JUST ENERGY TRANSITION

Scenarios Mexico

IDFC International Development Finance Club FACILITY

CAF DEVELOPMENT BANK OF LATIN AMERICA AND THE CARIBBEAN

Just Energy Transition / Scenarios Mexico

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Just Energy Transition

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DEVELOPMENT BANK OF LATIN AMERICA AND THE CARIBBEAN

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TABLES AND GRAPHICS

List of abbreviations

AFOLU	agriculture, forestry, and other land use
BAU	business as usual
CAGR	compound annual growth rate
CAPEX	capital expenditures
CCUS	carbon capture, use and storage
CENACE	National Energy Control Center *(Centro Nacional de Control de Energía)*
CENAGAS	National Natural Gas Control Center *(Centro Nacional de Control del Gas Natural)*
CEPAL	Economic Commission for Latin America and the Caribbean
CFE	Federal Electricity Commission *(Comisión Federal de Electricidad)*
CNG	compressed natural gas
CNH	National Hydrocarbons Commission *(Comisión Nacional de Hidrocarburos)*
CNUEE	National Commission for the Efficient Use of Energy *(Comisión Nacional para el Uso Eficiente de la Energía)*
CRE	Energy Regulator *(Comisión Reguladora de Energía)*
EE	energy efficiency
FSRU	floating storage regasification unit
GCRI	global climate risk index
GDP	gross domestic product
GDPpc	gross domestic product per capita
GHG	greenhouse gases
HDI	human development index
IEA	International Energy Agency

IEPS	Special tax on production and services *(impuesto especial sobre producción y servicios)*
INGEI	national inventory of greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
JET	just energy transition
LEAP	SEI's low emissions analysis platform
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MUSD	millions of US dollars
NCRE	non-conventional renewable energy
NDC	nationally determined contributions
NZ	net zero
OLADE	Latin American Energy Organization
PEMEX	Petróleos Mexicanos
PPP	purchasing power parity
SEI	Stockholm Environment Institute
SENER	Mexican Secretary of Energy
SHW	sanitary hot water
SieLAC	Energy Information System for Latin America and the Caribbean
TJ	terajoule
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

Foreword

1. General objective

The general objective of the project was to develop a methodological approach to define the concept of just energy transition (JET) in a national context, with potential application in the CAF – development bank for Latin America and the Caribbean – member countries and to evaluate the proposed approach in Brazil, Colombia, Mexico, Peru, and the Dominican Republic.

2. Specific objectives

The specific objectives of this report are the following:

1. to define a methodological approach to address the just energy transition in the region in a comprehensive way;
2. to diagnose the national energy systems (target countries) – in particular, the power systems – in the context of the energy transition process;
3. to define national scenarios for the low-carbon development model of the energy transition in the target countries, including those elements to be electrified in energy sectors that are currently not being served by the power sector, within the prospective requirements;
4. to model the viable energy transition alternatives in the previously defined context.

3. Organization of the Just Energy Transition series

In order to meet the objectives indicated above, the study was conducted between October 2022 and October 2023. The series was organized into seven reports.

1. Just Energy Transition / Conceptual framework for the region. Analysis in the national context
2. Just Energy Transition / Projection assumptions
3. Just Energy Transition / Scenarios for Brazil
4. Just Energy Transition / Scenarios for Colombia
5. Just Energy Transition / Scenarios for Mexico
6. Just Energy Transition / Scenarios for Peru
7. Just Energy Transition / Scenarios for the Dominican Republic

The reports were organized following the alphabetical order of their names.

4. Organizational aspects

This report has been financed by CAF and is published to communicate the results and conclusions obtained to the community interested in Latin American development. Therefore, the document has not been prepared following the procedures of an official document. Some of the sources cited in this report could be informal documents that are difficult to obtain.

The conclusions and opinions expressed herein are exclusively those of their authors and should not be attributed to CAF or GME, their affiliates, or executive directors, and do not necessarily reflect their points of view.

CAF and GME do not guarantee the accuracy of the data included in this publication and accept no liability whatsoever for the consequences of its use. The colors, borders, names, and classifications of any map in this report do not imply any judgment by CAF on the legal or otherwise condition of the territories, or the approval or acceptance of such borders.

Edgar Salinas, Juan Ríos, and Walter Cont from CAF formed a working team that established the terms of reference and development of the abovementioned reports by GME consultants.

The GME team – in alphabetical order – was composed of Agustín Ghazarian, Coline Champetier, Darío Quiroga, Francisco Baqueriza, Nicolás Barros, Laura Souilla, Ramón Sanz, and Roberto Gomelsky.

5. Scenarios: Mexico

This report contains the analysis of the energy transition in Mexico and is organized into four chapters.

- **Diagnosis and base line.** This chapter establishes the diagnosis of the base line in terms of sources and energy uses, characteristics of the power sector, environmental aspects (greenhouse gas (GHG) inventories, commitments), and institutional, regulatory, and public policy aspects, among others. It allows us to present the starting point of the energy projections and to identify the main characteristics that may condition the just energy transition strategy.
- **Energy projection methodology.** This chapter summarizes the low-emissions analysis platform (LEAP) model and its use to model emissions in the energy sector[1].
  Energy demand projection methodologies are presented by sector, subsector, use, and source, as well as the power generation modeling. It also describes the three projection scenarios contemplated and the main assumptions considered.
- **Transition scenarios.** This chapter presents the projections in terms of emissions and energy demand for the three scenarios previously defined (Business as Usual (BAU), Net Zero 2050 (NZ 2050), and Net Zero 2060 (NZ 2060)). It details the results by sector and the main explanatory assumptions, and presents the needs in terms of energy transition investment related to the power sector and its end uses. It concludes with the starting point and the end point of the main transition indicators by scenario.
- **Proposal for the roadmap for a just energy transition.** The roadmap describes the public policies to be developed and the segments that require concessional finance or support to accompany the just energy transition scenarios previously presented.

1 More specifically, the LEAP (Low Emissions Analysis Platform) model was used to model the emissions related to burning fuel.

Foreword

1. General characterization

Socio-economic aspects

Mexico is the tenth most populated country in the world, with a population of over 130 million people. The population density is approximately 66 inhabitants per km^2 and 81 % of the population lives in urban areas.

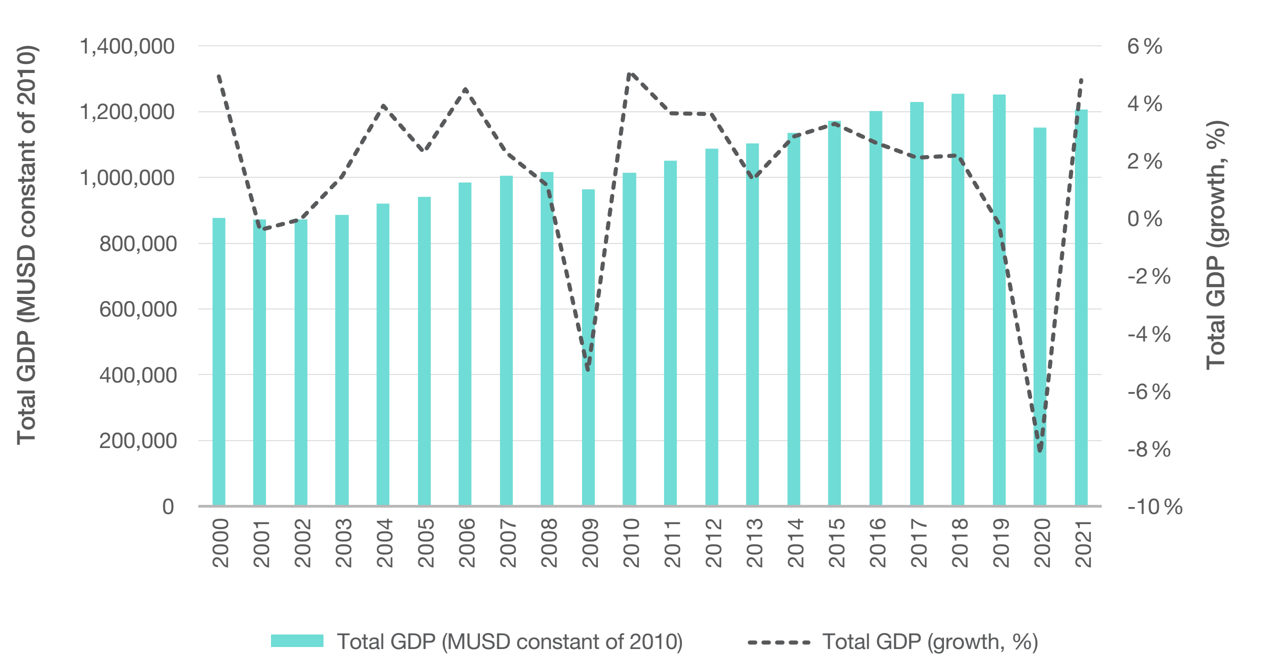
Table 1 Socio-economic indicators

Indicator/Country	Mexico
Total population (2021, million)	130.26
Population density (inhab./km^2)	66
Urban population (%)	81 %
GDP per capita 2021 (USD at constant prices of 2010)	9.255
Extreme poverty index 2020	9.2 %

Source: Own preparation based on data from the World Bank and CEPALSTAT.

Except for certain cases, Mexico has experienced steady economic growth in the last decades, with an annual average of around 1.5 % (2000-2021). In 2020, the impact of the COVID-19 pandemic on the Mexican economy was significant (-8.2 %) like in many other countries in the region.

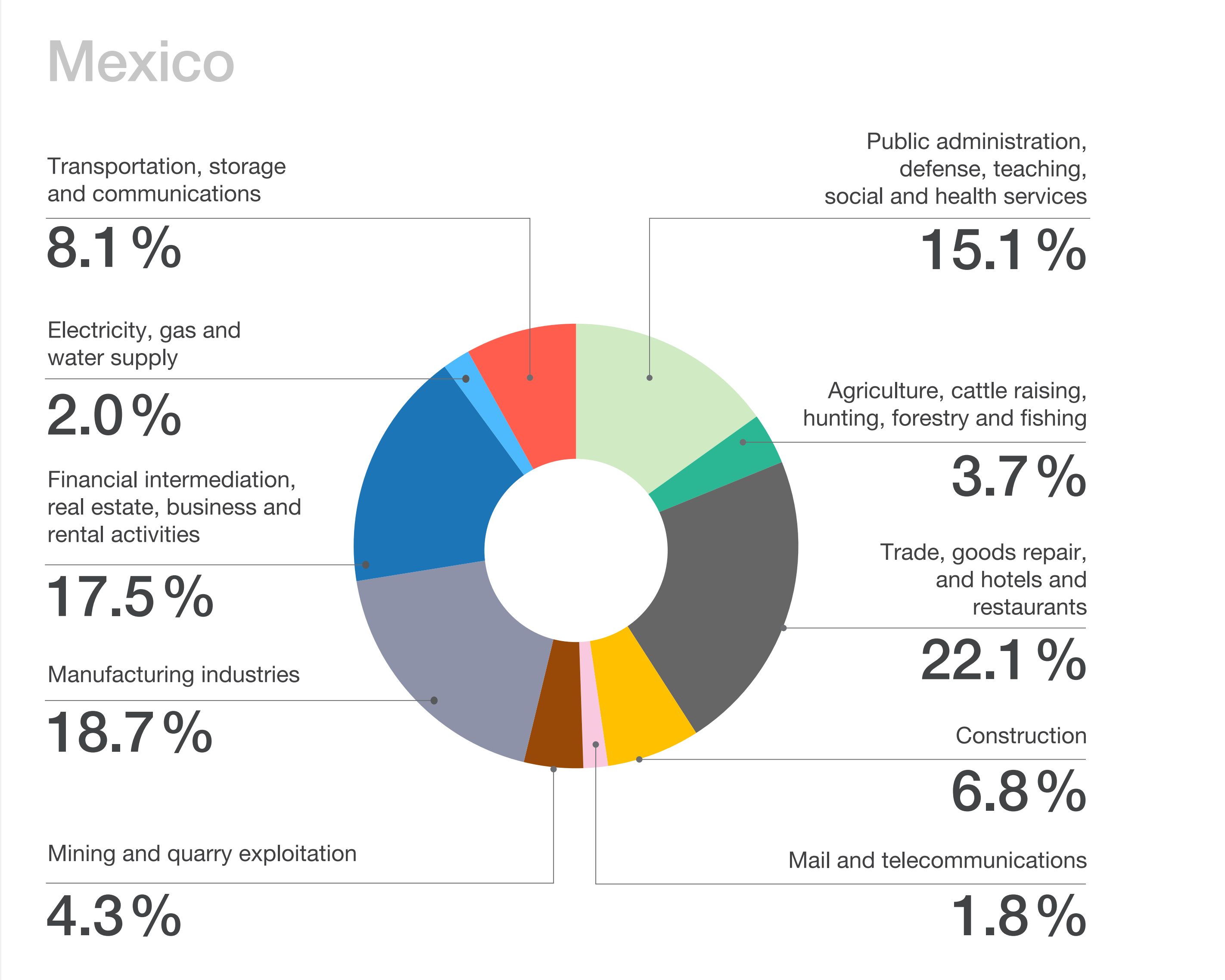
Graphic 1 GDP and annual growth rate, MUSD constant of 2010 and %



Source: Own preparation based on data from the World Bank.

It has a diversified economy, in which the commercial, hospitality, and restaurant sector accounts for 22.1 % of its gross domestic product (GDP), followed by the manufacturing industry (18.7 %), financial intermediation (17.5 %), and public administration (15.1 %).

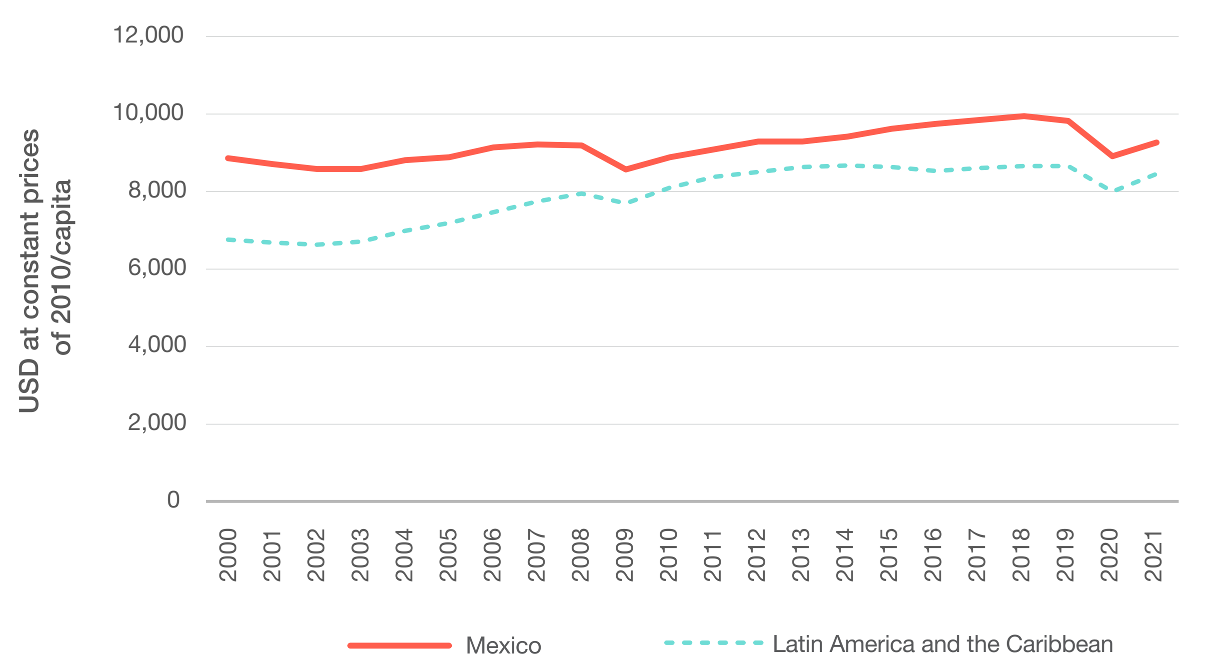
Graphic 2 GDP by sector, 2021, %



Source: Own preparation based on data from CEPAL

Except for certain particular years, the GDPpc has not suffered any significant changes in the last 20 years. In 2021, it was 9,255 constant US dollars (USD) of 2010 per capita, slightly above the average in the region.

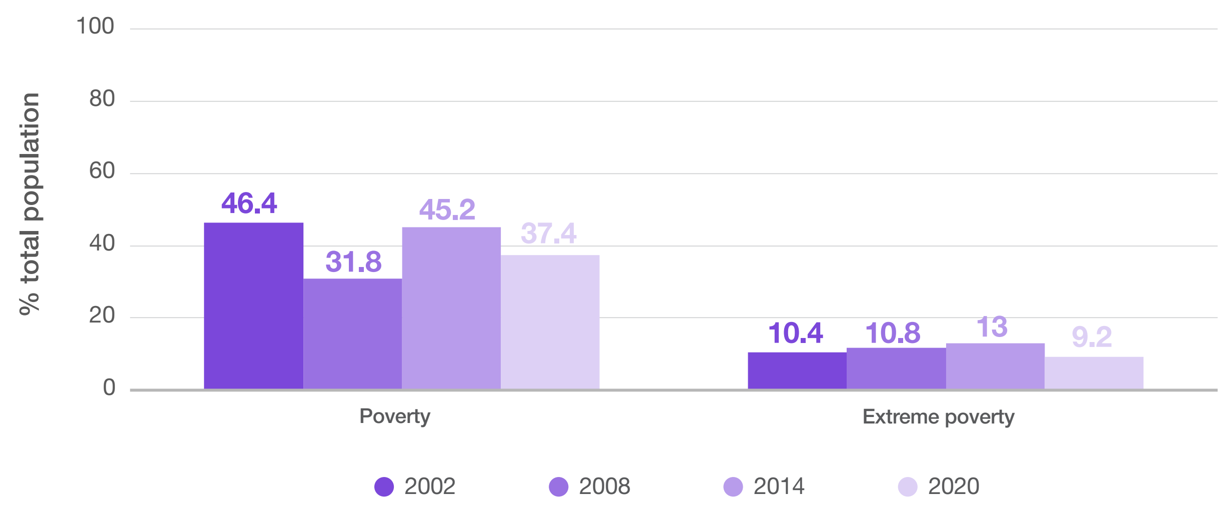
Graphic 3 GDP per capita, constant USD of 2010



Source: PIB per cápita, USD constantes de 2010 per cápita

Mexico has high poverty and extreme poverty rates of around 40 % and 9.2 %, respectively. No major changes have been identified in the last two decades.

Graphic 4 Incidence of poverty and extreme poverty by year, %



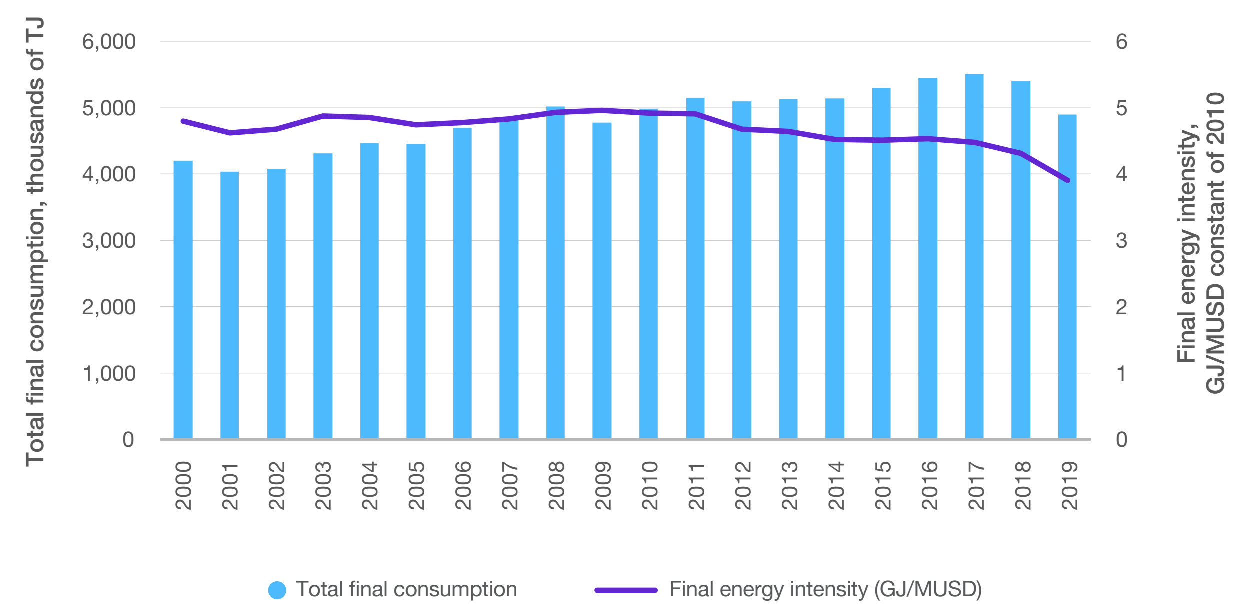
Source: Own preparation based on data from CEPALSTAT.

Socio-economic and energy indicators

Energy intensity of the economy

Final energy intensity[2] decreased between 2000 and 2019 (cumulative -19 %) whereas total final consumption grew to 16 % for such period, which represents an annual average of 0.8 %.

Graphic 5 Total final consumption versus final energy intensity, 10^3 TJ and GJ/MUSD constant of 2010



Source: Own preparation based on data from sieLAC, OLADE[3].

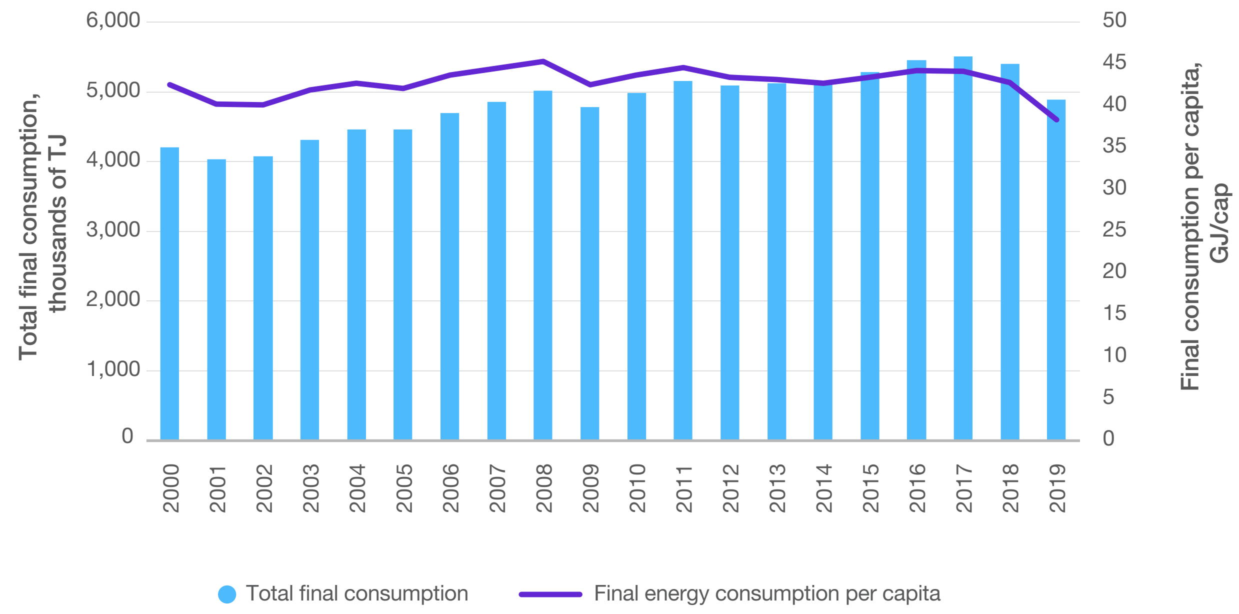
2 It is defined as the relation between final energy consumption and GDP at constant USD of 2010.

3 Data on energy intensities calculated internally in the system with data from the World Bank and the energy consumptions in the national energy balances.

Consumption per capita

The growth of final energy consumption per capita was lower than that of total final consumption in the period 2000-2019 (-0.43 % vs. 0.82 %), continuing its downward trend.

Graphic 6 Total final consumption versus final consumption per capita, 10^3 TJ and GJ per capita



Source: Own preparation based on data from sieLAC, OLADE.

Local prices

The following end user prices refer to Mexico. Compared to the region, Mexico's prices are generally in line with the rest, except for diesel, where it shows higher prices, like Peru and Uruguay. The prices of electricity, natural gas, or other fuels are close to the average in the region.

Table 2 Prices of the main energy products in Mexico, cut-off year 2018

Energy product	VAT %	Special taxes	Price
LPG (residential)	16 %	Yes	0.94 USD/kg
Regular gasoline	16 %	Yes	0.93 USD/l
Premium gasoline	16 %	Yes	1.01 USD/l
Diesel (transportation)	16 %	Yes	0.99 USD/l
Fuel oil (industrial)	16 %	Yes	0.33 USD/l

Source: OLADE - https://www.olade.org/publicaciones/precios-de-la-energia-en-america-latina-y-el-caribe-informe-anual-abril-2021/

Note: Fossil fuels are taxed with the special tax on production and services (IEPS), which has three components. The federal IEPS taxes gasolines and diesel. The state IEPS taxes gasolines and diesel. The IEPS by carbon content taxes all fossil fuels, except natural gas.

Energy aspects

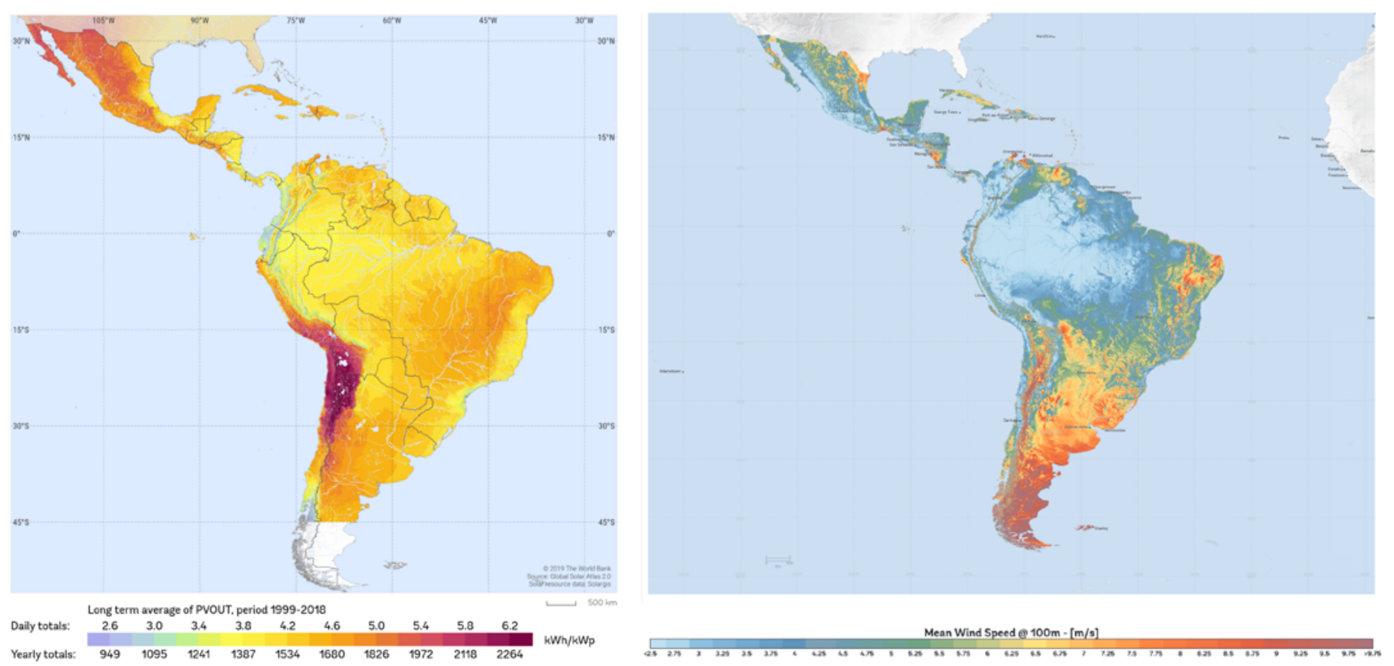
Reserves and total fuel supply (production, imports and exports)

Mexico has significant fossil energy resources although they have shown a sustained fall in recent years.

As to its solar resource, according to the Global Solar Atlas, Mexico shows a value of 1,949 kWh/kWp in 10 % of the areas with greater photovoltaic production, and an average of 1,796 kWh/kWp. As a reference, the global resource for 10 % of the areas with more irradiation has been established at 1,736 kWh/kWp and the average global resource is 1,576 kWh/kWp. The greatest concentration of solar resource is located in the northwest of the country. On the other hand, its wind resource in 10 % of the areas with more wind is equal to or greater than 432 W/m^2, where the mean wind speed at 100 meters is 7.1 m/s or more. Graphic 7 illustrates the solar and wind resources in Latin America and the Caribbean.

Graphic 7 illustrates solar and wind resources in Latin America and the Caribbean.

Graphic 7 ▶ Potential solar resource (kWh/kWp) and mean wind speed at 100 m (m/s)



Source: Global Solar Atlas (World Bank)[4] and Global Wind Atlas (World Bank)[5].

Mexico's availability of resources is evidenced both in its power generation mix and in the final demand by fuel. It has exported a large amount of oil and is a net importer of petroleum products and natural gas.

4 Global Solar Atlas, World Bank Group, https://globalsolaratlas.info/download/latin-america-and-caribbean

5 ws_LAC.pdf

Table 3 ▶ Fuel reserves, hydroelectric potential, and infrastructure, 2019, Mexico

Reserves				Potential	Installed capacity	
Oil	Natural gas	Coal	Uranium	Hydro energy	Refining	Power generation
6,066	273	1,211	0	53	1,640	79.6
Mbbl	Gm³	Mt	10^6 bep	GW	kbbl/day	GW

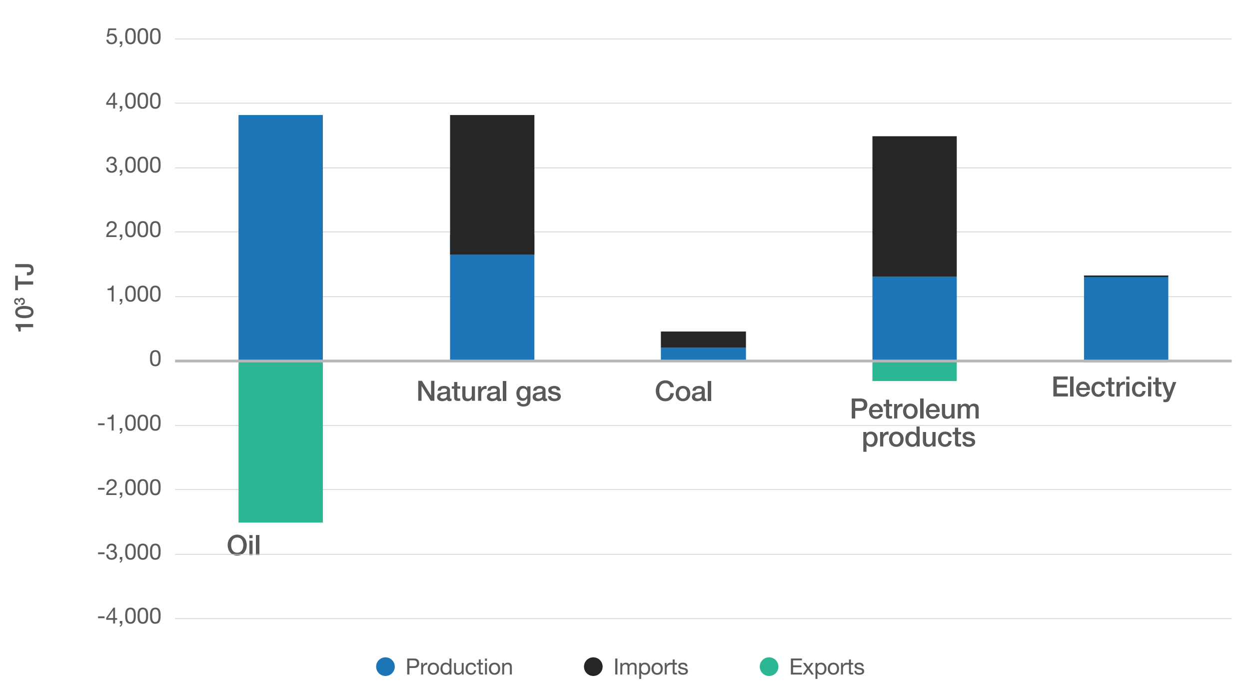
Source: sieLAC, OLADE.

Table 4 ▶ Wind and solar resources, Mexico

Resources		
Wind (10% of the areas with more wind)	Solar (average)	Solar (10% largest production)
7.1	1,796	1,949
m/s	kWh/kWp	kWh/kWp

Source: Own preparation based on Global Solar Atlas and Global Wind Atlas (World Bank).

Graphic 8 ▶ Production, imports and exports by main sources, 2019, 10^3 TJ



Source: Own preparation based on data from sieLAC, OLADE.

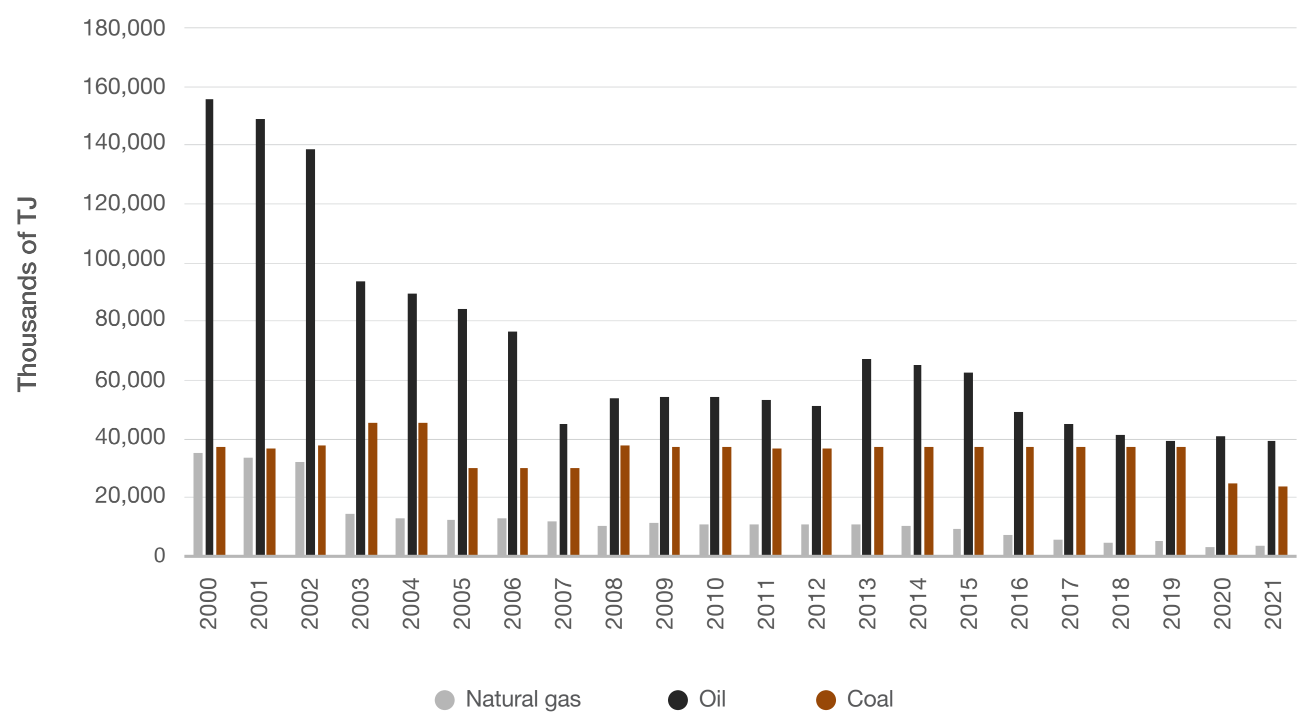
In 2019, Mexico was the third natural gas producer in Latin America, the Caribbean, and South America, after Argentina and Trinidad & Tobago. As to coal and oil, it was in the second position after Colombia and Brazil, respectively.

It exports most of its oil production (an average 54.5 % in the last 20 years) and this percentage has shown a rise in the last few years (reaching 64 % in 2019).

It locally consumes its natural gas and coal production and must also import these two fuels. In 2000, oil, natural gas, and coal reserves were 24,631 Mbbl, 1,222 Gm^3 and 1,848 Mt. At present, they stand at 6,066 Mbbl, 273 Gm^3, and 1,211 Mt, respectively.

In 2019, it imported a greater amount of natural gas and coal than the amount produced (135 % and 119 %, respectively).

Graphic 9 ▶ Evolution of proven oil, natural gas, and coal reserves, Mtep

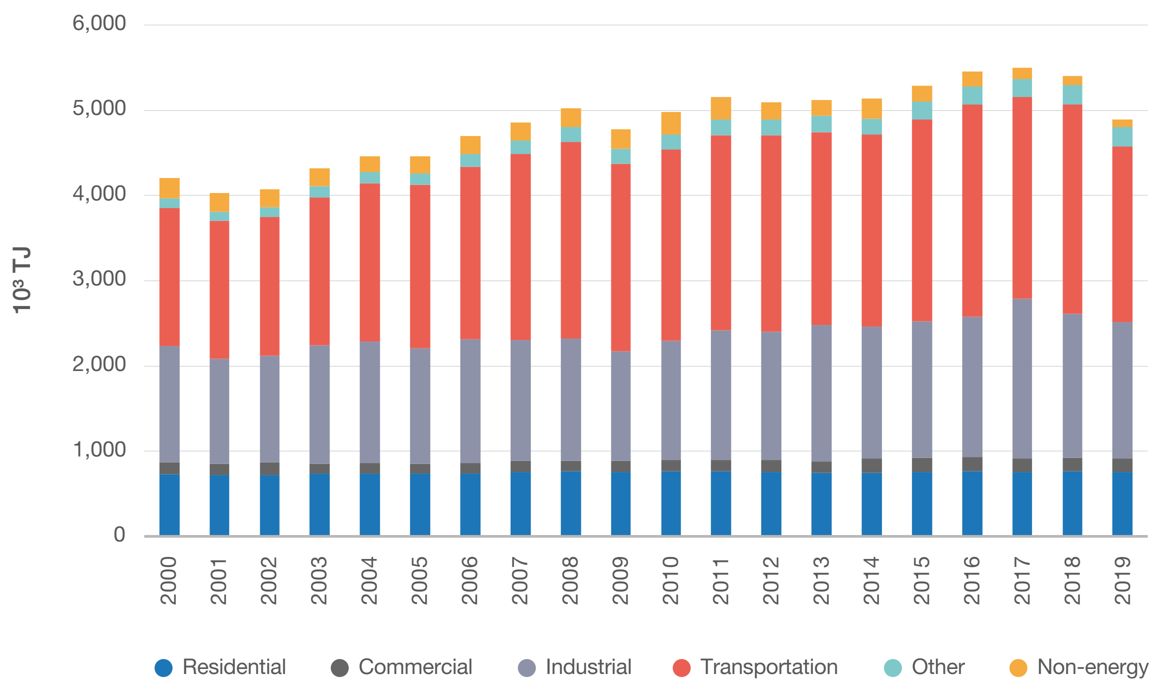


Source: sieLAC, OLADE.

Final consumption by source and sector

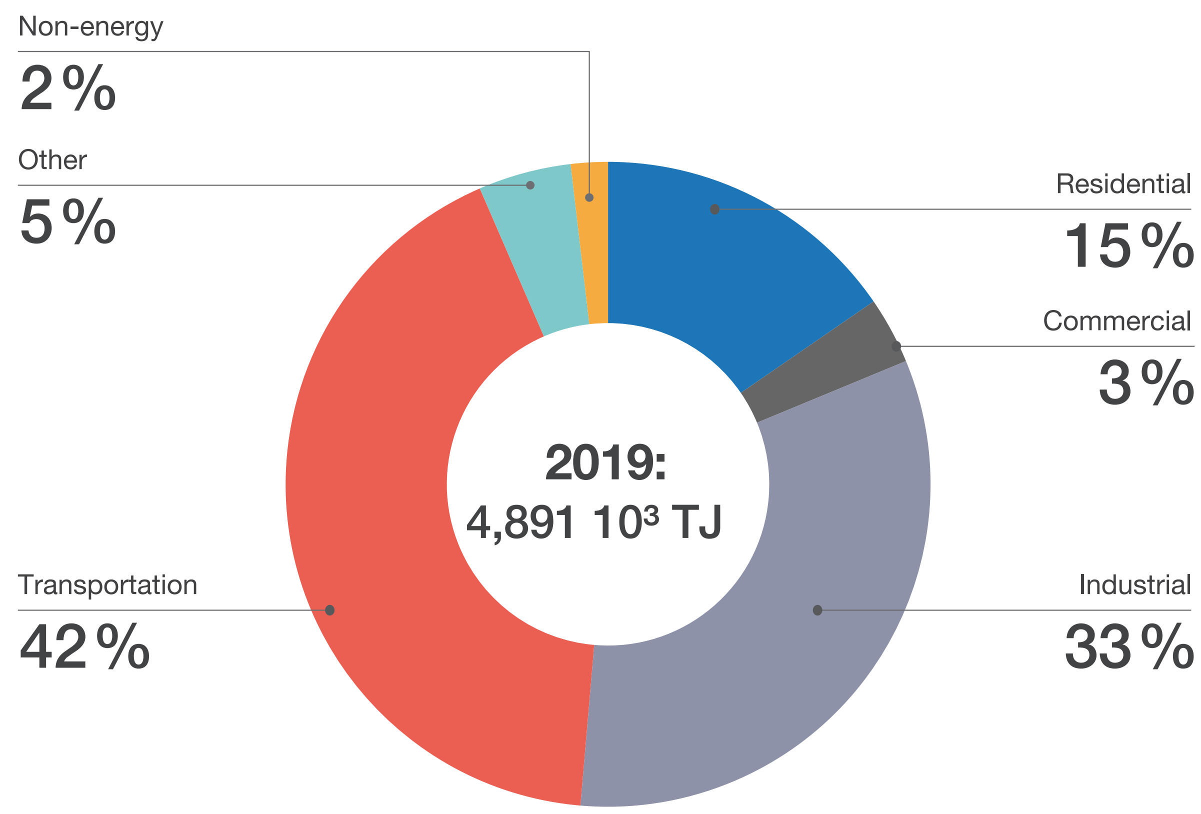
Transportation was the sector with the greatest consumption in 2019 and its relative weight has increased in the last 20 years (from 38 % to 42 %), peaking in 2016 (46 %). On the other hand, residential demand remains quite stable (it grows at an annual average of 0.14 %) and loses relative weight in total final consumption (17 % in 2000 and 15 % in 2019). The industrial sector grows at an annual average rate of 1.6.

Graphic 10 A ▶ Final consumption by sector, 10^3 TJ and %



Source: Own preparation based on data from sieLAC, OLADE.

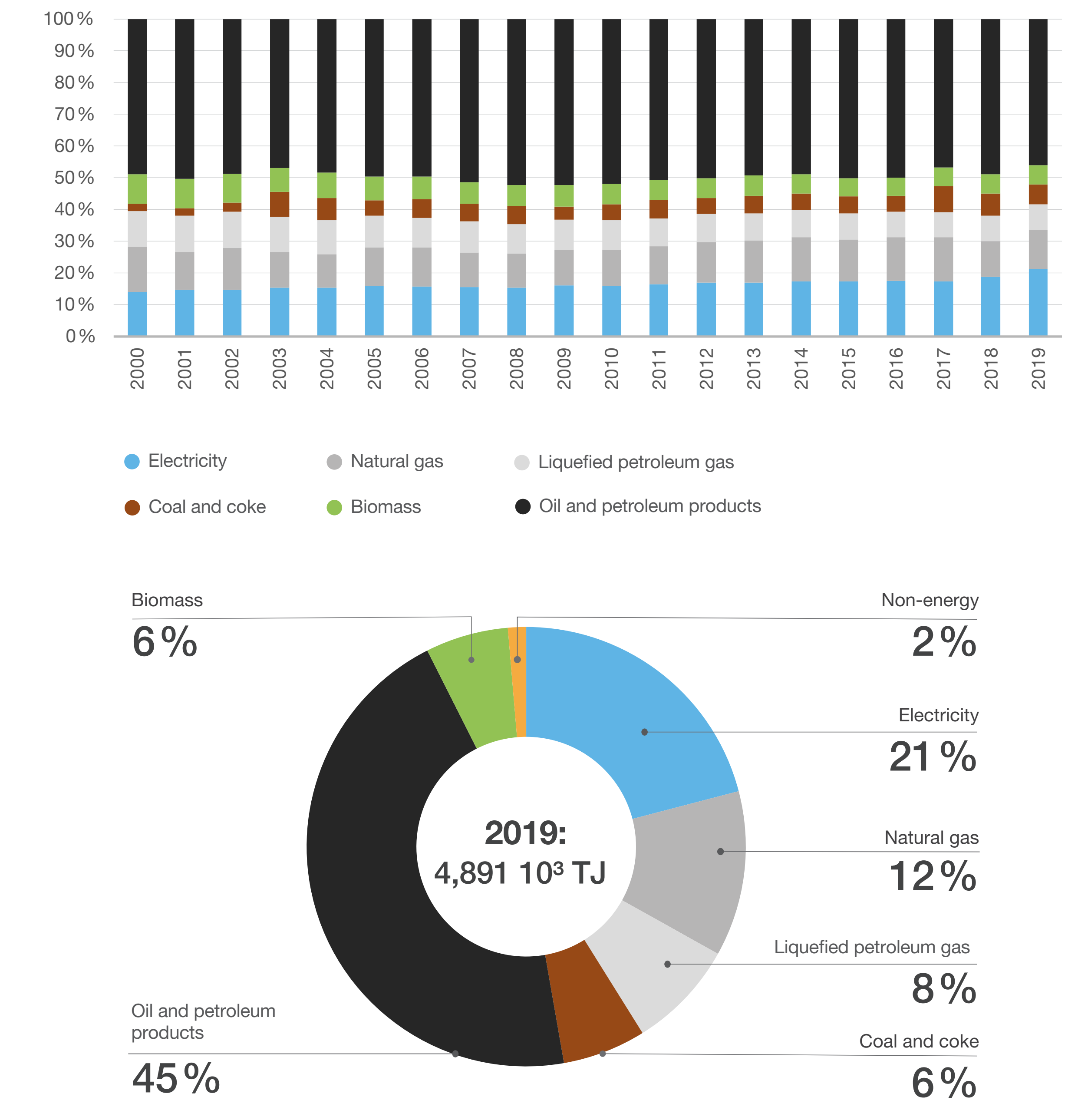
Graphic 10 B ▶ Final consumption by sector, 10^3 TJ and %



Source: Own preparation based on data from sieLAC, OLADE.

By source, electricity, coal, and coke are the sources whose shares grew the most during the analyzed period (from 13 % to 21 % and from 2 % to 6 %, respectively), to the detriment of the other energetics.

Graphic 11 Final consumption by source, 10^3 TJ and %



Source: Own preparation based on data from sieLAC, OLADE. “Non-energy” category not included in the historical evolution

Climate profile

Climate change scenarios and risks to the energy sector

Mexico is a country with great climate diversity because of its geographical location and its topography. It is characterized by a rainy season from May to October, with the heaviest rainfall in the months of July and August. It also has tropical storms and hurricanes in the rainy season, especially in the Pacific coastal areas and in the Gulf of Mexico.

The Intergovernmental Panel on Climate Change (IPCC) has developed different climate change scenarios for the world, including Mexico. These scenarios describe different possible futures for the global climate based on the greenhouse gas (GHG) emission levels. The IPCC’s climate change scenarios for Mexico identify several risks to the energy sector. The main vulnerability is the impact on hydroelectric, wind, and solar generation. In Climate Change 2022: Impacts, Adaptation and Vulnerability[6], prepared by the IPCC, a possible reduction of over 20% in hydro generation is mentioned for scenarios RCP4.5 and RCP8.5. Installed hydroelectric capacity in Mexico reaches 15 % of the total, according to the document Panorama Energético de América Latina y el Caribe[7].

6 https://www.ipcc.ch/report/ar6/wg2/
7 https://www.olade.org/wp-content/uploads/2023/01/Panorama-ALC-13-12-2022.pdf

On the other hand, the risks associated with climate change include a rise in energy demand for climate control, a reduction in solar and wind production in some regions in the country, and risks to energy infrastructure related to extreme climate events (storms, floods, etc.), among others.

As mentioned above, it is important to point out that Mexico experiences tropical storms and hurricanes in the rainy season, especially in the Pacific coastal regions and in the Gulf of Mexico. The existence of extreme climate events may affect the energy infrastructure (including transmission and distribution grids) as well as production in mining and energy production sites.

In addition, the global climate risk index (GCRI)[8] indicates the level of exposure and vulnerability to extreme climate phenomena. In the period 2000-2019, Mexico occupied the 59th position among 180 countries (the first position is the position with the greatest exposure and vulnerability).

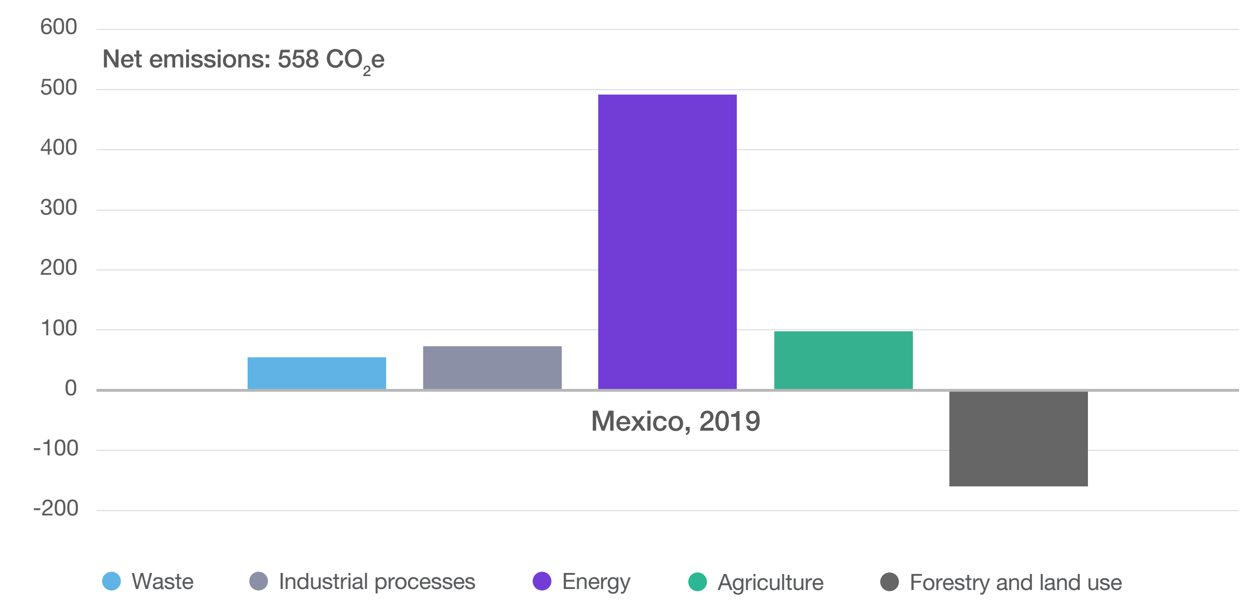
GHG contribution in the base year

According to the latest National Greenhouse Gas Inventory (INGEI), net total emissions in 2019 were 558 $MtCO_2e$[9]. The energy sector (that is, emissions from burning fuels and fugitive emissions) is the sector with the most emissions on a national basis. The forestry and other land uses sector shows net absorptions.

8 The GCRI comprises four indicators: number of deaths, number of deaths per 100,000 inhabitants, sum of losses in USD at PPP, and losses per GDP unit. The final ranking considers these indicators with different weights and in a 20-year period. https://www.germanwatch.org/en/19777

9 Whithout Without considering the absorption of the other land uses sector (193 MtCO2e in 2019), total emissions were 760 $MtCO_2e$.

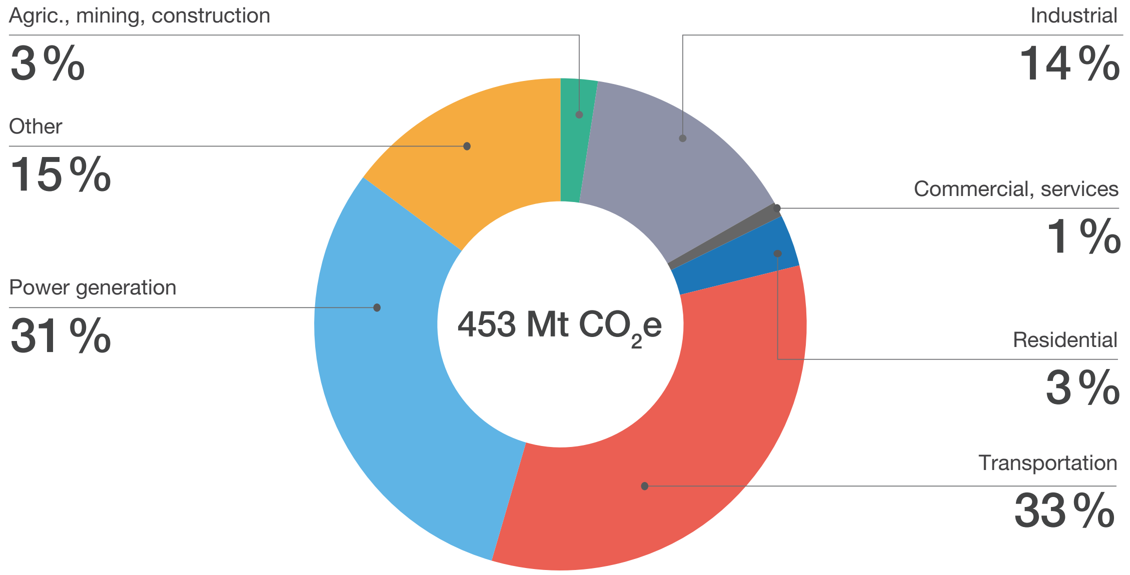
Graphic 12 Net total emissions*, 2019, $MtCO_2e$



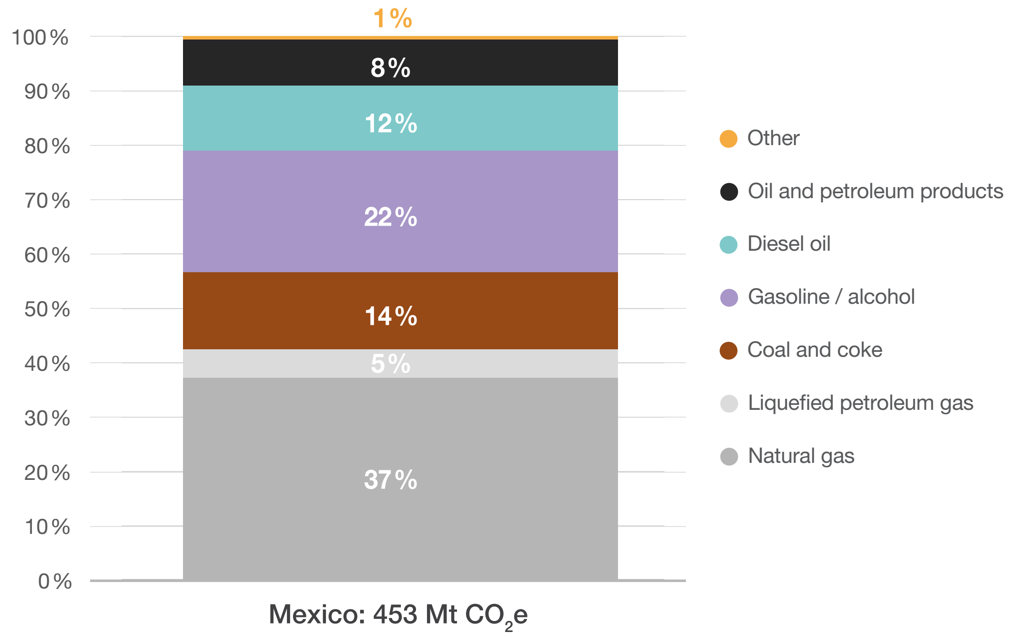
Source: Own preparation based on the national GHG emissions inventory (INECC, 2019)

When analyzing the energy sector (emissions resulting from burning fuels and fugitive emissions), it is possible to analyze the emissions by sector and by source. The data in Graphic 13 is based on the estimation of CO_2 emissions conducted by the Latin American Energy Organization (OLADE) (sieLAC).

Graphic 13 Estimated emissions from the energy sector, by sector and by source, $MtCO_2e$, 2019



Emissions by source



Source: Own preparation based on estimations made by sieLAC, OLADE. The differences observed between the historical data and the estimations made by sieLAC may be due to differences in the estimation methodology.

The transportation sector accounts by itself for one third of the emissions in the sector. The main fuels consumed by the sector are diesel and gasoline. Power generation accounts for another third of the sector's emissions, mainly due to natural gas burning (followed by the use of coal and liquid fuels, to a lower extent).

National commitments (NDC and Paris Agreement)

Even though Mexico is committed to reduce CO_2 emissions both in the medium (NDC 2030)[10] and long terms (Paris Agreement), its current energy policy presents challenges for full alignment with CO_2 emission reduction targets.

Three points can be mentioned in detail.

- In 2021, a civil association filed an action for enforcement of rights (amparo, in Spanish), questioning the lack of ambition of nationally determined contributions (NDC) updated in December 2020.
- In 2022, Mexico presented a detailed NDC including an unconditional emission reduction target compared to a BAU scenario of up to 35% in 2030 and a target conditioned to international support of up to 40% in 2030. This NDC update only includes targets for 2030 and fails to mention a net zero target in the long term. It also explicitly eliminates the objective of reaching an emissions peak in 2026 mentioned in the 2016 NDC.

10 NDC by country (https://unfccc.int/NDCREG).

- Mexico signed the Paris Agreement; therefore, it is committed to "substantially reducing the greenhouse gas emissions to limit the increase in global temperature in this century to 2 °C and make efforts to limit this increase to even more, only 1.5 °C". However, it still does not have any studies on long-term decarbonization pathways nor has it established a clear net zero emissions commitment in the long term[11].

In recent years, some actions that compromise the progress of the climate agenda in Mexico have been observed[12].

11 https://climateactiontracker.org/countries/mexico/targets/

12 https://www.sei.org/wp-content/uploads/2023/01/transicion-energetica-sei2023.002.pdf and https://climateactiontracker.org/countries/mexico/

"The IPCC climate change scenarios for Mexico identify several risks related to the energy sector. Among them is a potential reduction of over 20% in hydroelectric generation."

2. Institutional, regulatory, and public policy aspects

Sectoral government

Table 5 lists the main institutions in the energy sector.

Table 5 Mapping of institutions in the energy sector

Institution	Function
Secretary of Energy's Office (SENER)	- Definition of policies in the oil, gas, and electricity sectors - Planning of the oil, gas, and electricity sectors.
Petróleos Mexicanos (PEMEX)	- Expansion of the hydrocarbon sector.
Federal Electricity Commission (CFE)	- Expansion of the electricity sector.
Energy Regulatory Commission (CRE)	- Regulation of oil, gas, and electricity.
National Energy Control Center (CENACE)	- Administrator of the electricity market.
National Natural Gas Control Center (CENAGAS)	- Administrator of the oil and gas market.

Source: Own preparation.

Main regulatory concepts

Table 6 indicates whether there is price regulation and a competitive market with free access for each energy sector and each segment, pursuant to the current legislation.

As mentioned, some setbacks have been observed in climate policy and greenhouse gas emission reductions, including, for example, strong support for PEMEX and CFE to increase their share in the fuels and electricity markets[13]. This has led to barriers that affected national and international private investors; for example, the tenders for oil concessions and long-term electricity auctions were interrupted.

Table 6 Main regulatory concepts by sector and segment

Sector	Segments	Price regulation	Market
Electricity	- Generation - Distribution - Transmission - Commercialization	- Transmission - Distribution and retail commercialization	- It is competitive in generation and commercialization of large users (qualified users). - Free access in all segments of the chain.
Natural gas	- Exploration and exploitation - Transportation - Distribution - Commercialization	- Transportation - Distribution and retail commercialization	- It is competitive in exploitation, exploration, and commercialization of large users (qualified users). - Free access in all segments of the chain.
Oil	- Exploration and exploitation - Transportation - Refining - Distribution and commercialization	- Refining is an activity regulated by the CRE. - First-hand selling prices of fuel regulated by the CRE (import parity). - Imports subject to previous permits from SENER.	- Exploitation and exploration: the tender for oil concessions (National Hydrocarbons Commission, CNH) determines payment to federal treasury and the allocation of the extracted volumes between the Mexican government and the company. - Transportation is regulated (CRE). Refining (competitive): permit from SENER is required for entry. - Distribution and commercialization are regulated by the CRE.

Cont'd

13 https://climatetrackerlatam.org/historias/transicion-energetica-atrapada-entre-pemex-y-cfe/

Cont'd.

Sector	Segments	Price regulation	Market
Coal	- Exploitation - Commercialization	- No price regulation.	- Exploitation: The Secretary of Economy (SE) awards the areas. - Commercialization: prices are not regulated. - The most important buyer is the CFE (national electricity company): possible monopsony.

Source: Own preparation with data from the regulators.

Public policy aspects

Energy efficiency policies

In 2016, the Energy Transition Act established the provisions that regulate the mechanisms and procedures for the implementation of the law in terms of sustainable use of energy, clean energy, and reduction of polluting emissions from the electricity industry. The main energy efficiency policies, measures, and programs are described briefly in Table 7.

Table 7 Energy efficiency in Mexico

Aspect	Concept	Country progress
Labeling regulations	Sector	- Construction, commercial, and industrial
	Program	- The Energy Transition Act provides that the equipment and appliances with significant energy consumption and included in the catalog prepared by the National Commission for the Efficient Use of Energy (CONUEE) must have an energy efficiency label.
	Minimum energy efficiency standards (MEPs)	- No

Cont'd

Cont'd

Aspect	Concept	Country progress
Sectoral policies[14]	Public sector	√
	Transportation	√
	Residential	√
	Commercial and industrial	√
Energy efficiency fund	Type	– The CFE created the Energy Efficiency Trust Fund to promote efficient consumer policies.
	Name	– Trust Fund for Electric Energy Savings (FIDE)
	Other	– Specific financial resources to implement energy efficiency policies.
Promotion and cultural change	Labeling	√
	Training programs and workshops for the public and private sectors	√
	Development of programs, and dissemination and demonstration campaigns	√
	Social participation, consultations, and public access to information	√
	Inclusion of energy efficiency in syllabuses	√
	Energy efficiency awards, honors, and/or recognition	√

Source: Own preparation based on the document *Leyes de Eficiencia Energética en América Latina y el Caribe*, OLADE and data from the CFE.

14 National Commission for the Efficient Use of Energy *(Comisión Nacional para el Uso Eficiente de la Energía)*

Pricing, subsidy, and incentive policies

Subsidies and taxes on fuel prices

Electricity and gas. There are no explicit subsidies for electricity and gas tariffs. However, since 2016, the CFE has received annual contributions from the national budget to cover its costs.

Gasolines and diesel. No direct subsidies for fuel prices are reported in Mexico. However, since 2019, the Secretary of the Treasury and Public Credit *(Secretaría de Hacienda y Crédito Público)* has granted fiscal incentives to reduce the tax burden (federal IEPS) and avoid transferring any variations in the international prices of gasolines and diesel totally to consumers. Prices are fixed through an import parity system established by the CRE.

Taxes

The following taxes apply to fuel prices.

a. **Special tax on production and services (IEPS).** This is a tax on the production and import of fossil fuels; it is determined and applied on an annual basis. It taxes regular gasoline (under 91 octanes), premium gasoline (91 octanes or more), diesel, and other fossil and non-fossil (bioenergetic) fuels.

   The IEPS has three components: the federal and the state components tax gasolines and diesel through a fixed rate that is revised annually, whereas the third component taxes the carbon content though a fixed rate that is updated annually (see subsection c below). Natural gas production and imports are exempted from this tax.

   Taxpayers have been partially or totally exempted from paying the federal component of the IEPS since 2019.

b. **Value Added Tax (VAT).** Pursuant to the applicable law, the tax is paid on the disposal of goods, the provision of services, imports and use or temporary enjoyment of goods and services. The general rate is 16 % in the interior of the country and 10 % in bordering areas. As from 2011, the VAT in bordering areas was reduced to 11 % and later in 2019 it was fixed at 8 % (similar to the sales tax rates applied in the border states of the United States of America). As from January 2014, the LPG rate is 16 % all over the country.

c. **Tax on carbon.** The fiscal reform presented in late 2013 approved the carbon tax in Mexico and it has been applied since January 2014. Mexico did not have green taxes as environmental management instruments. It is included in the law on the special tax on production and services together with other taxes. Each fossil fuel has a different tax rate depending on the amount of carbon dioxide it contains. This value is determined in the annual update performed by the Intergovernmental Panel on Climate Change (IPCC). The special tax on production and services for fossil fuels indicates an approximate value of USD 5 per carbon ton, depending on the content of this gas in each fuel, according to the IPCC. However, as indicated above, natural gas is exempt from paying this tax.

Incentives for renewable energy

From the constitutional reform of late 2013 and until 2018, renewable projects were carried out through medium and long-term energy auctions for energy, capacity, and clean energy certificates (CEL).

However, in the last four years, the power sector has faced several changes in terms of strategy, and these changes have affected the investors’ trust in future investment in renewable energy. The Government’s current priority is to strengthen the role of the state-owned company *Comisión Federal de Electricidad* (CFE). Private companies have faced challenges to invest in renewable energy projects on a large scale due to delays in obtaining the permits and technical requirements that increase the investment costs.

Moreover, the Government has tried to modify the legal framework of the energy sector through instructions from CENACE (power system operator), the CRE (regulator), the SENER (Secretary of Energy), and the amendment of the Electricity Industry Act (*Ley de la Industria Eléctrica*, LIE) and the National Constitution. All these amendments have been taken to court and, to a large extent, halted.

In 2021, the President sent an amendment to Congress for the purpose of establishing a dispatch system that gave priority to the CFE plants (the oldest and least efficient), among others. In 2022, the Supreme Court of Justice maintained such modifications. Therefore, the legal cases against the LIE will continue and will be solved by the courts.

As to the reform of the Constitution, the House of Deputies has rejected the President's proposal and he has announced that during the rest of his administration, he will not send another proposal relating to the energy sector.

In addition, one of the main existing incentives to develop new projects is the possibility to opt for the accelerated depreciation of assets for fiscal purposes. The Mexican development banks also propose soft loans to promote investment in renewable energy projects

Distributed generation

CRE's Resolution RES/142/2017 established the detailed regulation for distributed generation. The regulation covers model contracts, the methodology to calculate the consideration, and the general technical specifications applicable to distributed generation and distributed clean generation plants. It is considered that distributed generation is exempt; that is, it does not need a permit issued by the CRE. The maximum limit to be considered distributed generation is low: 0.5 MW capacity, which limits its development.

Creation of a carbon market

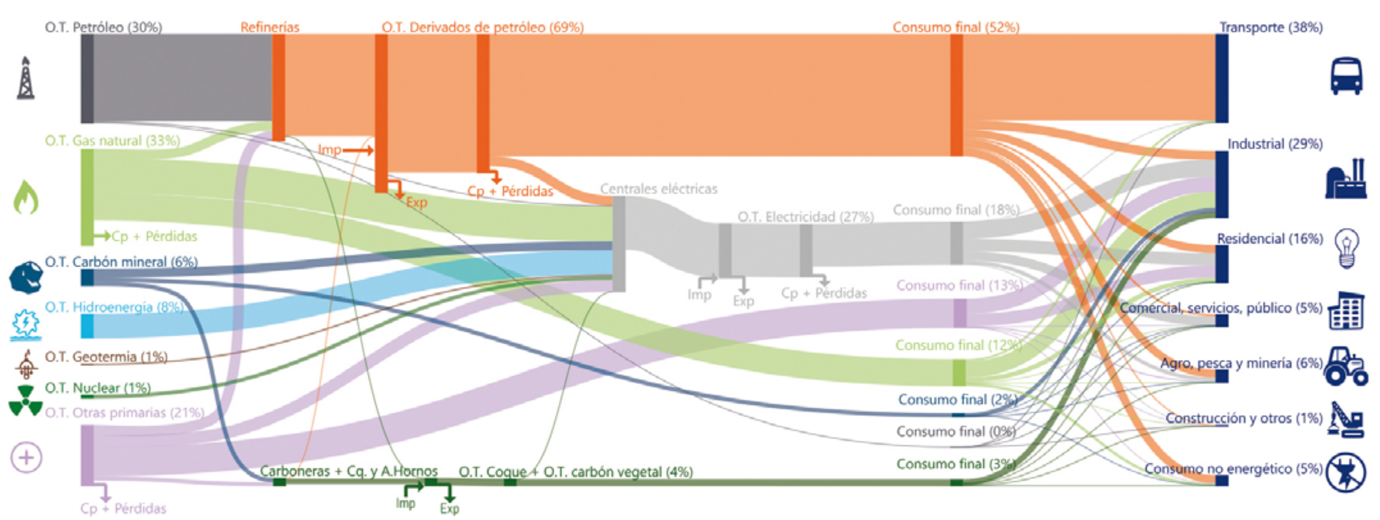
In addition to the tax on carbon, the Mexican state is developing a set of economic and market instruments.

In 2013, the Mexican Stock Exchange and the Mexican Government promoted the creation of the platform MEXICO2 as a market initiative jointly supported by the Mexican Stock Exchange and the Financial Integration System (SIF ICAP), the Embassy of the United Kingdom in Mexico, the United Nations Environment Programme (UNEP), the Secretary of Environment and Natural Resources (SEMARNAT), the National Forestry Commission (CONAFOR), and the National Institute of Ecology and Climate Change (INECC).

3. Energy balance, 2019 and 2022

The energy balance records energy flows from production, energy imports and exports, and transformation to final consumption in the different socio-economic sectors for a certain period (one year). Graphic 14 is a graphic representation (Sankey diagram) of the year 2019, considered as the base year for this study.

Graphic 14 ▶ Energy balance, 2019



Source: *Panorama energético de América Latina y el Caribe 2020*, OLADE.

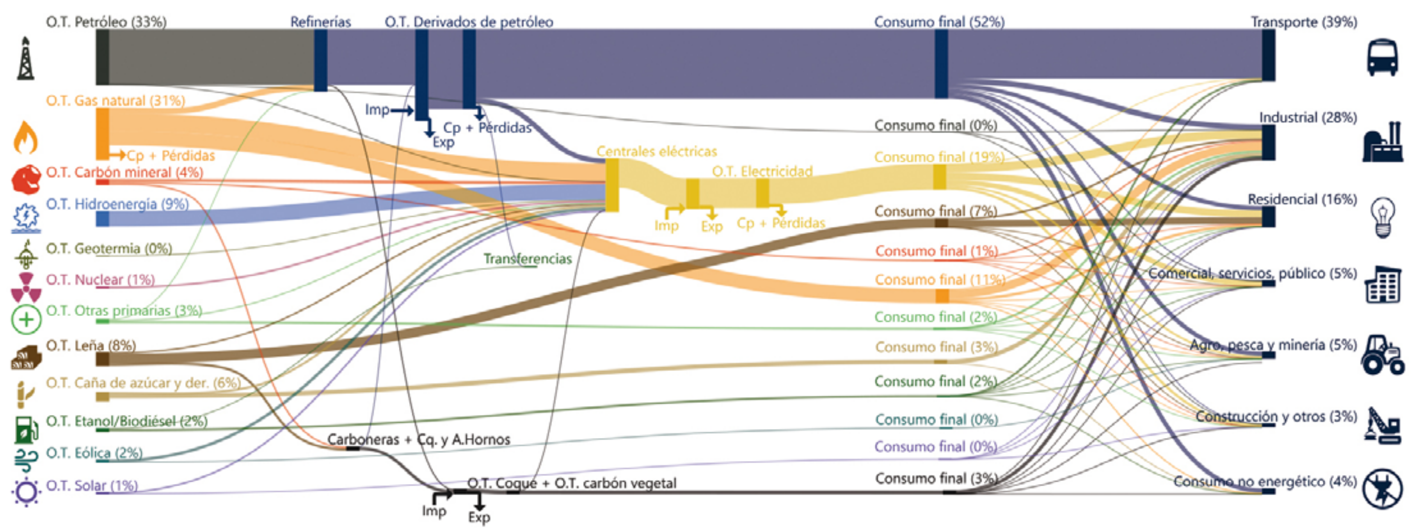
The energy balance allows us to summarize some of the main characteristics of the Mexican energy sector:

- The prevailing role of natural gas (63 %) and oil (17 %) in primary energy supply;
- The significant share of electricity production from natural gas;
- The role of electricity in final consumption, still limited (19 %);
- The sectors with the greatest final consumption are transportation (45%), industry (31 %), and residential (14 %);
- The large proportion of petroleum product imports.

The latest energy balance available (2022), which shows some differences with the energy balance of 2019, is also presented:

- Greater weight of oil (27 % versus 17 %) and less weight of gas (54 % versus 63%) in terms of primary energy supply;
- Greater weight of the transportation sector (47 %) and less weight of the industrial sector (26 %) in terms of final consumption;
- An important increase in the share of electricity in final consumption (from 19 % to 24 %).

Graphic 15 ▶ Energy balance, 2022



Source: *Panorama energético de América Latina y el Caribe 2020*, OLADE, December 2023.

4. Evolution of the energy demand by sector and source

The national energy balance allows us to visualize the dynamics of the energy sector over time through the analysis of time series of the main variables that are part of the country's energy matrix and a comparison of the structures and indicators in different years of a historical period.

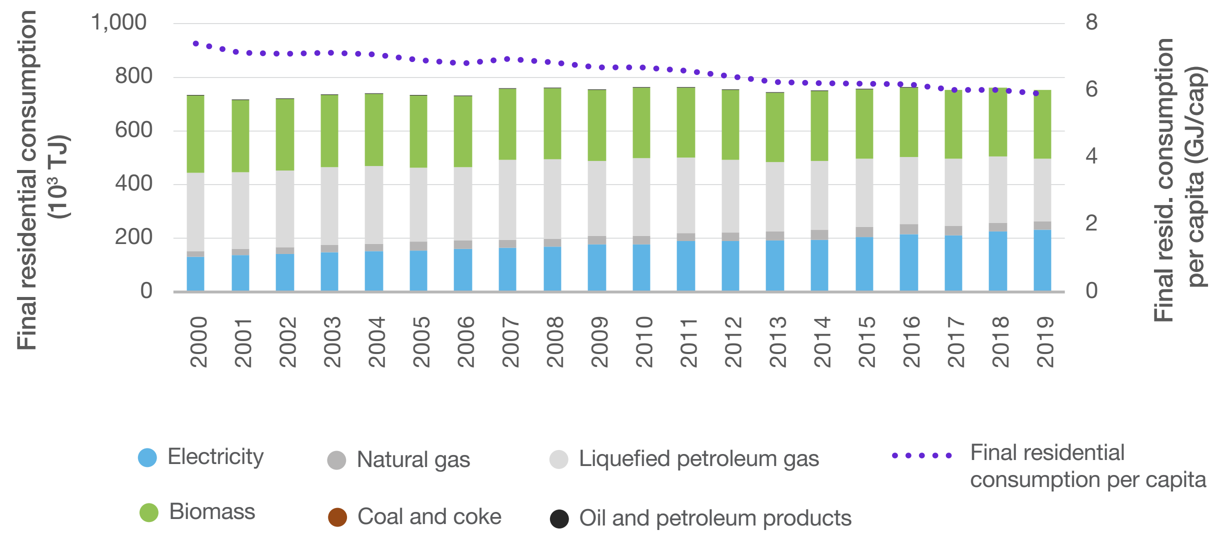
The following paragraphs include, in addition to the energy demand by source, additional data required to characterize this demand, such as the share of demand by energy use (only available for the residential sector), the description of the vehicle fleet, sectoral energy intensity, etc.

Residential sector

Residential consumption has remained constant in the last few years. We can observe an annual average fall of 1 % per capita. By source, we can describe the following characteristics:

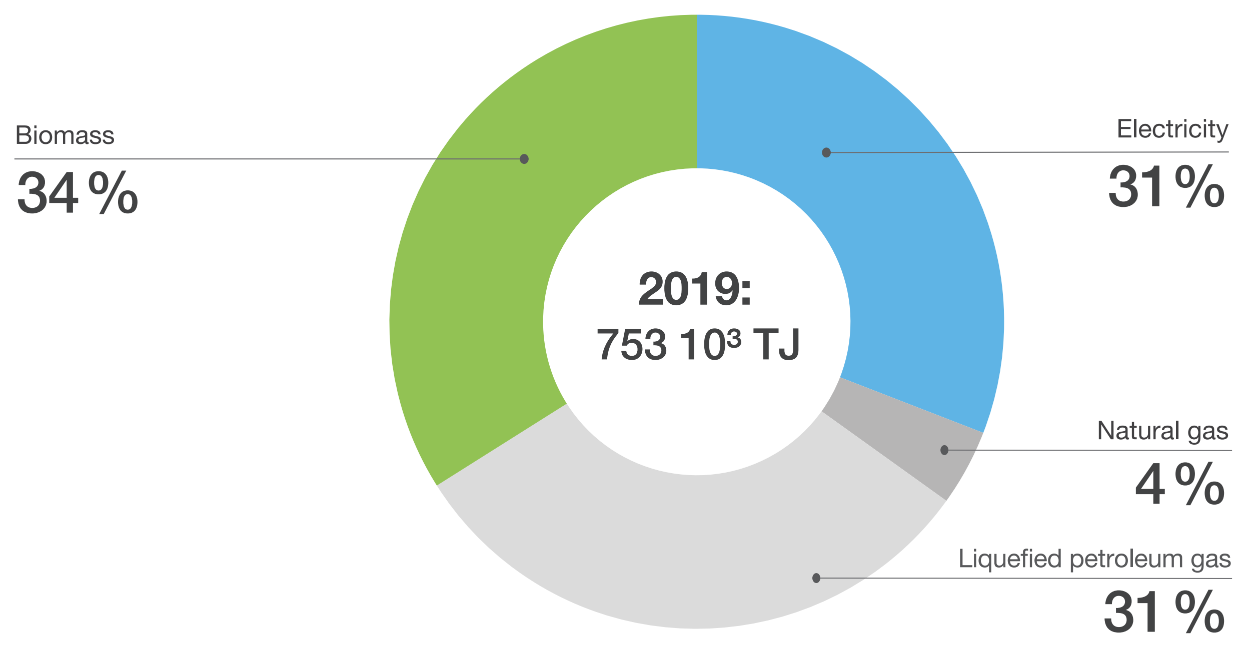
- High biomass consumption (firewood) although its volume and proportion have decreased slightly in the last two decades;
- Slight drop in LPG consumption, which fell from 40 % in 2000 to 31 % in 2019;
- Increase in final electricity consumption from 130 TJ in 2000 to 232 TJ in 2019.

Graphic 16 A Residential sector: evolution of final consumption by source, 10^3 TJ and final residential consumption per capita (GJ per capita)



Source: Own preparation based on data from sieLAC, OLADE.

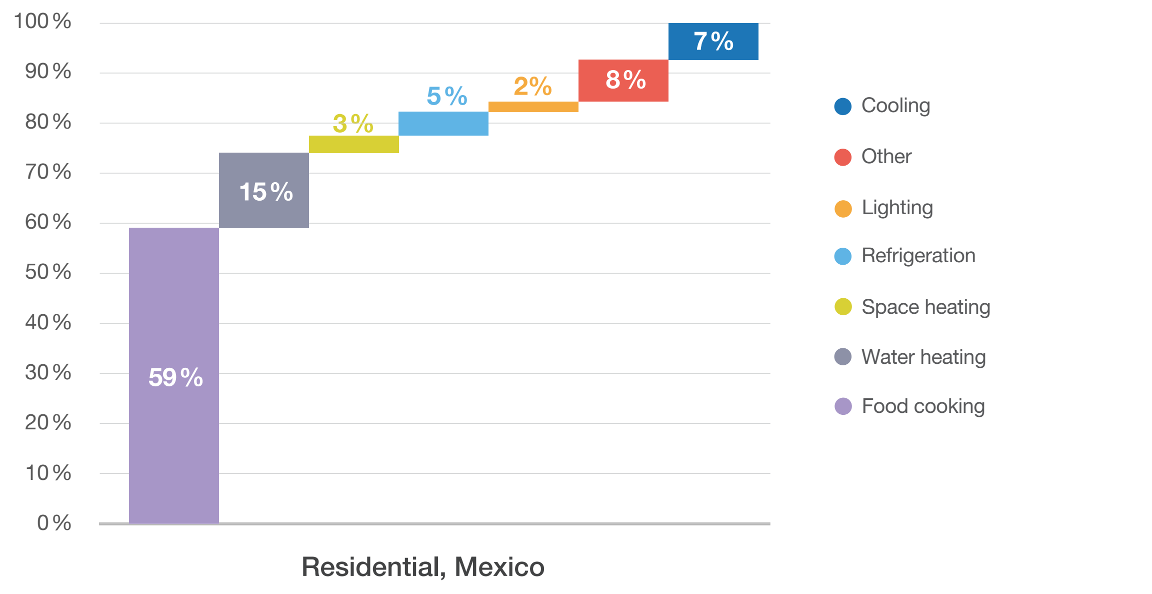
Graphic 16 B Residential sector: evolution of final consumption by source, 10^3 TJ and final residential consumption per capita (GJ per capita)



Source: Own preparation based on data from sieLAC, OLADE.

As to energy consumption for end uses, 59 % refers to cooking food and 15 % to water heating. The most relevant uses reserved to electricity are limited (refrigeration, air conditioning, and lighting).

Graphic 17 ▶ Residential sector: energy consumption by end-uses



Source: Own preparation based on data from the report *Patrones de consumo energético del sector residencial en Mexico*, Mexican Government, CONACYT.

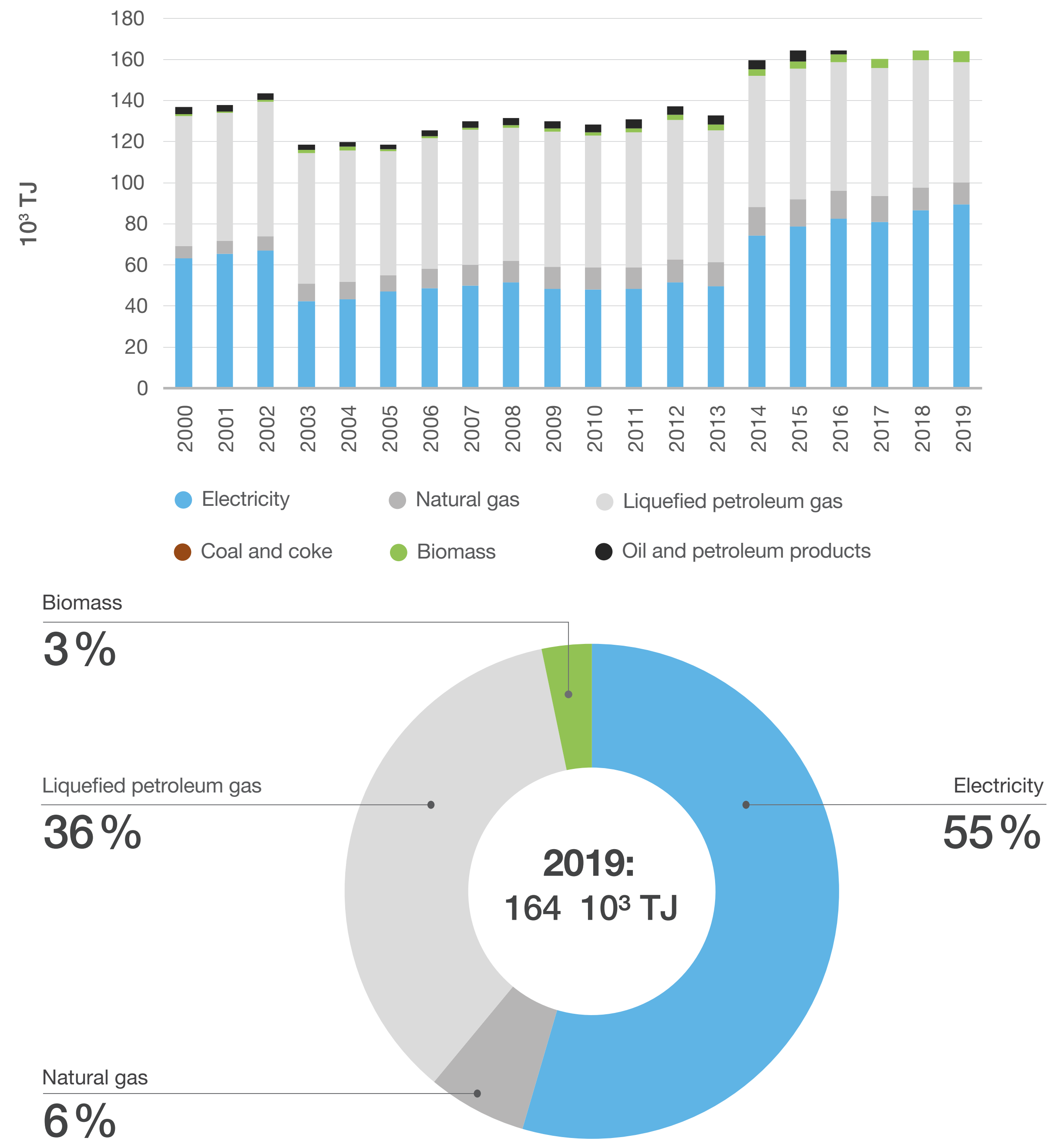
Commercial, service, and public sector

The final consumption of the commercial, services, and public sector has increased in the last 20 years (annual average, 1.0 %). In the period 2003-2012, a significant fall in power consumption was detected; it could be the result of a change in the statistical counting methodology (value allocated to the construction sector and others). By source, the following characteristics can be pointed out:

- a high share of electricity and LPG in total consumption (91 % in 2019);
- elimination of oil and petroleum products as from 2017.

Diagnosis and base line
1 2 3 4
1 2 3 4 5 6 7 8

Graphic 18 ▶ Commercial and public sector: evolution of final consumption by source, 10^3 TJ



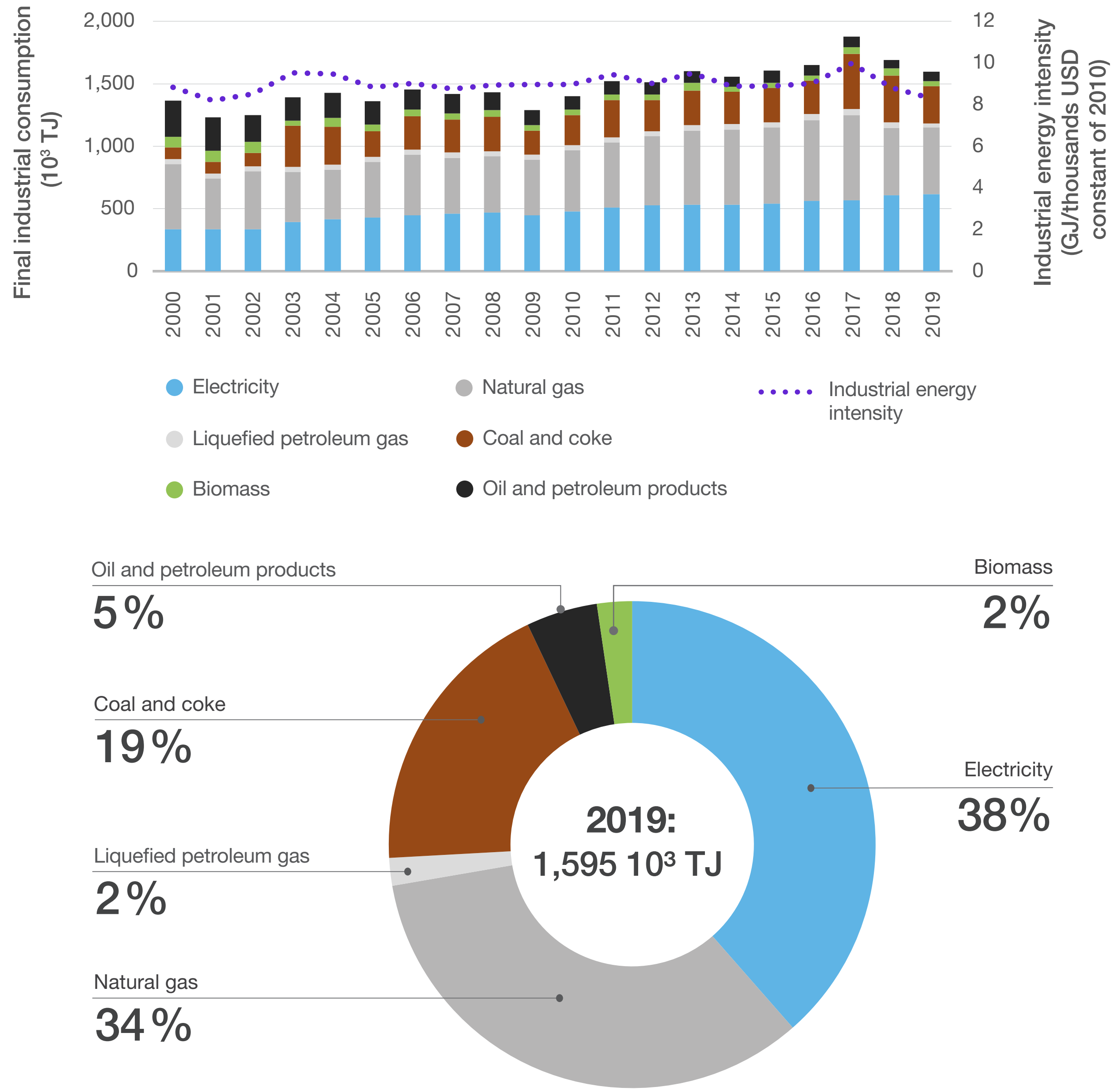
Source:Own preparation based on data from sieLAC, OLADE.

Industrial sector

Final industrial consumption has increased irregularly in the last 20 years, with an annual average growth of 0.8 %. By GDP unit, the energy intensity of the industrial sector has also been irregular, although it has decreased in the period. This may be due to the modification of the country's industrial matrix and the impact of the energy efficiency measures on the sector. By source, the following characteristics can be pointed out:

- electricity increased its share from 25 % in 2000 to 38 % in 2019;
- coal and coke increased their share;
- oil and petroleum products decreased their share.

Graphic 19 Industrial sector: evolution of final consumption by source (10^3 TJ), industrial energy intensity (GJ/ thousands of constant USD of 2010)



Source: Own elaboration based on data from sieLAC, OLADE.

Transportation sector

Demand by source

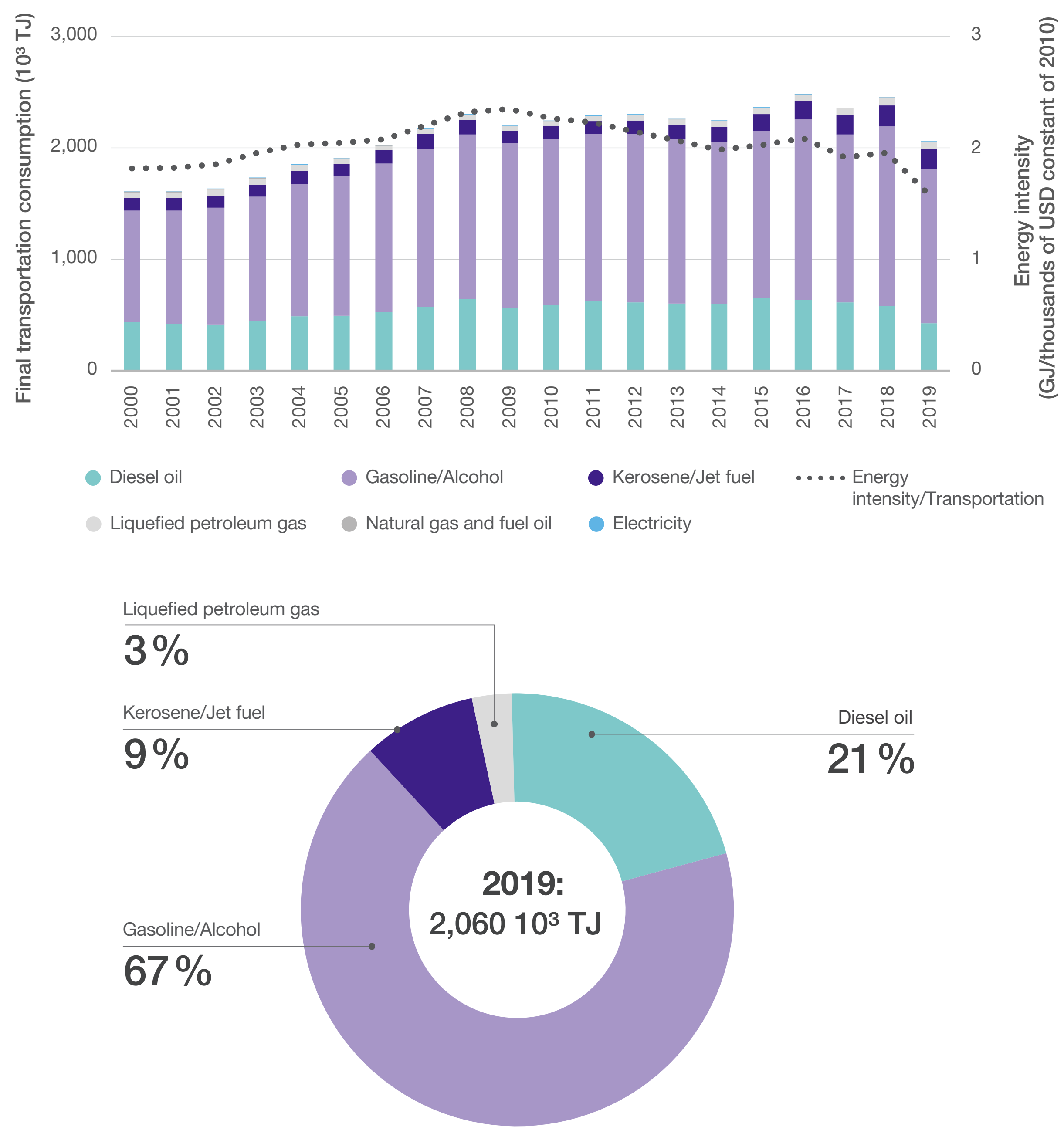
Final consumption in the transportation sector has increased in recent years (annual average 1.3 %). By GDP unit, the energy intensity of the transportation sector[15] peaked in 2008 to later fall to a value that, in 2019, was lower than that of 2000. By source, the following characteristics can be pointed out:

- high consumption of gasoline, alcohol, and diesel, the most frequently chosen by road transportation;
- a very minor role of gas and electricity in the sector at present.

15 The The energy intensity of the transportation sector is calculated as transportation energy consumption/total GDP. The GDP of the transportation sector alone is not considered. Transportation consumption is carried out by all the economy.

Diagnosis and base line

Graphic 20 Transportation sector: evolution of final consumption by source and year 2019, 10^3 TJ



Source: Own preparation based on data from sieLAC, OLADE.

Vehicle fleet and consumption by type

Table 8 shows the total road vehicles and their share by type. In Mexico, around two thirds of the road vehicles are cars and light trucks, followed by freight transportation, which reaches 22 %.

Table 8 ▶ Number of road vehicles, total and by type, 2019, Mexico

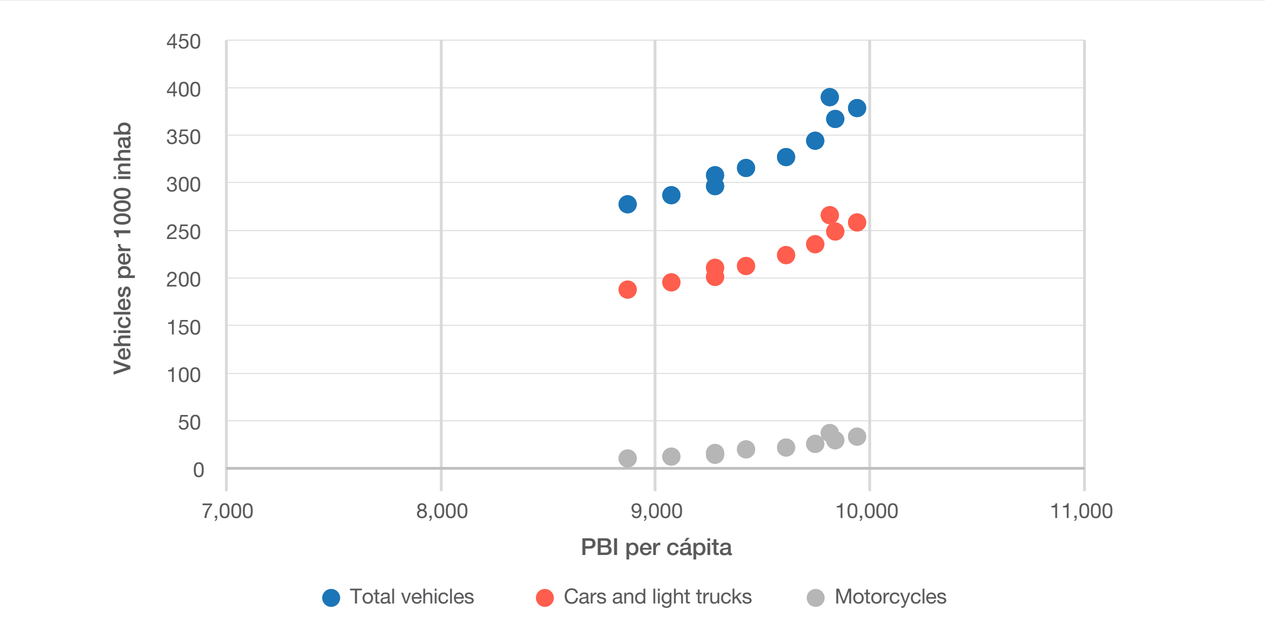
	2019
Cars and light trucks	67 %
Motorcycles	10 %
Buses	1 %
Freight	22 %
Total	3 %
Total	49,869,688

Source: Own preparation based on data from the National Institute of Statistics and Geography (INEGI).

Mexico develops its vehicle fleet with the increase in GDP per capita; in particular, the number of cars and light trucks grows more than that of motorcycles.

Diagnosis and base line

Graphic 21 ▶ Vehicle fleet vs. GDP, 2010-2019



Source:Own preparation based on data from INEGI.

Table 9 shows fuel consumption by transportation type and by fuel.

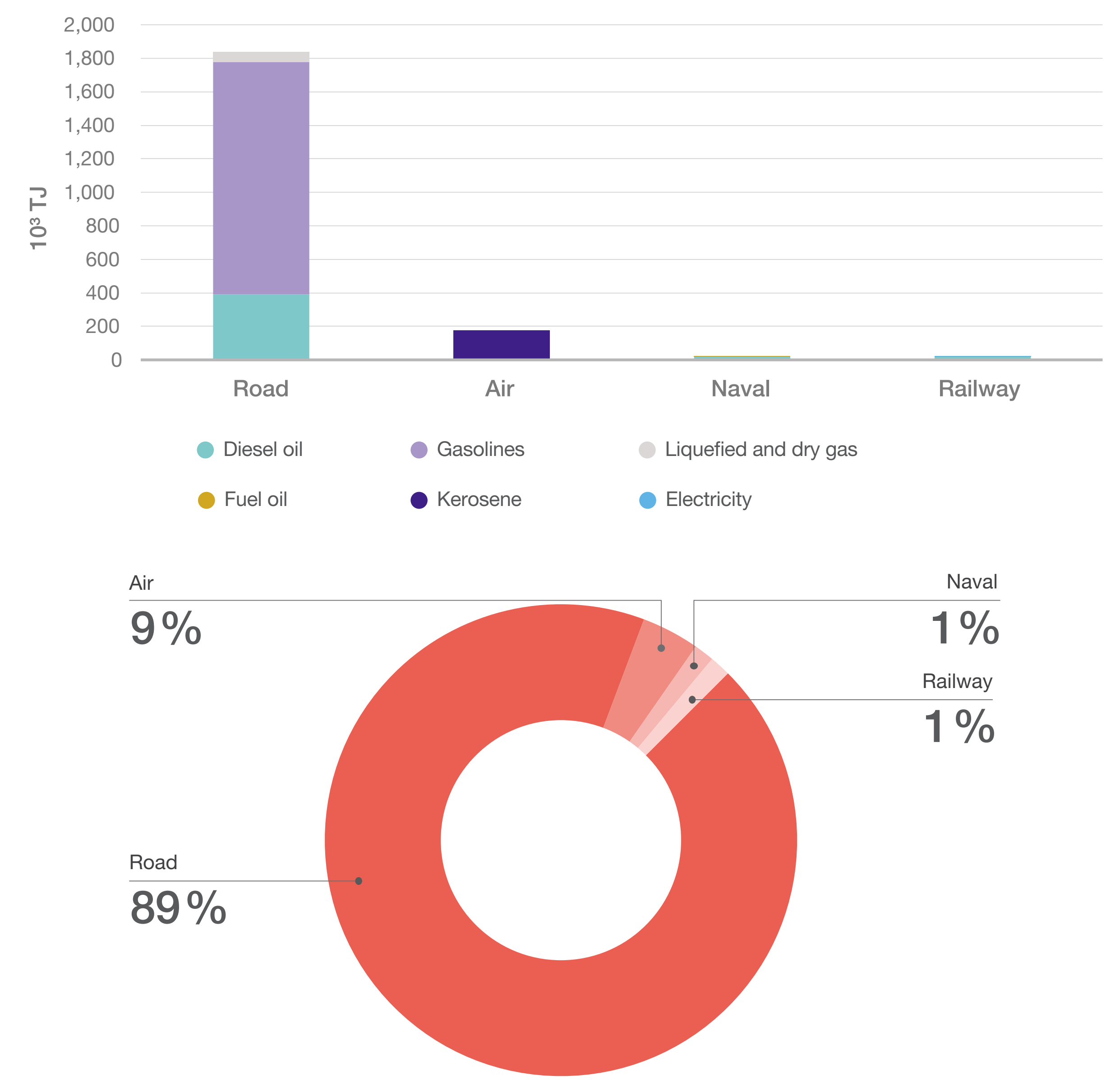
Table 9 ▶ Consumption by transportation type and by fuel type, 10^3 TJ and %, 2019, Mexico

	Total consumption (10^3 TJ)	Diesel	Gasolines	Liquefied and dry gas	Fuel oil	Kerosene	Electricity
Road	1,839	21 %	75 %	3 %	-	-	-
Air	176	-	1 %	-	-	99 %	-
Naval	21	89 %	-	-	11 %	-	-
Railway	19	99 %	-	-	-	-	1 %

Source: Own preparation based on data from the Energy Information System, Mexico.

Road transportation accounts for 89 % of total consumption in the sector, followed by air transportation with 9 %.

Graphic 22 ▶ Transportation sector: final consumption by type and fuel, 10^3 TJ



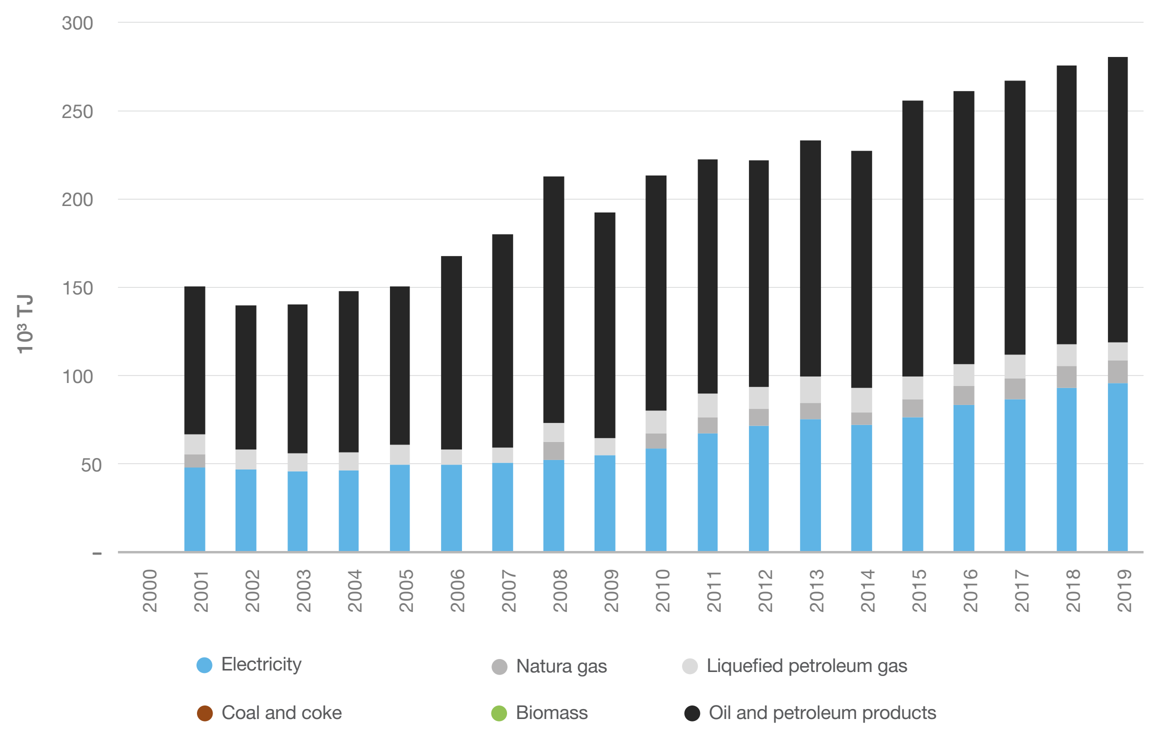
Source: Own preparation based on data from the Energy Information System, Mexico.

Agricultural, fishing, mining, and construction sector

The final consumption of the sector has grown in the last 20 years (annual average 3.6 %). By source, the following characteristics can be pointed out:

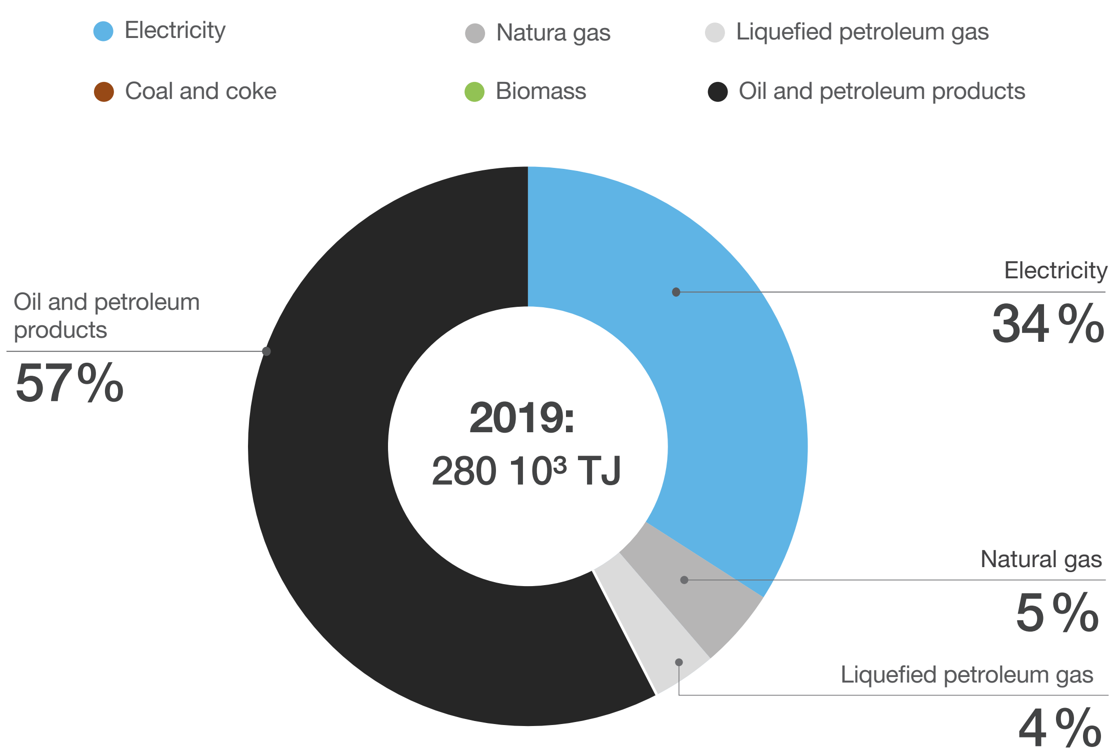
- very relevant share of oil and petroleum products: close to half the total consumption of 2019 (62 %);
- almost total supply of electricity to meet the rest of the demand.

Graphic 23 A ▶ Other sectors: evolution of final consumption by source, 10^3 TJ



Source: Own preparation based on data from SENER, OLADE.

Graphic 23 B Other sectors: evolution of final consumption by source, 10^3 TJ



Source: Own preparation based on data from SENER, OLADE.

By subsector, we can mention that the agricultural sector adds up to around two thirds (68 %) of the demand; the mining sector, slightly less than one third (27 %); and construction, the rest.

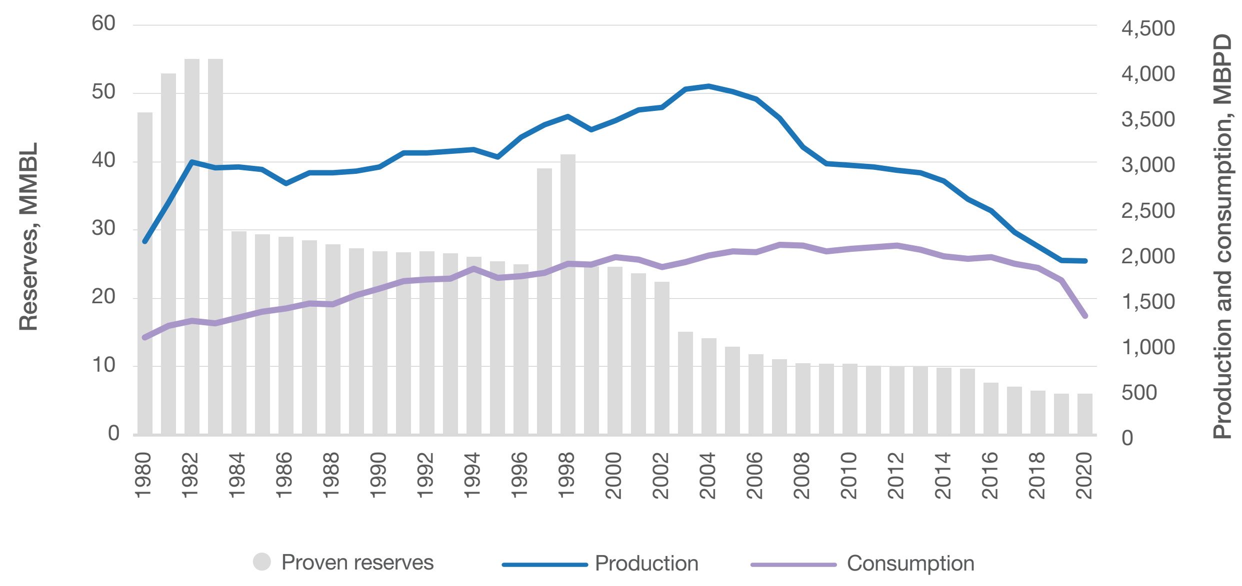
5. International trade

Mexico is an oil exporter and – since a few years ago – a net natural gas and coal importer, as the national production is not sufficient, although it has reserves.

As mentioned above, oil and gas reserves in Mexico were very important, although they declined over time. In the 1980s, the country was the second oil producer and exporter in Latin America after Venezuela.

Currently, there are reserves/production for about 9 years; oil exports continue but to a lesser degree than in the past in relative terms. Internal consumption (refinery processing) has dropped in the last five years, which has led to the import of refined products, gasolines and diesel, LPG, and others.

Graphic 24 Mexico: oil reserves, production and consumption



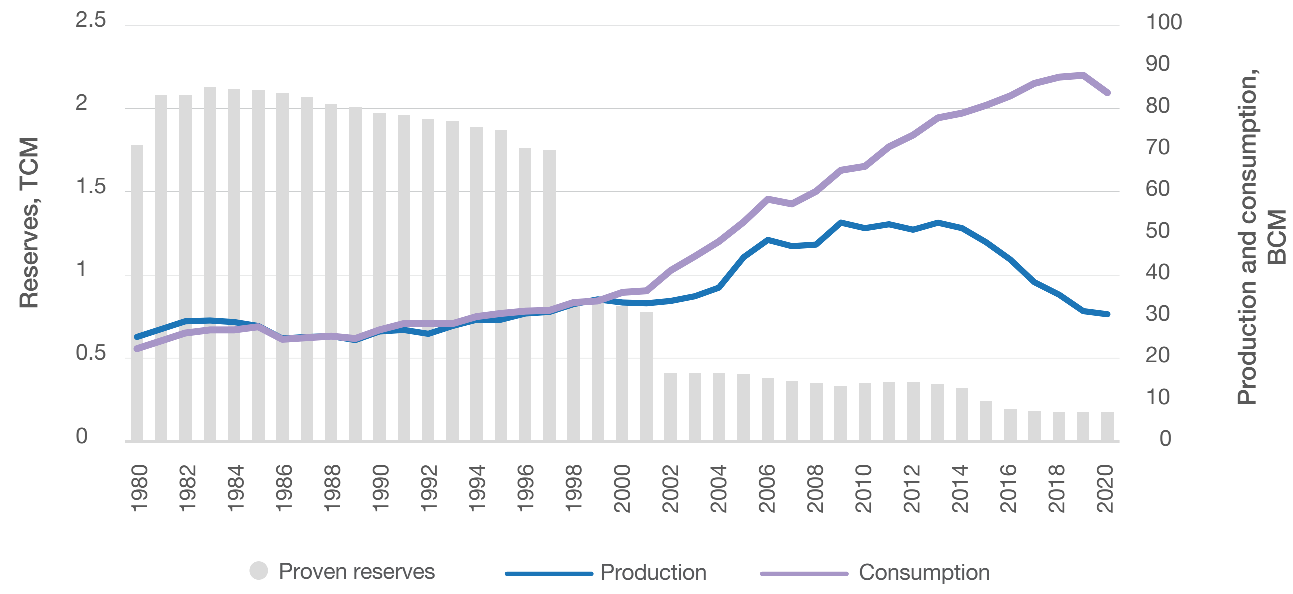
Source: Own preparation based on data from *BP Statistical Review of World Energy* 2022.

Natural gas reserves have also declined and the national production cannot cover the demand, which grew fast. This growth was driven by power generation from plants, mainly combined cycles. This type plants account for over 60% of total generation as a result of the opening of the market to independent power producers using gas.

Thus, and especially in the last decade, Mexico has imported increasingly larger amounts of gas. These imports came mainly from gas pipelines in the United States and in the form of LPG until 2019 (year in which the marine pipeline from the south of Texas to Tuxpan starts operating).

Diagnosis and base line

Graphic 25 Mexico: natural gas reserves, production and consumption



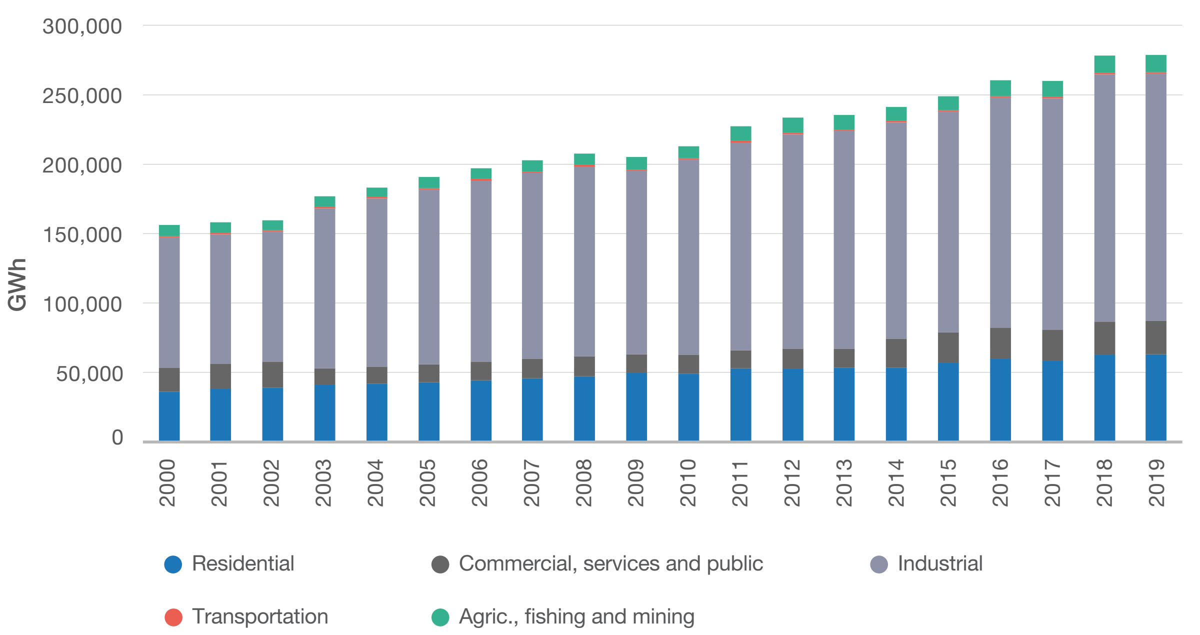
Source: Own preparation based on data from *BP Statistical Review of World Energy* 2022.

6. Power sector

Power demand

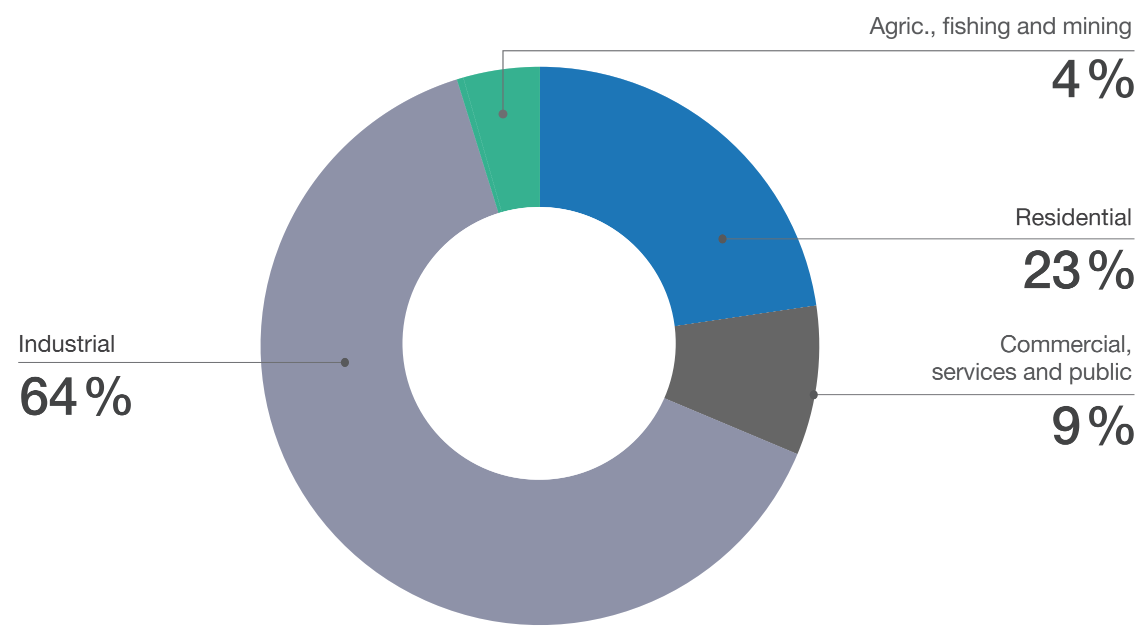
Graphic 26 shows final power consumption broken down by sector of the economy.

Graphic 26 A Final power consumption by sector, 2000-2019, and year 2019, GWh



Source: Own preparation based on data from sieLAC, OLADE..

Graphic 26 B Final power consumption by sector, 2000-2019, and year 2019, GWh



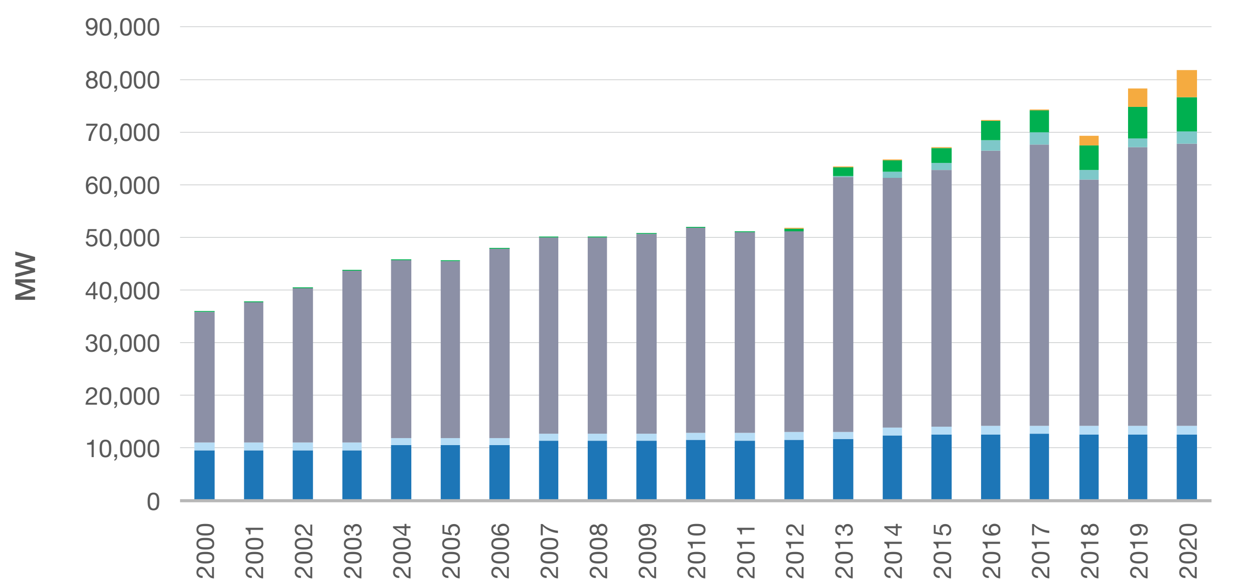
Source: Own preparation based on data from sieLAC, OLADE.

Long and short-term growth trends are evidenced through the growth rates in the last 20 years and 5 years, close to 3 % in both cases. In 2019, the average composition of power consumption in Mexico is represented, in the first place, by the industrial sector (64 %), followed by the residential sector (23 %) and the commercial, services, and public sector (9 %). In the last 20 years, the share of the industrial and residential sectors in the total electricity consumption has remained relatively constant (the industrial sector grew the most, from 60 % in 2000 to 64 % in 2019). The commercial, services, and public sector decreased slightly its share whereas the agricultural, fishing, and mining sector gained importance. In 2019, peak demand reached 48.8 GW in the National Electricity System (SEN).

Installed capacity

Net effective capacity is 78 GW[16] in 2019. Around two thirds refer to non-renewable thermal plants followed by 16 % of hydro generation. Thermal plants run 40 % on natural gas, 20% on petroleum products, and 7 % are coal-fired.

Graphic 27 Installed capacity 2000-2020, MW

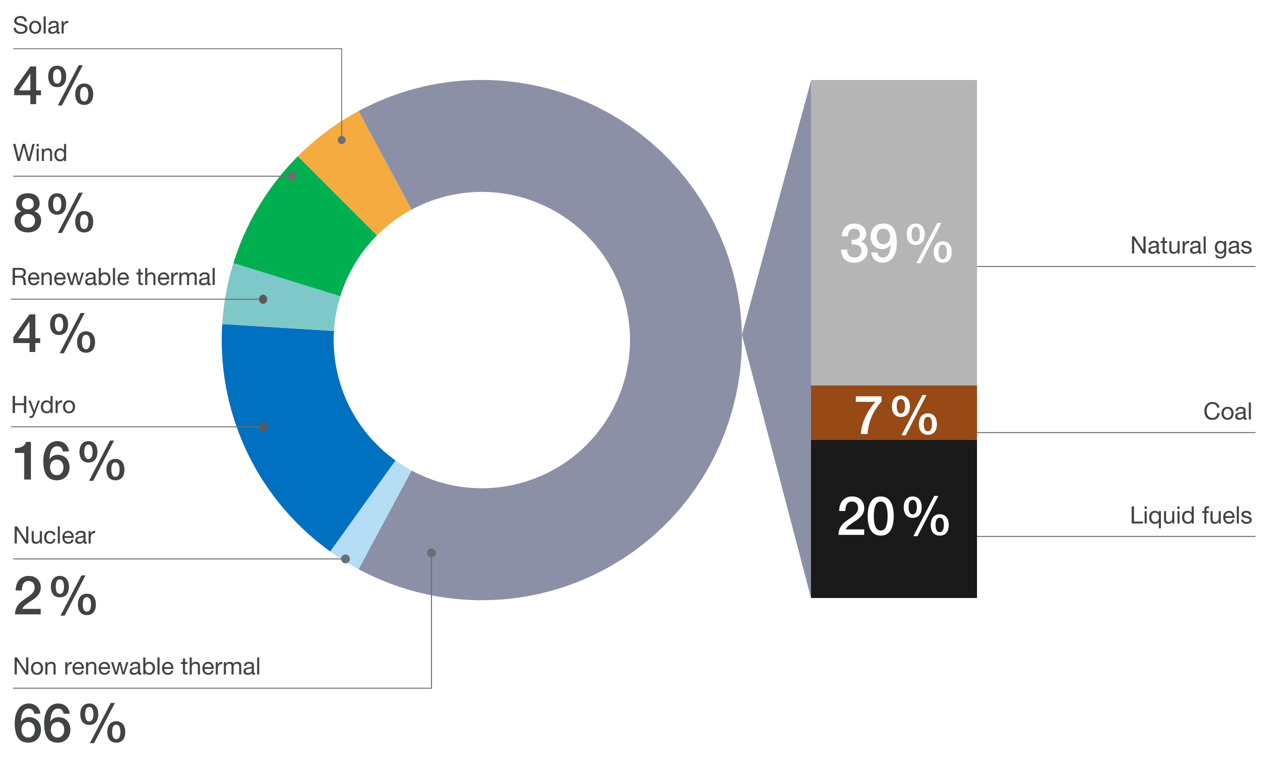


Source: Own preparation based on data from sieLAC, OLADE.

16 https://www.gob.mx/sener/articulos/prodesen-2020-2034

Diagnosis and base line

Graphic 28 Installed capacity by source, 2019, %



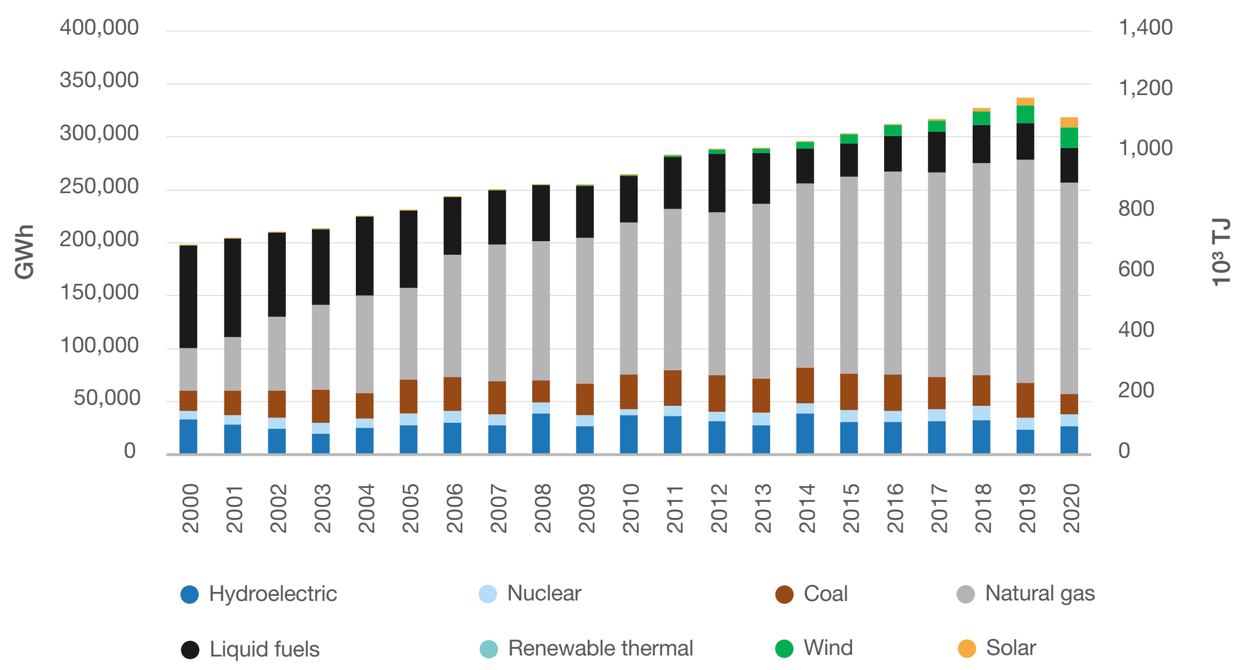
Source: Own preparation based on data from the energy information system, SENER.

In the last seven years, generation expansion in Mexico was achieved mainly through the incorporation of new thermal plants with gas-fired combined cycles (CCGT) and the migration from conventional thermal generation to CCGT; this was driven by better efficiency and the lower emission factor of the CCGT. Moreover, there was an important increase in new renewable energy, especially solar, wind, and efficient cogeneration. This increase was driven by the Electricity Industry Act (LIE) and a fall in costs. From 2012 on, we can observe a rise in the participation of wind energy and in 2018, the entry of solar technologies, which reached an installed capacity of 5,962 MW and 3,378 MW respectively. It should be pointed out that Mexico is one of the three countries in Latin America that has nuclear plants, like Argentina and Brazil. The only nuclear plant is Laguna Verde, with an installed capacity of 1.64 GW; the first unit has been operating since 1990 and the second, since 1995.

Power generation

We can observe a sustained increase in natural gas as a source of power generation in the period 2000-2019, from 20% to 63% of total production. On the other hand, the consumption of liquid fuels dropped in such period. Finally, hydraulic energy varied within the range of 19,852 GWh to 39,224 GWh, with an annual average of 30,231 GWh.

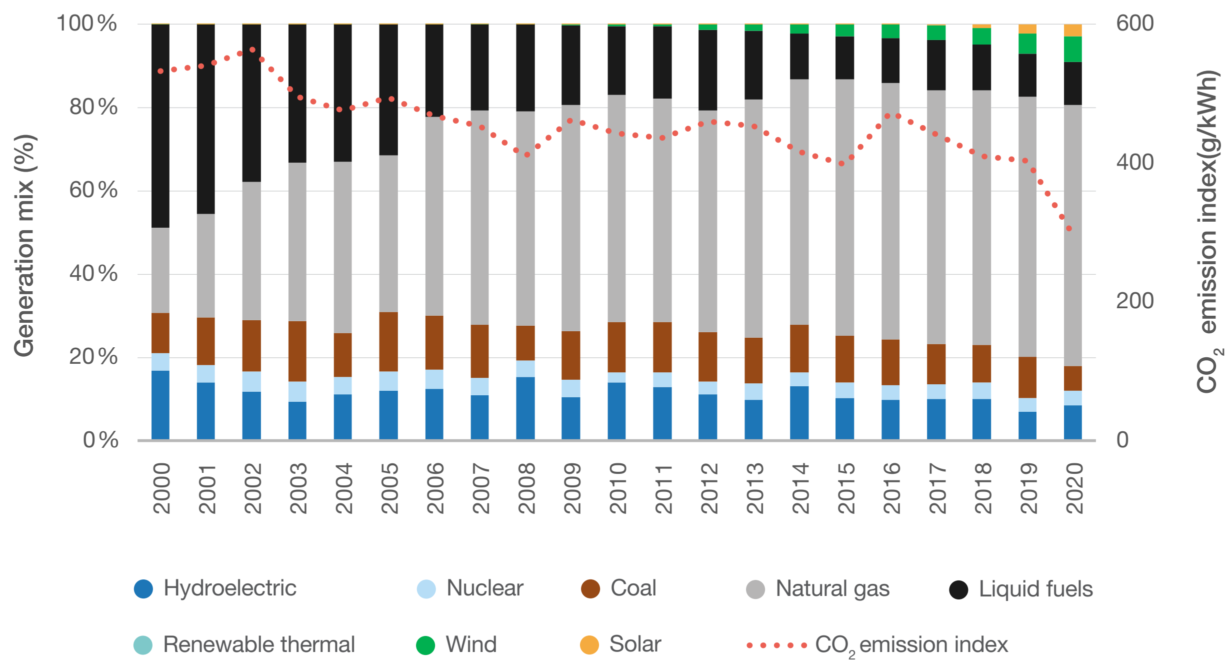
Graphic 29 Power generation by source, 2000-2020, GWh and 10^3 TJ



Source: Own preparation based on data from Our World in Data (OWID).

Diagnosis and base line

Graphic 30 Power generation by source, 2000-2020, % and CO_2 emissions index of the power g/kWh



Source: Own preparation based on data from OWID and sieLAC-OLADE.

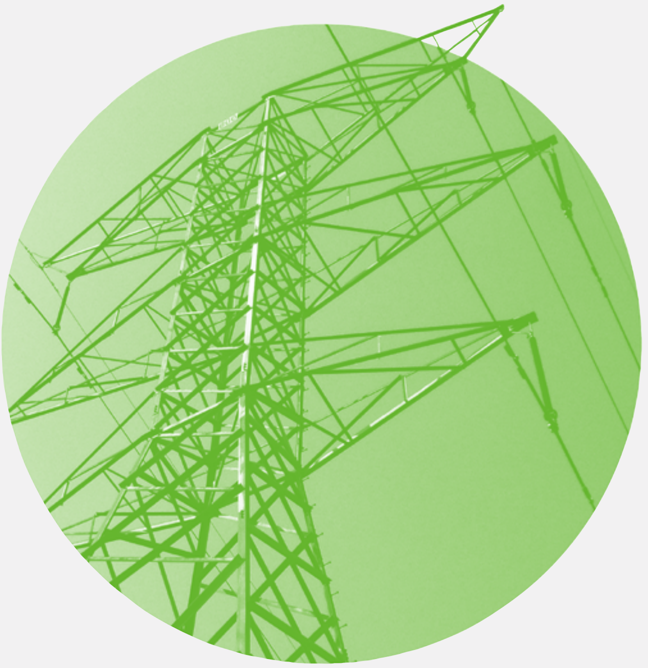
The fall in liquid fuel and coal consumption led to a fall in the CO_2 emissions index of the sector.

7. Existing power grids and gas pipelines

The National Electricity System (SEN) in Mexico includes three systems:

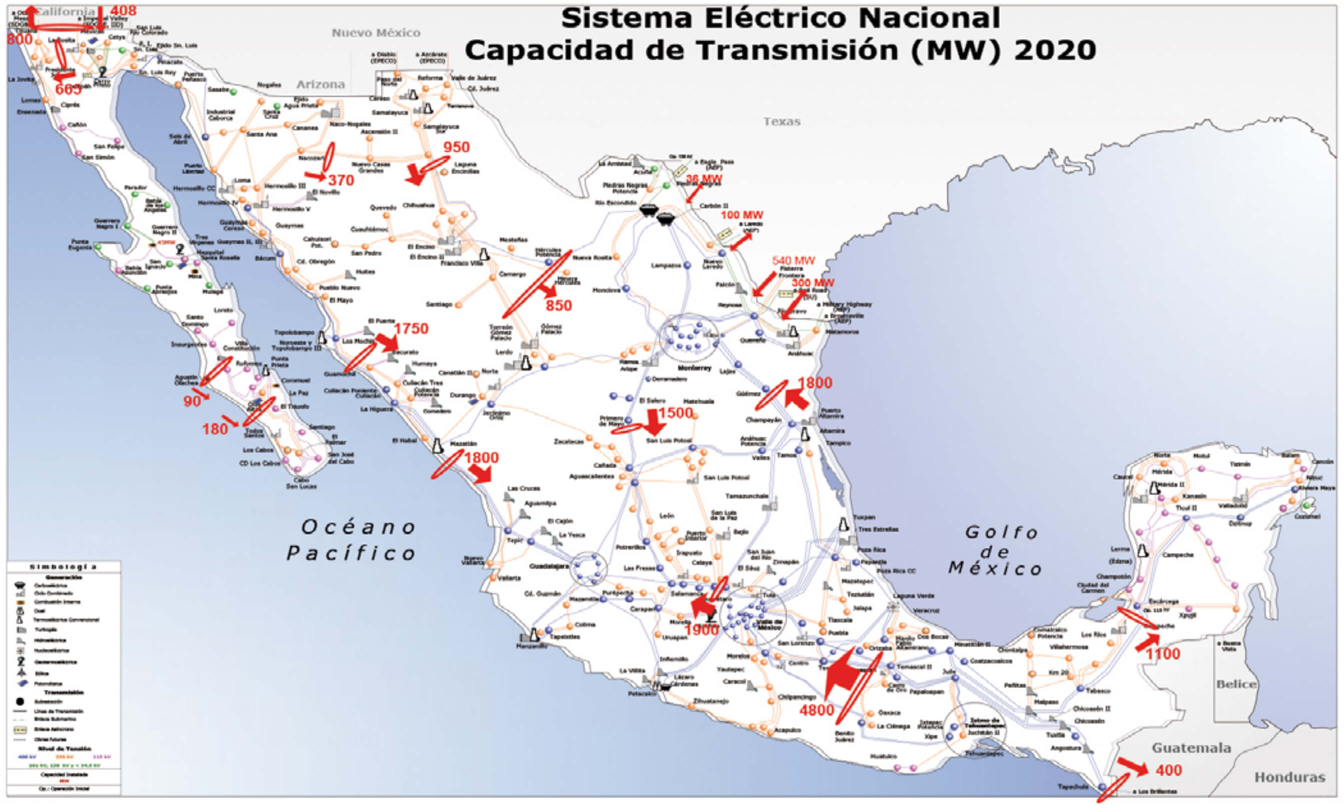
- the National Interconnected System (SIN), which comprises seven of the ten regions;
- the Baja California System (BC) in the north of the California peninsula, and
- the Baja California Sur (BCS) and Mulegé (MLG) in the south of the California peninsula.

At present, these three systems are isolated from each other. Mexico currently has 108,018 km of transmission lines (2018, CENACE). The electrification rate is 99%.



Diagnosis and base line

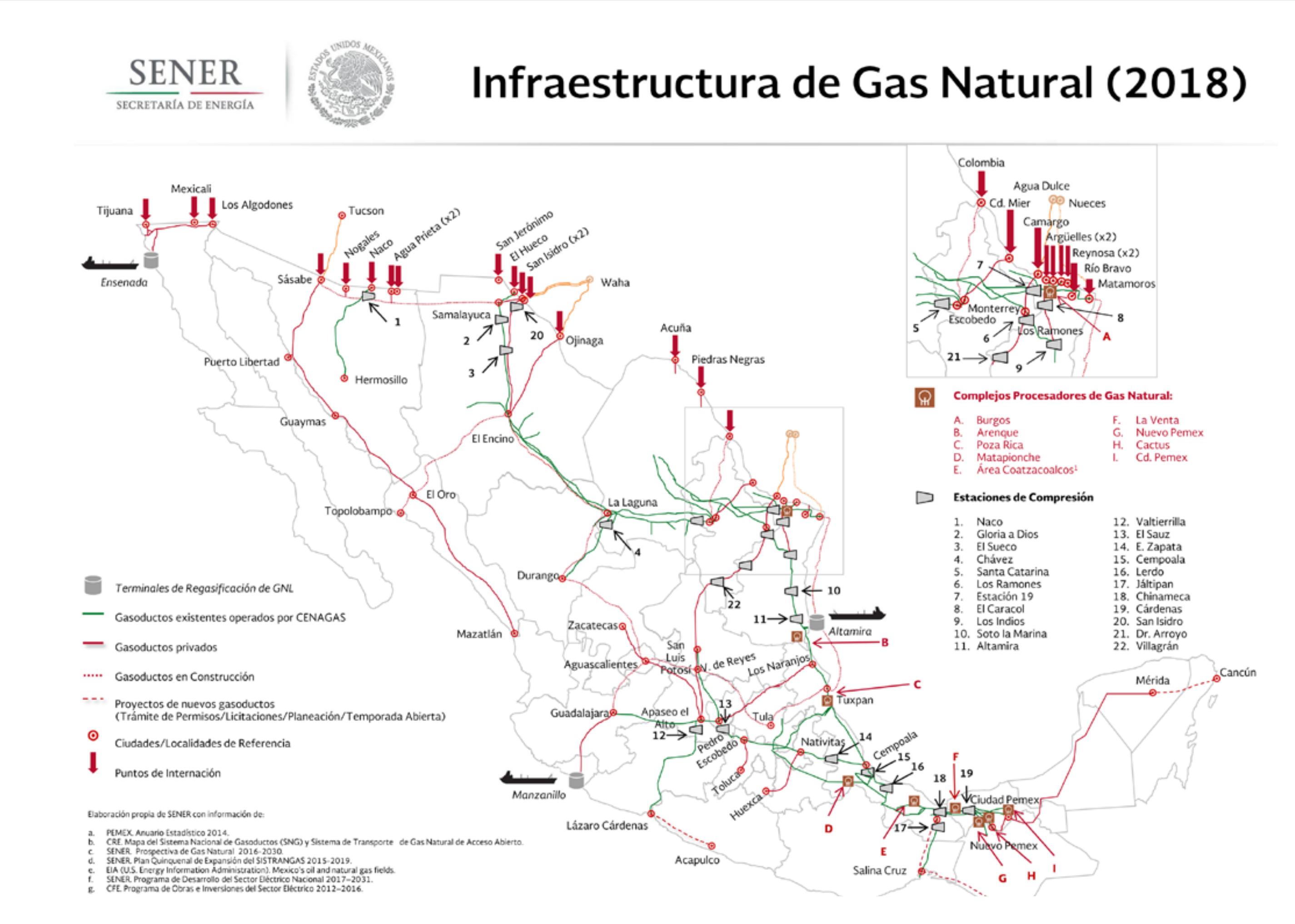
Graphic 31 National Electricity System, 2020, Mexico



Source: CENACE.

The National Integrated Natural Gas Transportation and Storage System *(Sistema de Transporte y Almacenamiento Nacional Integrado de Gas Natural,* SISTRANGAS) consists of a total 10,336 km of gas pipelines with a total transmission capacity of 6,413 MMpcd. In addition, private ducts operate 8,385 km and include the Mexicali system in the northwest of Mexico; the duct from the Manzanillo LNG import terminal to Guadalajara, and the extension of the duct from Ciudad Pemex to Cancún in the Yucatan peninsula. The total length of the gas pipeline network is over 18,721 km.

Graphic 32 ▶ Gas pipeline network, 2018, Mexico



Source: CENACE.

Approximately two-thirds of the installed capacity corresponds to non-renewable thermal power plants, with a significant presence of gas-fired combined cycles (CCGT). In recent years, there has also been a significant increase in renewable energy, especially solar, wind, and efficient cogeneration, driven by the incentives of the Electricity Industry Act.

8. Conclusions

Mexico shows a current reality with certain relevant characteristics as a base line to face the energy transition towards carbon neutrality.

- The performance of the Mexican economy has shown sustained but low economic growth (~2% annually).
- The incidence of poverty is still high; around 40% of the population lives below the poverty line and around 10% below the extreme poverty line. The reduction in poverty, which is inherent in a transition process to face the climate change (the United Nations' definition of sustainability refers to three main areas: social, economic, and environmental) implies the generation of new demands for goods and services, among them energy.
- There are public policies to foster the use of renewable energy, and others are still being discussed and approved.
- There are no explicit subsidies for electricity and gas, although the CFE receives contributions from the State to operate.
- There is a federal tax on carbon of USD5 per ton of CO_2.
- From the point of view of energy resources, 25% of Mexico's hydroelectric potential is being used, if one considers all the potential estimated by the Federal Electricity Commission (CFE) and the Energy Regulator (CRE). However, due to their cost and eventual environmental impact, the number of projects under development is Mexico is very limited.
- Mexico has a nuclear plant in operation and the CFE has plans for future developments.
- Mexico has great solar – and to a less extent – wind and hydro potential.
- Decline in oil and gas reserves..
    - For some time, this situation has generated debate in Mexico. Since the so-called energy reform of 2013, gas-fired power generation has been promoted through the expansion of the gas pipeline network, which has strongly affected its generation capacity. In the oil and gas industry, the tenders for exploration and production areas incentivized investment marginally; an important gas pipeline network was built to feed future generation plants of the state-owned company.
    - In the legal framework, private participation was allowed and even the role of the state-owned PEMEX was redefined; however, the market conditions in those years failed to produce the expected success.
    - More recently, […] the new energy model has already attracted new investment in the Mexican oil basins. Since its enactment, 107 contracts have been granted, signed between 2016 and 2018, to allow the investment of 73 different companies. This opening of the oil sector has allowed for relevant investment in seismic exploration as well as undertakings to develop new wells (CNH, 2023).
    - As regards the energy transition, the country is facing the near exhaustion of oil and gas resources; therefore, the sunk costs of the decline of the industry are much lower and may favor the acceleration of the process.

Diagnosis and base line

- This means that Mexico may start from the remaining base of hydroelectric resources, supplemented by solar and wind renewable generation, and nuclear, and promote the development of new technologies such as hydrogen, in addition to what it is doing in terms of electric transportation, changes in the consumer profile of the industry and the tourist sector, which is a fundamental source of foreign currency for the country, among other actions.

2 Energy projection methodology

1. Base year and planning horizon

The base year considered for the projection, and previously described in the chapter “Diagnosis and base line”, is 2019. The planning horizon starts in 2019 and ends in 2060.

2. Projection modeling

General description

In order to conduct the study, a low-emissions analysis platform (LEAP) model, developed by the Stockholm Environment Institute (SEI), was used. The LEAP model is a (software) tool used to analyze energy policies and assess climate change mitigation. In this case, it was used to model the emissions from the energy sector relating to burning fuel in Mexico.

In terms of modeling methodologies, the LEAP model is particularly versatile.

- It starts from the information from the energy balances, which guarantee the integrity of the data used.
- Energy demand can be projected by using methodologies:
  - bottom-up, from specific detailed data to a total projection, or
  - top-down.

In this study, bottom-up modeling was selected and the demand was divided into sectors (residential, industrial, transportation, etc.) which, in turn, were subdivided into subsectors and uses.

- Energy supply offers a wide range of simulation methodologies that allow us to estimate an annual power generation dispatch or incorporate the results of other more specialized optimization models.

The modeled demand sectors are projected according to an activity level and an explanatory variable, summarized in Graphic 33 in a simplified manner.

Graphic 33 Sectors, activity levels, and explanatory variables.

Sector	Nivel de actividad	Variable explicativa
Residential	Population	Consumption per capita
Road transportation	Target variable, vehicle fleet	Average consumption per vehicle
Non-road transportation	Total GDP	Energy intensity
Industrial	Sectoral GDP	Energy intensity by subsector and use
Commercial, Services, and Public Sector	Sectoral GDP	Energy intensity
Agricultural, fishing, mining, and construction	Sectoral GDP	Energy intensity

Source: Own preparation.

The sectoral GDP is one of the main drivers of energy demand growth, particularly for production sectors, while the evolution of the population plays an important role in the energy demand growth of the residential sector. The road transportation sector depends on the evolution of the number of vehicles which, in turn, is related to the GDP per capita in the case of passenger transportation and the GDP in the case of freight transportation. Non-road transportation is projected on the basis of the global GDP.

The modeling adopted for this study is described below in more detail by demand sector and for the power sector. Given that the decarbonization strategy seeks to replace fossil fuels (coal, oil, and petroleum products, natural gas, etc.), the value chain associated with these fuels was not analyzed in detail, assuming that there will be enough supply.

Demand by sector

Residential sector

In order to analyze and project energy consumption in the residential sector, the **projection of the population and of unitary consumption** are estimated by use and by source per capita.

Residential consumption has two kinds of energy uses: heat uses (mostly cooking, sanitary hot water (SHW), space heating), which use different fuels with substitution potential, and electrical uses (lighting, refrigeration, etc.). The following analyses apply to each group.

- **Heat uses**
  - **Cooking.** The historical consumption trends used for future projections are analyzed in terms of useful energy[17] per 1,000 inhabitants. Fuel substitution assumptions by scenario (replacement of firewood with electric appliances or others running on natural gas) are presented.

17 According According to OLADE, IADB, 2017, final energy is “the amount of energy source consumed in each economic and social sector in the country”. On the other hand, useful energy is “the amount of energy actually used to perform the productive task of the consuming equipment or device, for example, the necessary heat that food must absorb to be cooked”.

- **SHW and space heating.** Given that these sectors are incipient and this type of consumption takes place with the increase in GDP per capita, a percentage of the current consumption observed in Spain and Portugal (countries with similar climate conditions to the region) is extrapolated as target consumption[18]. A broader implementation of energy efficiency measures and assumptions on the types of fuel to be used are also presented.

- **Other electrical uses.** Electrical uses (lighting, refrigeration, air conditioning, water pumping, electronics, etc.) are projected based on a historical regression against the GDPpc, which reflects the increase in electrical uses as the standard of living increases. In addition, energy efficiency enhancements are considered.

Commercial, services, and public sector

In order to estimate the energy consumption of the commercial sector, we started from the consumption in 2019 and projected it **based on the GDP growth and energy intensity obtained for the base year**, by source, without discriminating by end use. Different assumptions are presented in terms of energy efficiency and fuel substitution.

18 It is assumed that the increase in purchasing power (GDP per capita) entails an increase in the demand due to the higher levels of comfort enjoyed by the individuals. This implies an increase in current consumption to international levels compatible with a decent standard of living.

Industrial sector

Industry was projected with information on energy consumption in 2019, broken down with an International Standard Industrial Classification (ISIC) digit, additional to that of the sector's GDP, that is, **by activity subsector**. In Mexico, seven subsectors were modeled according to the energy balance. The categories other industries (a subsector that covers several areas of industry); iron and steel; and cement and glass are those with more relevance in connection with energy consumption. In the case of Mexico, final consumption by use (direct heat, indirect heat, motive force, etc.) could not be disaggregated for lack of information.

In turn, for each industrial subsector, consumption is broken down by energy end use (direct heat, indirect heat, motive force, etc.) and by source.

Expected GDP growth, together with energy intensity by subsector and use obtained for 2019 are used for the energy consumption **projection**, mainly based on the final and useful energy balances available. The assumption was that the subsectors will maintain their share of the total industrial GDP during the planning horizon[19]. Energy efficiency is modeled through a reduction in energy intensity while fuel substitutions are performed in terms of useful energy, with annual rates of participation.

Transportation sector

The transportation sector is projected pursuant to the following structure to reflect the main drivers that vary in each segment:

- road passenger transportation (cars, motorcycles, buses, etc.);
- road freight transportation (trucks, truck tractors);
- other (air, maritime/river, railway).

19 This This assumption implies that no structural changes are modeled within the industrial sector and the same GDP growth rate is applied to all the subsectors.

Road passenger transportation

To estimate the energy consumption level or the activity level of road passenger transportation, the following were estimated:

- **evolution of the vehicle fleet** (number of motorcycles, cars, light trucks, buses, etc.;
- **average consumption by vehicle** calculated as the average annual distance traveled, divided by performance in km by energy unit.

Projection of the passenger vehicle fleet

- Private transportation (motorcycles, cars, light trucks)

In the first place, the countries with high development levels were identified and the average number of cars and motorcycles per 1,000 inhabitants in these countries was estimated. Such average was used as a long-term **saturation point** (2060), and projections were made using a logit function[20] to estimate the number of future private transportation vehicles.

In addition, to calculate the number of vehicles by type (motorcycles/cars), Law's conclusions (Law, 2015) on the relation between **the number of motorcycles per 1,000 inhabitants and GDP per capita** shaped like an **inverted "U"**[21], were used. This implies that, at first, the number of motorcycles per 1,000 inhabitants has a positive relation to GDP per capita until it peaks; from there on, as the development level of the countries increases, the number of motorcycles starts to fall and the number of cars increases.

- Public transportation (bus)

20 The The logit function or logistic curve or S-shaped curve is a mathematical function used in population growth models, product introductions, etc. Such function is a refinement of the exponential model for magnitude growth. In product introduction, growth is initially exponential; after some time, the growth rate decreases; finally, at maturity, growth stops.

21 Law, Hamid & Goh (2015), *The motorcycle to passenger car ownership ratio and economic growth: A cross-country analysis.*

Like in the case of private transportation, the average number of passenger vehicles per 1,000 inhabitants in developed countries was considered as an expected saturation point for developing countries in the long term. A logistic function was also used.

Road freight transportation

To estimate the energy consumption level or the activity level of the freight transportation sector, the following were estimated:

- **evolution of the vehicle fleet** (number of trucks + truck tractors), and
- **average consumption per vehicle** calculated as the annual average distance traveled divided by performance in km per energy unit.

Projection of the freight vehicles fleet

In order to estimate the future evolution of the freight vehicle fleet, the freight transportation fleets were projected with the linear regression method using the total GDP (measured at PPP of 2017) as an independent variable.

Freight transportation is segmented into two types of trucks: trucks and truck tractors; the latter are heavy-duty trucks with trailers. The shares of each type of truck were projected as constant.

Air, maritime/river, and railway sector

Energy consumption for the sector was projected based on the global GDP growth and the energy intensity obtained for 2019, for each type of transportation, by source and without discriminating by end use.

Agricultural, fishing, mining and construction sector

Energy consumption for this sector was **projected based on the GDP growth and energy intensity** obtained for 2019, by source and without discriminating by end use. The transition measures considered were enhancements in terms of energy efficiency and fuel substitution.

Power sector

The starting point was the current composition of installed capacity and generation. To cover the growth of the sector in the short and medium terms, the development of the power sector considers the projects under construction or the winners of auctions with a high degree of certainty and progress.

In the future, the expansion of the generation fleet will depend on:

- the relative competitiveness of the expansion options (renewable projects, particularly solar and wind, are believed to become more and more competitive due to the projected reduction in construction and development costs);
- the maximum project development potential by technology, as published at national level. This potential is considered a maximum limit;
- energy policy decisions included in the generation expansion plan;
- the local context regarding the development of projects by type.

Energy projection methodology

The expansion of the generation fleet considers aspects such as:

- the average production factor, by technology and by country, for renewable projects;
- the firm energy or capacity that each technology can provide;
- the minimum production factor from which new thermal projects are developed;
- the estimation of power demand[22], including losses and own consumption.

The analysis is carried out on an annual basis (that is, it is not a detailed hourly simulation exercise but a high-level estimation, as a first estimation in the context of a long-term energy transition analysis).

Even though most countries will need flexibility means (storage, demand management) to accompany the development of non-conventional renewable energy (NCRE), a high-level estimation was carried out in the chapter on financing[23].

22 The projections presented in this report do not include the power demand associated with the electrolysis process to produce green hydrogen for local consumption and/or export, or the related electrical capacity.

23 Current technologies are not competitive and productivity enhancements are expected, which prevents us from establishing with certainty the degree of penetration they could reach.

“Detailed modeling of energy demand, broken down by sector, branches, end-uses, and fuel types, along with the projection of energy supply by technologies, enables precise analysis of different emission profiles and substitution opportunities.”

3. Scenarios and global framework

Definition of the scenarios

Three scenarios were studied to characterize different pathways towards a just energy transition. See the detailed description in the chapter “Methodological section and assumptions”, *Just Energy Transition / Projection Assumptions report*.

The **Business as Usual (BAU)** scenario represents the expected evolution **following national public policy guidelines and the current trends**. The assumptions are based on the analysis of recent historical trends in terms of energy transition in each analyzed country, as well as on the paths traveled by more developed countries, to identify mitigation measures that can be rapidly implemented. Even though no disruptive changes are expected in this scenario and it is not possible to meet the net zero emissions target during the planning horizon, investment is required to continue with the energy transition policies that are being carried out in Mexico.

On the other hand, the Net **Zero 2050 (NZ 2050) and Net Zero 2060 (NZ 2060)** scenarios are based on the terms established in Article 4 of the Paris Agreement[24]. Both scenarios focus on reducing GHG emissions from the

24 Paris Agreement, paragraph 4.1: “achieve a balance between anthropogenic emissions by sources and removals by sinks of GHG in the second half of the century”.

energy sector[25] to a permissible minimum[26], so that the country can manage the absorption of CO_2 in the general balance of the national GHG inventory[27].

These scenarios require major investment and addressing different topics to **transform the current energy sector deeply**. Such topics include, for example, strengthening the technological bases, training human resources, energy planning, regulatory commissioning, infrastructure expansion, and instruments to develop the market for the new energy resources, as well as **changes** – in some cases disruptive – in the energy matrix, among others.

Projections of the socio-economic variables

GDP per capita and GDP

In line with the grounds for a **just energy transition (JET)**, the scenarios presented are accompanied by similar socio-economic development in the region, **reaching sufficient GDP per capita levels to be considered high-income countries.** In the case of Mexico, the GDP per capita stands at approximately USD 38,000 per capita at PPP in 2060, with a 1.6% annual growth rate during the period.

25 The analysis performed focuses on the emissions related to burning fuel, both in energy demand processes by sector and in power generation. GHG emissions from other sectors (e.g., industrial processes, waste, fugitive emissions, etc.) are not detailed in this study, but are broadly estimated and are subtracted to estimate the national reduction potential.

26 It is assumed that emission reduction must be achieved through an effective combination of regulatory measures, market efficiency promotion, technology transfer, and investment.

27 It is assumed that CO_2 absorptions will result from measures implemented in the agricultural, forestry, and other land uses (AFOLU) sectors or via the adoption of CO_2 capture, use, and storage technologies (CCUS).

Energy projection methodology

Table 10 Socio-economic indicators and CAGR 2019-2060 (%)

		2019	2030	2040	2050	2060	CAGR period
GDP per capita	USD of 2017, PPP per capita	20,064	22,351	26,638	31,746	37,835	1.6%
Total GDP	MUSD of 2017, PPP	2,509,774	3,006,961	3,757,355	4,564,218	5,403,887	1.9%
Population	1,000 inhabitants	125,085	134,534	141,055	143,772	142,829	0.3%

Source: Own preparation.

The GDP by sector is projected assuming that the share of each sector is maintained pursuant to 2021 values. This results in a GDP growth rate by sector equal to the total GDP growth rate.

Population

As to the projection of the population, information from CEPALSTAT[28] was used. A deceleration in population growth is expected in Mexico in the future, with long-term negative growth.

28 https://statistics.cepal.org/portal/cepalstat/dashboard.html?theme=1&lang=es

4. Main assumptions of the energy sector

The general framework of the study covers the definition of assumptions for **five target countries**. Even though each country has its own characteristics, the study **standardizes, whenever possible, the assumptions used** and assumes that the countries will undergo similar processes for the just energy transition. The particularities inherent in each country were considered, such as the coal industry in Colombia, biofuels in Brazil, natural gas at very competitive prices in Mexico, gas in Peru, and fossil natural resource shortage in the Dominican Republic, among others.

In order to meet the decarbonization targets set in each scenario, the assumptions considered were more ambitious in the case of the net zero (NZ) scenarios. The main assumptions are based on the measures described below.

- **Energy efficiency enhancements.** This is applied in all sectors, with equipment replacements, more thermal efficiency in households, optimization of the use of energy in industrial processes, and technological replacements towards more efficient appliances and facilities, more efficiency in transportation vehicles, etc.

- **Behavior changes.** This refers, in particular, to the reduction in average distances traveled by vehicle (km/vehicle) as a result of digitalization in society (remote work, etc.), the development of public transportation, logistics enhancements, and the shift from freight transportation by truck to the railway system.

- **Fuel substitution.** In most of the sectors, there is a trend towards further electrification of energy uses, except for industrial uses or subsectors where there are low electrification possibilities. In these cases, the replacement of fuels with more CO_2 emissions by natural gas or the use of CO_2 capture and storage technologies are the projected options. Hydrogen and low-emission derivatives may also contribute to the decarbonization of the industrial sector (fertilizers, refining) and of heavy road, maritime, and air transportation (synthetic fuels).

- **Power generation matrix with non-fossil technologies.** A very significant development of renewable energy and, in some cases, nuclear energy, is incentivized, as well as the phase-out of coal-fired plants and plants running on liquid fuel. It is important to remember that power generation composition is a key element in scenarios where a strong electrification of the consumption matrix is proposed to guarantee that this substitution will have the expected effect in terms of GHG reduction. This integration of renewable energy must be accompanied by the development of grid infrastructure, smart grids, and batteries to facilitate the integration of variable power generation.

The assumptions detailed by sector are presented in the chapter “Results and assumptions by sector”. It is important to point out that the sectors with the most emission reduction potential in absolute values are the transportation and industrial sectors, which nowadays are responsible for around two thirds of the emissions from the energy sector.

1. Global results

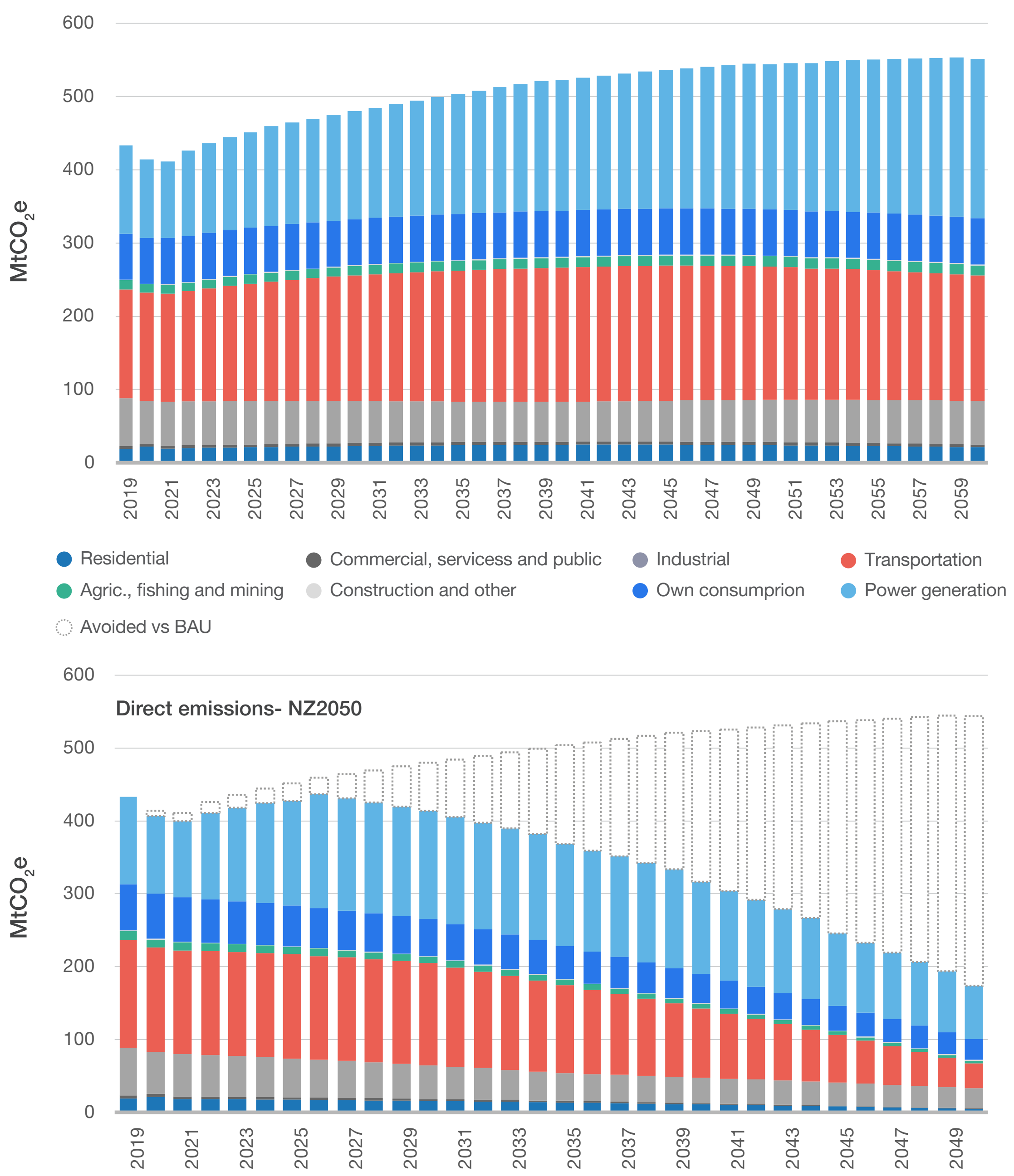
The global results presented below reflect the sum of the assumptions adopted by each sector.

Emissions by sector

In the **BAU scenario**, the emissions related to burning fuels grow at an average annual rate of 0.6 %, from 423 $MtCO_2e$ in 2019 to 551 $MtCO_2e$ in 2050. Even though this **increase** is sustained, it is **lower than the expected GDP growth**, which shows a certain environmental improvement in the economy. The transportation and power generation sectors account for 70 % of emissions in the long term. This scenario is well above the country's CO_2 absorption capacity, estimated at 150 $MtCO_2$ per year[29], which evidences the great energy transition efforts required.

29 https://climateactiontracker.org/countries/mexico/. Absorptions must cover not only the energy sector but also the IPPU sector, residues, etc.

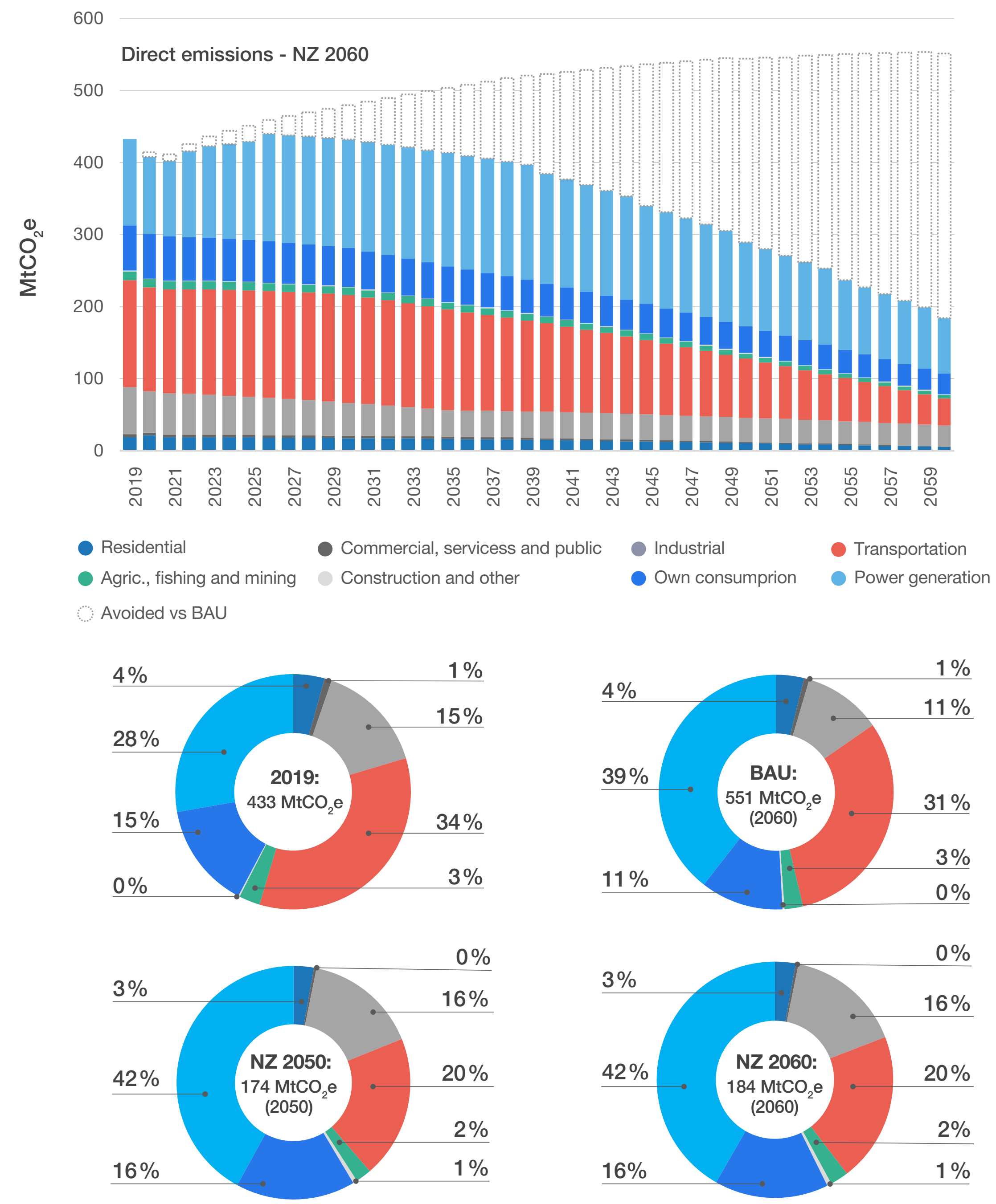
Graphic 34 A Direct emissions (final consumption and generation) by sector, $MtCO_2e$[30]



Source: Own preparation. Direct emissions do not reflect the absorption potential of carbon capture.

30 To meet the NZ scenarios target, 50 $MtCO_2$ of CCS are also incorporated. They are expected to develop mainly for thermal power generation and large industrial sites.

Graphic 34 B Direct emissions (final consumption and generation) by sector, $MtCO_2e$[30]



Source: Own preparation. Direct emissions do not reflect the absorption potential of carbon capture.

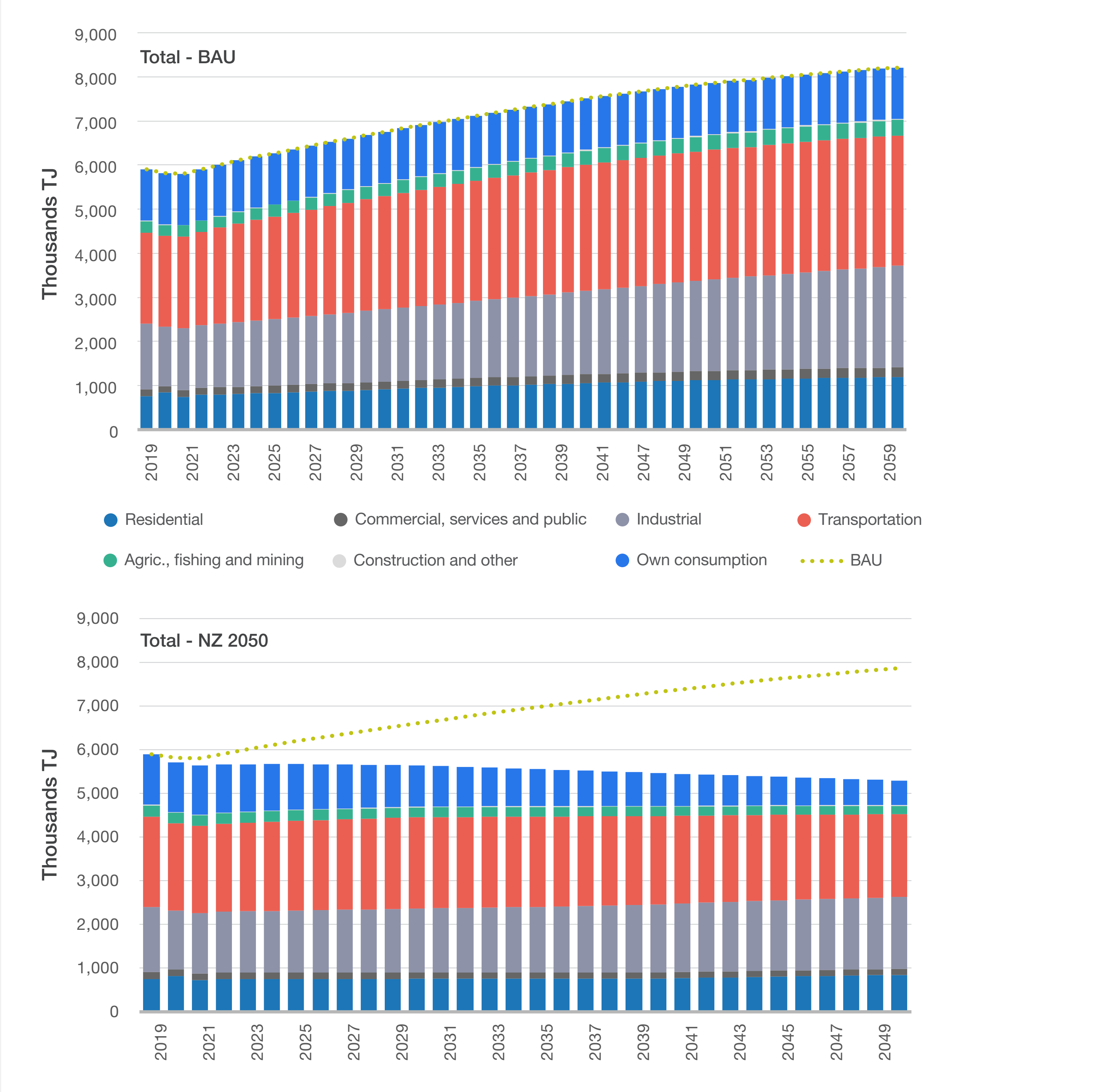
In the **NZ scenarios**, direct emissions fall to 174 $MtCO_2e$ in 2050 in the NZ 2050 scenario and to 184 $MtCO_2e$ in 2060 in the NZ 2060 scenario. If we consider the annual carbon capture of 50 $MtCO_2$ in both scenarios, the resulting emissions fall to 124 $MtCO_2e$ in 2050 in the NZ 2050 scenario and 134 $MtCO_2e$ in 2060 in the NZ 2060 scenario. This estimated carbon capture and storage (CCS) potential will allow reducing the direct emissions from the industrial sector and from power generation, thus meeting **the net zero emissions target**. The average annual emission reduction pace is -4.0% for the NZ 2050 scenario and -2.8% in the NZ 2060 scenario.

To meet the net zero emission target, **total emissions should reduce by two thirds during the planning horizon**, compared to current emissions.

Energy demand by sector

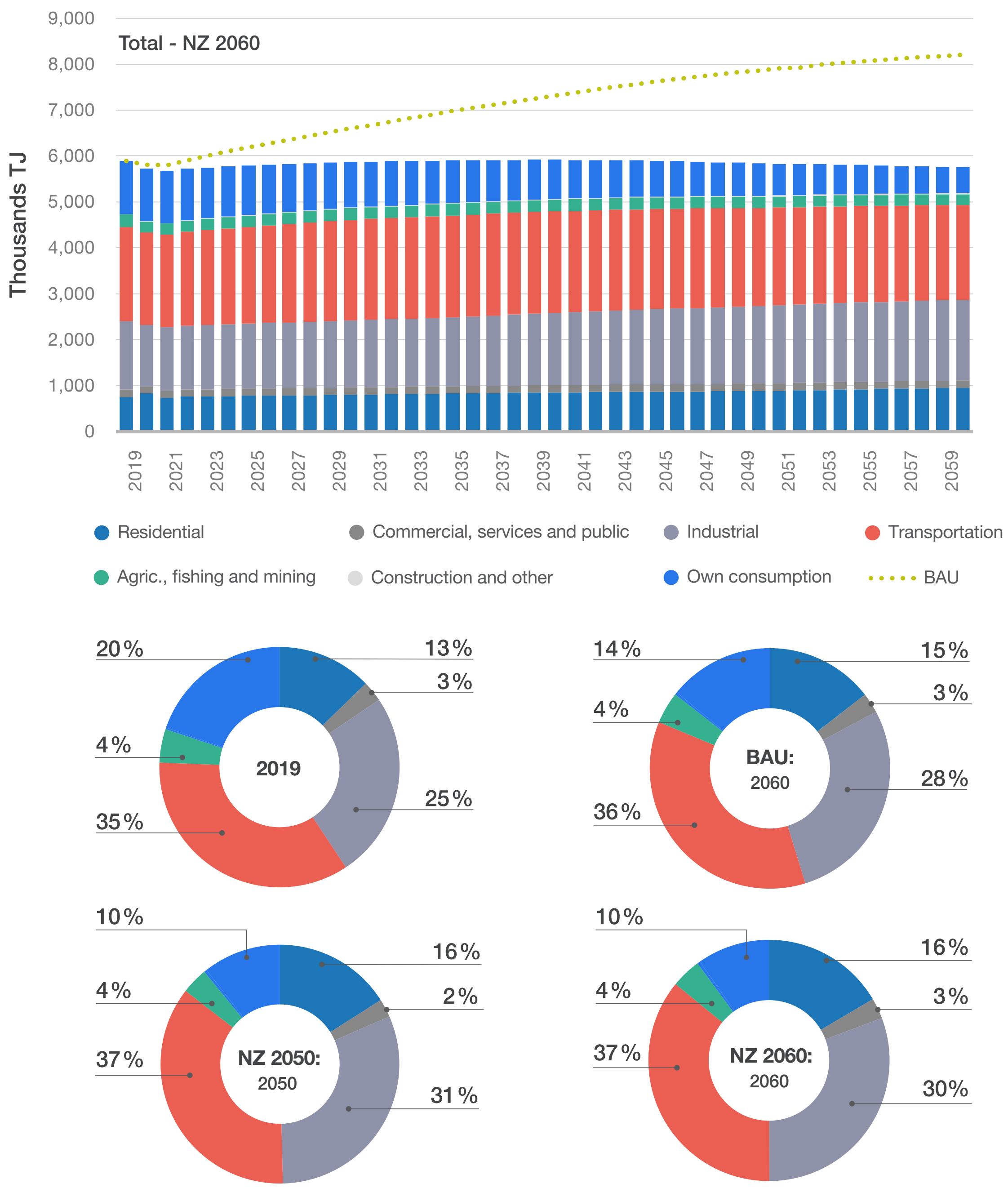
In the BAU scenario, the demand grows by 39% during the analyzed period and reaches around 8,300 thousand TJ in 2060. In the NZ scenarios, the demand remains relatively constant due to the stronger effects of efficiency and fuel substitution.

Graphic 35 A Final consumption and own consumption, by sector and scenario (thousands of TJ)



Source: Own preparation. Non-energy consumption is not included.

Graphic 35 B Final consumption and own consumption, by sector and scenario (thousands of TJ)



Source: Own preparation. Non-energy consumption is not included.

Table 11 Total demand by scenario, thousands of TJ and CAGR (%)

Demand (thousands of TJ)	2019	2030	2040	2050	2060	CAGR (%)
BAU	5,899	6,603	7,320	7,865	8,205	0.8 %
NZ 2050	5,899	5,641	5,464	5,388		-0.3 %
NZ 2060	5,899	5,874	5,936	5,900	5,851	0.0 %

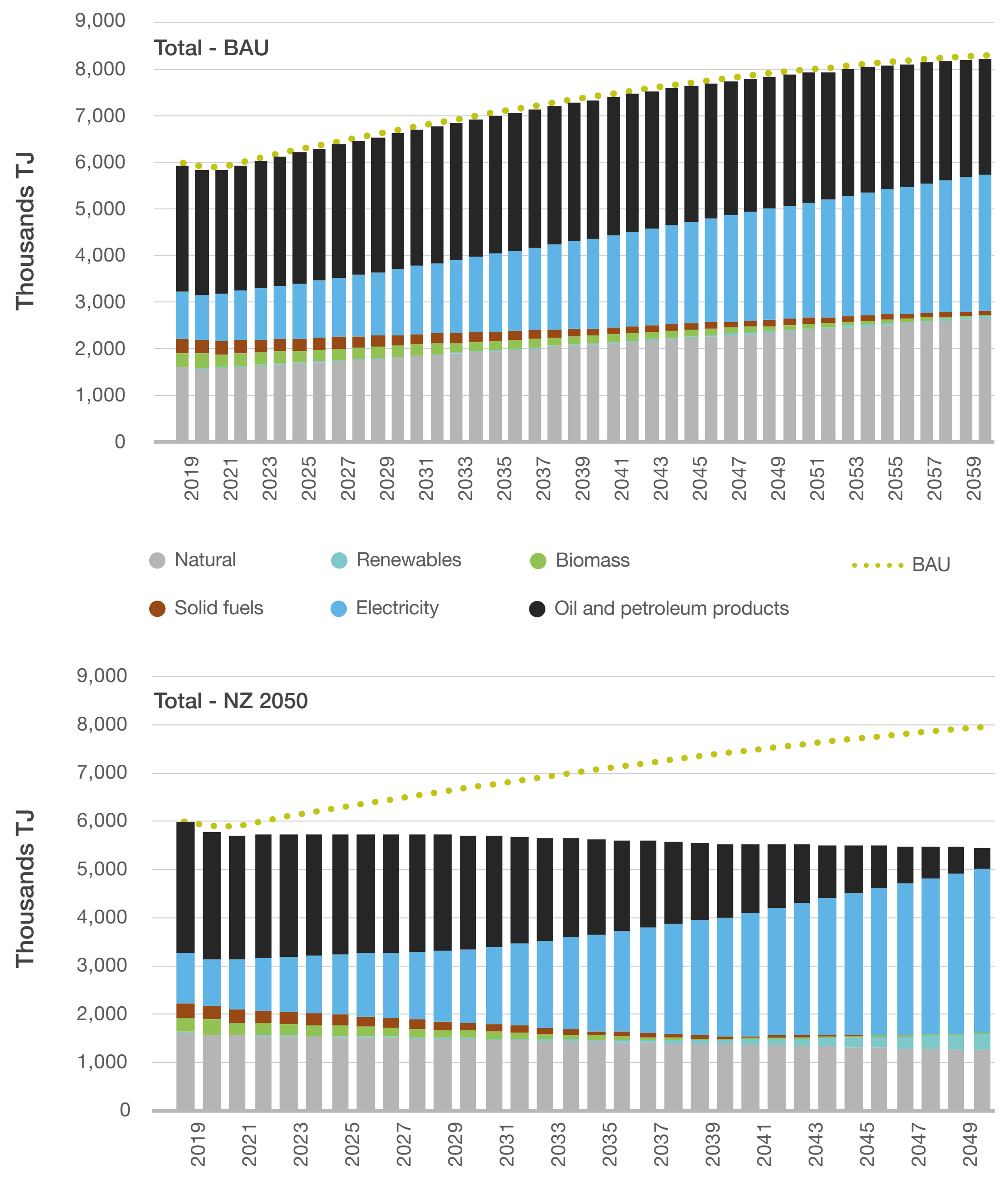
Source: Own preparation. Non-energy consumption is not included.

In all the scenarios, the relative participation of the demand by sector does not change very significantly and the transportation, industry, and residential sectors continue adding up to over 80 % of the demand. Most of the sectors have similar growth rates, which evidences that **all the sectors participate in the transition efforts.**

Energy demand by source

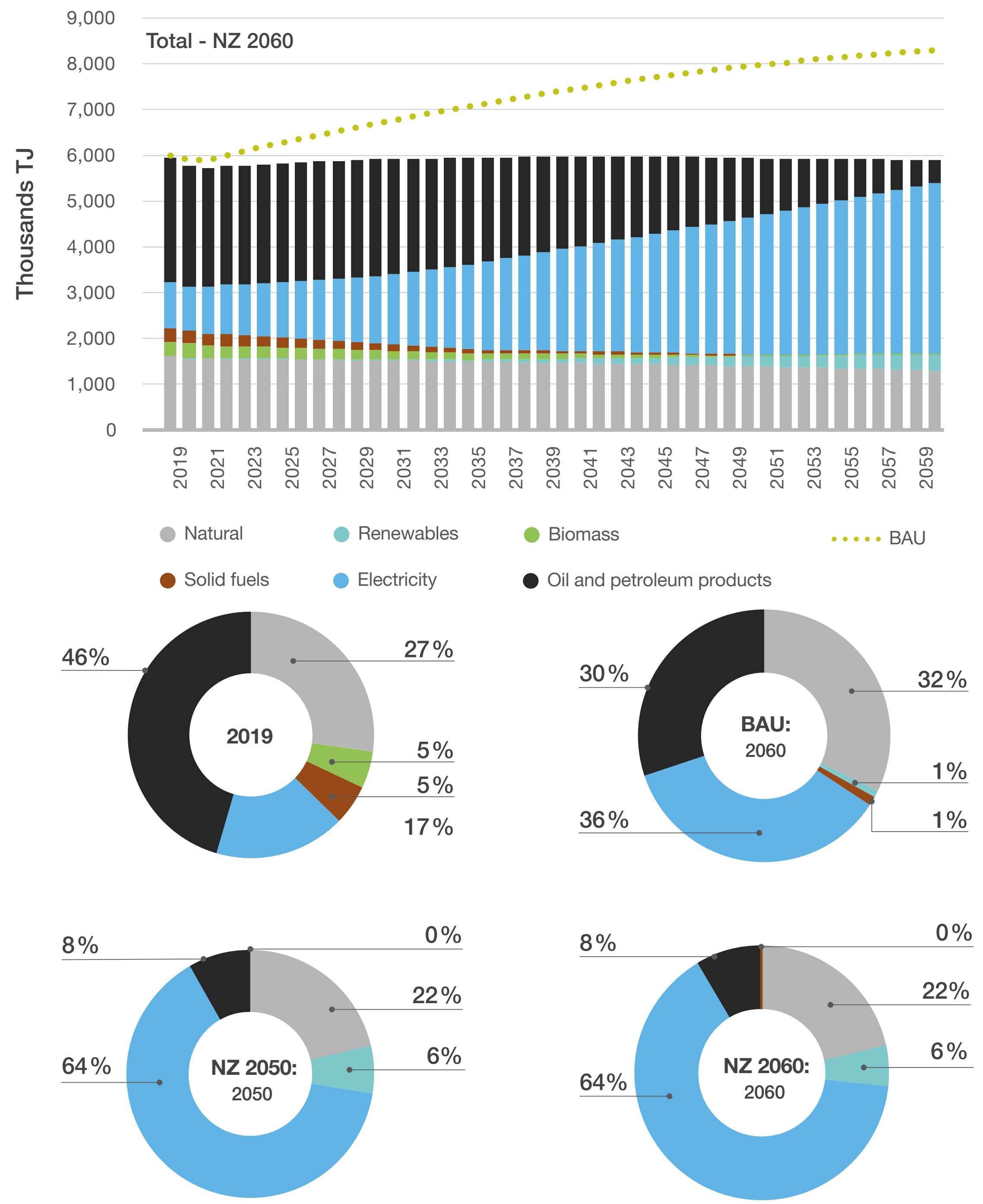
By fuel, **a strong trend towards electrification** of the demand can be observed in all the scenarios. The BAU scenario reflects stability in oil and petroleum products while the increase in demand is covered by electricity and natural gas. The NZ scenarios present stronger electrification hypotheses (approximately 65 % of total final consumption). Hydrogen derivatives and solar thermal energy are developing in the long term at the end of the planning horizon.

Graphic 36 A Final consumption and own consumption by source and scenario (thousands of TJ)



Source: Own preparation. Note: The renewables category refers to solar thermal energy or hydrogen derivatives. The oil and petroleum products category includes LPG.

Graphic 36 B Final consumption and own consumption by source and scenario (thousands of TJ)



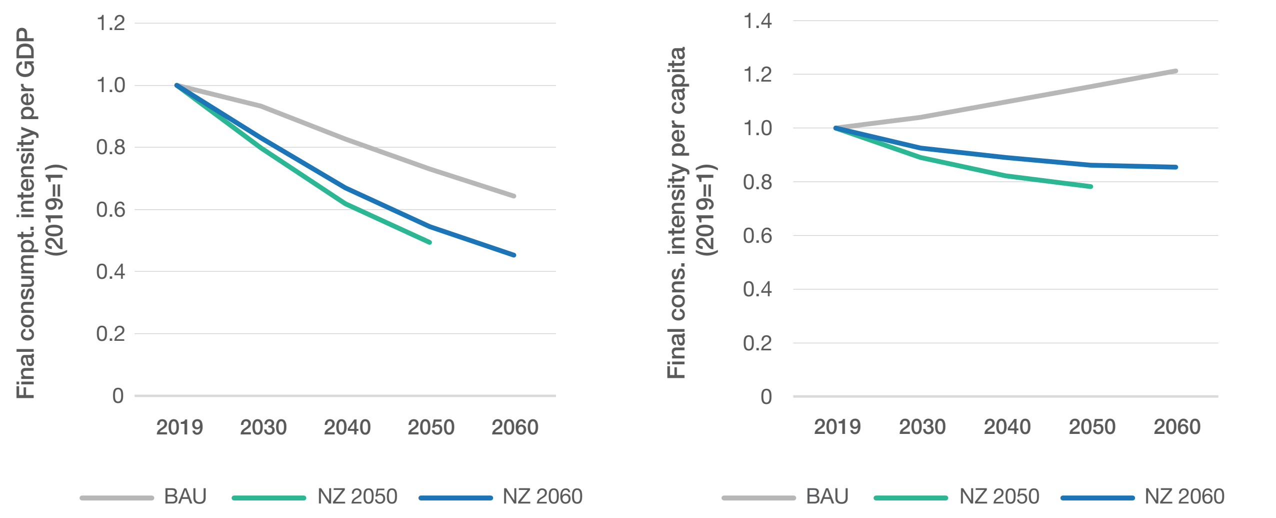
Source: Own preparation. Note: The renewables category refers to solar thermal energy or hydrogen derivatives. The oil and petroleum products category includes LPG.

Energy and environmental intensity

In the BAU scenario, energy intensity measured in economic terms (final consumption/total GDP) is reduced by about 40% in the period (annual -1.1 %), whereas in the NZ 2050 and NZ 2060 scenarios, it is reduced by over 50 % (annual -2.2 % and annual -1.9 %, respectively).

Measured in terms of population (final consumption per capita), total unitary consumption grows by around 20 % whereas in the NZ scenarios it falls by around 20 %. These evolutions evidence the necessary evolution of final consumption to meet the net zero emissions target and cover the current consumption gaps.

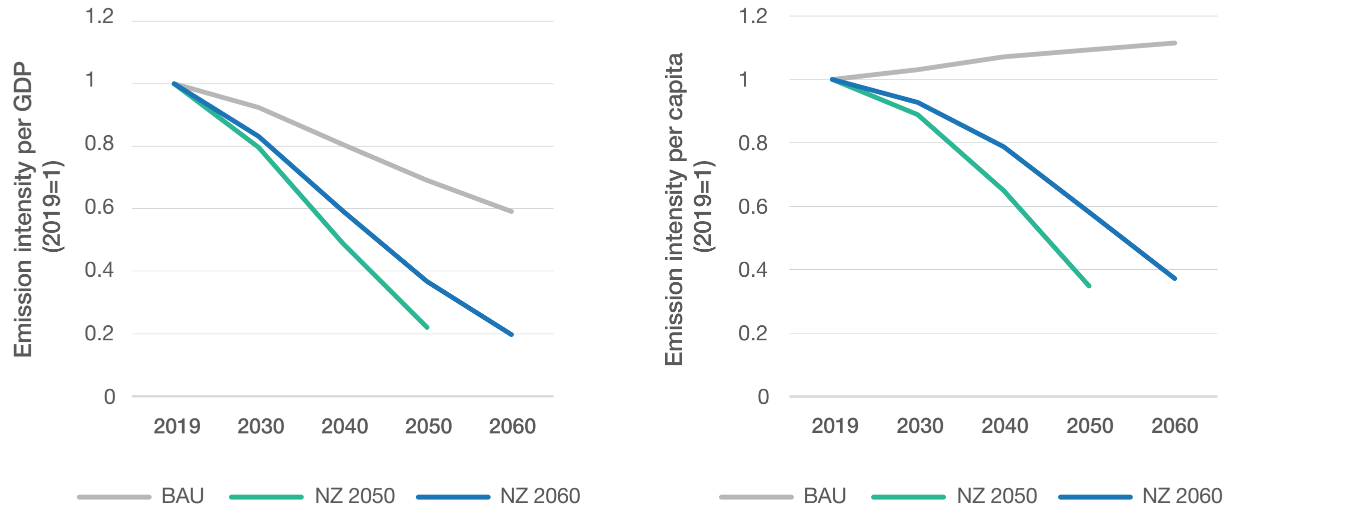
Graphic 37 Unit Energy Intensity (2019=1), thousands of TJ/Million USD PPP 2017 (left) and thousands of TJ per capita (right)



Source: Own preparation.

A significant reduction in energy intensity is required to meet the Paris Agreement targets. This reduction reflects the **decoupling between economic development and energy consumption**. The assumptions adopted to implement the proposed solutions (see *Just Energy Transition / Projection Assumptions report*) to energy transition in Mexico aim to reach a high future decarbonization level and **promote a more developed and efficient economy**.

Graphic 38 Unitary environmental intensity (2019=1), tCO_2e/thousands USD PPP 2017 (left) and tCO_2e per capita (right)



Source: Own preparation.

Unitary environmental intensity, measured in terms of economy (GHG emissions/ total GDP) and population (GHG emissions per capita), is more significantly reduced than energy intensity for all the scenarios and shows the emission reduction by energy unit consumed. To achieve net zero emissions, the emissions by GDP unit of the base year should be reduced by 80 %.

2. Results and assumptions by sector

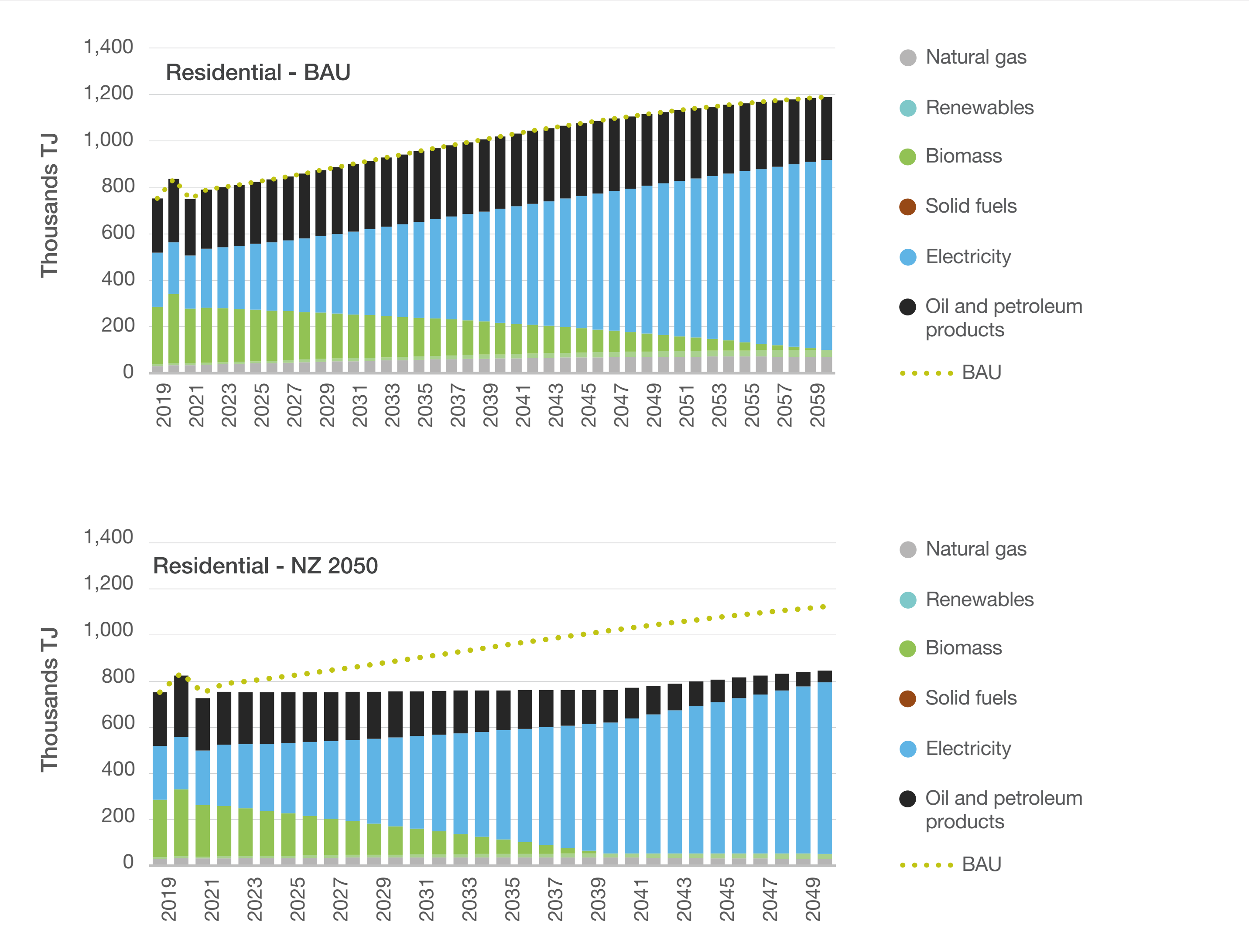
Residential sector

The residential sector accounted for 13 % of the energy demand in 2019. It is responsible for a limited number of GHG emissions (19 $MtCO_2e$), but there is potential to reduce them even further with energy transition measures. This sector is characterized by:

- high biomass consumption, with great electrification potential (and, in turn, large efficiency gains). This biomass consumption (34 % of the sector's final consumption) relates to the most vulnerable sectors of the population; that is, its replacement is possible in a context of higher standards of living and support programs for the sector. Cooking end uses account for over 50% of the sector's final consumption;
- other uses (SHW, home appliances, air conditioning, etc.) with growth potential, as the standard of living improves, in line with what was observed in developed countries.

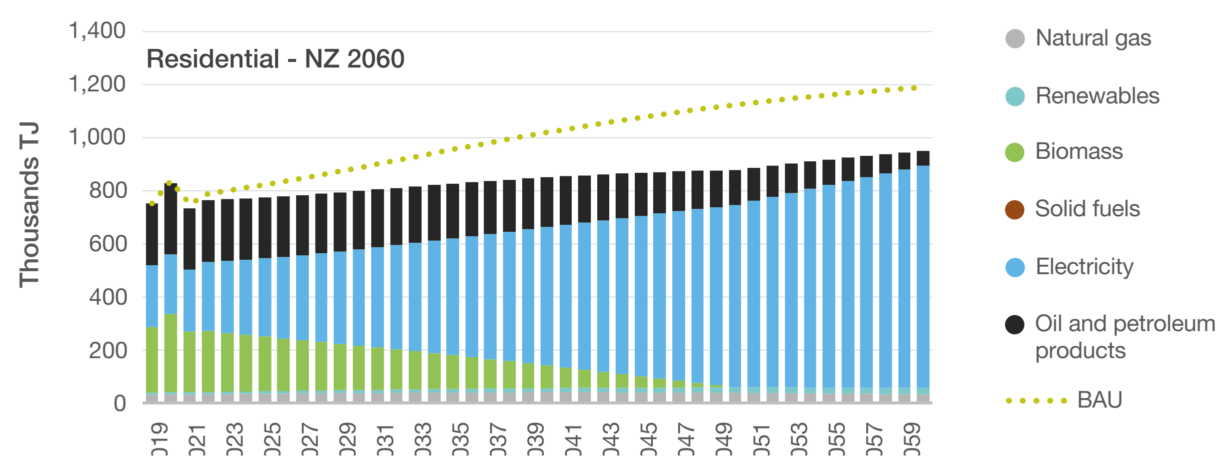
31 It is estimated that the use of electricity or natural gas instead of firewood for cooking allows for very significant final energy savings.

Graphic 39 A ▶ Residential sector: results by fuel and by scenario, 10^3 TJ



Source: Own preparation. Note: The renewables category refers to solar thermal energy. The oil and petroleum products category includes LPG. The peak demand observed in 2020 refers to real data

Graphic 39 B Residential sector: results by fuel and by scenario, 10³ TJ

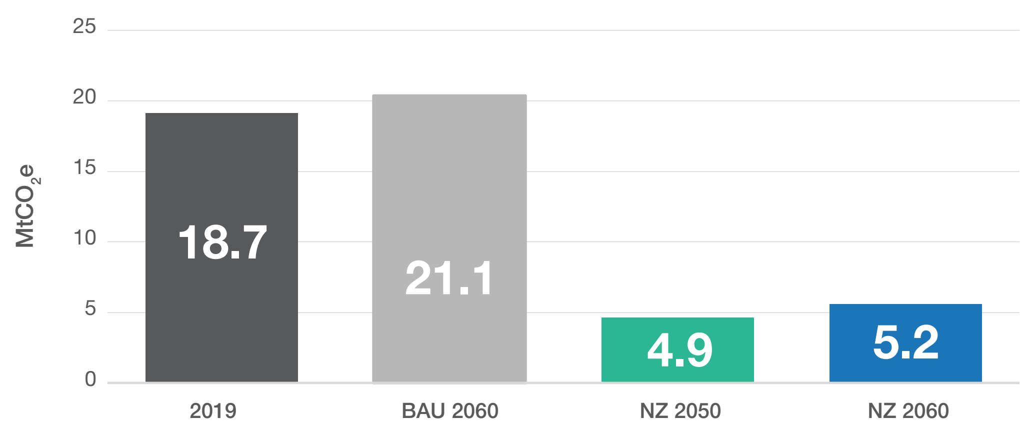


Source: Own preparation. Note: The renewables category refers to solar thermal energy. The oil and petroleum products category includes LPG. The peak demand observed in 2020 refers to real data

In the BAU scenario (graphic on the left), we can see a 58 % increase in residential energy demand in the period (annual 1.1 %), mainly driven by the new electrical uses (including air conditioning) of water heating and space heating that are expected to accompany the increase in the projected standard of living. This growth is higher than that of the population (14 % in the period). Firewood is replaced towards the end of the period, following historical trends. Oil and petroleum product consumption remains relatively constant. Electric consumption grows both for electric cooking and for other uses.

In the NZ 2050 and NZ 2060 scenarios, power consumption covers a large part of final consumption (88 % for both scenarios); there is a natural gas surplus, LPG, and solar thermal energy is introduced to heat sanitary water. In turn, biomass replacement takes place faster. More energy efficiency efforts, both for appliances and buildings, allow compensating for the new uses that accompany the increase in GDP per capita to a large extent (the energy intensity of the sector, measured as demand per capita, is quite stable in the period).

Graphic 40 Residential sector: direct emissions by scenario, $MtCO_2e$



Source: Own preparation.

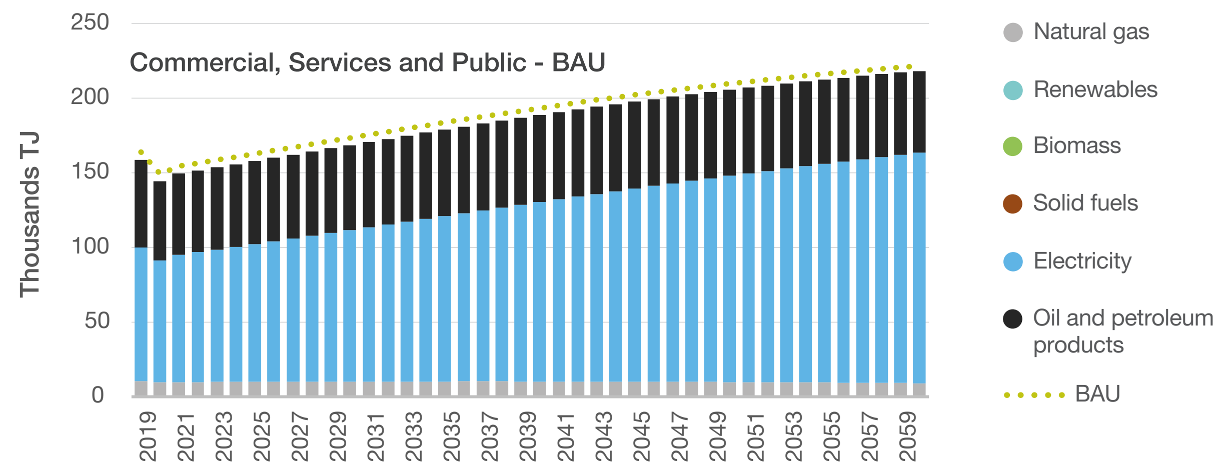
CO_2e emissions grow slightly in the BAU scenario, whereas they decrease by over 70 % in the NZ scenarios in the long term, thanks to energy efficiency and electrification measures.

In practice, the energy transition measures required to limit GHG emissions in the residential sector relate to mature technologies (electric ovens, more efficient electrical appliances, heat pumps for space heating or climate control, more thermal efficiency in the home, etc.). However, their implementation entails a massive effort from all households and covering consumption gaps for lower-income households, thus ensuring a just transition.

Commercial, services, and public sector

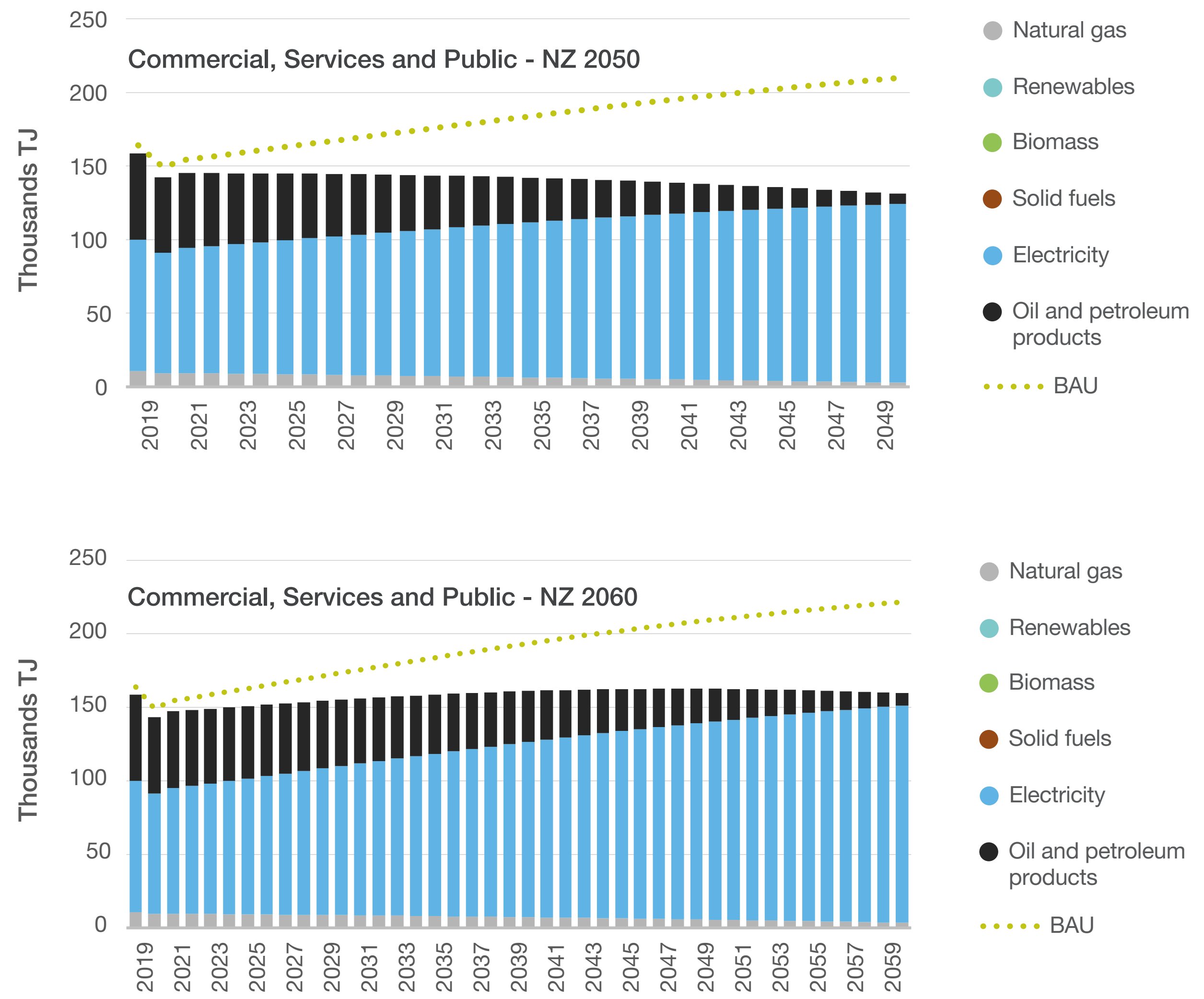
The commercial, services, and public sector (CSP) is composed of the public administration, hospitals, hotels, and stores, etc. It is often a sector with little weight in terms of energy consumption (3 % of the total, in 2019) compared to the transportation, industrial, and residential sectors. It starts from an electrification rate of 74 % in 2019 and energy uses with electrification potential (SHW, space heating, motive force, cooking, etc.), as in the case of the residential sector. There is also potential for more energy efficiency, both in equipment and the buildings themselves (thermal renovation of existing buildings, application of strict thermal regulations for new buildings).

Graphic 41 A CSP sector: results by fuel and by scenario, 10^3 TJ



Source: Own preparation. Note: The oil and petroleum products category includes LPG. The low demand observed in the period 2020-2022 refers to real trends and to the impact of the GDP decrease in the short term.

Graphic 41 B CSP sector: results by fuel and by scenario, 10^3 TJ

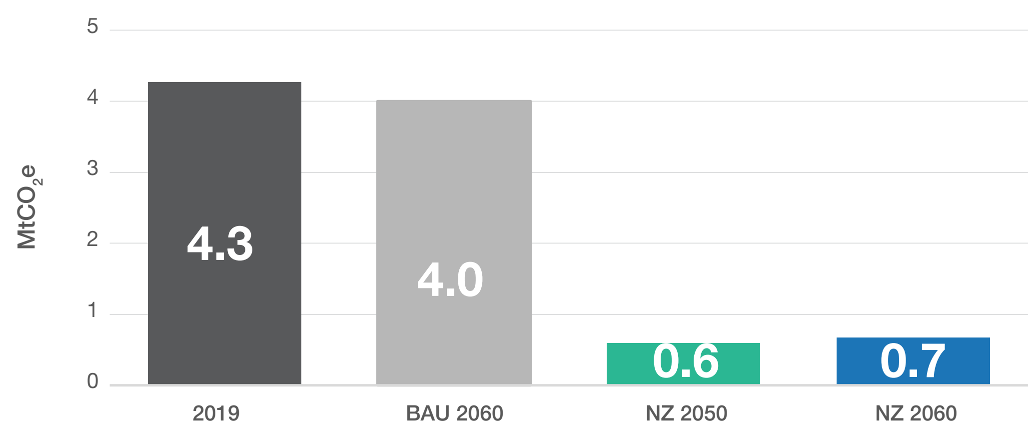


Source: Own preparation. Note: The oil and petroleum products category includes LPG. The low demand observed in the period 2020-2022 refers to real trends and to the impact of the GDP decrease in the short term.

In the BAU scenario, the fuel share remains constant. Even though the sector's GDP is almost doubled, the energy demand grows by around 35 % due to energy efficiency measures.

For the NZ scenarios, there is almost total electrification of the sector (≥95 %), with a remnant of oil and petroleum products in the last year. Constant demand is achieved in the NZ 2060 scenario and a 20 % reduction in the demand by 2050 in the NZ 2050 scenario, compared to the demand in 2019. Efficiency enhancements account for a large part of this phenomenon.

Graphic 42 ▶ CSP sector: direct emissions by scenario, $MtCO_2e$



Source: Own preparation.

CO_2e emissions fall slightly in the BAU scenario whereas they fluctuate between 10 % and 20 % in the NZ scenarios.

The energy transition measures required to limit GHG emissions in the commercial, services, and public sector include mature technologies related to refrigeration, lighting, and direct or indirect heat uses; therefore, electrification must be prioritized and the efficiency of the appliances should be enhanced. Although it has little weight at energy level, the sector itself is heterogeneous, with consumption related to cooking and refrigeration uses in restaurants, IT equipment and lighting in offices, mixed end uses in hospitals or schools, etc.

Industrial sector

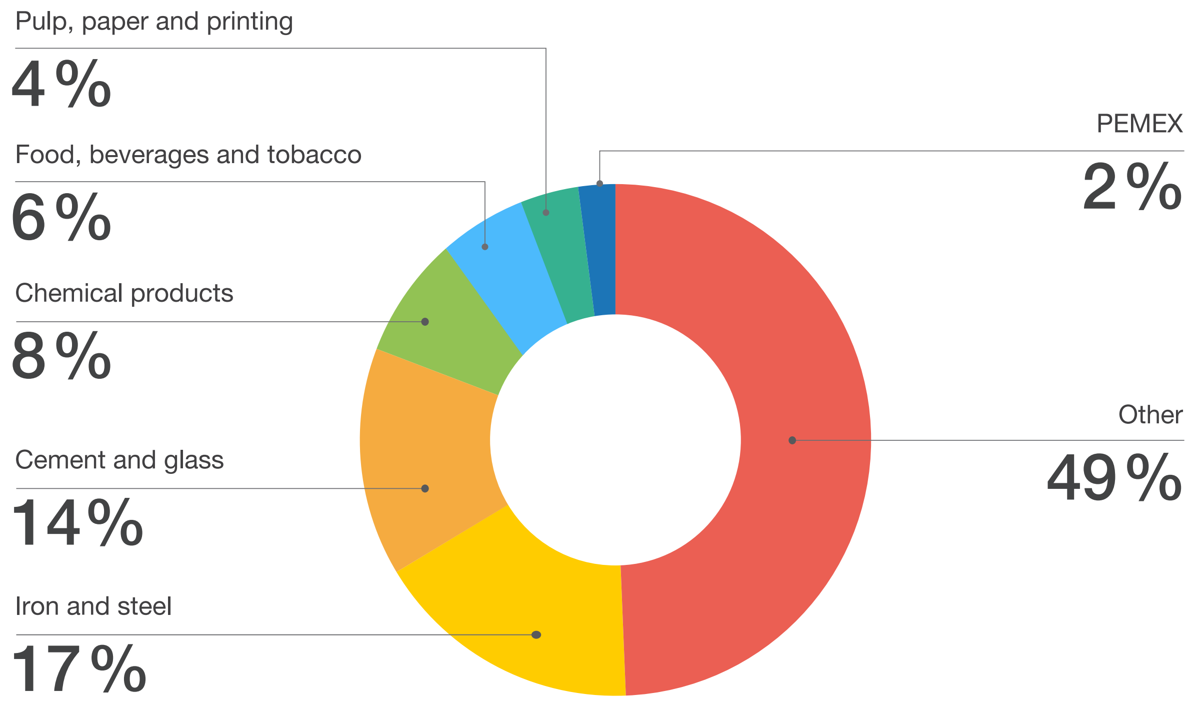
The industrial sector is composed of several industrial subsectors and is the second with the largest energy demand (25 % in 2019) after the transportation sector. Its starts from low penetration of electricity (38 %), conditioned by several sectors that are difficult to electrify, such as the steel and cement industries.

It is important to remember that fuel substitution possibilities may vary considerably from one industrial subsector to another, given the variety of existing industrial processes. To make the projections, the industrial subsectors were grouped together into a limited number of subsectors. The analysis focused more in detail on the subsectors with the greatest consumption and their associated uses.

Projections by subsector

Mexico's National Energy Balance presents the information on the industrial sector broken down into various subsectors grouped together into seven areas.

Graphic 43 ▶ Industrial sector: energy consumption by industrial subsector, 2019, %



Source: Own preparation based on data from Mexico's energy balance.

Other industries; iron and steel; and cement and glass account for 80 % of the energy consumption in the sector. There is no information on fuel consumption by industry and use in Mexico; therefore, the analysis is conducted in an aggregate manner for all the uses of each subsector.

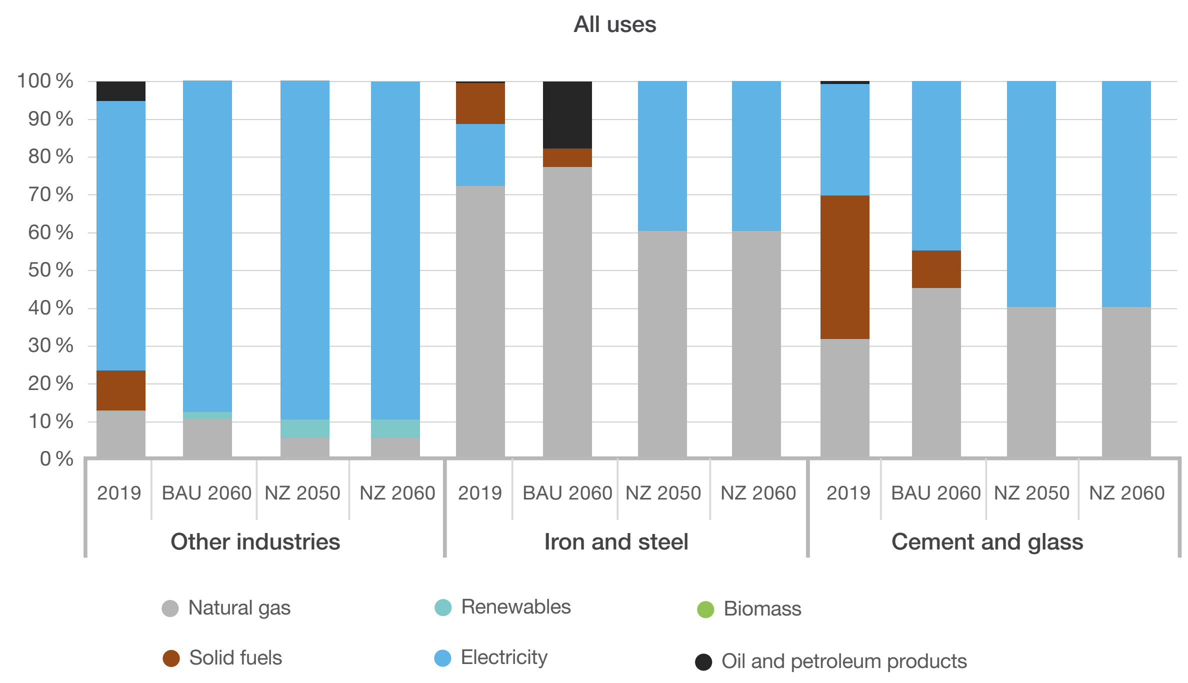
Transition measures focus on **enhancements in terms of efficiency and fuel substitution.** Energy efficiency is achieved thanks to the optimization of energy use in industrial processes and technological replacement to more recent and efficient appliances and facilities.

The substitution assumptions considered for Mexico are as follows.

- Natural gas and LPG completely replace fuel oil and diesel in the next decade and a progressive penetration of solar thermal energy is assumed in some sectors for indirect heat.
- In the case of the sectors with low substitution potential, carbon capture and storage technologies are considered in the long term in the scenarios (IEA, 2021) with limited annual absorption[32].

Graphic 44 shows the evolution of final consumption for the main subsectors.

Graphic 44 ▶ Industrial sector: evolution of the main relevant industrial subsectors by scenario (%)



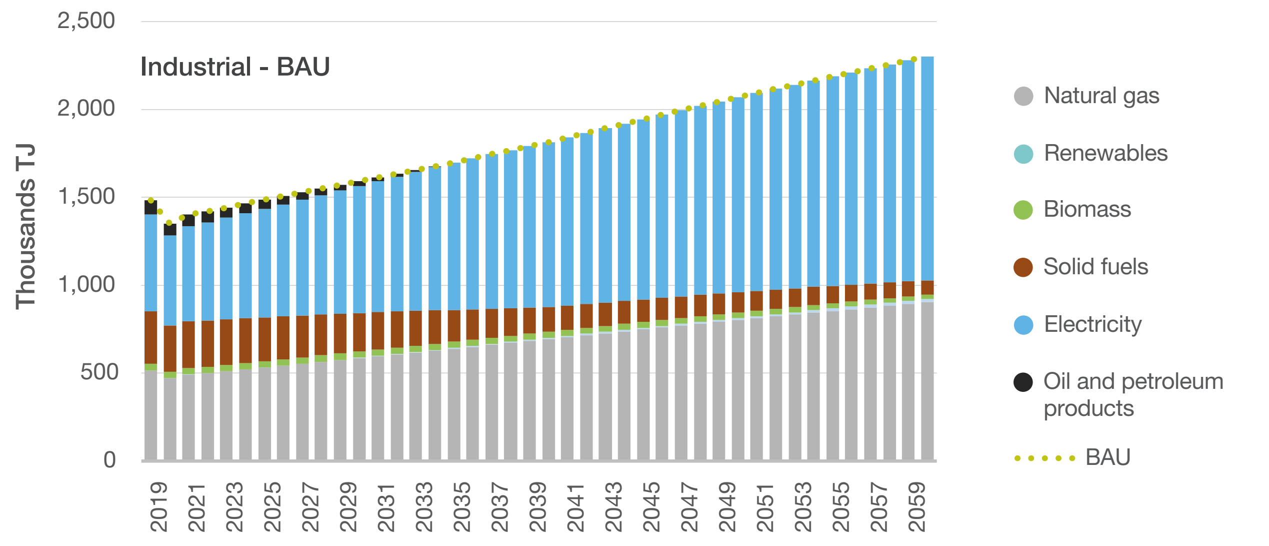
Source: Own preparation. Note: The renewables category refers to solar thermal.

32 Based on current knowledge on geological storage potential in Mexico, a limited annual absorption of 50 $MtCO_2$ was considered for all uses. It is expected that a large part of this potential will allow reducing the emissions from large-scale power generation plants. There are pilot projects in Mexico to show the viability of capturing CO_2 in CCGT generation plants.

Results

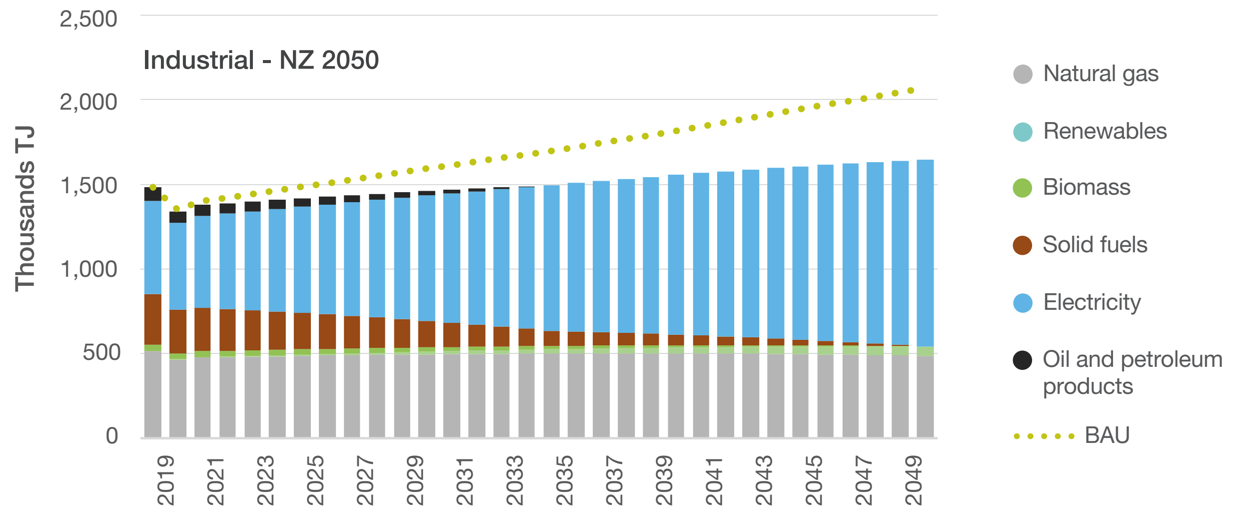
Even though an increase of 115% in the GDP of the sector has been projected, the demand in the BAU scenario grew by 55% due to fuel substitution and energy efficiency measures. The electrification of the final demand will grow from 38% to 55%.

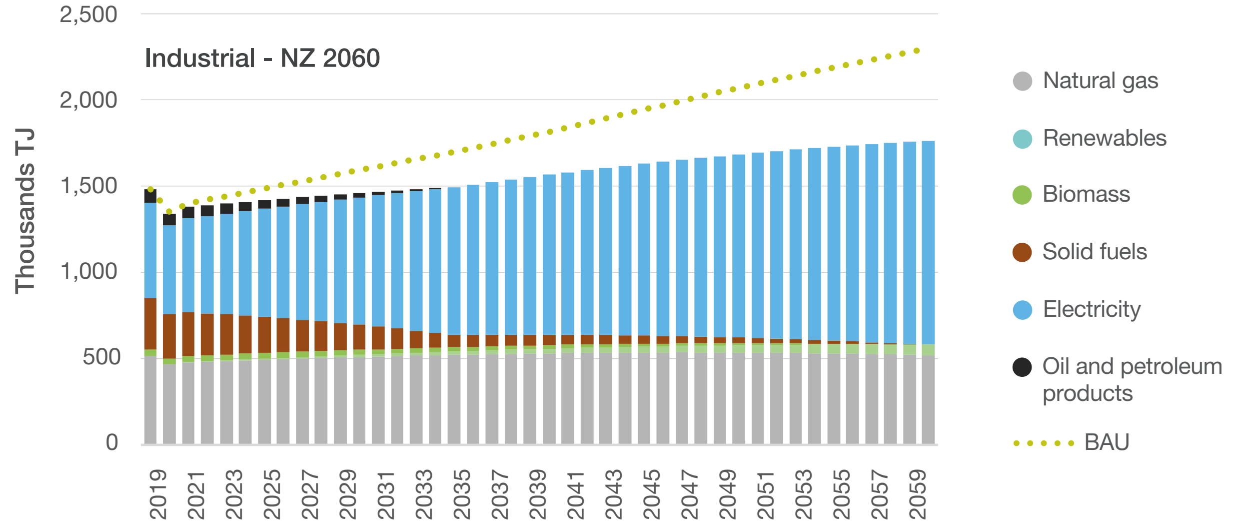
Graphic 45 A Industrial sector: final consumption by fuel and by scenario, 10^3 TJ



Source: Own preparation. Note: The renewables category refers to solar thermal. The drop in demand observed in the period 2020-2022 refers to real trends and to the impact of the fall in the GDP in the short term.

Graphic 45 B Industrial sector: final consumption by fuel and by scenario, 10^3 TJ

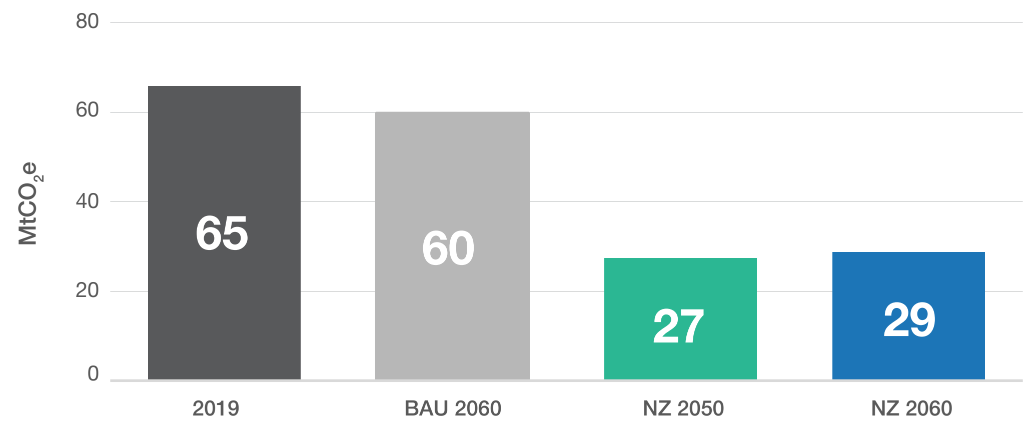




Source: Own preparation. Note: The renewables category refers to solar thermal. The drop in demand observed in the period 2020-2022 refers to real trends and to the impact of the fall in the GDP in the short term.

Coal consumption is completely substituted in the NZ scenarios. The electrification of the sector doubles in the period (from 38 % to 67 %).

Graphic 46 ▶ Industrial sector: direct emissions by scenario, $MtCO_2e$



Source: Own preparation.

CO_2e emissions fall slightly in the BAU scenario. On the other hand, emissions halve in the NZ scenarios in the long term thanks to energy efficiency, fuel substitution, and carbon capture measures. Carbon capture, which could be developed firstly for large scale industrial sites, should be added to these reductions, as well as the proximity of storage.

The energy transition measures required to limit GHG emissions in the industrial sector relate to existing technologies worldwide but that are not always mature. As years go by, it will be necessary to gradually adapt the industrial processes with the best technological option available over the years and, in turn, rethink the processes in a comprehensive manner.

"In the industrial sector, natural gas and LPG are expected to completely replace fuel oil and diesel, and a gradual penetration of solar thermal energy in some sectors is assumed. Technical difficulties are recognized for electrifying the metallurgical and cement industries."

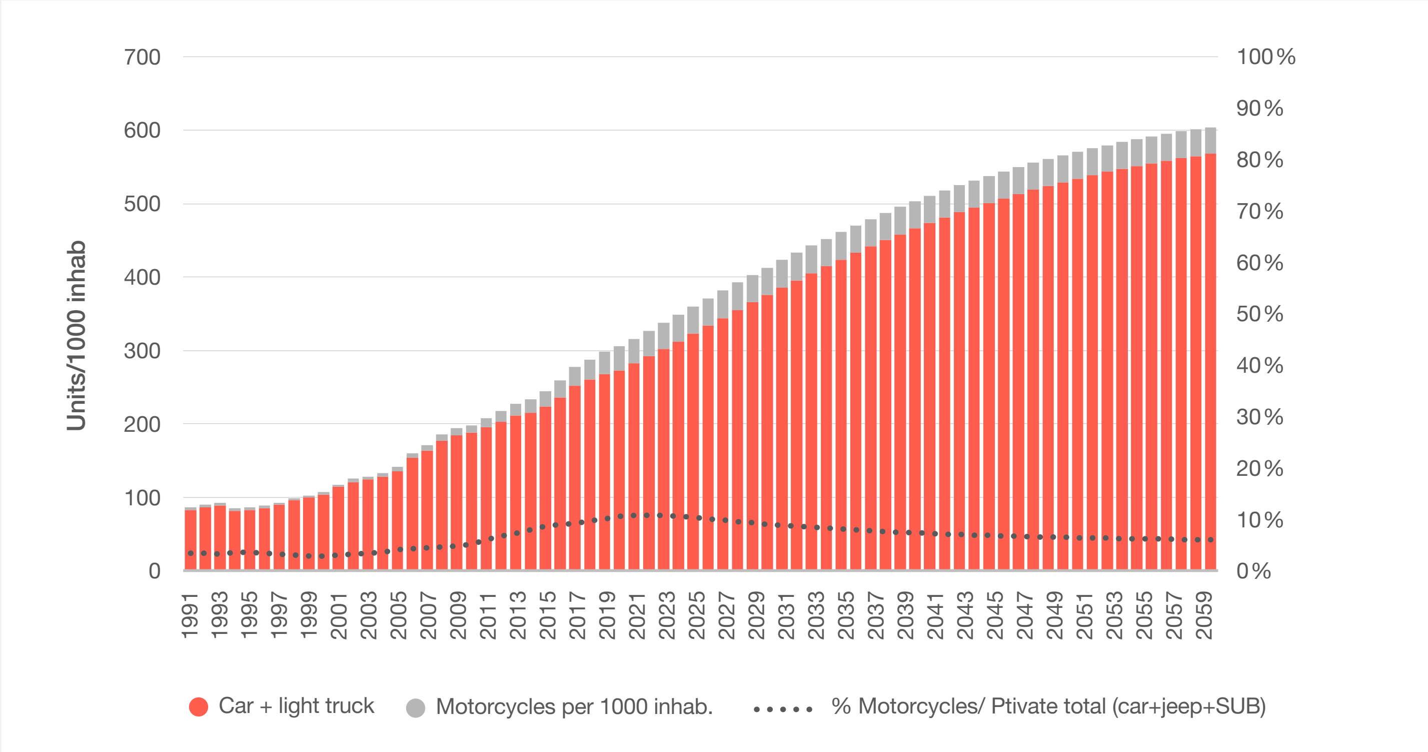
Transportation sector

In Mexico, the transportation sector is the maximum energy consumer (35% in 2019) and greenhouse gas emitter. It mainly consumes liquid fuels (diesel, gasoline, etc.). Even though electric vehicle sales have increased worldwide in recent years, these vehicles account for a small portion in Mexico. Road transportation accounted for 90% of total final consumption in 2019, led by road passenger transportation (47%).

Road passenger transportation

Energy consumption from road transportation mainly depends on the evolution of the number of vehicles. A **significant increase in motorization** is expected in all the scenarios, in line with the growth in the standard of living. Unlike other countries in the region, motorization in Mexico means mainly cars and small trucks, although an increase in the possession of motorcycles per inhabitant has been observed in recent years. 604 vehicles per 1,000 inhabitants are projected for 2060, 67% of which are motorcycles and 947% are cars.

Graphic 47 Number of private vehicles per 1,000 inhabitants and share of motorcycles (%)



Source: Own preparation.

In this motorization context, measures will be required to promote energy transition in order to limit the increase in GHG emissions. The main measure to contemplate is the **electrification** of the vehicle fleet, which reduces emissions and total consumption (a reduction of 75% to 80% in consumption by km compared to a standard vehicle). The use of hybrid vehicles also allows for a significant reduction in unitary energy consumption. In the case of cars, it is estimated that their share will be 30% electric by 2060 and 20% hybrid in the BAU scenario. Instead, in the NZ scenarios, an 80% share of electric and 20% of hybrid must be reached by the end of the period. In addition, the electrification of the motorcycle and public bus fleet is expected until 100% of the fleet is reached in both scenarios within the planning horizon (see *Just Energy Transition / Projection Assumptions report*).

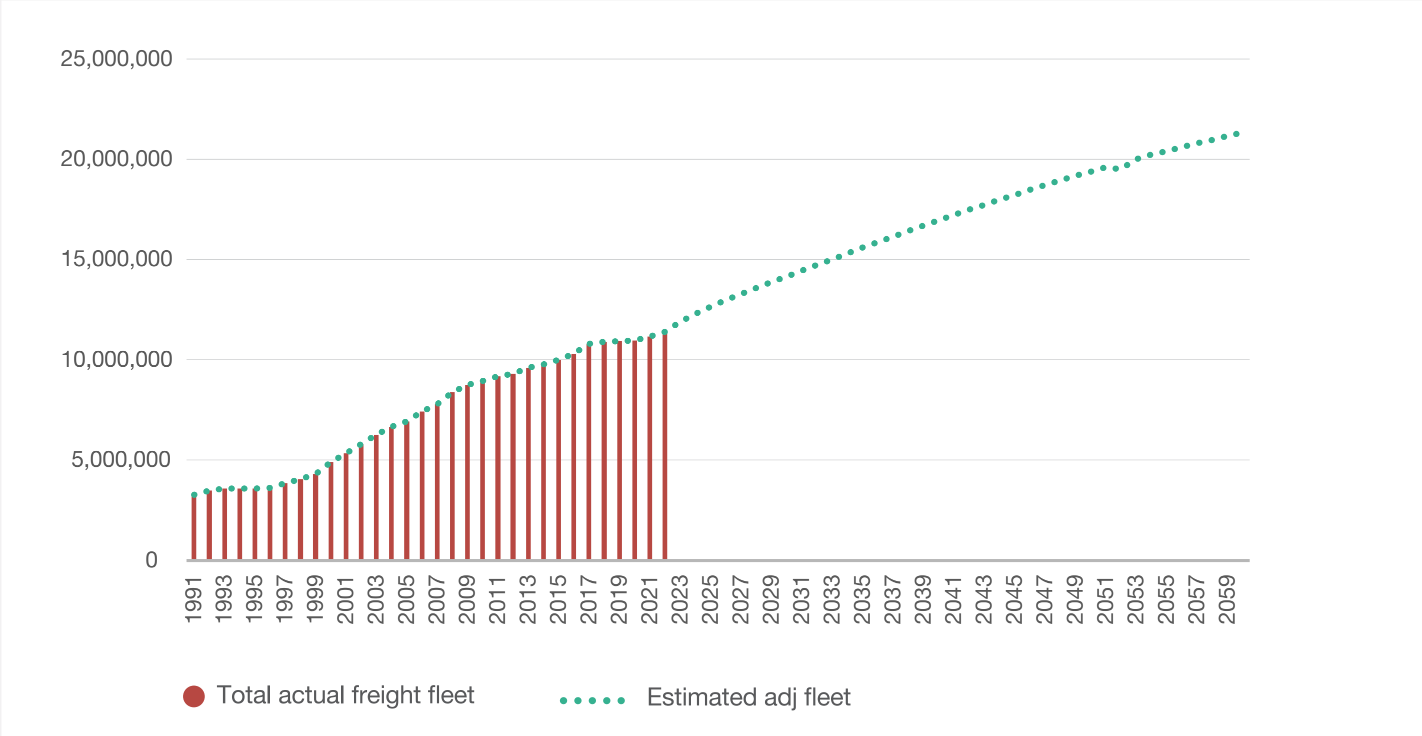
In line with historical observations, the average efficiency of the vehicle fleet is expected to improve due to technological enhancements and/or the reduction in vehicle weight.

Finally, a decrease in the average distances traveled is envisaged by vehicle (km/vehicle) as a result of the **digitalization** of society (remote work, etc.) and greater penetration of **public transportation** systems.

Road freight transportation

Road freight transportation grows with economic activity (GDP), taking into account the historical elasticity of income. In this context, sustained growth in the number of freight vehicles is expected in the period (1.7% annual average), both for trucks (80.2% of the total) and for truck tractors.

Graphic 48 ▶ Total number of freight vehicles



Source: Own preparation.

In this context of increasing vehicle fleet, energy transition measures will be required to limit the increase in GHG emissions. These actions will promote energy transition fuels pursuant to the time horizon considered: CNG, LNG, electricity (now available), and hydrogen derivatives (as from 2040). It is assumed that natural gas (CNG, LNG) will play an important role in the period 2030-2040. Moreover, the energy transition must be accompanied by vehicle **performance enhancement, logistics enhancement, and a shift to railway**.

It has been assumed that, in the BAU scenario and for 2060, 10% of the truck fleet will be electric, 40% will run on CNG and the rest will continue on diesel. As to truck tractors, 50% of the fleet is expected to use LNG and 50% diesel. In the NZ scenarios, more transition efforts are required, with 80% electric trucks and 60% truck tractors in the long term. Electrification appears as a relevant alternative for trucks and truck tractors, but a smaller electrical penetration is expected for truck tractors, as technological solutions to transport very heavy loads for long distances are still being developed and electrification is not always a solution. Hydrogen cells may also play an important role in this segment in the long term. Natural gas allows starting the transition in both segments.

Air, naval, and railway transportation

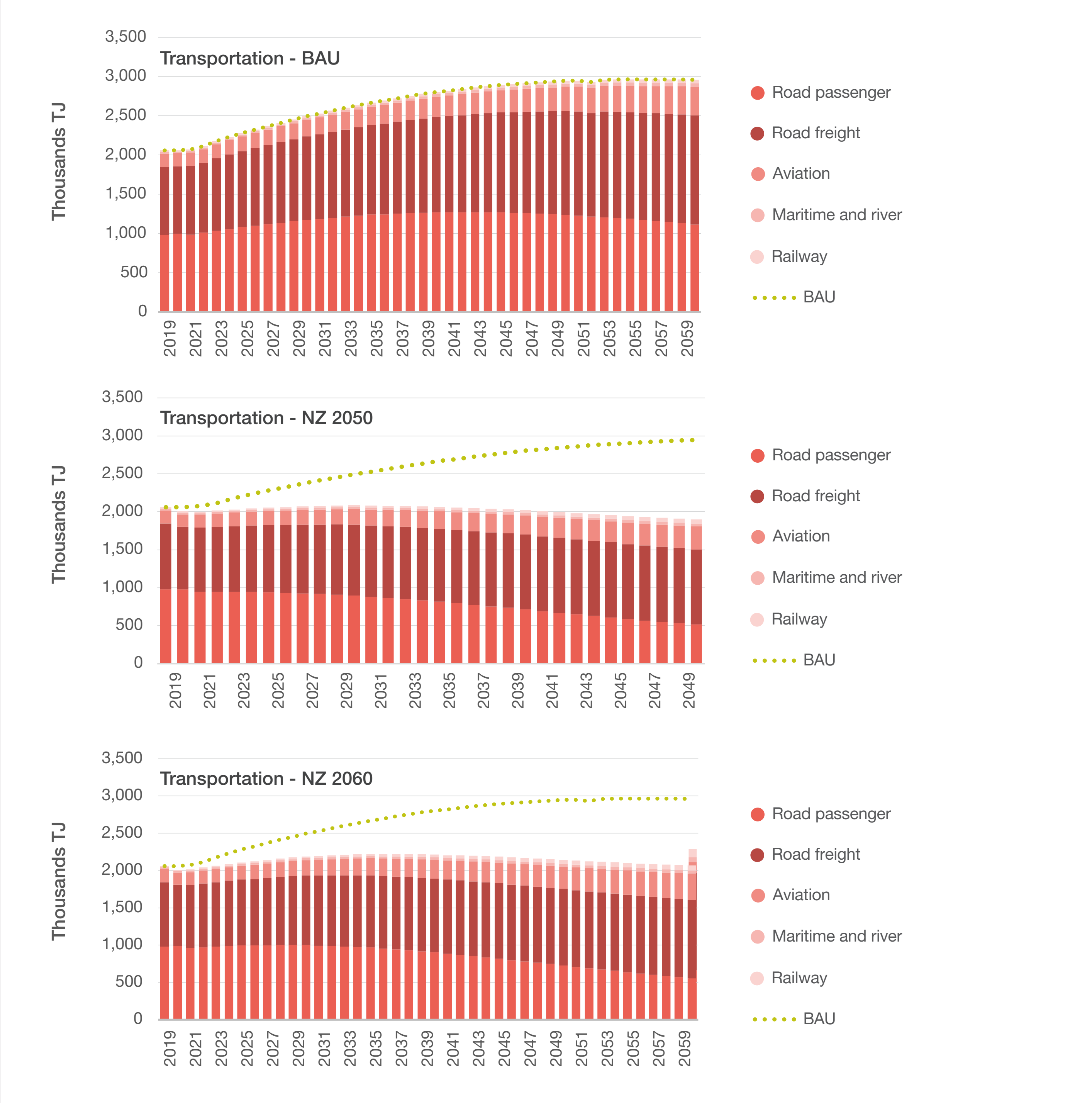
These sectors are more difficult to transform (in particular, the air and maritime/river subsectors are not electrifiable). Some of the energy transition options available are synthetic fuels and ammonia (H_2 derivatives), contemplated in the NZ scenarios.

Results

In the BAU scenario, energy consumption in the transportation sector grows by 44%, driven by the freight sector. Electricity grows considerably in the private and public passenger sectors whereas natural gas becomes relevant in the freight sector.

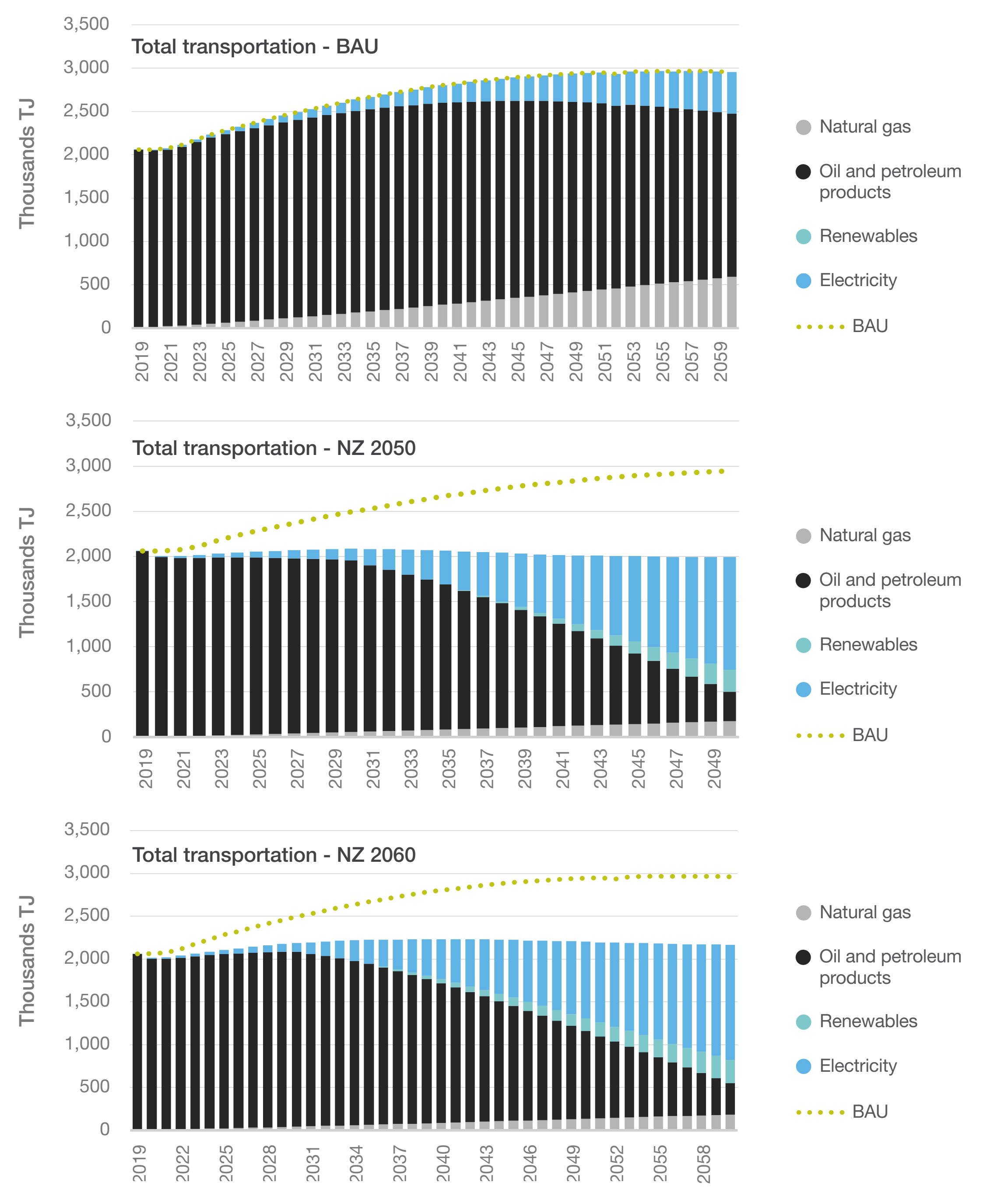
Transition scenarios

Graphic 49 A ▶ Transportation: final consumption by type/fuel and by scenario, 10^3 TJ



Source: Own preparation.

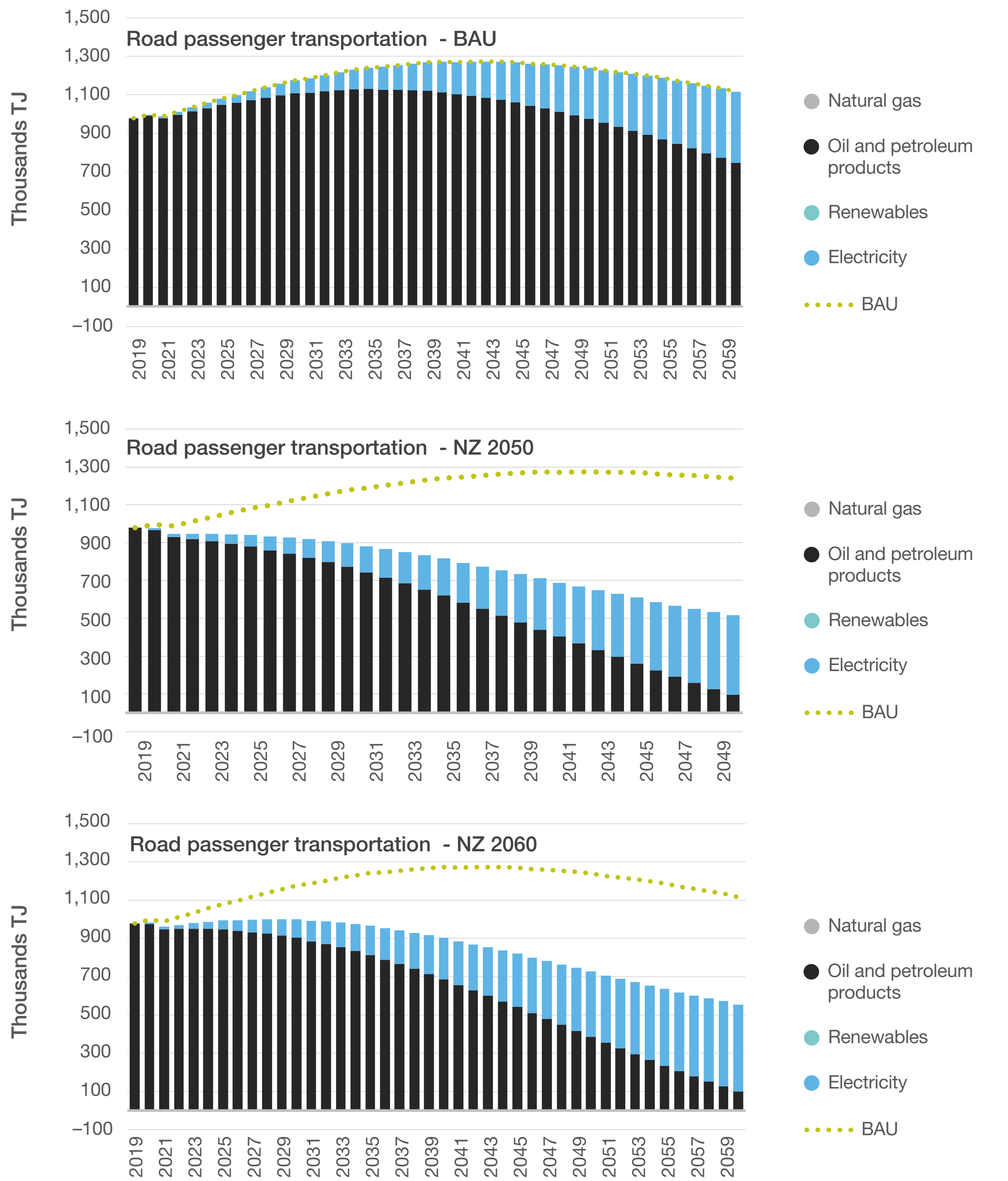
Graphic 49 B ▶ Transportation: final consumption by type/fuel and by scenario, 10^3 TJ



Source: Own preparation.

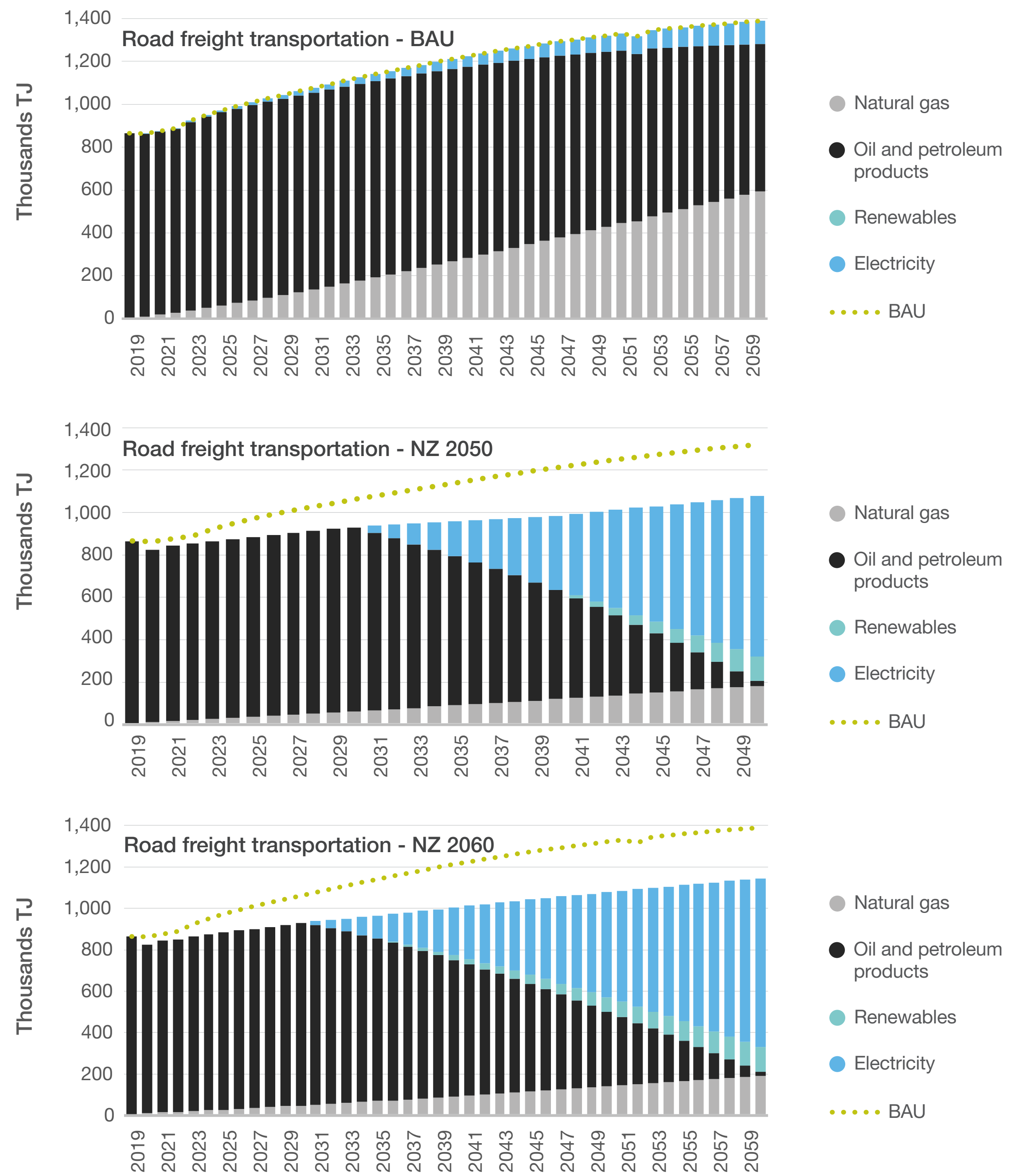
For the NZ 2050 scenario, energy demand in the transportation sector decreases due to the measures to promote electric transportation and synthetic fuels. In the passenger sector, electric penetration increases strongly, whereas the rest use gasoline in hybrid motors. As to freight transportation, electrification appears as the main alternative for trucks and truck tractors; hydrogen cells play a more limited role. Bearing in mind these considerations, the passenger sector reduces its energy consumption considerably whereas the freight transportation sector grows slightly. The NZ 2060 scenario is very similar to the one mentioned above, with a slower implementation of the measures.

Graphic 50 A Final consumption of road passenger and freight transportation, by fuel and by scenario, 10^3 TJ



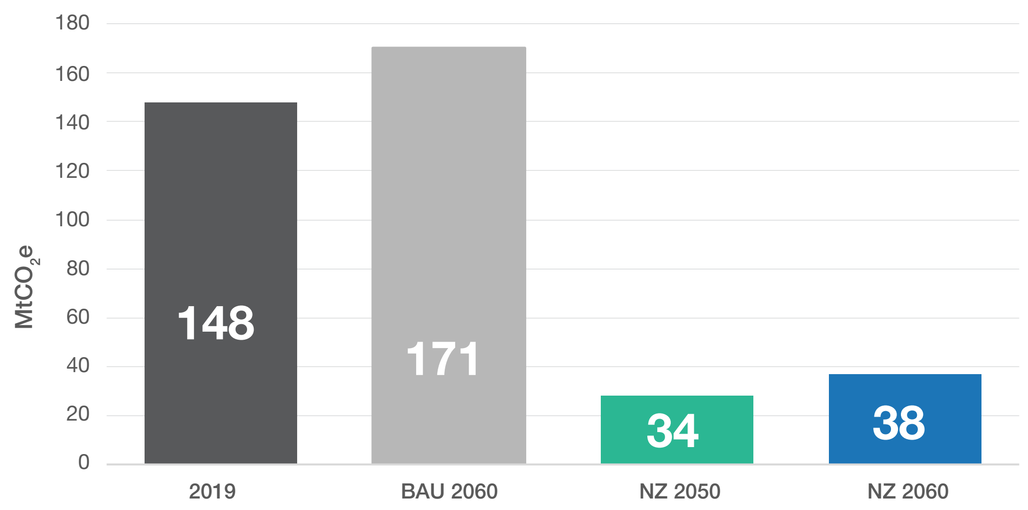
Source: Own preparation.

Graphic 50 B Final consumption of road passenger and freight transportation, by fuel and by scenario, 10^3 TJ



Source: Own preparation.

Graphic 51 ▶ Transportation sector: direct emissions by scenario, $MtCO_2e$



Source: Own preparation.

CO_2e emissions grow in the BAU scenario (+15 %) but at a slower pace than that of the vehicle fleet. On the other hand, emissions fall by over two thirds in the NZ scenarios in the long term, thanks to fuel substitution (mainly electrification), energy efficiency, and behavior change measures.

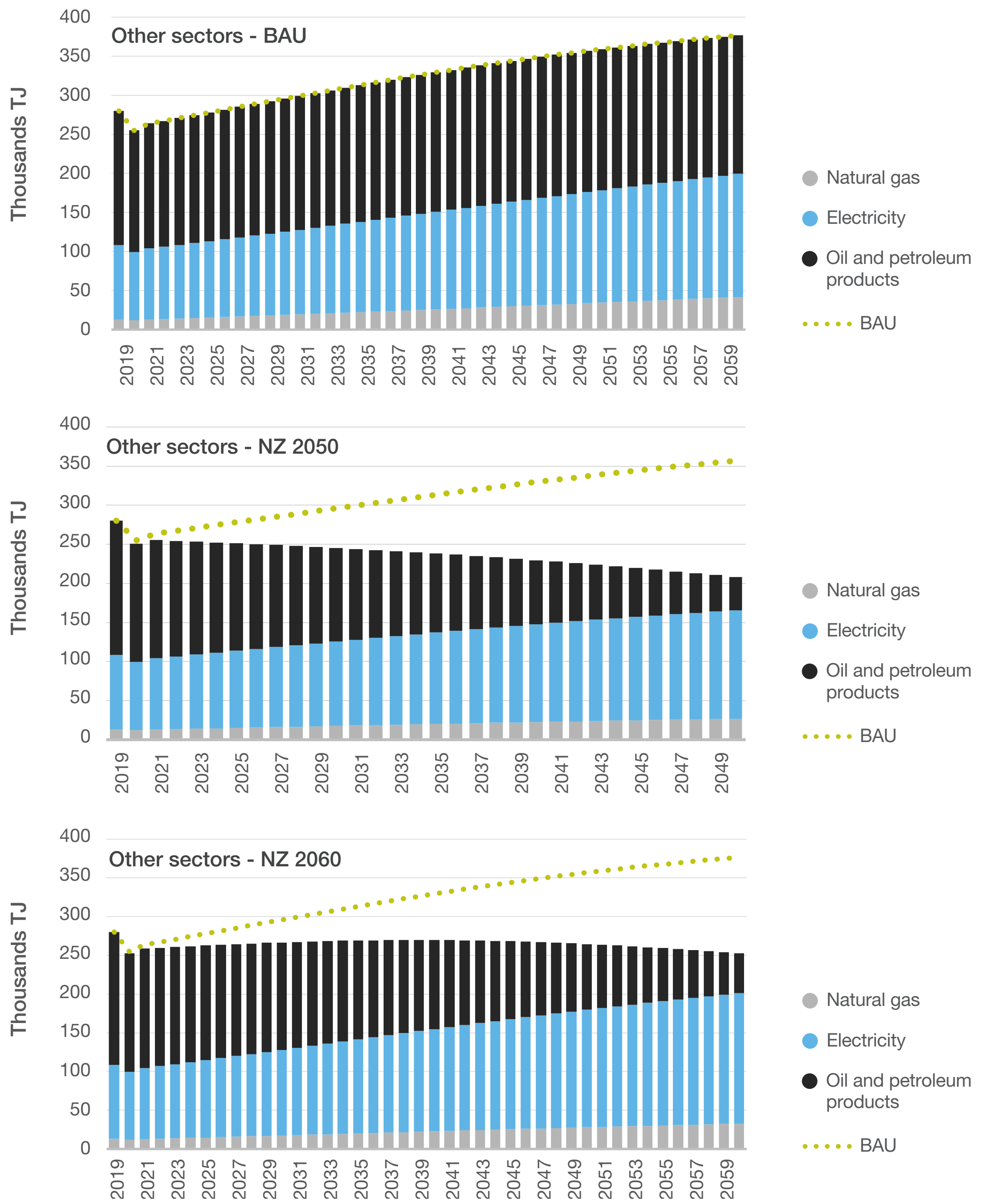
The energy transition measures required to limit GHG emissions in the transportation sector relate to mature technologies for the light vehicle segment and developing ones for the other segments. Substantial changes are expected in all scenarios, given the strong motorization associated with economic growth.

Agricultural, fishing, mining, and construction sector

The agricultural, fishing, mining, and construction sector, along with the commercial, services, and public sector, are the sectors with the lowest energy consumption. The electrification of the sector is low (34 % in 2019). When analyzing the demand by subsector, we can see the importance of the agricultural sector, which accounts for 68 % of the total in Mexico, whereas the mining sector stands at 27 %, and the construction sector, accounts for the rest. The three sectors show electrification potential. The mining sector has high potential to electrify the uses related to motive force or mining trucks, among other things, whereas strong electrification of agricultural machinery is expected in the long term, in line with the trends observed in this subsector. There is also potential to increase the energy efficiency of the equipment in both subsectors.

In the BAU scenario, the demand of this sector grows by around 0.7 % annually (cumulative 31 % in the period), which causes the sector to electrify gradually, more in line with the historical trend. An enhancement of the sector's energy intensity is observed (GDP growth is higher than that of demand, annual 1.9 % versus annual 0.7 %).

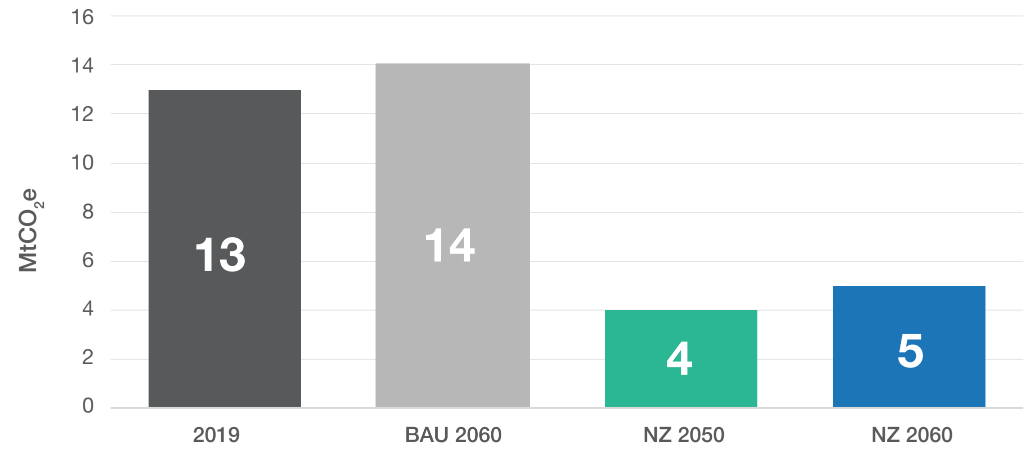
Graphic 52 ▶ Results of the agricultural, fishing, mining, and construction sector, by scenario (10^3 TJ)



Source: Own preparation. The fall in demand observed in the period 2020-2022 refers to real trends and to the impact of the decrease in GDP in the short term.

In the NZ scenarios, a great level of electrification is achieved; natural gas, oil, and petroleum products are the drivers for the rest. Consumption remains relatively constant in the analyzed period in the NZ 2060 scenario due to the combined effect of greater energy efficiency and the savings from the expected electrification of some uses. In the NZ 2050 scenario, the demand falls more strongly.

Graphic 53 ▶ Agricultural, fishing, mining, and construction sector: direct emissions by scenario ($MtCO_2e$)



Source: Own preparation.

CO_2e emissions remain almost constant in the BAU scenario. On the other hand, emissions fall to one third approximately in the NZ scenarios in the long term, thanks to the electrification of the sector and energy efficiency efforts.

The energy transition measures required to limit GHG emissions in the sector relate to technologies that are expected to have matured worldwide in the next few years, such as the use of electric agricultural machinery and electric mining trucks.

Power sector

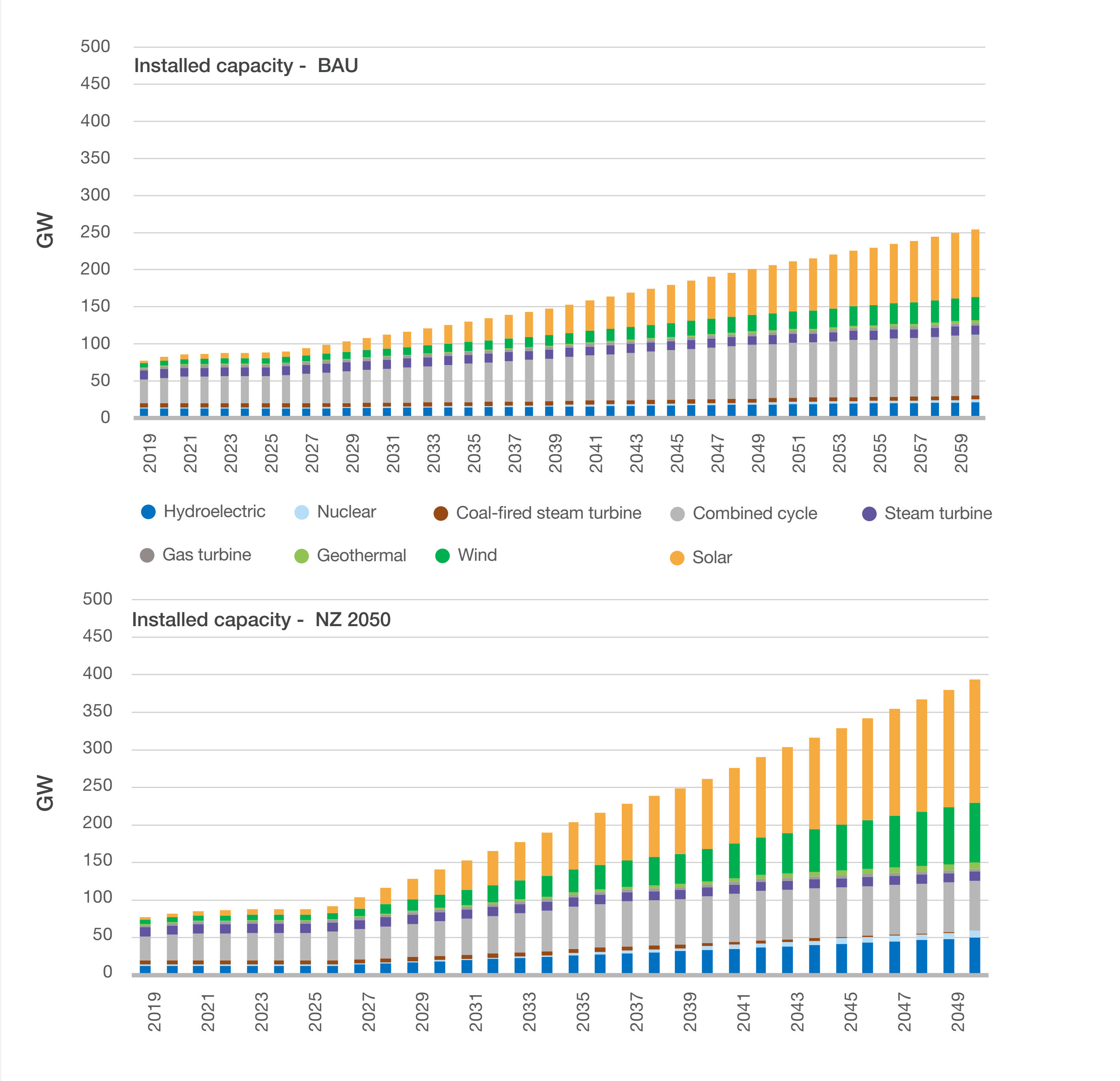
Mexico starts from a predominantly fossil electricity mix (expressed in installed capacity); it only has 32 % of renewable energy (16 % hydro, 1 % geothermal, 8 % wind, and 5 % solar).

In all the scenarios presented, an increase in solar and wind capacity is expected, and – to a lesser degree – hydro. In the BAU scenario, the additional renewable capacity to be installed is 124 GW, 87 GW of which is solar, 25 GW wind, 9 GW hydro, and 3 GW geothermal. In the NZ scenarios, more renewable capacity needs to be installed to cover the greater power demand and ensure a significant reduction in GHG emissions. In the NZ 2050 scenario, the addition of 278 GW of renewable energy is expected, 160 GW of which will be solar; 74 GW, wind; 37 GW hydro, and the rest geothermal. In the NZ 2060 scenario, the installation of 312 additional GW of renewable energy is required, 176 GW of which is solar and 85 GW wind, 42 GW hydro, and the rest geothermal. The installation of 12 GW of nuclear energy is also envisaged in the NZ 2060 and 10 GW in the NZ 2050 scenario.

In all the scenarios, the installation of new thermal plants is also required, particularly combined cycles (CCGT), which play a backup role, as well as batteries and smart grids, which participate in a better integration of renewable energy in the grid.

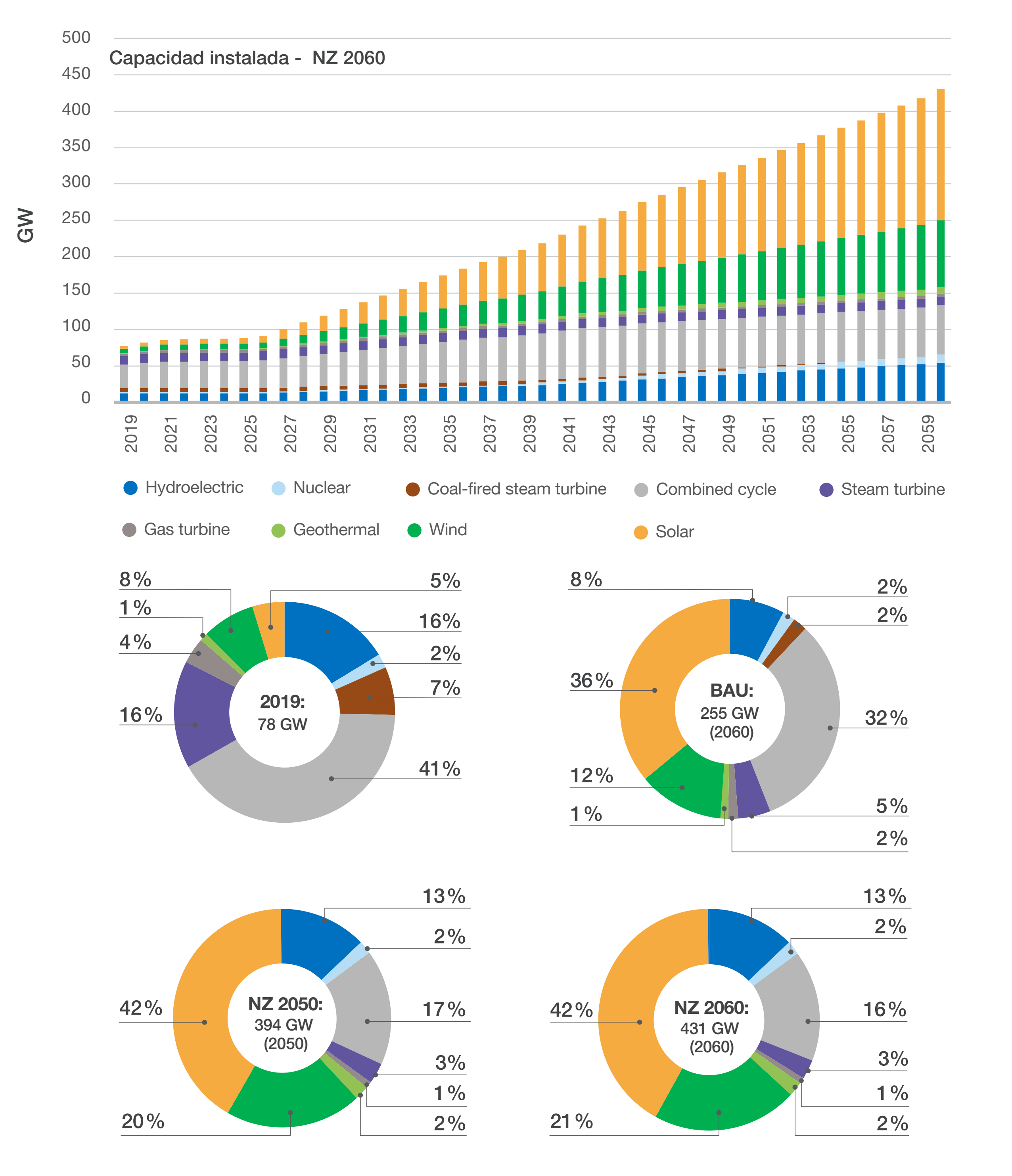
Transition scenarios

Graphic 54 A ▶ Projection of installed capacity by source and by scenario, GW



Source: Own preparation.

Graphic 54 B ▶ Projection of installed capacity by source and by scenario, GW



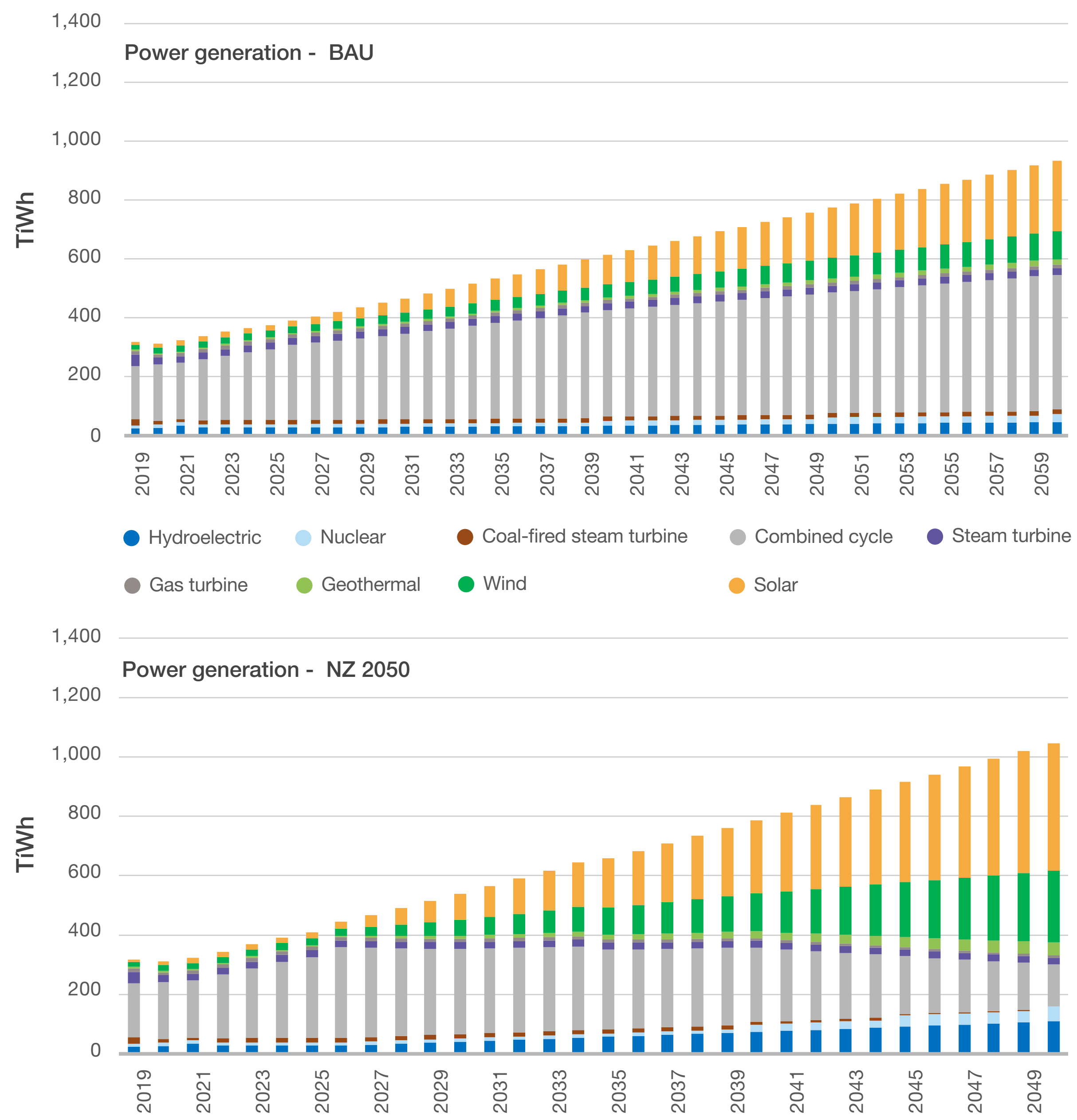
Source: Own preparation.

In the BAU, NZ 2050, and NZ 2060 scenarios, power demand grows by between 190% and 270%, whereas installed capacity increases by between 225% and 455 %. A much higher growth of the generation fleet than the growth observed in the last 20 years is required.

In all the scenarios, the power generation matrix becomes more renewable, with over 75% of generation free from emissions in the NZ scenarios. A development of carbon capture and storage technologies is expected in the long term in the NZ scenarios[33].

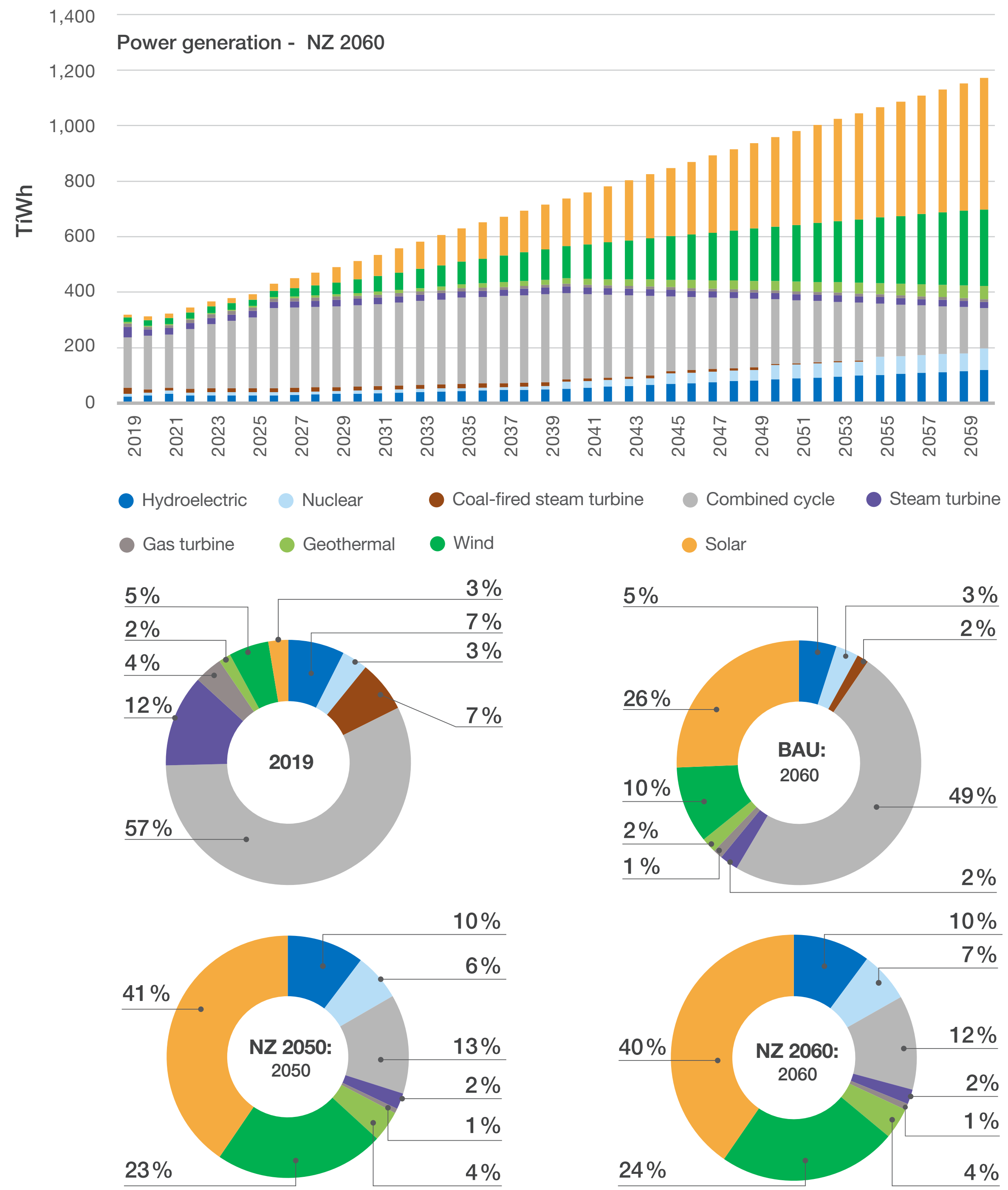
33 Based on the current knowledge on Mexico's potential geological storage, an annual limited absorption of 50 $MtCO_2$ is expected for all uses. A large portion of this potential is expected to reduce emissions from large-scale power plants. In Mexico, there are pilot projects to show the viability of capturing CO_2 in generation plants (CCGT).

Graphic 55 A ▶ Projection of power generation by source and by scenario, TWh



Source: Own preparation.

Graphic 55 B ▶ Projection of power generation by source and by scenario, TWh



Source: Own preparation.

3. Energy transition financing

Total investment related to each scenario is presented in this section as a result of all the energy transition measures described above.

The main items requiring investment are shown below, including a brief description of the assumptions used to derive the amounts presented in the following sections.

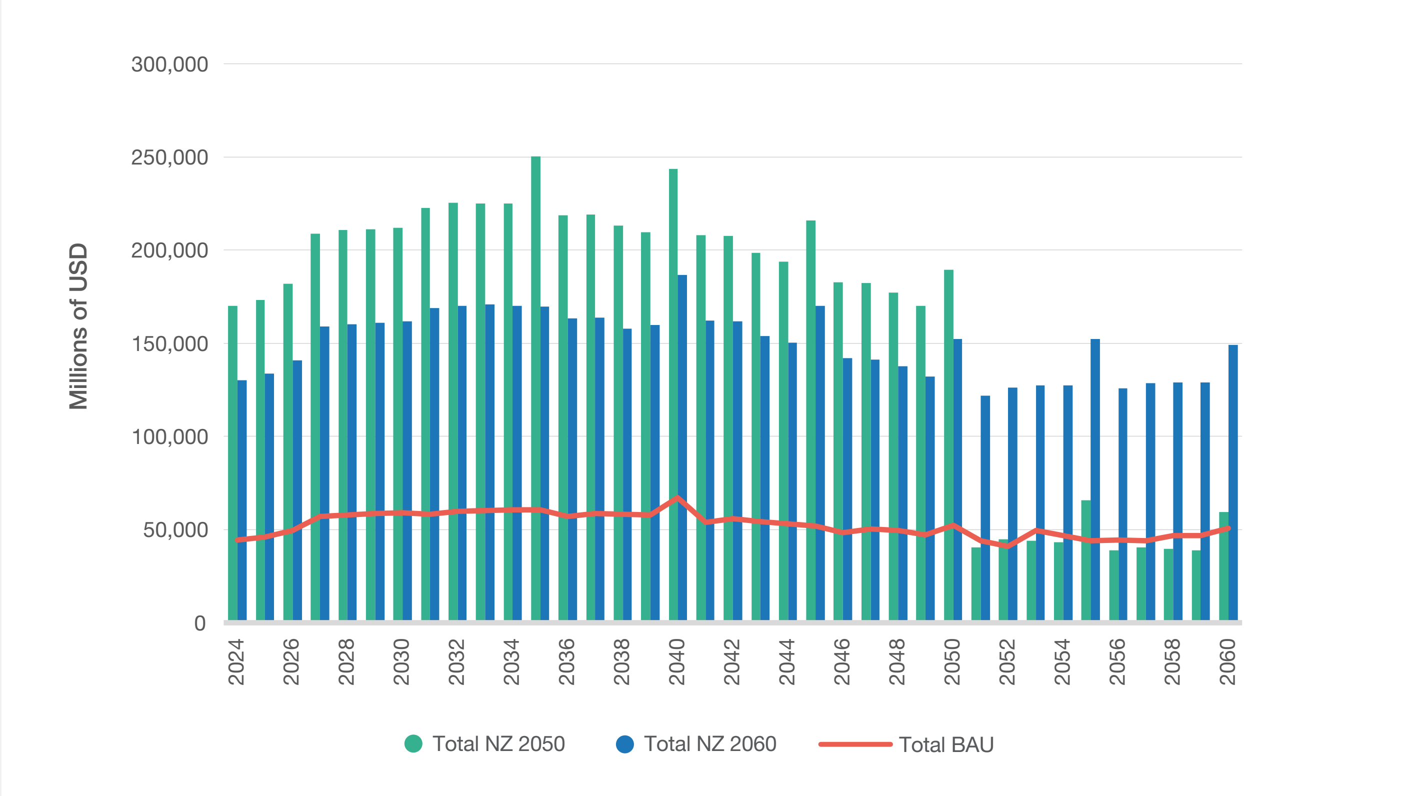
Total investment

Investment is calculated on an annual basis and the total investment amount is applied as of the first year in which it is possible to reduce CO_2 emissions. This is a simplification of the model, as large investment must take place in advance, from one to five years before, depending on construction times or the implementation of the investment considered (hydro plants, for example, are characterized by a construction period of several years).

Transition scenarios

Graphics 56 and 57 show the estimated total annual investment by scenario, in millions of USD and as a percentage of the GDP, according to the guidelines and assumptions described in “Investment”, in the chapter “Methodological section and assumptions” in the *Just Energy Transition / Projection assumptions report*.

Graphic 56 Estimated annual investment (millions of USD)

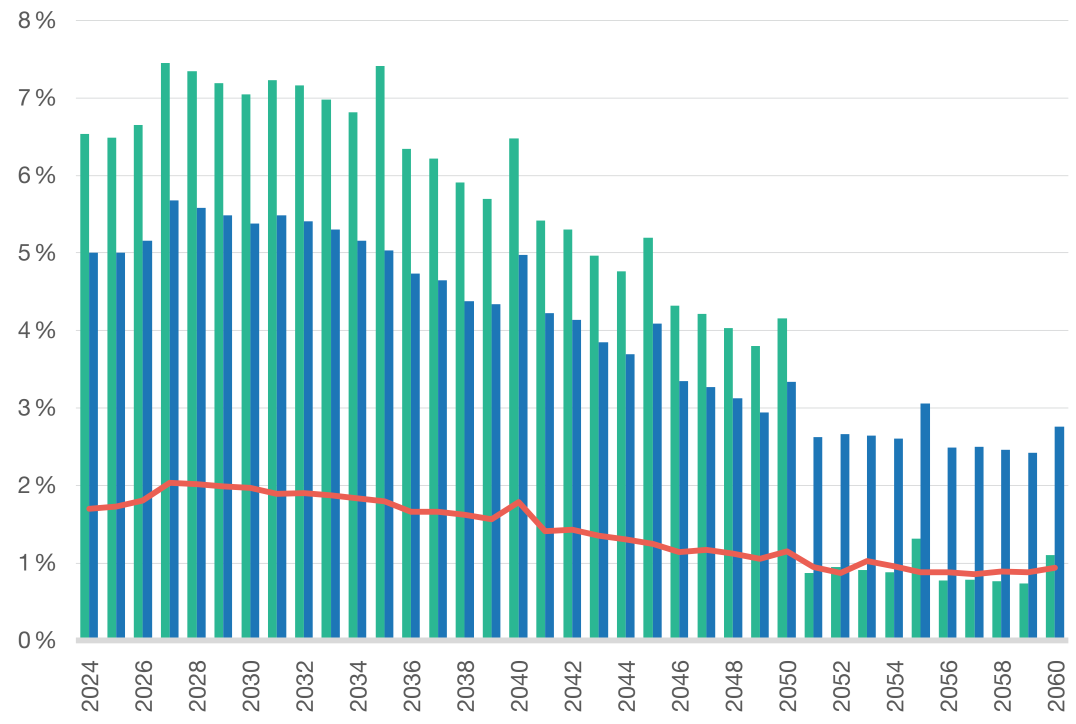


Source: Own preparation.

The cumulative investment in the period 2024-2060 is approximately USD 1,946,000 million for the BAU scenario, USD 6,002,000 million for the NZ 2050 scenario, and USD 5,547,000 million for the NZ 2060 scenario.

By year, fairly stable investment is observed in the BAU scenario. In the NZ scenarios, there is a slight upward trend in the first 10 or 20 years and a slight downward trend in the long term, which evidences the fall in the unitary cost of some of the transition technologies in the long term, particularly electric vehicles. As from 2051, investment in the NZ 2050 scenario is lower than in previous years and similar to the BAU scenario. The maximum annual investment in the BAU scenario is approximately USD 67,000 million whereas it amounts to around USD 250,000 million in the NZ 2050 scenario, and USD 187,000 million in the NZ 2060 scenario, which implies almost trebling or quadrupling the annual investment in the NZ scenarios in some specific years.

Graphic 57 Estimated annual investment in % of GDP (%)



Source: Own preparation.

The investment effort, measured in GDP percentage, is very significant at the start of the planning horizon and reaches 2 % in the BAU scenario, over 7 % in the NZ 2050 scenario, and over 5% in the NZ 2060 scenario if total investment in electric motorization is considered (see section "End uses for more detail").

Investment by type is presented below.

Power sector

Investment in the power sector includes:

- investment in new power generation plants, in line with the generation expansion presented in the "Electrical uses" subsection, pursuant to CAPEX prices projected by the National Renewable Energy Institute (NREL) to start up new facilities[34];
- investment in infrastructure and flexibility, including the concepts of smart grids, batteries, and modernization of old hydro plants, estimated at an additional 15 %[35] to investment in power generation. This investment is key to facilitate the integration of intermittent power generation in the electric dispatch;
- investment in transmission and distribution grids, which accompanies the very significant growth in power demand as a result of the projected economic growth and the electrification of end uses, based on a 16 % share of transmission and 44 % of distribution[36];

34 Table 9, *Just Energy Transition / Projection Assumptions.*

35 This generic amount is in line with the global investment amounts estimated by the International Renewable Energy Agency (IRENA) in its report *World energy transitions outlook 2023: 1.5 °C pathway.*

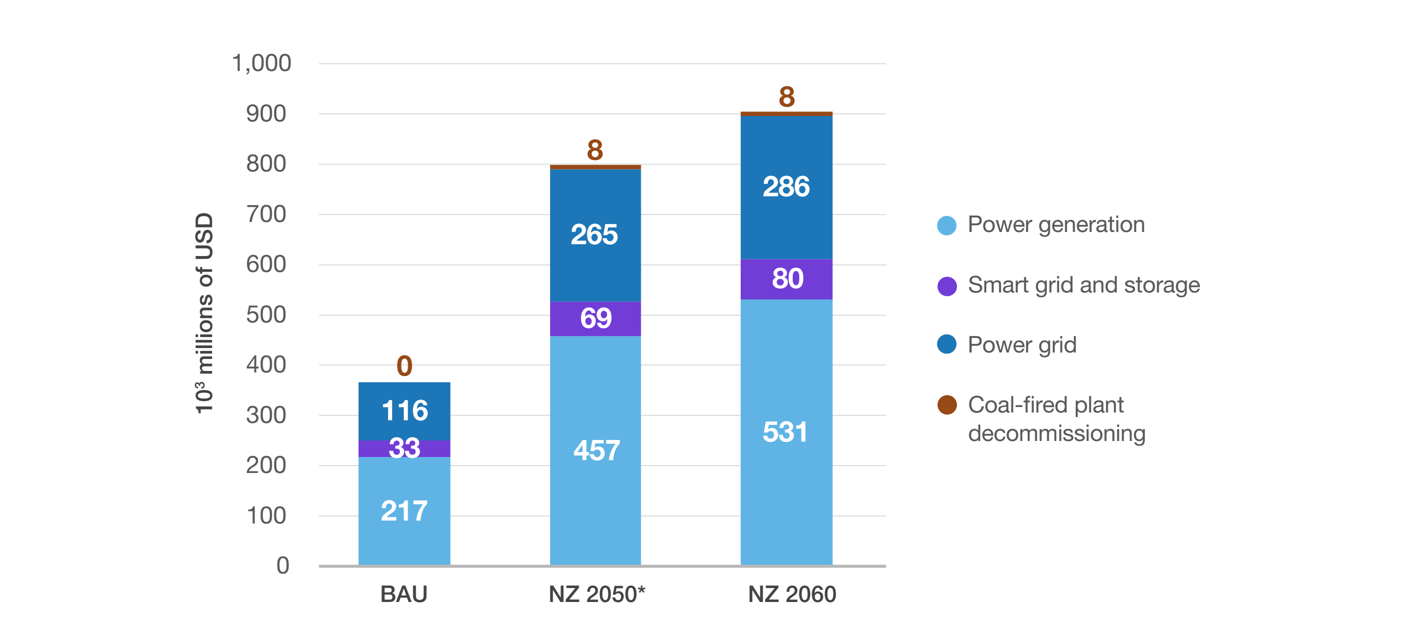
36 See again the *Just Energy Transition / Projection Assumptions report*.

- the estimated investment required for the phase-out of coal-fired plants before the end of their useful life (stranded assets or sunk assets) was estimated by using 50 % of the CAPEX of a new coal-fired thermal plant published by the NREL[37].

It is important to point out that, even though the addition of new power generation capacity grows in the long term, the unitary costs of the renewable technologies are expected to fall gradually over time as a result of the technological enhancements and the returns to scale originating in the sector's growth.

The cumulative investment in the transition period is presented below for each scenario.

Graphic 58 ▶ Power sector: cumulative investment in the transition period (billions of USD)

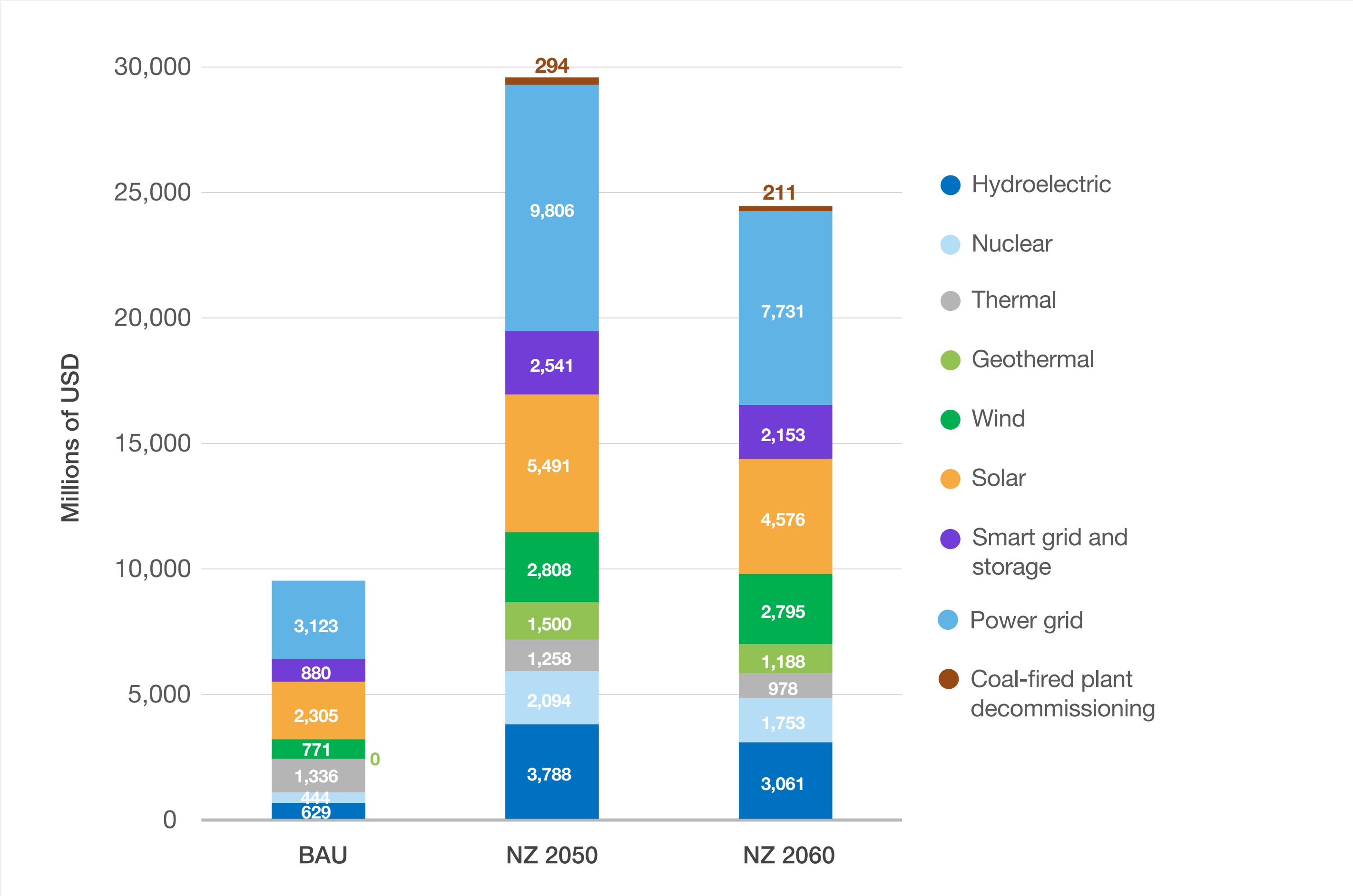


Source: Own preparation. *Investment in the NZ 2050 scenario refers to the period 2024-2050 whereas it refers to the period 2024-2060 in the other scenarios.

37 Table 10, *Just Energy Transition / Projection Assumptions*

The cumulative investment related to the power sector is approximately USD 365 billion in the period 2024-2060 for the BAU scenario; USD 799 billion in the period 2024-2050 for the NZ 2050 scenario; and USD 904 billion in the period 2024-2060 for the NZ 2060 scenario. The investment related to power generation, smart lines, and storage adds up to around two thirds of this, whereas investment in the power grid is about one third.

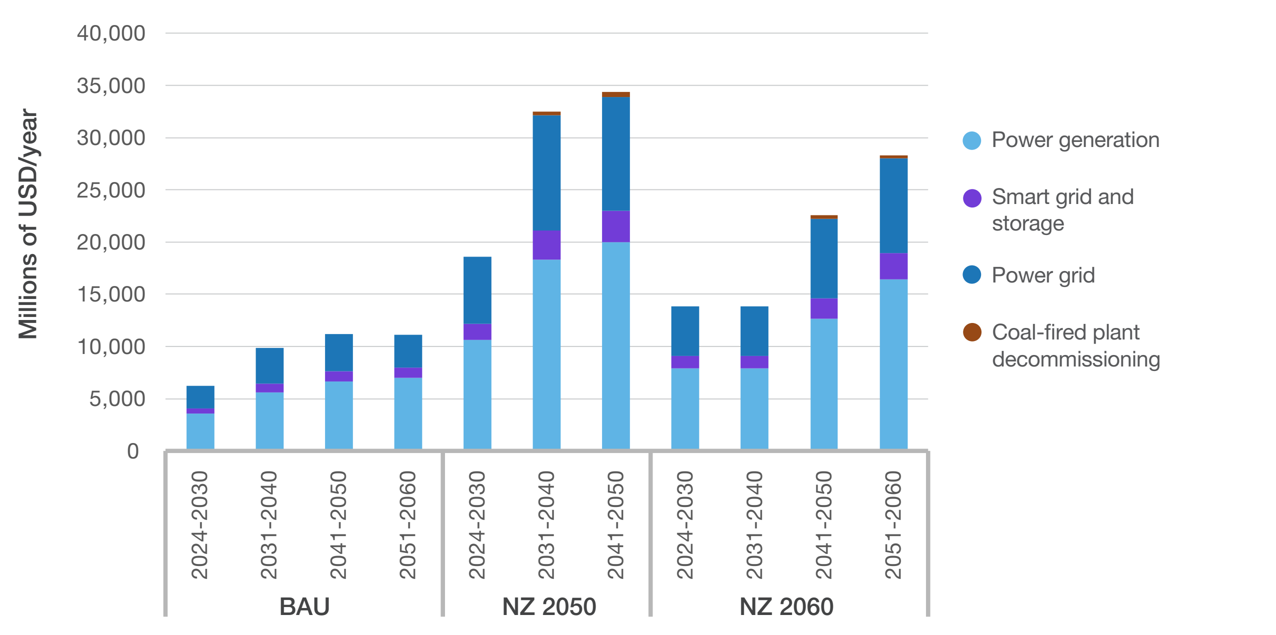
Graphic 59 ▶ Power sector: average annual investments by type (millions of USD)



Source: Own preparation.

By year (average value), the required investment is higher in the NZ 2050 scenario with USD 29,580 million. The NZ 2060 scenario follows with USD 24,445 million and, finally, the BAU scenario with USD 9,868 million. By technology, the investment in power generation with the largest participation is solar, hydro, and wind. Even though the cumulative hydro capacity to be installed is lower than the wind or solar capacity, the unitary CAPEX of the former is two to four times higher, depending on the technology and the year considered.

Graphic 60 Power sector: annual investment by period (millions of USD-year)



Source: Own preparation.

By time interval, the need for investment grows over time. This need for investment occurs in a context of demand growth as a result of the strong economic development and the electrification of end uses.

End uses

From the point of view of investment related to energy end uses, it is possible to mention the following:

- road transportation sector, in which the total investment[38] in electric vehicles (EV) and hybrid vehicles (VH) is estimated on the basis of the unitary CAPEX projected by IRENA, and on the number of new vehicles, as well as the charging stations, based on a calculation of the number of stations required and a unitary cost;
- energy efficiency measures, electrification, use of alternative fuels (hydrogen and its derivatives, among others), and behavior changes with an impact on the end uses sectors, except for road transportation and the carbon capture, use, and storage technology (CCUS). A proxy[39] was considered by final consumer sector, equal to a unitary CAPEX expressed in USD/ton of avoided emissions, times the savings in emissions in each sector;
- carbon capture and storage (CCS)[40], which is presented as an option for very polluting industrial sectors with higher CO_2 emissions which are difficult to transform.

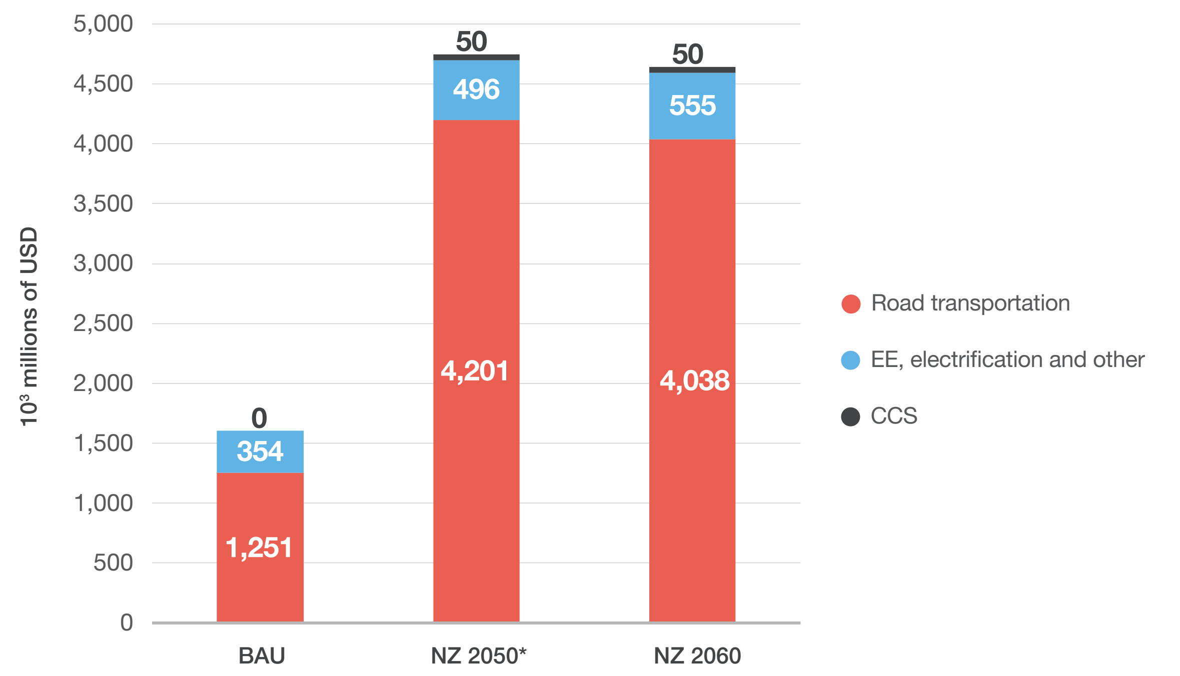
Graphic 61 presents the cumulative investment in the transition period for each scenario.

38 This investment does not consider the necessary replacement of EVs at the end of their lives or the anticipated replacement of batteries.

39 This equivalent CAPEX by sector was estimated based on a study conducted by the Climate Change Committee (CCC).

40 The related investment was estimated on the basis of the interannual difference (year N less year N-1) of the emissions absorbed by industry, times the unitary CAPEX of a CCU project capable of storing 1 $MtCO_2$ per year. This unitary cost was estimated at USD 1,000 per CO_2 ton absorbed.

Graphic 61 ▶ End uses: cumulative investment in the transition period (10^3 millions of USD)



Source: Own preparation. * Investment in the NZ 2050 scenario refers to the period 2024-2050, whereas it refers to the period 2024-2060 in the rest of the scenarios.

The cumulative investment related to end uses is approximately USD 1,605,000 million in the period 2024-2060 for the BAU scenario; USD 4,747,000 million in the period 2024-2050 for the NZ 2050 scenario; and USD 4,643,000 million for the period 2024-2060. The investment related to road transportation amounts to approximately 75% and 80% of this investment if total investment related to EVs and HVs required for this segment is contemplated. If only the cost overruns related to this investment (calculated in a simplified way as the difference in cost between buying EV, HV and investing in charging stations, and buying a vehicle that runs on fossil fuel) are considered, road transportation adds up to less than half of the investment related to end uses (see Graphic 62, dark red segment referring to electrification cost overruns).

Graphic 62 illustrates the difference between both concepts for road transportation.

Graphic 62 ▶ Road transportation: annual investment by period (millions of USD/year)

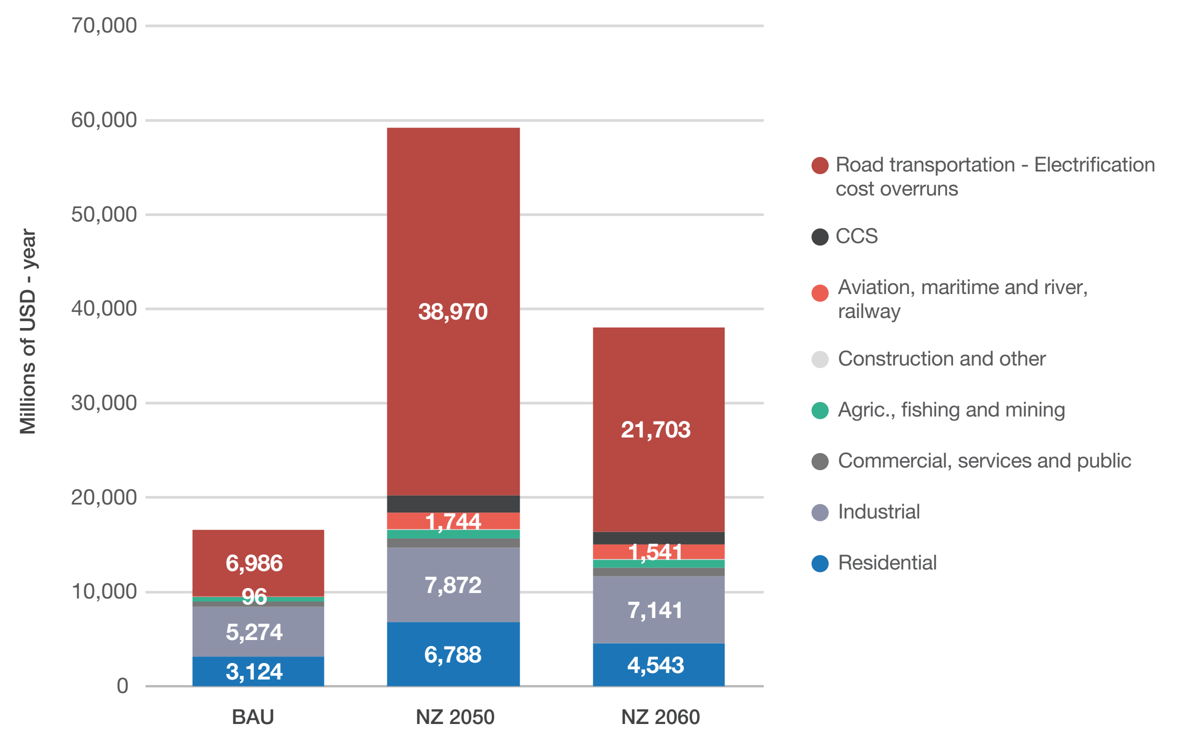
Source: Own preparation..

It should be pointed out that all the analyzed scenarios present a future reduction in the cost of electric vehicles of about 60% during the period. In addition, the scenarios contemplate an increase in motorization, evidenced through the possession of vehicles per 1,000 inhabitants, as indicated in the assumptions by sector. The need for investment includes two major effects: access to mobility and mobility electrification. The latter represents lower cost overruns in the long term due to the competitiveness of EVs against vehicles running on fossil fuels in almost all the vehicle segments.

It is important to remember that an increase in the possession of cars and a reduction in their annual unitary use were estimated for private passenger transportation. Other schemes may also exist, such as shared autonomous vehicles, which could partially reduce the total number of vehicles and their associated investment.

Graphic 63 presents investment by type, without considering the cost of motorization.

Graphic 63 End uses: average annual investment by type (millions of USD/year)



Source: Own preparation. This graphic does not consider the cost of motorization.

By year (average value), the investment required is higher in the NZ 2050 scenario, since the transformation of the sector should be achieved fast. By technology, the investment with more participation is that of the road transportation sector, followed by the industrial and the residential sectors.

"In the NZ scenarios, investments show a slight upward trend in the first 10 to 20 years and a slight downward trend in the long term, reflecting the reduction in the unitary cost of some of the transition technologies in the future, particularly electric vehicles."

4. Main transition indicators

Table 12 presents some of the indicators of the just energy transition.

These indicators illustrate the increase in the penetration of renewable energy in final consumption and power generation, energy intensity enhancements in the sector, the use of energy per capita, and the penetration of electric mobility, among other aspects related to the just energy transition.

Table 12 Indicadores por horizonte de tiempo y escenario

Number	Potential indicators	Unit	2019	BAU 2060	NZ 2050	NZ 2060
E-2.1	Share of renewable energy in total final energy consumption	%	10 %	16 %	54 %	55 %
	Share of renewable energy in power generation	%	14 %	43 %	78 %	78 %
E-2.1bis	Installed renewable energy generation capacity	GW	24	147	302	335
E-2.2	Energy intensity measured on the basis of primary energy and GDP	TJ/ MUSD PPP 2017	3	1.5	1.2	1.1
E-2.3	Efficiency of energy conversion	%	43 %	50 %	50 %	50 %
	Efficiency of energy distribution	%	83 %	83 %	83 %	83 %
E-2.4	Energy intensity by sector (industrial)	TJ/ MUSD PPP 2017	3.6	2.6	2.2	2.0
	(Agricultural, fishing, and mining)		1.3	0.8	0.5	0.5
	(Services and commercial)		0.1	0.1	0	0
	(Transportation)		0.8	0.5	0.4	0.4
E-2.5	Energy intensity in the residential sector	TJ/ 1,000 inhabitants	6	8.3	5.9	6.7
E-2.6	Penetration of electricity in the transportation sector	%	0.2 %	16 %	63 %	62 %
E-2.7	Penetration of natural gas in the transportation sector	%	3 %	20 %	9 %	8 %
	Penetration of hydrogen in the transportation sector	%	0 %	0 %	12 %	12 %
S-1.4	Energy use per capita	TJ/1,000 inhabitants	38.4	58.1	38.1	41.6
A-1.1	GHG emissions per year, energy*	$MtCO_2e$	433	551	124	134

Source: Own preparation. *Fugitive emissions are not included.

1. The environment of the transition

Projections

When analyzing the results of the projections of the energy matrix in Mexico in the long-term NZ scenarios, we observe more consumption electrification, a reduction in the demand for liquid fuels, and an increase in natural gas consumption. In turn, we can divide the projection into three stages: the preparation stage between 2020 and 2030, the implementation stage with strong investment between 2030 and 2040, and the development stage as from 2040.

Graphic 64 Roadmap: stages

Stage I - Preparation → Stage II - Implementation → Stage III - Development

STAGE I – Preparation (between 2020 and 2030). Investment levels are still low, due to the following:

- the emphasis of the current federal administration to promote the use of fossil fuels as a measure to "strengthen" the national energy companies;

- the relative inertia of the first years of the period (particularly for power generation and energy infrastructure, projects may take several years before being commissioned);
- it is expected that electric vehicles and batteries for power generation will not be as massive and competitive as in the following decades.

In this period, we can point out investment in energy efficiency, renewable generation (in particular, solar and wind) and its associated transmission grid, and the start of the phase-out of highly polluting technologies (coal and fuel oil) and their replacement by electricity or natural gas.

It should be pointed out that Mexico still lacks a roadmap for green hydrogen and does not have a public policy for mining essential minerals for a decarbonization route (for example, lithium).

In the second half of this period, we can point out investment in energy efficiency, renewable generation (in particular, solar and wind) and its associated transmission grid, and the partial phase-out of highly polluting technologies (coal and fuel oil) and their replacement by electricity or natural gas. At present, Mexico is a net importer of coal, natural gas and its derivatives, and an oil exporter.

The country has four LNG plants and three regasification terminals that allow it to supplement the domestic gas supply for power generation and industrial uses until 2019. In addition, two floating storage and regasification units (FSRU) are about to start operating to meet the demand of the CFE in 2023. There are several projects for new natural gas liquefaction plants, but they will not contribute to national supply because the LNG will be exported to other regions (Asia or Europe).

In Mexico, the convenience of granting fiscal stimuli to acquire electric vehicles that go beyond the exemption from the tax on the possession of cars and the green (registration) plate should be analyzed.

STAGE II - Implementation (between 2030 and 2040). It is assumed that the technologies for the use of renewable sources are massive, available, and have high demand. The CAPEX of the energy transition technologies (in particular, electric vehicles, power generation, and batteries) continue their downward trend, which allows for their massive development.

In this decade, the introduction of clean technologies and the enhancement of energy efficiency in the value chains of the energy sector gain speed, investment in natural gas is maintained, and the supply of hydrogen-based technologies starts.

Public policies to modernize and expand the transmission and distribution grids gain speed, so that they can accept and transport clean energy for long distances in an efficient way (minimizing technical losses) and give way to a smart grid that permits the electrification of things (electric vehicles, solar roofs, etc.).

Energy efficiency and electro-mobility policies are promoted with financial and human resources, and the adequate legal framework to reduce GHG emissions.

STAGE III - Development (as from 2040). Clean technologies are already mature and massive; therefore, their prices are competitive and the cost of the transition is more related to accelerating the phase-out of the polluting technologies. Investment in the sectors responsible for CO_2e emissions stops, for example, in natural gas, and this marginally gives way to the technologies that replace it, such as hydrogen and CCUS.

These actions will generate a discussion on the stranded assets, especially in connection with oil refining. In the last few years, PEMEX built a new refinery and increased its share to 1-00% in another refinery in Texas, U.S.A., it invested resources in modernizing the rest of the Mexican refineries and granted fiscal stimuli to enhance its financial balance. The energy transition will cause these assets to stop or to reduce their operations before the end of their useful life.

Implications for public policies

Mexico's human development index (HDI) was 0.779 (high indicator) in 2019, which positions the country in the category of high human development and in the 74th position out of 189 countries and territories[41]. Moreover, it is not a country in Annex I to the Paris Agreement. Therefore, its policies must focus on those that allow it to meet its emission reduction targets and the need for its economy to grow in order to reach the maximum emissions in the shortest possible time; it is likely to meet the net zero emissions target after 2050.

Stage I - Preparation

In preparation stage I, Mexico's policies must focus on the following points:

1. **Public policies.** Mexico has a legal framework aimed at complying with the Paris Agreement with a General Climate Change Act and an Energy Transition Act that establish emission reduction targets and the adoption of clean energy. In this period, Mexico will have to start implementing this legislation by passing second-level rules required to comply with its international commitments. These policies must integrate the concepts of the JET.

2. **Access.** Reach full electricity coverage of the electricity services in order to displace and substitute firewood (and other inefficient and highly polluting fuels) in the residential sector, especially in marginal rural areas. The Electricity Industry Act, passed in 2014, defined mechanisms to accelerate rural electrification. The CFE, the national electricity company,

41 The UNDP establishes four categories: low (less than 0.55), medium (between 0.55 and 0.70), high (between 0.70 and 0.80), and very high (over 0.80).

stopped being obliged to carry out rural electrification; this objective and its targets were transferred to the SENER. This Secretary must generate rural electrification plans and offer support to the different utilities to extend their grids to areas that were previously not connected. The SENER must develop distributed generation projects, mainly community photovoltaic solar and on roofs, in areas with difficult access.
In this period, Mexico must continue these policies in order to meet the JET.

3. **Energy efficiency.** Promote energy efficiency in all the segments of the economy (residential, industrial, commercial, transportation, agricultural, public sector, etc.) in order to reduce energy consumption.
The programs should be reinforced, for example, solar roofs in government buildings (on a national and subnational basis).
Until 2022, Mexico had a National Commission for the Efficient Use of Energy (CNUEE) to develop energy efficiency policies and programs. At the beginning of 2023, the functions of this commission were transferred to the SENER.
Mexico has a fleet of freight transportation vehicles that are on average over 19 years old. Therefore, it must promote replacement and scrappage programs for equipment and vehicles in order to retire the oldest equipment and vehicles[42].
Programs should be implemented to promote the enhancement of constructive aspects in existing houses by adopting thermal insulation and other equipment (for example, efficient space heating and air conditioning systems, solar roofs, rainwater recovery, etc.).
Through the CNUEE, Mexico promoted the development of programs to facilitate investment in energy efficiency, which in many sectors implies the adoption of mature technologies. This policy could be promptly applied to implement the just energy transition.

42 In the past, this kind of programs have already been carried out; however, their results were not the expected ones mainly because of poor coordination between the government agencies involved and the lack of sufficient funds to reduce the average age in a significant way.

4. **Renewables and natural gas.** Mexico is located south of one of the most abundant and competitive basins in the world. Due to its geographical position and the reduction in gas prices in the United States, Mexico started a process of massive gasification of its energy and electric matrix in the last 12 years. The CFE is still promoting the development of gas pipelines and combined cycles to replace liquid fuels.
Since the passing of the Electricity Industry Act in 2014, the energy sector has started a process of gradual introduction of NCRE. The continuous reduction in the levelized prices of clean renewable technologies makes them more and more competitive against natural gas and other fossil fuels; therefore, efforts must be made to promote the incorporation of more amounts of renewable energy driven by specific tenders for the sector.
Natural gas is the transition fuel in the short and medium term in Mexico, given that it is the most environmentally friendly and in order to facilitate the massive entry of renewable energy.

5. **Subsidies and prices.** In order to be effective, energy efficiency policies require redesigning price schemes and focusing subsidies on people with unfulfilled energy needs so that prices can reflect their costs and encourage the adoption of efficient technologies. In some cases, this will imply subsidizing the demand and not supply.
The IEPS adjustment scheme for gasolines and diesel must be eliminated so that their domestic prices may reflect international prices and their demand may fall.
As to the CFE, approximately 98% of residential consumers receive some indirect subsidy at present. That is, electric tariffs do not cover their cost. The agricultural sector is the other sector subsidized in the same way.
A gradual electricity tariff adjustment is required so that agricultural and residential consumers face the cost of receiving electricity. The lower-income population could directly receive a transfer to ensure that their needs are fulfilled.

6. **Regulations.** Promote fiscal and financial incentives to foster investment in renewable energy and energy efficiency.
Promote banking regulations to incentivize loans associated with energy transition (renewable sources and transition fuels) and penalize investment in the oil and petroleum products chain.
Within the fiscal incentives, taxes on carbon should relate to the international prices of carbon credits so that they adequately reflect the mitigation cost[43]. At present, the price of carbon implicit in the fiscal burden of the IEPS by carbon content is ~5 USD/tCO_2e, which is substantially lower than international prices.
Develop regulations to foster policies related to hydrogen and CCUS in order to reduce uncertainty in these businesses and allow for their development in the long term.

7. **Transition fuels.** The consolidation of gas supply and its transportation systems must take place in this period, guaranteeing that the production, import, and storage projects that are developed can be depreciated with no cost overruns.

8. **Reconversions.** Mexico is a net natural gas and coal importer and an oil – and to a lesser degree – natural gas and coal producer. Coal and fuel oil-fired generation plants must be phased-out and replaced. At present, there are two regions with coal-fired generation in Guerrero y Coahuila. The effects of industrial reconversion in those areas could have high impact on those communities; therefore, support plans for the population and retraining of the workers should be designed.
Mexico is a hydrocarbon-related country with large investment in infrastructure associated with oil and gas, and it is expected that some of these assets will be operative after 2050. However, the impact of the reduction of the activity should be anticipated in some regions, such as Campeche, and reconversion plans need to start being implemented in this decade.

43 It is important to mention that price signals should be constant over time in order to be effective; therefore, developing levelized mitigation costs could be another alternative.

At the same time, efforts should be focused on projects such as the transformation of freight transportation to LNG and CNG.
Unlike other countries, Mexico has not progressed in offering vehicle fuel that meets U.S. or European standards. The CRE granted permits to PEMEX to continue producing diesel with more sulfur content[44]. Therefore, the substitution of the freight vehicle fleet running on diesel with LNG or CNG is beneficial.

9. **Smart grids.** Modernize energy infrastructure by promoting investment in smart grids and energy storage systems to facilitate the integration of renewable energy and enhance supply reliability. The federal Government must analyze and cover the costs of introducing smart grids for lower consumptions as part of the agenda to facilitate energy efficiency.
These efforts can be accompanied by changes in the maximum limit to distributed generation (0.5 MW capacity) to accelerate its adoption. Moreover, a modernization strategy for consumption metering systems is required, to introduce bidirectional smart meters with remote communication.

10. **Transportation.** Foster clean energy in transportation, including electric vehicles and their associated charging infrastructure, and promote vehicles running on natural gas (CNG and LNG) as transition fuel for freight transportation. Due to the access to natural gas imported from the United States at very competitive prices, the transition period may extend more than in other countries in the region.
The Secretary of Environment and Natural Resources (SEMARNAT) presented its National Electric Mobility Strategy (ENME)[45] in May 2023. The ENME proposes targets to be met and priority actions and incentives to be developed. In particular, it proposes that all vehicles sold as from 2040 must be zero emissions, in line with the Glasgow Climate Pact for Electromobility.

44 It should be indicated that in 2022, nearly 60% of the fuel consumed in Mexico was imported from refineries in the United States that meet such standards.
45 https://www.gob.mx/cms/uploads/attachment/file/832517/2.3.ENME.pdf

Policies to introduce electric railways also constitute a mechanism to accelerate energy transition and replace freight transportation running on liquid fuels. Therefore, studies, layout-related expropriations, and tenders to develop these projects should be promoted.
The energy transition in Colombia will last between ten and twenty years after 2050; therefore, gas-fired technologies will have time to be depreciated.
Recently, and due to the integration of production chains from Mexico, the United States and Canada, railway companies of the three countries have created railway networks between them. This may be a factor towards the accelerated adoption of electric trains in Mexico.
Because of its initial situation and its access to cheap natural gas, the energy transition will extend between ten and twenty years after 2050, which will offer time for the depreciation of gas-fired technologies.

11. **Markets.** Develop secondary markets in the power sector, focusing on electricity trading and its financial derivatives (futures, swaps, options, etc.) to allow the residential and commercial segments to select the energy sources they want to acquire and allow the industrial sectors to calculate their prices in the very long term. This also implies going deeper with the reforms in the power sector to adopt schemes of the Consumer Choice type, whereby regulated end users can choose the electricity supplier that suits them best.

12. **Education.** Promote education policies on energy transition to develop habits regarding energy consumption in the population. During this stage, the energy transition should be included at all education levels and in awareness campaigns addressed to society.

Stage II - Implementation

In the second stage, there will be more investment.

1. **Public policies.** Develop the transition plans to NZ in the planning horizon that is finally defined.
   Energy efficiency. Promote energy efficiency in all segments of the economy (residential, industrial, commercial, transportation, agricultural, public sector, etc.) in order to reduce energy consumption. The alignment of prices, subsidies, banking regulations to foster the energy transition and the introduction of a carbon price in line with international markets (through taxes or emission trading markets) should be drivers for this investment.
   Promote equipment and car replacement and scrappage programs, focusing on trucks and cars, given the expected advance in EV development and prices.
   These programs must promote electric vehicles and trucks running on LNG and CNG to use the competitive advantage of this fuel.

1. **Subsidies and prices.** Fossil fuel prices and electricity tariffs must be designed to internalize environmental and remediation costs, and subsidies should be established for people with unfulfilled energy needs. In this way, consumers will modify their consumer decisions and producers and importers will make better production decisions.

3. **Regulations.** Foster tariff schemes that envisage investment in mitigation and adaptation to climate change.
   Promote restrictive regulations for the vehicle fleet in order to incentivize the replacement of highly polluting units and the design of cities that allow the use of alternative transportation systems (electric public transport, bicycles for short distances, etc.).

Develop further regulations to allow for generation massification with renewable energy.
Within the fiscal incentives, it should be established that taxes on carbon should relate to remediation and adaptation costs and they should not fall behind for lack of updating with the required frequency.
Develop regulations to promote policies based on hydrogen and CCUS technologies to reduce uncertainty in such businesses.

4. **Social aspects.** Propose socio-environmental agreement schemes to make the development of hydrogen projects and CCUS technologies viable, as well as clean power generation in marginated communities and compensation for regions that must change their production orientation (from fossil to clean energy or to another type of production of goods or provision of services).

5. **Transition fuels.** Maintain the investment in the gas sector and promote CNG and LNG in transportation and power generation as a mechanism to ensure the phase-out of part of the hydrocarbon value chain in the last stage.

6. **Reconversions.** Since Mexico has had strong investment in gas pipelines, refineries, and regasification terminals in the last 15 years, these assets will be operative for the whole third decade of the cycle. However, given the impact on some regions like Campeche, reconversion plans need to be developed in this period.
Develop public reconversion policies in the regions that have abandoned coal and in those that will have to abandon hydrocarbon production.

7. **Smart grids.** Consolidate the energy infrastructure by promoting investment in smart grids and energy storage systems to facilitate the integration of renewable energy and enhance supply reliability.
The introduction of smart metering systems seeks to provide more adequate price signals to energy consumption.

In addition, data transmission schemes should be envisaged to be able to create a safe data administration scheme of the centralized transmission and distribution grid (including cybersecurity aspects) without neglecting distributed generation.

8. **Transportation**. Foster clean technologies in transportation, including electric vehicles and their associated charging infrastructure, and promote freight vehicles running on LNG or CNG as transition fuel.
Implement electric railway transportation to transport cargo and passengers.

9. **New technologies.** Develop concessional financial instruments to implement hydrogen and CCUS technology projects[46].

Stage III - Development

In the third stage, efforts are concentrated on few objectives.

1. **Energy efficiency.** Promote energy efficiency in all segments of the economy (residential, industrial, commercial, transportation, agricultural, public sector, etc.) in order to reduce energy consumption. The alignment of prices, subsidies, financial regulations to promote energy transition, and a carbon price (carbon tax or emission trading systems) should foster this investment.
Promote replacement and scrappage programs for equipment and cars, focusing on all the equipment using liquid fuels. Start programs to shift freight transportation to electricity and hydrogen depending on the technology available.

46 Several pilot projects are being proposed to finance hydrogen and CCUS; however, these mechanisms seek to allow an increase in the amount of funds through the development of these technologies. Here, what is proposed is financing technologies that have already been developed.

2. **Subsidies and prices.** Prices must be defined in the energy markets and subsidies for people with unfulfilled energy needs should be maintained.
3. **Regulations.** Within the fiscal incentives, carbon price mechanisms should reflect social costs so that they incentivize scrappage and the replacement of such equipment.
4. **Reconversions.** Financially assist those regions and production sectors affected by the phase-out of oil extraction assets and coal mine exploitation assets.
5. **Transportation.** Promote clean technologies in transportation, hydrogen, and electrical, and their associated charging infrastructure. Implement transportation by electric railway, and electric or hydrogen-based freight and passenger transportation.
6. **New technologies.** Promote the massive adoption of the new technologies with proven emission reduction, such as new energy efficiency practices, CCUS, and hydrogen.

"During preparation, transition strategies must be undertaken in regions with coal-fired electricity generation to prevent social externalities (Guerrero and Coahuila). Additionally, environmental standards for national production of automotive fuel will need to be updated."

2. The roadmap

In order to develop the roadmap, three stages have been proposed. In the first stage, there are two phases, one for debate and another for development, where the public policies to be developed and the segments that require concessional financing or support are defined. Table 13 shows the policies by topic and the expected action.

The debate phase is focused on conceptualizing with the countries the implications of the just energy transition between 2024 and 2025. This transition raises the need to combine economic plans that allow high growth rates and an enhancement of the population's quality of life through public policies that focus on reducing energy needs.

Moreover, the just energy transition must also discuss the financing of the transition measures in line with the content of Article 7 of the Paris Agreement.

Table 13 ▶ Roadmap to be promoted by CAF

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Public policies	- Integrate the concepts of JET in the plans of the SEMARNAT, SENER and the Secretary of the Treasury and Public Credit (SHCP).	- Issue the first plans for the JET integrating clear decarbonization targets in the long term.	- Adjust JET plans to the deadlines to meet decent standard of living goals.	
Access	- Achieve total coverage of electricity services. - Achieve universal access to clean cooking (firewood substitution).			

Cont'd

Cont'd

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Energy efficiency	- Design, finance and implement replacement policies for home appliances (refrigerators, air conditioning, space heaters, etc.). - Implement stronger policies to promote natural gas in freight transportation and seek financing to replace old commercial vehicles with low efficiency with LNG and CNG equipment. - Promote studies for business reconversion in order to eliminate the use of coal and fuel oil.		- Continue the replacement policies, including all types of appliances and insulating equipment in the home. - Promote plans to replace commercial and private vehicles with low efficiency with vehicles running on LNG or CNG in the case of the former and start introducing electric vehicles in the residential sector.	- Continue the replacement policies, including all types of appliances and insulating equipment in the homes. - Promote plans to replace freight vehicles with low efficiency with electric or hydrogen-based vehicles. - Massively introduce electric vehicles in the residential sector.
Energy subsidies	- Analyze the subsidy system, its legal and economic considerations, and propose enhancements so that they do not modify price signals and thus consumer and investment decisions of the economic agents. - Reduce the State's contribution.	- Modify rules that support subsidies to grant them to people below the poverty line. - Implement new subsidy mechanisms focused on a target population.	- Focus subsidies on the inhabitants with unfulfilled energy needs.	
Fuel prices	- Eliminate the liquid fuel price mitigation system through reductions in the IEPS to reinforce the vehicle reconversion process.	- Modify the regulations by introducing a price mechanism that gradually reflects international market prices. - Modify the regulations by introducing modifications in the subsidy system.	- Increasingly internalize remediation costs in fuel prices, either through taxes on emissions or emission trading systems.	

Cont'd

Cont'd

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Tariffs of public services	- Propose regulations that allow for decoupled tariffs, which are necessary to remunerate companies.	- Establish decoupled tariffs (that is, tariffs that reflect their economic costs).	- Internalize investment in mitigation and adaptation in the tariffs.	
Regulations	- Strengthen fiscal and financial incentive policies that promote investment in renewable energy and energy efficiency. - Promote financial regulations that incentivize loans associated with energy transition (renewable sources and transition fuels). - Reinforce the regulatory agencies, guarantee their technical, legal, and budget independence. Recover the lost human capital.		- Promote regulations that favor electric, hybrid or natural gas-based vehicles in order to incentivize the replacement of highly polluting units. - Within the fiscal incentives, carbon taxes should relate to remediation and adaptation costs. - Develop regulations to foster policies related to hydrogen and CCUS in order to reduce uncertainty in these businesses.	- Within the fiscal incentives, carbon taxes should reflect their social cost so that they incentivize scrappage and the replacement of this equipment.
Transportation	- Promote the reconversion of freight transportation fleets to electric railways and vehicles running on LNG and CNG.		- Promote the introduction of electric vehicles in the private segment. - Continue promoting electric trains.	- Start promoting trains and vehicles running on hydrogen for freight transportation.
Socio-environmental aspects for project development			- Propose socio-environmental agreements to make the development of hydrogen and CCUS projects viable.	
Fuel transition	- Allow banking regulations to finance the gas sector.	- Maintain investment in the gas sector and promote LNG and CNG in transportation as a mechanism to ensure the phase-out of part of the hydrocarbon value chain in the last stage. - Continue taking advantage of the competitive prices of importing natural gas.		

Cont'd

Cont'd

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Reconversions		- Start studies on the impact on communities related to the exploitation of coal, other minerals, and oil. - Develop strategic plans to reconvert regional economies associated with extractive industries to ensure the JET.	- Implement strategic plans to reconvert regional economies associated with extractive industries to ensure the JET.	- Establish programs to mitigate the impact of the JET on the sectors that could not achieve their reconversion.
Phase-out of plants running on fuel oil		- Establish regulations to phase out coal and fuel oil-fired plants that remain operational.		
Phase-out of hydrocarbon assets	- Establish a plan of additional assets to be developed for the transition. - Start developing plans to reconvert hydrocarbon-dependent economies in order to create regulations and business rules that allow promoting new businesses in the region.	- Implement promotional regulations and rules for strongly hydrocarbon-based areas. - Develop compensation and contribution plans to provide resources to areas that will reconvert.	- Start financing policies to make new business viable in the region.	- Implement financing policies to make new businesses viable in the region. - Develop the necessary policies to relocate the population in case reconversion plans are not effective.
Development of smart grids (AMI)	- Analyze the mechanisms to integrate smart grids in transmission and distribution, and international financing to allow for a better administration of the system as a whole.	- Introduce smart metering		

Cont'd

Cont'd

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Integration of renewable energy and storage systems	- Develop detailed certification, operation, and remuneration rules for storage services.	- Include storage systems in the planning to expand generation, transmission, and distribution in the sector to integrate large amounts of renewable energy.		
Operation of distribution and transmission grids in a coordinated way		- Develop integrated operation mechanisms between distributors and transporters.		
Development of secondary electricity markets		- Deregulate commercial and residential commercialization to introduce consumer decisions based not only on prices but also on the type of energy produced. - Introduce derivative markets for all energy segments. - Advance in competition schemes at end supply level for regulated consumers.		

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