Atlas of Energy Efficency

Brazil | 2022

Indicators Report

MINISTÉRIO DE MINAS E ENERGIA

GOVERNO FEDERAL
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Ministério de Minas e Energia

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This report has one special chapter...

which provides a detailed analysis of the iron and steel industry in Brazil, a result of cooperation between EPE, the International Energy Agency (IEA) and the Instituto Aço Brasil (IABr). This chapter presents a national and international analysis of the steel industry sub-sector, with a special focus on advances in energy efficiency and carbon emissions mitigation.

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Sumário

Objective

Objective

The main objective of this document is to monitor the progress of energy efficiency in Brazil, through the use of indicators. In 2020 the first "Atlas of Energy Efficiency in Brazil - Indicators Report" was published - with analysis up to the year 2018. This document updates and complements, in a more condensed way, the first report with data up to the year 2021. This document consolidates the sixth cycle of EPE's work in the development of the database of energy efficiency indicators.

Definitions

ODEX

ODEX is an indicator that determines the progress of energy efficiency. It can be aggregated by sector (industrial, residential, services and transport) or for the economy as a whole. ODEX is used by the European Union in the ODYSSEE database program for monitoring efficiency gains.

ODEX by sector (e.g. industry) is based on unit consumption indexes by sub-sector (cement, ceramics, textiles, etc...), weighted by their share in the total energy consumption of the sector. The unit consumption per sub-sector can be expressed in different units in order to provide the best proxy for the evaluation of energy efficiency, be it the consumption per household, physical production, or number of vehicles, for example.

For the present report, 2005 was considered as the base year (value = 100), essentially due to the availability of data for most sectors from that year on. The decrease in the unit consumption index from 100 in 2005 to 80 in 2020, for example, represents an energy efficiency gain of 20% over the analyzed period. In contrast, if ODEX increases from 100 to 120, there will have been a deterioration in energy efficiency over the years in question.

In the case of global ODEX, the same method is applied with weighting factors, based on the shares of the total final energy consumption of each sector.

For the purposes of this technical note, the industrial, residential and transportation sectors were considered. The other sectors (energy, services and agriculture and livestock) were not included due to the unavailability of data.

Energy Intensity

Energy intensity refers to the amount of energy required to produce one unit of 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$, R$, m², ton-kilometers, passenger-kilometers, among others).

Hypothetical examples:

- Industrial Energy intensity: 100 toe/U$ ppp 2010
- Energy intensity of residential building: 0.5 toe/m²
- Energy intensity of commercial building: 200 KJ/m²
- Energy intensity in the transport sector: 1,000 toe/tkm

The energy intensity of an economy corresponds to the ratio of the Total Energy Supply divided by the Gross Domestic Product of the country. This indicator is usually used to measure a country's energy efficiency. Nevertheless, it is important to consider that this ratio does not necessarily express energy efficiency, since a country can have a low energy intensity and be inefficient from an energy point of view. Just consider the case of a small country that has its economy based on the tertiary sector, which may have a lower energy intensity than another large nation whose economy is based on industrial production. However, the second country can use energy for its industries more efficiently than the first uses it to develop its economy based on trade and services.

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

In this report, the indicator will be calculated 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 the energy that reaches end-use sectors 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 classified, 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 were classified according to the Brazilian Energy Balance, with the exception of some energy-intensive sectors, for better representation of 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, that is, consumption from sources coming from the different transformation centers, which have as a destination different sectors of the economy. 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 manufacture of thermoplastics.
- **Final energy consumption** corresponds to the use of sources by economic sectors as energy.

INOVA-E

The INOVA-E digital platform was developed to make data on Brazilian investments in Research, Development and Demonstration (RD&D) in energy accessible to diverse audiences. This platform aims to deepen the understanding of investment trends in RD&D in energy and support various organizations including the EPE, the MME and the MCTI, in the formulation and promotion of public policies, research and new investments in the area of energy innovation. The strategic information made availabe at INOVA-E was organized in a single database providing an unprecedented overview of innovation efforts in the energy sector in Brazil.

Public RD&D investment - Public RD&D investments are calculated based on reimbursable and non-reimbursable RD&D projects expenditures carried out through public institutions that foster innovation in Brazil. The statistics presented on this platform gathered data from the following federal agencies: BNDES, CNEN, CNPq, FINEP; and also from the state of São Paulo: FAPESP.

Publicly oriented investment in RD&D - Publicly oriented investments refer to private investment induced by public policies, being compulsory for companies in the energy sector. These are resources that fit into public programs whose purpose is to induce companies to invest in RD&D. Within the scope of this platform, publicly oriented investments refer to RD&D projects regulated by Brazilian Electricity Regulatory Agency (ANEEL) and National Agency for Petroleum, the Natural Gas and Biofuels (ANP) agencies.

For more details, visit:

Panorama dos investimentos de inovação em energia no Brasil

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Transport Sector

Activity

Activity in the Transport sector is internationally represented by the indicators passenger-kilometer and ton-kilometer transported. Passenger-kilometer is a unit that presents the work relative to the displacement of a passenger over a distance of one kilometer. Similarly, ton-kilometer is the unit that represents the work relative to the displacement of a ton of cargo at a distance of one kilometer. Also called 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 represents the volume of fuel used 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 tonne oil equivalent [toe]).

Transport Sector

Light Duty Vehicles (by size)[1]

Automobile

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

Light commercial vehicles

- **Utility Vehicle** – vehicle for freight transportation with GCVW of up to 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.

GCVW– Gross combined vehicle weight; MTC – Maximum Traction Capacity;
[1]Código Nacional de Trânsito, available at: http://www.planalto.gov.br/ccivil_03/leis/l9503compilado.htm;
[2]Anuário da Anfavea 2022, available at: https://anfavea.com.br/anuario2022/2022.pdf;
PBT – Total Gross Weight; CMT – Maximum Traction Capacity

Introduction

Share of renewables in the Energy mix

Historically, Brazil stands out for being a country with a high percentage of renewable sources in its total energy supply when compared to the rest of the world. Over the last 20 years, the share of renewables in the Brazilian energy mix has remained stable at over 40%, a level that has been challenging to maintain. More recently, between 2011 and 2014, there was a reduction in the share of renewables in the energy mix due to a drop in hydropower supply. As of 2015, renewable sources have resumed their growth trajectory with the expansion of the supply of sugarcane products, wind and biodiesel, reaching 45% in 2021.

Figure 1 – Share of renewable sources in the Total Energy Supply (TES): international comparison
Source: EPE (2022a)

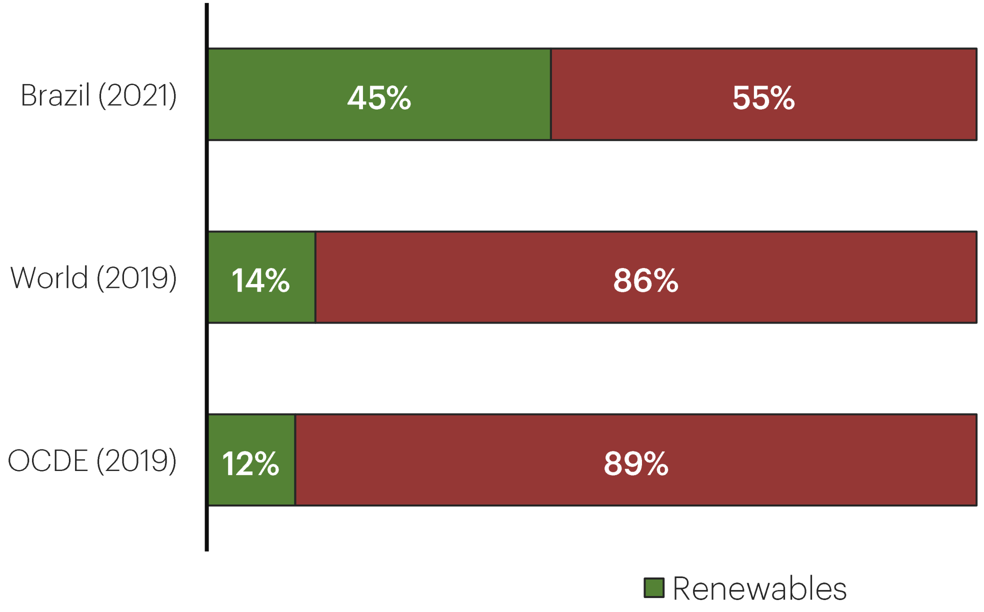
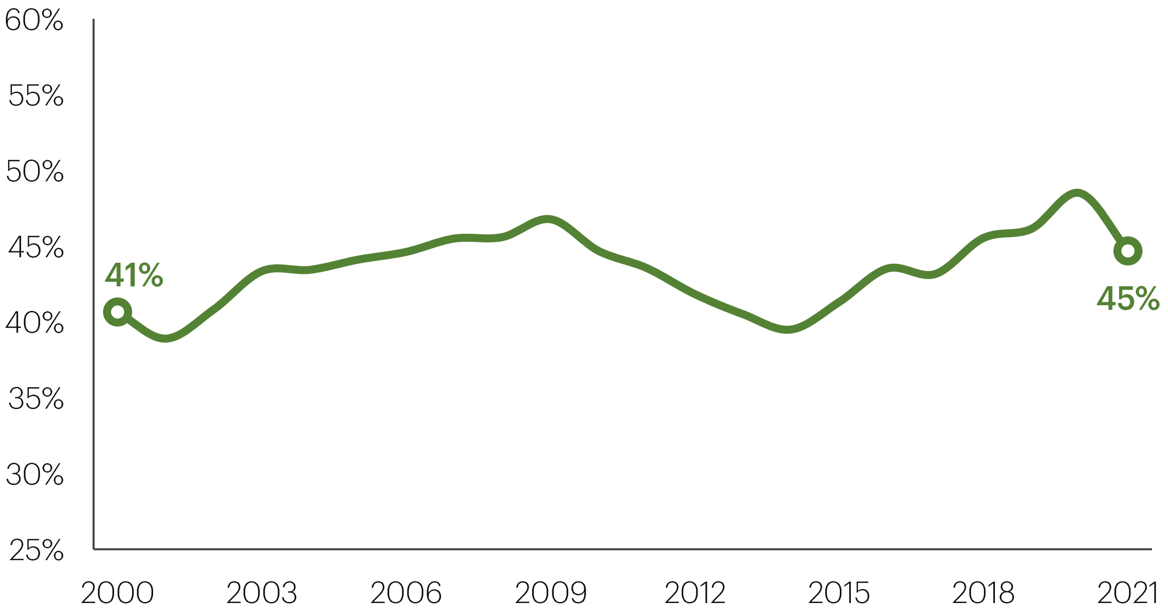


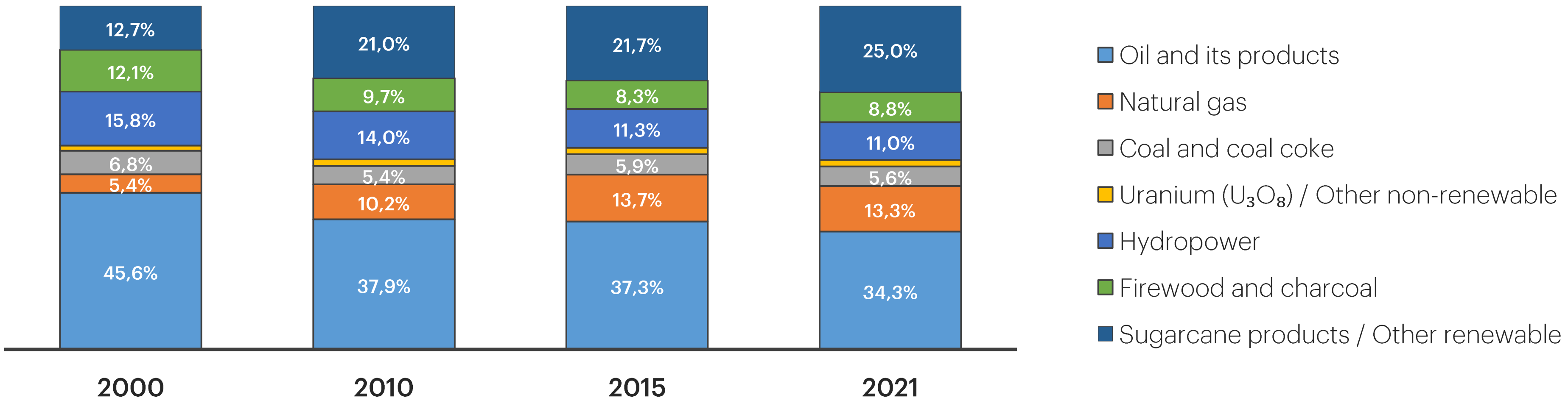
Figure 2 – Share of renewable sources in the Total Energy Supply (TES) – 2000 to 2020
Source: EPE (2022b)



Evolution of final energy consumption by source

For non-renewable sources, oil and its products maintain the largest share. However, natural gas was the standout category, significantly increasing its share of the energy mix from 5.4% in 2000 to 13.3% in 2021 due to its use in thermoelectric power plants and extension of the pipeline network, which enabled its use both in industries and in residential, commercial and public buildings.

Figure 3 – Energy consumption by source in selected years
Source: EPE (2022b)



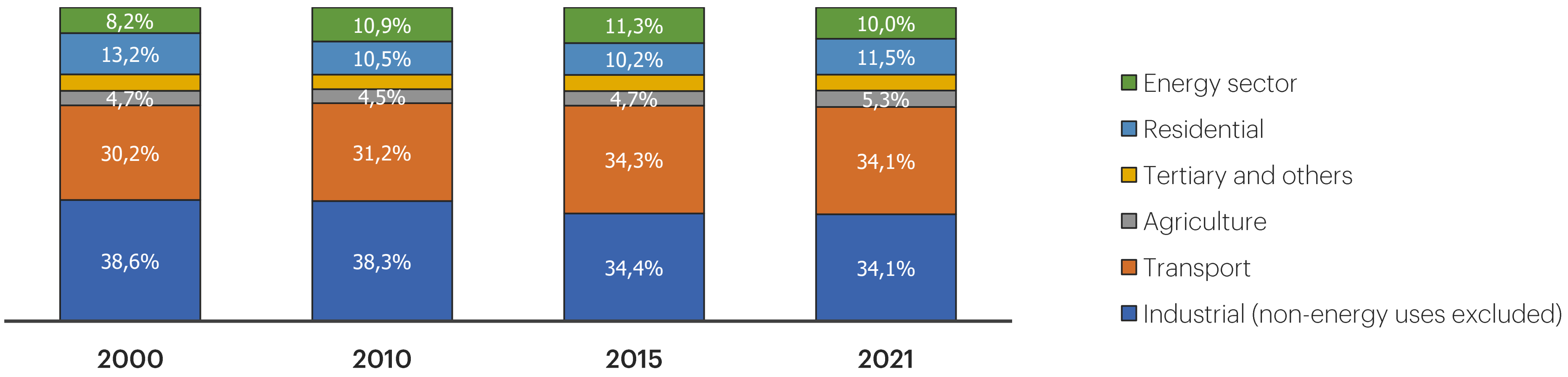
Renewable sources, on the other hand, developed at a faster pace, due to the expansion of the sugar-ethanol sector, and the strong expansion of other renewable sources, Notebly wind power, black liquor and biodiesel. From a negligible share in 2000, wind energy grew to the point that it contributed 6.2 million toe to the energy mix in 2021, while black liquor, which is directly associated with the pulp and paper industry, contributed another 10.1 million toe in 2021. Biodiesel has been favored by the policy of adding this fuel to fossil diesel. In 2021, the percentage reached 10% in November, after reaching levels of 13%, 10% and 12% throughout the year. Brazil is the second largest producer of biodiesel in the world, only behind the United States and the most used raw material for its manufacture in the Brazil is soy oil.

Evolution of energy consumption by sector

The main movement observed in this period was the retreat of industry's share as opposed to the advance of the transportation and energy sectors. The transportation sector even surpassed industrial consumption in 2018 and 2019. In the following year, due to the Covid-19 pandemic and the consequent reflections on the economy, the transportation activity retreated by 6.4%. In 2021, with the gradual resumption of energy consumption, the sector recovered and was almost equal to the consumption of the industrial sector.

Figure 4 – Energy consumption by sector in selected years

Source: EPE (2022b)



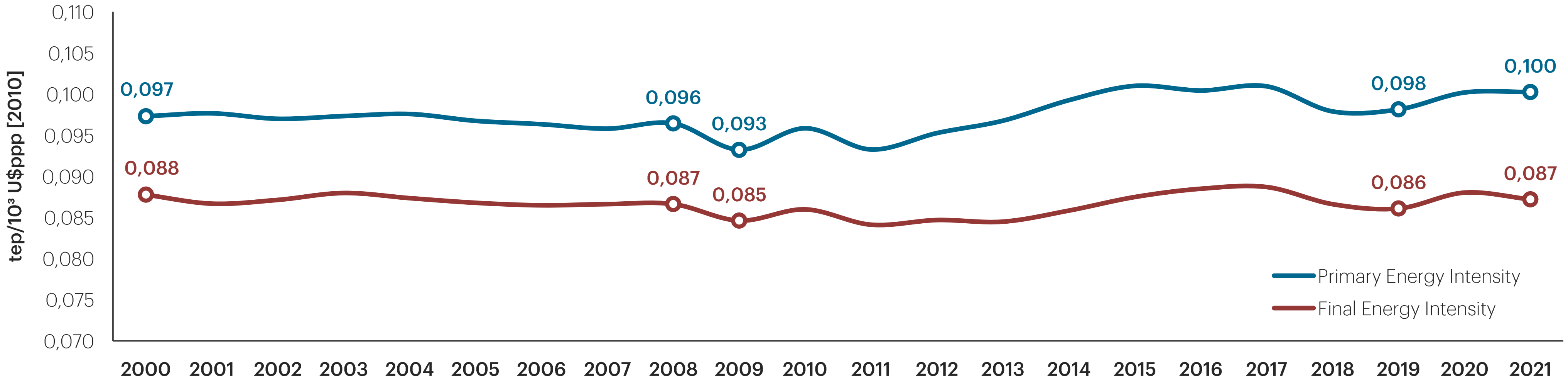
The cement/steel aggregate that consumes more than 20% of all energy for the industry grew at a faster pace than the transport sector, which in the same period had its energy consumption evolving at an average annual rate of 2.8%. The cement industry, besides the gradual reduction of the clinker/cement ratio from 73.2% in 2000 to 68% in 2021, had its clinker production (intensive in energy consumption) growing at an average annual rate of almost 2.0%. The steel industry in turn expanded its physical production at an average annual rate of 1.25%. The energy sector, driven by oil and ethanol production, which in the period grew at annual rates of 4.1% and 5.0%, had its energy consumption in 2021 increased by 12.0 million toe compared to 2000.

Energy Intensity

In 2000-08, primary energy intensity remained stable at around 0.097 toe/10³ US dollars (USD) at purchasing power parity (PPP) [2010]. Similarly, final energy intensity stabilized at values close to 0.087 toe/10³ USD PPP [2010]. In 2009, the effects of the international crisis on industry contributed to a reduction in primary energy intensity to 0.093 toe/10³ USD PPP [2010]. In that year in particular, it was possible to observe the shutdown of more inefficient (less competitive) units with higher energy intensities

Figure 5 – Evolução da intensidade energética no Brasil

Source: EPE (2022b)



Between 2010 and 2013, primary and final intensities grew at rates of 0.9% and 0.1% per year respectively, reflecting growth in Total Energy Supply that outpaced growth in GDP. Between 2014 and 2021, primary energy intensity grew by 0.4% per year, even with the economy in recession (an average contraction of -0.2% per year). In the same period, final energy intensity grew by 0.4% per year. This upward trend in energy intensity may be associated with the growth in production of low value-added, energy-intensive items aggregated together in the production schedule, as compared to other manufactured products.

RD&D Investments in Energy Efficiency

In competitive sectors such as industry, energy efficiency is part of the day-to-day production process, because without efficiency, many businesses would have difficulty competing. Technological changes are among the main sources of wealth creation and long-term economic growth.

According to the INOVA-E[1] platform, between 2013 and 2020, Brazil has invested more than 2 billion reais on research, development and demonstration (RD&D) in energy efficiency projects arising from public or publicly oriented[2] investments. Almost half of this amount came from BNDES, while ANEEL and Finep corresponded to 25% and 18%, respectively.

Figure 6 – Evolution of RD&D investments in Energy Efficiency
Source: EPE (2022c)

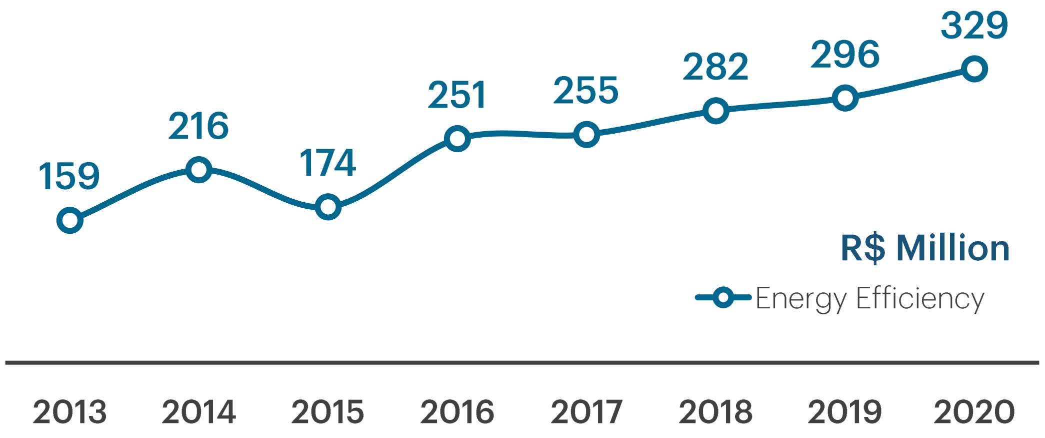
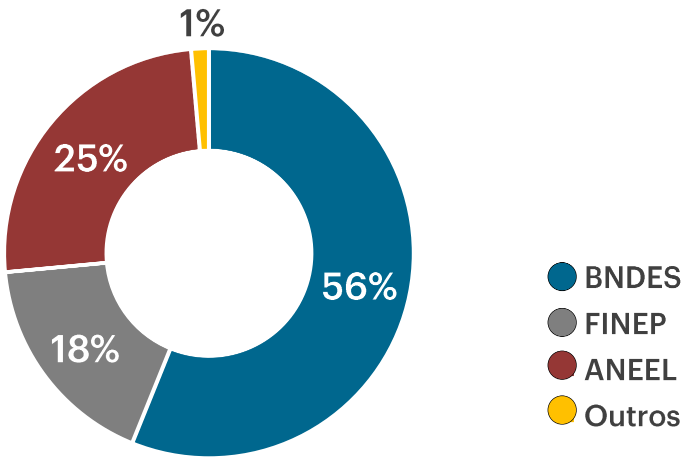


Figure 7 – Origin of resources for Energy Efficiency investments
Source: EPE (2022c)



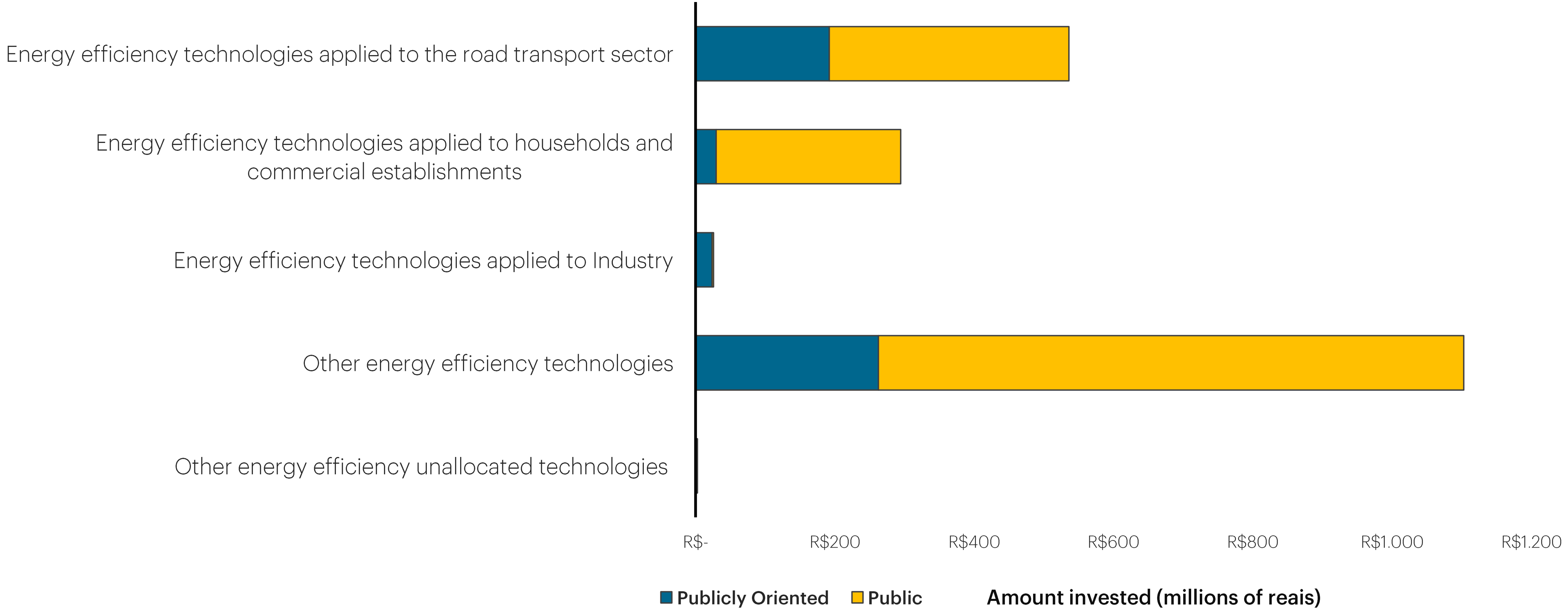
Data from INOVA-E point to an annual average investment of more than 245 million reais over eight years of historical series, considering public and publicly oriented resources in R&D projects in Brazil.

[1] For more details about the INOVA-E, acess the chapter Definições

[2] For more details about the meaning of the expressions "public" ou "publicly oriented", acess the chapter Definições

RD&D Investments in Energy Efficiency

Figure 8 – Nature and modality of investments, in millions of reais - 2013 to 2020
Source: EPE (2022c)

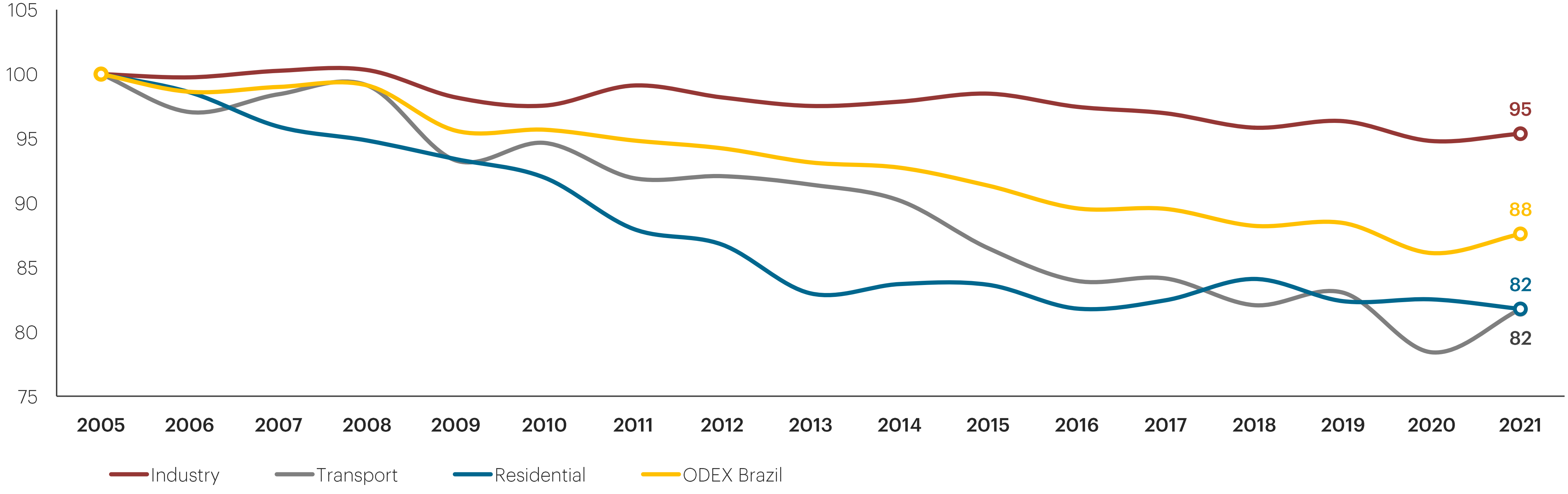


ODEX

In this report, 2005 was set as the base year (100), covering the industrial, residential, transport sectors and Brazil as a whole. In this period, all sectors analyzed showed efficiency gains, with the largest gains (18%) occurring in the transport and residential sectors. The ODEX calculated in 2021 shows that the country became 12% more energy efficient in the period (since 2005).

Figure 9 – ODEX Brazil

Source: Compiled by EPE



Buildings

Evolution of consumption in buildings: residential, commercial and public sectors

The main energy source used in the buildings is electricity. Households use 45% electricity, 23% LPG and 26% firewood. Commercial and public buildings, on the other hand, use electricity with a 92% share.

Figure 10 – Total energy demand in buildings
Source: EPE (2022b)

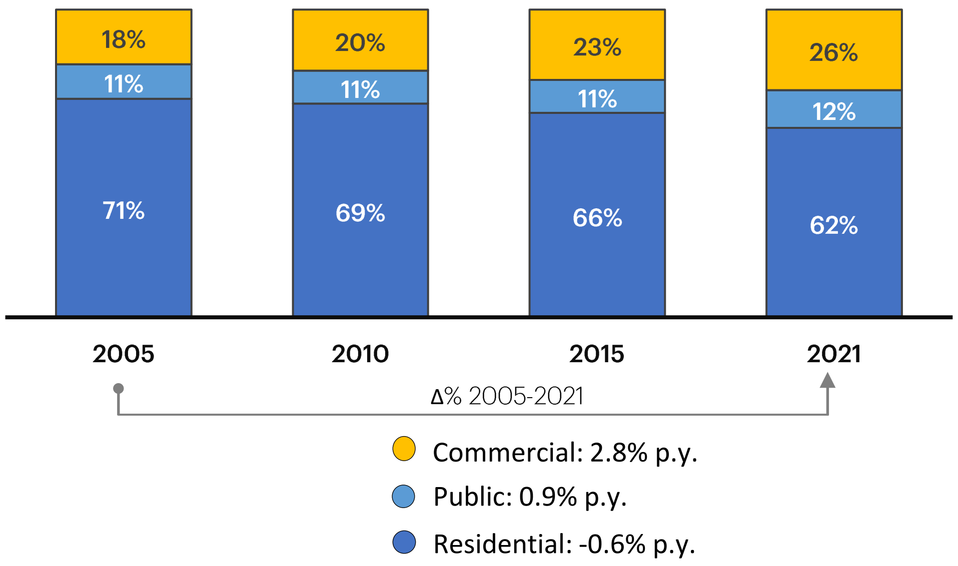
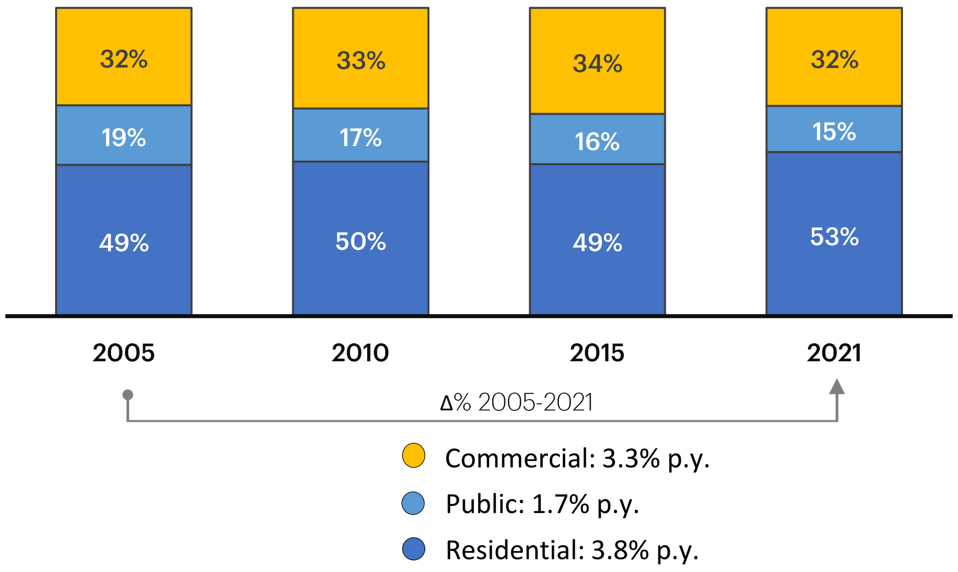


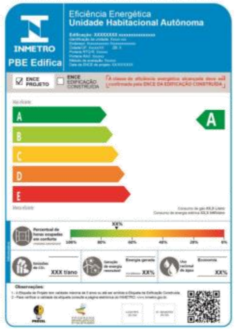
Figure 11 – Electricity demand in buildings
Source: EPE (2022b)



Buildings consume 50% of the country's electricity and because they have a large electricity consumption, this segment has the greatest potential for electrical efficiency. Between 2015 and 2020, the Procel Seal for Buildings will avoid energy consumption of 29.25 GWh in constructed buildings, estimates PROCEL (Procel, 2021). The Procel Seal for refrigeration equipment, lighting, air conditioners, and ceiling fans is estimated to save 20.3 TWh/year.

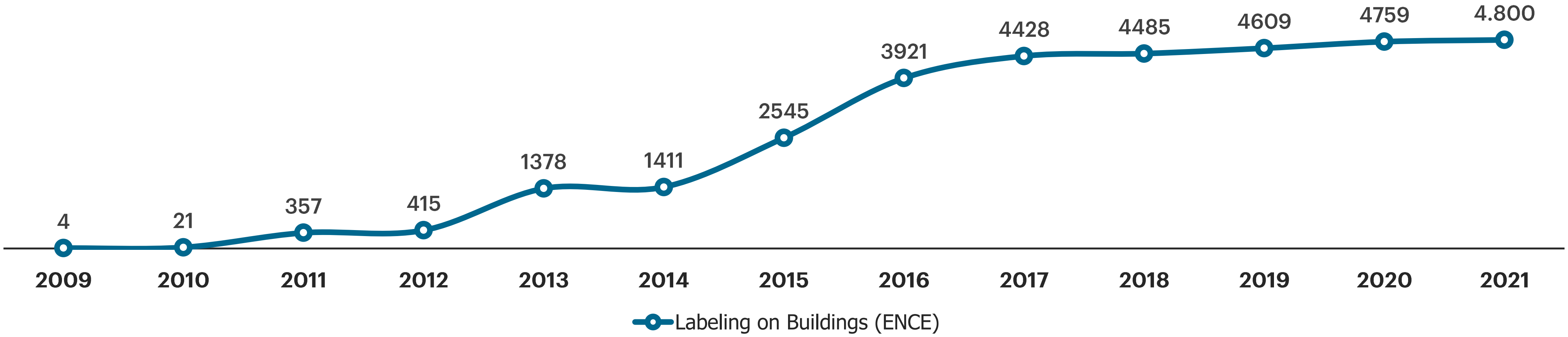
Note: the public sector includes public lighting and sewerage.
[1] According to the historical series, electricity has been the main source since 2008.

Evolution of Labeling on Buildings - Brazilian Labeling Plan (PBE Edificações)



The labeling of buildings in Brazil completes 13 years, with the publication of the methodologies for the classification of the level of energy efficiency for commercial, service and public buildings. In 2010, for residential buildings. The label can be applied to the project and to the building already constructed. The cumulative data in the Figure show the potential for penetration of this policy, which informs the performance requirements of the building.

Figure 12 – Evolution of the National Label for Energy Conservation in Buildings – ENCE (number of labels)
Source: INMETRO (2022)



In September 2022, the new conformity assessment method for residential, commercial, service, and public buildings was approved. The adoption of the methodology will be mandatory as of May 1, 2024. This new methodology brings important advances and enables PBE Edifica to be aligned with the Brazilian performance standard for residential buildings NBR 15575/2021, and allows the consumer to have information about the potential consumption of the building or residential unit, and also how much energy savings are possible compared to a standard building.

Note: PBE is the Brazilian Labeling Program

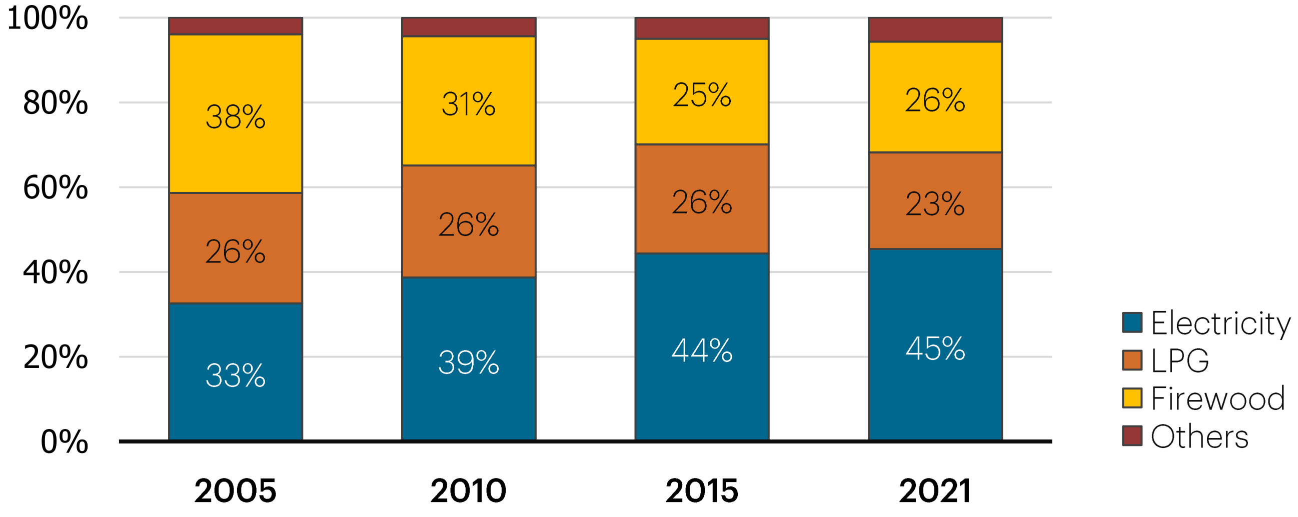
Residential Sector

Evolution of energy consumption by source in households

Electricity continues to be the energy source most used in Brazilian households, with an evolution in the energy participation of about 12.8 p.p. from 2005 to 2021. It has widespread use in homes, and can be used for air conditioning, conservation, cooking and food preparation, water heating, lighting, laundry, entertainment, communications, personal beauty, and in electrical and electronic equipment.

Figure 13 – Energy consumption by source in households – selected years

Source: Compiled by EPE



Liquefied Petroleum Gas (LPG) maintains an intermediate participation (23% in 2021), with its main use associated with the cooking of food.

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

Solar thermal energy is also aggregated in Other and its use is related to the heating of water.

A reduction in the consumption of firewood for cooking food from 2005 to 2015 is perceived, due to the improvement in the economic conditions of families. The energy participation of firewood increased in 2021 compared to 2015, due to the adverse economic situation of the country, replacing LPG (more expensive) in poorer homes.

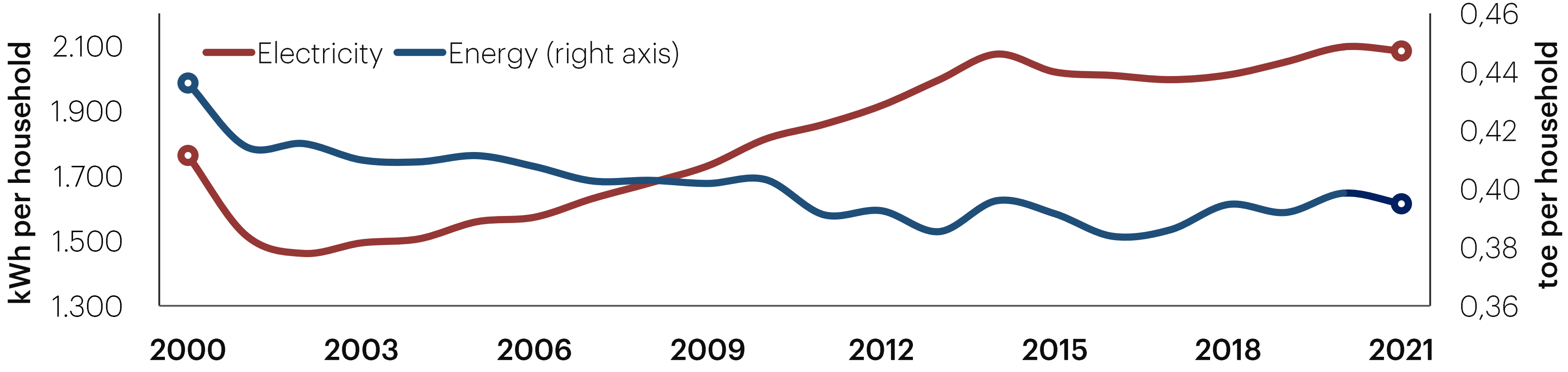
Note: the Notation "p.p." refers to percentage points.

Evolution of electricity and energy consumption in households

While energy consumption per household fell by 9.5% (0.5% per year) from 2000 to 2021, electricity demand per household grew by 18.3% (0.8% per year) over the same horizon. Energy and electricity demands fell sharply in 2001 due to the rationing of electricity in the country, which stimulated a change in habits and promoted energy efficiency measures in Brazilian households.

Figure 14 – Electricity and energy consumption by household

Source: Compiled by EPE



The demand for electricity increased from 2000 to 2021 due to the economic progress of families, the advance of credit for buying appliances, government policies for connections, especially in rural areas, and housing programs and stimuli to reduce the Brazilian housing deficit. In another sense, energy consumption fell during the period as a result of the reduction in the use of less energy-efficient sources (traditional biomass - firewood and charcoal) and the consequent substitution by more modern sources (LPG, NG and electricity). It is important to note that energy consumption per household began to increase from 2014, due to the return of the use of traditional biomass for cooking food, replacing the relatively more expensive LPG, especially in poorer families with the economic crisis.

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 labels.

These initiatives have been implemented in the country since 1984, with the creation of the Brazilian Labeling Program (PBE), coordinated by INMETRO, which started to produce comparative energy performance labels for equipment, providing consumer education and stimulating the manufacture of more efficient products by the industry.

In 1993 the PROCEL (for electrical equipment) and CONPET (for products that use fuels derived from petroleum and natural gas) labels were created in order to value the most energy efficient devices.

There are complementary actions that seek to reduce energy demand in homes, including performance standards (ABNT NBR NO 15.220 and NO 15.575), labeling standards (PBE Edifica) and building endorsement seals (Procel Edifica), as well as encouraging the use of alternative energy generation systems in social interest housing (HIS).

Due to the estimated decline in the average annual consumption per equipment of 13.6% between 2005 and 2021 (-0.9% p.a.), it was estimated a reduction in residential electricity consumption of air conditioners of 2.3 TWh in 2021, a consequence of the regulations of minimum energy efficiency indexes initiated by the Interministerial Ordinance MME/MCT/MDIC NO 364 published in 2007 and which was revised in 2011 by Interministerial Ordinance NO 323, in 2018 by Interministerial Ordinance NO 2 and in 2020 by INMETRO Ordinance NO 234.

Due to the estimated retraction in the average annual consumption per equipment of 9.0% between 2005 and 2021 (-0.6% p.a.).), it was estimated a decrease in the residential electricity consumption of refrigerators of 1.4 TWh in 2021, a consequence of the regulations of minimum energy efficiency indexes started in 2007 by the Interministerial Ordinance MME/MCTI/MDIC NO 362, and which was revised in 2011 by the Interministerial Ordinance NO 326, in 2018 by the Interministerial Ordinance NO 01 and in 2021 by INMETRO Ordinance NO 332.

Continuing the policies initiated from Law NO 10.295 of 2001, known as the Energy Efficiency Law, it is considered important that the regulations of minimum energy efficiency indexes can be extended to other appliances for residential use, prioritizing those with higher average consumption per equipment.

Penetration of Solar Heating Systems (SAS) in households

The conversion of the sun's 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 certain energy service.

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

While, for consumers, the use of SAS can reduce the total expenditure with energy, for the electric sector its use can reduce the consumption in the grid, the peak demand in critical periods and the technical losses in the system, contributing to postpone new investments in generation, transmission and distribution. Finally, from the environmental point of view, the use of SAS can help to reduce GHG emissions.

The total accumulated area of collectors reached around 21 million m² in 2021 (ABRASOL,2021). It is noteworthy that the residential sector was the main destination of sales of SAS solutions in 2021, with 76% of the total new area installed, followed by the commercial (14%), services (5%), industrial (4%) and social projects (1%) (ABRASOL,2021). In regional terms, the Southeast stands out (54% of sales in 2021) (ABRASOL,2021).

Residential solar thermal energy is destined mostly for heating water for bathing and swimming pools, which can be located inside homes or in leisure areas of buildings. It was estimated that the avoided energy consumption in the country's residences was 746 thousand toe in 2021 through the use of SAS.

Figure 15 – Solar Heating Systems (SHS) in households
Source: Compiled by EPE

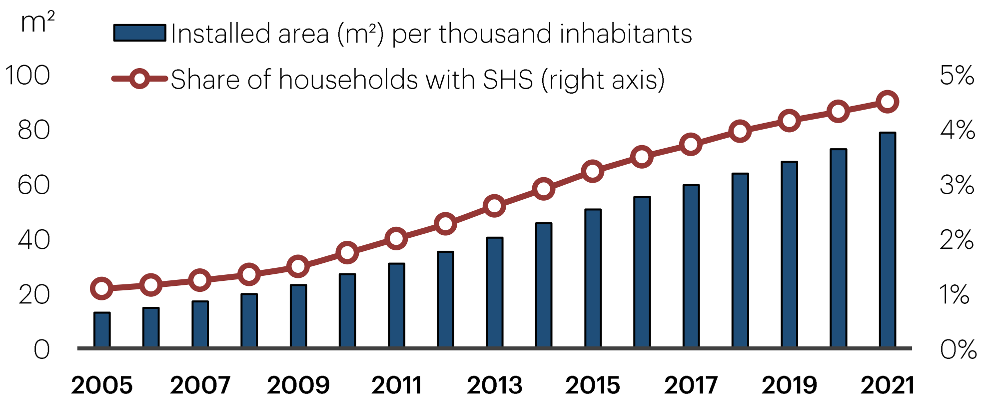
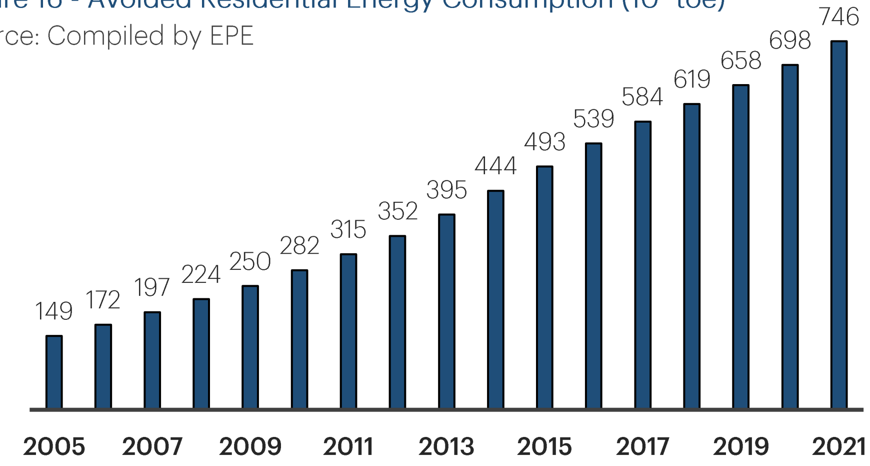


Figure 16 - Avoided Residential Energy Consumption (10³ toe)
Source: Compiled by EPE



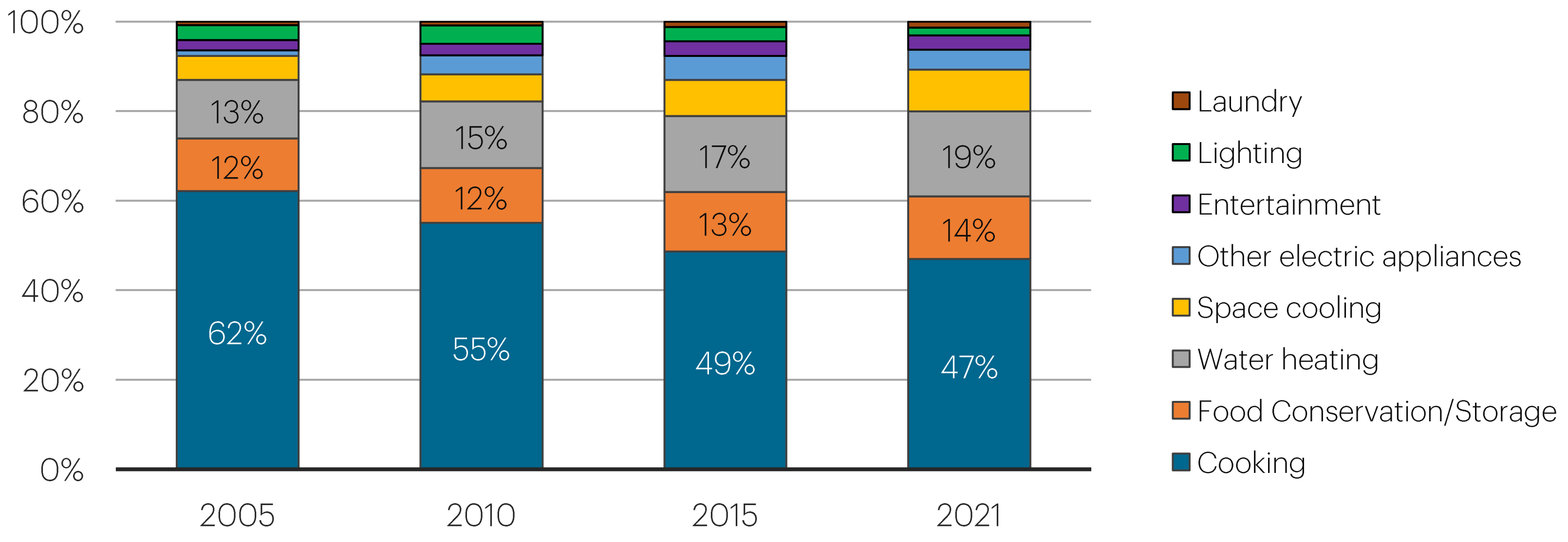
Evolution of energy consumption by final use in households

The main final use of energy in Brazilian residences is food cooking, followed by food conservation and water heating. The reduction in the energy participation of food cooking in the period between 2005 and 2021 can be explained by the energy transition process of the most disadvantaged families who substitute the consumption of traditional biomass for more modern and efficient fuels as they progress economically. Lighting, on the other hand, has been losing participation over time due to the increasingly widespread use of more efficient light bulbs, especially compact fluorescent and LED technology.

The increase in the participation of electric and electronic equipment can be explained by the increase in their ownership by families, which accompanies a transition in technology and habits.

Figure 17 - Evolution of the energy participation of end uses in the residential energy demand

Source: Compiled by EPE



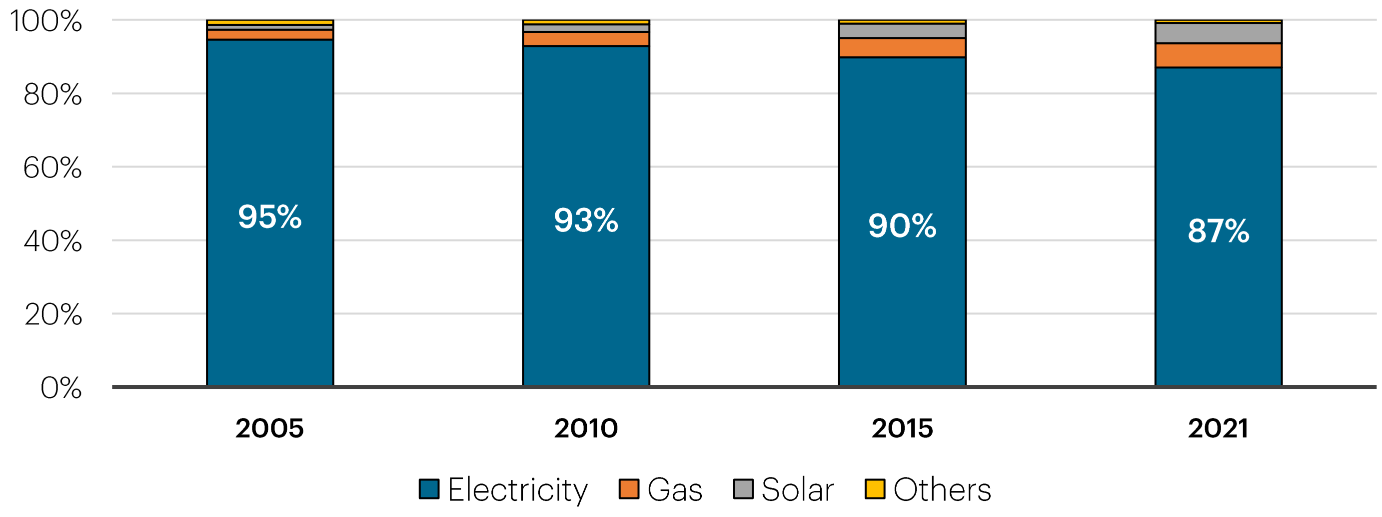
Room air conditioning has been gaining participation due to the increase in the use of air conditioners as families can afford them, replacing fans and air circulators, which are relatively cheaper and consume less energy. The induction can also occur due to the presence of warmer days on average over the years.

Evolution of the percentage of households that heat water by energy source

Electricity is the energy source most used by Brazilian households for heating water via electric showers. It was estimated that the average possession of electric showers in the country was 0.72 equipment/household in 2021 and the participation of households that use electricity to heat water reached 87% in the year. Furthermore, the share of households using solar thermal energy to heat water reached 5% of all households heating water in 2021.

Figure 18 - Evolution of the percentage of households that heat water by energy source

Source: Compiled by EPE



Gas heaters, which may be instantaneous or storage, are an alternative to electric showers, especially in urban areas with gas distribution infrastructure. It has been estimated that the share of households using gas for heating water will reach 7% by 2021.

This equipment is standardized by the Brazilian Labeling Program (PBE), coordinated by INMETRO. In addition, there are legislations of minimum rates for gas heaters, initiated by the publication in 2008 of the Interministerial Ordinance MME/MCT/MDIC NO 298 and which was revised in 2011 by the Interministerial Ordinance NO 324.

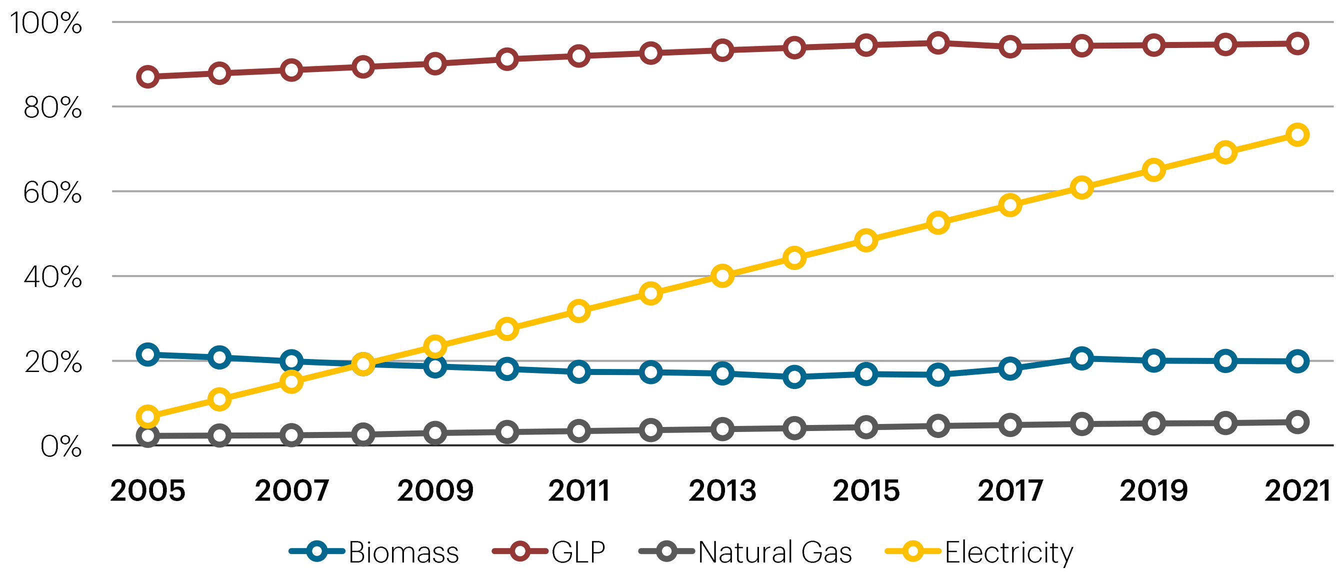
There are regions of the country that are very hot, such as the North and Northeast, which may contribute to the low percentages of households that heat water for bathing, as illustrated by the Survey of Equipment Ownership and Usage Habits - PPH 2019 (PROCEL/ELETROBRAS). Calculations by EPE using the data collected in this survey estimate that about 35% of Brazilian households did not heat water for bathing in the country in 2019, and in the North (94%) and Northeast (88%) these statistics were much higher.

Evolution of the percentage of households that cook food by energy source

LPG can have a large capillarity in Brazil, reaching 95% of national households by 2021. The use of natural gas is still small (5.5% of national households), basically restricted to urban areas of cities with distribution infrastructure.

Figure 19 - Evolution of the percentage of households that cook food by source in relation to the total number of national households

Source: Compiled by EPE



The use of electricity in food preparation has been growing over time, reaching just over 70% of all Brazilian households by 2021. With the evolution of technology and the decreasing cost, the possibilities for people to acquire these types of electrical appliances for home use are increasing, as they are practical and generate good results. Included in this set of equipment are **microwaves, electric ovens and stoves, sandwich maker, grills, toasters, electric fryers, electric stoves**, among other devices.

The participation of traditional biomass (firewood and charcoal) for cooking food in the country's homes fell between 2005 and 2015 due to the progress of the economic situation of the most disadvantaged Brazilian families, but showed a reversal movement from 2015 to 2021, due to the worsening of the economic picture.

Electricity – Final uses, ownership and average annual consumption by appliance

Figure 20 – Residential electricity consumption by end use

Source: Compiled by EPE

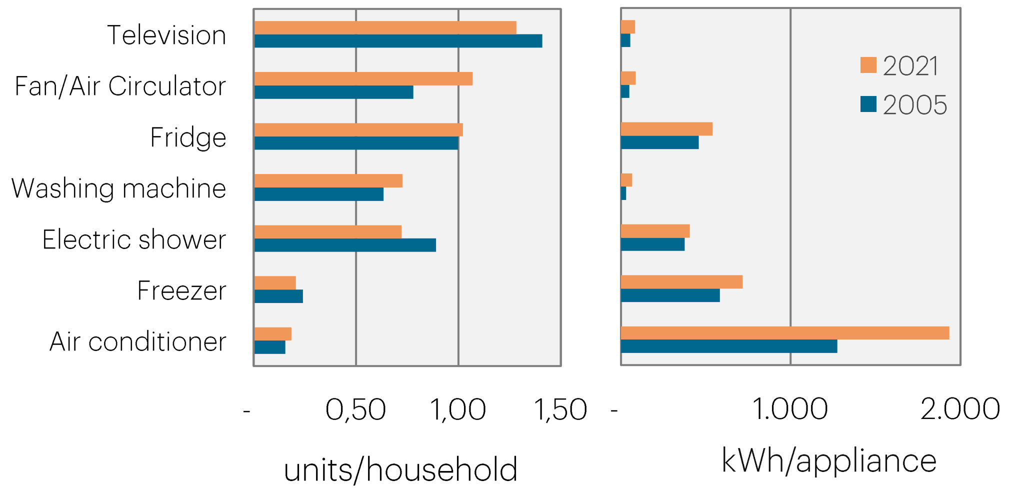
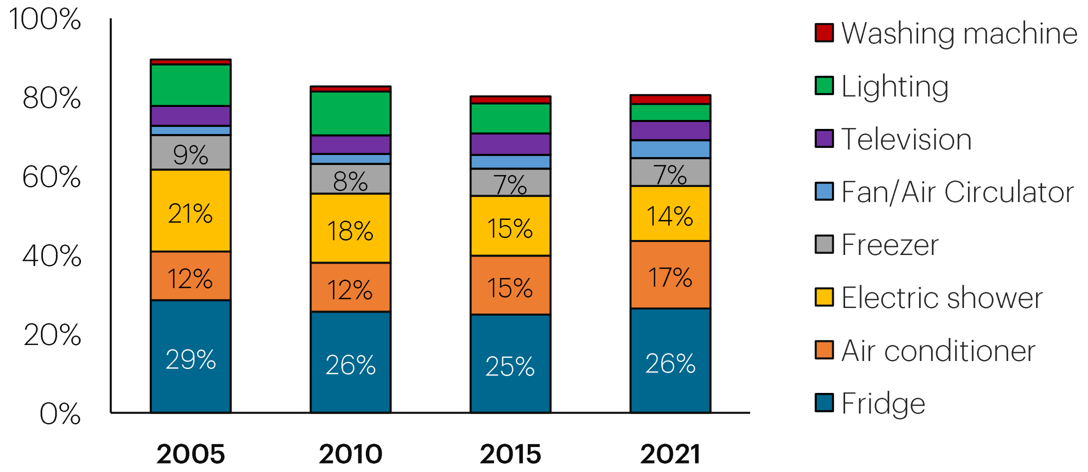


Figure 21 – Ownership and average annual consumption by equipment type

Source: Compiled by EPE



Food preservation is the end use with the highest consumption per household in the country, due to the fact that refrigerators are in practically all Brazilian homes, stay on 24 hours every day of the year and have a significant specific consumption.

Despite the low ownership of 0.18 equipment/household for air conditioners in 2021, they have the highest average consumption per appliance, resulting in the second position among the most electro-intensive in 2021 (about 17% of the total residential consumption in the year). Fans and Air Circulators have a slightly higher ownership than 1 appliance/household, being a lower cost solution for room air conditioning.

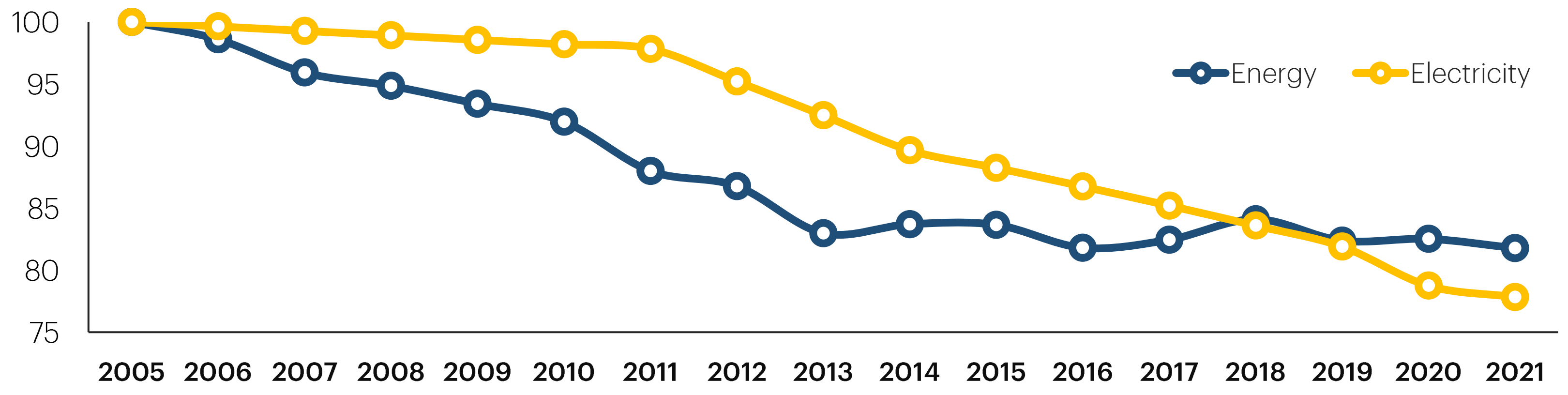
The ownership of freezers and electric showers fell between 2005 and 2021. In the case of freezers, the reduction is largely a result of the change in the habits of families in recent decades that have stopped replacing equipment that has reached the end of its useful life, being scrapped.

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

Residential ODEX

ODEX is an indicator used to evaluate the energy efficiency gain over a period. This measure for households aggregates the consumption trend of the different end uses (in the case of energy), or equipment (in the case of electricity), based on their weights in total consumption.

Figure 22 – Evolution of residential ODEX calculated for total energy and electricity
Source: Compiled by EPE



While the ODEX calculated for energy showed a drop of 18.2% (1.2% p.y.) between 2005 and 2021, the retraction of the ODEX for electricity was 22.2% (1.6% p.y.). It can be observed that in recent years the decline of the indicator is more significant for electricity, suggesting the importance of this source in residential energy conservation in the country.

The indicators associated with energy consumption in households suggest that when we consider the main end uses, as well as the main electrical equipment, we observe a trend toward energy efficiency in the Brazilian residential sector between 2005 and 2021. In addition to inducing public policies, energy efficiency is the result of complex interactions which include economic, social, technological and behavioral factors of families.

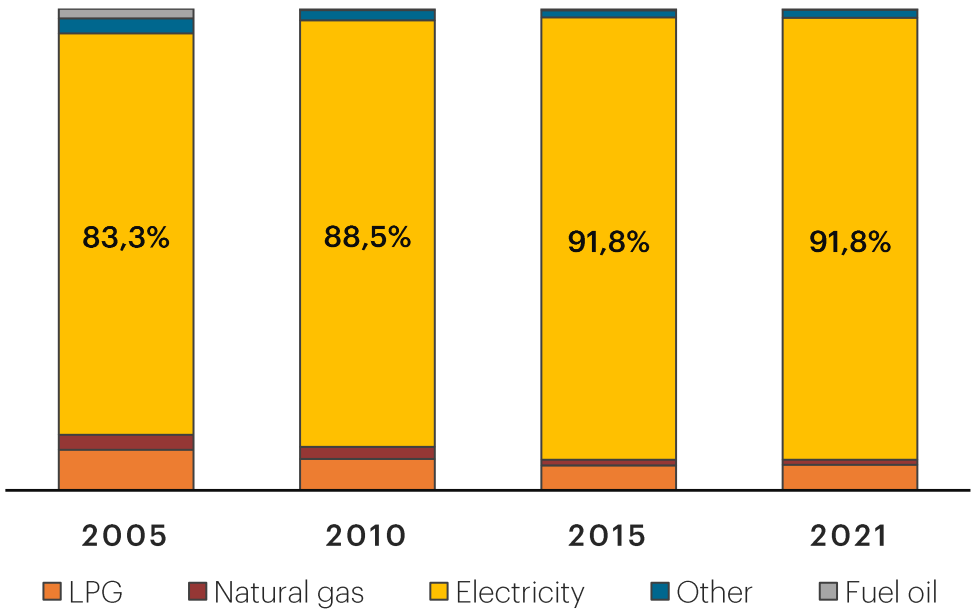
For electricity, there has been a reduction in the average specific consumption of the national stock of equipment, due to the first purchase or replacement by more efficient appliances of those at the end of their useful life or that have become unused. In turn, the return to the use of firewood in times of weakened economic conditions and the increase in the cost of LPG, especially for low-income families, influenced the behavior of the energy indicator as of 2014.

Services

(commercial and public services)

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

Figure 23 – Final energy consumption in the service sector
Source: EPE (2022b)



The final energy consumption in the sector comes mostly from electricity, LPG and natural gas. It is worth noting that the final consumption data do not include the use of natural gas for electricity generation, according to BEN's methodology.

LPG consumption has stabilized since 2005 around the 600 ktoe level, influenced by the ANP's resolution 22/2005 Art.30, which forbids the use of LPG in:

- Saunas;
- Caldeiras;
- Aquecimento de piscinas, exceto para fins medicinais;
- Motores de qualquer espécie, inclusive aqueles para fins automotivos, exceto empilhadeiras e equipamentos industriais de limpeza movidos a motores de combustão interna.

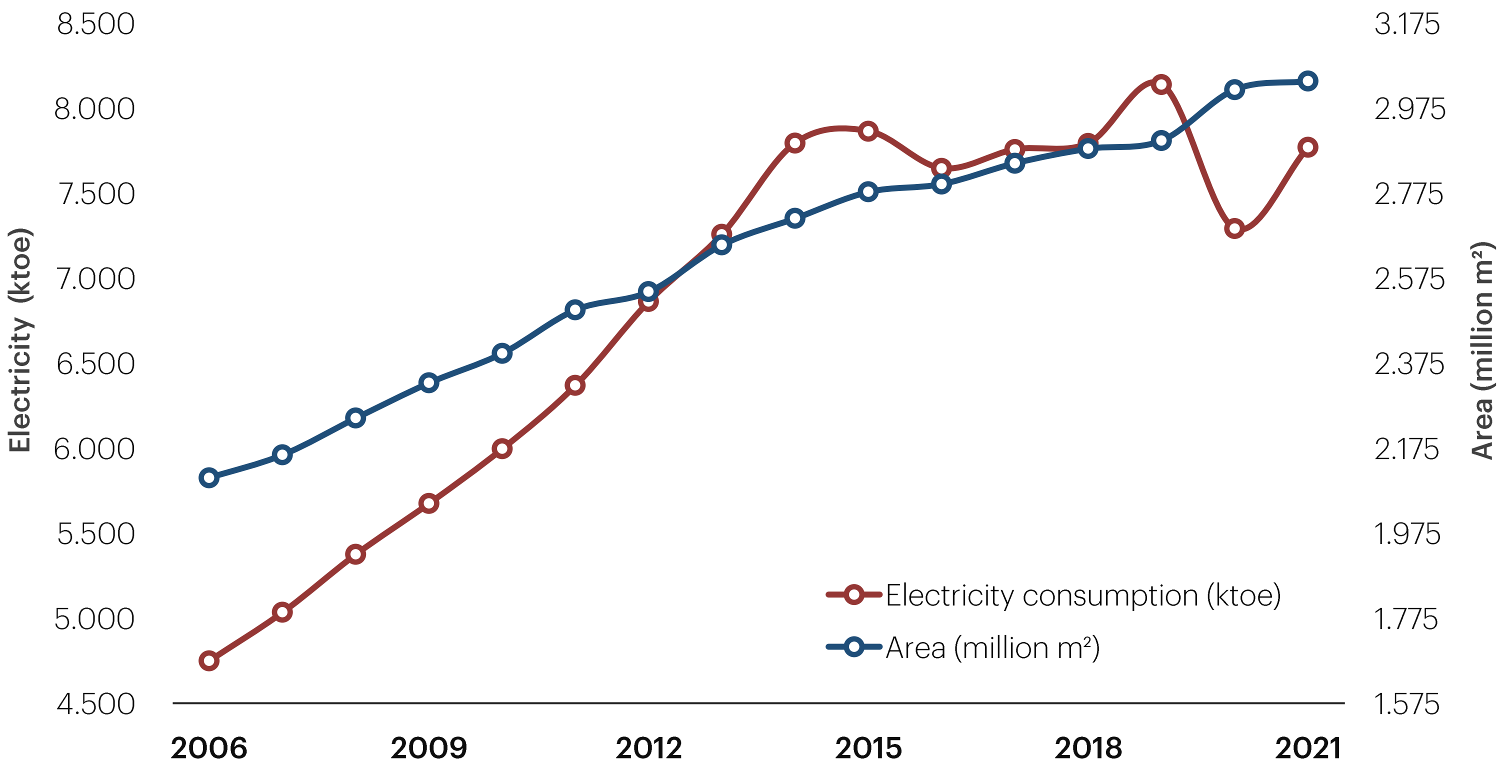
Electricity continues to gain importance in the final consumption of the sector in the period 2005-2021, and may be associated with several factors such as the increased ownership of electrical equipment in establishments, increased automation and process control, replacement of the use of secondary sources, among other factors. In the period 2019-2020 **electricity had a 10% reduction, due to the shutdown of the sector's activities, especially those said to be non-essential in the context of the pandemic. Throughout 2021, although on-site activities have partially resumed, the electricity consumed is still 6% below the pre-pandemic level.**

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

Analysis: Commercial Sector

It is observed, for the period 2006-2021 a growing increase in the area of commercial establishments with an average annual rate of 2.5%, while in the same period the sector's electricity consumption shows an increase of 3.3% p.a. According to ABRAVA's economic bulletin (2021), the sale of central refrigeration equipment such as Chiller, VRF and Package grew 9% per year between 2010-2014, decreased 1.8% p.a. from 2014-2021, confirming the aforementioned consumption evolution.

Figure 24 – Evolution of Energy Consumption and Area in the Commercial Sector
Source: Compiled by EPE



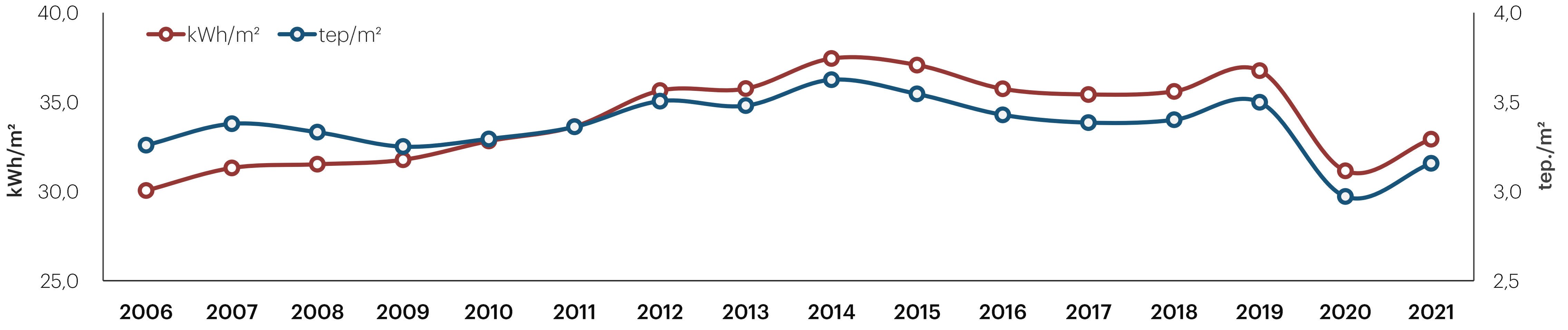
In 2020, the area of the segments grew 4.1% in relation to the previous year, driven by the expansion of the segments Hospitals, emergency rooms, information dissemination, among others. On the other hand, the paralyzation or reduction of activities corroborated the closure of some commercial establishments, especially bakeries, confectioneries, bars, and restaurants. It is worth mentioning that such measures, necessary to combat the spread of the COVID-19, have led to the operational adaptation of the commercial sector, intensifying the implementation of e-commerce systems, delivery services, telecommuting, distance learning modalities, among others. Thus, while the area of establishments expanded by 4.1% compared to 2019, electricity consumption reduced by 10.4%. In 2021, despite the return to face-to-face activities, pre-pandemic consumption levels have not yet been reached.

Analysis of sectoral indicators: evolution of consumption per m² of commercial and public buildings

Energy consumption per square meter in commercial and public buildings grew in the period from 2006 to 2014, especially as the ownership and use of electric appliances increased. However, from 2014 on, the indicator shows stability until 2019 culminating in a steep decline in the pandemic year of Covid-19. 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 contributing factors that corroborate for the illustrated trajectories, such as:

- The implementation of Aneel Resolution 414/2010 which reclassified part of the electricity consumption of condominium buildings, previously accounted for in the residential sector, to the commercial sector.
- The climate effect that intensifies/attenuates the use of environmental conditioning equipment: air conditioners, fans, among others.
- Hydric, Economic and Sanitary Crises. Economic and Sanitary crises over the last years.

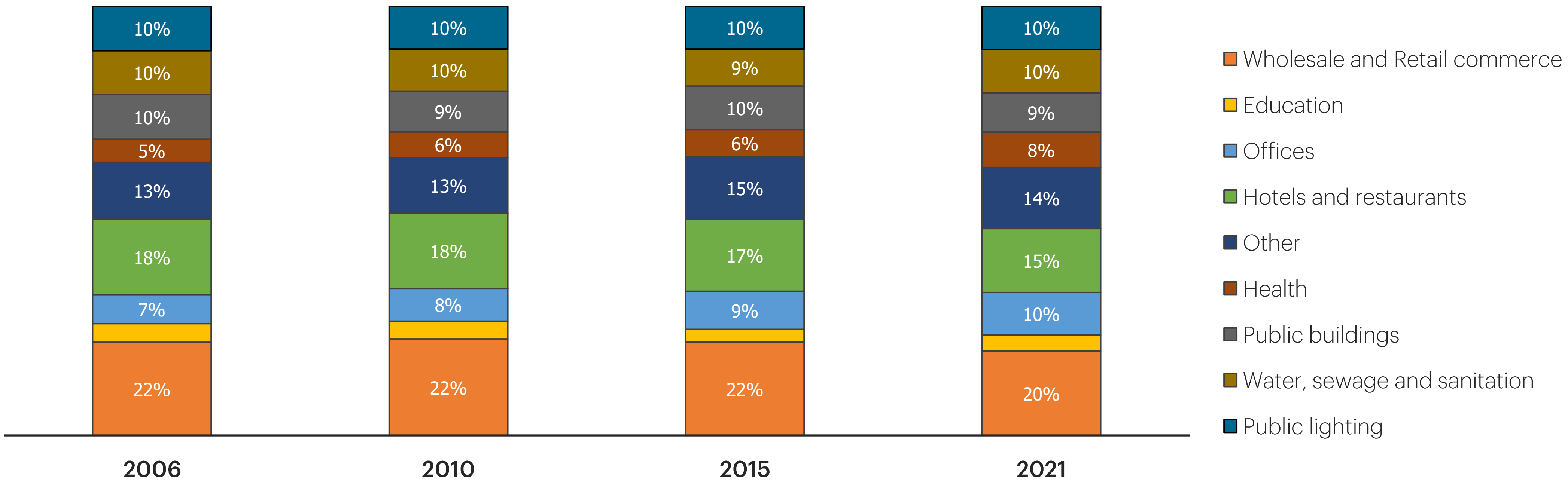
Figure 25 – Consumption[1] per square meter
Source: Compiled by EPE



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

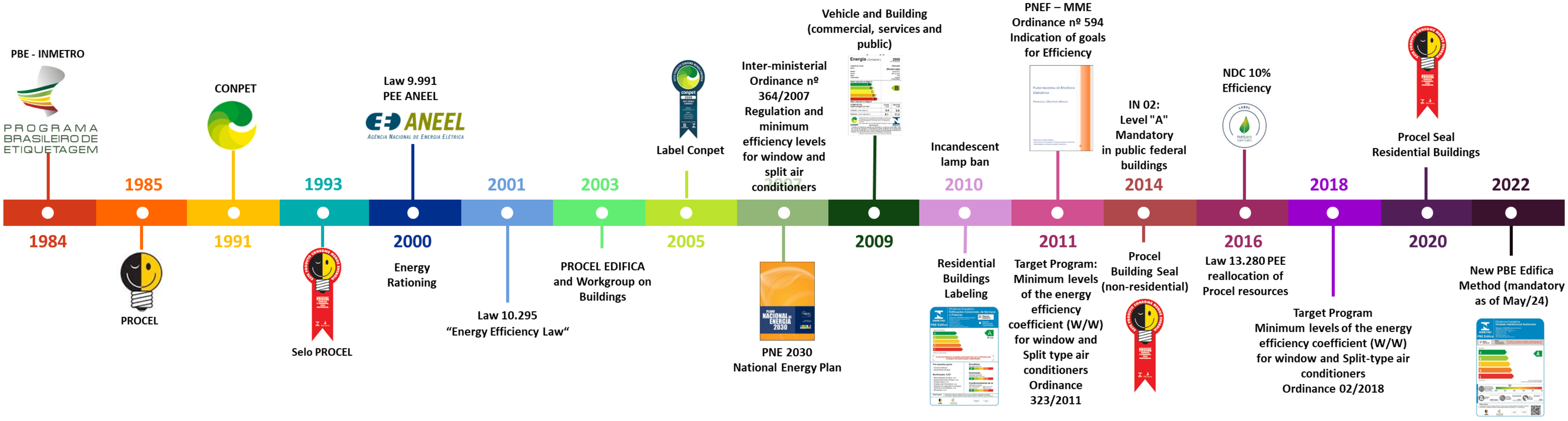
Energy consumption by segment 2006-2021

Figure 26 – Energy consumption by segment in the services sector
Source: Compiled by EPE



The services sector, intrinsically heterogeneous, presents some homogeneity in the annual energy amounts consumed per segment over the period. However, in 2020, with the COVID-19 pandemic, the health segment gained participation in final energy consumption to the detriment of the retail, hotel and restaurant segments. In 2021, despite the partial return to face-to-face activities, the percentage share among segments did not differ significantly compared to 2020.

Energy Efficiency Policies Timeline



Policy Integration Vision

Regulates minimum efficiency or maximum energy consumption indices

MPES
Law 10.295 of 2001
Energy Efficiency Law

Implement the policies and develop the market

Programs for Efficiency Programs (PEE/ANEEL/PAR PROCEL)

Energy Efficiency

Ranks the energy performance

PBE
ENCE

Procel Seal

Awards the most efficient products

Industry

Evolution of energy consumption, value added and intensity of the Brazilian industry

- Between 2001 and 2013 there is a growth trend in industrial activity and energy consumption in industry, interrupted at one point during the energy crisis (2001) and the global recession caused by the international financial crisis (2008/2009), as indicated in Figure 28.
- As indicated in Figure 29, historically until 2015, energy intensity remains relatively stable at a level below the current level, while industrial GDP per capita tends to average lower between 2015 and 2021 compared to the previous period.
- Between 2010 and 2013 the economy recovers with GDP growth concomitant with a reduction of 1.1% per year in industrial intensity.
- The trajectory reverses between 2014 and 2020. The economic crisis associated with the deteriorated domestic scenario is reflected in the retraction of the per capita industrial GDP by 3.1% per year due to the reduction in production of domestic industrial goods with some exceptions.
- Likewise, there was an increase in energy intensity of 2.1% per year with a greater participation of energy-intensive industries and an increase in the idleness level of the transformation industry sector.
- Throughout 2021, there were still impacts from the consequences of the COVID-19 pandemic on the operation of industrial plants and energy consumption and, consequently, on industrial energy intensity.

Figure 27 – Total Energy Supply, final industrial energy consumption and industrial value-added
Source: Compiled by EPE, using EPE (2022b) e IBGE (2022)

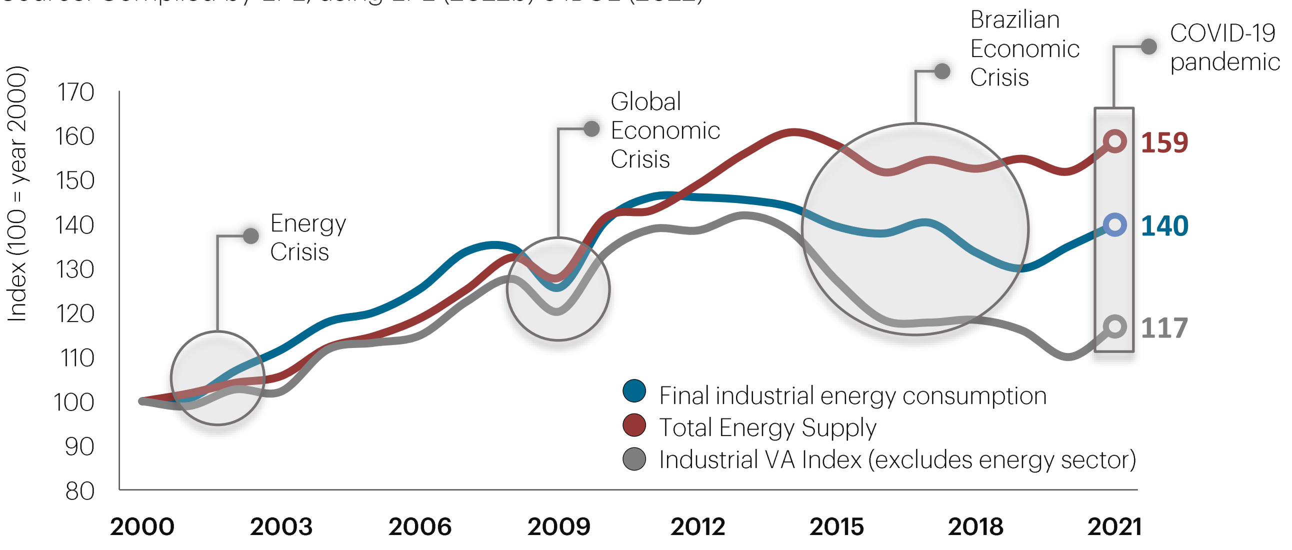
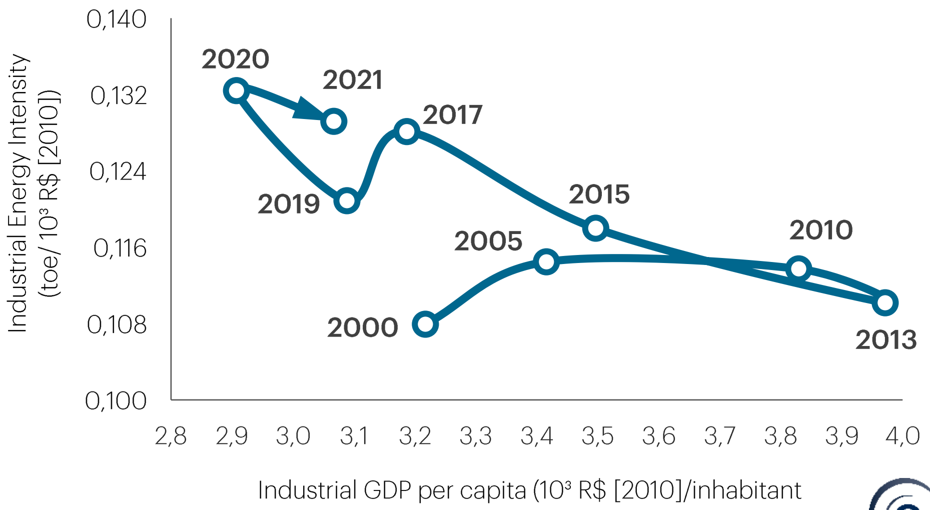
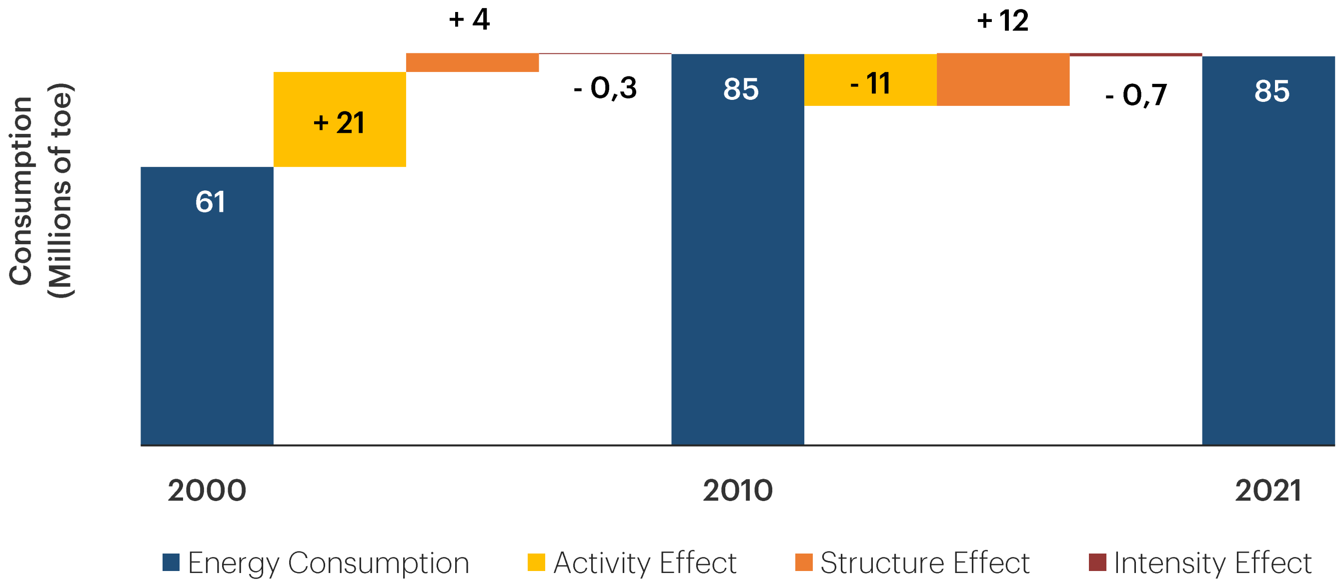


Figure 28 – Path of energy intensity and GDP per capita in industry
Source: Compiled by EPE using EPE (2022b) e IBGE (2022)



Decomposition analysis: between 2000 and 2021 industrial energy consumption increased by 1.6% per year...

Figure 29 – Breakdown of changes in industrial energy consumption
Source: Compiled by EPE, using EPE (2022b) and IBGE (2022)



The three main effects that make up the variation in industrial consumption are: the value added (variations in the level of activity), the relative participation of the industrial segments (i.e. the structure of industry) and the intensity of each segment.

Between 2000 and 2010 there was a large increase in industrial activity, moderate change in structure while the intensity effect was slight. The industries that grew the most in the period were food and beverages, mining and pelletizing, and pulp and paper.

After the impacts of COVID-19, the 2010 level of industrial consumption is almost resumed in 2021. Since 2014 there has been a reduction in industrial activity (by the various economic crises that impacted the industrial sector), and also by energy efficiency gains. However, this reduction is offset by the structure effect.

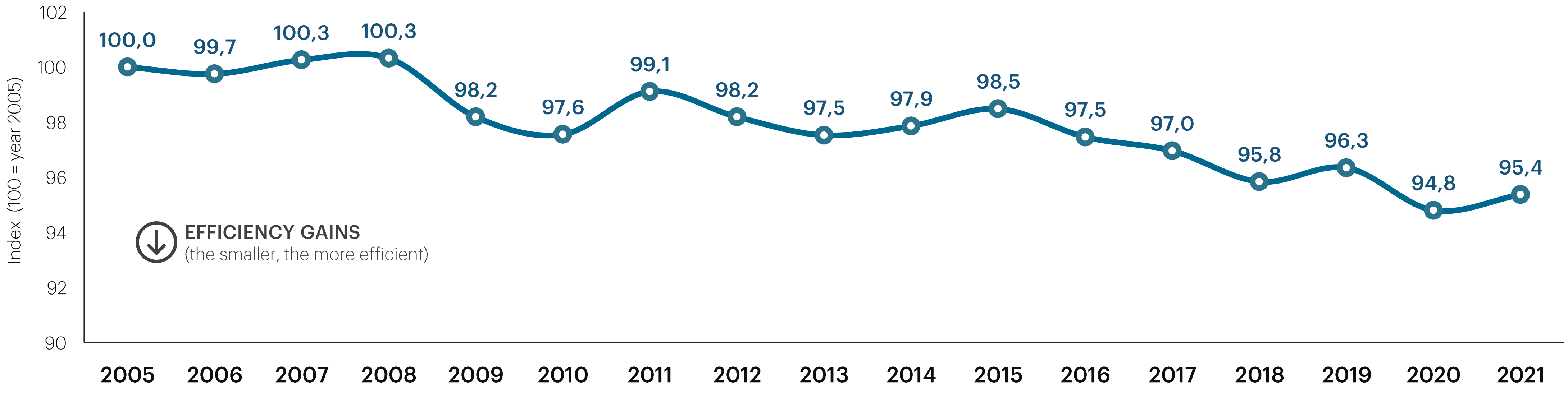
The food and beverage and paper and cellulose industries stand out for growing throughout the horizon. However, in the first period, practically all the segments grow, with little structural variation. In the second period, several industries reduce their activity and lose participation, especially textile and other industries, with energy-intensive segments predominating - increasing the intensity of the national industry.

Industrial ODEX

To calculate the ODEX, specific consumption based on physical production was considered for the steel, pulp and paper, cement and sugar segments, and energy intensity for the other food, textile, chemical, ceramic, ferroalloy, other metallurgy, mining and other industries, depending on the availability of information.

Figure 30 – Industrial ODEX

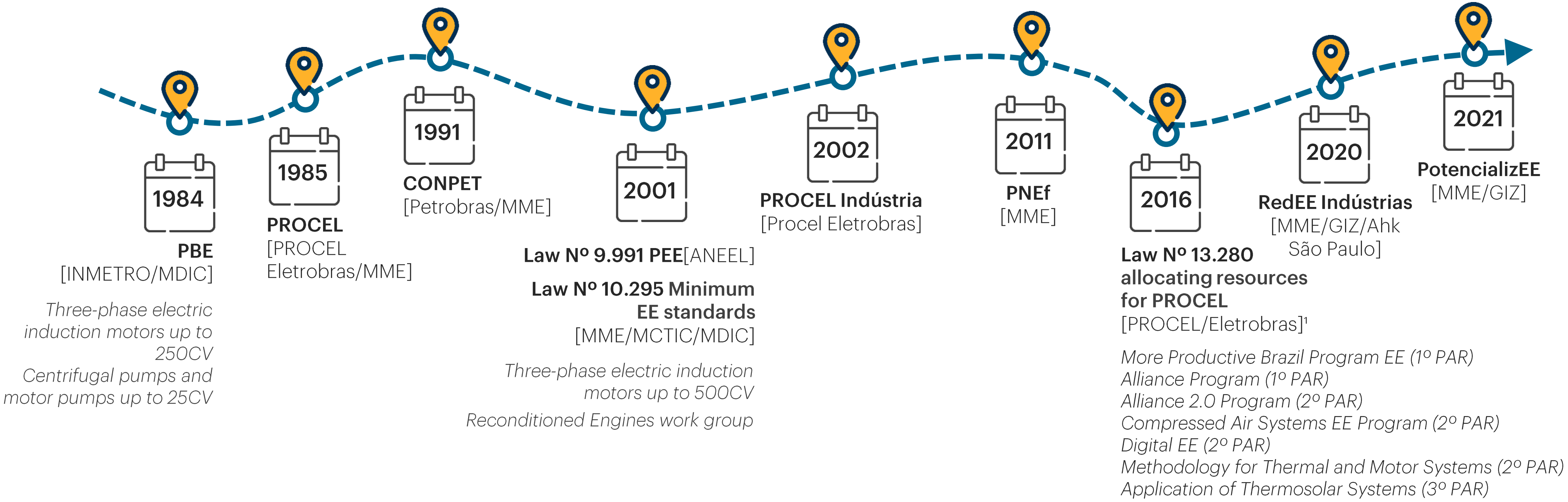
Source: Compiled by EPE



In 2021 the industry ODEX reached the value 95.4, which corresponds to an energy efficiency gain of 4.6% compared to 2005 (average reduction of 0.3% per year). Although the industrial ODEX represented relative efficiency loss between 2020 and 2021, the steel and ferroalloy segments contributed the most to energy efficiency in industry.

Timeline: current energy efficiency policies

Figure 31 – Main highlights of energy efficiency policies related to the industrial sector
Source: EPE. Images; Icons made with Freepik - www.flaticon.com



> Historically, policies and programs have encouraged the modernization of the industrial park through the continuous improvement of processes and the use of more efficient equipment, as well as from many other energy efficiency measures that are applicable and still aim to expand energy savings in the industrial sector. Energy efficiency is one of the important vectors of competitiveness of the industry and also enhances gains in technological innovation in the country.

[1] Non-exhaustive list

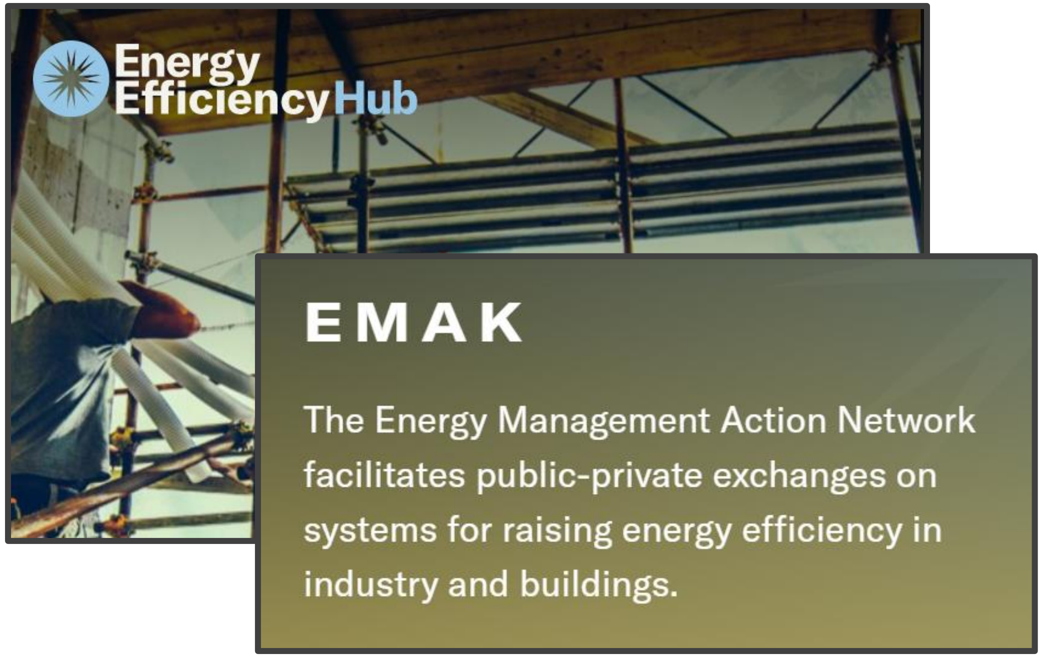
Important current initiatives for the industrial sector

Figure 32 – PotencializEE and the Energy Efficiency Hub (EEHub)
Source: PotencializEE[1]

The PotencializEE program in numbers

The results expected by the Program, until 2024, in small and medium industries in the State of São Paulo in numbers:

- 425 projects
- 5260 industries made aware
- +1,000 energy diagnostics
- 1.1 million tons of CO_2 equivalent
- 7,267 GWh



Such initiatives stand out for their objectives of boosting the exploitation of energy saving opportunities and promoting energy management. The improvement of energy efficiency by leveraging potential gains with the supply of technical support and accessible credit to small and medium-sized industrial companies (in the state of São Paulo) and the development of networks among decision-makers/managers in the area, are, respectively, the main actions of PotencializEE - Program for Transformative Investments in Energy Efficiency in Industry and of the "Energy Management Action Network for Industrial Efficiency" (EEHub EMAK).

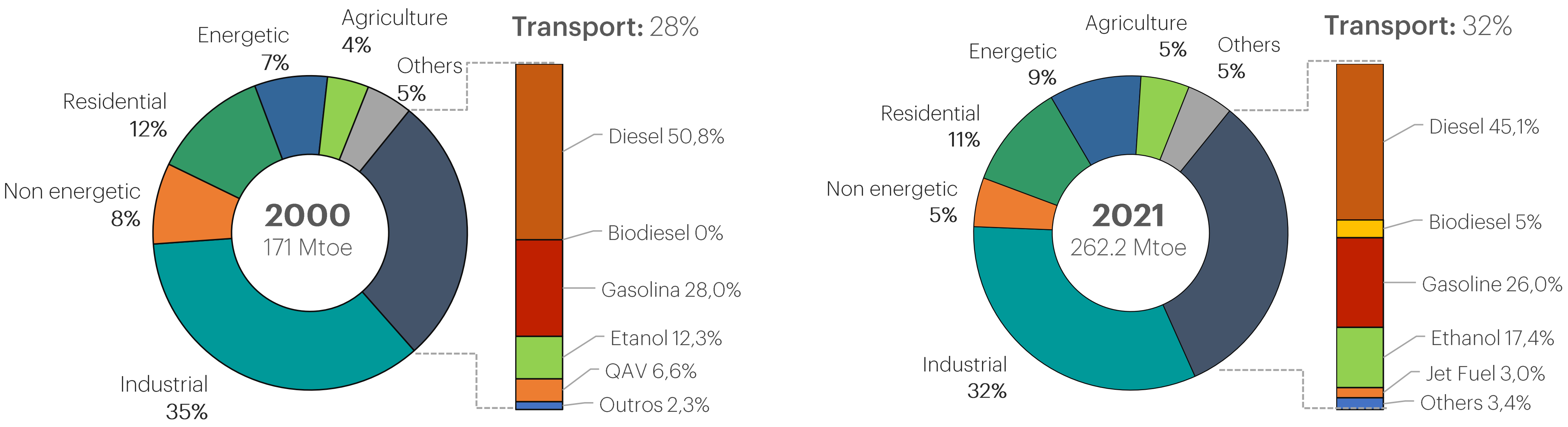
[1] Images: www.programa-potencializee.com.br/Energy Efficiency Hub

Transport

Evolution of energy consumption in the transport sector

In 2021, national energy consumption increased by 3.5% over 2020, a rate lower than the GDP increase of 4.6%. The effects of the Covid-19 pandemic are still being felt, but recovery can already be seen in some modes of transportation. There was a 3.7% increase in energy demand in the sector. The good performance of agribusiness and exports increased the demand for cargo transportation, putting upward pressure on the demand for diesel oil. There was also an increase in the share of individual passenger transport, with its participation rising from 31% in 2020 to 32% in 2021.

Figure 33 – Final consumption and the transport sector in Brazil in 2000 and 2021
Source: Compiled by EPE, with data from EPE (2022b)



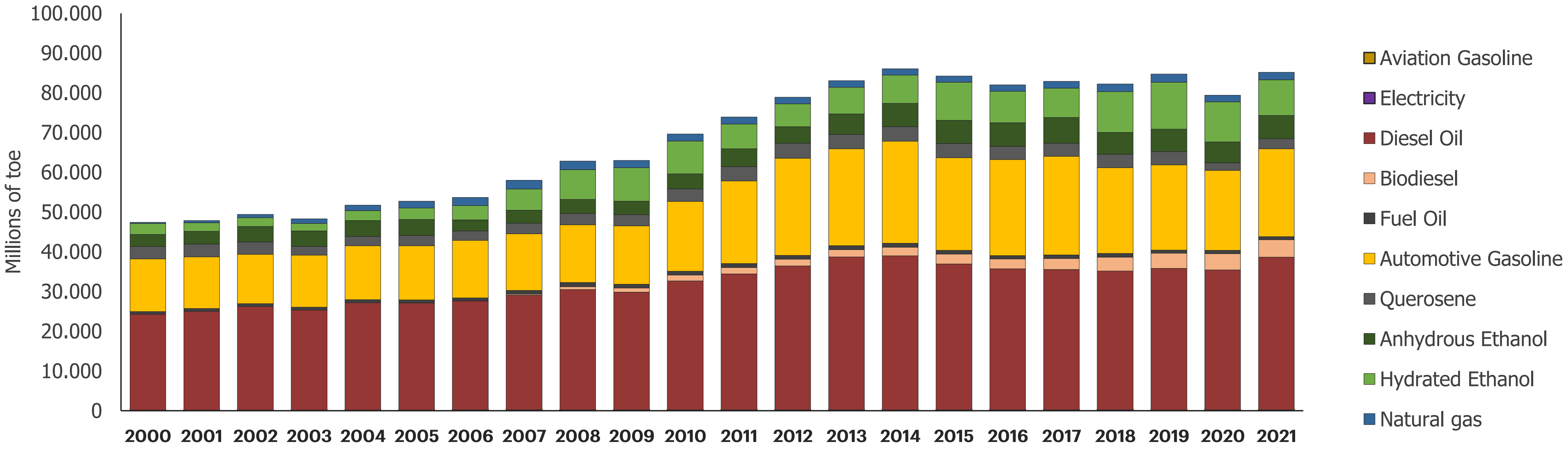
Evolution of the share of energy consumption in the Transport Sector

The sector's energy demand grew 2.8% per year between 2000 and 2021, when an increase in passenger and cargo transportation was observed, due to increased consumption of goods, greater mobility of the population, and growth in agricultural and industrial production. This occurred in line with the growth of the GDP.

The airline and passenger transport sectors are still below pre-pandemic demand, with cargo transport the main contributor to the increase in diesel oil demand.

Figure 34 – Transport sector consumption by energy source (million toe)

Source: Compiled by EPE, with data from EPE (2022b)

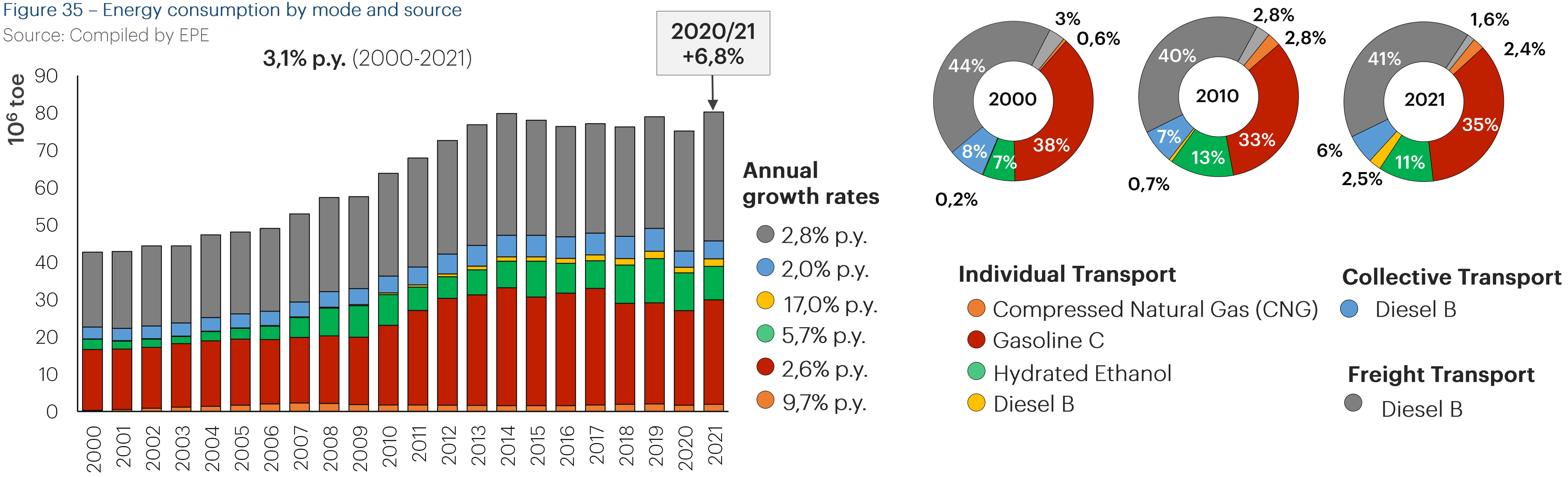


Evolution of energy consumption in road transport

Between 2000 and 2021, the demand for passenger transportation increased by 3.1% p.y., and that for freight transport demand grew 2.5% p.y. The year of 2021 was marked by the return of economic activities, directly influencing passenger and cargo transportation, with increases of 6.9%, and 7.0%, respectively.

Figure 35 – Energy consumption by mode and source

Source: Compiled by EPE



The growth in the participation of CNG and hydrated ethanol as energy sources in the road transport matrix is noteworthy. Both have a higher specific consumption than gasoline vehicles, and therefore have limited the sector's efficiency gains. However, they have reduced transport emissions and Brazil's imports of fossil fuels. In 2021, CNG presented a demand increase of 15.2%, with a gain in participation, while hydrated ethanol presented a reduction of 11.6% compared to 2020. Under this condition, hydrated ethanol loses share in the energy matrix compared to C gasoline, whose demand increased by 10.4%.

Passenger Transport

In 2020, the pandemic had a strong impact on the energy demand for transported passengers in Brazil, especially due to the decrease in the number of passengers in public transport, but also due to the lower sharing of private vehicles, reducing the number of passengers per car.

The supply of passenger transport recovered strongly in 2021, with an increase in the number of trains, cars and buses in circulation. However, this increase was not fully accompanied by a rise in the number of people carried, since, despite the advance of vaccination, the emergence of new strains of Covid-19 caused the return to face-to-face work to be delayed. In this context, many buses, trains, subways, and aircraft continued to have lower occupancy than in the pre-pandemic periods. In the airline industry, this effect was mitigated by the withdrawal of older aircraft from operation, and also by the use of more efficient aircraft. These more efficient aircraft were previously used for international flights, where the level of performance recovery is well below that observed for domestic flights.

As far as passenger demand in 2021 is concerned, the most significant advance has been in individual road transport. Partly because of the fear of contamination in public transport, the population prioritized individual transport. The share of light vehicles in transport activity was 53% in 2019, 71% in 2020, and 68% in 2021.

Figure 36 – Energy intensity by mode [toe/(10^6 p.km)]
Source: Compiled by EPE

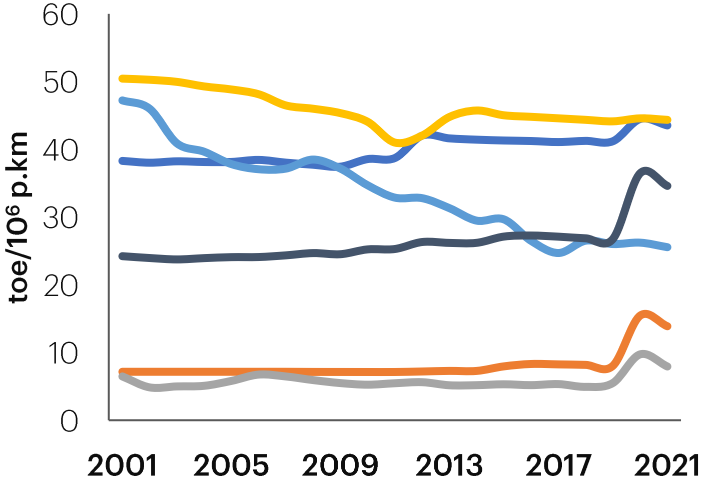
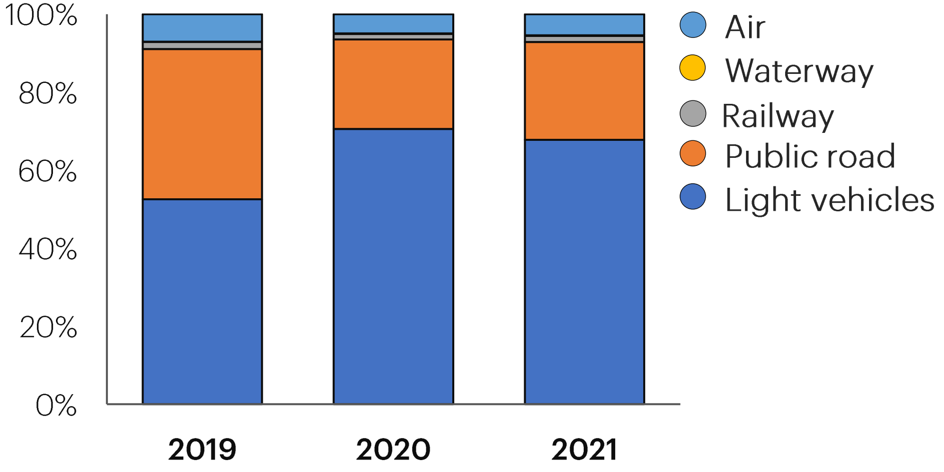


Figure 37 – Activity by mode [p.km]
Source: Compiled by EPE



Note: "p.km" means passenger-kilometer

Individual passenger transport

Figure 38 – Light Vehicle fleet and specific consumption - 2000 to 2021
Source: Compiled by EPE

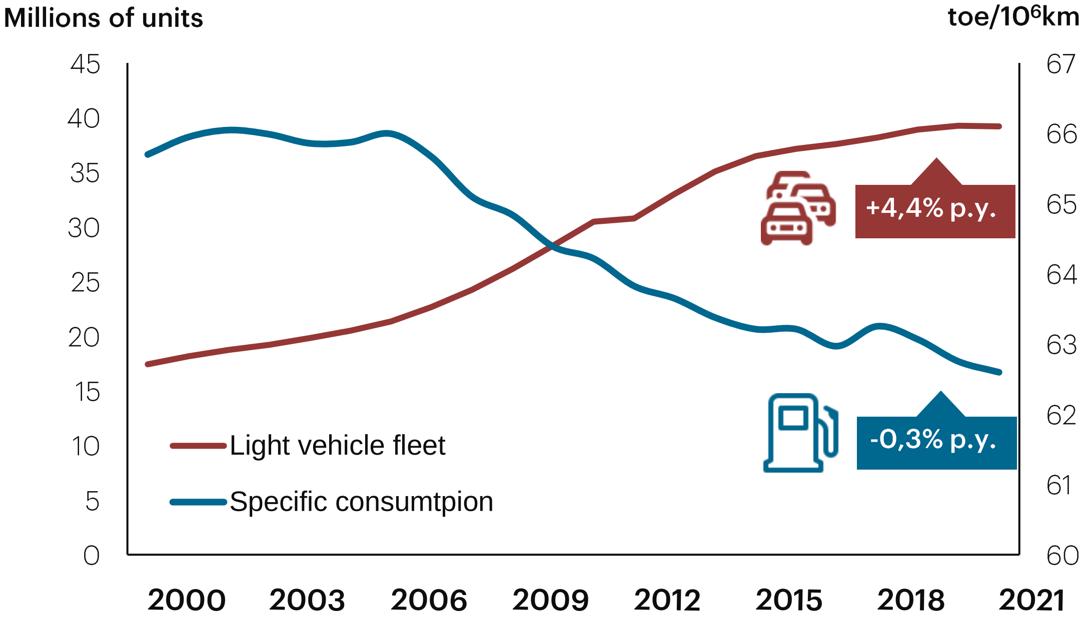
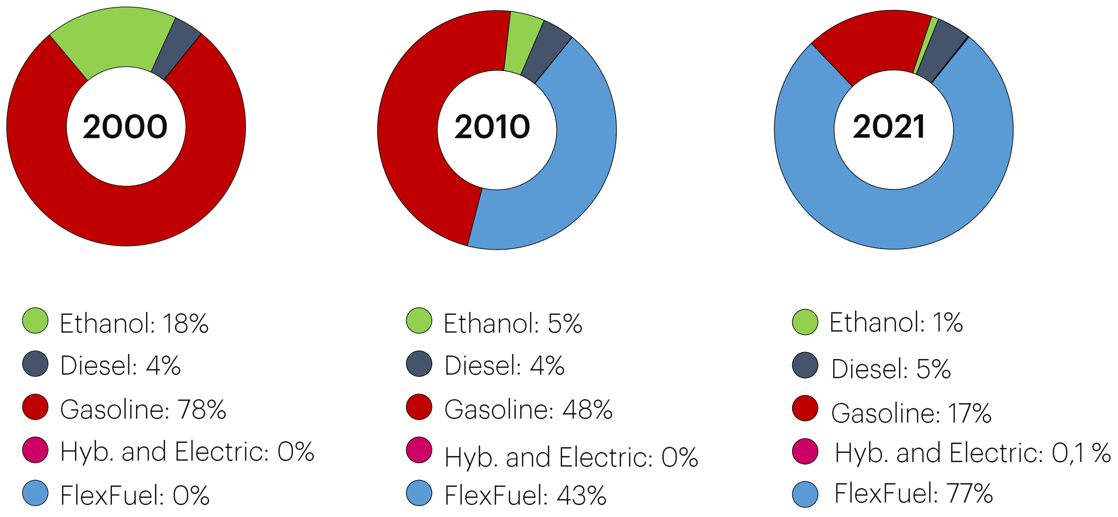


Figure 39 – Light Vehicles fleet per fuel type – selected years
Source: Compiled by EPE



Car sales kept pace with the growth of Brazilian per capita income throughout the 2000s.

The Brazilian Vehicular Labeling Program, Inovar Auto and Rota 2030 promoted the improvement of energy efficiency of new vehicle engines.

The increase in the share of flex fuel vehicles in the fleet advanced rapidly, which had an influence on the average efficiency of the light vehicle fleet, since they presented lower efficiency than the dedicated analogues.

The increase in the licensing of sporty light commercial vehicles (SUVs) also raised the specific consumption of the fleet, since they are less efficient vehicles.

In 2021, the fleet of flex and diesel vehicles increased, despite a reduction in the total fleet, especially due to the scrapping of the gasoline vehicle fleet.

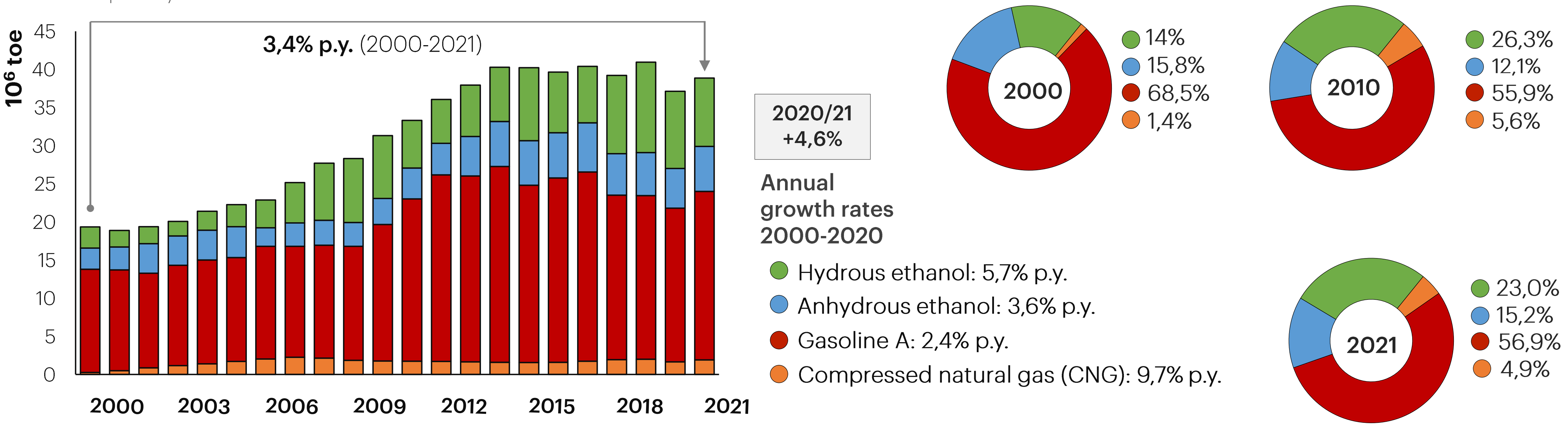
The highlight is the licensing of electrified cars and light commercial vehicles in 2021, which increased by 77% to 35,000 units, reaching 1.8% of the total licensing in the country.

Otto cycle and individual road transport

The expansion of the flex fuel vehicle fleet has allowed an increase in demand for hydrous ethanol.

Figure 40 – Energy consumption by source

Source: Compiled by EPE



2021 was a year of recovery in fuel demand and mobility. The spread of vaccination allowed people to begin to leave their homes and resume their normal lives. But the fear of new strains caused many people to choose individual transport, which explains the 4.6% growth rate in energy consumption by light vehicles. Hydrous ethanol had a difficult year, with demand falling 11.6%. Gasoline has to compensate for this lack of ethanol availability, increasing by 9.8% in 2021.

Freight transport

At the beginning of the pandemic, throughout the first months of 2020, freight, especially by trucks, was negatively impacted. Despite this, it recovered quickly, ending the year with a growth of 5.8%. This good performance was recorded again in 2021, with the energy expended by freight transport increasing by 7%. One reason for the growth is the increased demand for goods, driven by mobility restrictions, and reduced spending on services. With the growth of e-commerce, diesel fuel consumption for transporting goods between factories and distribution centers and between distribution centers and end consumers has risen.

Another reason for the increased demand for cargo transportation in 2021 was the performance of agribusiness. This sector was favored by the growth in international demand, by the rise in international commodity prices, and by the devaluation of the national currency, raising the remuneration of farmers. The increase in the planted area, the harvest, and the exports increased the demand for roads between the producing centers and the port regions.

Rail demand also recovered, with the entry of new connections increasing the transport of agribusiness by rail. However, the negative impact of mining on the rail mode in the Southeast due to rains persisted, which explains the drop in the total share of the mode.

Figure 41 – Energy intensity by mode [toe/(10^6 t.km)]
Source: Compiled by EPE

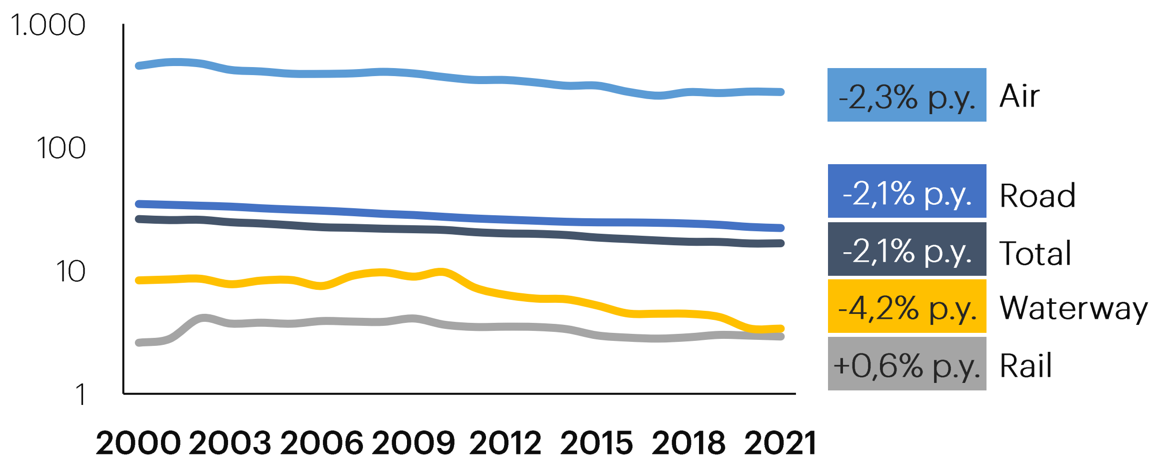
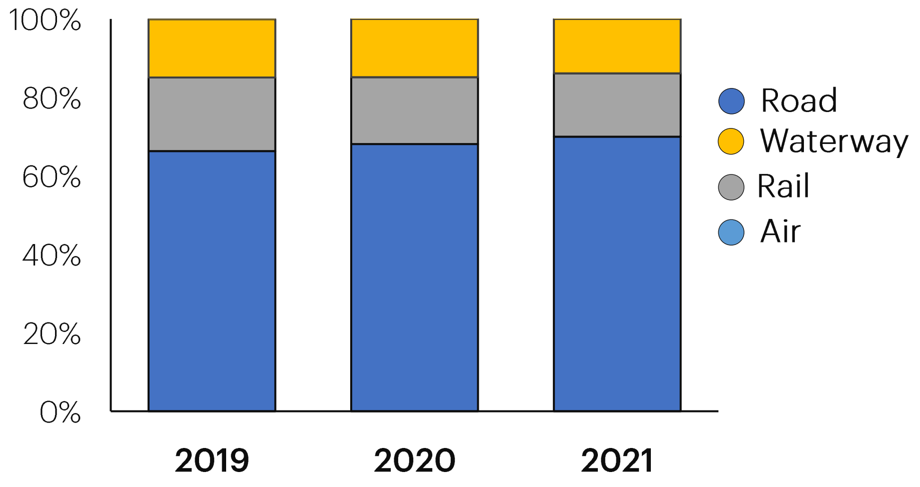


Figure 42 – Activity by mode [t.km]
Source: Compiled by EPE



Road freight transport

Figure 43 – Truck Fleet by Category (millions of units)
Source: Compiled by EPE

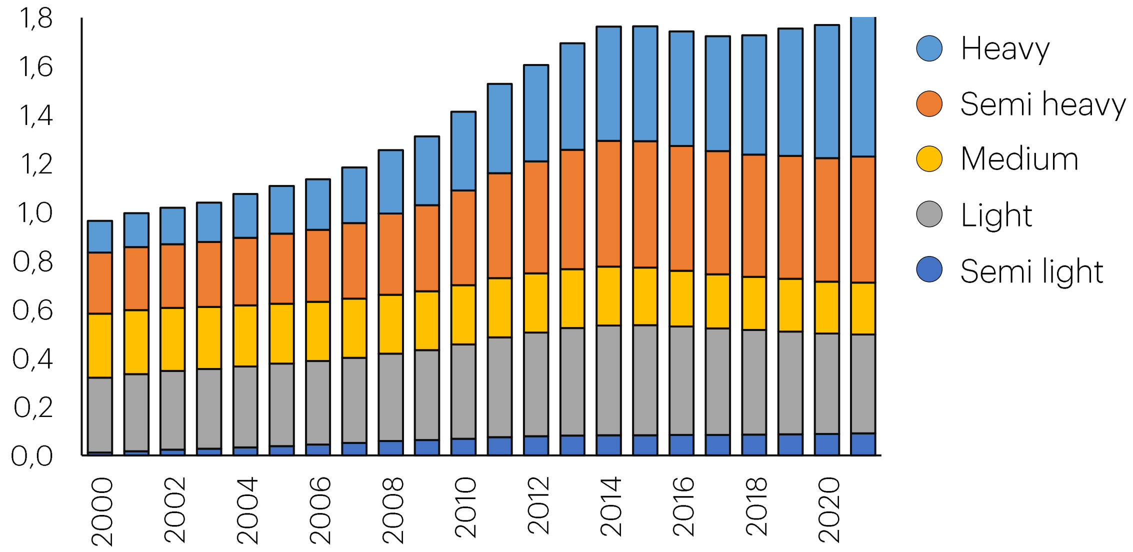
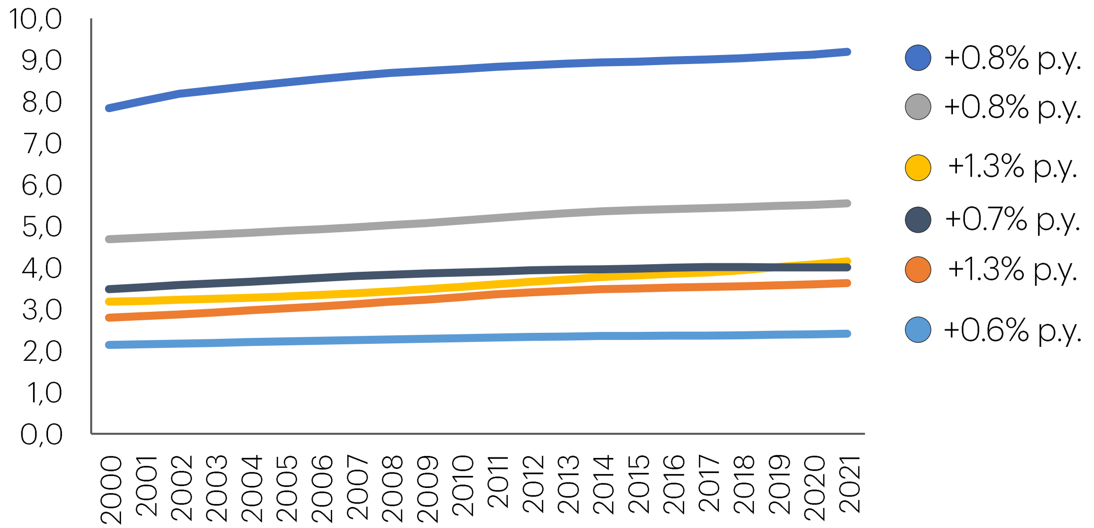


Figure 44 – Average energy efficiency of new vehicles sold (loaded) [km/L]
Source: Compiled by EPE



The Brazilian truck market recorded a strong recovery in 2021, leveraged by the resumption of economic activity, especially by the good performance of the agricultural, mining, construction, and e-commerce sectors. After being severely affected by the COVID-19 pandemic, the total licensing of new trucks in Brazil grew from 90 thousand units in 2020 to 129 thousand in 2021. It was the best result for the segment since 2014.

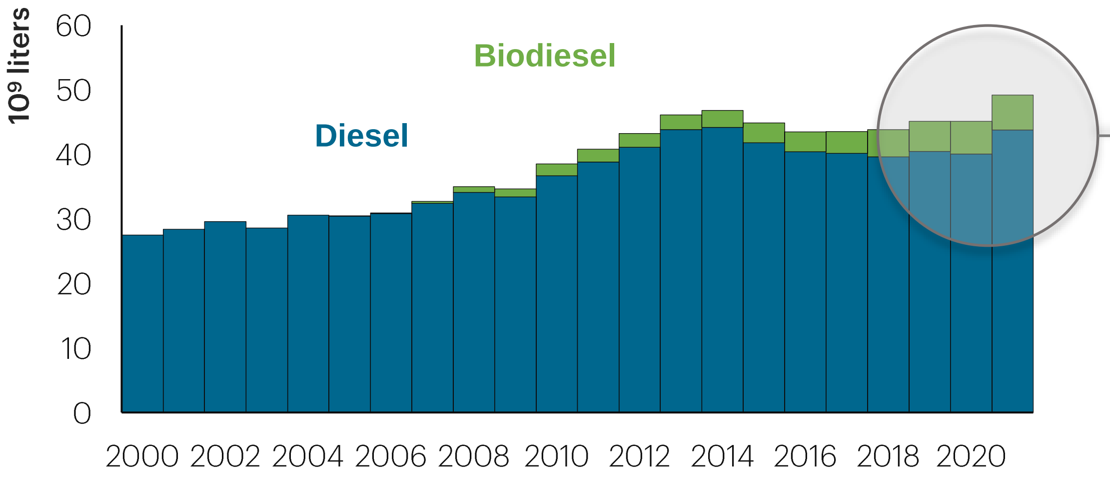
Note: The Vehicle Emission Control Program (Proconve) was instituted to reduce the levels of pollutant emissions by motor vehicles. The P8 phase applies to new heavy-duty vehicles sold as of January 1, 2023, and stipulates new maximum emission limits for exhaust gases, particulates, and noise, equivalent to the European Euro VI standard.

The introduction of new phases of the Vehicle Emission Control Program (Proconve) stimulated the adoption of more efficient engines to meet the new emission limits.

The energy efficiency of new vehicles did not evolve much in 2021. This may reflect the mandatory introduction of Proconve P8 as of January 2023. Major manufacturers may be saving innovations for the launch of new models. Nevertheless, an improvement of 1.9% is estimated for road freight transport efficiency, and 0.4% for total freight transport in 2021. This is mainly caused by increased sales of heavy-duty trucks, which consume less energy per ton-kilometer.

Diesel and biodiesel consumption

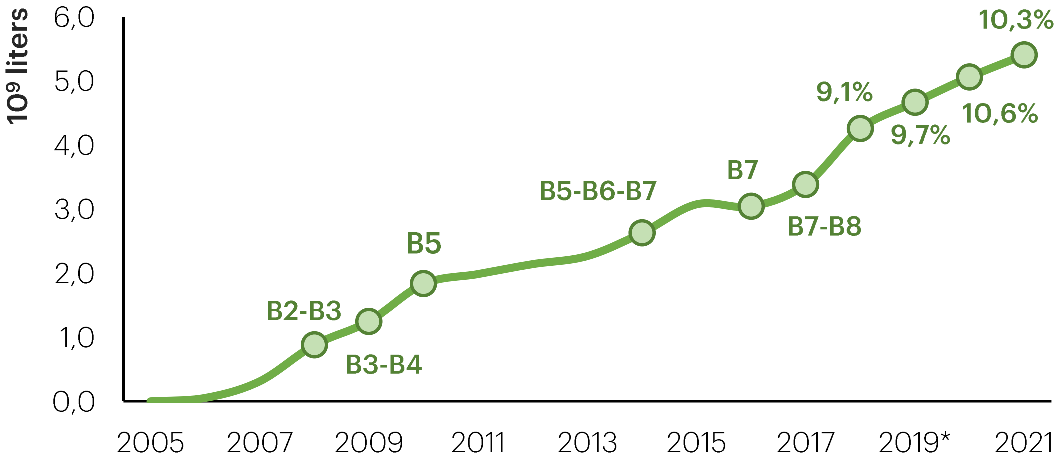
Figure 45 – Diesel and biodiesel consumption by trucks (10^9 liters)
Source: Compiled by EPE



Truck diesel demand grew by 2.8% per year between 2000 and 2019. And despite the pandemic, which reduced industrial production and consumption, and restricted the free movement of truckers at the beginning of the pandemic, on-road diesel demand retreated by only 1.0% in 2020, but soon after shot up by 9.3% in 2021.

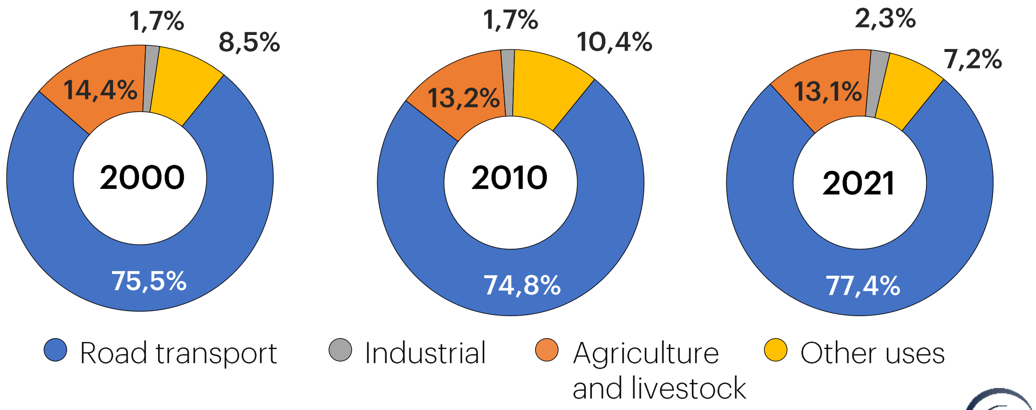
Despite the reduction in the biodiesel blend over 2021, demand for biodiesel rose by 7% due to increased demand. The rest had to be met by increased demand for fossil diesel, whose demand increased by 9.6%, or 3.5 billion liters.

Figure 46 – Evolution of biodiesel consumption and its addition percentages
Source: Compiled by EPE



*As a preventive measure to ensure the supply of the domestic market, the ANP carried out three temporary mandatory percentage reductions, throughout 2019 and 2020. These actions were also required in the year 2021.

Sectorial division of diesel oil use



Additional remarks – transport

Because of the pandemic, the transportation sector lost its position as the country's largest energy consumer to the industrial sector in 2020. However, demand in the sector rebounded strongly in 2021. Diesel demand reached new record highs. Demand for C gasoline and QAV is booming as mobility restrictions end, but has not yet recovered due to continued remote working. Public transportation is still heavily impacted.

The energy demand of passenger transport is predominantly associated with the fuel consumption of cars. This was particularly true in 2021, with many people avoiding public transportation. Despite this, keeping work remote or hybrid throughout most of the year, due to new Covid-19 strains such as Delta and Omicron, meant that demand remained dampened. Difficulties in global logistics chains also hampered even larger car sales throughout the year, hindering a larger increase in demand.

In 2021, the Otto cycle share of gasoline A rose from 52.5% to 55.2%, with hydrous ethanol falling from 27.9% to 23.6%. This is justified, above all, by the increased attractiveness of sugar on the international market and the variation in the spot price of Brent, which, among other factors, resulted in an increase in the PE/PG ratio.

Road transportation of cargo continued to predominate in 2021, and registered significant growth. The increase in the demand for goods and in e-commerce increased the consumption of diesel for transportation between factories, distribution centers, and homes. Rail and water transportation grew in 2021. However, most of the incremental demand, generated mainly by agriculture and cattle-raising with its growing exports, was met by heavy trucks, explaining the new records in diesel demand.

The mandatory participation of biodiesel in diesel B allowed the increase in its demand to be largely supplied by the biofuel, despite its lower energy intensity. Furthermore, the efficiency of the truck fleet improved in 2021, due to increased sales of new heavy trucks that are more efficient than the Brazilian average.

Special chapter on the steel industry

Important definitions

Terms

- **CCS:** Carbon capture and storage is the process known to the oil industry that uses the technique to increase oil and gas extraction, especially when the bedrock becomes less naturally available for production. In this case, the entire extraction infrastructure can be used for CO_2 reinsertion in order to increase oil/gas production and make the process simpler and more economically advantageous.
- **CCUS:** Carbon capture, utilisation and storage is the process that focuses on finding new and profitable uses for carbon, which includes everything from creating products to burning them as fuel.

Technological routes

Integrated Coke Route

It consists in the production of pig iron in blast furnaces from the combination of iron and coke (produced from metallurgical mineral coal), and then the manufacture of steel in basic oxygen converters and transformation into finished steel products in rolling mills.

Semi-integrated route[1]

It consists of producing steel from ferrous scrap. The process starts in the electric steel shop and does not require reduction equipment (sintering/pelletizing, coke oven and blast furnace).

Direct Reduction Integrated Route (DRI)

It consists of direct reduction module, electric melt shop and rolling mill. The direct reduction module uses iron and natural gas (or uncokeable coal) as main inputs, manufacturing directly reduced iron (DRI) and hot briquetted iron (HBI).

Integrated charcoal route

It uses charcoal as a reducer of iron ore (instead of coke) to make pig iron, which feeds a basic oxygen steel mill or even an electric steel mill.

[1] Because this technological route is more compact, such plants are often referred to as mini-mills (more currently, also called micro-mills).

Relevance of the world and national steel industry

The world steel industry is very important in the production chain, being intensely and positively related to economic development. It is estimated that for every US$ 1 of value added in the steel industry, another US$ 2.5 of value added is generated in other activities, as a result of purchases of raw materials, energy, goods and services.

In terms of employability, the global steel industry directly employed more than 6.1 million people in 2017. Just as or more important is the finding that for every job generated in the steel industry, 6.6 jobs were supported throughout its supply chain. This means that 40.5 million people worked in the steel industry's global supply chain in that year (OXFORD ECONOMICS, 2019).

The steel activity not only generates many jobs (directly and indirectly), but mainly they are of high quality. When dividing the total revenues of the industry by the number of workers, it turns out that the economic productivity exceeded $80,000 per job, which was three times the average of the global economy (OXFORD ECONOMICS, 2019).

A large industry, a high degree of economic interconnection, considerable generation of high quality jobs, and a substantial employment multiplier explain why governments, of the most different ideological hues, tend to grant a prominent role to the sector in question.

This is true both to stimulate new investments aimed at increasing installed capacity and to protect domestic production, even when the industry shows clear signs of low competitiveness. Thus, even in countries with high per capita incomes, governments often try to avoid the closure of steel mills (and the consequent disarticulation of production chains), either through subsidies or through nationalization.

Relevance of the world and national steel industry

The Brazilian steel industry has historically registered relevant trade balances, which can be considered an indicator of cost competitiveness. Due to recurrent trade defense measures adopted by other countries, the Brazilian industry ended up concentrating its exports in semi-finished products (slabs, in particular).

In any case, in 2021, the country's net exports of steel products were equivalent to 6 million tons, with net foreign exchange generation of around US$ 4.4 billion (Brazil Steel, 2022), thus contributing with 7.1% of the country's trade balance.

In the same year, the country was the thirteenth biggest exporter of steel products and the seventh biggest net exporter (WSA, 2022a). This is a significant result, since Brazil ranked 31st in 2021 in the world exports of the transformation industry (CNI, 2022). That is, compared to the Brazilian manufacturing industry, the steel industry presents a better export performance.

The massive investments aimed at expanding capacity, modernizing mills and enriching products should also be emphasized. In the 2012-2021 period, for example, at least US$ 14.5 billion were invested in the Brazilian steel industry (Aço Brasil, 2022).

The net revenues of the Brazilian steel industry will reach US$ 38.7 billion in 2021, generating 114,000 direct jobs (including outsourced ones).

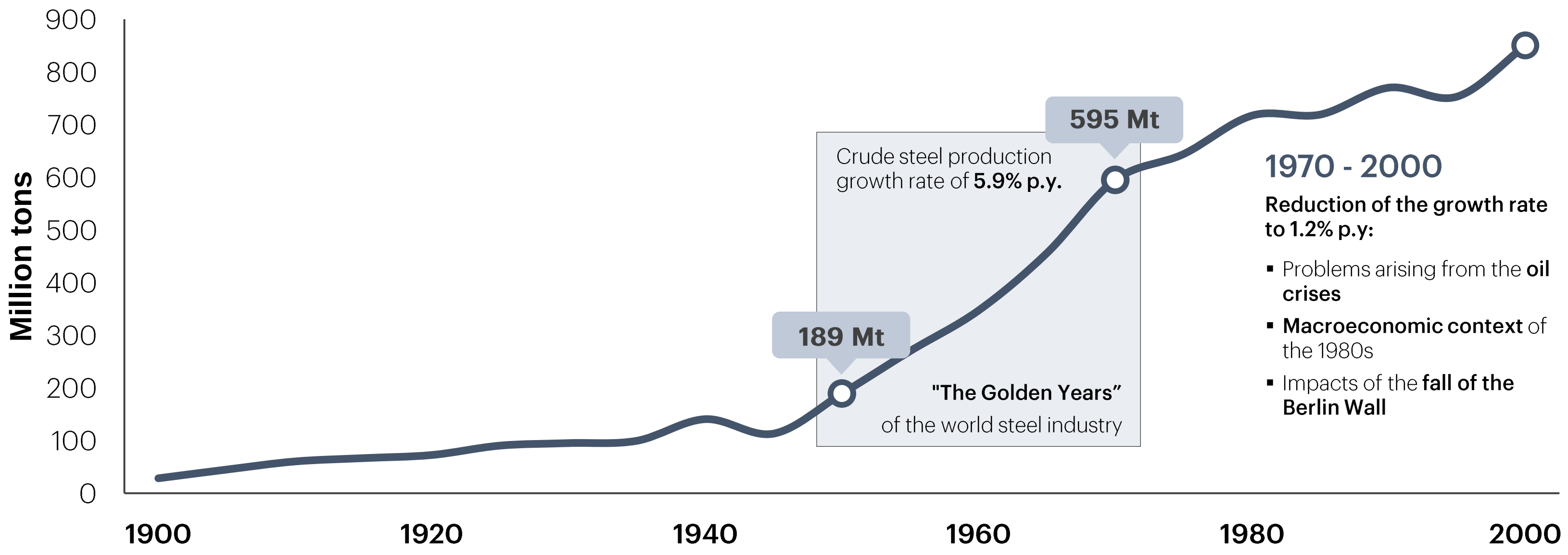
The Brazilian steel industry has a very diversified park, including the main segments of the industry.

A brief history of the world steel industry until 2000

Global steel production increased from 28 million tons in 1900 to 141 million tons in 1940. After World War II, the reconstruction efforts in Western Europe, combined with the expansion of steelmaking in Japan and the acceleration of production in emerging countries (including Brazil), the steel industry experienced major growth.

Figure 47 – World Steel Production, 1990-2000 (million tons)

Source: International Iron and Steel Institute (IISI, 1978), World Steel Association (worldsteel, 2022a)



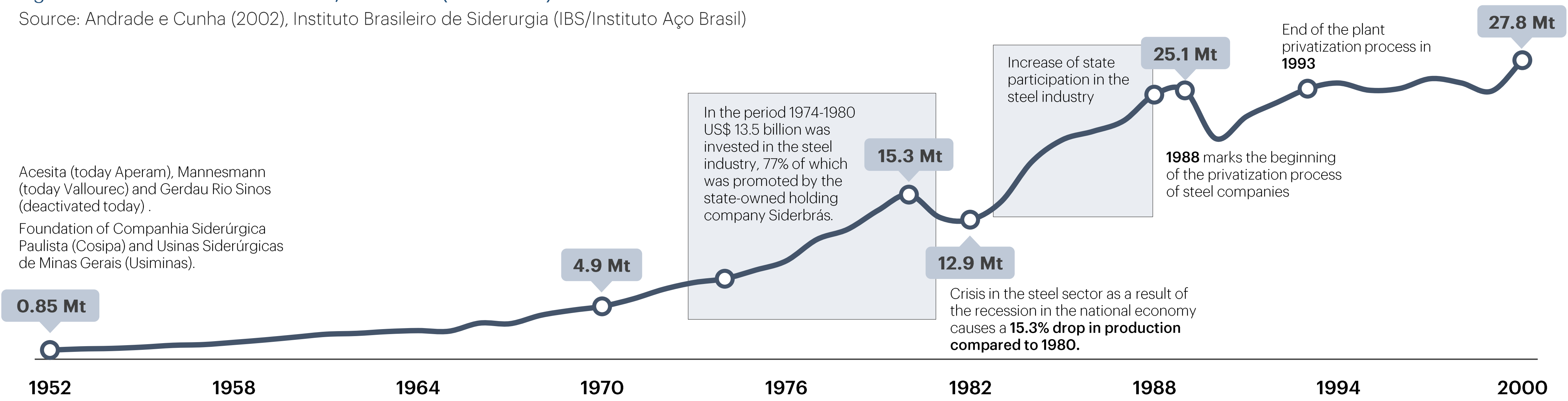
In the period 1950-1970, the average annual growth rate of the world crude steel production was 5.9%, reason why this phase is usually called the "golden years". However, with the problems derived from the oil crises in the 1970s, the macroeconomic context of the 1980s, and the impacts of the fall of the Berlin Wall, the industry reduced its average annual growth rate to 1.2% in the years 1970-2000.

A brief history of the Brazilian steel industry until 2000

The Brazilian steel production started in 1925, when the Sabará mill of the Companhia Siderúrgica Belgo-Mineira (CSBM) became the first integrated mill in South America, **using charcoal as a reducer**. From 1924 to 1946, Brazilian steel production increased from 4.5 to 342 thousand tons[1], and then the 1950's were marked by the entry of new mills...

Figure 48 – Brazilian Steel Production, 1952-2000 (million tons)

Source: Andrade e Cunha (2002), Instituto Brasileiro de Siderurgia (IBS/Instituto Aço Brasil)



In the period 1952-1970, Brazilian steel production increased from 847,000 tonnes to 4.9 million tonnes, and continued to grow in the 1970s, when it was chosen as one of the priority sectors of the Brazilian economy. The beginning of the 1980s marked a pronounced crisis in the Brazilian steel industry as a result of the recession in the national economy, which led to the growth of state participation in the Brazilian steel industry, which came to account for approximately 70% of Brazilian steel production by the end of that decade. Throughout the years following 1988 the privatization process was consolidated, and finalized in 1993.

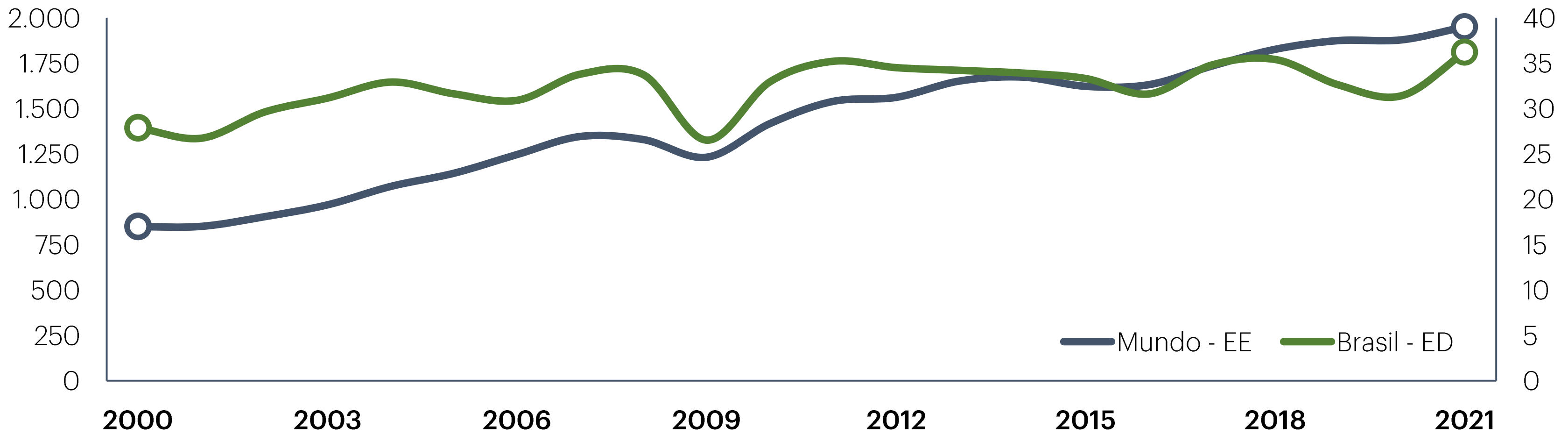
[1] Belgo-Mineira is responsible for 70% of it

Steel production from 2000

The world production of crude steel expanded from **849 million to 1.95 billion tons from 2000 to 2021**, an increase of 130% during the period, corresponding to an average annual growth rate of 4.0%. In turn, the Brazilian production in the period went from 27.9 million to 36.1 million tons, an accumulated expansion of 30% in the period, or 1.2% per year, as a result of a very unfavorable domestic macroeconomic scenario in several of the years considered.

Figure 49 – World (left) and Brazilian (right) steel production, 2000-2021 (millions of tons)

Source: World Steel Association (2009, 2019, 2021, 2022a)



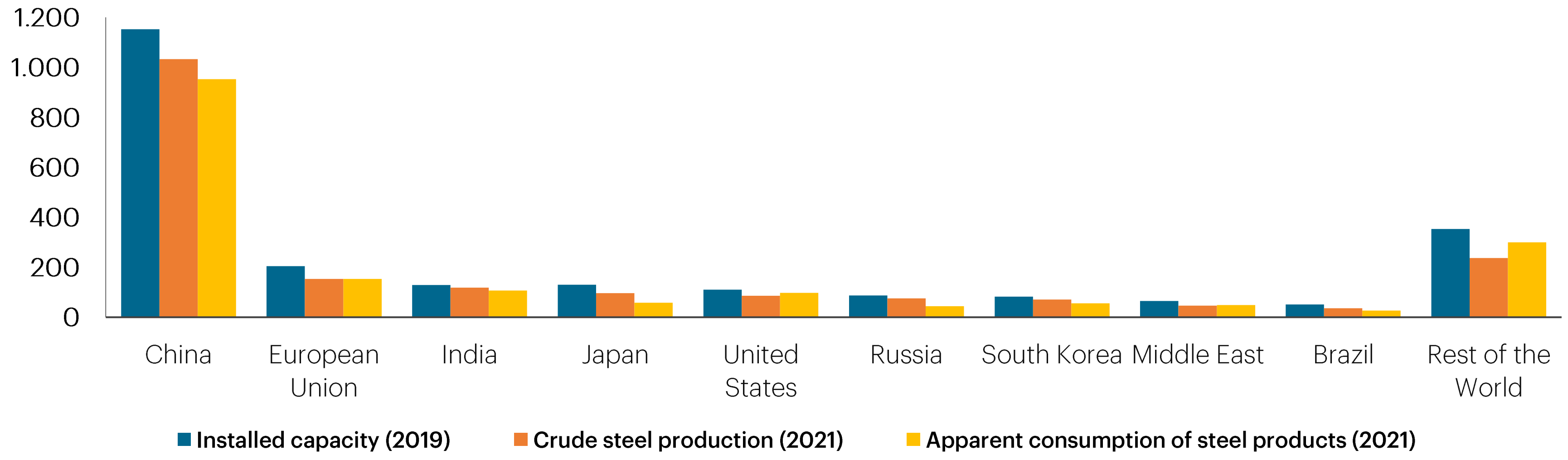
According to the World Steel Association (WSA), the share of developed countries in the demand for steel products declined from 59.2% to 21.8% between 2000 and 2021, while China's share increased from 16.6% to 51.8% and India's were 3.7% and 5.8%. This shows a substantial locational shift in consumption in favor of Asia, to the detriment of the North Atlantic countries. The share of the other emerging and developing countries (including Brazil) remained around the 20% level, although the Brazilian share itself decreased from 2.1% to 1.4%, respectively.

Steel production from 2000

China accounts for 49% of the industry's global installed capacity, 53% of crude steel production and 52% of the apparent consumption of steel products, that is, it is responsible for half of the world's steelmaking. In turn, Brazil accounts for 2.1% of capacity, 1.9% of production, and 1.4% of world demand.

Figure 50 – Installed capacity, regional crude steel production and consumption of steel products (2019 and 2021) (million tons)

Source: OECD (2020) and worldsteel (2022a)



Brazil's participation:

2.1%
of installed capacity

1.9%
of crude steel production

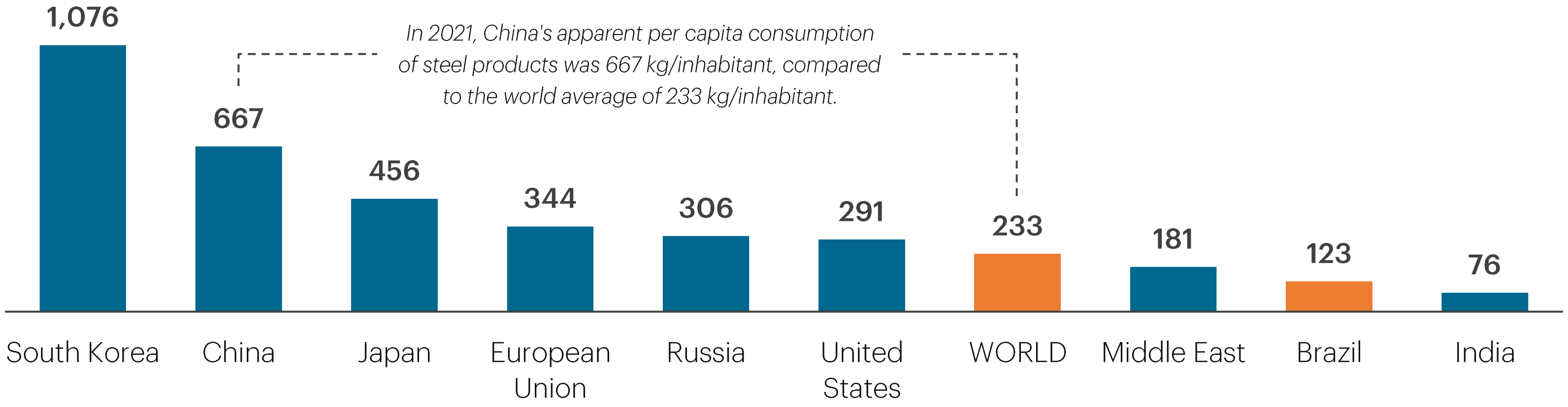
1.4%
of global demand

It is important to note that capacity and production refer to crude steel and demand refers to steel products, so they are not strictly comparable data. However, at the global level, to convert the crude steel data to steel products in 2021, it would be necessary to multiply by 94%. Information is presented for some relevant players, such as China, the European Union, India, Japan, the United States, Russia, South Korea, the Middle East, Brazil, and the Rest of the World.

Consumption of steel products

The South Korean situation stands out, with an indicator of 1,076 kg/inhabitant, a significant part of which is due to net exports of metal-mechanic products[1] generating an indirect steel trade surplus. Excluding this last variable, we obtain the so-called true consumption of steel products. In 2019, the last year with available information, South Korea's true consumption was 791 kg/inhab, compared to apparent consumption of 1,039 kg/inhab (WSA, 2022a). Still, this is well above the world average.

Figure 51 – Apparent per capita consumption of steel products, 2021 (kilograms per capita)
Source: worldsteel (2022a)



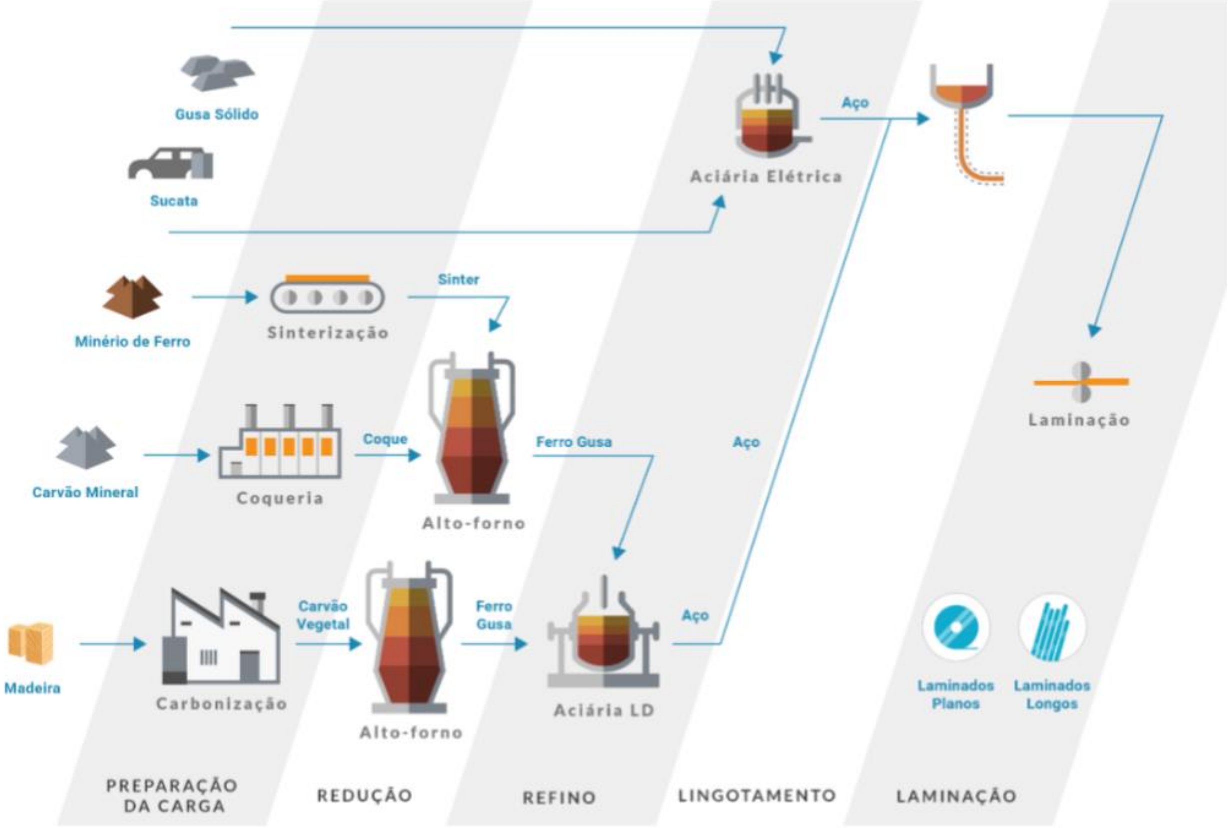
This difference is even more significant when considering that China obviously makes up the world average, being responsible for 18% of the global population. In Brazil, on the other hand, the apparent per capita consumption of steel products was 123 kg/inhabitant.

Despite the substantial efforts of the Brazilian steel industry to develop the domestic market, for decades the per capita demand has been stable and close to 100 kg/inhabitant. However, a necessary condition for the reversal of this trend is the increase in gross fixed capital formation (GFCF). Analyzing the period 2010-2019, so as to exclude the impacts of the Covid-19 pandemic, the average rate of GFCF/GDP in Brazil was 18.1% against the world average of 24.7% (WORLD BANK, 2022). This discrepancy is even more important when considering that Brazil, as an emerging economy, needs to significantly improve its infrastructure, which, in turn, is a steel-intensive activity.

[1] Machinery and equipment, automobiles, ships, household appliances, etc.).

Technological routes

In Brazil, the steel mills are classified according to their production processes into integrated and semi-integrated route.



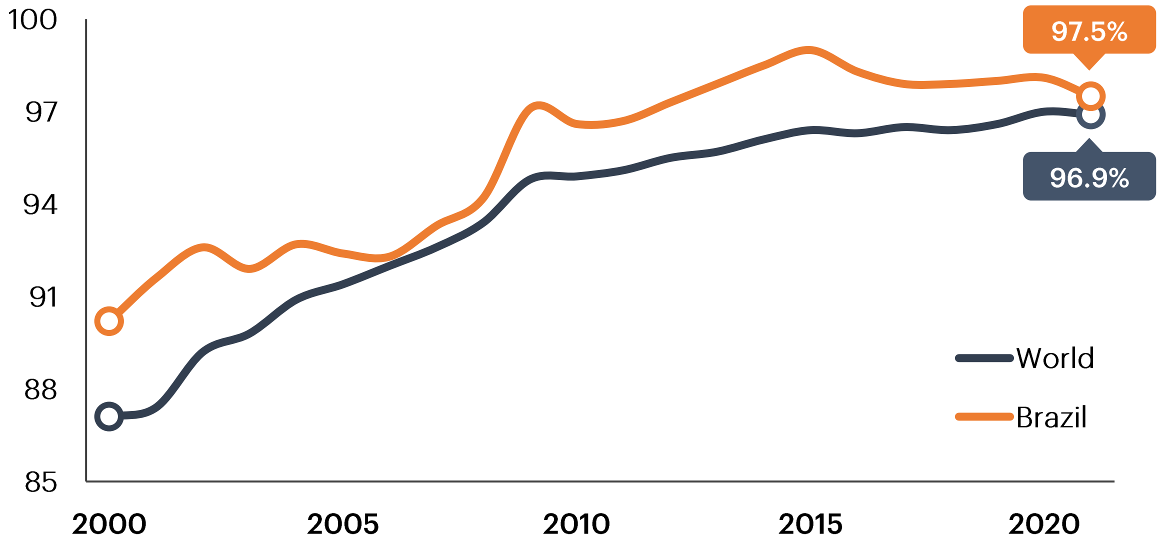
Integrated
Which operate the three basic phases (reduction, refining, and rolling); participate in the entire production process, and produce steel.

Semi-integrated
Which operate two phases: refining and rolling. These mills start with pig iron, sponge iron, or metallic scrap purchased from third parties to transform them into steel in electric steel shops and their subsequent rolling.

Continuous Casting Diffusion

The process of solidification of liquid steel can be done through conventional casting[1] or continuous casting. Continuous casting may be considered one of the radical innovations in the world's steel industry, since it now allows a high semi-finished/ liquid steel yield (around 98%), being more compact and conferring better quality to the final product.

Figura 52 – Rate of diffusion of continuous casting, World and Brazil, 2000-2021 (percent)
Fonte: worldsteel (2009, 2019, 2021, 2022a)



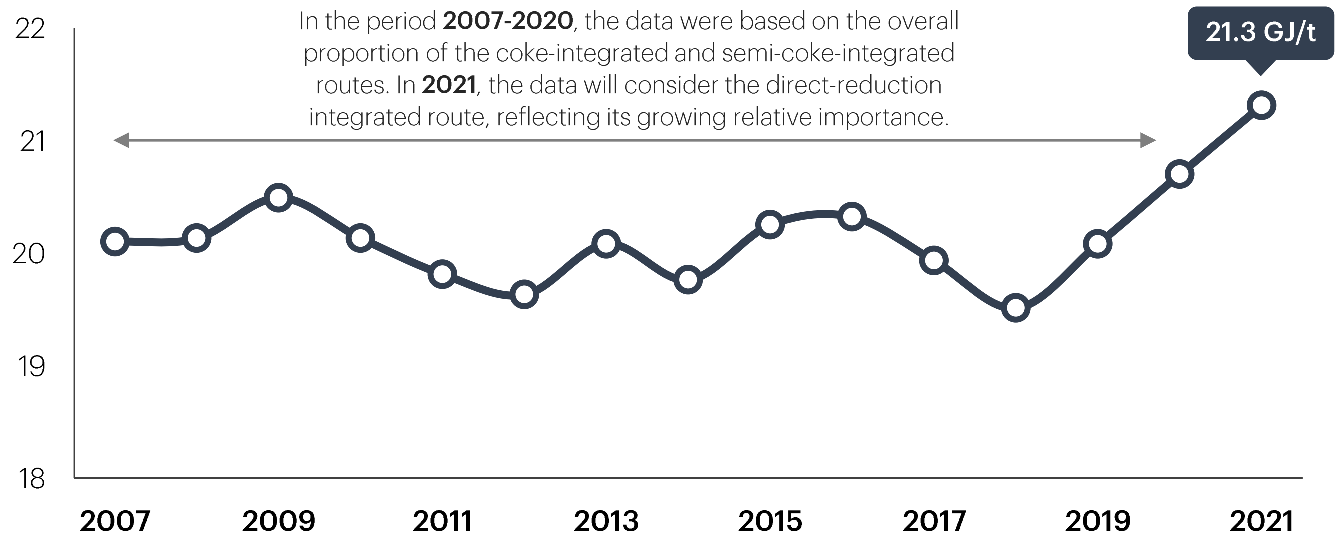
The worldwide diffusion of continuous casting increased from 78.1% (in 2000), to 94.9% (in 2010) and further to 96.9% (in 2021). During this period, the relative importance of continuous casting in Brazil was higher than the world average.

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

Energy Efficiency in the World Steel Industry

According to the World Steel Association (WSA), the aggregate specific consumption of the technological routes of the steel industry in 2021 was 21.31 GJ/ton of steel. However, this value, higher than the previous years of the series, is largely due to the WSA's methodological adjustment[1], which now considers the integrated route to direct reduction, as a reflection of its growing relative importance.

Figure 53 – Specific consumption of the world steel industry, according to WSA, 2007-2021 (GJ/ton of steel)
Source: worldsteel (2022b).



The aggregate energy intensity equals...

- **24.43 GJ/t of the Integrated Coke route**
- **25.29 GJ/t of the Integrated route to direct reduction**
- **10.04 GJ/t of the Semi-integrated route**

The 2007-2020 series was not recalculated, so the value reported in 2021 is largely explained by the adjustment in the methodology and does not represent a trend of increasing energy intensity

The trajectory of specific consumption in the world steel industry seems to have been one of stagnation. However, in 2020, steel mills abruptly reduced production volume, which negatively affected energy efficiency indicators. In addition, over time, the share of technological routes varied. For example, the share of the oxygen converter (the basis of the coke-integrated route) increased from 66.3% in 2007 to 70.6% in 2018 and 73.3% in 2020.

[1] The Figures start to consider the route integrated with the direct reduction as of 2021 and do not take into consideration the rolling mill activities.

Energy Intensity in the World Steel Industry

The IEA's reference values for the main process routes are based on Worldsteel energy data, adjusted for differences in accounting boundaries, particularly with respect to electricity. The main considerations of each are as follows:

Table 1 – Energy intensity by technological route according to IEA (GJ/ton crude steel)

Source: IEA (2020).

Methodology	Methodological considerations	Integrated to coke	Semi-integrated	Integrated with direct reduction
IEA	▪ all energy sources are computed in terms of final energy and employ a factor of 3.6 GJ/MWh for electricity. ▪ Coking plants and thermal power plants are considered in the balance in order to make comparison with worldsteel possible.	21.4	2.1	17.1
worldsteel	▪ electricity consumption in terms of primary energy, uses a conversion factor of 9.8 GJ/MWh of electricity (equivalent to a conversion efficiency of 37%). ▪ WSA discounts the credit for steel process gases.	22.7	5.2	21.8

The difference between the IEA and WSA[1] values is mainly due to the different treatment of electricity (primary versus final). Besides this, because of its low representation in the world steel industry, the IEA does not present energy intensity values for the integrated charcoal route.

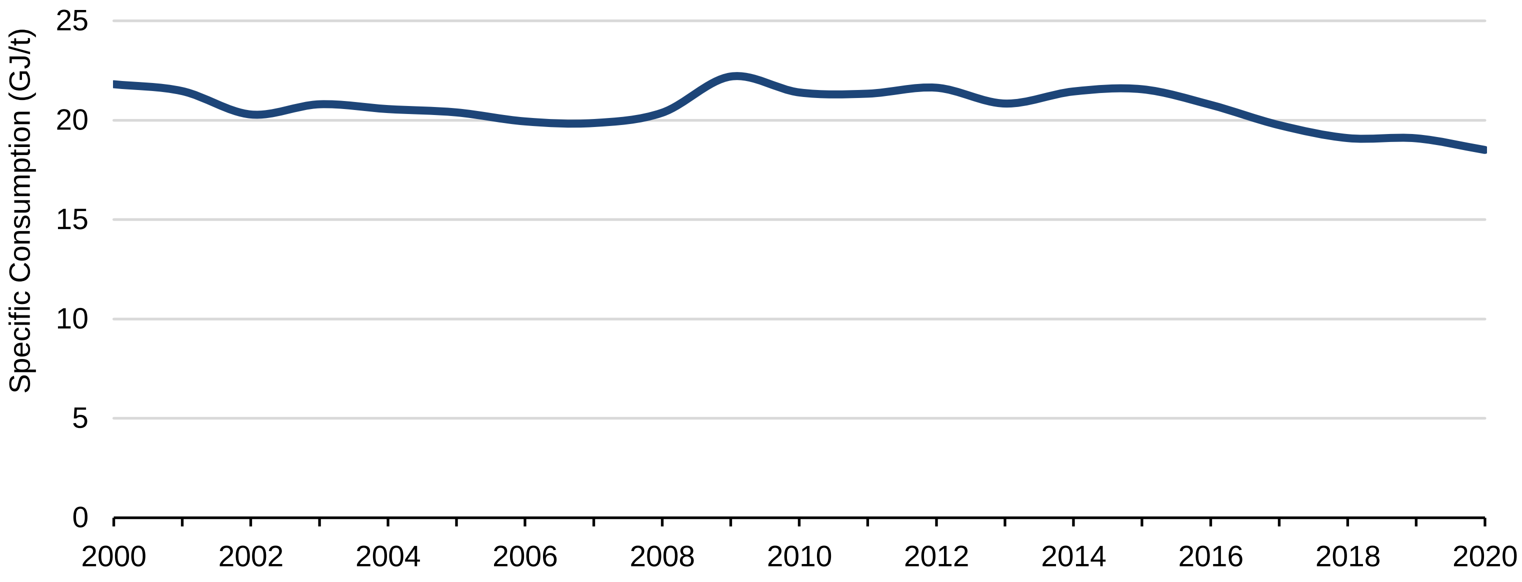
[1] The values will consider the route integrated to the direct reduction as of 2021
IEA data from 2020 and WSA data released in December 2022.

Energy Efficiency in the world steel industry

According to IEA Tracking Clean Energy Progress (2022), over the past two decades, the energy specific consumption of steel production has declined slightly, decreasing from approximately 21 GJ/ton of steel in 2000 to 19 GJ/ton of steel in 2019. In terms of energy demand, coal stands out, reflecting the high relative importance of the coke-integrated route.

Figure 54 – Energy demand and specific consumption of the world steel industry, 2000-2018 (GJ/ton of steel)

Source: worldsteel (2022b).



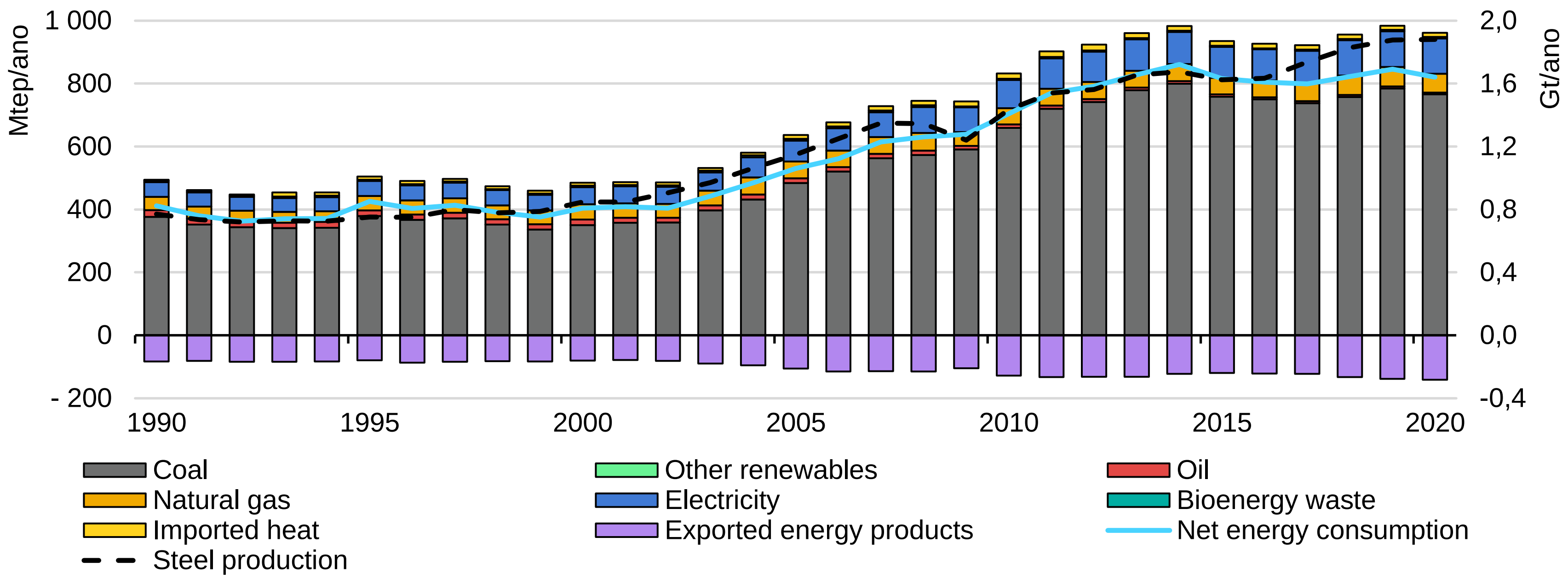
Steelmaking is highly energy intensive, accounting for 20% of industry energy consumption and 8% of the world's final energy use in 2019. It is the second largest industrial energy consumer, second only to the chemical sector, which demands a large amount of oil, gas, and coal as raw materials.

Final energy consumption in the world steel industry

Over the past three decades, the total energy consumption of the world steel industry has doubled. At the same time, steel production has grown 2.4 times (right axis of the graph), indicating that energy efficiency improvements have led to a modest reduction in the specific consumption of steel production.

Figure 55 - Final energy consumption in the steel industry

Source: IEA (2020), data updated to 2020



Notes: Gt = gigatonnes; Mtoe = million tonnes oil equivalent. "Exported energy products" refers to energy products that are produced but not used directly in the pig iron and steel sector (including coke plants and blast furnaces). Key examples of these exported energy products are steel gases (coke oven gas and blast furnace gas) and coke, and are identified with negative values in the Figure. "Net energy consumption" is the sum of the gross energy input to the sector (positive values in the Figure) and these negative exported quantities. Net energy consumption is the standard definition for sectoral energy consumption used in this publication, and simply refers to "energy consumption" elsewhere for simplicity.

Source: IEA analyses based on IEA (2020a), World Energy Balances, and various editions of the World Steel Association's Steel Statistics Yearbook.

Energy Transition

The commitment to the transition to a low carbon economy goes beyond sectorial boundaries. The steel industry has sought to join forces with its suppliers and customers to reduce GHG emissions, through the use of less carbon intensive raw materials and inputs and the development of lighter and stronger steels.

Worldwide, the steel industry is considered one of the most difficult and costly sectors to reduce GHG emissions, as it has already significantly reduced its energy consumption over the years (60% reduction in specific consumption since 1960, according to worldsteel 2019) by maximizing the use of process gases and energy conservation measures, among others. As such, further measures to reduce GHG emissions in the energy area are dependent on **public policies** and additional **investments** for the expansion of renewable energy generation units, such as wind and solar, and infrastructure development for hydrogen production and CO_2 transport and storage (CCUS). While the focus of this report is on the improvements available through energy efficiency, material efficiency achieved by extending the lifetime of products (such as buildings); improving the design of goods and using alternative materials and developing reuse and recycling chains can also play a major role in achieving decarbonisation ambitions.

Access to local, national, or differentiated transactional financing lines from public or private sources will be critical given the large investment amounts needed to develop disruptive technologies for low GHG steel production. In Brazil, existing financing lines could be reinforced to ensure competitiveness in the transition of existing assets to a low GHG emission scenario.

Policy examples

Many current policies focus on improving scrap use, while the first policies on low-carbon production are being implemented:

Table 2 – Policy examples
Source: IEA (2021).

Policy	Country	Year	Status	Jurisdiction
"France 2030" Investment Plan – Heavy Industry decarbonisation investment	France	2022	In force	National
Green steel production support	Belgium	2022	Announced	National
Climate Innovation Research Opportunity investment program	United States	2021	In force	National
Japan-Australia partnership on decarbonisation through technology	Japan	2021	In force	International
Federal Funding for Biocarbon Briquettes for Ferroalloy Production	Canada	2020	In force	National
Funding for Algoma Steel's climate action initiatives	Canada	2020	In force	National
Low-carbon and Zero-emissions Fuels Fund (including hydrogen)	Canada	2020	In force	National
Support package for UK Steel Company	United Kingdom	2020	In force	National
Guideline for Energy Efficiency Credit	People's Republic of China	2015	In force	National
Industrial Energy Management System ISO 50001	Phiilippines	2014	In force	National
Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE)	India	2008	In force	National

Industry Energy Efficiency Policy Package

Immediate opportunities

Implementing better energy management practices has been shown to deliver savings up to 15% in the first 1-2 years, with little or no capital investment.

Heavy industry accounts for over two thirds of global industrial emissions, while over **70% of short term industrial energy** efficiency savings are in light industry and SMEs.

A **Net Zero** Scenario milestone for heavy industry is to increase the share of steel production using electric arc furnaces, which generate **60% less emissions than conventional blast furnaces**, from 24% today to 53% in 2050.

REGULATION

- **Minimum Energy Performance Standards** for key equipment, such as motors and pumps, can drive up overall industrial efficiency levels.
- **Regulation to reduce energy use** extends beyond technology to target areas such as research and development, energy auditing, mandatory consumption reporting, energy management systems, and upskilling of the workforce.
- **Regulatory Instruments** yield best results when rooted in a good understanding of local context and include ambitious, regularly updated, standards.

INFORMATION

- **Benchmarking, indicators and other forms of detailed data**, allow governments to track the progress and success of policies and allow industries assess their energy performance, compare it to that of their peers and establish key areas for intervention.
- **Digital technologies** enable industries to track energy use in real time and unlock substantial energy and cost saving opportunities.
- **Sharing information on energy efficiency best practice** and industrial energy transition, through industry networks, helps industries raise ambition and improve energy performance.

INCENTIVES

- **Incentives** such as preferential finance, links to carbon trading, obligations and tax based measures can motivate crucial energy efficient decisions at the process design and equipment selection stage, supporting industry transition to near zero emission technologies.
- **Free or subsidised energy audits**, often targeted at SMEs and other sectors of strategic importance, can help rapidly increase energy efficiency.
- **Policies to foster Energy Service Companies** provide industry with access to significant external energy expertise and attractive structured financial packages.

Key recommendations

- Improve material efficiency, and facilitate a higher proportion of production from recycled material
- Implement strategies to create demand for near zero-emission steel to incentivise further development and deployment of near zero-emission primary production
- Expand international collaboration for low-carbon steelmaking
- Adopting CO_2 policies covering industry and expanding international co-operation
- Managing existing assets and near-term investments
- Increasing financing lines and R&D investment and deployment for low-carbon technologies

The difficulties of implementation of CCUS by the Brazilian steel industry

Carbon capture, utilization, and storage (CCUS)[1] has been touted as the technology with the greatest impact on reducing GHG emissions.

The practice of CCUS focuses on finding new and profitable uses for this carbon, which includes everything from building products to burning it as fuel again. For the steel industry, the practice is associated with conventional steelmaking processes, modified or even redesigned to lower emissions.

This is a very complex activity, because:

- the task of CO_2 separation is more difficult than in oil production, since, once separated, the CO_2 needs to be converted to liquid to be transported by pipelines to its final destination (where there is exploration), either onshore or offshore;
- if the CO_2 is not used as a substitute for other CO_2 used in the industrial area, or can become raw material for conversion into another carbon source, it needs to be injected and stored in a porous bed of large capacity, with the proper waterproofing protections to ensure its permanence in place indefinitely;
- finally, it is necessary to monitor the reservoirs, wells, aquifers and the atmosphere to ensure that there are no leaks and, if leaks are detected, corrective measures will need to be taken.

Just as an example of how local issues can translate into difficulties, one can analyze some aspects of the regions where the most significant steel companies are located in Minas Gerais, which was responsible for 29.8% of the Brazilian steel production in 2021. Investigating the predominant soil and aquifer characteristics in these regions, one can see the prevalence of two soil types (Red-Yellow Latosols and Red Nitossols) and a gneissic aquifer.

Any possibility of storage in the regions must overcome these extracts in depth and find a porous region for CO_2 storage as an impermeable layer covering that prevents the contamination of the upper aquifers. The alternative of transportation to nearby marine regions with characteristics such as the Pre-Salt tends to increase costs and infrastructure substantially. An analysis of the direct application of CCUS in the Brazilian steel industry should obviously take great account of local aspects, which is why companies have not yet shown commitment to the implementation of such technology in the country.

[1] CCUS is the acronim for Carbon, Capture, Usage and Storage.

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