some cases, generating additional heat for the process.

Use of By-Products

Modern furnaces capture valuable by-products, such as bio-oil and pyroligneous extract, which adds value to the process and expands the use of biomass.

Affordable Technology

Technologies such as the furnace-furnace system developed by the Federal University of Viçosa (UFV) enable small producers to adopt cleaner and more efficient practices.

The system connects small circular furnaces to a chimney with gas burners, reducing emissions and increasing efficiency, providing a sustainable and affordable solution.

Figure S18: Evolution of charcoal production furnaces, rectangular furnaces with gas burners and circular furnace-ovens systems with gas burning.

Source: Abrafe (2024)

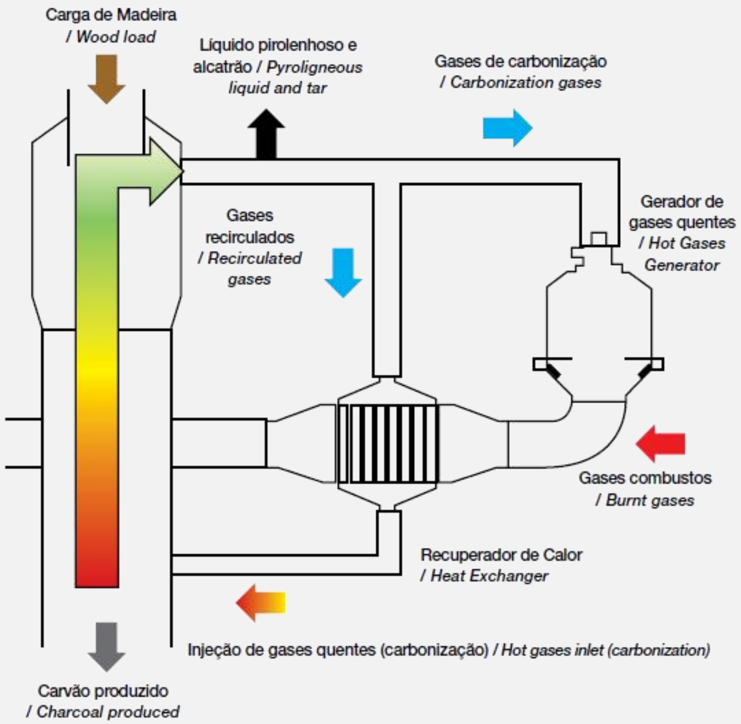
Hot tail | *Circular* | *Rectangular. 150 t wood capacity* | *Rectangular. 300 t wood capacity*

Evolution of the kilns

Rectangular ovens with gas burner

Circular furnace-ovens system with gas burning.

Figure S19: Vertical reactor for charcoal production / Flowchart Carboval System.
Source: Abrafe (2024)



1.6.1.2. Energy Mix of the ferroalloys and silicon metal sector

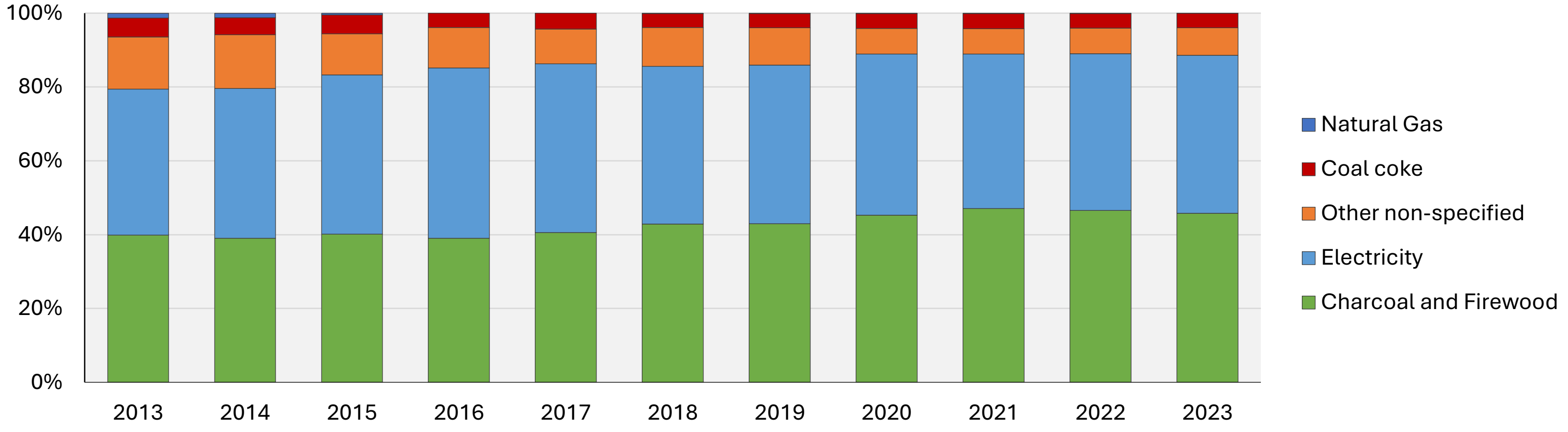
The production of ferroalloys is highly electro-intensive and, in addition to carbon sources, requires an extra source of energy, supplied by electrical energy. Ferroalloys and silicon metal are produced in electric reduction furnaces. In Brazil, the ferroalloys industry has the advantage of the Brazilian electricity matrix, which is highly renewable, mainly due to the availability of hydro, wind, solar and biomass sources.

The Brazilian electricity mix that constitutes the National Interconnected System (SIN) is predominantly renewable, with renewability rates above 80%, which significantly reduces the carbon footprint of ferroalloy production in the country. In order to ensure availability and competitiveness, the ferroalloy industry in Brazil has been investing heavily in alternative energy sources, such as solar and wind, in the self-production modality. The combined use of biogenic carbon (charcoal) and renewable sources of electricity places the production of ferroalloys and silicon in Brazil as the most renewable worldwide. This integrated energy model contributes to the reduction of greenhouse gas emissions and promotes a greener and more competitive industry globally.

Figure S20: Energy mix of the ferroalloys and silicon metal industrial segment

Source: EPE (2024a)

The combination of both sources can be strategically used to optimize ferroalloy production, balancing efficiency, cost, and environmental sustainability.



The choice of carbon source for the production of ferroalloys depends on several factors (availability, cost, environmental impact and technical requirements) and charcoal is the preferred choice in many cases, especially in Brazil, due to its renewability and lower impurity content. On the other hand, coal, depending on availability and costs, remains a viable alternative.

1.6.2. Alternative fuels

Another important advance in Brazil is the use of biogenic charcoal as a substitute for mineral coal in the production of ferroalloys. Biogenic charcoal, produced from plant biomass, has several environmental and economic advantages: Reduced CO_2 Emissions: Biogenic charcoal is a carbon neutral source, which means that the amount of CO_2 emitted during its burning is offset by the CO_2 absorbed by plants during their growth. This contributes significantly to the reduction of the industry's carbon footprint. The production of biogenic charcoal promotes the sustainable use of forest and agricultural resources, encouraging responsible forest management practices.

The use of charcoal reduces operating costs in the long run, as it can be produced locally, decreasing dependence on coal imports. In Brazil, the integration of renewable energies, such as solar, wind and hydroelectric, in the production processes of ferroalloys and metallic silicon is becoming a common practice. These energy sources not only reduce dependence on fossil fuels, but also lower operating costs in the long run and contribute to the sustainability of the sector.

Biogenic Carbon

Biogenic carbon is carbon that originates from biological sources, such as plants, animals, and other living organisms. It is part of the natural carbon cycle, being absorbed by plants during photosynthesis and released back into the atmosphere through respiration, decomposition of organic matter or burning of biomass.

Unlike fossil carbon, which is released from the burning of fossil fuels (such as oil, coal, and natural gas) and accumulates in the atmosphere, biogenic carbon is considered part of a closed cycle, since its emission does not increase the net concentration of CO_2 in the atmosphere in the long term. This means that biomass-based energy sources, which release biogenic carbon, are often seen as more sustainable alternatives, as long as the resource is managed in a renewable way.

Emissions from biomass combustion should be reported in the inventory separately from emissions from fossil fuel combustion. This is justified, because the CO_2 released in the combustion of biomass is equal to the CO_2 removed from the atmosphere during the photosynthesis process carried out by itself, allowing it to be considered "carbon neutral" and to be identified as biogenic CO_2. It is worth noting that emissions of other GHGs from biomass combustion, such as CH4 and N_2O, should be considered normally (PBGHG, 2008).

1.6.3. Energy Efficiency

The Specific Consumption for the production of ferroalloys and silicon metal in Brazil varied between 63.8 GJ/t[1] and 68.7 GJ/t over the last 11 years, remaining around an average value of 67.3 GJ/t. The Specific Consumption (Realized) of Electricity ranged between 7.29 kWh/t[2] and 8.54 kWh/t, remaining around an average value of close to 8 kWh/t over the years. The Specific Consumption values of ferroalloys and silicon metal production vary according to the participation of each alloy in the production mix, so that more energy-intensive alloys tend to increase the overall specific consumption of the industry.

Figure S21: Specific Energy Consumption (GJ/t) for ferroalloys and silicon metal production in Brazil (2013 – 2024)

Source: Prepared by EPE.

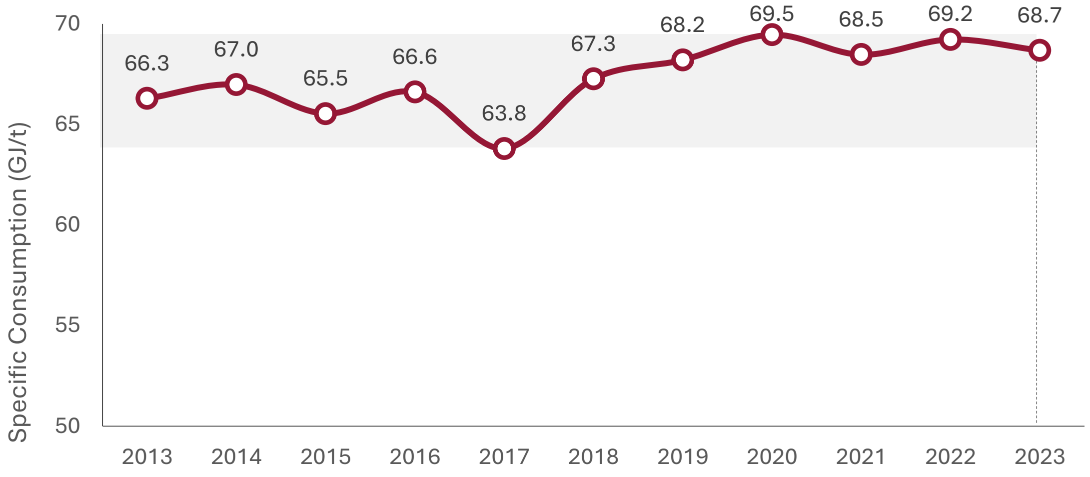
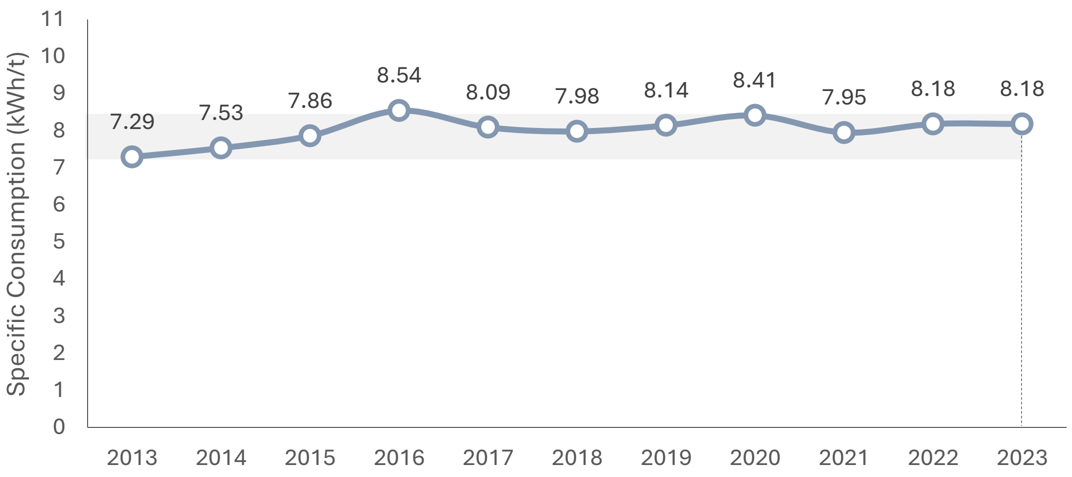


Figure S22: Specific Consumption (Realized) of Electricity (kWh/t) for the production of ferroalloys and silicon metal in Brazil (2013 – 2024)

Source: Prepared by EPE.



The production of ferroalloys and silicon metal is intensive in the use of electricity. Thus, the monitoring of the evolution of specific electricity consumption, in relation to reference standards of specific consumption by alloy, is a practice of the sector for the evaluation of energy efficiency. Similarly to specific energy consumption, specific electricity consumption varies depending on the share of different alloy types in the production mix.

[1] GJ/t denotes the unit of measurement Gigajoule per ton of ferroalloy and silicon metal.
[2] kWh/t denotes the unit of measurement Kilowatt-hours per ton of ferroalloy and silicon metal.

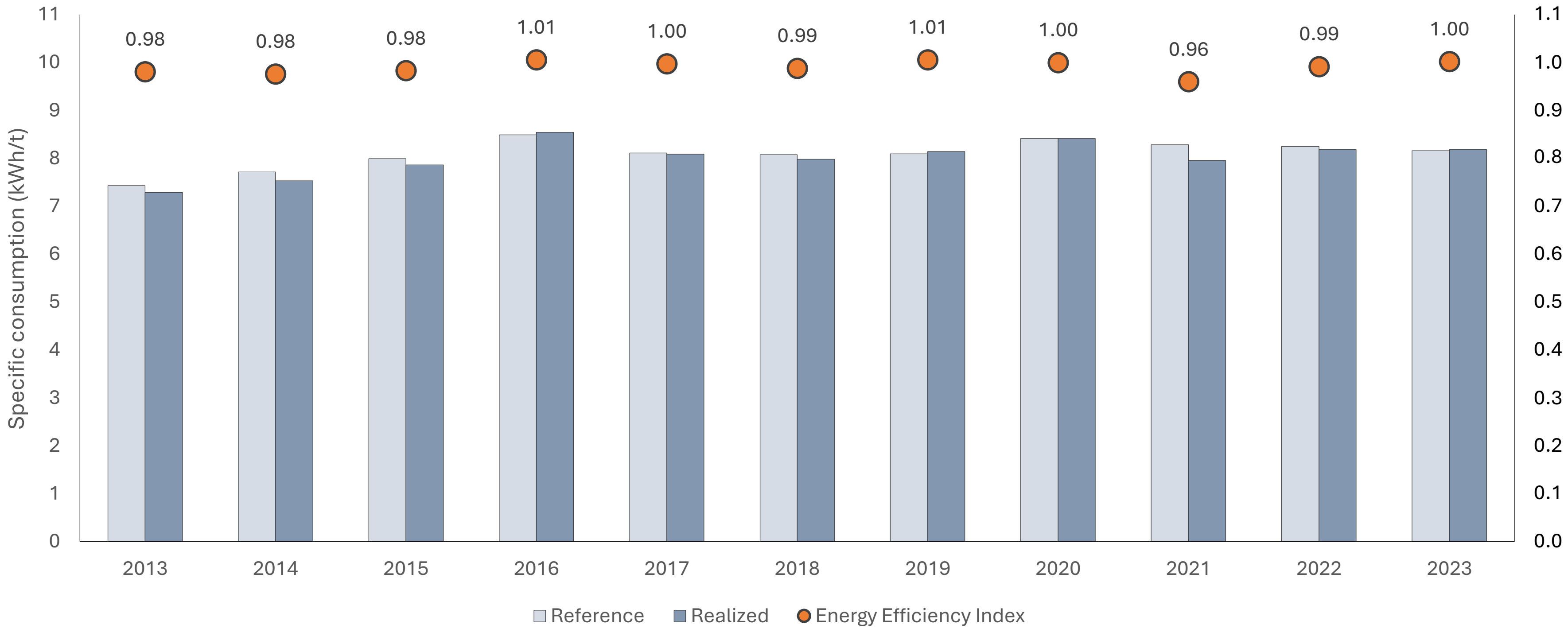
To determine the evolution of the efficiency in the sector's electricity consumption, the **Energy Efficiency Index** is evaluated as the ratio between the Specific Consumption of Electricity Realized and the Reference. The Specific Consumption (Realized) of Electricity results from the calculation of the total consumption of electricity of all companies in the ferroalloys and metallic silicon segment, divided by the total production of the sector in each year. The Specific Consumption (Reference) of Electricity is the weighted average of the specific reference consumption of each alloy (as shown in the table below), where the weights are the participation of each alloy in the physical production of each year.

Over the last few years, the index has presented values lower than or equal to 1 in most cases, indicating that the Specific Consumption (Realized) of Electricity has remained close to the reference standards of the Brazilian ferroalloys and silicon metal industry.

Figure S23: Evolution of the Energy Efficiency Index for the production of ferroalloys and silicon metal

Source: Prepared by EPE and Abrafe.

Reference Consumption (MWh/t)	
FeMn HC	3.5
FeSiMn	4.3
FeMn LC	2.8
FeSi 75%	8.6
FeSi 45%	5.2
CaSi	10.0
FeCr HC	5.3
FeSiCr	8.1
FeCr LC	3.6
FeNi	13.4
Si Metal	12.0
FeNb	4.0



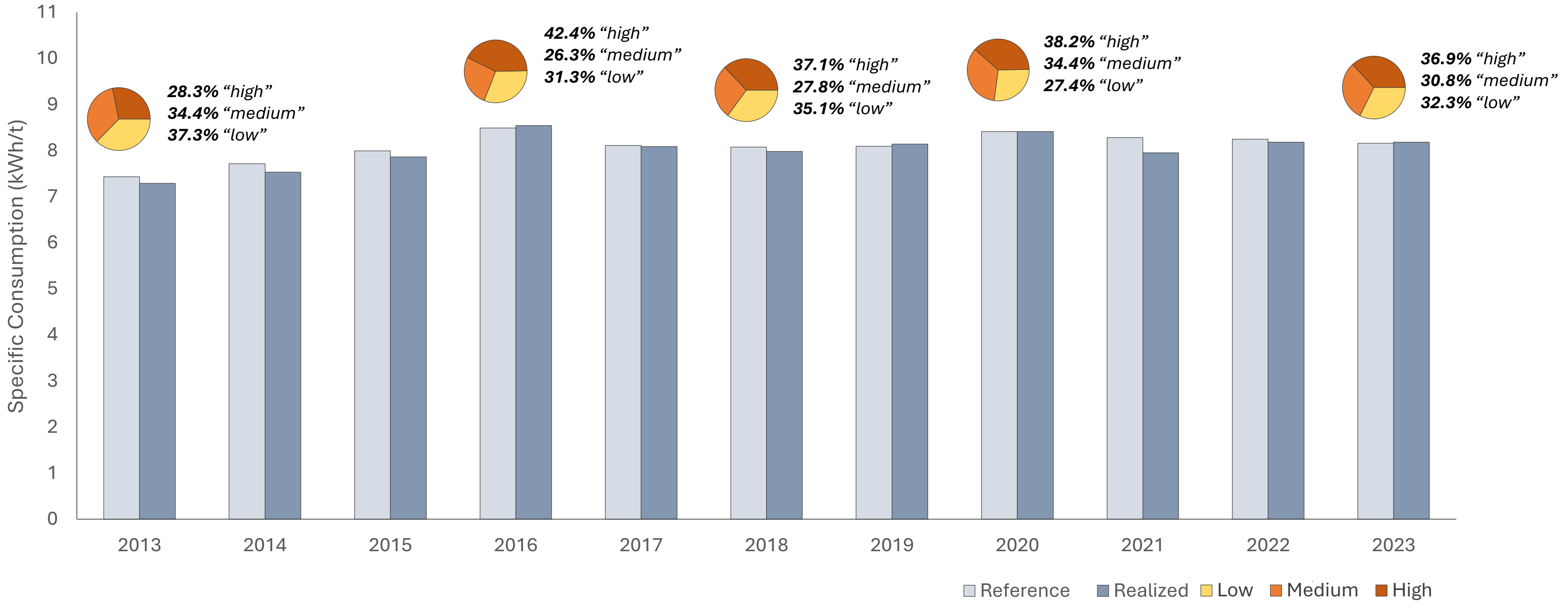
However, the fluctuations in the Specific Consumption of Electricity (Realized or Reference) are the result of the composition of the "mix" of ferroalloys and silicon metal production each year. Classifying the alloys according to their specific consumption as "high", "medium" and "low", it can be seen that, as the proportion of more electro-intensive alloys increases, so does the total Specific Electricity Consumption of production:

- **Specific Consumption** < 5 MWh/t as **“low”**
- 5 MWh/t ≤ **Specific Consumption** < 10 MWh/t as **“medium”**
- **Specific Consumption** ≥ 10 MWh/t as **“high”**

Figure S24: Evolution of Specific Electricity Consumption as a function of the production mix of "high", "medium" and "low" alloys specific reference consumptions

Source: Prepared by EPE and Abrafe.

Reference Consumption (MWh/t)		
FeMn HC	3.5	Low
FeSiMn	4.3	
FeMn LC	2.8	
FeCr LC	3.6	
FeNb	4.0	
FeSi 45%	5.2	Medium
FeCr HC	5.3	
FeSi 75%	8.6	
FeSiCr	8.1	
CaSi	10.0	High
FeNi	13.4	
Si Metal	12.0	



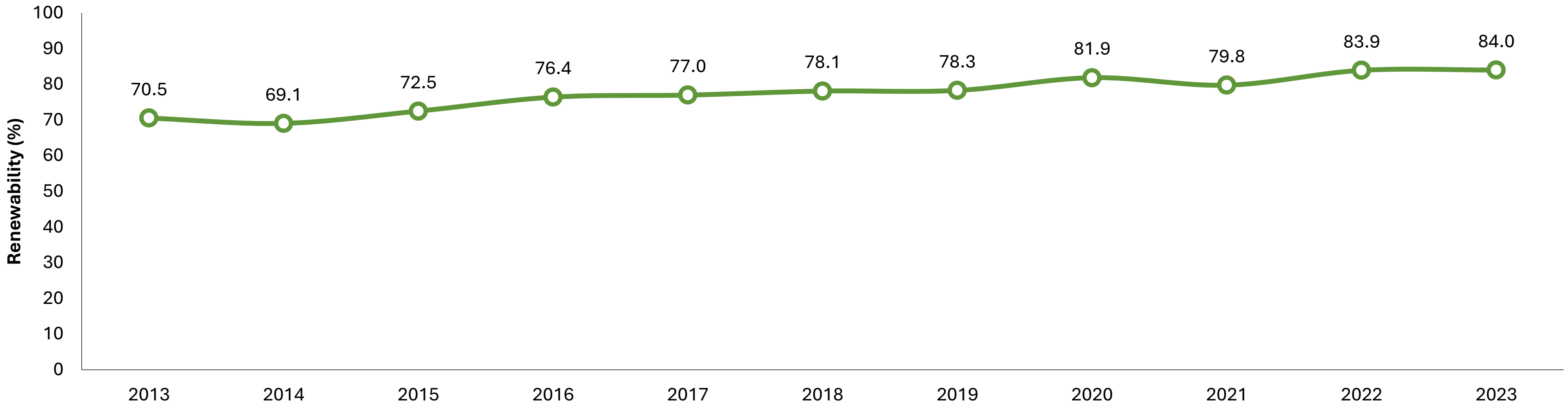
1.7. Emissions

1.7.1. Renewability of the sectoral mix

The energy matrix of the ferroalloys segment is mainly composed of Charcoal and Firewood and Electricity, which contributes to the maintenance of renewability levels of around 80% in the recent period. The renewability of the Brazilian electricity matrix is a key factor in achieving these results, since over the years it has been generated predominantly from renewable sources such as hydraulic, biomass, wind and solar.

Figure S25: Renewable of the energy mix of the ferroalloys and silicon metal sector

Source: Prepared by EPE.



The renewability of the ferroalloys and silicon metal industrial segment contributes to the increase in the renewability of the Brazilian industry in general, since the percentage of the use of renewable sources is above the average of the industrial segments (64.7% in 2023).

1.7.2. Emissions inventory

The inventory of emissions from the ferroalloys and silicon metal sector was prepared by ABRAFE, in partnership with FIEMG, CIT-SENAI and SINFERSI, in compliance with FIEMG's Zero Carbon Mission Program[1], and following the principles of the Brazilian GHG Protocol Program[1]: relevance, completeness, consistency, transparency and accuracy. Eleven units of associated companies participated in the inventory, more than 60% of ABRAFE. The report presents significant data on the production and greenhouse gas (GHG) emissions of these industries for the base year 2022, as follows:

Production and Growth

Silicon metal production in 2022 reached 219 thousand tons, representing an increase of 89% compared to 2015. The production of ferroalloys of ABRAFE's members was 770 thousand tons, demonstrating a significant growth over the years. With the use of 86% of the installed capacity, ABRAFE members together produced 989 thousand tons of products in 2022.

Jobs and Regional Development

The companies associated with ABRAFE generate more than 60 thousand direct and indirect jobs, surpassing pre-pandemic employment levels. In addition, the sector contributes to regional development, with most of the production units located in Minas Gerais. The human development index (HDI) of municipalities with factories in the sector is higher than that of equivalent municipalities in the same region.

Resource Consumption

The production of ferroalloys and silicon metal requires a significant consumption of charcoal and electricity. In 2022 1,534 million tons of charcoal and 11,016 GWh of electricity were used. The sector already uses 84% of energy from renewable sources, compared to 62% of the national industry average.

Verified Emissions

Emissions were accounted for and converted to tons of carbon dioxide equivalent (tCO_2e), totaling 529,212.67 tCO_2e in 2022. Considering Scope 1 emissions, 419,805.87 tCO_2e were accounted for. In Scope 2, 109,406.80 tCO_2e were accounted for and the Industrial Processes category was the main responsible for emissions, with 358,819.60 tCO_2e.

> Scope 1 is made up of the categories of emissions associated with the sources that belong to or are controlled by the organization, that is, direct emissions. Scope 2 emissions are indirect and refer to the acquisition of electricity consumed by the organization.

[1] Details about FIEMG's Zero Carbon Mission Program can be found at: Missão Carbono Zero

[2] Details of the Brazilian GHG Protocol Program can be found at: Programa Brasileiro GHG Protocol

The practices adopted by the Brazilian ferroalloys and silicon metal sector, such as the use of charcoal and renewable energy, result in a significantly lower carbon footprint and demonstrate Brazil's leading role in the decarbonization of the global industry. In order to illustrate the decarbonization potential of this sector, ABRAFE prepared an exercise in its inventory with the adoption of scenarios, identifying the possibility of further reducing its emissions.

The exercise consisted of comparing the current situation in Brazil with the practices carried out by the average of countries in the rest of the world, represented by the fossil scenario, which considers production from an essentially fossil thermal energy matrix and the use of mineral coal as a source of carbon for the processes.

Emissions Scenarios

- **Fossil Scenario:** hypothetically considers the use of thermal energy and coal, totaling **2,587,120.80 tCO_2e**.
- **Current Situation:** has 79.5% fewer emissions than the fossil scenario, with **529,212.67 tCO_2e**.
- **Decarbonized Scenario:** proposes the use of 100% charcoal, associated with the use of renewable energy, resulting in **224,212.59 tCO_2e**.

The data in Table S3 allow us to conclude that the current situation of the Brazilian ferroalloys and silicon metal sector represents a high degree of decarbonization for each of the alloys listed in relation to what can be represented by a fossil scenario.

The biggest highlights are the FeSi, CaSi and Si metal alloys, with decarbonization potentials equal to or greater than 85%.

Table S3: Performance of Emission Reduction by Product in the Brazilian Scenario

Source: Abrafe (2024)

Product	Emissions of tCO_2e/t of alloy (Scope 1 + Scope 2)		
	Fossil Scenario	Current Situation	% Decarbonisation
FeMn[1]	3.01	1.18	61
FeSiMn	2.98	1.17	61
FeMn HC	3.16	1.16	63
FeMn MC	2.99	1.51	49
FeSi	7.11	0.68	90
CaSi	7.61	1.15	85
Si metal	5.78	0.72	88
Total Production	4.68	0.96	80

> The inventory shows that the sector uses a high proportion of renewable energy, contributing to a significantly lower carbon footprint compared to other countries, and also reinforces the importance of accounting for GHG emissions as a management tool for setting goals, assessing risks and opportunities, improving relationships with stakeholders, and participating in GHG emissions disclosure programs and carbon markets.

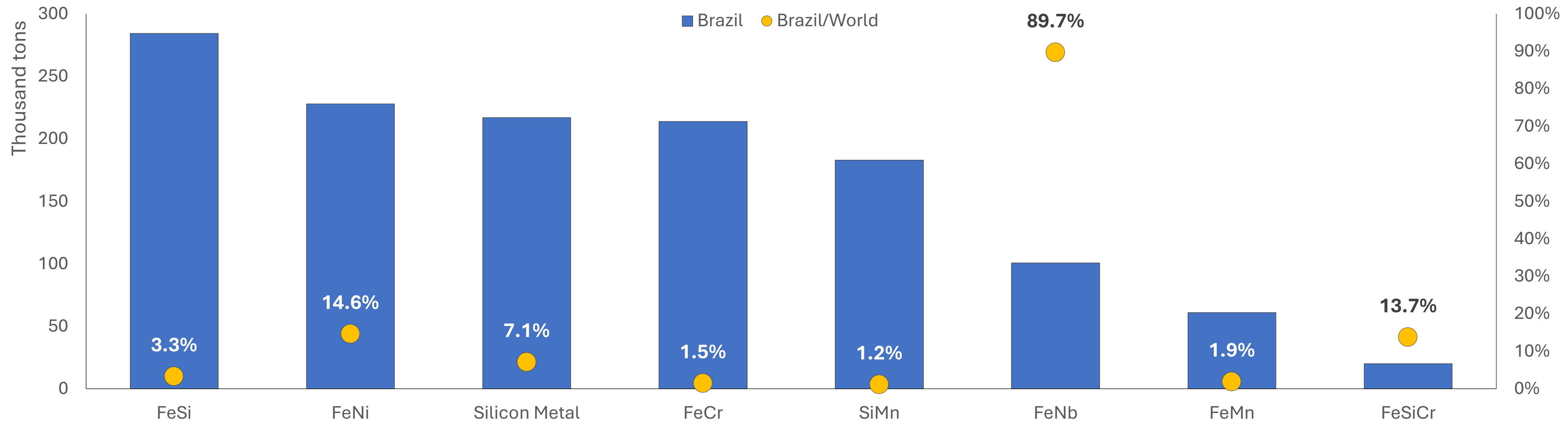
[1] Decarbonization of, for example, in the case of FeMn, of 61% refers to the reduction from 3.01 tCO_2e/t of alloy (Fossil scenario) to 1.18 tCO2e/t of alloy (Current Situation).

2.3. World production of ferroalloys and Brazilian participation

The world production of ferroalloys and silicon metal in 2021 accumulated about 61.4 million tons, while Brazil was responsible for about 1.3 million tons, representing 2.1% of the world share. However, Brazil's presence in the international scenario varies significantly depending on the type of alloy, with absolute prominence in Ferro-Niobium (89.7%) and relevant shares in the production of Ferronickel (14.6%), Ferro-Silicon-Chromium (13.7%) and Silicon metal (7.1%).

Figure S26: National production by type of alloy (left axis) and its participation in the international scenario (right axis)

Source: Prepared by EPE and Abrafe.

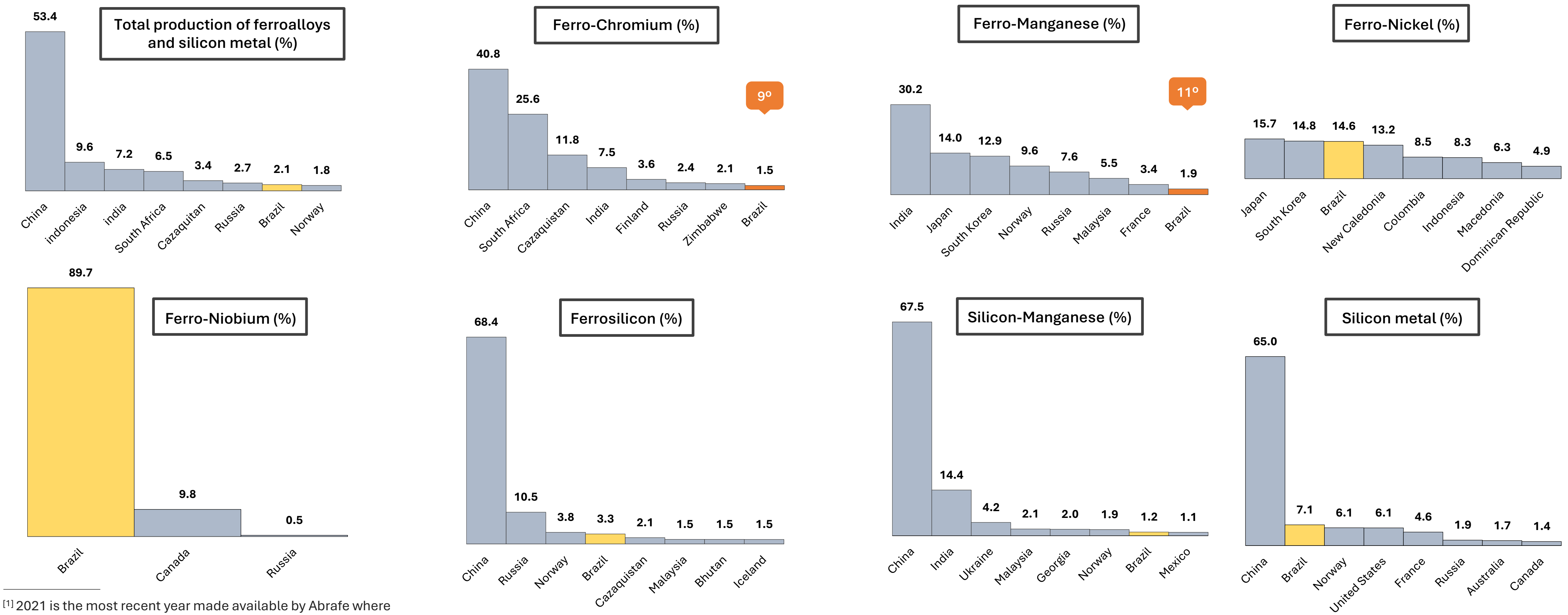


The world production of Ferro-Niobium is mostly concentrated in Brazil, followed by Canada and Russia. According to the Geological Survey of Brazil, Brazil holds 95% of the world's known reserves, and the most significant are found in Minas Gerais, Amazonas, Goiás, Rondônia and Paraíba (SGB, 2024).

The following are the rankings of countries in terms of share (%) in the international production of ferroalloys by type of ferroalloy and silicon metal in 2021[1], highlighting Brazil's position in ferroalloy markets in which the country is not among the top 7.

Figure S27: Share of national production by type of alloy in the international scenario

Source: Prepared by EPE and Abrafe.



[1] 2021 is the most recent year made available by Abrafe where it is possible to make comparisons between countries.

2.3.1. Public and Private Policies for the Competitiveness of Brazilian Industry

Strategies for Cost Mitigation

In order to reduce difficulties such as electricity costs, high taxes, deficient logistics infrastructure and obstacles in environmental licensing, some public policies and private initiatives can be improved:

1. **Renewable Energy Auctions:** The ferroalloys industry participates in auctions of renewable sources (solar, wind, biomass), signing long-term contracts (PPAs) at more competitive prices.
2. **Self-production and PPAs:** Encourage self-generation of energy and long-term contracts with renewable energy suppliers, ensuring fixed and predictable prices, protecting against market volatility.
3. **Energy Efficiency:** Invest in advanced technologies for electric furnace control and intelligent systems that optimize energy consumption in real time.

Other Factors Affecting Competitiveness

Além dos custos de energia, outros fatores, como infraestrutura logística deficiente, retenção de créditos de ICMS, burocracia e altos encargos de licenciamento ambiental, também precisam ser enfrentados:

1. **Logistics Infrastructure:** Invest in the modernization of ports, railways and highways, creating efficient logistics corridors for the flow of ferroalloys.
2. **Return of ICMS (Tax on the Circulation of Goods and Services) Credits:** Automate and simplify the return of ICMS credits to exporters, creating a digital platform with defined deadlines, alleviating the financial impact on companies.
3. **Improvements in Environmental Licensing processes:** Digitizing the licensing process in order to make it more agile and less costly, and simplifying the processes associated with projects with less environmental impact, encouraging clean technologies and responsible environmental practices.

Regulation of the Carbon Market and Valorization of Planted Forests

To value the role of planted forests in CO_2 capture, it is essential that Brazil advances in the regulation of the carbon market:

1. **Incentives for Forests and Carbon Credit Certification:** Implement incentive policies for companies that invest in reforestation aimed at carbon sequestration and certify forests for carbon capture monetization, as occurs in the voluntary market.
2. **Neutralization of Emissions:** Invest in planted forest projects to neutralize operational emissions and strengthen the industry's position in international markets, such as Europe, which apply environmental barriers (CBAM)[1]. Efforts must be directed so that the benefits of these practices are duly recognized in international agreements.

[1] CBAM: On May 16, 2023, the European Union (EU) published Regulation 2023/956, which creates the Carbon Border Adjustment Mechanism (CBAM), whose objective, in its transitional phase, is to collect data and, in the regular phase, to charge for greenhouse gas (GHG) emissions incorporated in certain energy-intensive products imported by the European Union.

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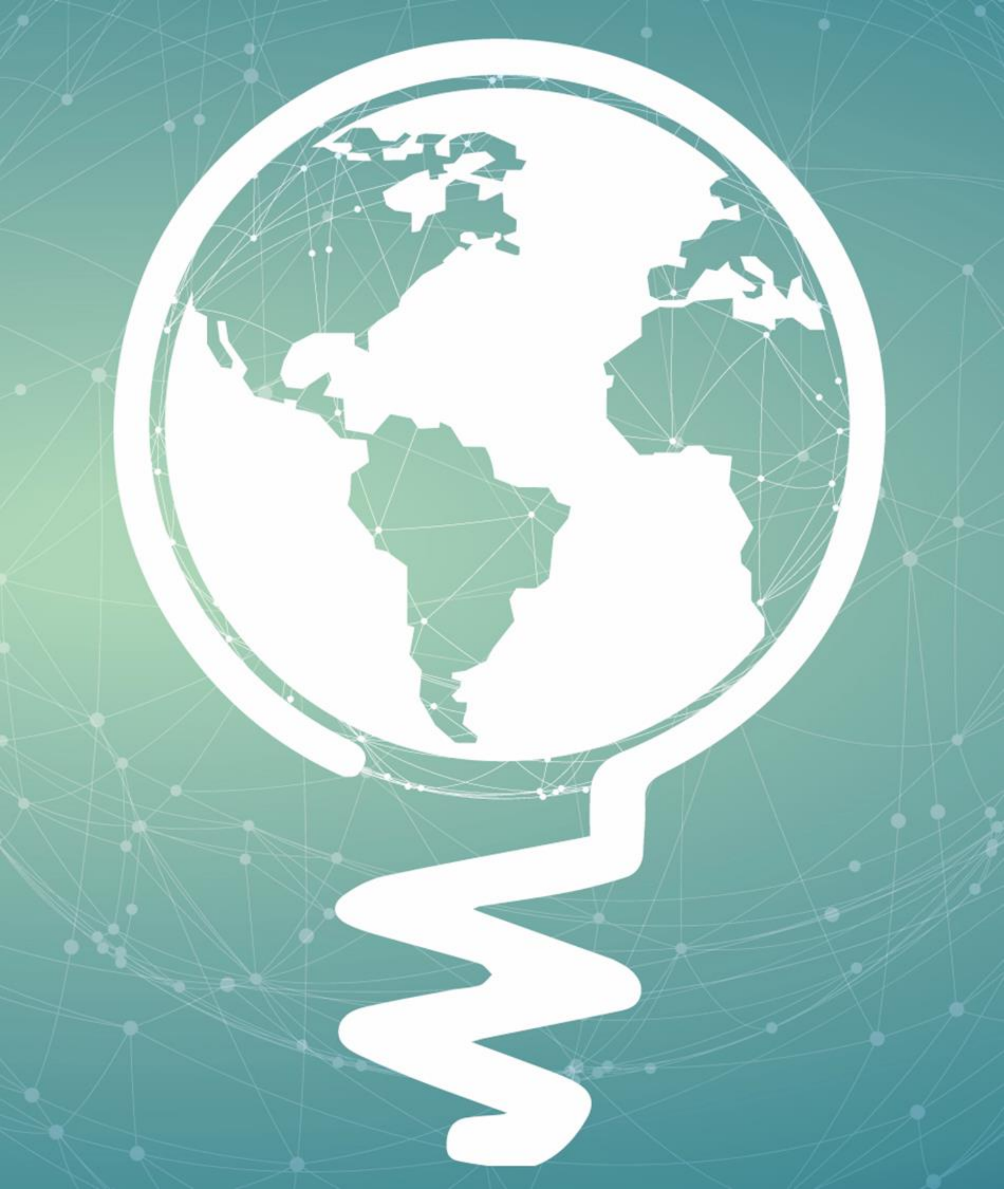

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