JUST ENERGY TRANSITION

Scenarios for Colombia

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CAF DEVELOPMENT BANK OF LATIN AMERICA AND THE CARIBBEAN

Just Energy Transition / Conceptual framework for the region, Analysis in the national context

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Just Energy Transition

Scenarios for Colombia

DEVELOPMENT BANK OF LATIN AMERICA AND THE CARIBBEAN

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List of abbreviations

List of abbreviations

AFOLU	agriculture, forestry and other land use
AMI	advanced metering infrastructure
BAU	Business as usual
BECO	Colombian Energy Balance
CAPEX	capital expenditures
CAT	Climate Action Tracker
CAGR	compound annual growth rate
CCUS	carbon capture, use, and storage
CNG	compressed natural gas
DANE	National Administrative Statistics Department (Departamento Administrativo Nacional de Estadísticas)
EE	energy efficiency
FAER	Financial Support Fund for the Energization of Interconnected Rural Areas (Fondo de Apoyo Financiero para la Energización de las Zonas Rurales Interconectadas)
FAZNI	Financial Support Fund for the Energization of Non-Interconnected Areas (Fondo de Apoyo Financiero para la Energización de las Zonas No Interconectadas)
FENOGE	Fund for Non-Conventional Energy and Efficient Energy Management (Fondo de Energías No Convencionales y Gestión Eficiente de la Energía)
FEPC	Fuel Price Stabilization Fund (Fondo de Estabilización de Precios de los Combustibles)
FSSRI	Solidarity Fund for Subsidies and Revenue Redistribution (Fondo de Solidaridad para Subsidios y Redistribución de Ingresos)
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
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IREES	Resource Efficiency and Energy Strategies Institute (Institut für Ressourceneffizienz und Energiestrategien)
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
NCRE	non-conventional renewable energy
NZ	net zero
OLADE	Latin American Energy Organization
PPP	purchasing power parity
PROURE	Program for the Rational and Efficient Use of Energy
SEI	Stockholm Environment Institute
SHW	sanitary hot water
sieLAC	Energy Information System for Latin America and the Caribbean
SIN	National Interconnected System
TJ	terajoules
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
UPME	Colombia's Energy Mining Planning Unit (Unidad de Planeamiento Minero Energético)
WEC	World Energy Council
XM	electricity market administrators
ZNI	non interconnected areas

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 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 (target countries) energy systems – 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 achieve 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: Colombia

This report contains the energy transition analysis for Colombia and is organized into four chapters.

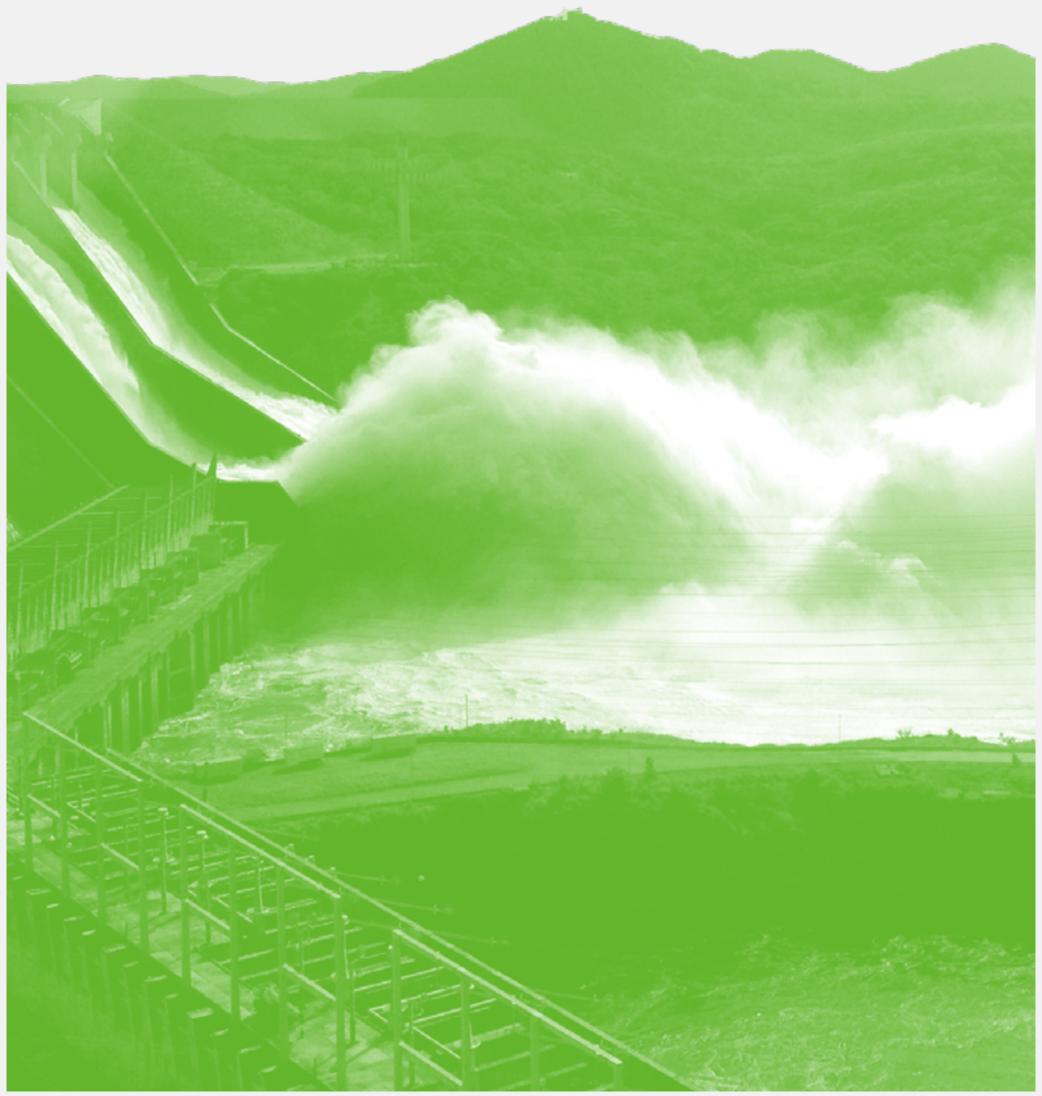
- **Diagnosis and base line.** This chapter establishes the diagnosis of the base line in terms of sources and energy uses, characteristics of the power sector, environmental aspects (greenhouse gas (GHG) inventories, commitments), and institutional, regulatory, and public policy aspects, among others. 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.

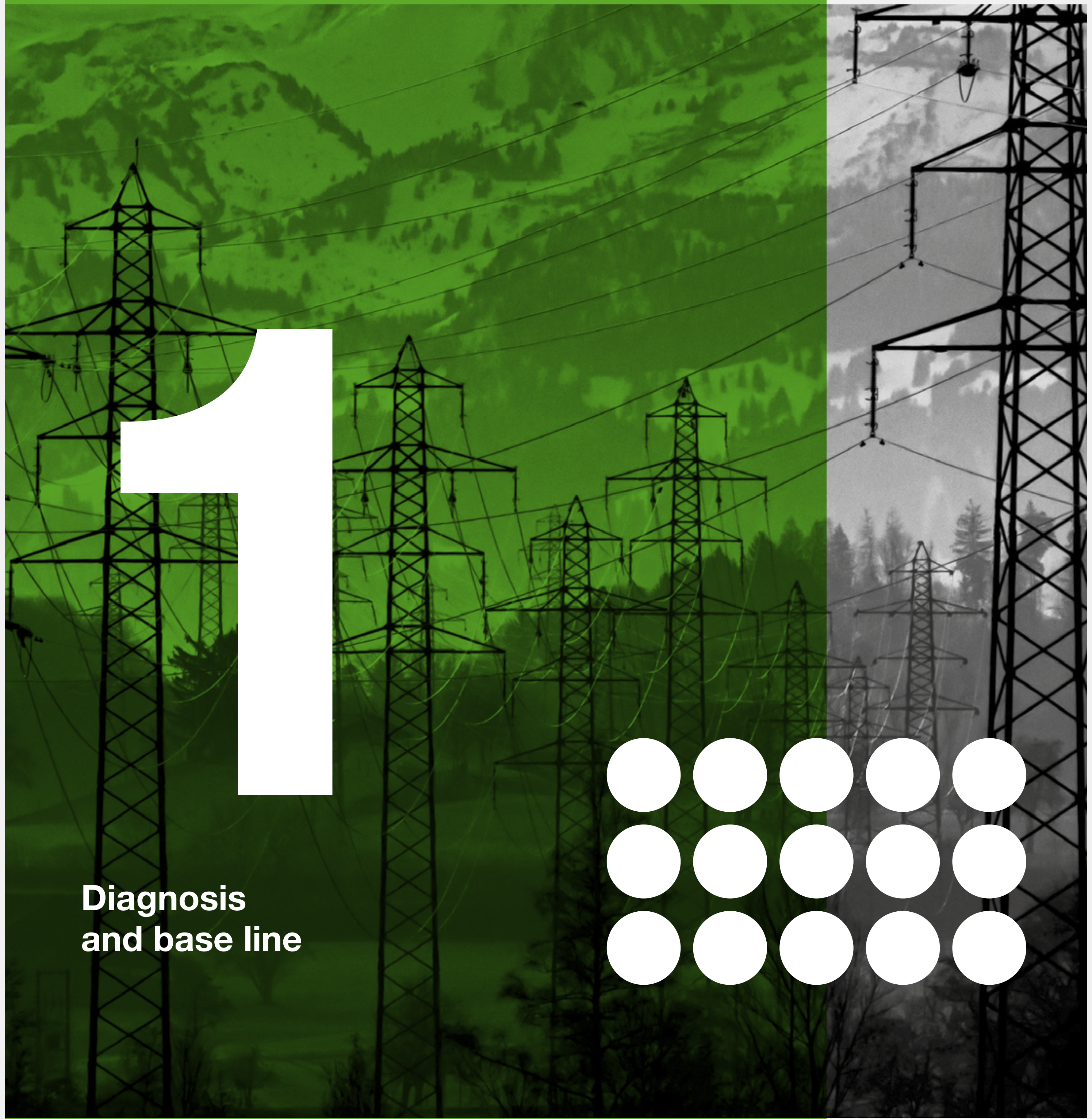
- **Energy projection methodology.** This chapter summarizes the low-emissions analysis platform (LEAP) model and its use to model emissions in the energy sector[1].
  Energy demand projection methodologies are presented by sector, subsector, uses, and sources, as well as the power generation modeling. 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.

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

- **Proposal for a 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. General characterization

Socio-economic aspects

Colombia is the fifth largest country in Latin America in terms of area and the third in terms of population. Most of the population lives in cities (81 %, a quarter of which lives in cities with over 1 million inhabitants).

Table 1 Socio-economic indicators

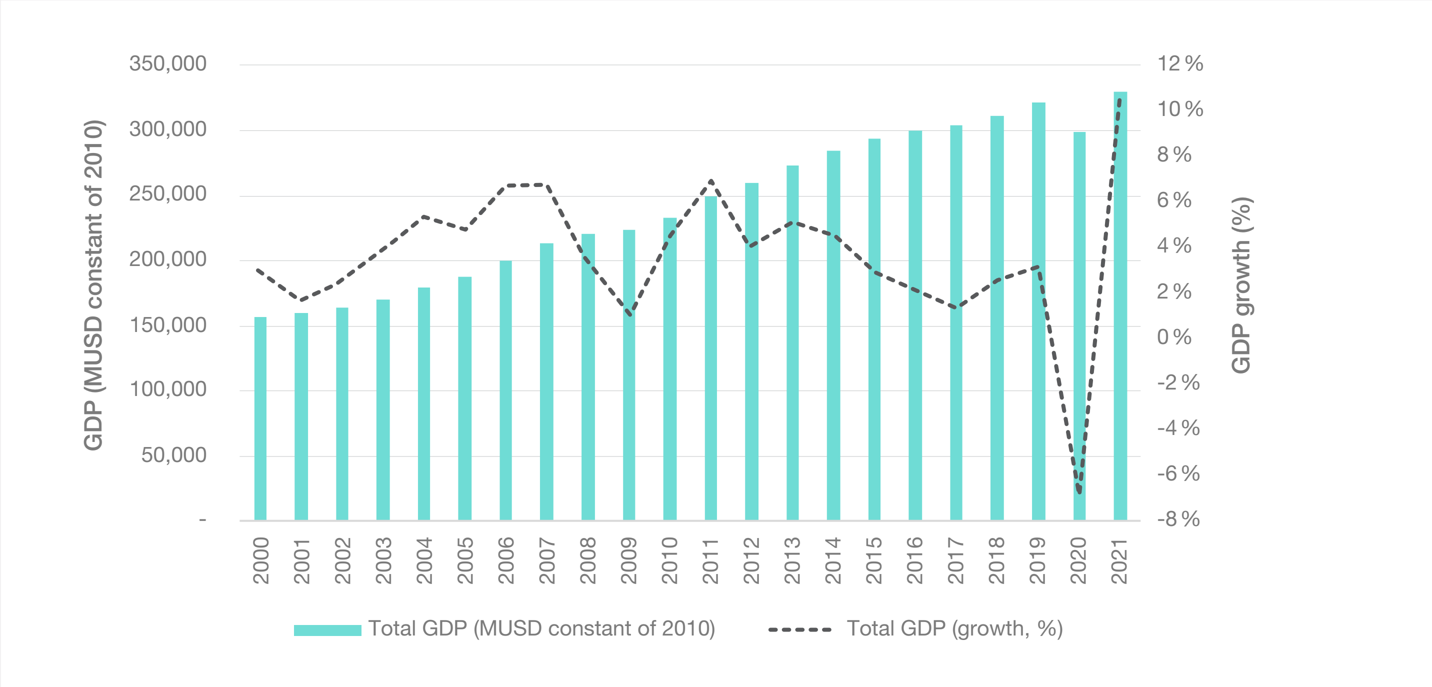
Indicator/Country	Colombia
Total population (2021, millions)	51.27
Population density (inhab. /km2)	45
Urban population (%)	82 %
GDP per capita 2021 (USD at constant 2010 prices)	6,443
Extreme poverty index 2020	19.2 %

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

Colombia was the fourth largest economy in Latin America in terms of nominal gross domestic product (GDP) in 2021. Historically, Colombia has experienced strong economic growth, with an annual growth of around 3.7 % (between 2000 and 2021). In the 2000s, Colombia benefited from the rise in raw material prices (especially oil prices) and the competitive exchange rates. More recently, in the last five years, its economic growth has slowed down. In 2020, the impact of the COVID-19 pandemic was significant in Colombia, as in many other countries in the region.

Diagnosis and base line

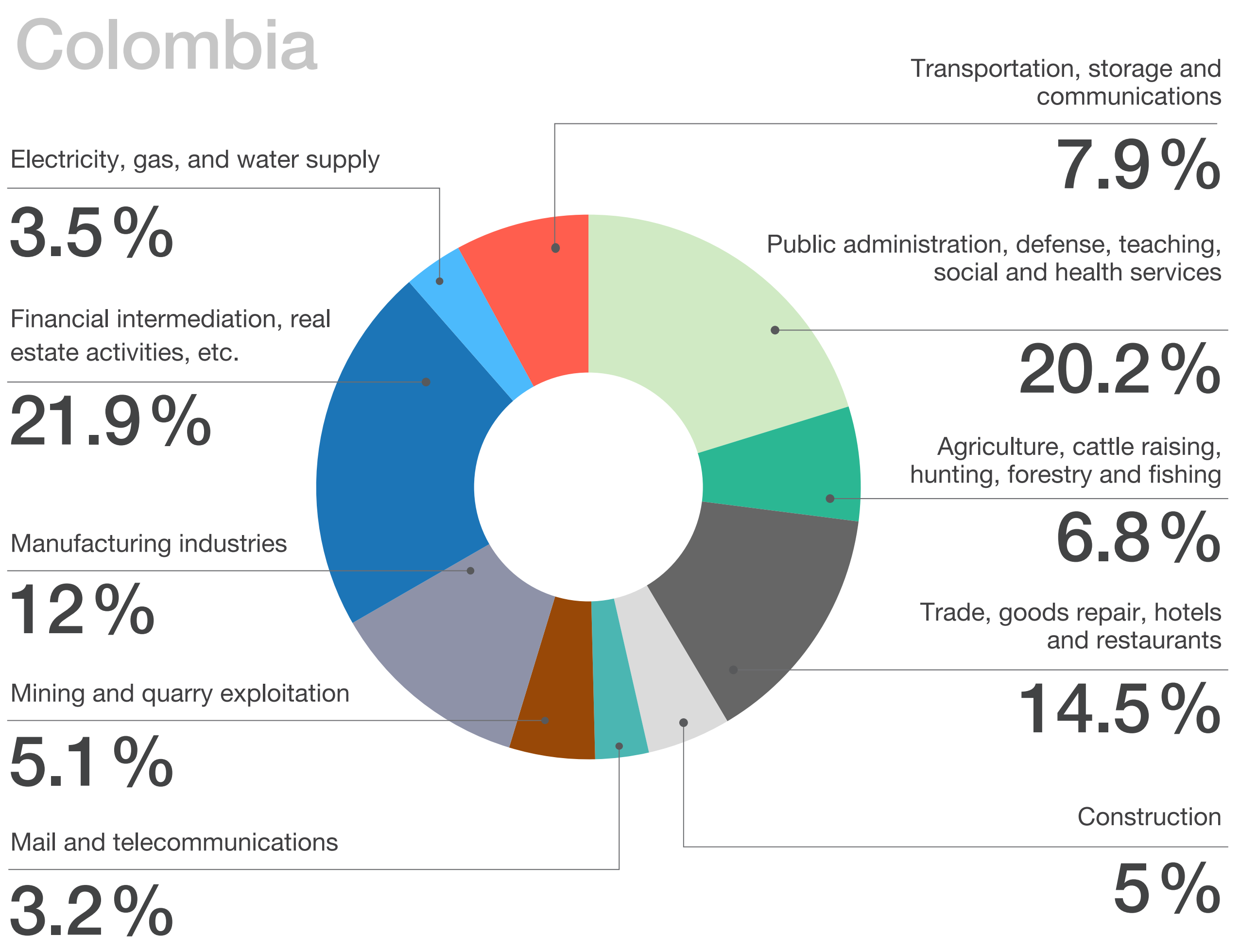
Graphic 1 GDP and annual growth rate, millions of constant USD of 2010 and %



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

In spite of being a producer, especially of primary goods (such as coffee and mineral products), Colombia has managed to diversify its economy and nowadays its main economic sector is services, followed by the industrial sector, and the agricultural sector. In 2019, its main exports in terms of prices were crude oil, coal, and refined oil.

Graphic 2 ▶ GDP by sector, 2021, %

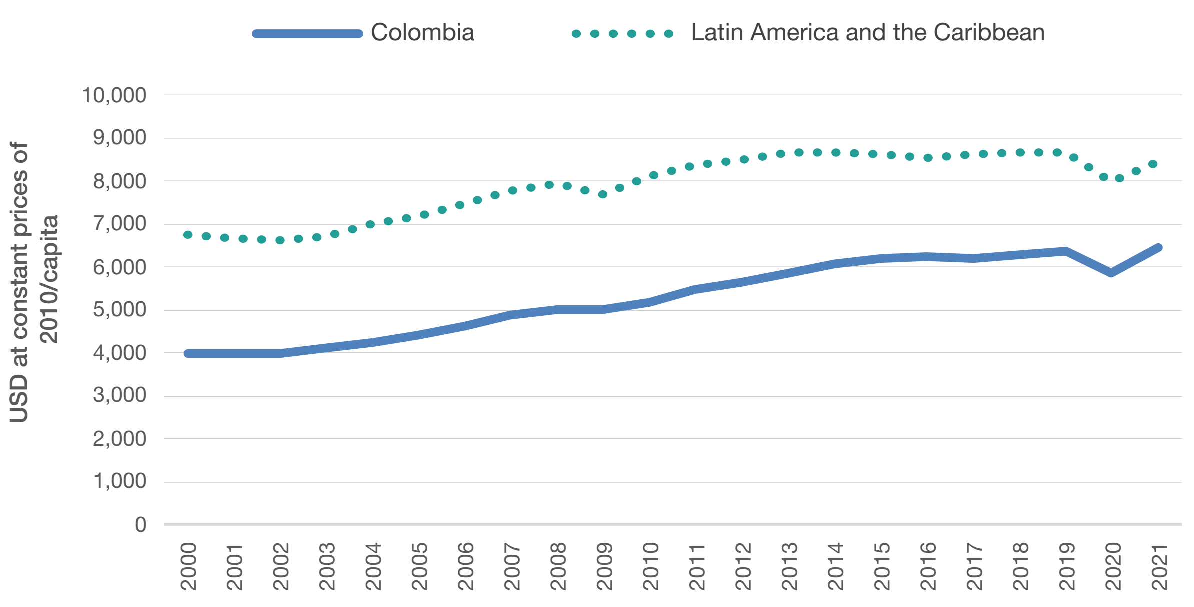


Source: Own preparation based on data from CEPAL.

Diagnosis and base line

Except for certain specific years, the GDP per capita has recorded an upward trend in the last 20 years. In 2021, it was 6,443 constant USD dollars of 2010 per capita, below the average in the region.

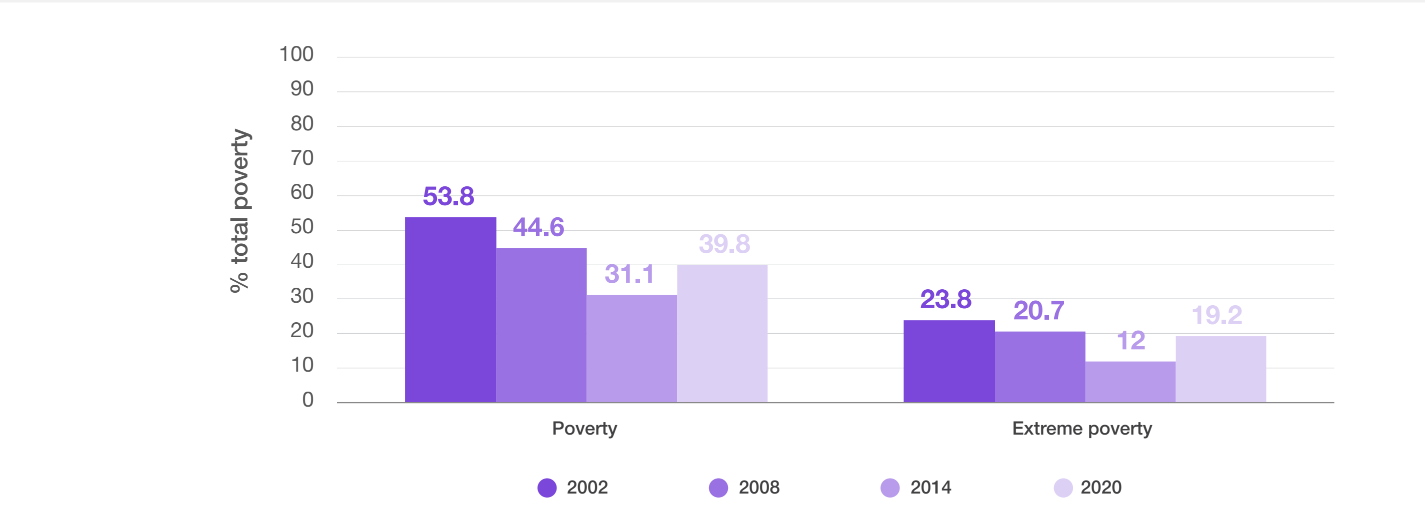
Graphic 3 ▶ GDP per capita, constant USD of 2010 per capita



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

Colombia's historical economic performance did not result in widely shared prosperity, as it has one of the worst income distributions in Latin America (GINI index of 0.5 in 2021). The poverty rate fell in the period 2002-2014, but rose again in 2020. At present, 19 % of the population live in extreme poverty situations.

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



Source: Own preparation based on data from CEPALSTAT.

Socio-economic and energy indicators

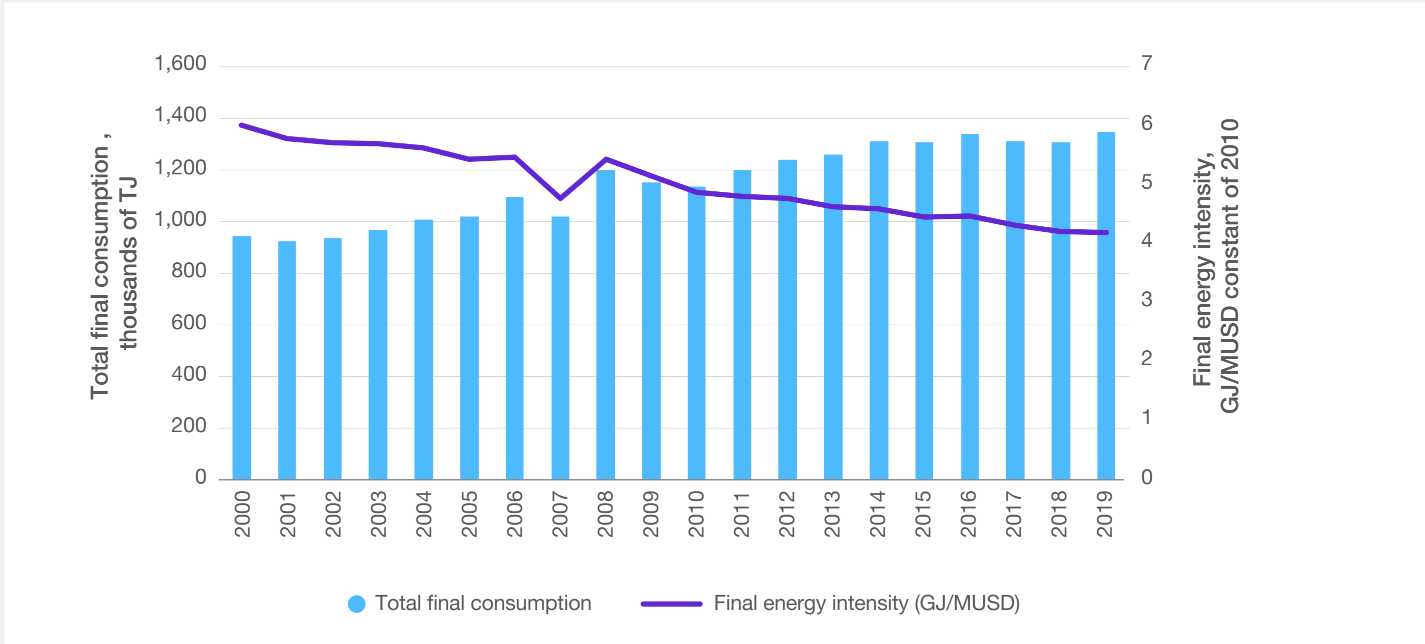
Energy intensity of the economy

Final energy intensity[2] reduced significantly in the period 2000-2019 (cumulative -30 %, annual average -1.9 %) whereas total final consumption rose at an average annual pace of 1.9 %. his reduction can be partially explained by the progressive

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

evolution of the economy towards a services economy and the impact of certain energy efficiency enhancements[3], among other factors.

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



Source: Own preparation based on data from sieLAC, OLADE[4] .

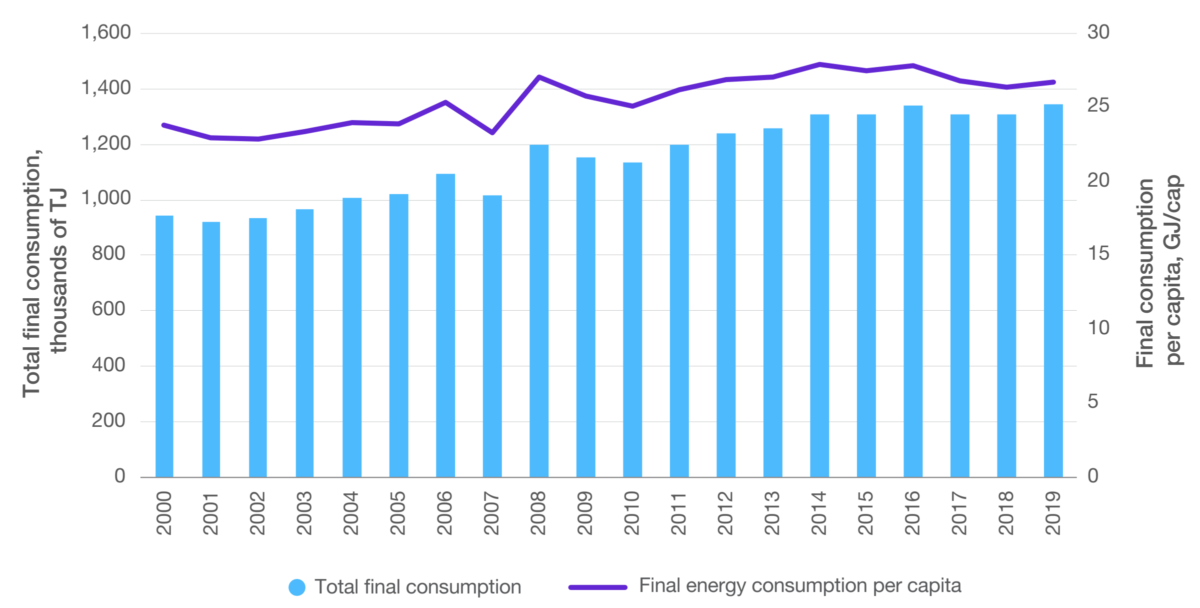
3 For example, the savings from the Program for the Rational and Efficient Use of Energy (PRORURE) promoted by Colombia's Energy Mining Planning Unit (UMPE), which implied investment in the energy and transportation sectors, and in other sectors such as the replacement of bulbs with more efficient energy-saving units and LED bulbs, substitution of LPG for firewood for cooking, certain enhancements in urban transportation (for example, Transmilenio).

4 Data on energy intensities calculated internally in the system, with GDP data from the World Bank and data on energy intensity from the national energy balances.

Consumption per capita

The growth in final energy consumption per capita was lower than that of total final consumption in the period 2000-2019 (0.6 % vs. 1.9 %) and slowed down until it stabilized in 2016-2019.

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 are Colombia's end consumer prices. Both for natural gas in the commercial sector, regular gasoline, and aviation fuel (jet fuel), Colombia shows low pieces. For the rest of the energy sources, prices are close to the average in the region.

Table 2 Prices of the main energy resources in Colombia, cut-off year 2018

Energy resource	VAT %	Special taxes[5]	Price[6]
Electricity (residential)	-	-	146.25 USD/MWh
Electricity (commercial)	-	-	131.90 USD/MWh
Electricity (industrial)	-	-	101.88 USD/MWh
Natural gas (residential)	-	-	12.59 USD/MBtu
Natural gas (commercial)	-	-	11.44 USD/MBtu
Natural gas (transportation)	-	-	4.6 USD/MBtu
Natural gas (industrial)	-	-	4.0 USD/MBtu
LPG (residential)	-	-	0.64 USD/kg
Regular gasoline	19 %	Yes	0.66 USD/l
Diesel	19 %	Yes	0.65 USD/l
Jet fuel	19 %	Yes	0.38 USD/l
Fuel oil (power generation)	19 %	Yes	0.18 USD/l
Fuel oil (industrial)	19 %	Yes	0.20 USD/l

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

5 The current special tax on gasoline is USD 0.04 per liter and the one on special gasoline is USD 0.08 per liter, and equal 5 % and 7 %, respectively.

6 Prices include charges for carbon tax, and special taxes on energy and electricity production, which are collected in the first transaction and are not part of the taxes applied to consumers. The special tax on electricity is 4% and the one on the value of energy production is 7%; the carbon tax levies natural gas, coal, jet fuel, gasolines, LPG, and fuel oil. These taxes are paid as part of the value chain costs.

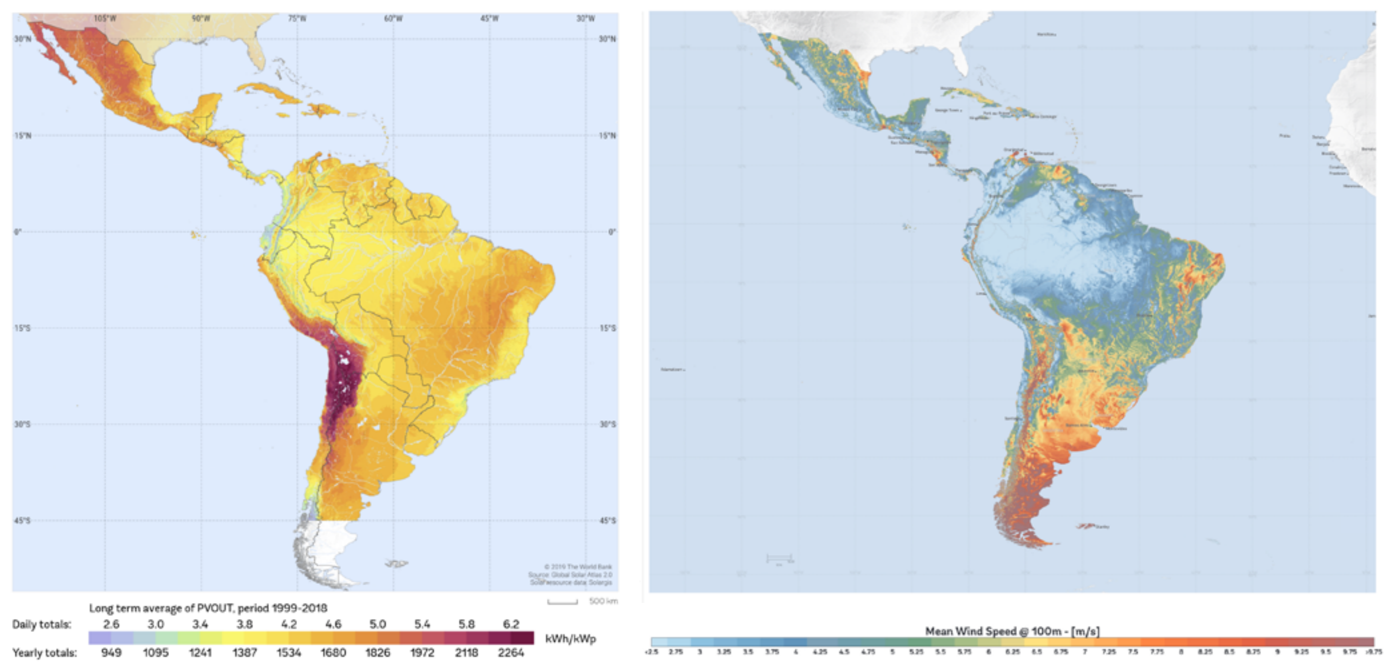
Energy aspects

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

Colombia has significant energy resources, particularly charcoal, coal, oil, and hydro power. As to its solar resource, according to the Global Solar Atlas platform, Colombia shows a value of 1,573 kWh/kWp for 10 % of the areas with the greatest photovoltaic production and an average of 1,478 kWh/kWp. As a reference, the global resource for 10% of the areas with the greatest irradiation was established at 1,736 kWh/kWp and the global resource average was established at 1,576 kWh/kWp. The greatest concentration of the solar resource is in La Guajira peninsula and in Orinoquia. On the other hand, its wind resource for 10 % of the areas with more wind is equal to or higher than 259 W/m^2, where the mean wind speed at 100 meters is 5.9 m/s or more. In the windiest localities in La Guajira (10 %), there are winds of 10.6 m/s at 100 meters.

Diagnosis and base line

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



Source: Global Solar Atlas (World Bank)[7] and Global Wind Atlas (World Bank)[8].

Colombia's resource availability is evidenced both in the power generation mix and in the final demand for fuel. Hydro power is a significant part of electricity production and fossil fuels play an important role in the supply of primary energy. It also has a great refining capacity that allows it to supply both its internal demand and its exports.

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

8 ws_LAC.pdf

Table 3

Fuel reserves, hydroelectric potential, and infrastructure, 2019, Colombia

Reserves				Potential	Installed capacity	
Oil	Natural gas	Coal	Uranium	Hydro power	Refining	Power generation
2,041	90	5,912	0	56.2	374	17.6
Mbbl	Gm³	Mt	10^6 bep	GW	kbbl/day	GW

Source: sieLAC, OLADE.

Table 4

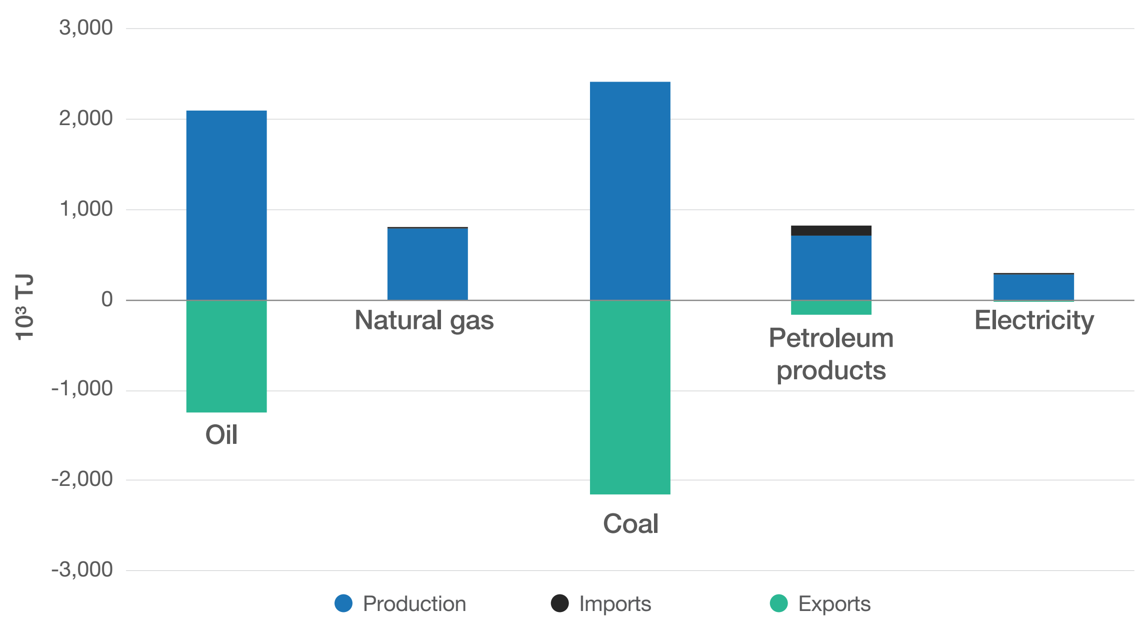
Wind and solar resources, Colombia

Resources		
Wind (10 % of the areas with more wind)	Solar (average)	Solar (10 % largest production)
5.85	1,497	1,573
m/s	kWh/kWp	kWh/kWp

Source: Own preparation based on Global Solar Atlas and Global Wind Atas.

Graphic 8

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



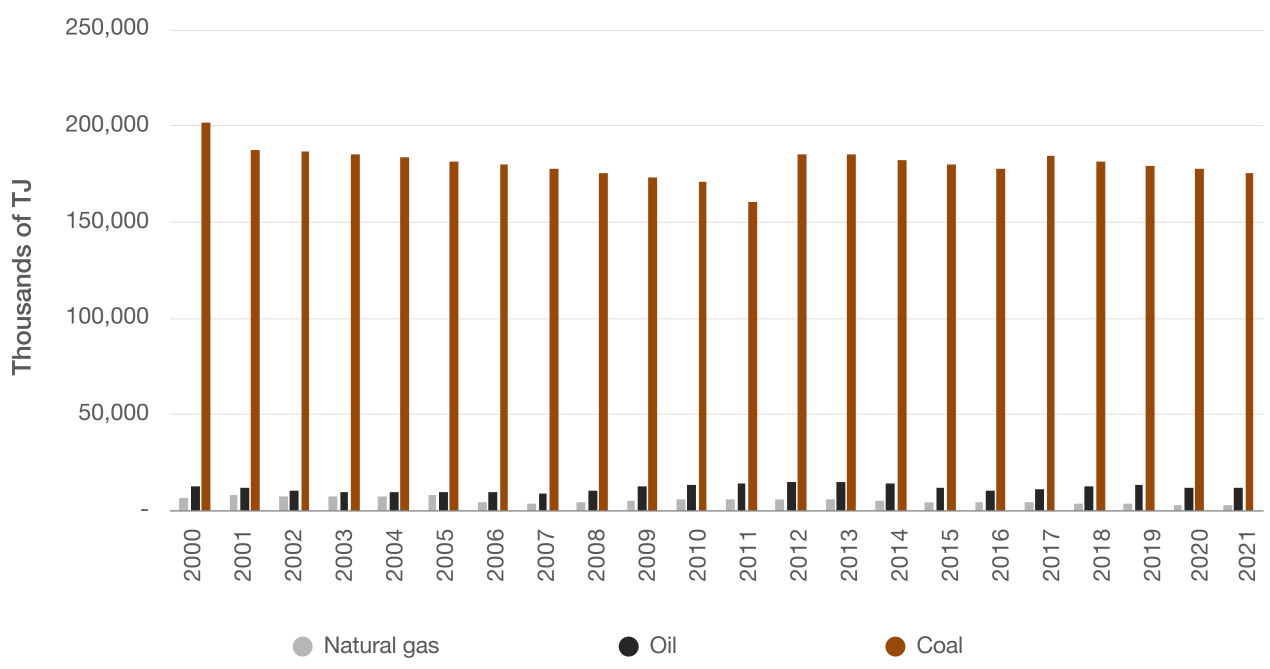
Source: Own preparation based on data from sieLAC, OLADE.

Colombia is the first coal-producing country in Latin America (12th coal producer in the world) and the fourth oil producer (2022 - sieLAC, OLADE and *Agencia Nacional de Minería de Colombia*). It exports most of its coal production (almost 90 %) and an important part of its oil production (about two thirds). It consumes its natural gas production locally and imports liquefied natural gas (LNG) through the regasification terminal at Cartagena.

Recently, power exchanges with Ecuador[9] have been more limited in volume and largely take place by way of imports in low hydrology situations in Colombia, although exports to Ecuador have been very important in the past and accounted for up to 13 % of the energy delivered to the Ecuadorian interconnected system. Globally, Colombia is a net energy-exporting country[10].

Its proven reserves of coal and oil have been maintained in the last few years, whereas natural gas reserves have decreased slightly and this trend is expected to continue unless new proven natural reserves are discovered.

Graphic 9 Evolution of proven oil, natural gas, and coal reserves, thousands of TJ



Source: sieLAC, OLADE.

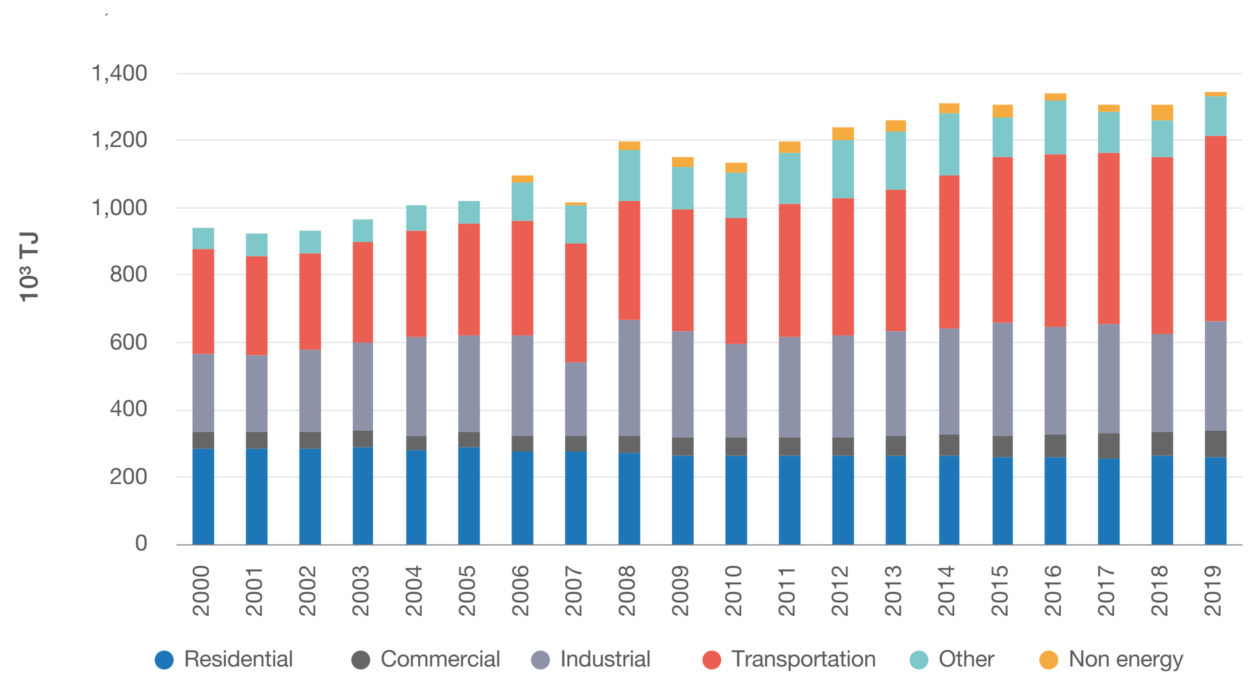
9 Power exchanges with Venezuela are historically very limited and inexistent at present.

10 Its energy foreign dependence index (relation between total energy imports less total exports divided by total energy supply) is at around -200 %.

Final consumption by source and sector

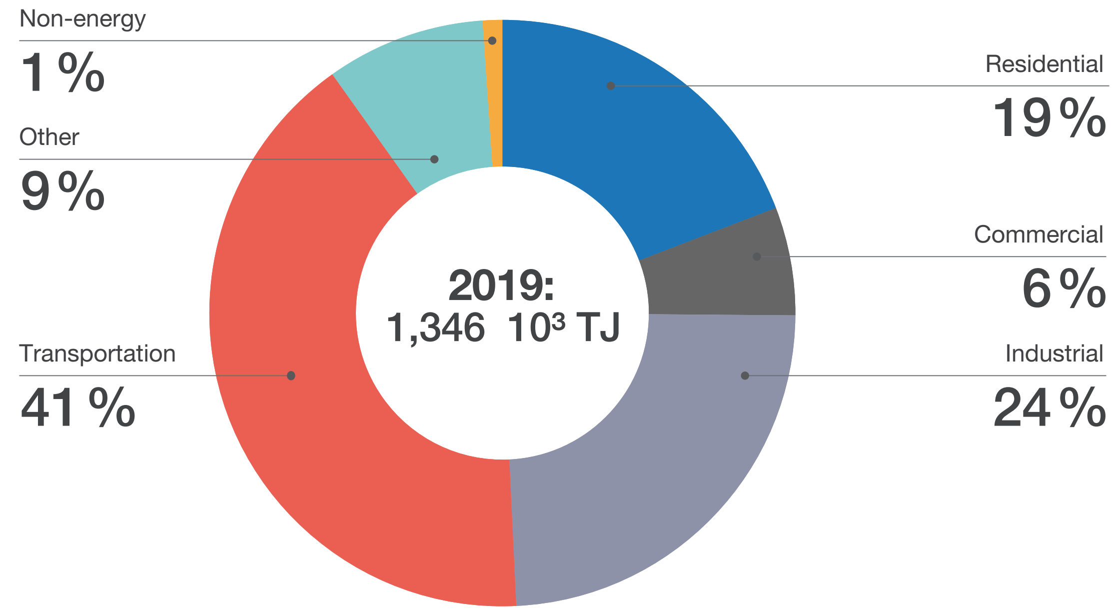
Transportation was the sector with the most consumption in 2019 and its relative weight has increased in the last 20 years, from 33 % to 41 %. On the other hand, residential demand remains quite stable and loses relative weight in the total final consumption. The industrial sector grows hand in hand with total final consumption.

Graphic 10 A Final consumption by sector, 10^3 TJ



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

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

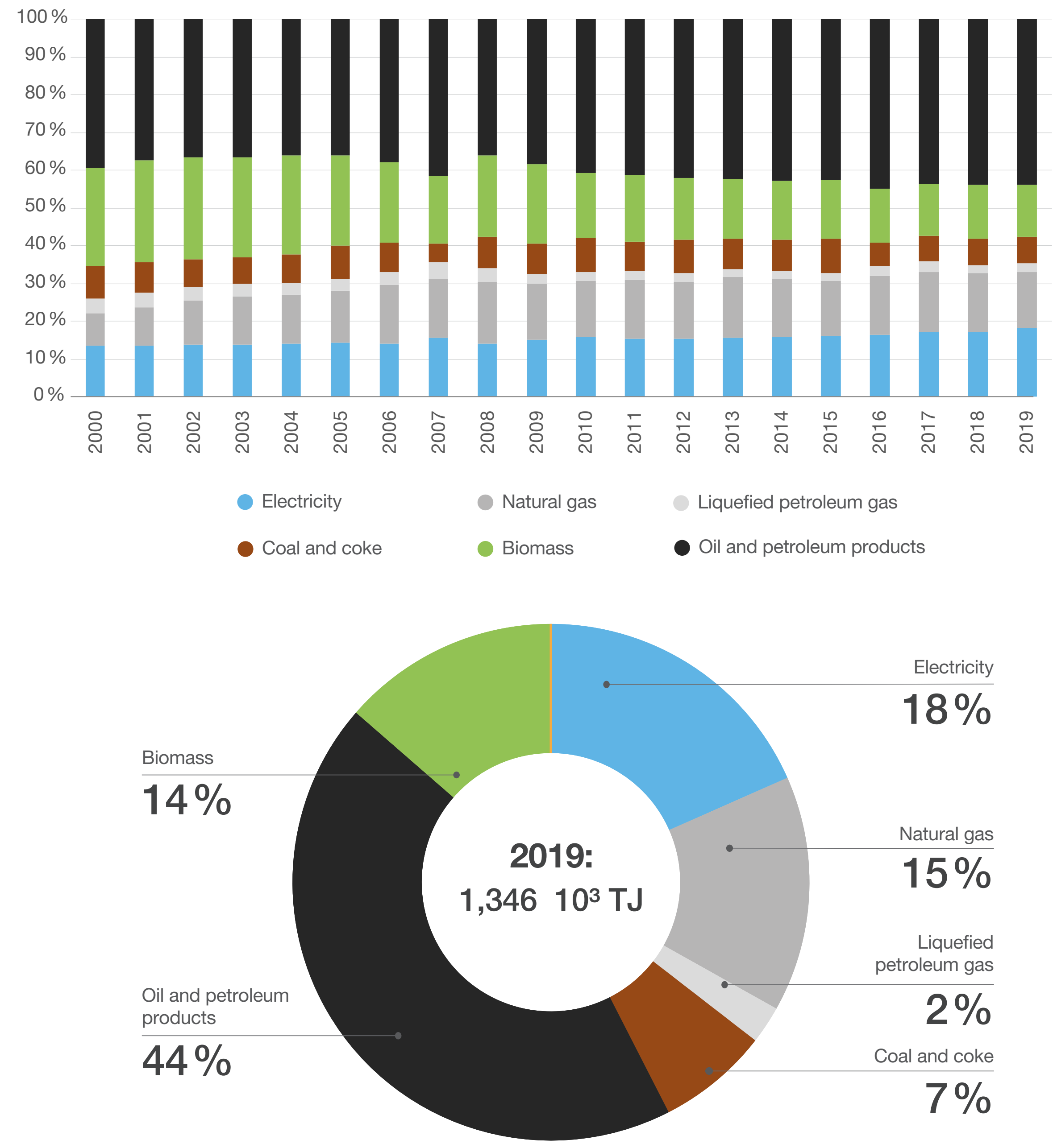


Source: Own preparation based on data from sieLAC, OLADE.

By source, electricity, natural gas, oil, and petroleum products are those with more importance in the matrix, to the detriment of biomass, coal, and liquefied petroleum gas (LPG).

Diagnosis and base line

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



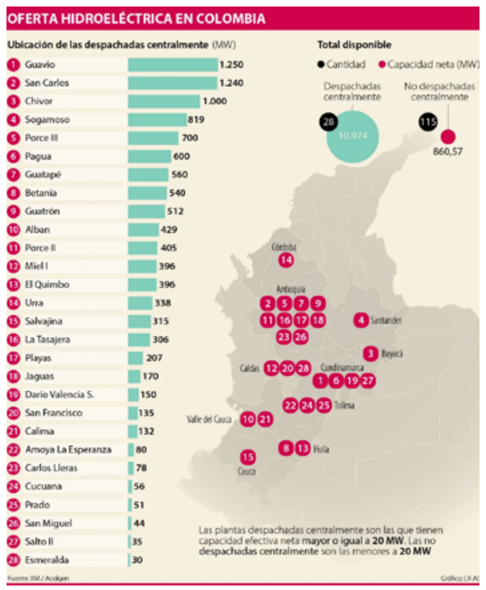
Source: Own preparation based on data from sieLAC, OLADE.

Climate profile

Climate change scenarios and risks to the energy sector

Because of its geographical location, Colombia has a high level of annual rainfall (over 3,000 mm annually), much higher than the world rainfall average (900 mm annually). The country is divided into five hydrographic areas, as shown in Graphic 12.

Graphic 12 Hydrographic areas and location of the hydro plants, 2019



Source: IDEAM and *La República*, 19/02/2019.

Rainfall in Colombia varies depending on the region. The lowest rainfall values recorded are in the north of the country, in La Guajira, and the highest in the Pacific region. In the Andean region, where the country's hydroelectric plants are located, rainfall has a more diverse behavior. The valleys in the Oriental mountain range, Alto Magdalena, and Alto Cauca show a low rainfall level whereas the central area of the valleys of the Magdalena and Cauca Rivers shows maximum rainfall levels.

Colombia faces two environmental phenomena that significantly affect its hydrology levels: El Niño, which generates extreme drought conditions due to very low rainfall levels and severely affects the country every four to six years, and La Niña, which unlike El Niño, shows excessive rainfall.

Pursuant to Colombia's long term climate strategy E2050 to meet the Paris Agreement:

> [...] The climate change scenarios for Colombia (2011-2100), prepared in the context of the Third National Communication (TNC, in Spanish) of the United Nations Framework Convention on Climate Change (UNFCCC) (IDEAM et al., 2017) show that the behavior of the mean annual temperature towards mid-21st century (between 2040 and 2070) may suffer a gradual average increase of up to 1.6 °C.
>
> These temperature increases may continue until reaching a 2.1 °C increase in continental areas in 2100. In addition, the expected rainfall behavior shows, like in the case of temperature, uneven changes in the country. Possible increases may occur until mid-century, mainly in certain sectors of the Andean region while in other geographical regions, like the Caribbean and Amazonia, a reduction in rainfall of between 10 % and 40 % may occur (IDEAM et al., 2015; 2017).

The climate change scenarios of the Intergovernmental Panel of Experts (IPCC) identify several risks related to the energy sector in Colombia. Like in Brazil, changes in rainfall regimes may affect hydro generation, which is very relevant in Colombia. For example, in *Climate Change 2022: Impacts, Adaptation and Vulnerability*[11]: "it is projected that hydroelectric energy production will decrease by ~10 % in the dry scenario RCP4.5 by 2050 (Arango-Aramburo et al., 2019)".

From the point of view of generation, not only hydro generation is vulnerable to climate change; both wind and solar generation may be affected by changes in rainfall and temperature. All this may impact on an increase in capacity to be installed so as to compensate for the reductions in hydro, wind, and solar potential.

Moreover, the existence of extreme events, like storms and floods, may affect the energy infrastructure (including transmission and distribution grids) and even interfere in the exploitation of hydrocarbons, a subsector that is currently very relevant to the country.

The effect of the climate change is not only limited to the supply-side. Changes in temperature may lead to changes in the demand for refrigeration in the residential and commercial sectors, which may generate requirements in the transmission and distribution grids. On the other hand, the global climate risk index (GCRI)[12] indicates the level of exposure and vulnerability of extreme climate phenomena. As to the period between 2000 and 2019, Colombia is positioned 38th out of 180 countries (1 is the position with the most exposure and vulnerability).

11 https://www.ipcc.ch/report/ar6/wg2/

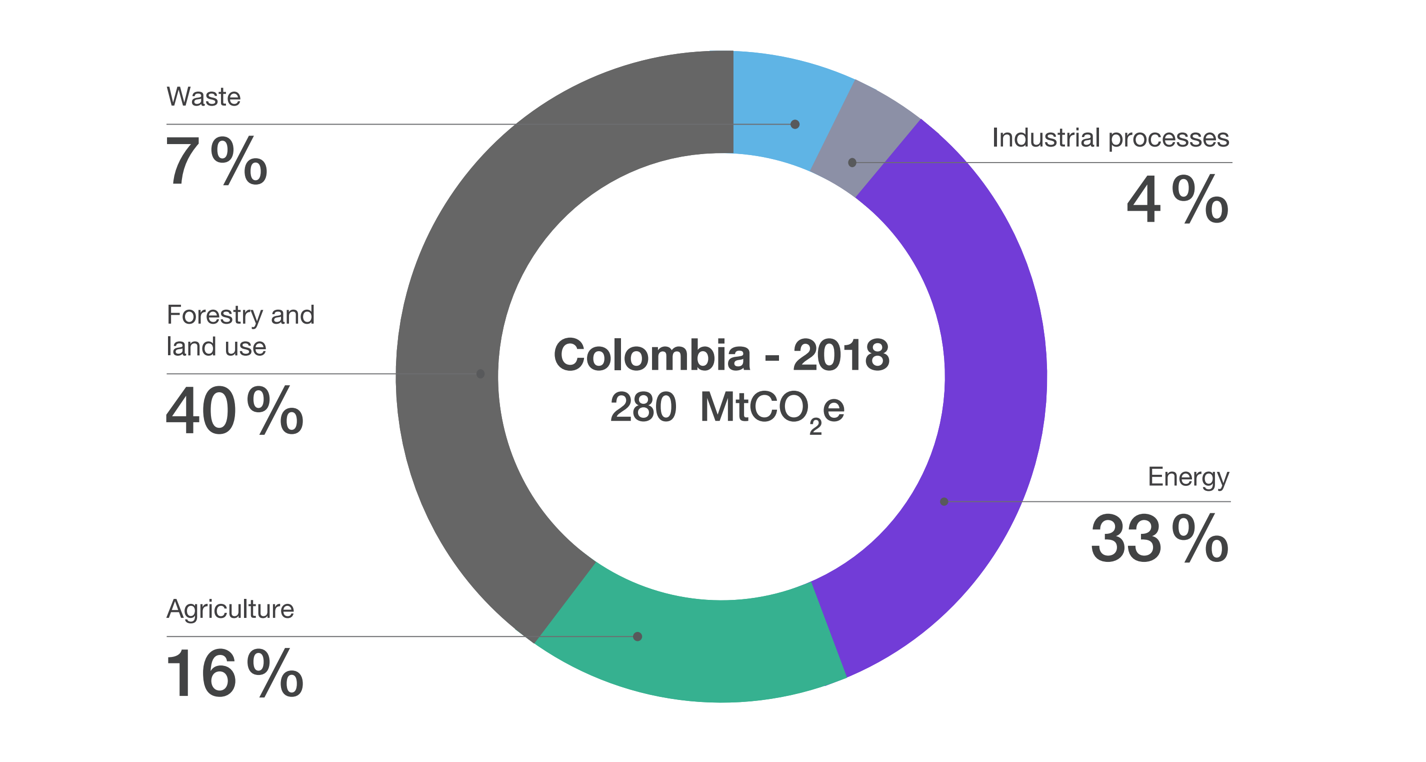
12 The GCRI comprises four indicators: number of deaths; number of deaths per 100,000 inhabitants; sum of losses in USD at power purchasing parity; and losses by gross domestic product unit. The final ranking considers these indicators with different weights and in a 20-year period.https://www.germanwatch.org/en/19777

Diagnosis and base line

GHG contribution, base year

Pursuant to the latest National Greenhouse Gases Inventory (INGEI), net total emissions in 2018 were 280 MtCO2e, 33 % of which related to the energy sector (that is, emissions from burning fuel and fugitive emissions) and 56 % to agriculture, cattle-raising, forestry, and other land uses.

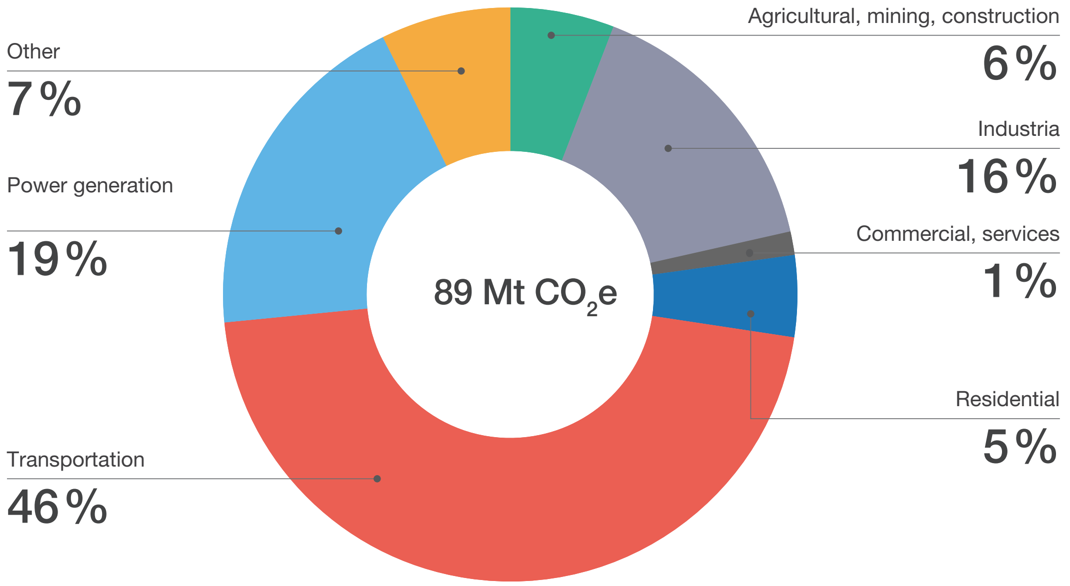
Graphic 13 Net total emissions, $MtCO_2e$



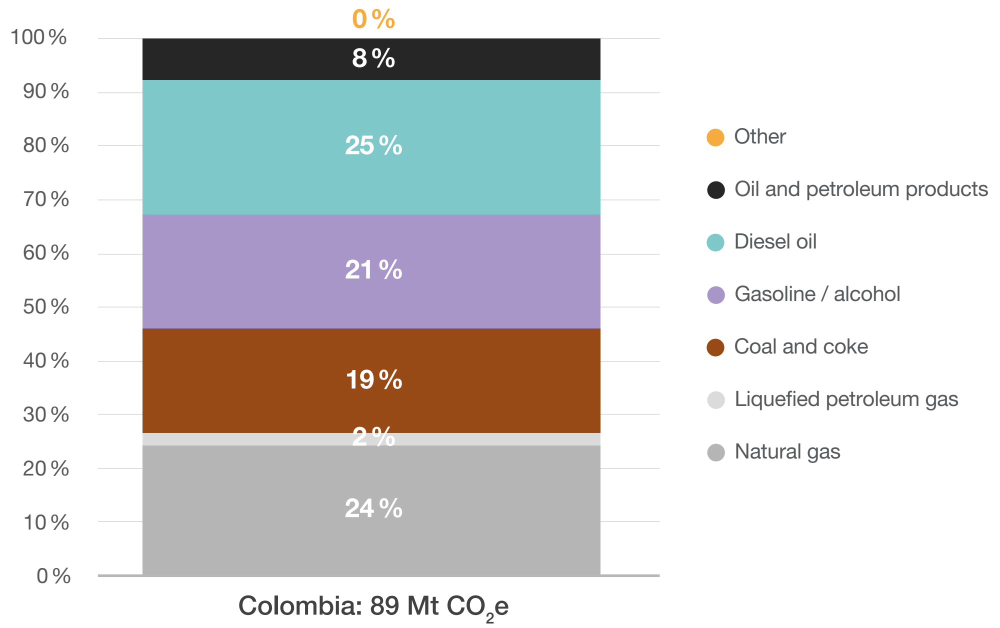
Source: Own preparation based on the national GHG emissions inventory (UNFCCC, 2018).

When specifically observing 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 14 is from an estimation of CO_2 emissions conducted by the Latin American Energy Organization (OLADE) (sieLAC).

Graphic 14 Estimated emissions from the energy sector, by sector and by source, $MtCO_2e$, 2019



Emisisions by source



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

The transportation sector accounts for around half of the energy-based emissions. The main fuels consumed by the sector are diesel and gasoline. In the second and third places, power generation and industry would account for 19 % and 16 % of the emissions in the sector, mainly due to burning coal and natural gas in both cases.

National commitments (NDC and the Paris Agreement)

Regarding commitments to reduce CO2 emissions, the following elements can be pointed out.

- The absolute target for 2030 (nationally determined contributions 2030 (NDC 2030), 169 $MtCO_2e$)[13] equals a 51 % reduction in emissions with respect to the emissions projection in 2030 in the reference scenario. Colombia is also committed to:
  - reducing black carbon emissions by 40 % compared to 2014, and
  - setting carbon budgets for the period 2020-2030 no later than 2023.
- Colombia signed the Paris Agreement, under which it 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". In practice, it is committed to reaching carbon neutrality "by 2050".

In November 2021, Colombia set a target of net zero GHG emissions by 2050 as a Long-Term National Strategy (E2050)[14] to the UNFCCC[15]. The strategy includes different scenarios and pathways towards decarbonization.

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

14 https://unfccc.int/sites/default/files/resource/COL_LTS_Nov2021.pdf This document is later than the PEN 2020-2050, which defines a long-term vision for the Colombian energy sector and identifies possible pathways to achieve it.

15 United Nations Framework Convention on Climate Change.

In December 2021, through the Climate Action Act, Law No. 2169 of 2021, Colombia undertook to promote low development in carbon in the country by establishing adaptation and mitigation targets.

In 2023, the UPME presented a National Energy Plan (PEN, in Spanish) updated for the period 2022-2052[16], which contains several scenarios with different pathways towards GHG emission reduction.

According to the organization Climate Action Tracker (CAT), Colombia needs to take stronger measures to make sure to honor its commitments. In order to strengthen climate action, some of the recommendations made by CAT are a commitment to abandoning coal, strengthening the electric vehicle target for 2030, and accelerating the establishment of cargo infrastructure.

16 https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN_2020_2050/Actualizacion_PEN_2022-2052_VF.pdf

Colombia has significant energy reserves and potential, particularly solar (32 GW), onshore wind (30 GW), and offshore wind (110 GW), to meet the growing future electricity demand.

2. Institutional, regulatory, and public policy aspects

Sectoral government

Table 5 includes a list of the main institutions in the energy sector.

Table 5 Mapping of institutions in the energy sector

Institutions	Function
Ministry of Mines and Energy (MME)	Define policies in the oil, gas, and power sectors
Energy Mining Planning Unit (UPME, in Spanish)	Plan and expand the oil, gas, and power sectors
Energy and Gas Regulatory Commission (CREG, in Spanish)	Regulate the oil, gas, and power sectors
Power System Operator (XM)	Administrate the electricity market
Natural Gas Market Manager	Administrate the fuels market

Source: Own preparation.

Main regulatory concepts

Table 6 describes the existence of price regulation and a competitive market for each energy sector and segment.

Table 6 Main regulatory concepts by sector and segment

Sector	Segments	Price Regulation	Market
Power	- Generation - Distribution - Transmission - Commercialization	- Transmission - Distribution and retail commercialization	- Competitive in generation - Free access in all the segments of the chain
Natural gas	- Exploration and exploitation - Distribution - Transmission - Commercialization	- Transmission - Distribution and retail commercialization	- Competitive in exploitation and exploration - Free access in all the segments of the chain
Oil	- Exploration and exploitation - Transportation - Refining - Distribution and commercialization	- Transportation by ODENSA with price regulation - Subsidies to hydrocarbon consumption	- Competitive with leadership of Ecopetrol - Refining strongly dominated by Ecopetrol
Coal	- Exploitation - Commercialization		- Free pricing

Source: Own preparation.

Public policy aspects

Energy efficiency policies

In 2001, Law No. 697, “through which the rational and efficient use of energy is encouraged, which promotes the use of alternative energy, and establishes other provisions”, defined the fundamentals of energy efficiency in Colombia.

Since then, various multi-annual action plans have been defined under the name Program for the Rational and Efficient Use of Energy (*Programa de Uso Racional y Eficiente de la Energía* (PROURE)). The latest plan approved covers the period 2022-2030 and sets the indicative energy efficiency targets for the residential, transportation, tertiary, industrial, thermoelectric, hydrocarbon, mining, building, storage, and thermal districts sectors.

The plan serves as a guideline for state intervention in energy efficiency initiatives. The main energy efficiency policies, measures, and programs are briefly described in Table 7.

Table 7 Energy efficiency in Colombia

Aspect	Concept	Country progress
Labeling regulation	Sector	Commercial and industrial
	Program	The Rational and Efficient Use of Energy Act (URE, in Spanish) establishes the creation of the URE program (PROURE).
	Minimum energy efficiency standards (MEPs)	No MEPS available.
Sectoral policies	Public sector	√
	Transportation	
	Residential	
	Commercial and industrial	
Energy efficiency fund	Type	Public trust fund
	Name	Non-Conventional Energy and Efficient Energy Management Fund (FENOGE)
	Other	
Cultural promotion and 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: Document *Leyes de Eficiencia Energética en América Latina y el Caribe*, OLADE.

Pricing, subsidy, and incentive policies

Subsidies and taxes on fuel prices

Subsidies

Electricity and natural gas. Colombia has a system of subsidies to final residential energy demand that takes the form of reduced tariffs for certain groups in society. The current system of subsidies to the energy demand functions mainly around the Solidarity Fund for Subsidies and Income Redistribution (FSSRI), created through Law No. 142 of 1994 as a cross subsidy fund where users with greater payment capacity subsidize those who lack it.

The current focus of the subsidies is based on a stratification system: users from strata 1,2, and 3 receive electricity subsidies whereas those in residential strata 5, 6 and commercial users make contributions through a surcharge. The focus is similar in residential natural gas, except that stratum 3 is not a recepient. Large users and industrial consumers are not a part of the subsidy system.

Gasoline and diesel. According to the IMF, in Colombia there are automatic gasoline and diesel pricing mechanisms that link the evolution of the retail prices of such fuels to the international price. Monthly price adjustments have, respectively, a limit of 3% and 2.8% for gasoline and diesel. Price moderation is achieved through a Fuel Price Stabilization Fund (FEPC, in Spanish). In addition, internal prices are fixed at an export parity price (FOB), since Colombia imports refined products in some years and the difference is financed by the Price Stabilization Fund (FEPC). The deficit produced by this financing scheme is expected to amount to 2.5 % of the GDP in 2022.

Taxes

The following taxes are applied on fuel prices.

Value Added Tax (VAT). It is a national tax levied on service provision and on the sale or import of goods in the national territory. The VAT rate varies depending on the kind of goods or services; in general, it is 19 %. The VAT is applied on all energy consumption (gasolines, electricity, LPG, and natural gas).

Global tax. It was established under Law No. 681 of 2001, which determined a fixed tax in national currency on regular gasoline, fuel oil for heavy motors (ACPM, in Spanish), or diesel. The global tax is a little lower in Bogota. The central government collects this value and should normally destine it to road maintenance. It is not applied in border towns.

Surcharge. It was fixed under Law No. 488 of 1998. The applicable surcharge for regular ad extra gasoline is 25 % on the reference retail price by gallon, as provided by law. In addition, the surcharge on diesel is 6% on the reference retail price by gallon. The money collected is distributed among municipalities, departments, and the National Government. These resources are destined to financing road infrastructure works carried out by local entities, among other uses. As provided under Law No. 788 of 2002, the surcharge applicable on gasoline is 25 % and 6 %, in the case of diesel (ACPM), on the reference retail price by gallon.

Diagnosis and base line

Tax on carbon. Colombia implemented a tax on carbon through Article 221 (Part IX) of Law No. 1819 of 2016 in order to disincentivize the use of fossil fuels that generate GHG emissions during combustion. The carbon tax is applied on the first activity of the supply chain for the sale, import, or self-consumption of any of the fossil fuels taxed in Colombian territory, specifically gasoline, kerosene, jet fuel, diesel (ACPM), and fuel oil[17]. Liquefied petroleum gas is only taxed in sales to industrial users, whereas natural gas is only subject to the tax in the petrochemical and refining industry. The tax is a fixed amount by unit (gallon or cubic meter). The tax exempts alcohol fuel (ethanol), biodiesel produced from vegetables, fuels sold in the departments of Guainía, Vaupés and Amazonas, and the sale of marine diesel and refueling for international deliveries.

Incentives to renewable energy

Main laws

Law No. 1715 of 2014 (through Decree No. 2143 of 2015, later amended by Law No. 1955 of 2019 and Decree No. 829 of 2020) establishes fiscal, customs, and accounting incentives for companies investing in non-conventional energy sources projects.

Fiscal incentives

- Annual reduction in income tax to encourage research, development, and investment in the field of electric power production from non-conventional energy sources (NCES) and efficient energy management.
- Exemption from VAT on goods and services used to develop non-conventional renewable energy (NCRE) projects.

17 A fixed amount by volume or weight unit is applied, for example, natural gas: 36 COP/m³ (around 17 COP/tCO2e) and fuel oil: 238 COP/gallon, etc.

Customs incentive. Exemption from paying customs duties on the import of machinery, equipment, materials, and supplies to be used in the development of new NCRE projects.

Accounting incentive. Accelerated depreciation of goods at an annual depreciation rate no higher than 20 %, applicable to machinery, equipment, and civil works required for the projects that have been acquired after the effective date of this law.

Distributed generation CREG Resolution 174-21 established clear rules for small generators, the installation of distributed generation, and invoicing.

Main funds

At present, there are four state-owned funds that may contribute to the development of renewable energy in the National Interconnected System (SIN) and in non-interconnected areas (ZNI, in Spanish).

- Non-Conventional Energy and Efficient Energy Management Fund (FENOGE). This fund is applied both in the SIN and in the ZNI. The FENOGE is financed with resources from the FAZNI, among others.
- Financial Support Fund for the Energization of Non-Interconnected Areas (FAZNI).
- National Royalties Fund. It was financed with revenues from non-assigned royalties.
- Financial Support Fund for the Energization of Rural Interconnected Areas (FAER).

Diagnosis and base line

Long-term auctions

In Colombia, the main barrier to the development of non-conventional renewable energy has been the absence of long term contracts, which results in difficulties to finance these projects.

In this context, the Ministry of Mines and Energy has supplemented the auction mechanism of the reliability charge (CxC, in Spanish) through the definition of an alternative long-term auction scheme in order to promote non-conventional renewable energy. Specific auctions were carried out in 2019 and 2021. Renewable auctions between private parties were also performed in 2021. Finally, in 2021, large-sized batteries were auctioned.

Creation of a carbon market

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

One of them is the Carbon Tax Non-Accrual Mechanism (*Mecanismo de No Causación del Impuesto al Carbono*, in Spanish), regulated under Decree No. 926/2017, which allows the tax to be paid with emission reduction certificates or GHG removals. Law No. 2277 of 2022 reduced the use of compensations to 50 %.

The other mechanism is the National Program of Transactional Emission Quotas (*Programa Nacional de Cupos Transables de Emisión*), which seeks to create an emission trading system or regulated carbon market. This instrument was created through Law No. 1931/2018, and currently operates under the name Emissions Reduction System (Sistema para la *Reducción de Emisiones* (*Sistema RE*)).

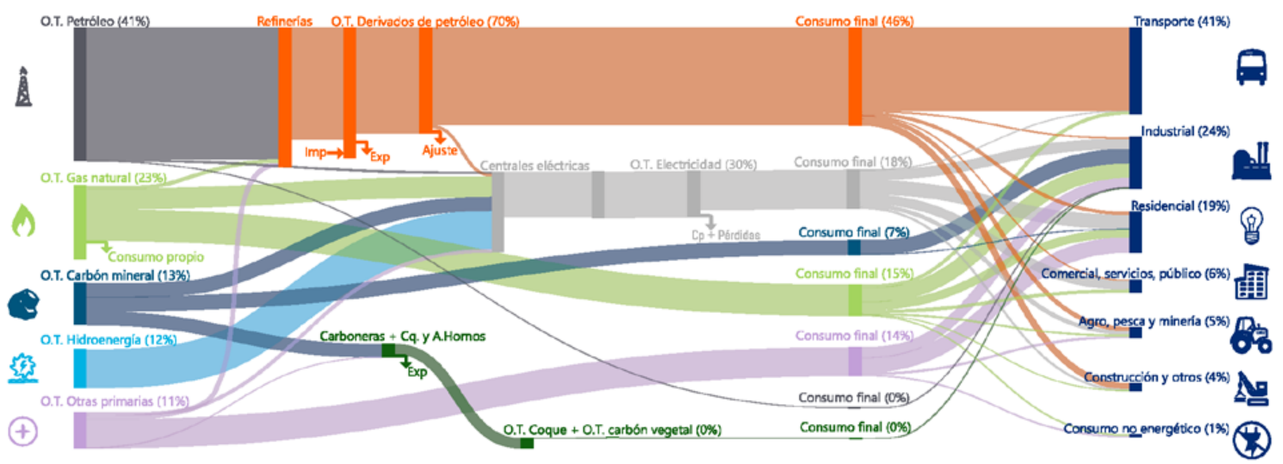
There is a roadmap to implement the *Sistema RE*, which was approved in the tenth session of the Intersectoral Commission on Climate Change and has three phases. The first phase is the regulation, the second is institutional and operational, and then the third phase is the startup, which is expected for 2024-2025.

Diagnosis and base line

3. Energy balance, 2019 and 2022

The energy balance records the energy flows from energy production, exports and imports, transformation until final consumption in the different socio-economic sectors for a certain period (one year). Graphic 15 is a graphic representation (Sankey diagram) of the year 2019, the base year for this study.

Graphic 15 ▶ Energy balance, 2019



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

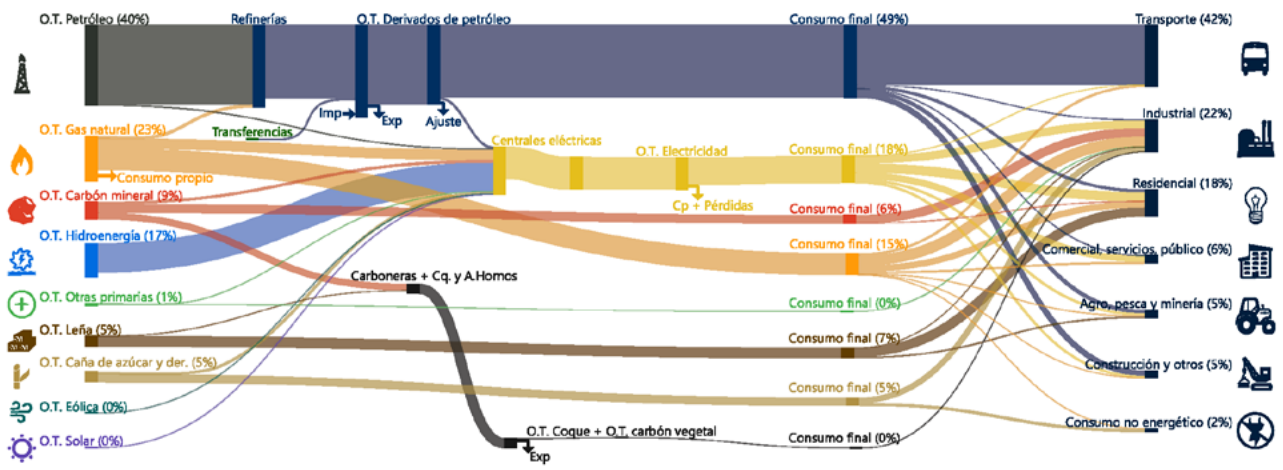
The energy balance allows us to summarize some of the main characteristics of the Colombian energy sector:

- the main function of oil (42 %), natural gas, and coal in primary energy supply;
- the significant share of hydroelectric production compared to total electricity;
- the function of electricity in the still limited final consumption (18 %);
- the sectors with more final consumption (transportation with 41 %, industry, residential).

We also present the latest energy balance available (2022), which shows slight differences with the energy balance of 2019:

- more weight of hydro energy (17 % versus 12 %) and less weight of coal (9 % versus 13 %) in terms of primary energy supply;
- slightly less influence of the industrial sector (22 % versus 24 %) in terms of final consumption.

Graphic 16 Energy balance, 2022



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

4. Evolution of energy demand by sector and sources

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.

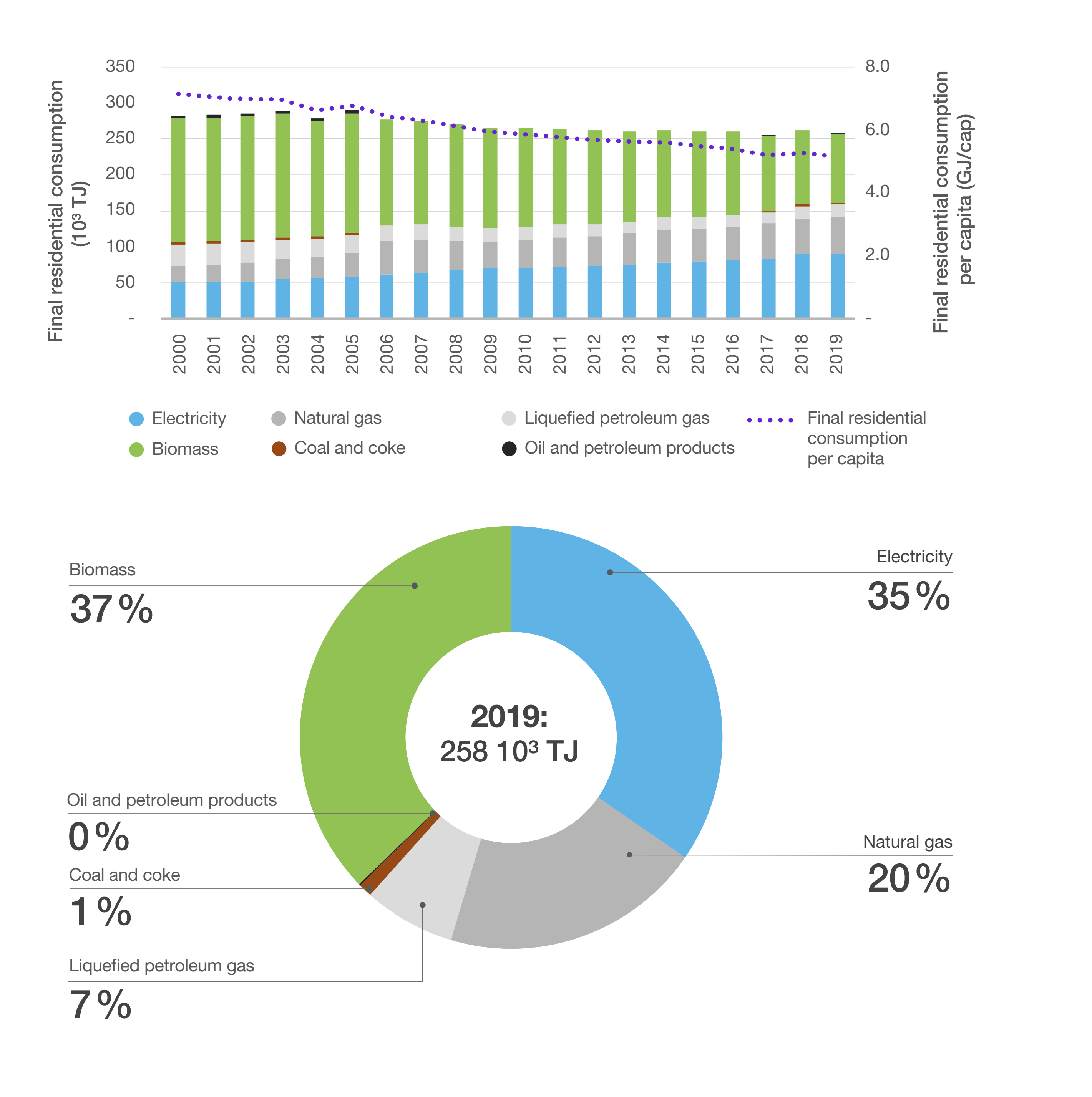
The following paragraphs include, in addition to the energy demand by source, additional data required to characterize this demand, such as the share of demand by energy use (useful energy balance), the description of the vehicle fleet, sectoral energy intensity, etc.

Residential sector

Final residential consumption has decreased slightly in the last 20 years (-0.5 % annual average). This decrease is more significant per capita (-1.7 % annual average) and evidences the changes in energy sources that allow less use of final energy for one same energy use. By source, the following characteristics can be pointed out:

- High consumption of biomass (firewood), although its volume and proportion have fallen significantly in the last two decades. According to the Colombian Natural Gas Association (Naturgas), around 1.2 million households (6 million people) still use firewood to cook;
- Increase in the final consumption of electricity and gas, in line with the rise in the rate to access the natural gas service (80 % at present) and new electrical uses. LPG consumption accounts for a quarter of total gas consumption (natural gas + LPG).

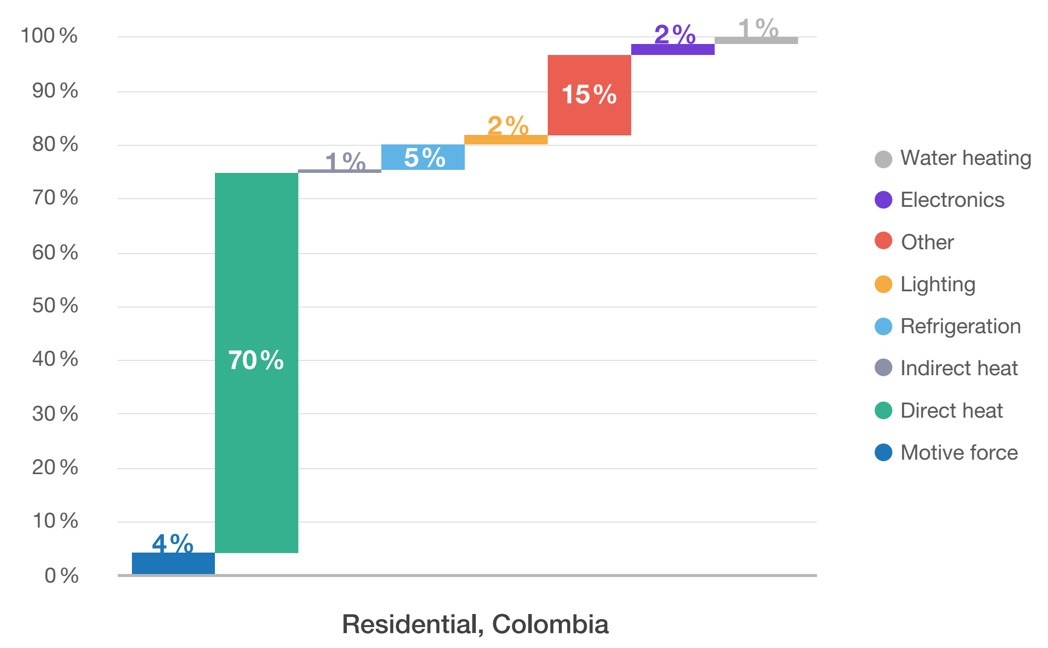
Graphic 17 ▶ Residential sector: evolution of final consumption by source, 10^3 TJ



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

In terms of energy consumption for end uses, 70 % of the total is related to direct heat (that is, cooking or space heating, mainly). Uses reserved to electricity are limited (lighting, refrigeration, electronics).

Graphic 18 Residential sector: energy consumption by end uses, 2015



Source: Own preparation based on data from the useful energy balance, 2015, IREES, TEP, Corpoema.

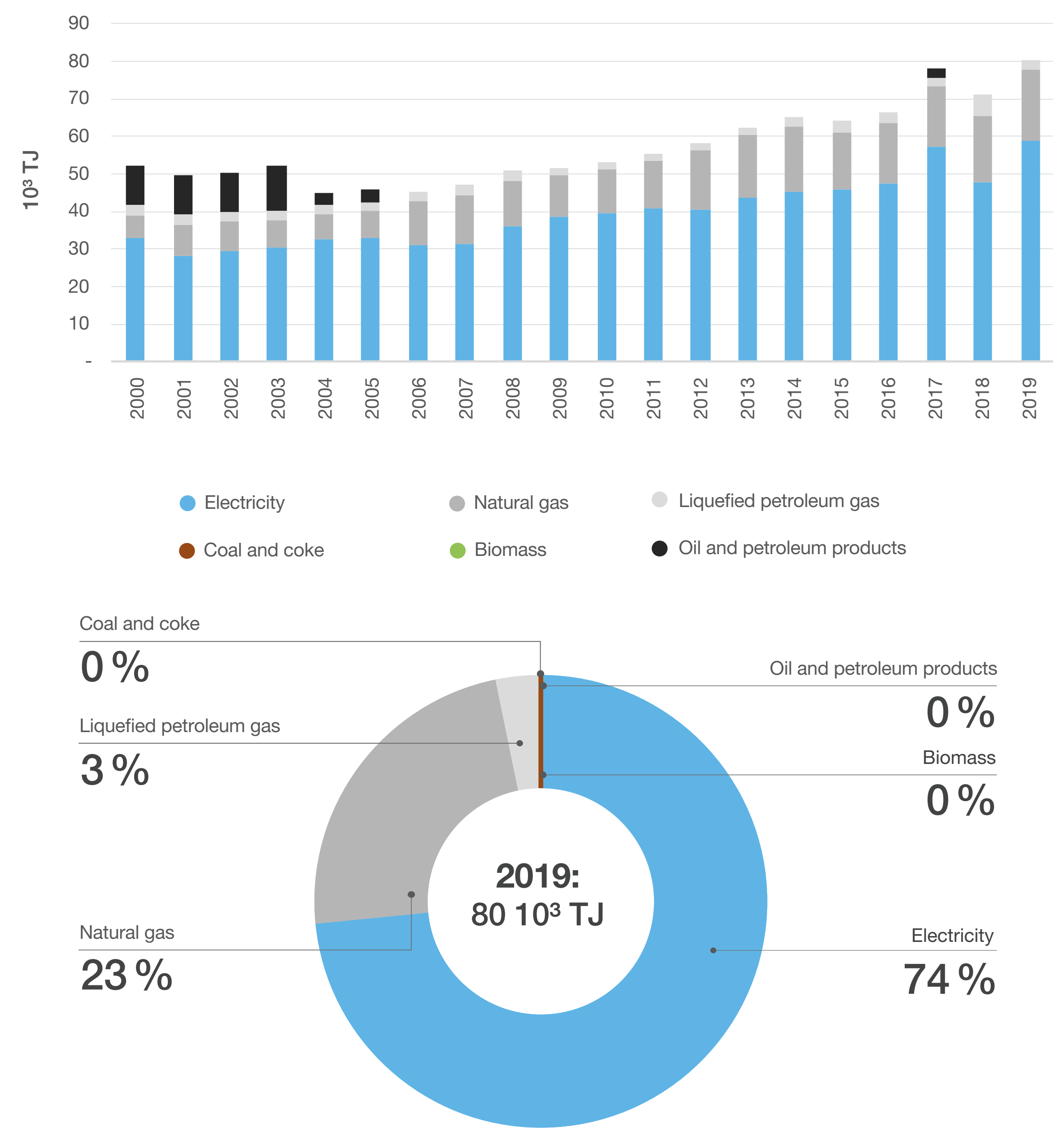
Commercial, services, and public sector

The final consumption of the commercial, services, and public sector has increased in the last 20 years (2.3 % annual average). By source, the following characteristics can be pointed out:

- high share of electricity in total consumption (74 % in 2019);
- supply of mainly natural gas and LPG to cover the rest of the demand.

Diagnosis and base line

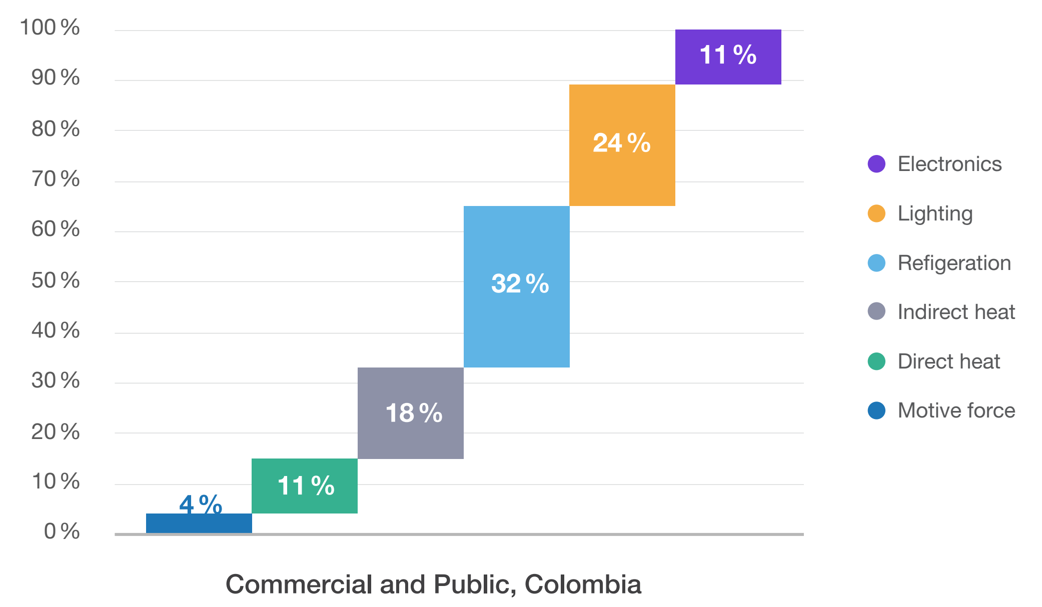
Graphic 19 Commercial and public sector: evolution of final consumption by source, 10^3 TJ



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

In terms of energy consumption for end uses, refrigeration and lighting uses – both electrical – are those with the most consumption. The share by end uses is very different from that of the residential sector.

Graphic 20 Commercial and public sector: energy consumption by use, 2015



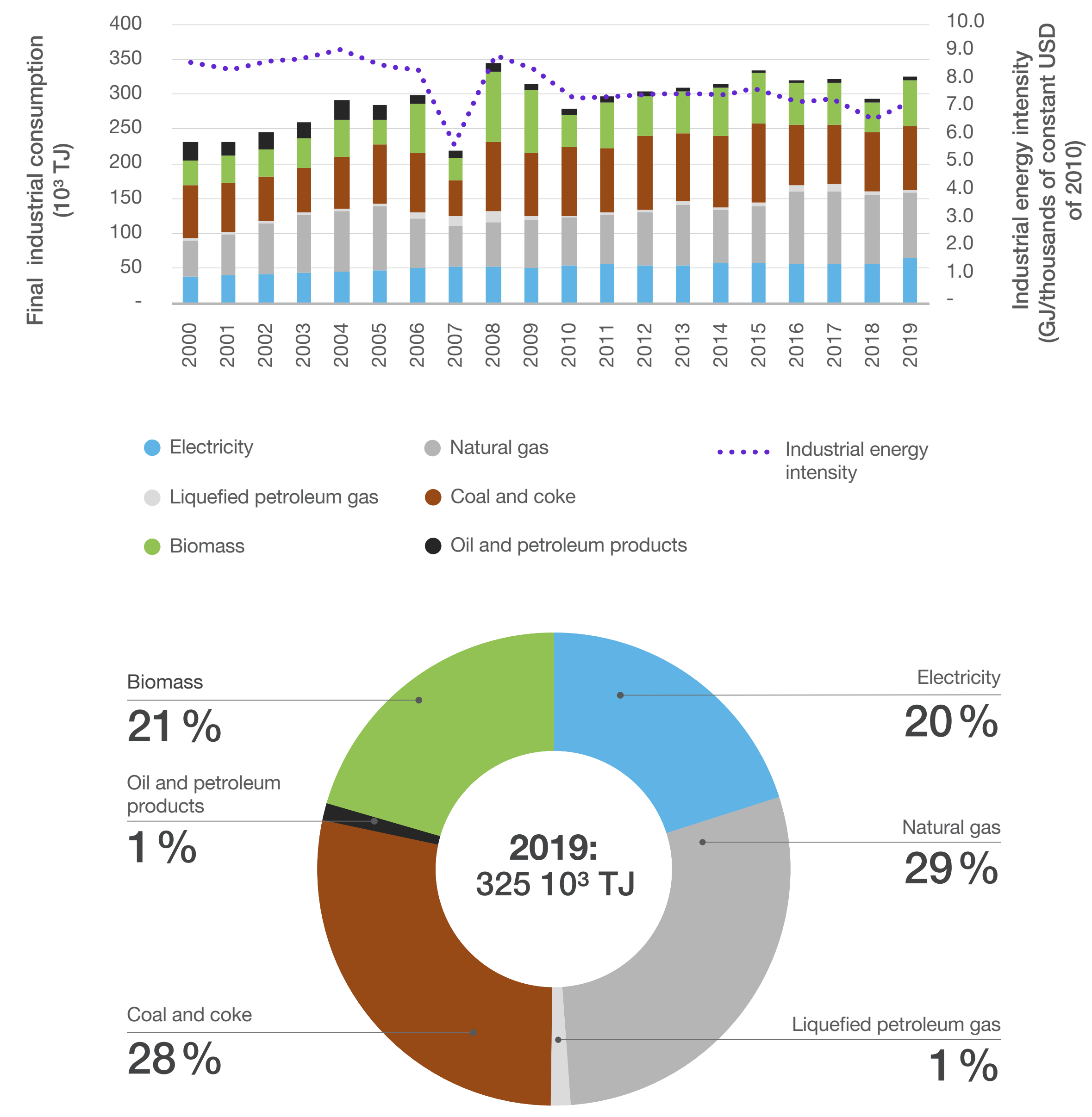
Source: Own preparation based on data from the useful energy balance, 2015, IREES, TEP, Corpoema.

Industrial sector

Final industrial consumption has increased in the last 20 years (1.8 % annual average) but this growth has slowed down in recent years, in line with the greater outsourcing of the economy. By GDP unit, energy intensity of the industrial sector fell in the period, which is evidenced in the country's industrial matrix and the impact of energy efficiency measures on the sector. By source, the following characteristics can be mentioned:

- The penetration by fuel continues being similar in all the period, with natural gas and coal by about 30 % and electricity and biomass (sugar cane and byproducts, mainly) by around 20 %;
- The use of oil and petroleum products is lower and has diminished.

Graphic 21 Industrial sector: evolution of final consumption by source, 10^3 TJ

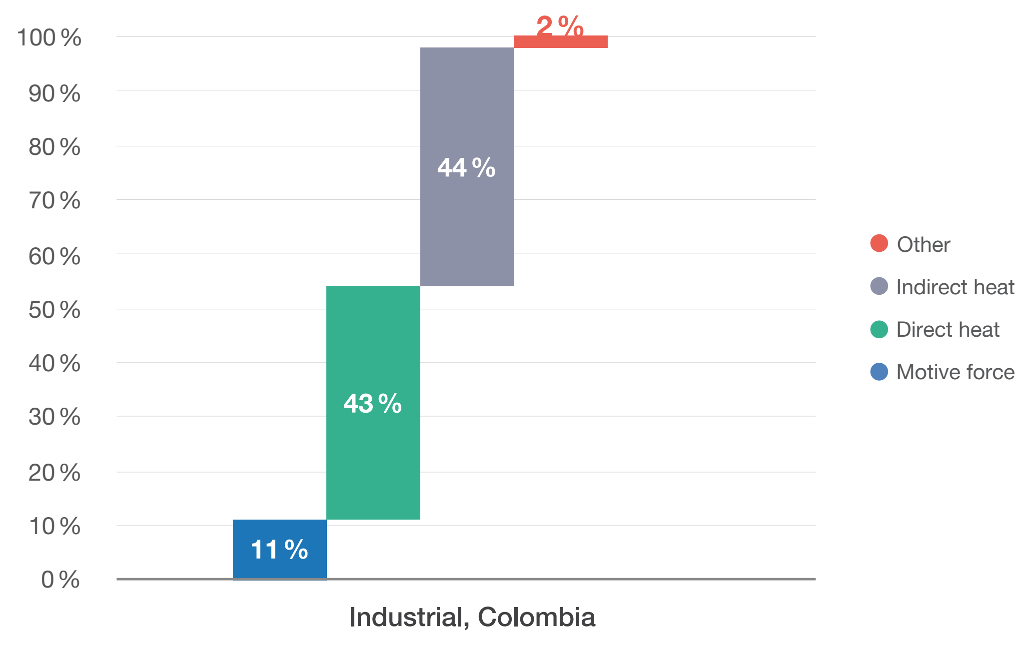


Source: Own elaboration based on data from sieLAC, OLADE.

In terms of energy consumption for end uses, the indirect heat and direct heat uses are those with the greatest consumption and add up to 87 %.

Graphic 22

Industrial sector: energy consumption for end uses, 2015



Source: Own preparation based on data from the useful energy balance, 2015, IREES, TEP, Corpoema.

Diagnosis and base line

Transportation sector

Demand by source

Final consumption in the transportation sector has increased steadily in the last 20 years (3.1 % annual average). By GDP unit, energy intensity of the transportation sector[18] decreased in the period, although there has been some stabilization in recent years. By source, the following characteristics can be pointed out:

- high diesel and gasoline consumption[19] (both fuels are the most chosen by road transportation);
- a very minor role of gas and electricity in the sector nowadays.

18 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 performed by all the economy.

19 At present, Colombia has regulated a mandatory mix of 10 % ethanol and biodiesel.

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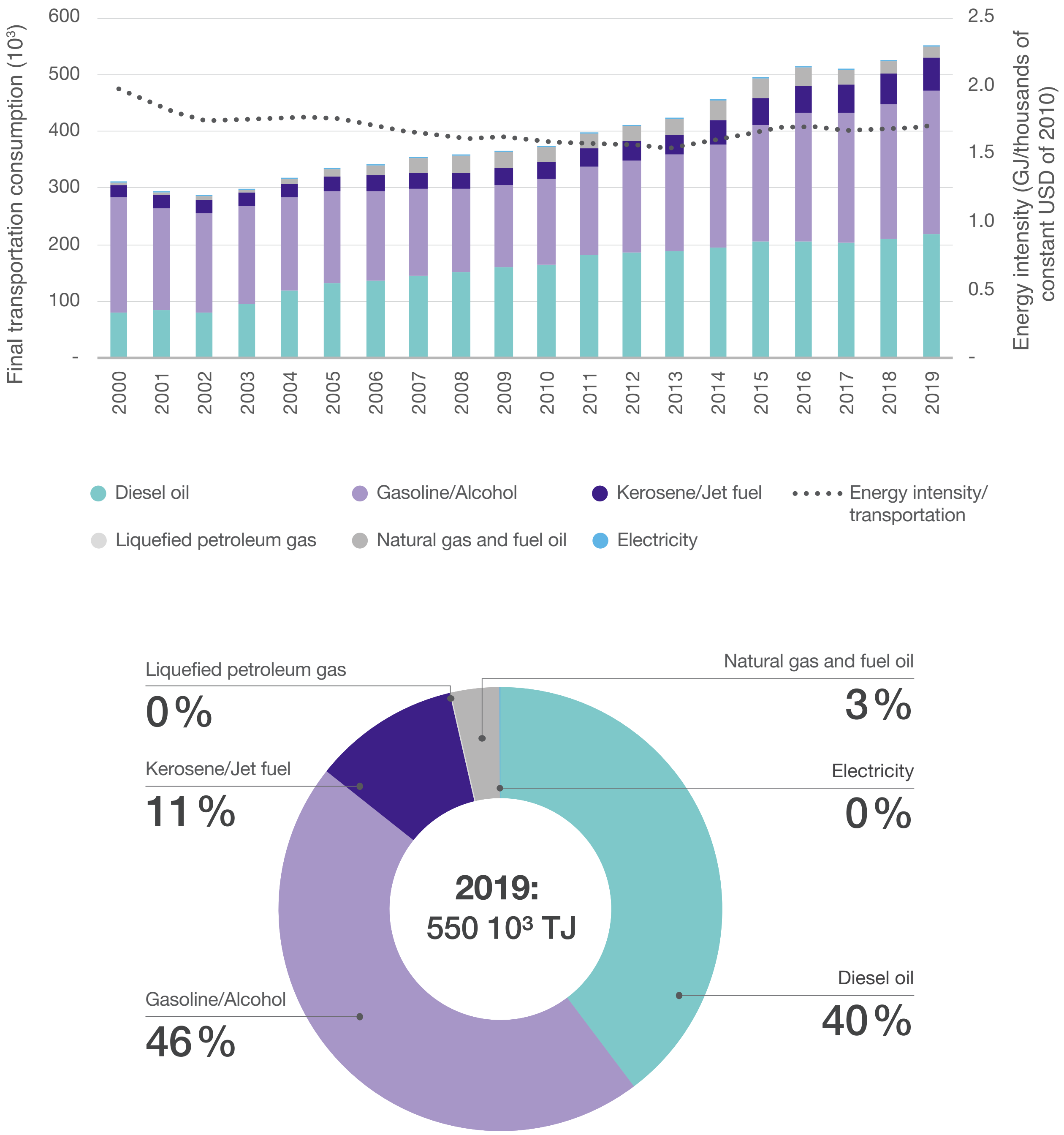
Graphic 23 Transportation sector: evolution of final consumption by source and year 2019, 10^3 TJ



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

Vehicle fleet and consumption by type

Table 8 shows the total road vehicles and their shares by type. In the region, Colombia differs from the other countries because of its high number of motorcycles, which account for 59% of the total fleet, against 23 % cars and 13 % light trucks.

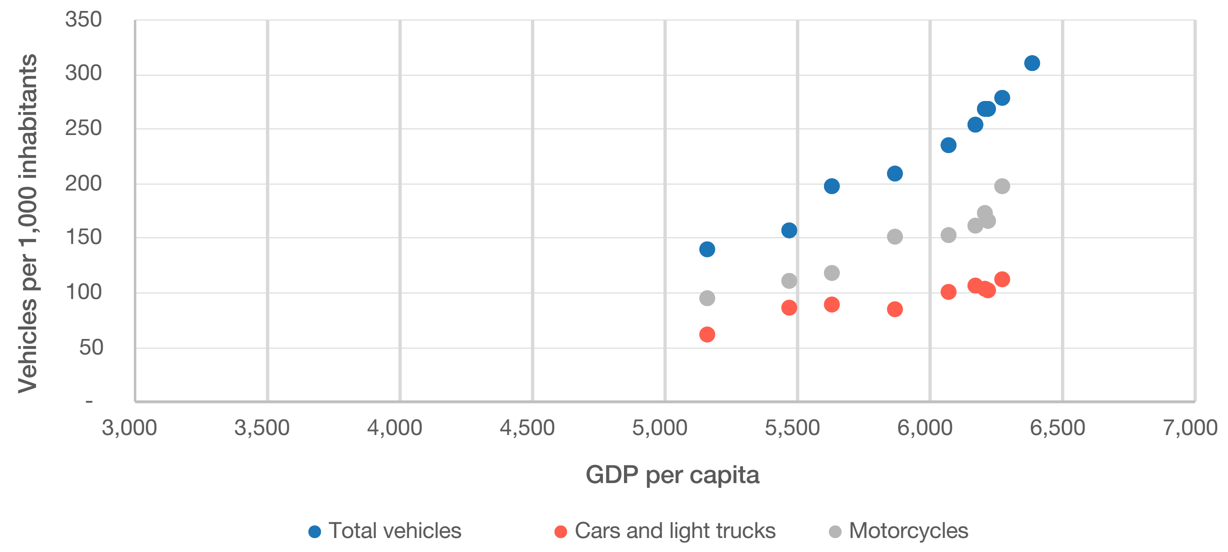
Table 8 Participation by type of road vehicle, 2019, Colombia

	2019
Cars	23 %
Light trucks	13 %
Motorcycles	59 %
Passengers (bus)	1 %
Freight	2 %
Heavy machines + dump	1 %
Other	0 %
Total	15,627,240

Source: Own preparation based on data from the Colombian Ministry of Transportation.

Colombia develops its vehicle fleet along with the increase in GDP per capita; in particular, the number of motorcycles grows more than that of cars.

Graphic 24 Vehicle fleet versus GDP per capita, between 2010 and 2019



Source: Own preparation based on data from the Colombian Ministry of Transportation.

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

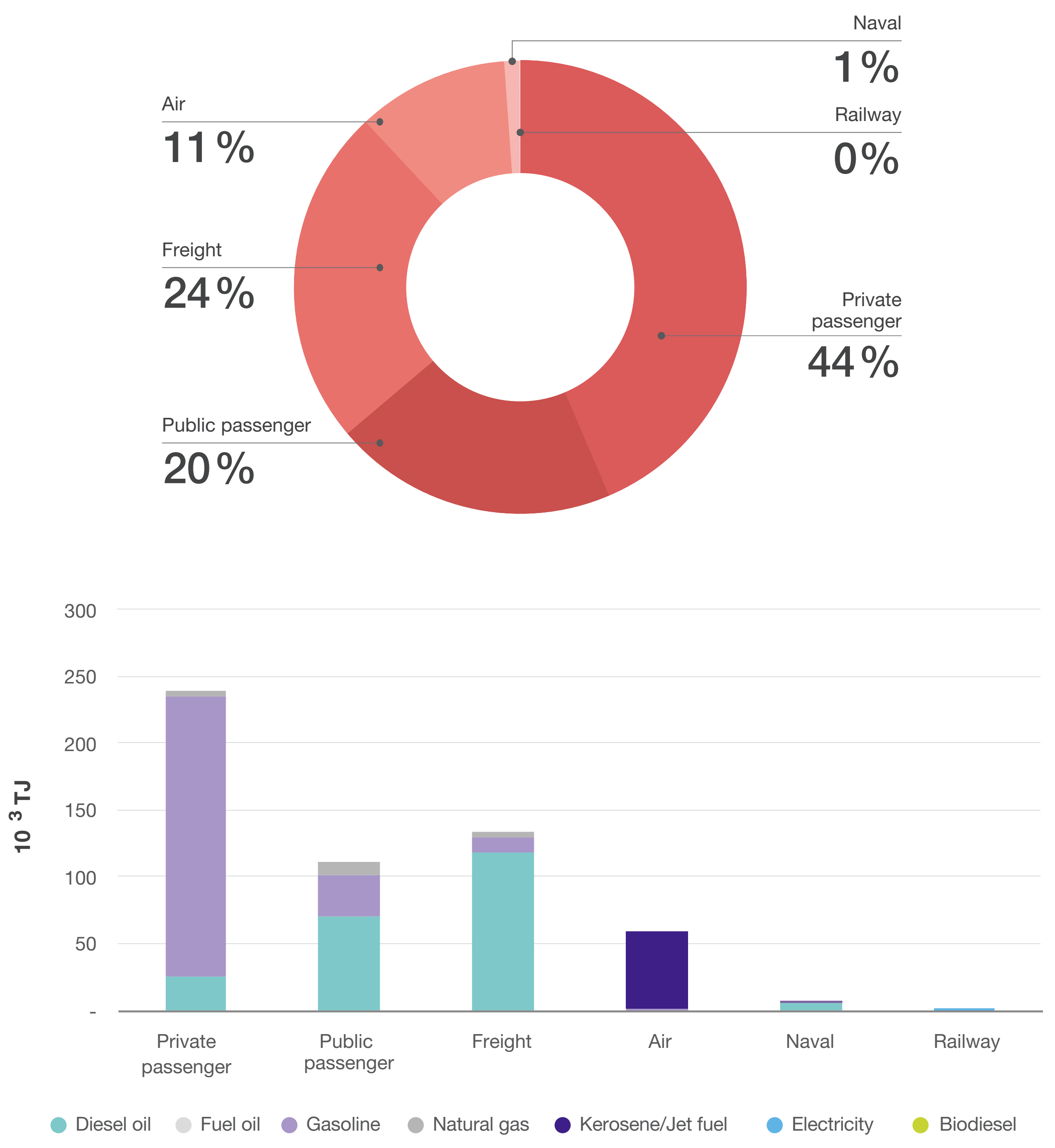
Table 9 Consumption by type of transportation and by fuel type, 10^3 TJ and %, 2019, Colombia

	Total consumption (10^3 TJ)	Diesel	Gasoline	Kerosene/ Jet fuel	Fueloil	Natural gas	Electricity
Passengers, private	240	10 %	87 %	-	-	2 %	-
Passengers, public	111	63 %	27 %	-	-	9 %	-
Freight	133	89 %	9 %	-	-	2 %	-
Air	60	-	1 %	99 %	-	-	-
Maritime/ River	6	82 %	5 %	-	13 %	-	-
Railway	0.4	-	-	-	-	-	100 %

Source: Own preparation based on data from the Colombian Energy Balance (BECO).

Public passenger transportation accounts for 30 % of total passenger transportation. Road freight transportation accounts for a fourth of the fuel consumption in the sector. In terms of consumption by fuel, private passenger transportation consumes mainly gasoline, whereas public passenger and freight transportation consumes mainly diesel. Natural gas and electricity have minor importance in the transportation sector at present.

Graphic 25 Transportation sector: final consumption by type and fuel type, 10^3 TJ



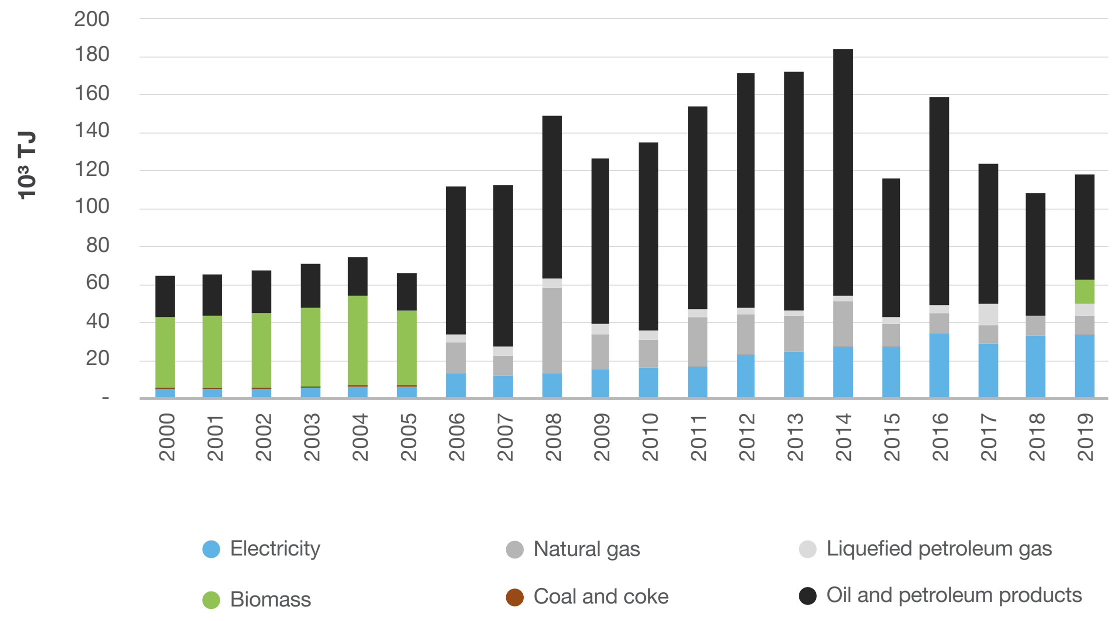
Source: Own preparation based on data from the Colombian Energy Balance (BECO).

Agricultural, fishing, mining, and construction sector

Final consumption has increased irregularly in the last 20 years (3.2 % annual average). By source, the following characteristics can be pointed out:

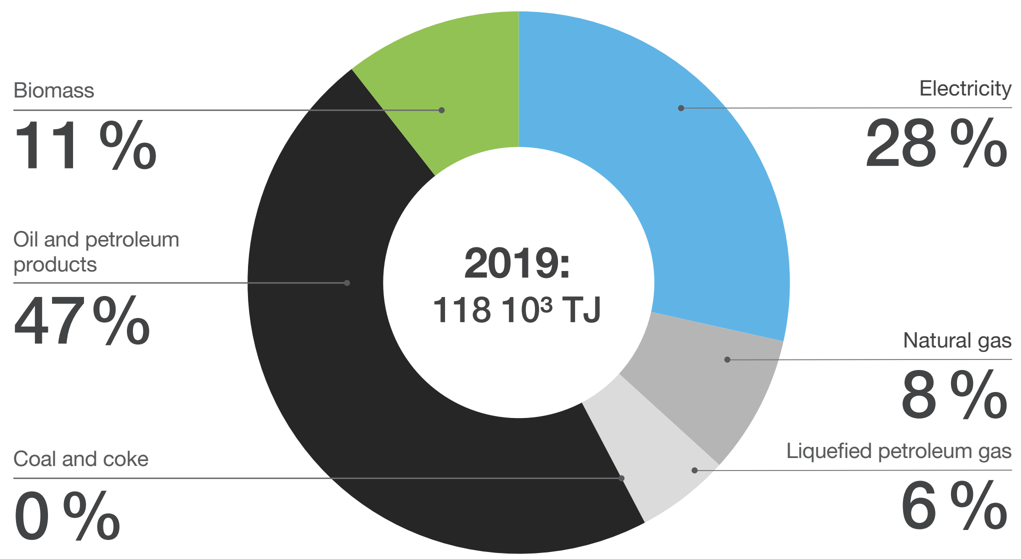
- the share of oil and petroleum products was close to half the total consumption in 2019 (47 %);
- supply, mainly electricity, followed by biomass, natural gas, and LPG to cover the rest of the demand.

Graphic 26 A Other sectors: evolution of final consumption by source, 10^3 TJ



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

Graphic 26 B ▶ Other sectors: evolution of final consumption by source, 10^3 TJ



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

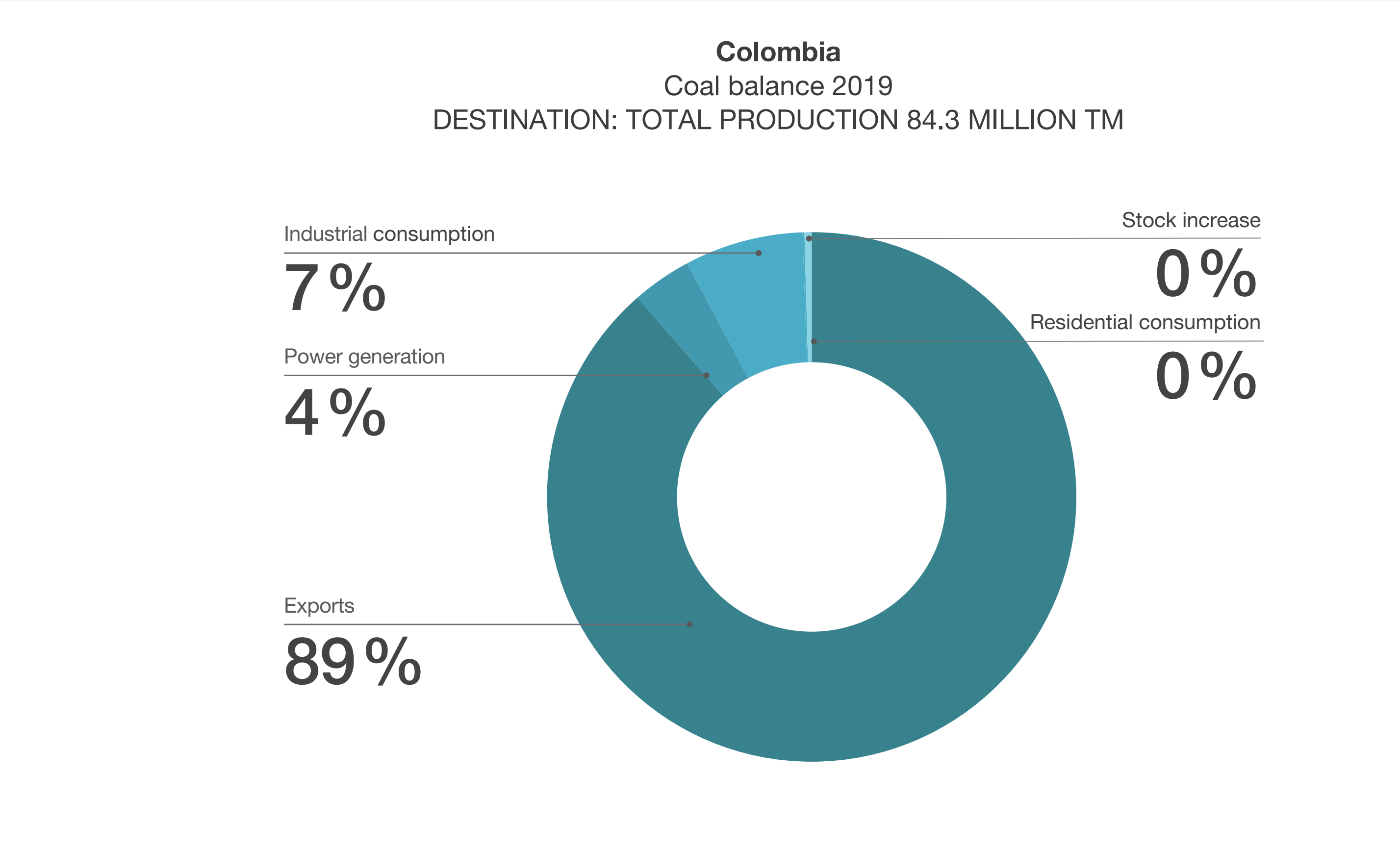
By subsector, we can mention that mining adds up around two thirds (64 %) of the demand; the agricultural sector, one third (34 %); and construction, the rest.

5. International energy trade

Colombia exports around 90 % of its coal production and around 60 % of its oil production.

Graphic 27 A

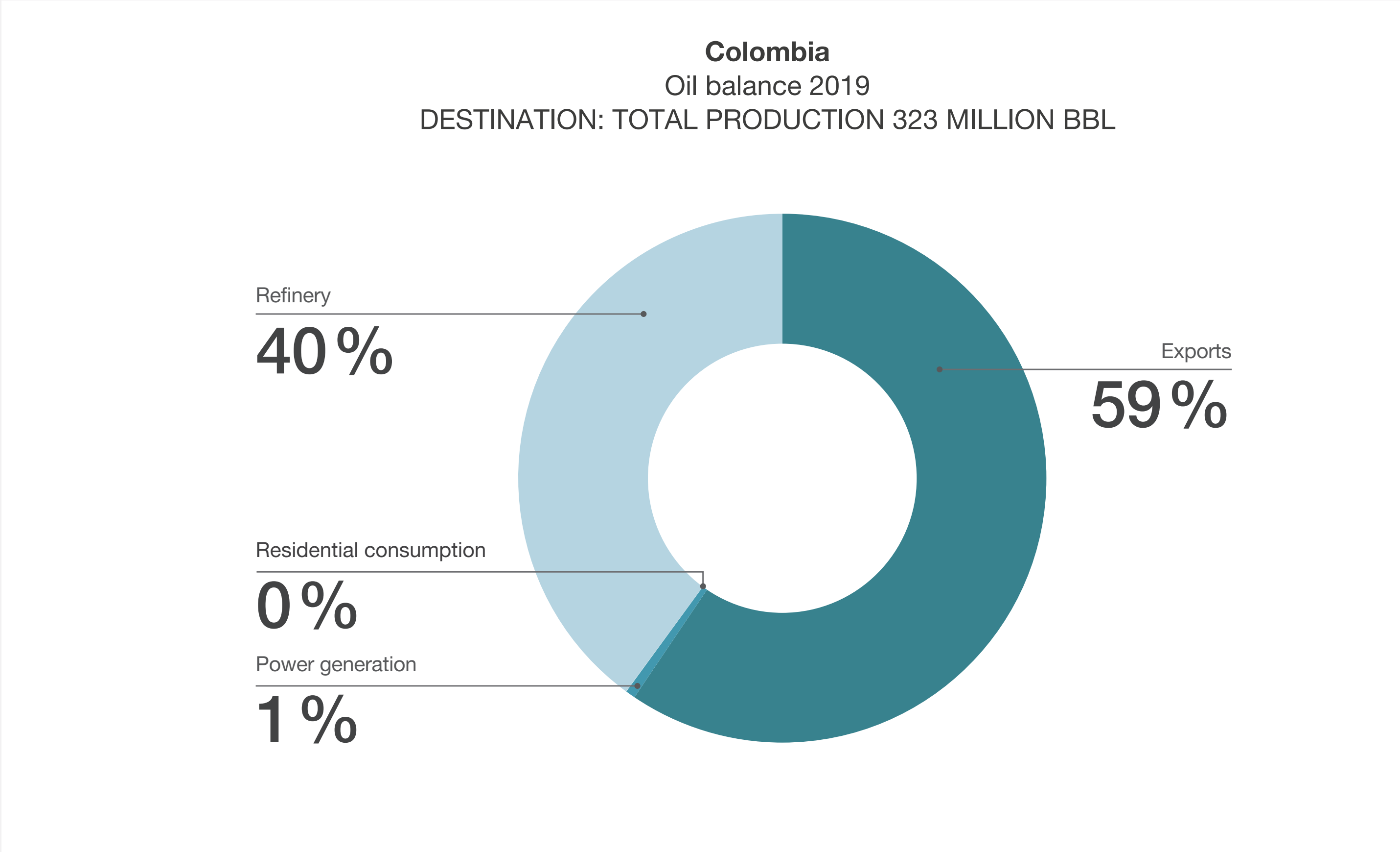
Oil and coal balance (% of production)



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

Graphic 27 B

Oil and coal balance (% of production)

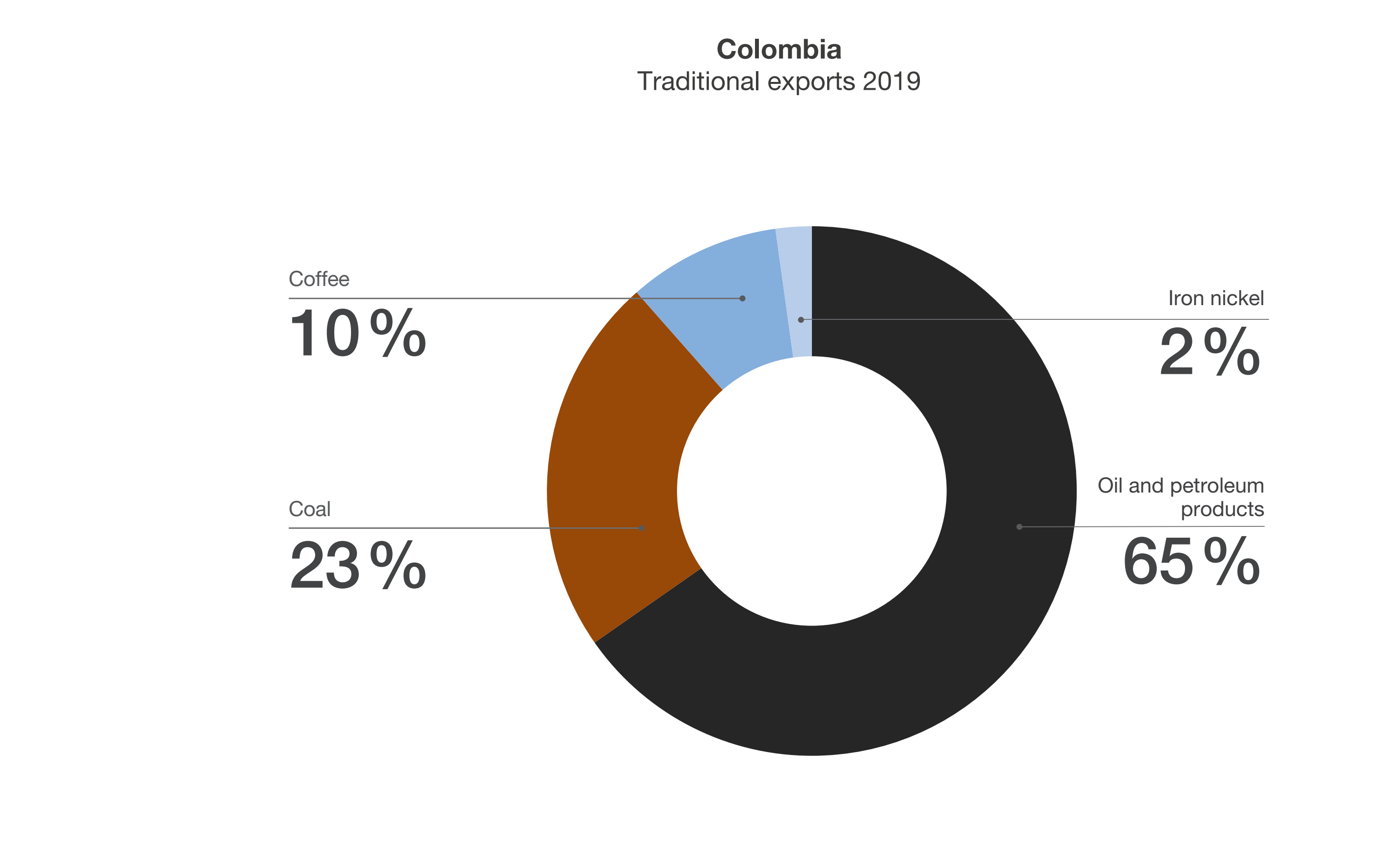


Source: Own preparation based on data from sieLAC, OLADE.

These exports of primary energy products are the main export item; in 2019, oil and coal accounted for 89 % of traditional exports (USD 24,500 million) and 55 % of total exports (USD 39,500 million), whereas fuel and mineral oil exports accounted for 8.5 % of the USD 52,700 million in exports.

Graphic 28 A

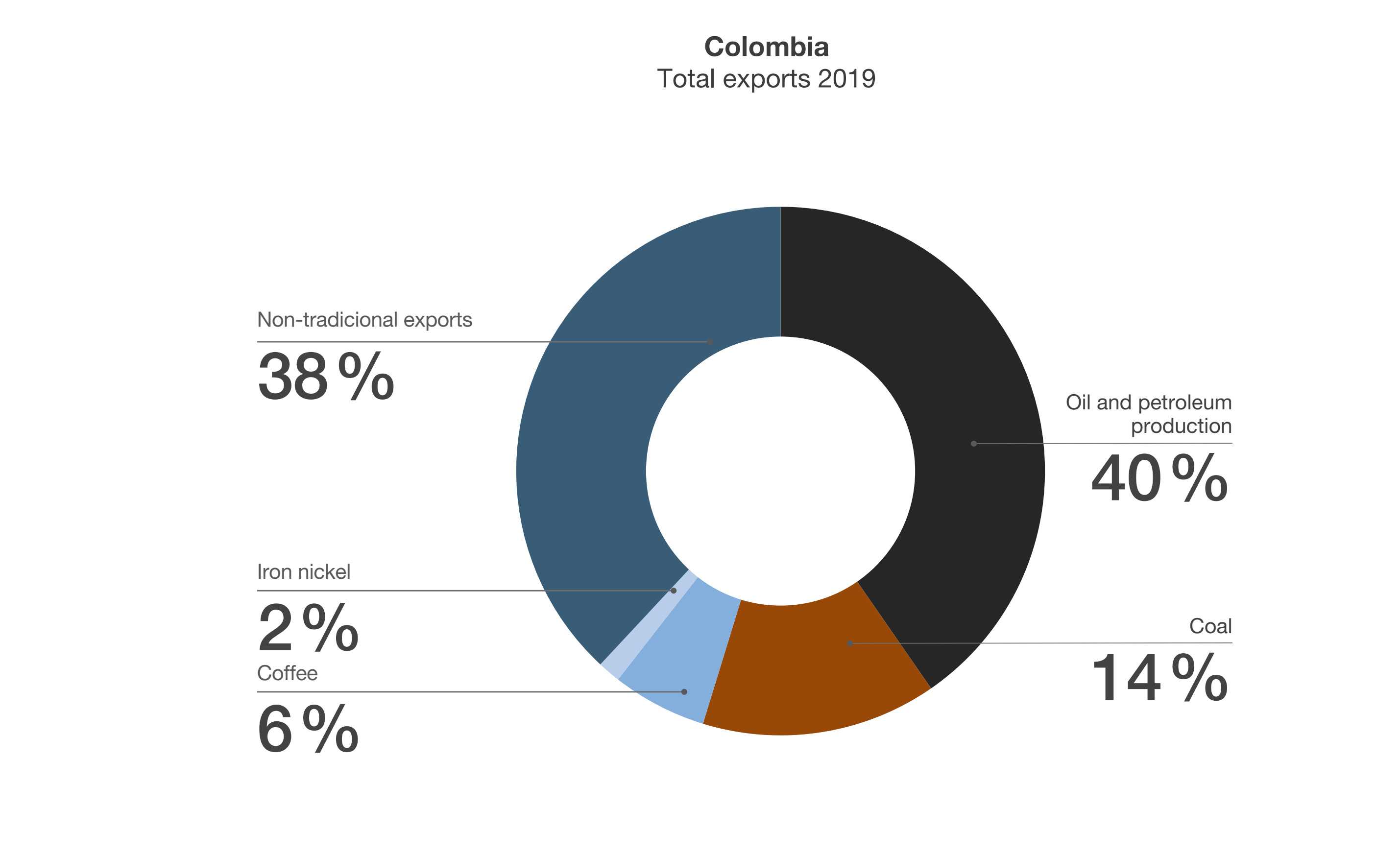
Share of oil and gas in exports, %



Source: Own preparation based on data from the National Administrative Statistics Department (DANE).

Graphic 28 B

Share of oil and gas in exports, %



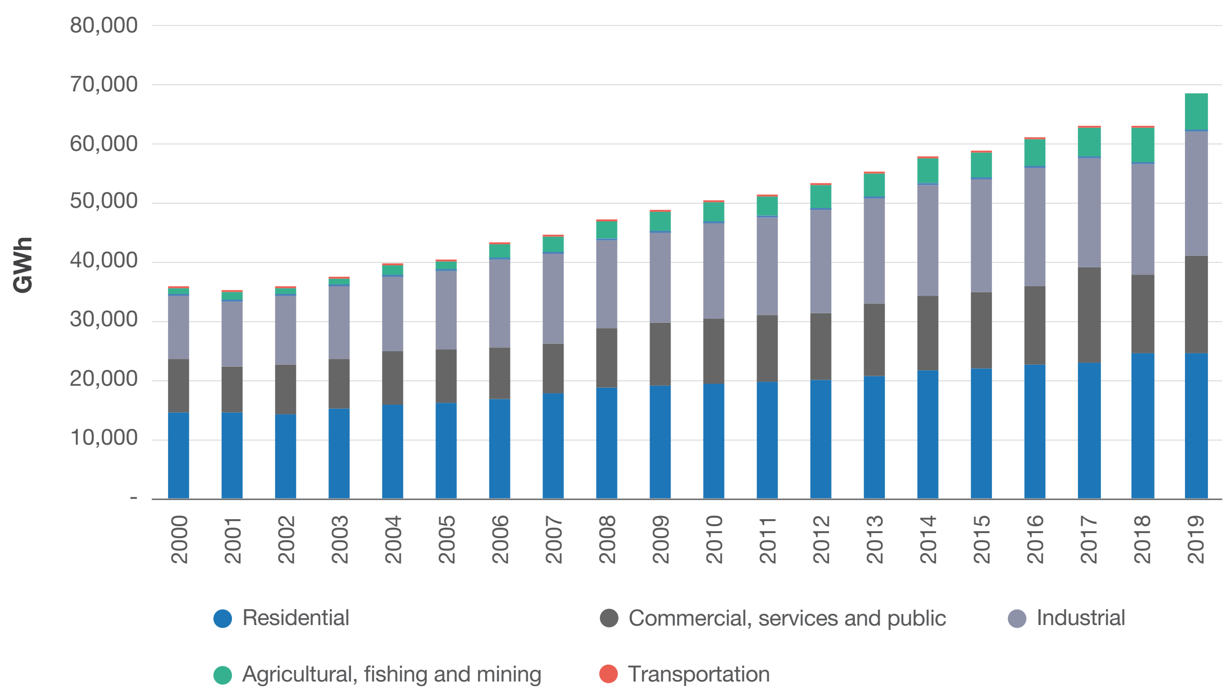
Source: Own preparation based on data from the National Administrative Statistics Department (DANE).

6. The power sector

Power demand

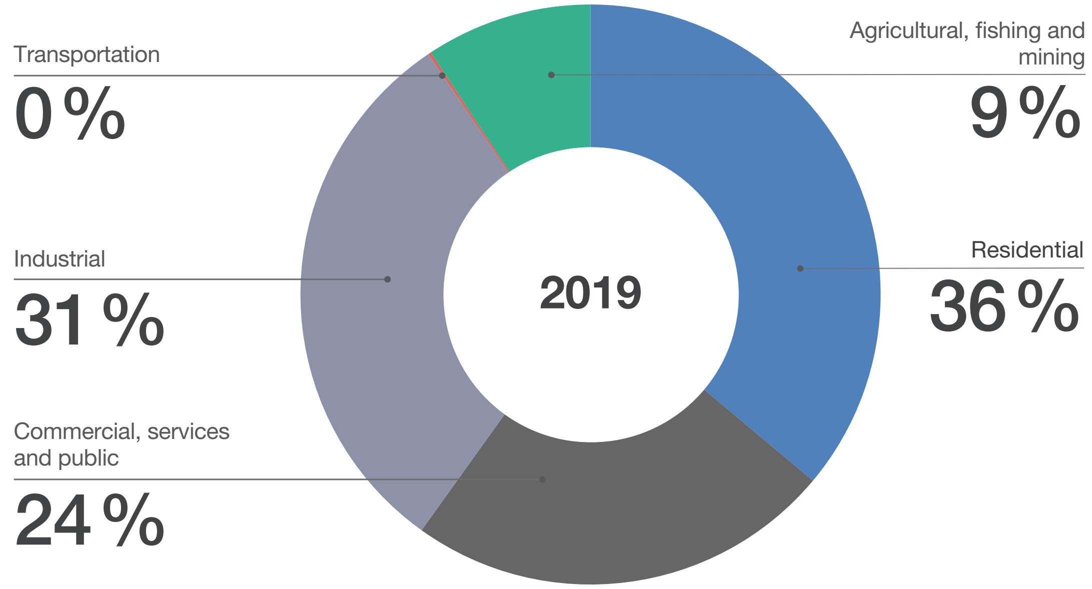
Graphic 29 shows the final power consumption, broken down by sector of the economy.

Graphic 29 A Final power consumption by sector, 2000-2019, and year 2019, GWh and 10³ TJ



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

Graphic 29 B Final power consumption by sector, 2000-2019, and year 2019, GWh and 10³ TJ



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

Short and long-term trends are visualized through the growth rates in the periods 2000-2019 and 2014-2019: in both cases, growth is 3.5 %.

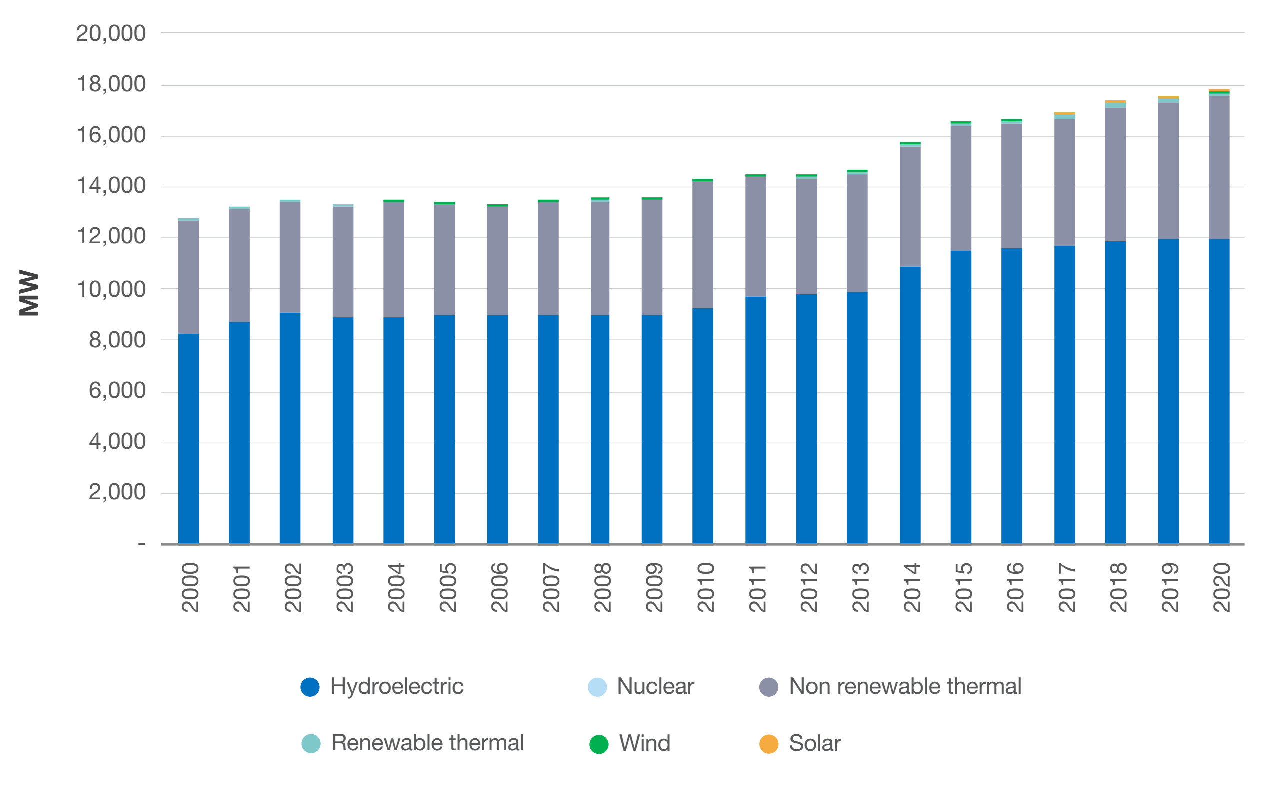
In 2019, the average composition of power consumption in Colombia includes, in the first place, the residential sector (36 %), followed by the industrial sector (31 %) and the commercial, services, and public sector (24 %). In the last 20 years, the share of the residential sector in total electricity consumption has remained constant. On the other hand, the Colombian economy has shifted towards a services economy.

In 2019, the peak demand in the interconnected system reached 10.6 % GW.

Installed capacity

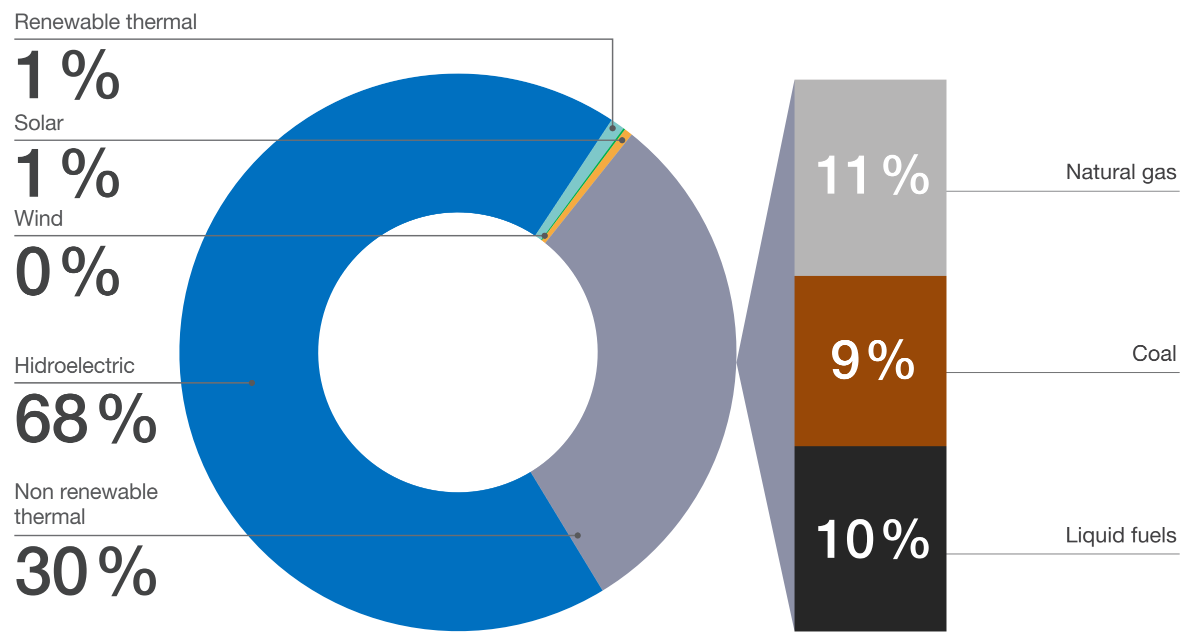
The net effective capacity is 17.5 GW in 2019, 92 % of which is centrally dispatched and 8 % is not dispatched centrally (plants under 20 MW). Around two thirds of the installed capacity is hydro plants, in many cases with reservoirs. Thermal plants are divided in similar portions between coal, gas, and liquids.

Graphic 30 Installed capacity between 2000 and 2020, MW



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

Graphic 31 Installed capacity by source, 2019, %



Source: Own preparation based on data from XM, system operator.

The generation fleet has an average weighted age of 26 years (with respect to the installed capacity of each plant).

In recent years, wind and solar projects started developing to diversify the generation matrix[20]. On the other hand, the *Hidro Ituango* project (2,400 MW) should be gradually and partially commissioned in the next few years .

Even though recent trends favor renewable generation plants, around 20 % (1,200 MW) of the thermal plants based on coal, natural gas, and fuel oil have been built in the last 10 years[21].

20 In particular, around 1.9 GW from solar projects and 2.1 GW from wind projects is being commissioned or is about to be commissioned in the next 24 months. These projects have generally been the winners of long-term energy contracts (CLPE, in Spanish) in auctions or in reliability charge auctions.

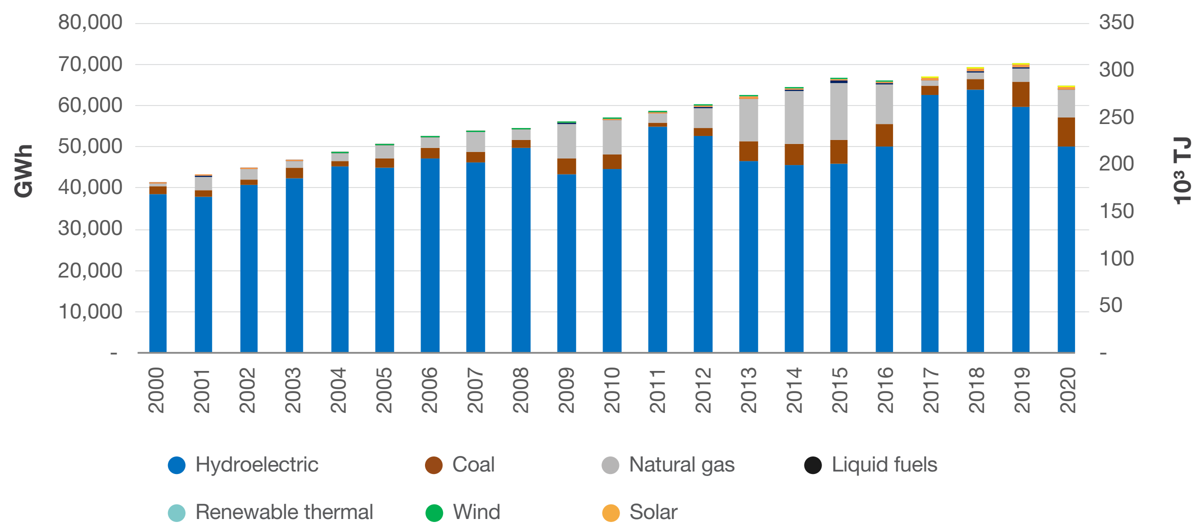
21 Officially, units 1 and 2 (600 MW) were commissioned at the end of November 2022 although some procedures to be able to fully operate are still incomplete.

Power generation

Colombia faces two environmental phenomena that significantly affect its hydrology levels: El Niño, which originates extreme drought conditions, and La Niña, which shows excessive rainfall.

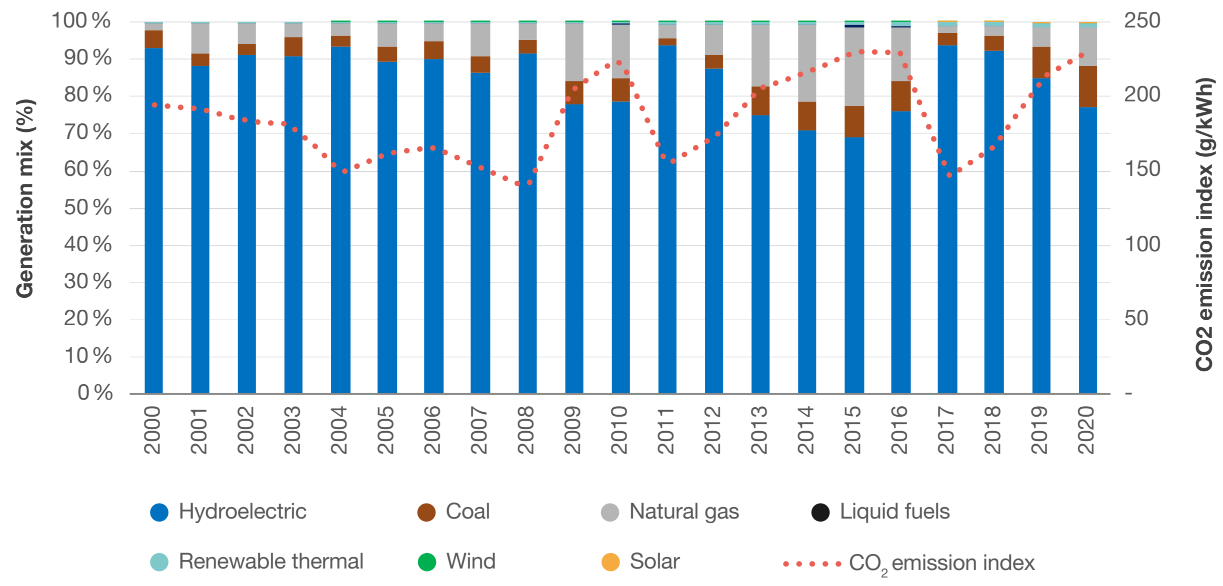
Between 2009 and 2010, between 2014 and 2016, and between 2019 and 2020, the increase in the thermal quota was due to the effects of El Niño. The increase in hydro participation between 2011 and 2012 and in 2017 was due to the effects of La Niña.

Graphic 32 Power generation by source, 2000-2020, GWh and 10^3 TJ



Source: Own preparation based on data from XM, system operator.

Graphic 33 Power generation by source 2000-2020, %, and CO_2 emission index of the power sector, g/kWh



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

The annual generation mix has direct impact on the CO_2 emission index, with higher values in the years when the share of thermal generation rises, especially coal-fired generation.

Finally, and due to the significant share of hydro generation in the generation composition, the prices at the Energy Pool (*Bolsa de Energía*) in the Colombian system have high volatility. They also show seasonality (rainy season from May to November and dry season from December to April).

7. Existing power grids and gas pipeline networks

The Colombian National Interconnected System currently has 29,534 km of power transmission lines, 17,212 of which are 220 kV, 230 kV and 500 kV lines that make up the National Transmission System (STN, in Spanish), and 12,243 km are lines from the Regional Transmission System (STR (in Spanish), which operates at 110 kV, 115 kV and 138 kV 4/3/2024, XM – Electricity Market Administrators), and 2,961 km of gas transportation network (2020, UPME).

In terms of electricity, the National Interconnected System (SIN, in Spanish) connects 48 % of the country's area and covers 96 % of the population. The non-connected areas (ZNI) account for 52 % of the national territory and serve 210,000 people.

As to natural gas, the rate of access to the natural gas service by pipeline is close to 80 % at present.

Graphic 34 National Transmission System, 2019

Source: UPME.

Graphic 35 ▶ Current transportation network and Natural Gas Supply Plan works, 2019

Source: UPME.

8. Conclusions

Colombia's present reality shows certain relevant characteristics as a base line to address the energy transition towards carbon neutrality.

- Even though the country's GDP per capita is still low and there is potential for more industrialization, the performance of the Colombian economy has shown steady historical growth, a favorable condition to sustain an energy transition process in the future.
- Even when the incidence of poverty and extreme poverty is high, its reduction – which necessarily will occur as part of the transition (the United Nations' definition of sustainability refers to three main areas: social, economic, and environmental) – will imply a rise in energy demand. This rise in energy demand will increase the need for investment but, at the same time, will allow markets to expand, which may improve competitiveness to introduce new low-emission technologies;

- The country has very important energy reserves and potential:
    - significant solar potential (32 GW), onshore wind potential (30 GW, particularly in Guajira) and technical offshore wind potential (110 GW)[22] that may play a major role to cover the growing power demand in the future;
    - total hydroelectric potential[23] of 56 GW, only around 20 % of which is used, which offers the opportunity of expanding its use, with the additional advantage that it allows for more generation firmness with intermittent and variable energy, such as solar and wind. Important oil and coal reserves: even though it exports both resources, this introduces a variable that must be considered to design a realistic transition process: the time required to meet the climate targets should allow for a transition based on sustaining the historical soundness of the economy;
    - the evolution shown by the development of carbon capture and storage (CCS) technologies may facilitate this process.

22 https://www.minenergia.gov.co/documents/5858/Espa%C3%B1ol_Hoja_de_ruta_energ%C3%ADa_e%C3%B3lica_costa_afuera_en_Colombia_VE_compressed.pdf

23 It is important to remember that: a) the hydroelectric potential should be updated due to major changes in elements such as the declaration of protected areas and restrictions to the construction of flow-regulation dams associated with power generation; b) part of the remaining potential is related to run-of-the-river plants with no regulation capacity beyond a few hours.

- Public policies and the organization of the energy sector are adequate, according to the indicators proposed in the conceptualization report[24].
    - Ambitious energy transition policy set by the government: National Long-Term Strategy (E2050) with the net zero GHG emission target for 2050.
    - However, it is necessary to seriously consider the sunk costs of the investment made to set deadlines.
    - Renewable energy auctions for power generation.
    - Energy efficiency plans (PROURE).
- Energy prices are distorted by a cross subsidy system between electricity and natural gas consumers and by a fuel price transfer scheme that is financed by the Fuel Price Stabilization Fund (FEPC, in Spanish).

24 See report Just Energy Transition. Conceptual definition and indicators for a group of countries.

- Energy demand
  - The economy, with growing participation of the tertiary sector, has led to a fall in the historical energy intensity.
  - Expected transition from the use of residential firewood to cleaner fuels.
  - Mainly urban population, which may facilitate the development of a more efficient and cleaner public passenger transportation system.
- Power sector and mining
  - Generation mix with low CO_2 emissions due to its high hydro generation composition.
  - Recently, strong investment in renewable generation to diversify the generation mix.
  - High vulnerability to the climate, particularly El Niño (drought) and dependence on back-up thermal plants in dry years.
  - Dependence of some regions in Colombia on the coal extractive industry, in economic and labor terms. The just energy transition plans must consider these social aspects when deciding to shut down facilities, both in the extractive industry and in the thermal plants.
  - Country's dependence on its economic revenues from oil and coal exports, which should be planned and replaced with other sources of revenues in the future.

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 related to fuel combustion in Colombia.

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

- The LEAP model starts with the information of 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 36 in a simplified manner.

Graphic 36 ▶ Sectors, activity levels, and intensive variables

Sector	Activity level	Intensive variable
Residential	Population	Consumption per capita
Road transport	Target variable, vehicle fleet	Average consumption by vehicle
Non-road transport	Total GDP	Energy intensity
Industrial	Sectoral GDP	Energy intensity by subsector and use
Commercial, Services, and Public sector	Sectoral GDP	Energy intensity
Agriculture, Fishing, Mining & 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.

Energy projection methodology

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

PIn order to analyze and project energy consumption in the residential sector, the **projection of the population and of unitary consumption** are estimated by energy 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 analysis applies to each group.

- **Heat uses**
  - **Cooking.** The historical consumption trends, used for future projections, are analyzed in terms of useful energy[25] per 1,000 inhabitants. Fuel substitution assumptions by scenario (replacement of firewood with electric appliances or others running on natural gas) are presented.
  - **ACS and space heating.** Given that these sectors are incipient and this type of consumption takes place with the increase in GDP per capita, the current consumption observed in Spain and Portugal (countries with similar climate conditions to those in the region) is extrapolated as target consumption[26]. A broader implementation of energy efficiency measures and assumptions on the types of fuel to be used is also presented.
- **Other electrical uses.** Electrical uses (lighting, refrigeration, air conditioning, water pumping, electronics, etc.) are projected from a historical regression against the GDPpc, which evidences 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 making a difference by end use. Different assumptions are presented in terms of energy efficiency and fuel substitution.

25 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".

26 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, **by activity subsector**. Seven subsectors were modeled; food, beverages, and tobacco; non-metal minerals; and unspecified industry are those with more relevance in connection with energy consumption. 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[27]. 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).

27 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[28] 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"**[29] 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)

28 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.

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

Similarly to 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 vehicle 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 in 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 making a difference by end use.

To enhance Colombia's climate action, it is recommended to commit to phasing out coal, strengthen the electric vehicle target for 2030, and accelerate charging infrastructure.

Agricultural, fishing, mining, and construction sector

Energy consumption in this sector was **projected based on the GDP growth and energy intensity** obtained for 2019, by source and without distinguishing it 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.

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 power demand estimation[30], 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[31].

30 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.

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

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 commitment during the planning horizon, investment is required to continue with the energy transition policies that are being carried out in Colombia.

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[32]. Both scenarios focus on reducing GHG emissions from the energy sector[33] to a permissible minimum[34], so that the country can manage the absorption of CO_2 in the general balance of the national GHG inventory[35].

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.

Projection 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 Colombia, the GDP per capita will reach USD 37,000 per capita at PPP in 2060, with a 2.3 % annual growth rate during the period.

32 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”.

33 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.

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

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

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

Indicator	Measuring unit	2019	2030	2040	2050	2060	TCMC
GDP per capita	USD per capita	14,616	18,182	23,116	29,389	37,364	2.3 %
Total GDP	MUSD	733,546	984,185	1,301,385	1,674,808	2,109,590	2.6 %
Population	1,000 inhabitants	50,187	54,130	56,298	56,988	56,460	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 population projection, the information from CEPALSTAT[36] was used. A deceleration in population growth is expected in Colombia in the future, with negative growth in the long term.

36 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 devices 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.

Energy projection methodology

- **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 byproducts 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 greatest emission reduction potential in absolute values are the transportation and industry sectors, which nowadays are responsible for around two thirds of the emissions from the energy sector.

Just Energy Transition - Scenarios Colombia

1. Global results

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

Emissions by sector

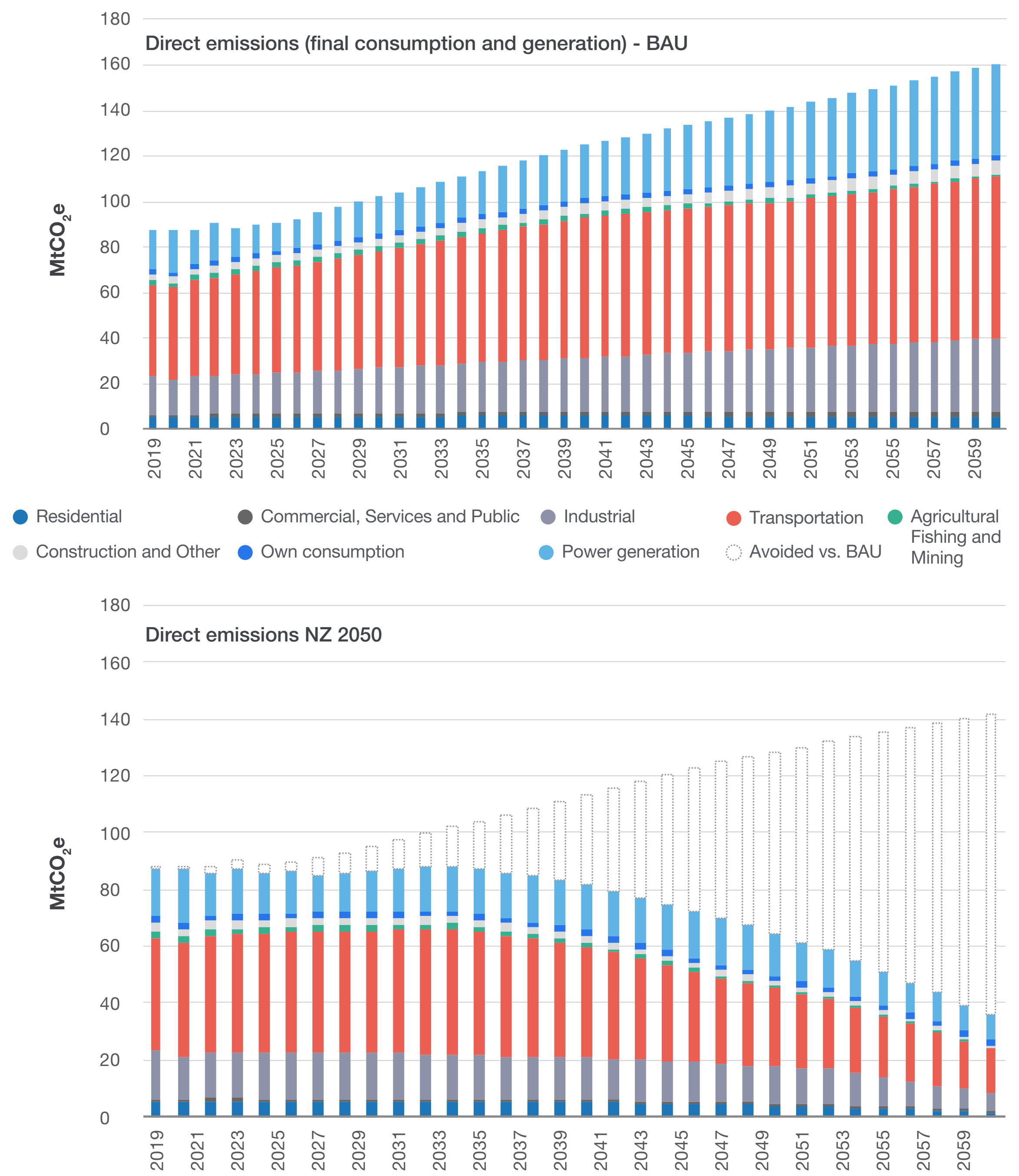
In the **BAU scenario**, the emissions related to burning fuels grow at an average annual rate of 1.5 %, from 87 $MtCO_2e$ in 2019 to 161 $MtCO_2e$ in 20160. Even though this **increase** is sustained, it is **lower than the expected GDP growth**, which shows a certain environmental improvement in the economy. The transportation sector continues being the greatest polluter in Colombia, followed by the industrial segment and, further behind, power generation. This scenario is well above the country's CO2 absorption capacity, estimated at 52.7 $MtCO_2e$ per year[37].

In the **NZ scenarios**, direct emissions fall to 36 $MtCO_2e$ in the NZ scenario 2050 and to 42 $MtCO_2e$ in the NZ scenario 2060, thus meeting the **net zero emissions target**. The average annual emission reduction pace is -2.8 % (for the NZ scenario 2050) and -1.4 % (NZ scenario 2060). The transportation sector continues having the most emissions.

37 https://climateactiontracker.org/countries/colombia/. Absorptions must cover not only the energy sector but also the industrial processes sector and the product use (IPPU), residues, etc. It is estimated that emissions should be lower than 250 $MtCO_2e$ in the energy sector.

Graphic 37 A

Direct emissions (final consumption and generation) by sector ($MtCO_2e$)

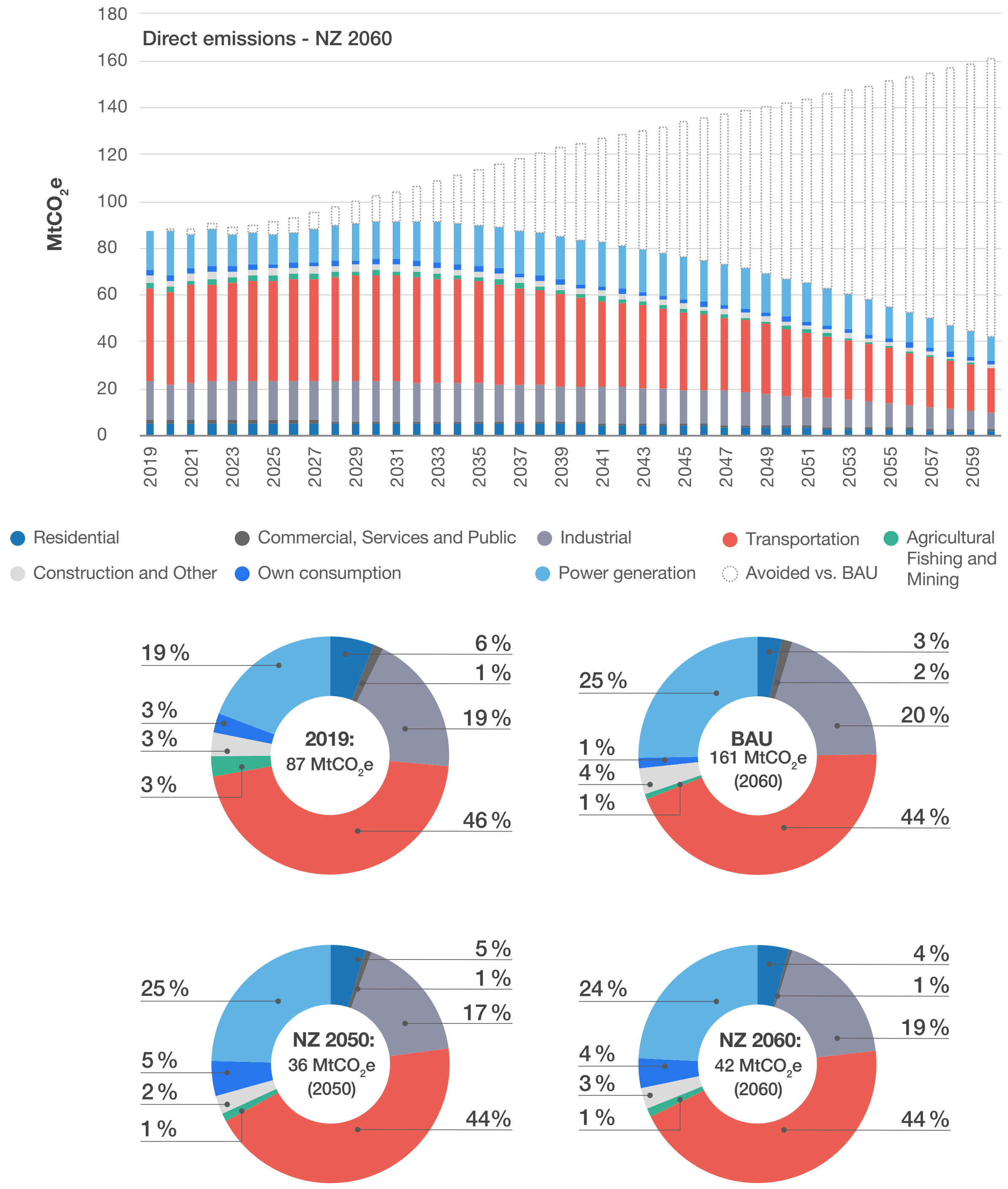


Source: Own preparation.

Transition scenarios

Graphic 37 B

Direct emissions (final consumption and generation) by sector ($MtCO_2e$)



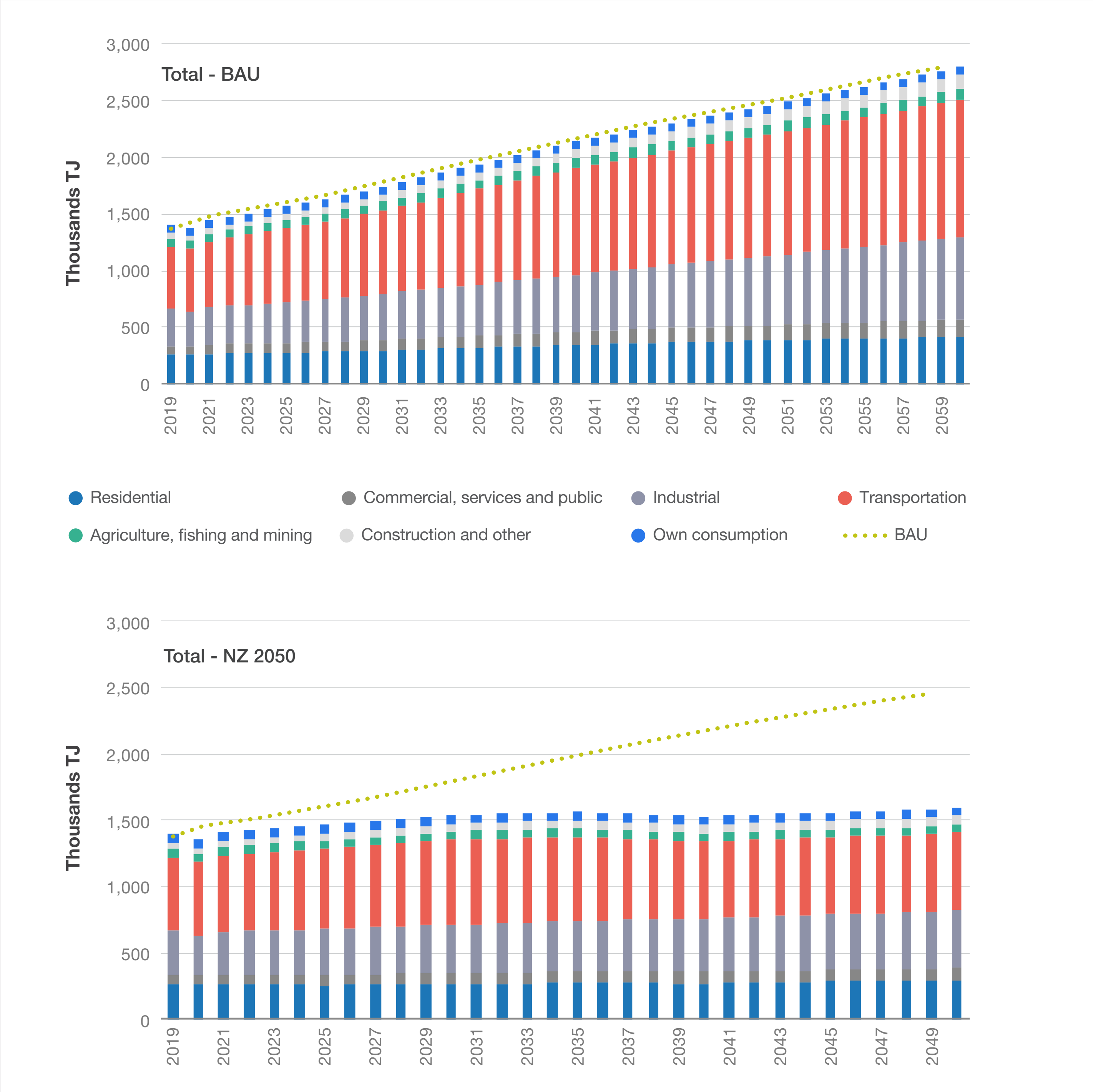
Source: Own preparation

To meet the net zero emission target, GHG emissions by sector should reduce by half during the planning horizon, compared to current emission.

Energy demand by sector

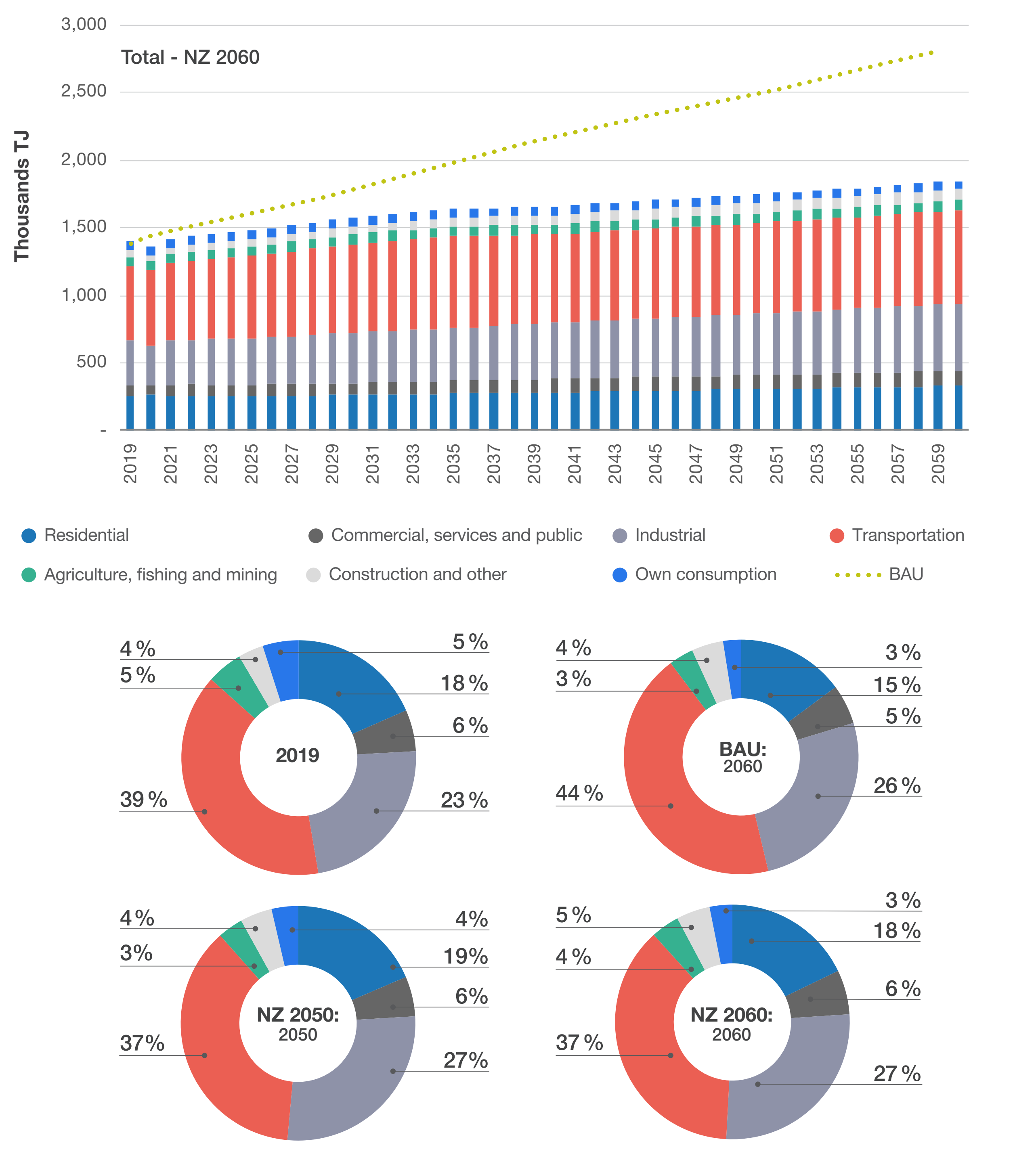
In the BAU scenario, the demand doubles during the analyzed period and reaches around 2,800 thousand TJ in 2060. In the NZ scenarios, the demand grows slightly due to the stronger effects of efficiency and fuel substitution. In all the scenarios, **demand growth is higher than that of GHG emissions.**

Graphic 38 A Final consumption and own consumption, by sector and scenario (thousands of TJ)



Source: Final and own consumption, by sector and scenario (thousands of TJ)

Graphic 38 B Final consumption and own consumption, by sector and scenario (thousands of TJ)



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

Table 11 Final consumption and own consumption by scenario, thousands of TJ and CAGR (%)

Demand (thousands of TJ)	2019	2030	2040	2050	2060	TCMC (%)
BAU	1,401	1,743	2,141	2,461	2,799	1.7 %
NZ 2050	1,401	1,539	1,527	1,589		0.4 %
NZ 2060	1,401	1,574	1,653	1,744	1,845	0.7 %

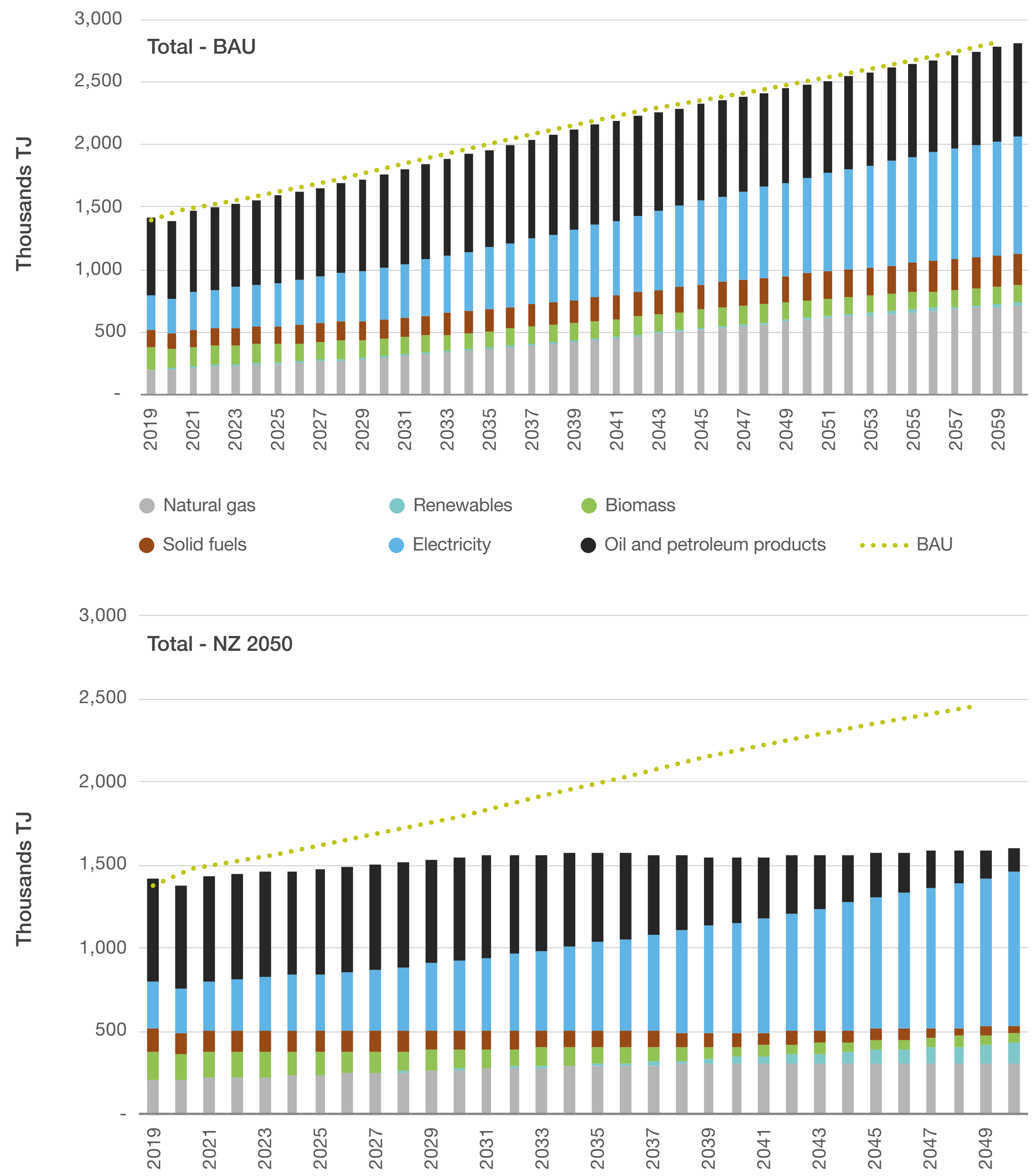
Source: Own preparation. Non-energy consumption is not included.

In all the scenarios, the relative participation of the demand by sector does not vary very significantly and the transportation, industry, and residential sectors add 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

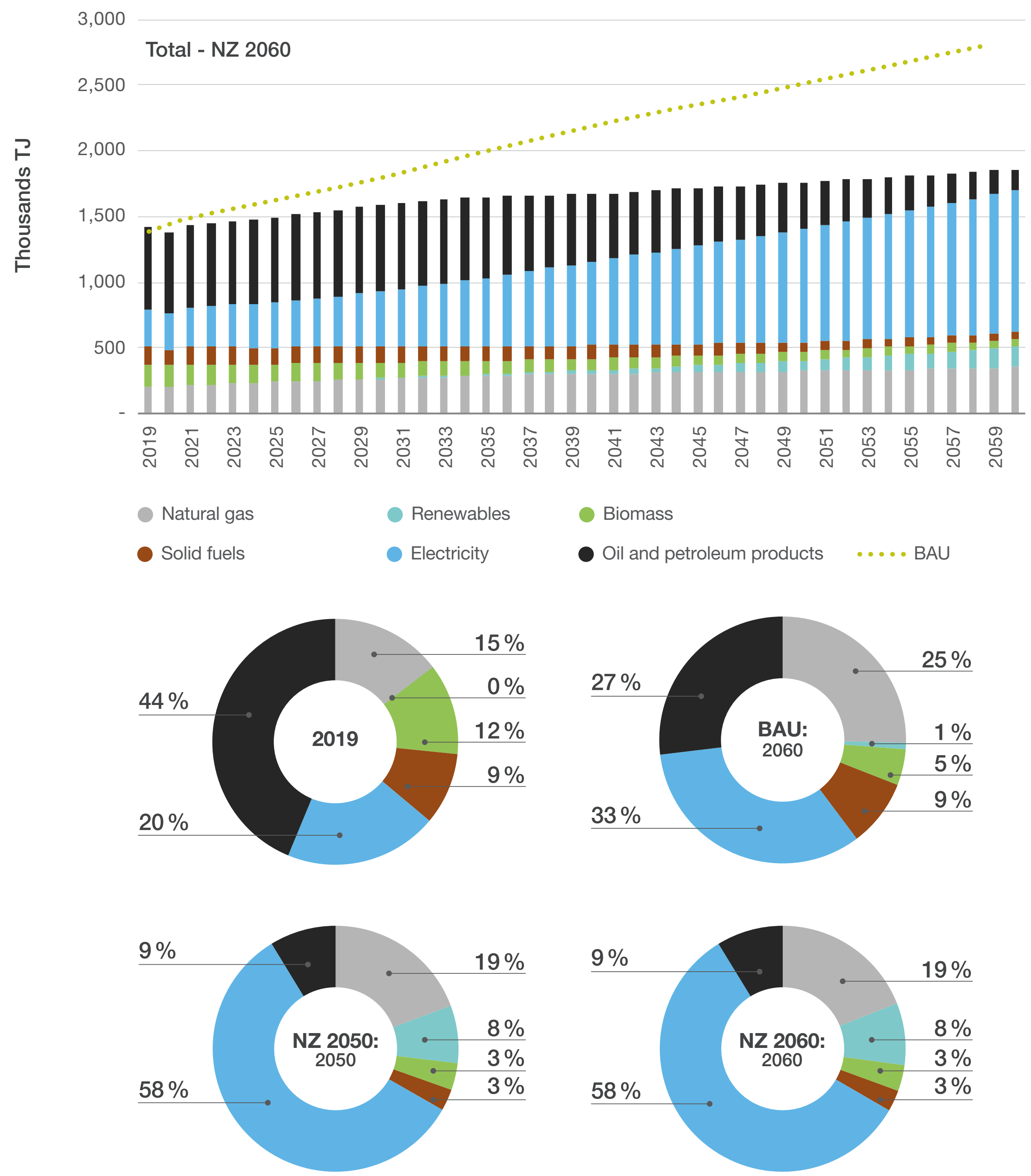
By fuel, **a strong trend towards electrification** of the demand can be observed for all the scenarios. The BAU scenario reflects stability in coal, biomass, and fossil fuel consumption whereas the increase in demand is covered by natural gas and electricity. The NZ scenarios present stronger electrification hypotheses (approximately 58 % of total final consumption) and partial replacement of coal and biomass as well as liquid fuels. Hydrogen byproducts and solar thermal energy are developing in the long term at the end of the planning horizon.

Graphic 39 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 byproducts. The oil and petroleum products category includes LPG.

Graphic 39 B Final consumption and own consumption, by source and scenario (thousands of TJ)



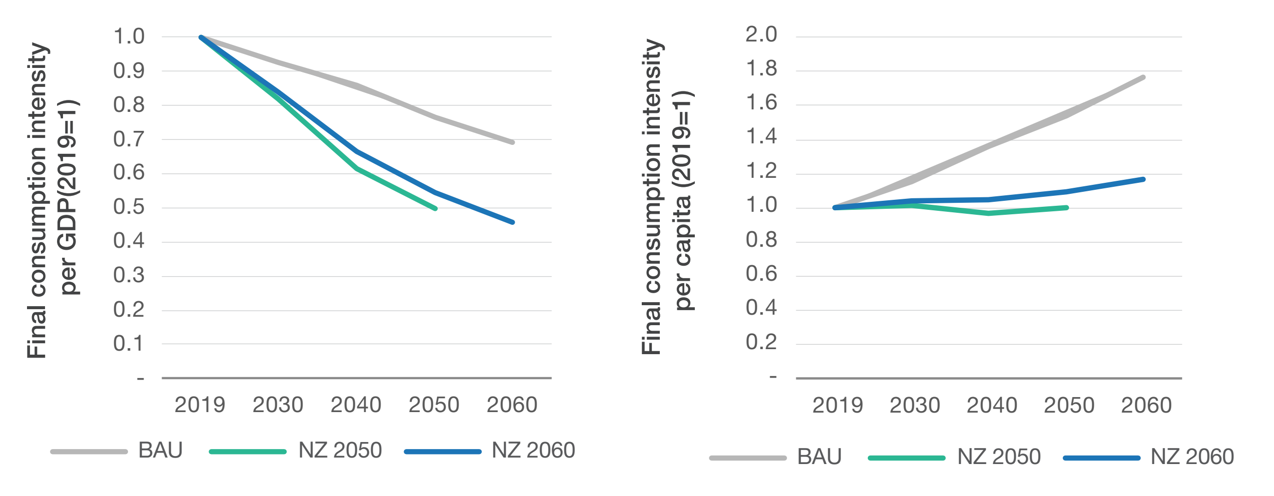
Source: Own preparation. Note: The renewables category refers to solar thermal energy or hydrogen byproducts. The oil and petroleum products category includes LPG.

Energy and environmental intensity

In the BAU scenario, energy intensity measured in economic terms (final consumption/total GDP) is reduced by around 30% in the period (annual -0.9 %), whereas in the NZ 2050 and NZ 2060 scenarios, it is reduced by over 50 % (annual -2.2 % and -1.9 %, respectively).

Measured in terms of population (final consumption per capita), total unitary consumption grows by around 75 % whereas in the NZ scenarios it remains quite stable. These alterations reflect the necessary evolution of final consumption to comply with the country's economic development and cover current consumption gaps.

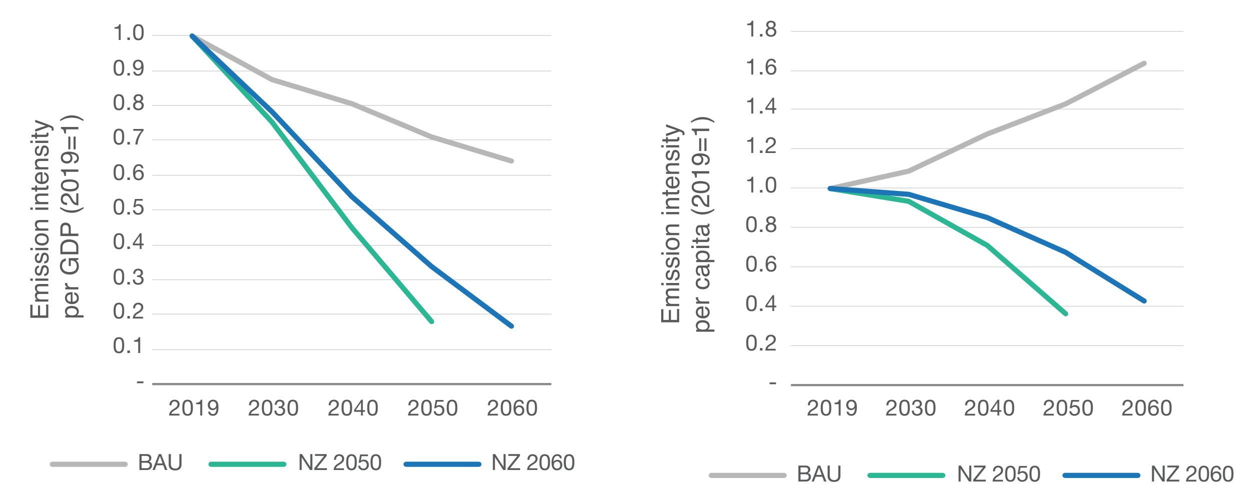
Graphic 40 Unitary energy intensity (2019=1), thousands of TJ/MUSD PPP 2017 (left) and thousands of TJ per capita (right)



Source: Own preparation.

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

Graphic 41 Unitary environmental intensity (2019=1), tCO_2e/thousands of 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 evidences the emissions reduction by energy unit consumed. To achieve net zero emissions, the emissions by GDP unit of the base year should be reduced by between 80 % and 85 %.

2. Results and assumptions by sector

Residential sector

The residential sector is the third sector in terms of energy demand (19 % in 2019). It is responsible for a limited volume of GHG emissions (5 Mt CO_2e), but there is potential to reduce them even further with energy transition measures. This sector is characterized by:

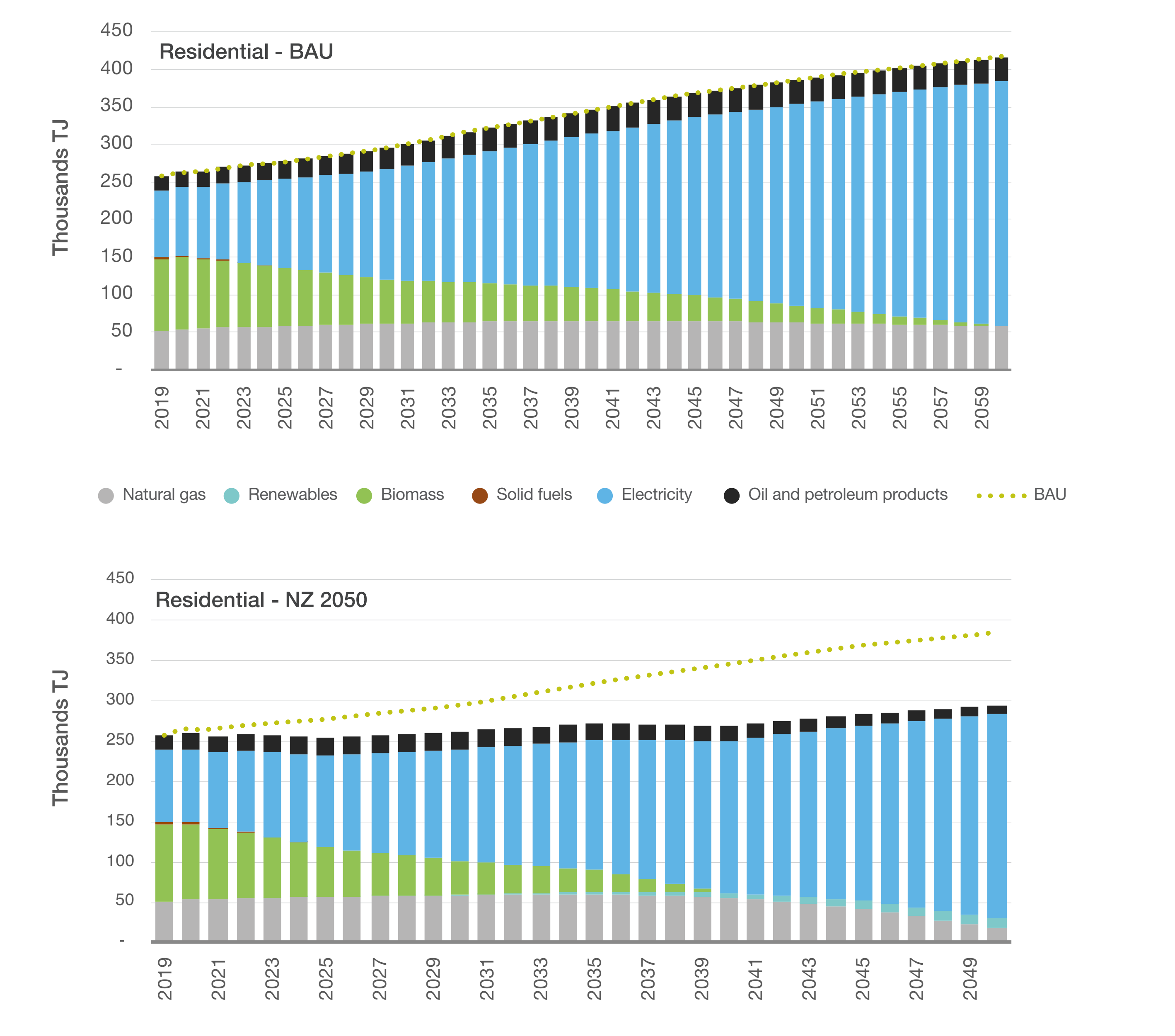
- high firewood consumption used for cooking, with great electrification potential (and, in turn, large efficiency gains[38]). This firewood consumption for cooking (37 % of the sector's final consumption) relates to the most vulnerable segments of the population; that is, its replacement is possible in a context of higher standards of living and support programs for the sector (for example, the National Firewood Substitution Plan to cook food[39]). Cooking end use accounts for 70 % of the sector's final consumption, one of the highest rates in the region;
- other uses (ACS, home appliances, air conditioning, etc.) with growth potential as the standard of living improves and in line with what was observed in developed countries.

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

39 https://www1.upme.gov.co/sipg/Paginas/Plan-nacional-sustitucion-le%C3%B1a.aspx

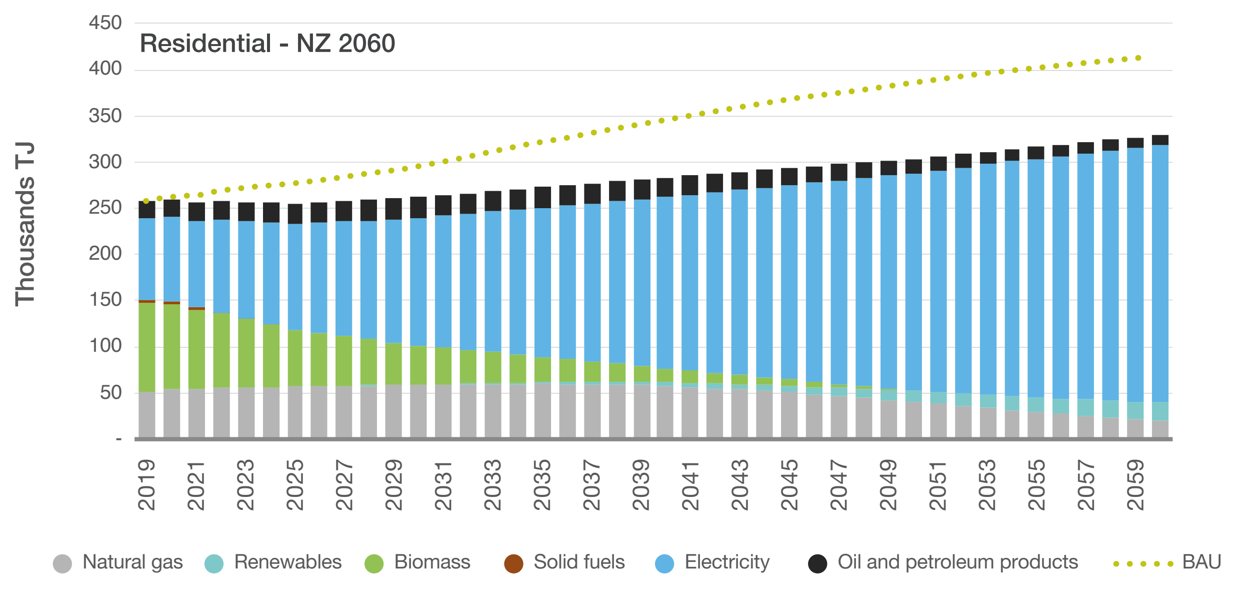
Transition scenarios

Graphic 42 A ▸ Residential sector: results by fuel and by scenario (10^3 TJ)



Graphic 42 B

Residential sector: results by fuel and by scenario (10³ TJ)



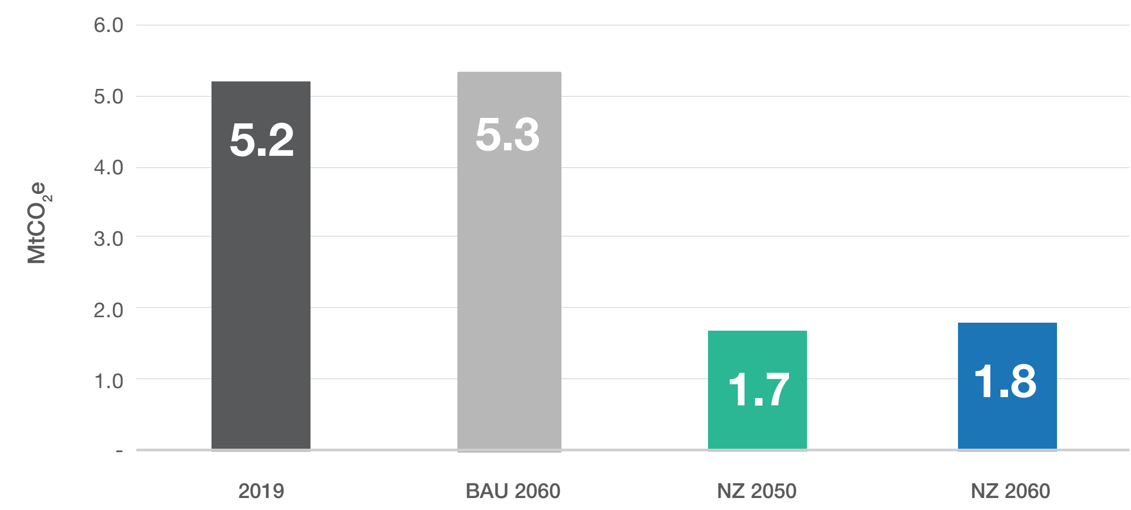
Source: Own preparation. **Note:** The renewables category refers to solar thermal energy. The oil and petroleum products category includes LPG.

In the BAU scenario (graphic on the left), we can see a 61 % increase in residential energy demand in the period (annual 1.2 %), mainly driven by the new electrical uses (including air conditioning, water heating, and space heating) that are expected to accompany the increase in the projected standard of living. This increase is higher than that of population (12 % in the period). Firewood is totally replaced at the end of the period, in line with the historical trends and Colombia's national objectives. Natural gas and LPG consumption remains relatively constant. Electricity 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 (86 % and 85 %, respectively); there is a natural gas surplus and solar thermal energy is introduced to heat sanitary water. In turn, biomass replacement occurs faster. More energy efficiency efforts[40], both for appliances and buildings, allow compensating, to a large degree, for the new uses that accompany the increase in GDP per capita (the energy intensity of the sector, measured as demand per capita, is quite stable in the period).

Graphic 43

Residential sector: direct emissions by scenario ($MtCO_2e$)



Source: Own preparation.

CO_2e emissions remain stable in the BAU scenario, whereas they decrease by two thirds in the NZ scenarios in the long term, thanks to the energy efficiency and electrification measures from clean generation sources.

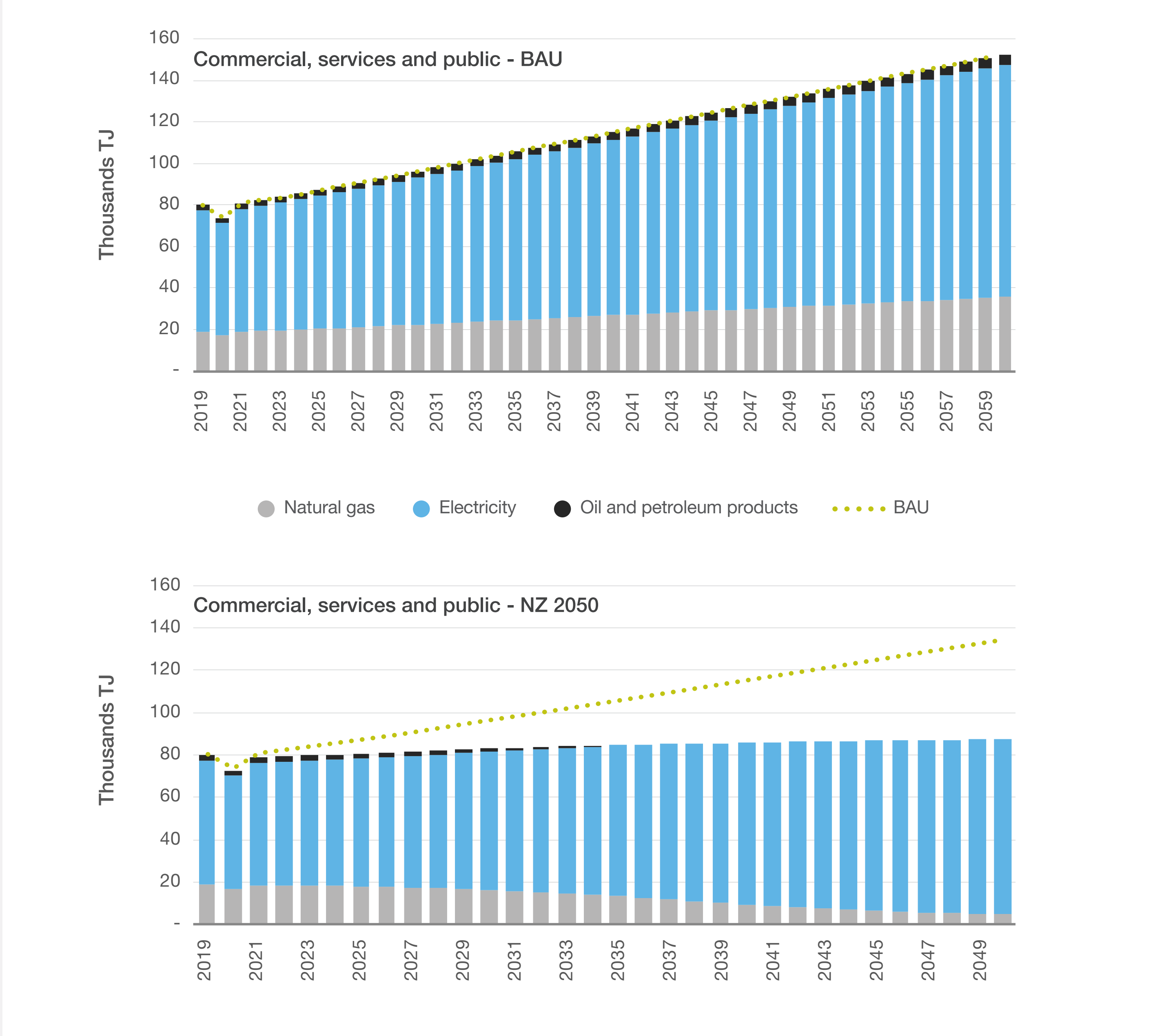
40 There are only two lines of action to increase energy efficiency in all sectors: technological change and good energy use practices. For example, the replacement of incandescent bulb lighting with discharge units (bulbs that save energy) and later by LED bulbs, which took place in most countries, produces, by itself, a reduction in installed lighting capacity of up to 80 %. However, this would result in a similar reduction in terms of energy consumption only if the same patterns of use previous to replacement were maintained. Otherwise, it may be higher if there is more care in the use of lights (with motion sensors, for instance); or it may be lower if all the lights are left on more time when switching to LED. Changing the technology is not enough; what is known as "good practices in the use of energy and operation and maintenance of facilities and equipment" should be applied.

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

Commercial, services, and public sector

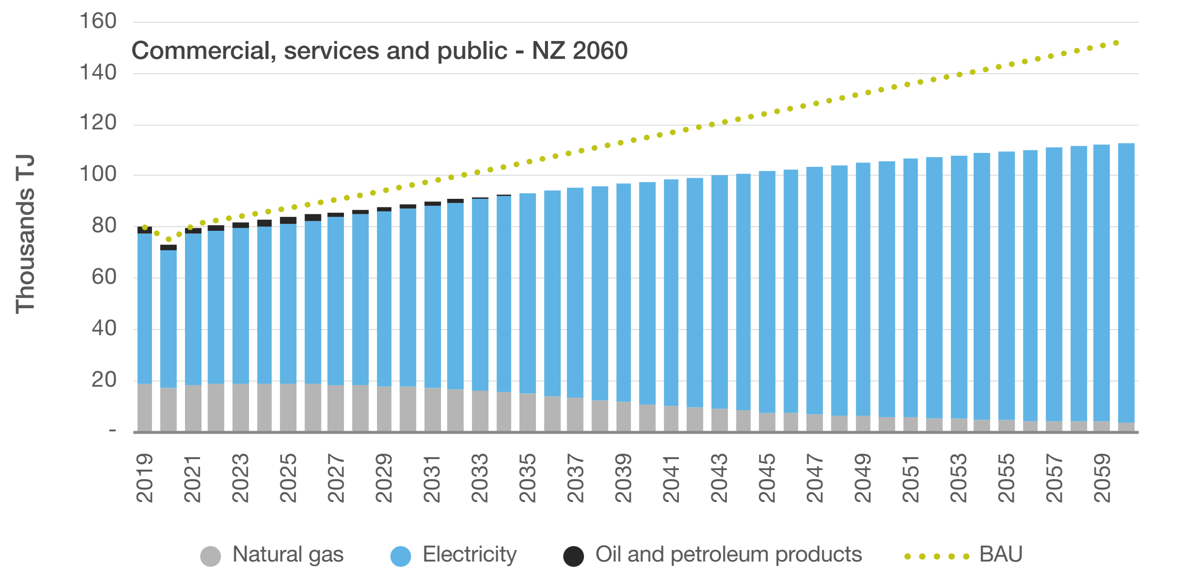
The commercial, services, and public (CSP) sector is formed by the public administration, hospitals, hotels, and stores, etc. It is often a sector with little weight in terms of energy consumption (6 % of the total, in 2019) compared to the transportation, industrial, and residential sectors. It starts from a high electrification rate (74 % in 2019) and end uses with electrification potential (ACS, 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 44 A Sector CSP: Results by fuel and by scenario (10^3 TJ)



Source: Own preparation. Note: The oil and petroleum products category includes LPG.

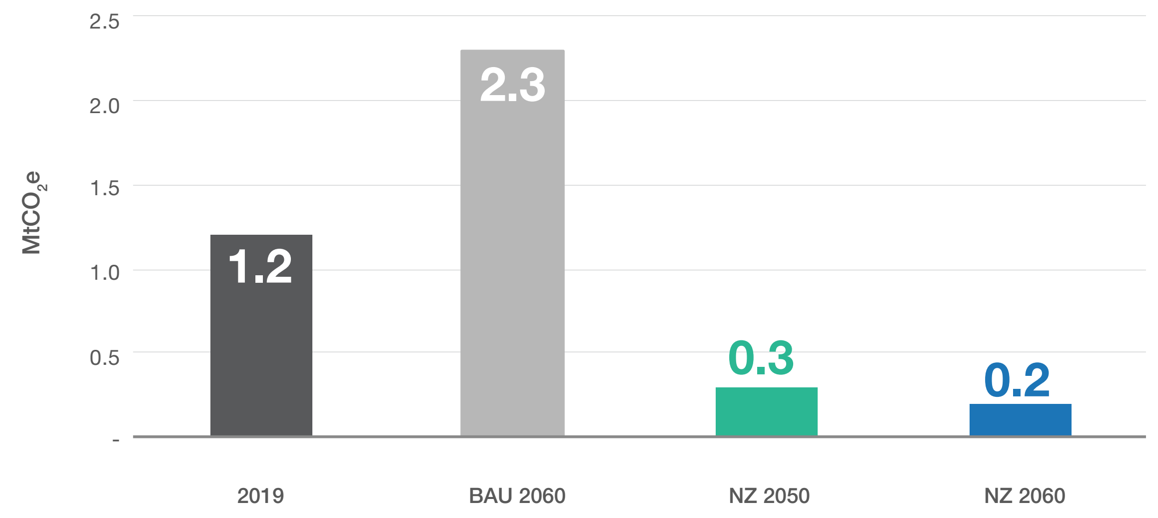
Grapgic 44 B ▶ Sector CSP: Results by fuel and by scenario (10^3 TJ)



In the BAU scenario, the fuel share remains constant. On the other hand, even though the sector's GDP has almost trebled, the energy demand grows by approximately 90 % due to energy efficiency measures.

For the NZ scenarios, almost the total electrification of the sector is considered (≥95 %), with a remnant of natural gas in the last year. A 26 % demand reduction is achieved by 2060 in the NZ 2060 scenario and 35 % by 2050 in the NZ 2050 scenario, compared to the BAU scenario. Energy efficiency enhancements explain a large part of this phenomenon.

Graphic 45 ▶ CSP sector: direct emissions by scenario ($MtCO_2e$)



Source: Own preparation.

CO_2e emissions grow in the BAU scenario but at a slower pace than the GDP, whereas they are between 25 % and 15 % in the NZ scenarios.

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

Industrial sector

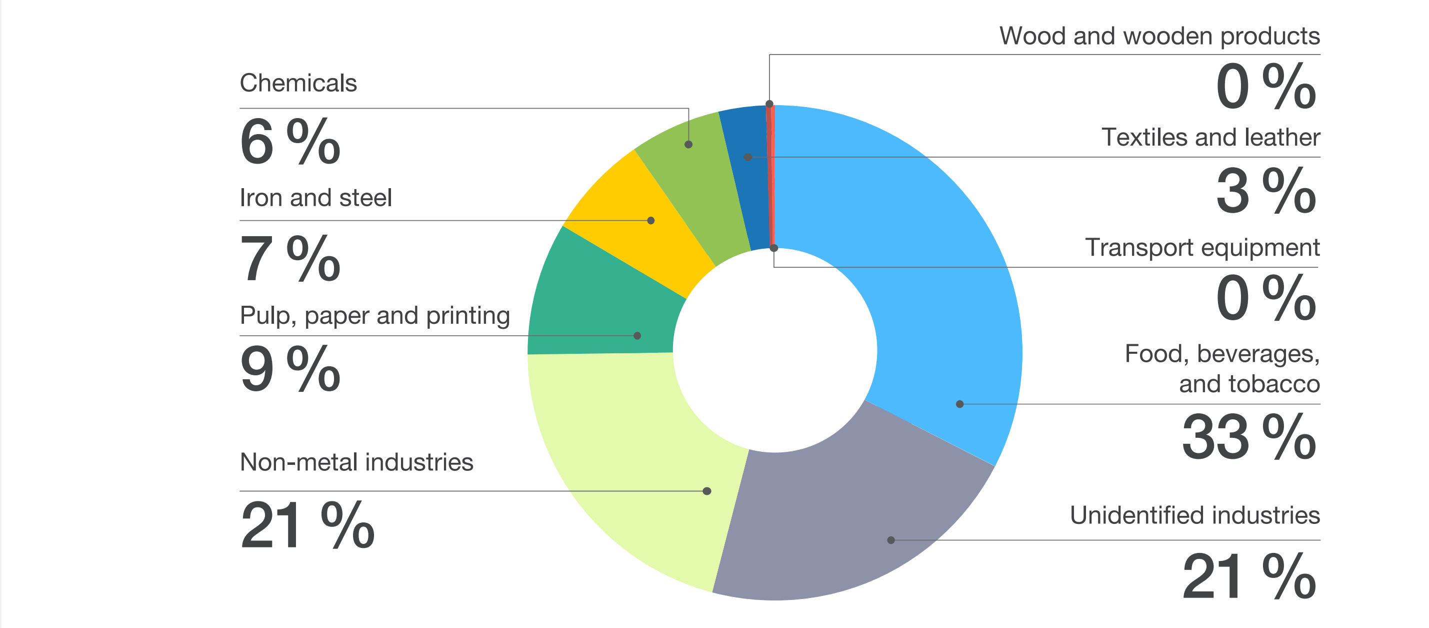
The industrial sector is formed by several industrial subsectors and is the second with the largest energy demand (24 % in 2019) after the transportation sector. Its starts from a low penetration of electricity (20 %), conditioned by several sectors that are difficult to electrify, such as the steel 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 subsectors

Colombia's National Energy Balance presents the information on the industrial sector broken down into 23 subsectors grouped together into 9 groups.

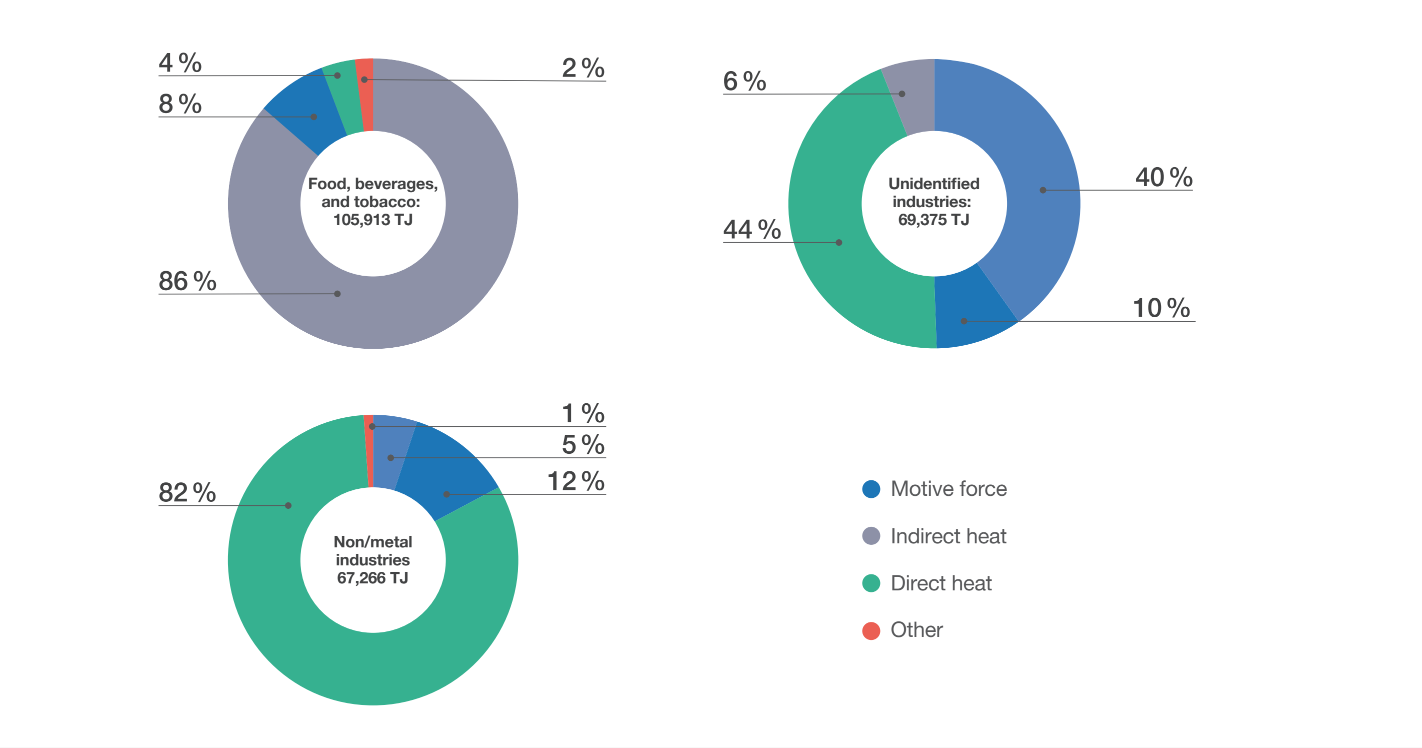
Graphic 46 Industrial sector: energy consumption by industrial subsector, 2019 (%)



Source: Own preparation based on data from the Colombian Energy Balance (UPME) and the Colombian Energy Balance (OLADE).

The food, beverages, and tobacco; non-metal minerals; and iron and steel subsectors account for 75 % of the energy consumption in the sector. Indirect heat use is predominant for the food, beverages, and tobacco category (86 %), while direct heat use predominates for the non-metallic minerals category (82 %). In the unspecified industry category, the predominant uses are direct and indirect heat, with 44 % and 40 %, respectively.

Graphic 47 Industrial sector: energy consumption of fossil fuel by use for the main subsectors (%)



Source: Own preparation based on data from the Useful Energy Balance for the residential sector (UPME).

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 towards more recent and efficient appliances and facilities.

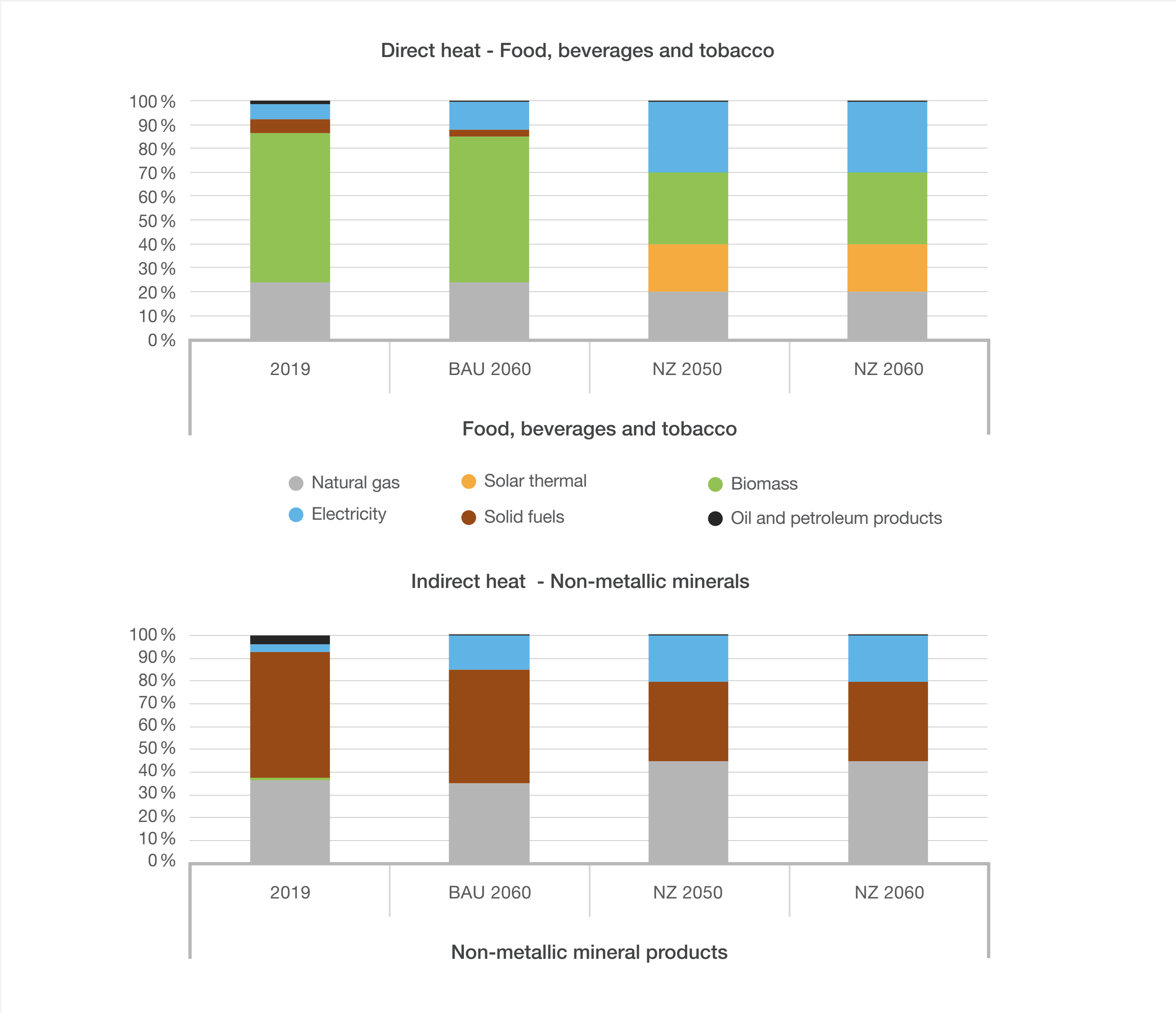
The substitution assumptions considered for Colombia are detailed below:

- a strong reduction in consumption (higher in the NZ scenarios) was considered for industrial subsections with high penetration of coal and substitution potential. Natural gas partially replaces coal.
- in the case of sectors with low coal substitution potential, long-term carbon capture and storage technologies are considered in the scenarios (IEA, 2021) with annual absorption limited to $MtCO_2$ in Colombia[41].
- natural gas and LPG fully replace fuel oil and diesel in the next decade and a gradual penetration of solar thermal energy for indirect heat is progressively assumed in some sectors.

Graphic 48 shows the evolution of final consumption by fuel for the main uses in the different scenarios.

41 Absorption potential in line with Colombia's long-term climate strategy E2050.

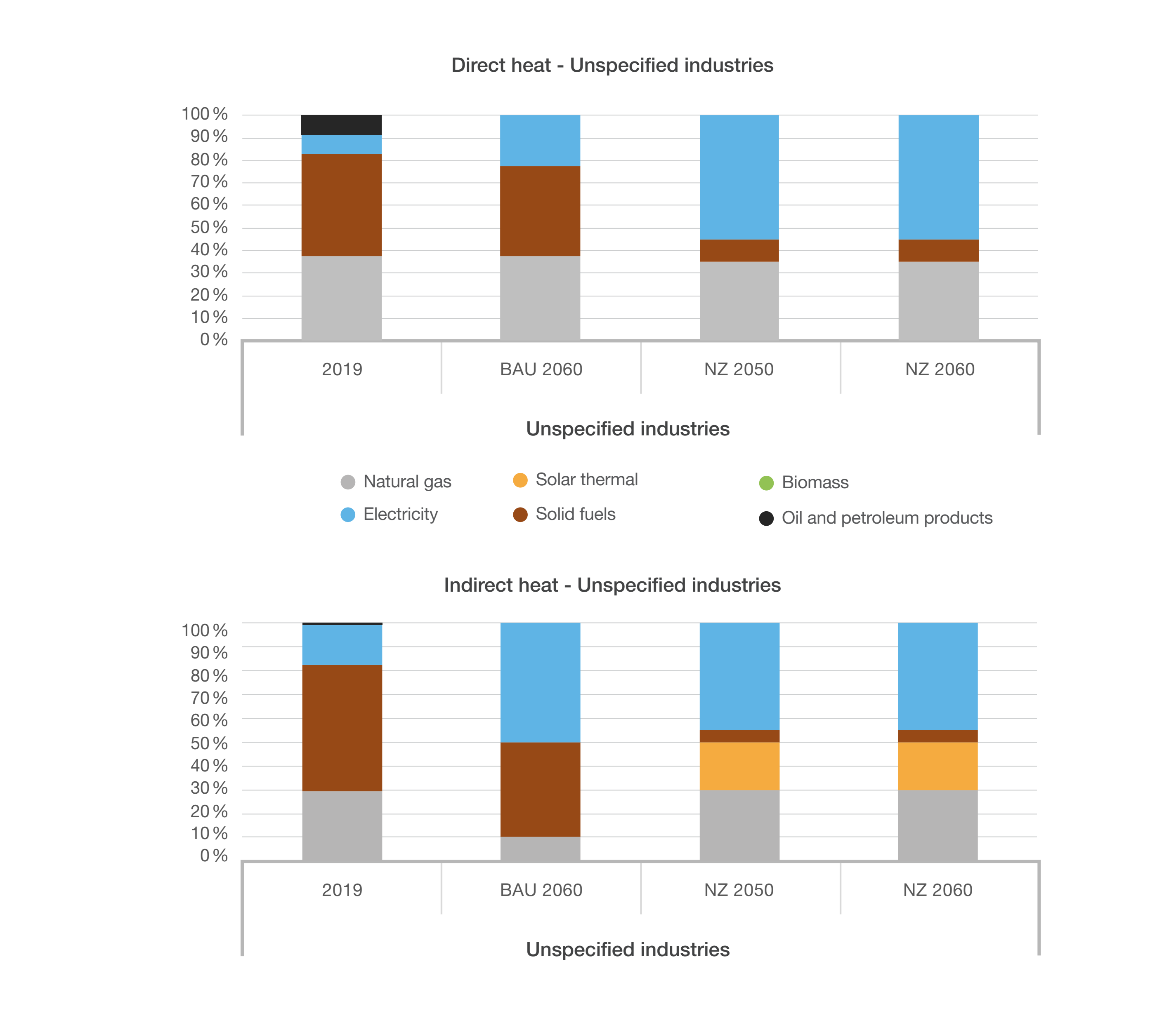
Graphic 48 A Industrial sector: evolution by scenario for the main uses in the most relevant industrial subsectors (%)



Source: Own preparation.

Graphic 48 B

Industrial sector: evolution by scenario for the main uses in the most relevant industrial subsectors (%)



Source: Own preparation.

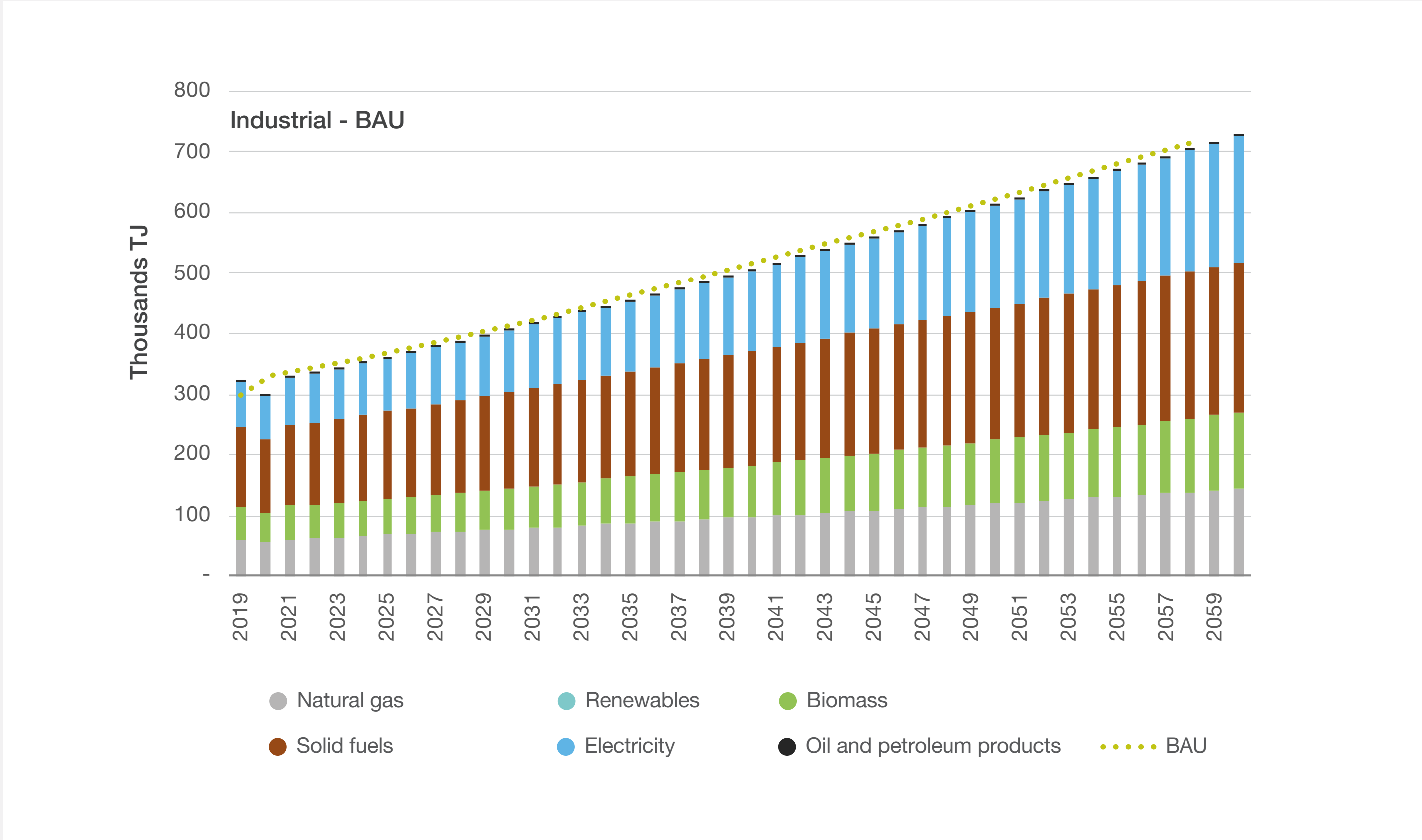
Transition scenarios

Results

Even though an increase of 188 % in the GDP of the sector has been projected, the final energy demand in the BAU scenario will grow by 124 % due to fuel substitution and energy efficiency measures. The electrification of the final demand will grow from 23 % to 27 %.

Graphic 49 A

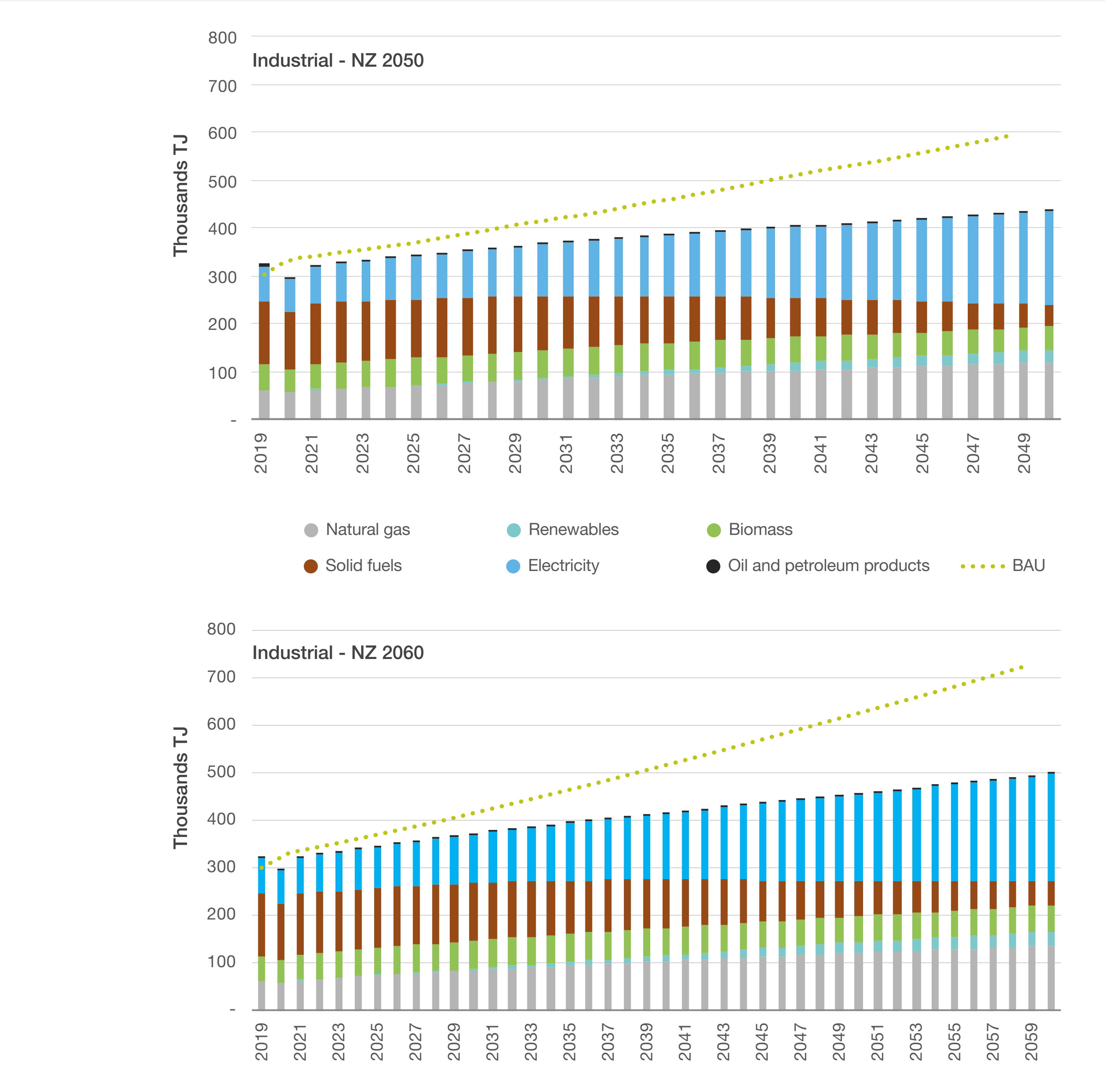
Industrial sector: final consumption by fuel and by scenario (10^3 TJ)



Source: Own preparation.

Graphic 49 B

Industrial sector: final consumption by fuel and by scenario (10^3 TJ)



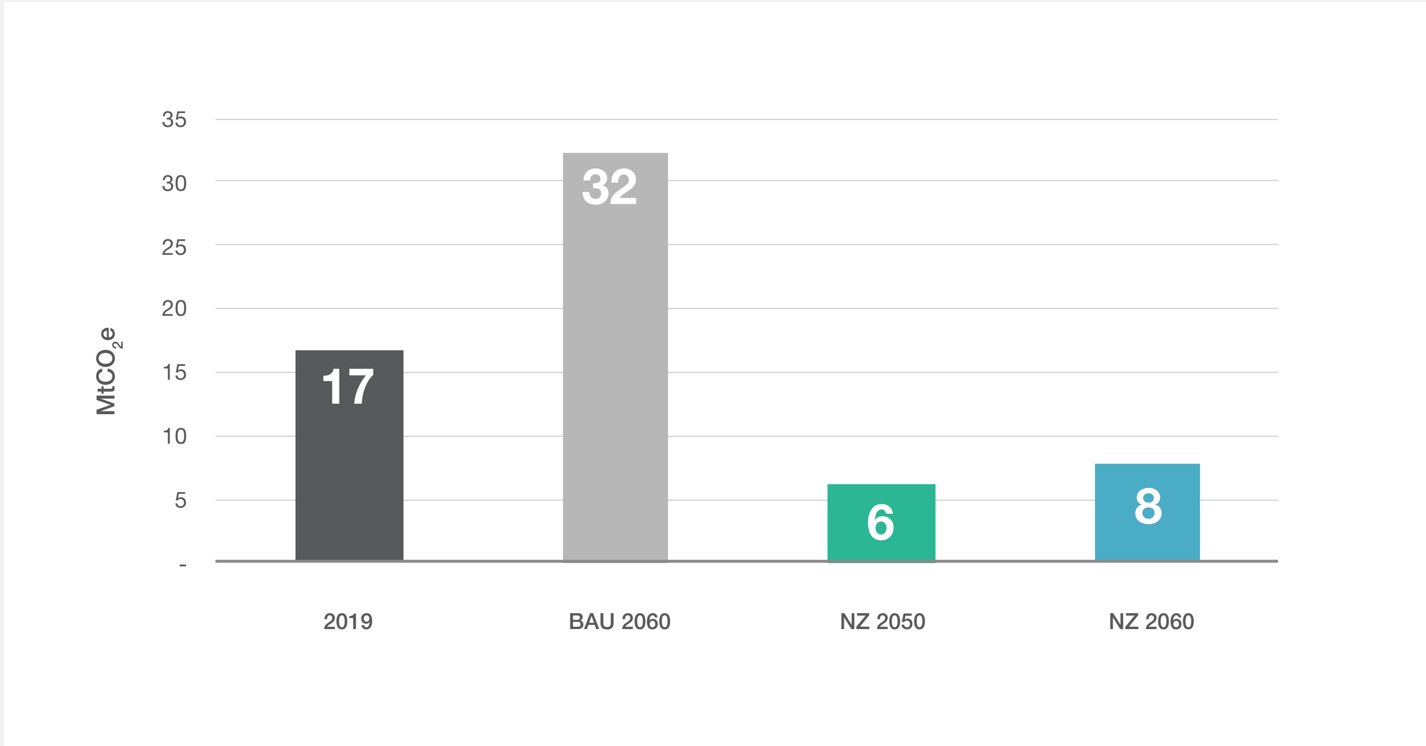
Source: Own preparation.

For the NZ scenarios, the consumption of coal falls although it is assumed that a certain amount could not be substituted in the sectors with more penetration of such fuel (non-metal minerals and unspecified industry). In addition, these sectors allow part of the coal industry to remain operative so as not to displace specialized populations in specific areas in Colombia. Biomass consumption remains quite stable in the planning horizon.

The electrification of the sector doubles in the period (from 23 % to 45 %).

Graphic 50

Industrial sector: direct emissions by scenario ($MtCO_2e$)



Source: Own preparation.

CO_2e emissions grow in the BAU scenario (+93 %), but twice more slowly than the GDP. On the other hand, emissions in the NZ scenarios fall twofold in the long term thanks to energy efficiency, fuel substitution, and carbon capture measures.

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

Transportation sector

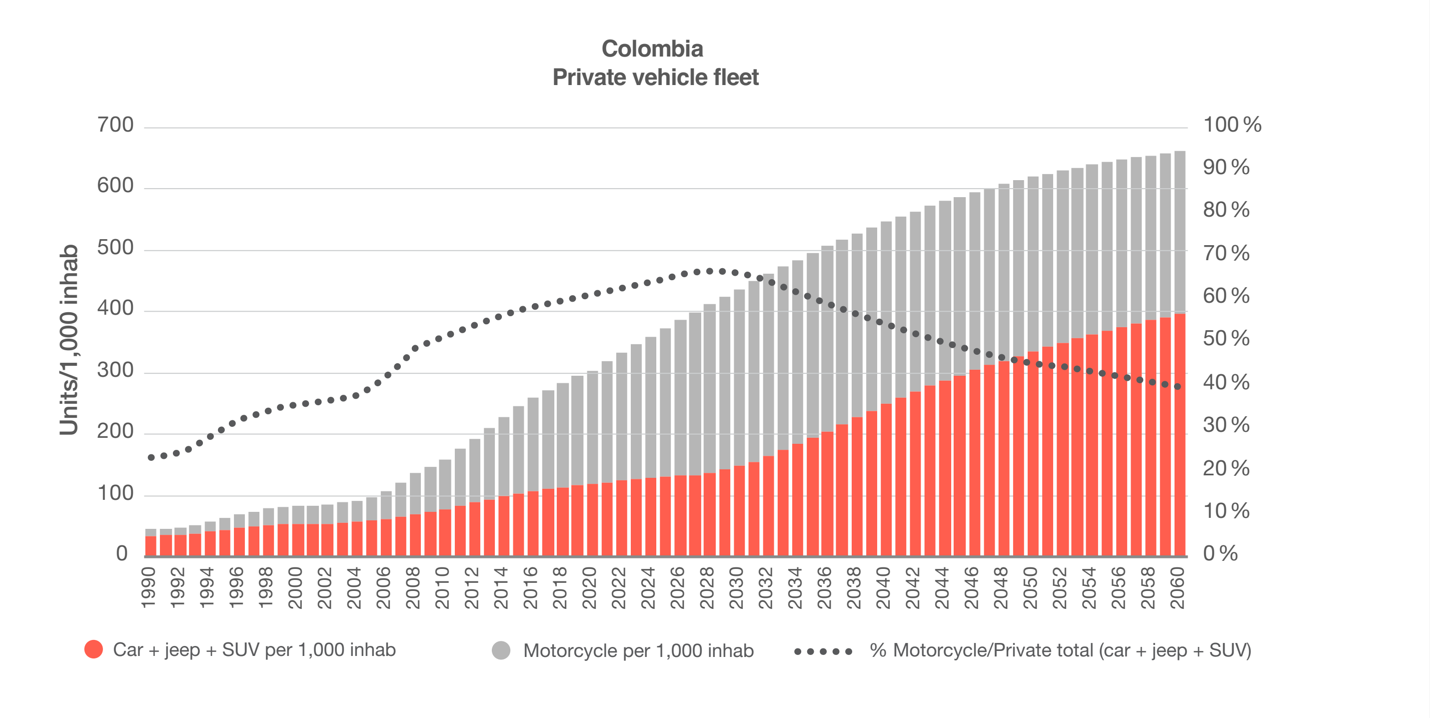
In Colombia, the transportation sector is the maximum energy consumer (41 % in 2019) and greenhouse gas emitter. It mainly consumes liquid fuels (diesel, gasoline, etc.). Even though electric vehicle sales have increased worldwide in recent years, these vehicles account for a small portion in Colombia. Road transportation accounted for 88 % of total final consumption in 2019, led by road passenger transportation (64 %).

Road passenger transportation

Energy consumption by road transportation mainly depends on the evolution of the number of vehicles. In all the scenarios, a **significant increase in motorization** is expected, in line with the growth in the standard of living and the recent trends in Colombia. This increase continues with the Colombian market trend of a rising number of motorcycles per 1,000 inhabitants observed in the last decade. Starting from a certain GDP per capita level, the motorization increase begins to focus on cars[42]. 661 vehicles per 1,000 inhabitants is projected for 2060, 40 % of which are motorcycles and 60 % are cars.

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

Graphic 51 ▶ 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. One of the main measures that could be contemplated 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 and 20 % hybrid in the BAU scenario in 2060. Instead, in the NZ scenarios, an 80 % share of electric vehicles and 20 % of hybrid is projected for the end of the period. On the other hand, 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, it is expected that the average efficiency of the vehicle fleet will improve due to technological enhancements and/or the reduction in vehicle weight.

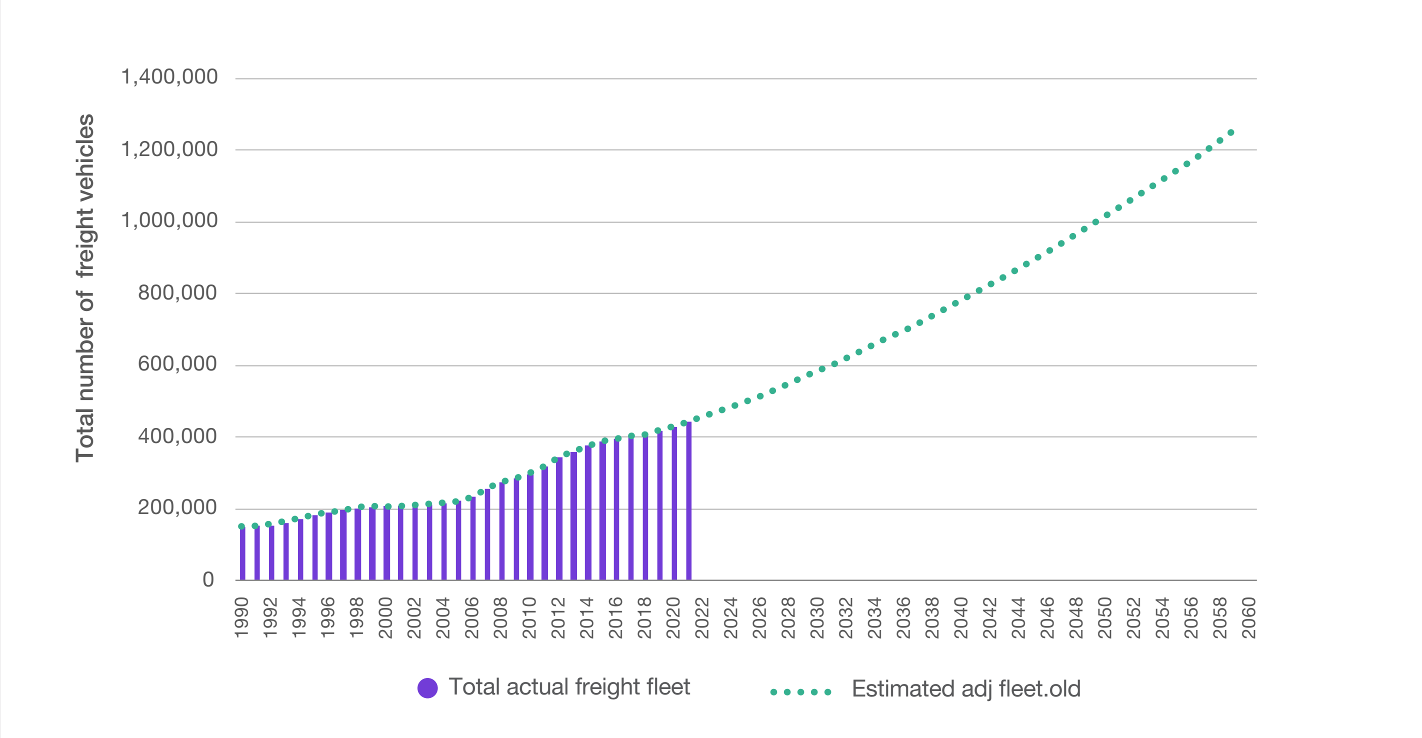
Finally, a decrease in the average distances traveled is expected by vehicle (km/vehicle) as a result of the **digitalization** of society (remote work, etc.) and greater penetration of **public transportation** systems.

Road freight transportation

The road freight fleet 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 (2.8 % annual average), both for trucks (84 % of the total) and for truck tractors.

Transition scenarios

Graphic 52 Total number of freight vehicles



Source: Own preparation.

In order to limit the increase in GHG emissions, it will be necessary to promote energy transition fuels pursuant to the time horizon considered: CNG, LNG, electricity (now available) and hydrogen byproducts (as from 2040). It is assumed that natural gas (CNG, LNG) will play an important role in the period 2030-2040. In addition, the energy transition must be accompanied by vehicle **performance enhancement, logistics enhancement, and a shift to railways**.

Nowadays, CNG accounts for a small percentage of the fleet. In the last five years, the appearance of trucks running on CNG has only occurred in some of the distribution regions as a result of the promotion of natural gas distribution companies. It was assumed that, in 2060 and in the BAU scenario, 10 % of the fleet will be electric, 40 % will run on CNG, and the rest will continue on diesel. As to truck tractors, it is expected that 50 % of the fleet will 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 the main alternative for trucks and truck tractors, but a smaller electricity penetration is expected for truck tractors, as technological solutions for very heavy freight transportation 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 helps to initiate the transition in both segments.

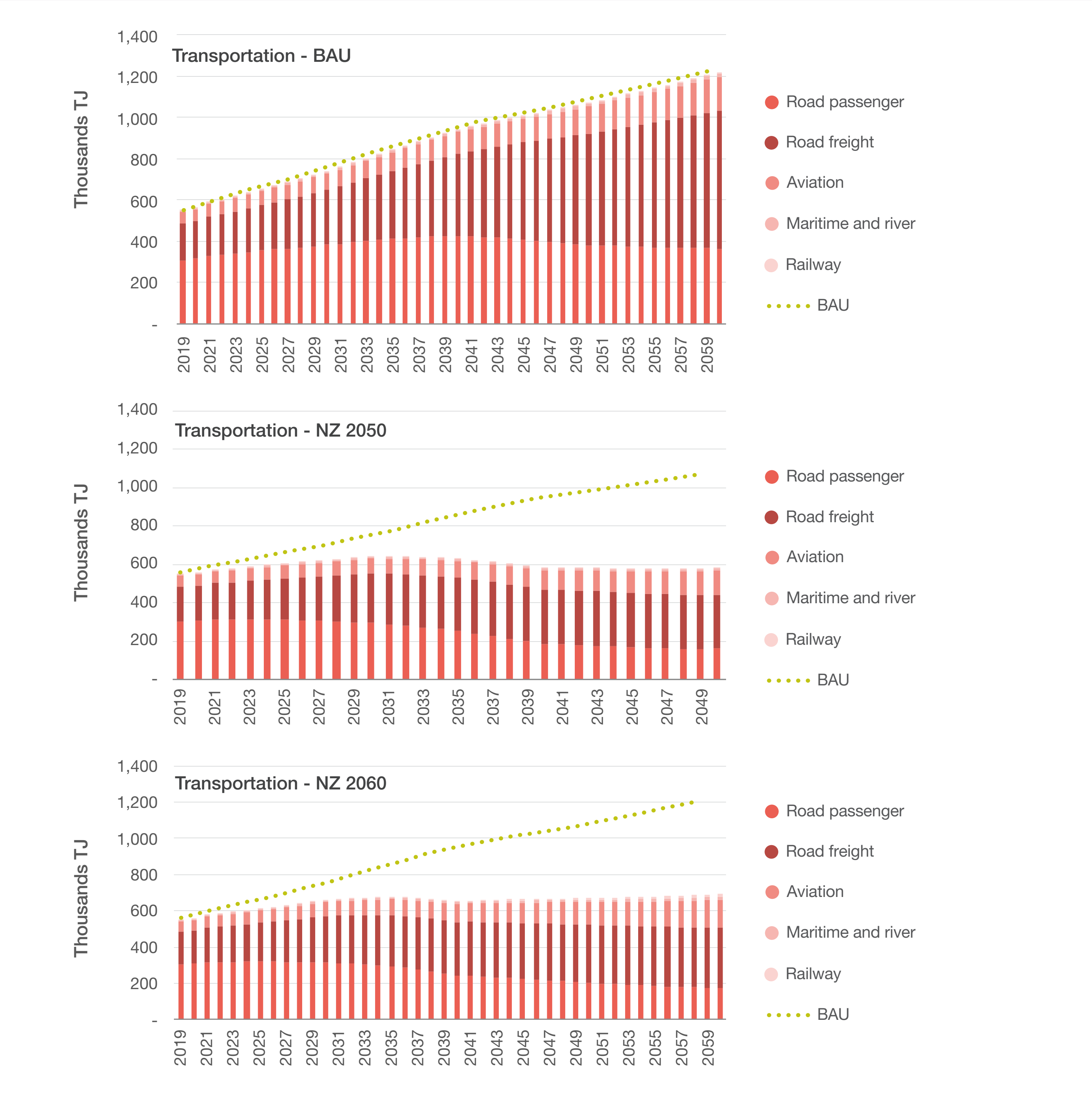
Air, naval, and railway transportation

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 byproducts), contemplated in the NZ scenarios.

Results

In the BAU scenario, energy consumption in the transportation sector grows by 121 %, driven by the freight sector. Oil and petroleum products consumption grows by 20 %, electricity grows considerably in the private and public passenger sectors, whereas natural gas becomes relevant in the freight sector.

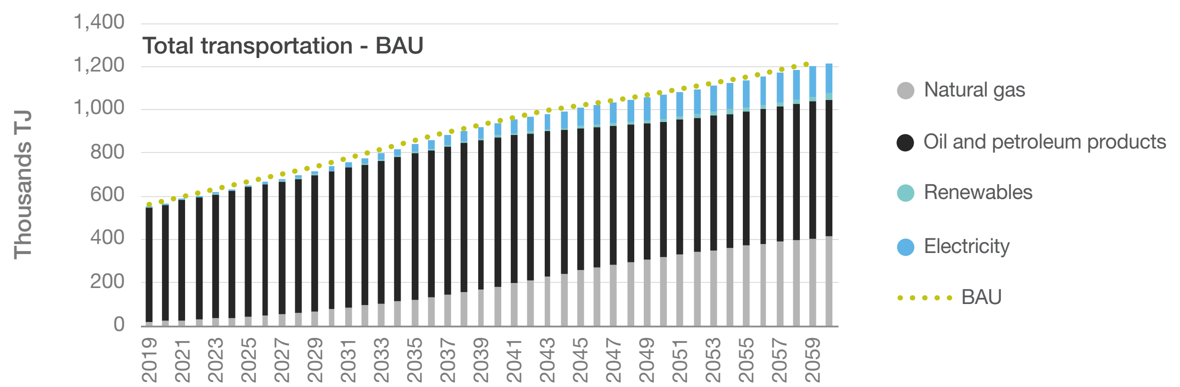
Graphic 53 A ▶ Transportation: final consumption by type/fuel and by scenario (10^3 TJ)

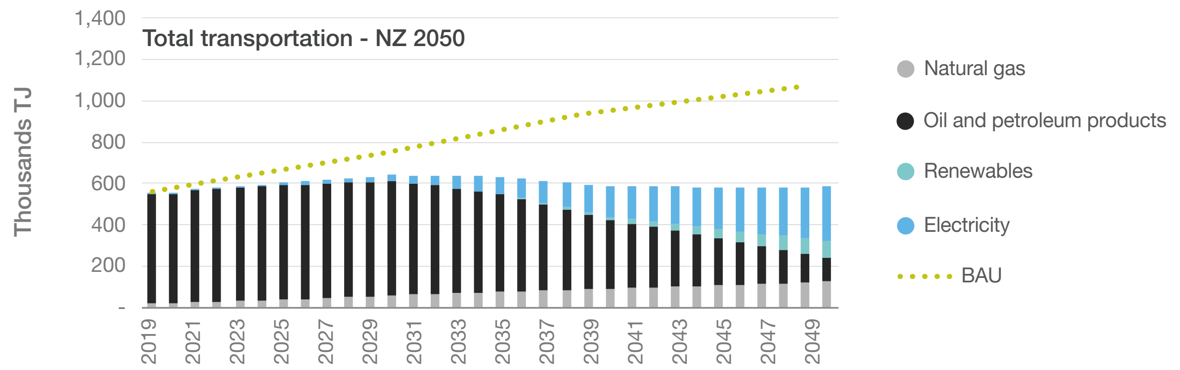


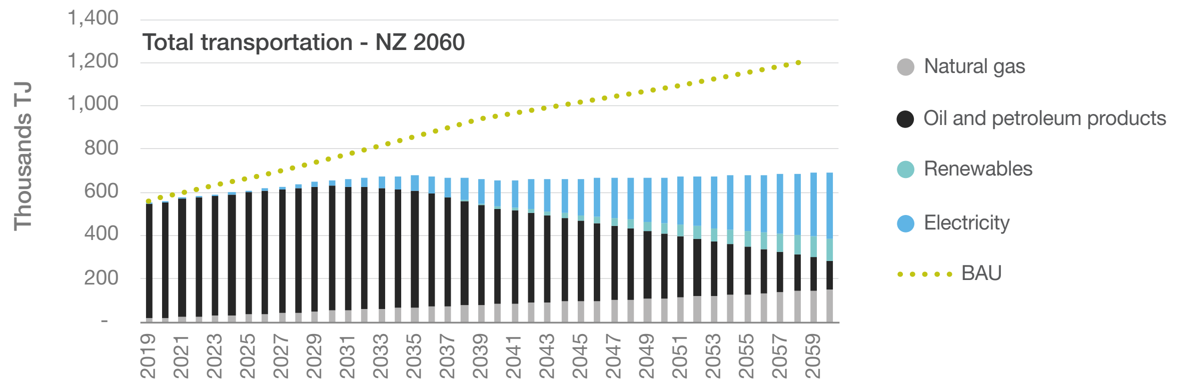
Source: Own preparation.

Graphic 53 B

Transportation: final consumption by type/fuel and by scenario (10^3 TJ)





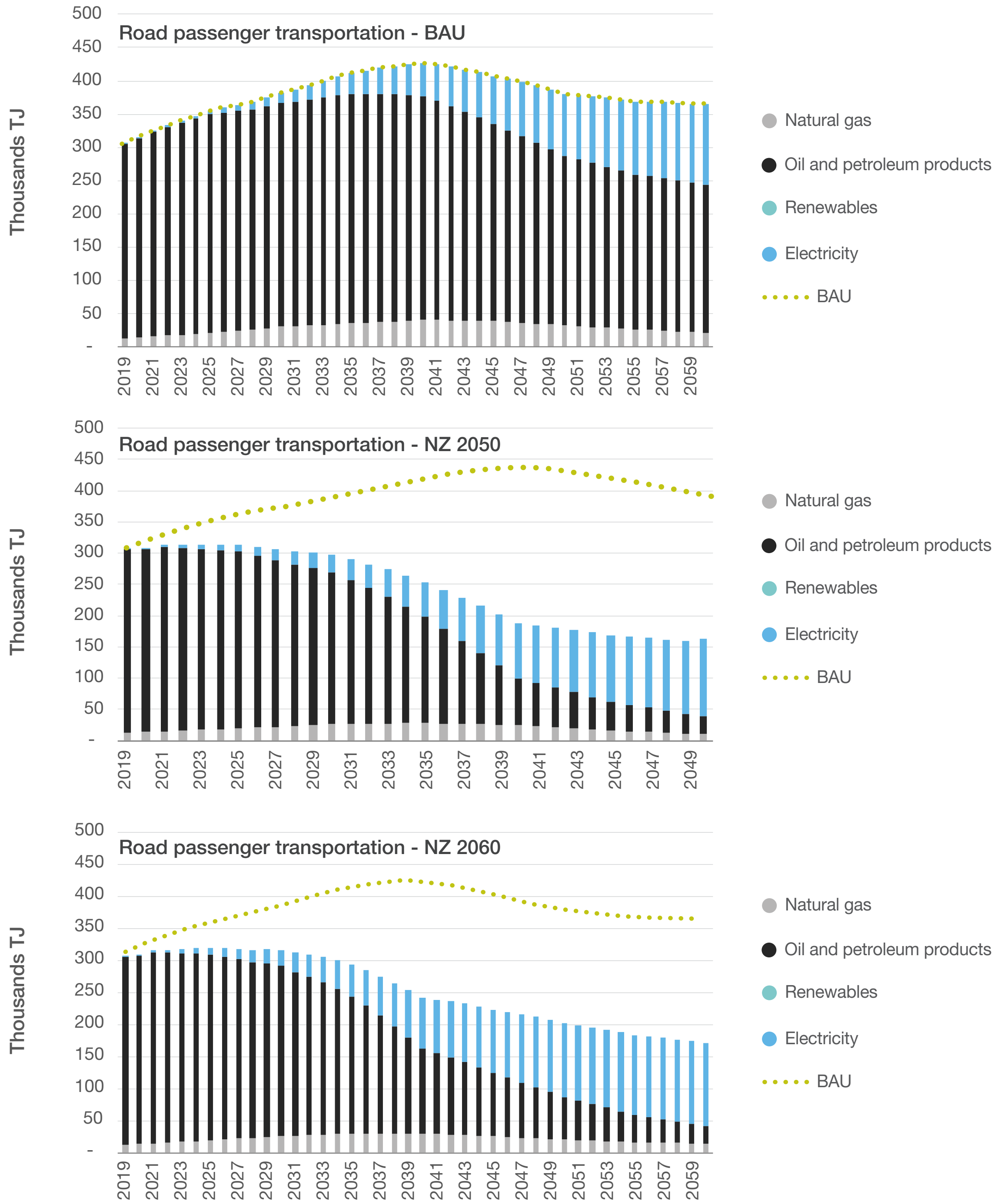


Source: Own preparation.

For the NZ 2050 scenario and in the analyzed period, energy demand in the transportation sector decreases due to the measures tending to promote electric transportation and synthetic fuels. In the passenger sector, the penetration of electricity increases strongly whereas the rest use gasoline in hybrid vehicles.

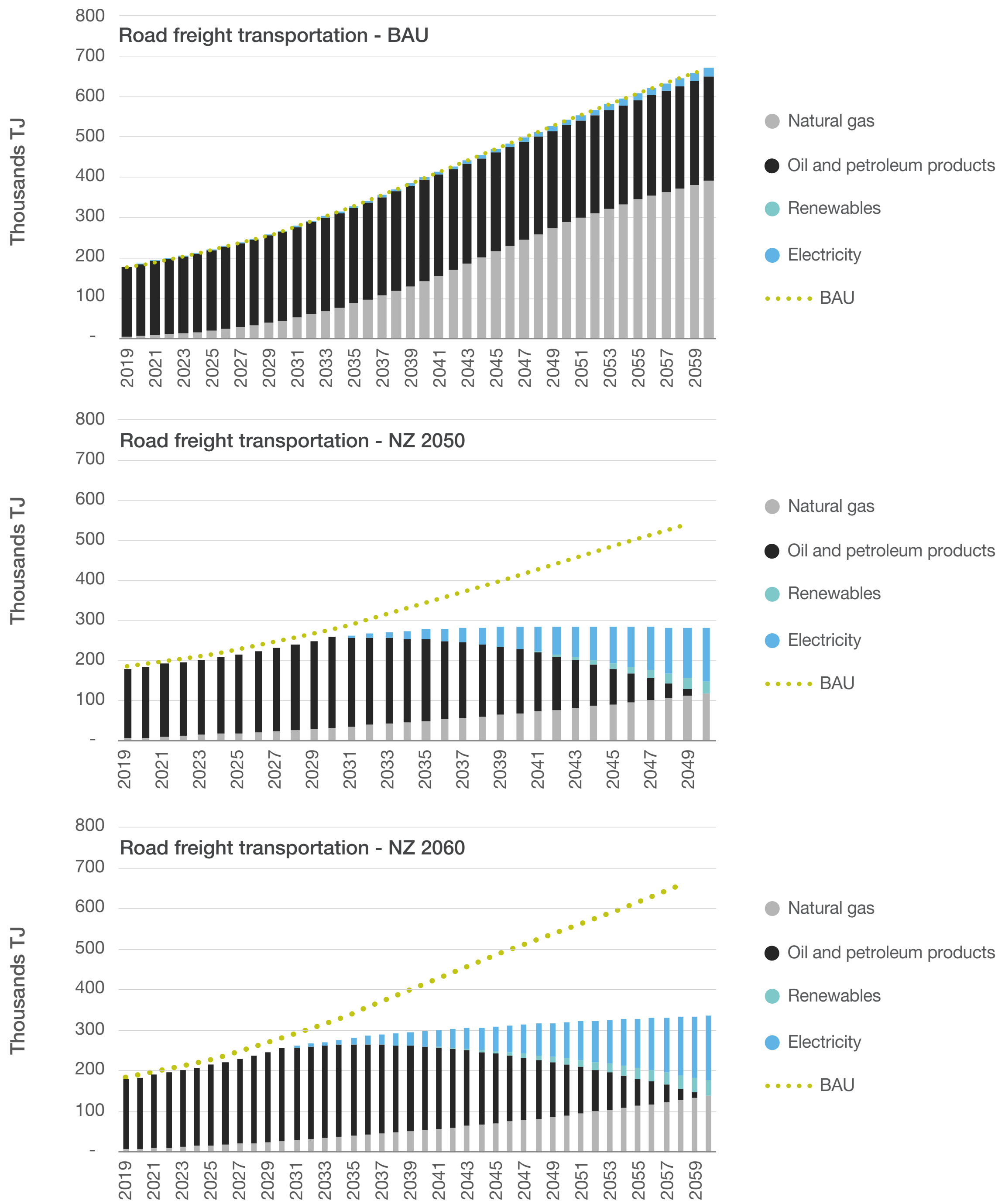
As to freight transportation, electrification appears once again the main alternative for trucks and truck tractors and hydrogen cells play a more limited role. According to these considerations, the passenger sector reduces its energy consumption considerably whereas the freight transportation sector grows slightly. The NZ 2060 scenario is very similar to the one mentioned above, with a slower implementation of the measures.

Graphic 54 A Final consumption of road passenger and public transportation, by fuel and scenario (10^3 TJ)



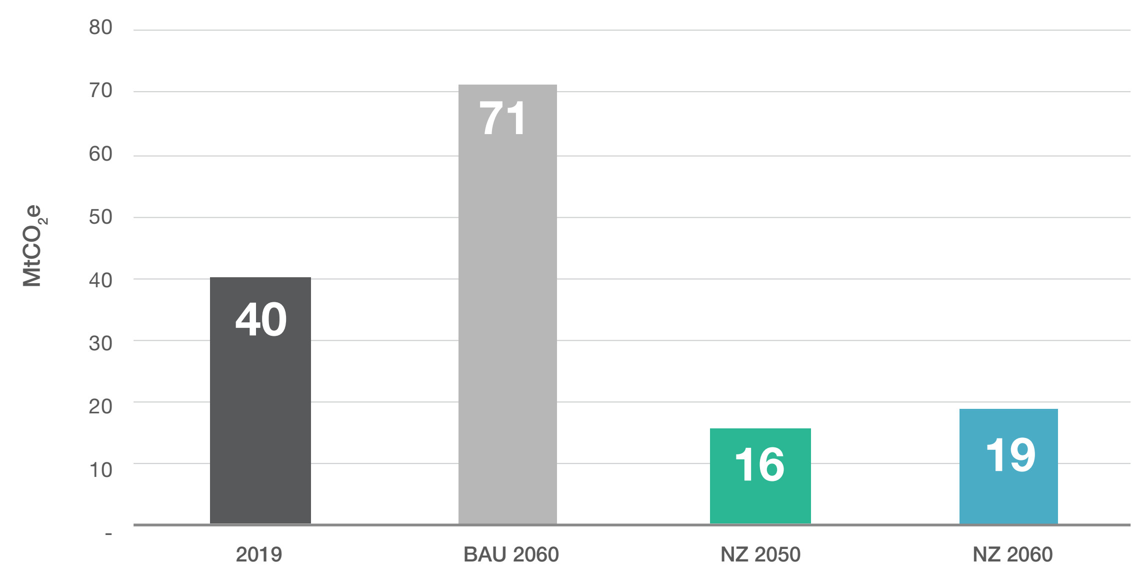
Source: Own preparation.

Graphic 54 B Final consumption of road passenger and public transportation, by fuel and scenario (10^3 TJ)



Source: Own preparation.

Graphic 55 Transportation sector: direct emissions by scenario ($MtCO_2e$)



Source: Own preparation.

CO_2e emissions grow in the BAU scenario (+78 %) but at a slower pace than that of the vehicle fleet. On the other hand, emissions fall more than twofold in the NZ scenarios in the long term, thanks to fuel substitution (mainly electrification), energy efficiency, and behavior change measures.

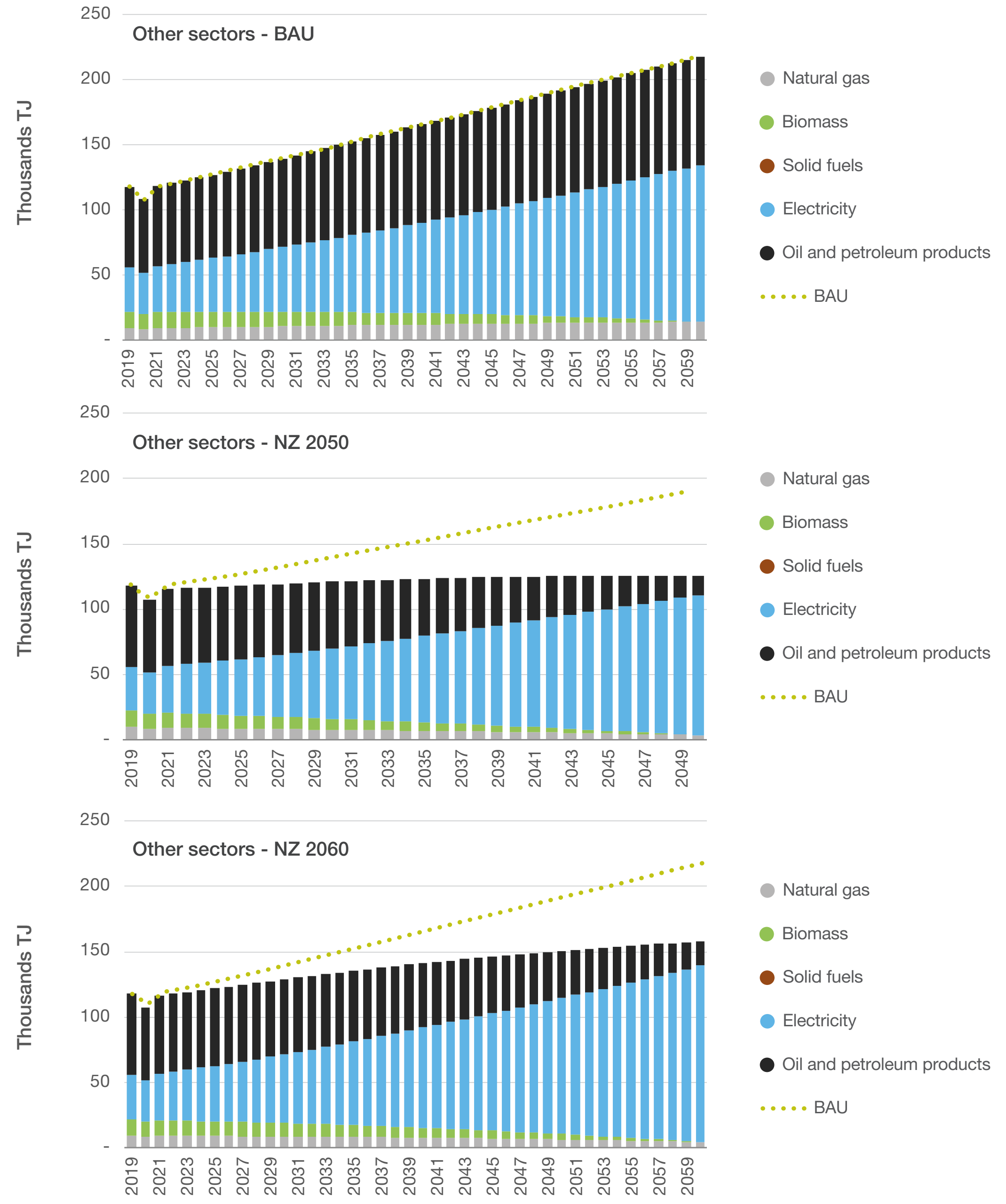
The energy transition measures required to limit GHG emissions in the transportation sector relate to mature technologies for the light vehicle segment and developing ones for the other segments. Substantial changes are expected in all scenarios, given the strong motorization associated with economic 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 (28 % in 2019). When analyzing the demand by subsector, we can see the importance of the mining sector, which accounts for 64 % of the total in Colombia, whereas the agricultural sector adds up 34 %. Both subsectors 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 1.5 % annually (cumulative 84 % in the period), which causes the sector to electrify gradually, more in line with the historical trend. An enhancement of the energy intensity of the sector is observed (GDP growth is higher than that of demand, annual 2.6 % versus annual 1.5 %).

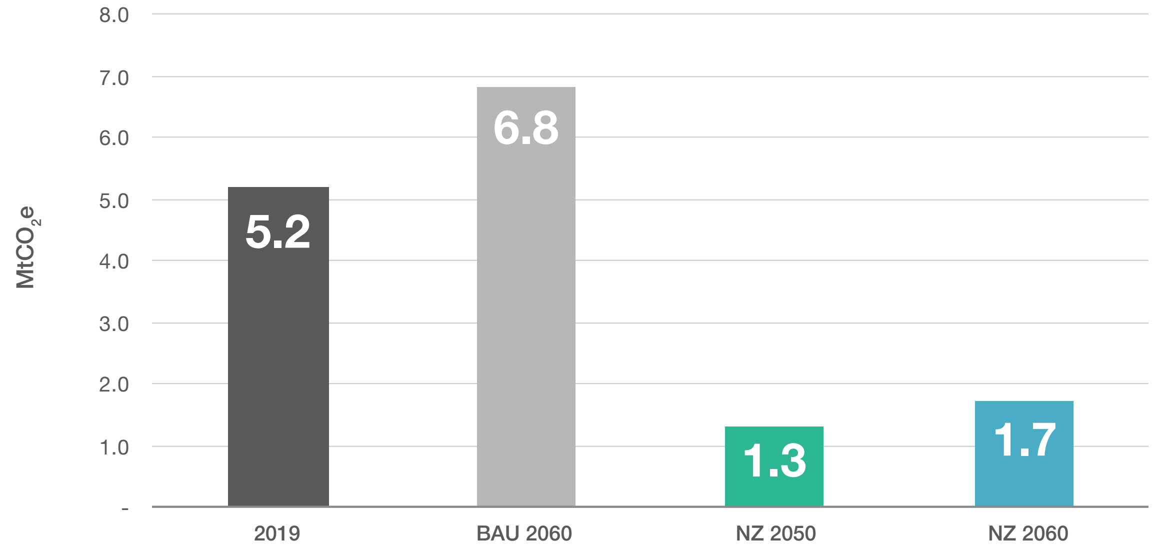
Graphic 56 Results of the agricultural, fishing, mining, and construction sector, by scenario (10^3 TJ)



Source: Own preparation.

In the NZ scenarios, almost total electrification is achieved; oil and petroleum products are the drivers for the rest. Consumption remains relatively constant in the analyzed period due to the combined effect of greater energy efficiency and the savings from the expected electrification of some uses.

Graphic 57 Agricultural, fishing, mining, and construction sector: direct emissions by scenario ($MtCO_2e$)



Source: Own preparation.

CO_2e emissions grow in a limited manner in the BAU scenario (+30 %), at a slower pace than the GDP. On the other hand, emissions fall more than threefold 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

Colombia starts from quite a clean power generation matrix, mainly because of the large hydroelectric participation in the national energy production. It has abundant natural resources, and great hydroelectric (56 GW), onshore wind (30 MW), offshore wind (50 GW), solar (32 GW), and geothermal (1.3 GW) potential, favorable to develop an electric generation fleet with low emissions. In recent years, Colombia has experienced great dynamism in developing renewable projects; this is expected to continue in the future, in a context of lower investment costs (capital expenditure (CAPEX)) of these technologies, with a favorable regulatory framework and the will to diversify the electricity matrix.

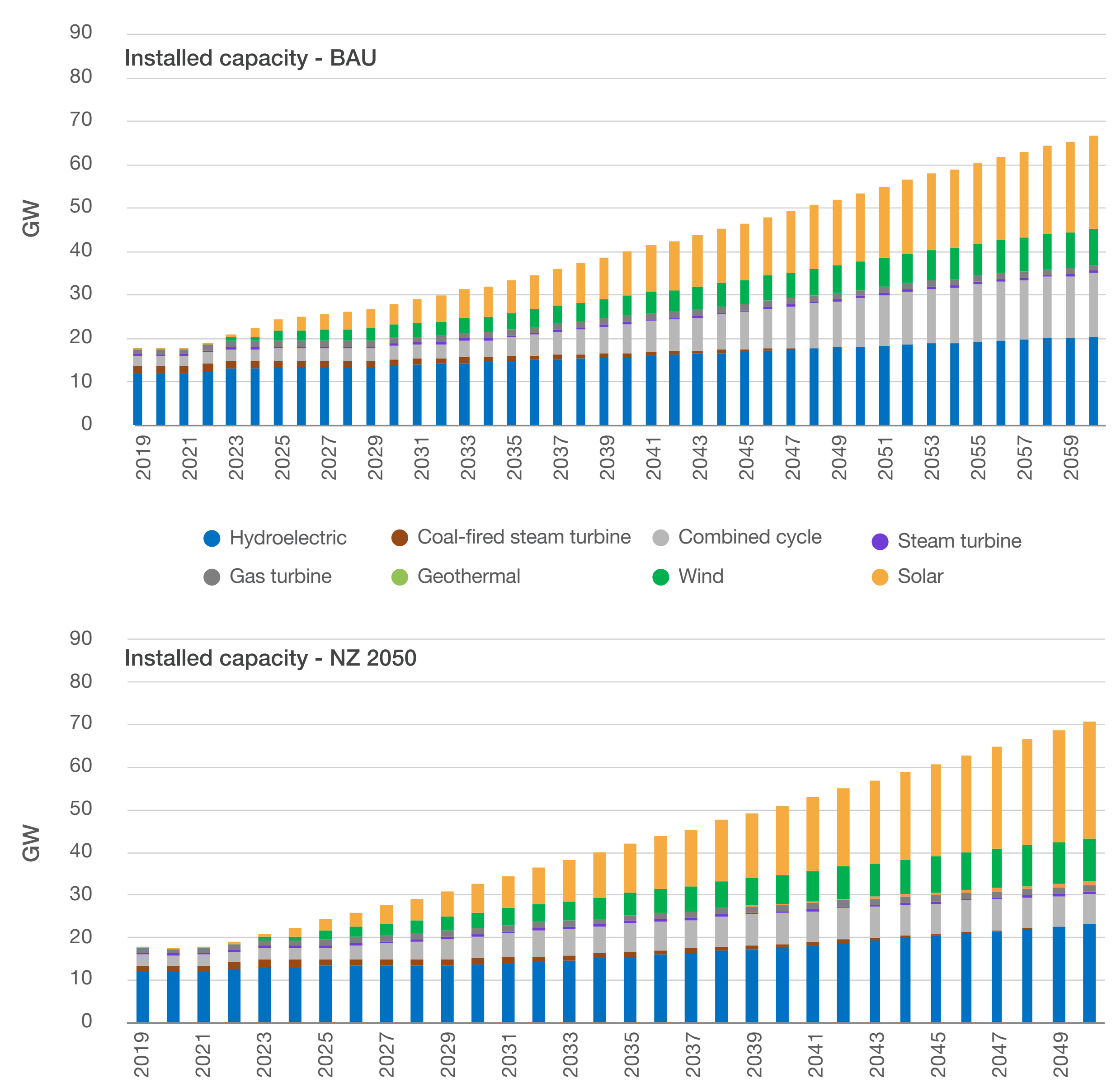
Growth of solar and wind capacity is expected in all the scenarios presented and, to a lesser degree, in hydro power, as well as the phase-out of coal-fired plants in the long term, as they are characterized by a very a high emission factor per energy unit.

In the BAU scenario, the additional renewable capacity to be installed is 38 GW, 21 GW of which is solar and 8 GW, is wind. 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 50 GW of renewable energy is expected, 27 GW of which will be solar; 10 GW, wind; and 11 GW, hydro. In the NZ 2060 scenario, the installation of 60 GW of renewable energy is required, 32 GW of which is solar and 12 GW, wind, and 15 GW is hydro.

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

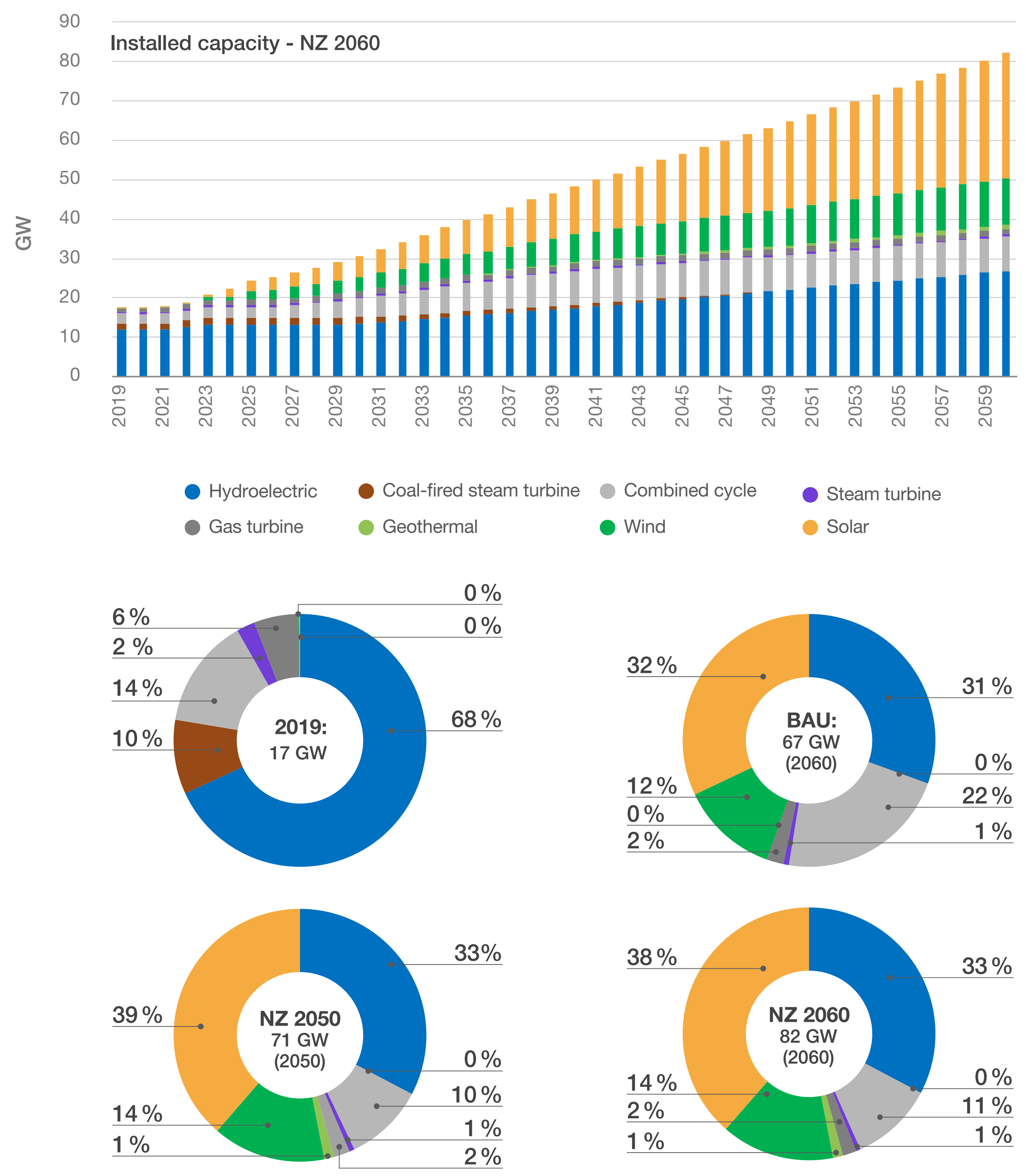
Transition scenarios

Graphic 58 A Projection of installed capacity by source and by scenario (GW)



Source: Own preparation.

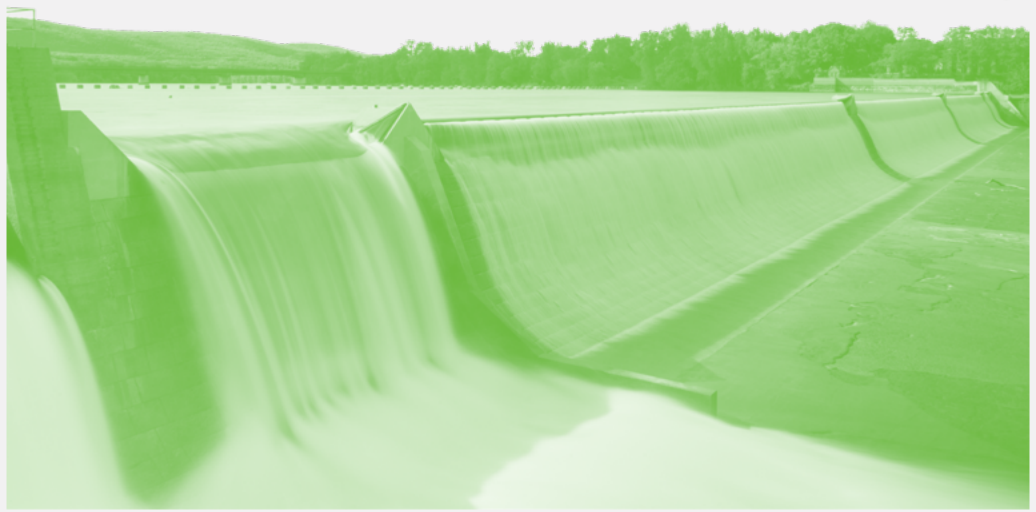
Graphic 58 B Projection of installed capacity by source and by scenario (GW)



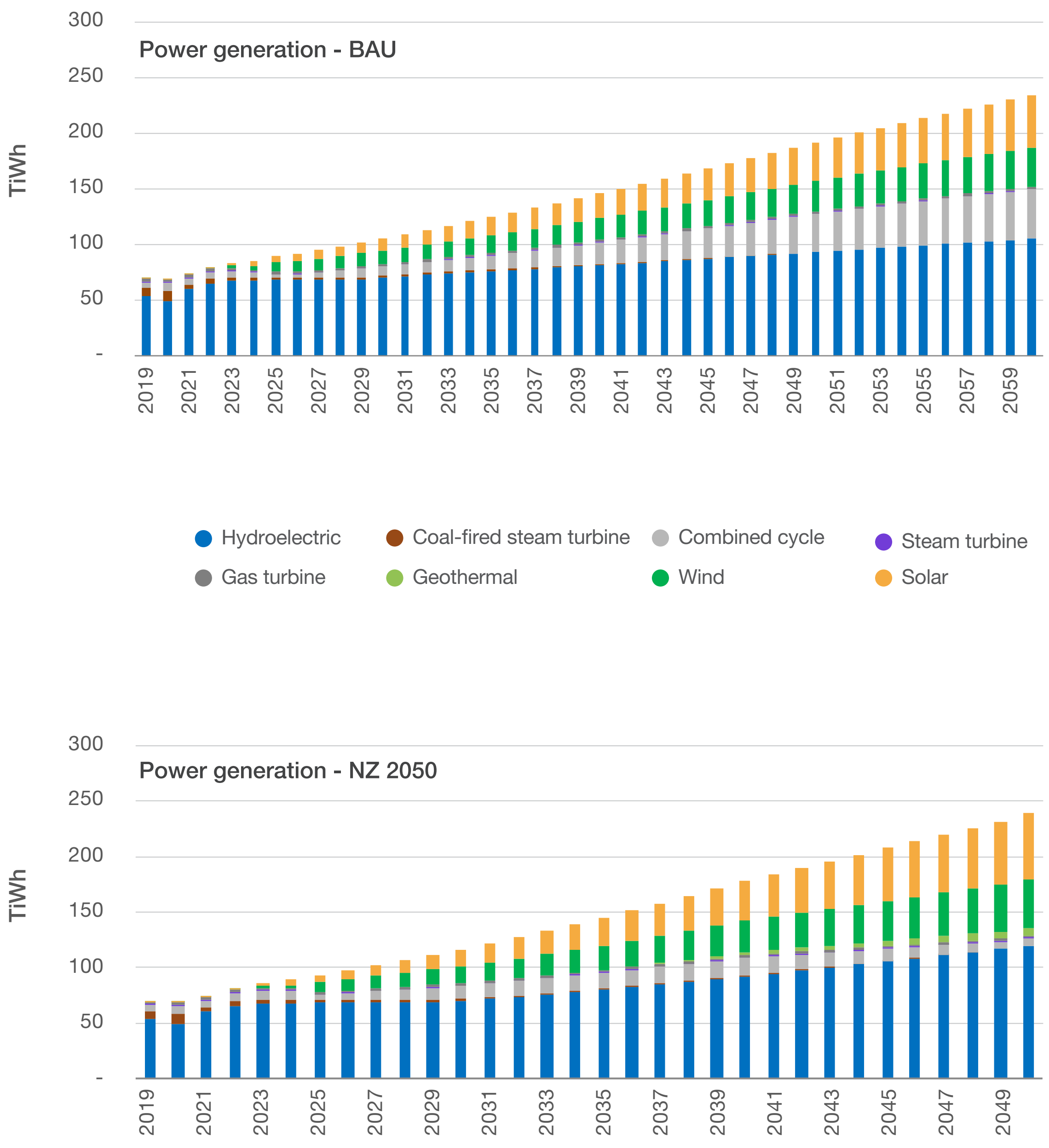
Source: Own preparation.

In the BAU, NZ 2050, and NZ 2060 scenarios, power demand grows by between 240 % and 300 %, whereas installed capacity increases by between 289 % and 370 %. 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 80 % of generation free from emissions in the BAU scenario and over 90 % in the NZ scenarios. Hydroelectric production continues playing an important role in all the scenarios, although lower than its current relevance.

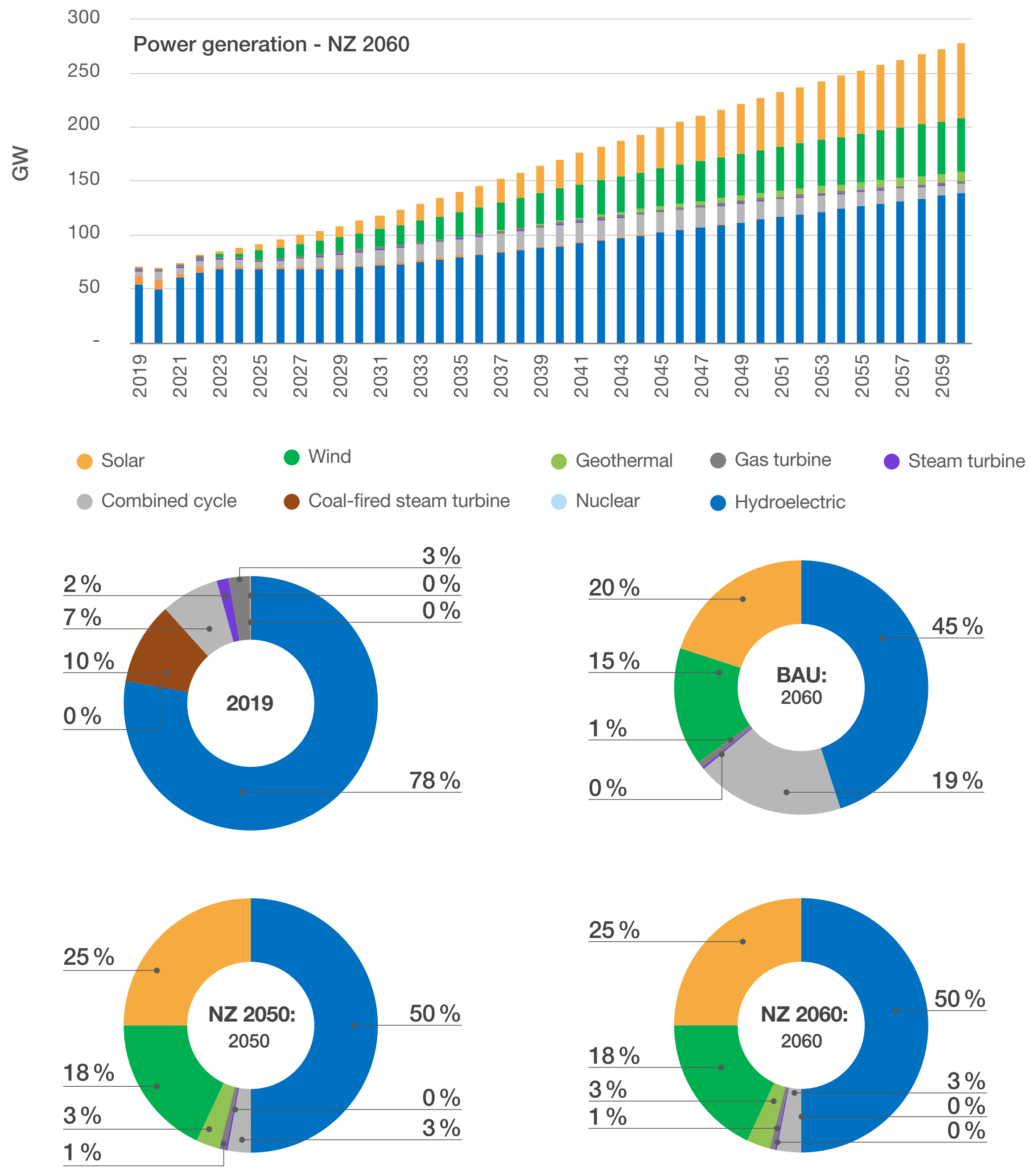


Graphic 59 A ▶ Projection of power generation by source and by scenario (TWh)



Source: Own preparation.

Graphic 59 B ▶ Projection of power generation by source and by scenario (TWh)



Source: Own preparation.

3. Energy transition financing

Chapter 3 presents total investment relating to each scenario as a consequence of all the just 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:

The main areas requiring investment are presented below, along with a brief description of the assumptions used to derive the amounts shown in the following sections:

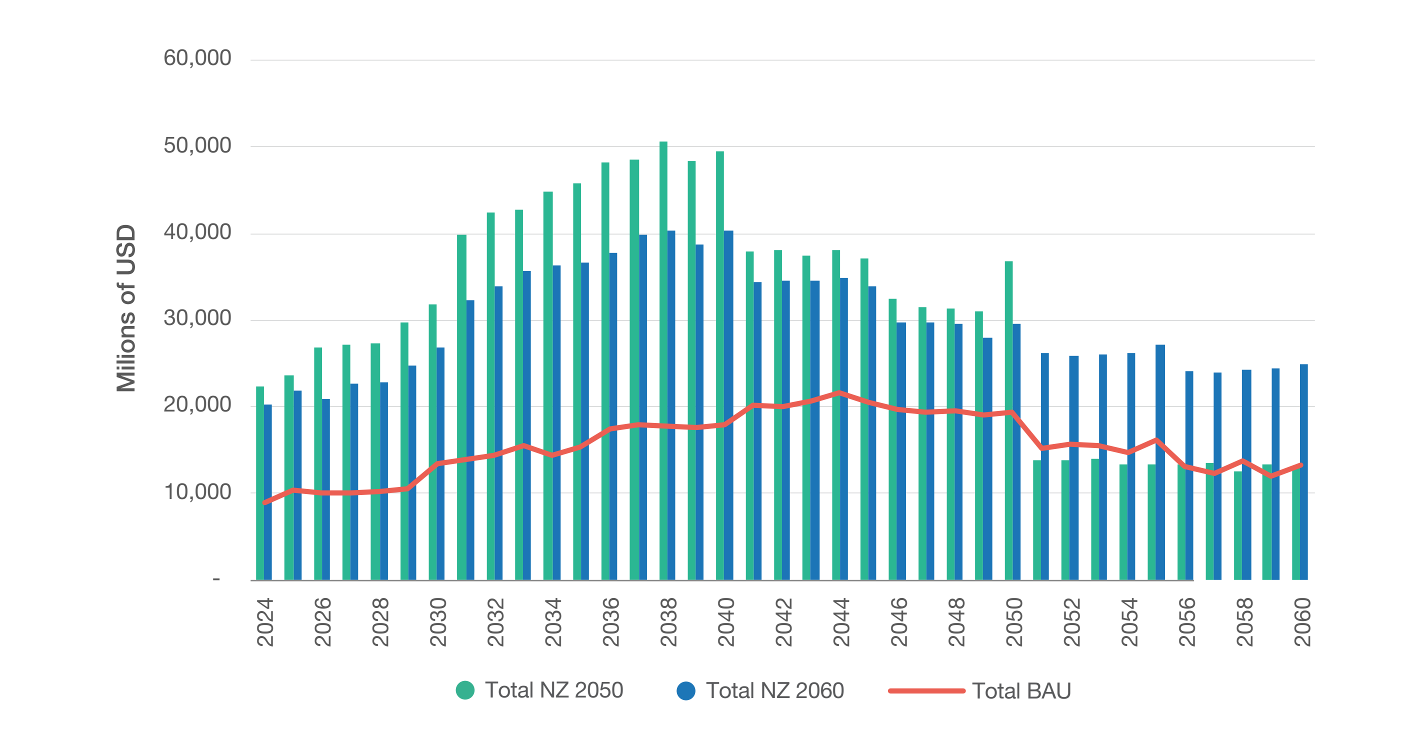
1. Power generation (and the need for additional power grids as well as flexibility measures);
2. Electrification of the road transportation sector (investment in electric vehicles and charging stations);
3. Energy efficiency measures and electrification of subsectors and end uses in the other sectors;
4. Use of technologies of the carbon capture and storage type.

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).

Graphics 60 and 61 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 item 5 "Investment" of the chapter "Methodological section and assumptions" in the *Just Energy Transition / Projection assumptions* report.

Graphic 60 Estimated annual investment (millions of USD)

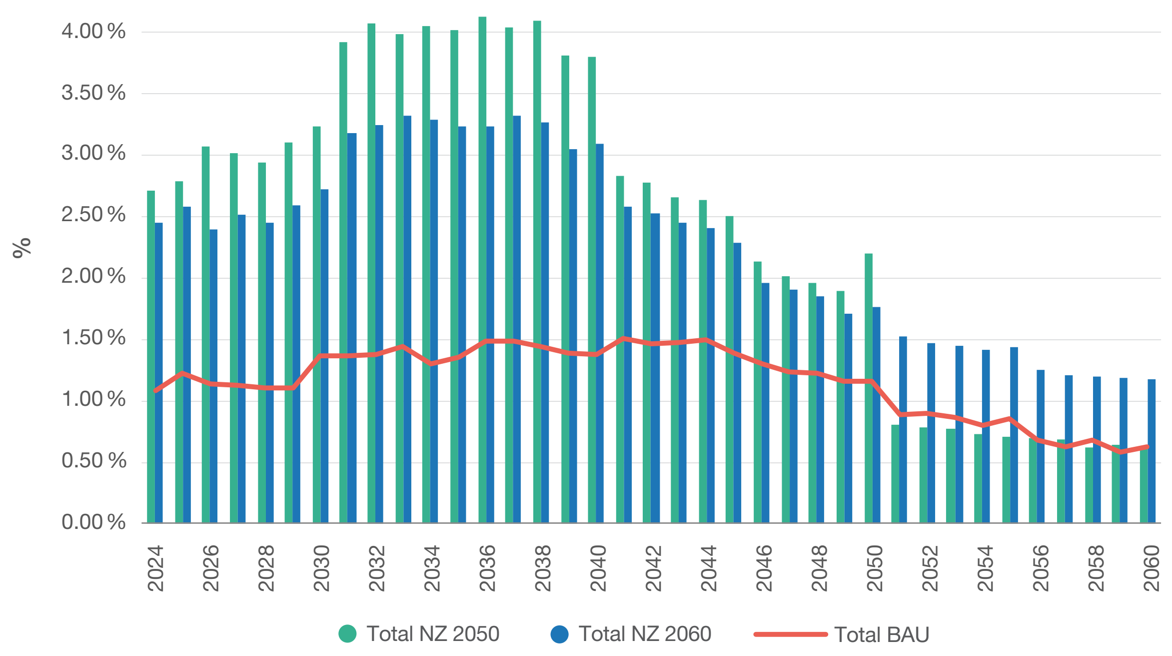


Source: Own preparation.

The cumulative investment in the period 2024-2060 is approximately USD 578 billion for the BAU scenario, USD 1,135 billion for the NZ 2050 scenario, and USD 1,104 billion for the NZ 2060 scenario.

By year, growing investment is observed until the period 2035-2040 in the NZ scenarios, and from there on, investment falls, which evidences the decrease in the unitary cost of some long-term transition technologies, particularly, electric vehicles. The maximum annual investment in the BAU scenario is approximately USD 22,000 million whereas it amounts to around USD 51,000 million in the NZ 2050 scenario and USD 40,000 million in the NZ 2060 scenario, which implies almost doubling annual investment in the NZ scenarios, as well as the need to anticipate the peak of investment compared to the BAU scenario. As from 2051, investment in the NZ 2050 scenario is lower and similar to the BAU scenario.

Graphic 61 Estimated annual investment in % of GDP



Source: Own preparation.

The investment effort, measured in GDP percentage, amounts to 1.5 % in 2036 in the BAU scenario, around 4 % in 2032-2038 in the NZ 2050 scenario, and 3.3 % in the same period in the NZ 2060 scenario.

Investments by type are 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 "Power sector" subsection, "Results and assumptions by sector" section, by using capital expenditure (CAPEX) prices projected by the National Renewable Energy Institute (NREL) to start up new facilities[43];
- investment in infrastructure and flexibility, including the concepts of smart grids, batteries, and modernization of old hydro plants, estimated at 15 % additional to investment in power generation[44]. 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[45];

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

44 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.*

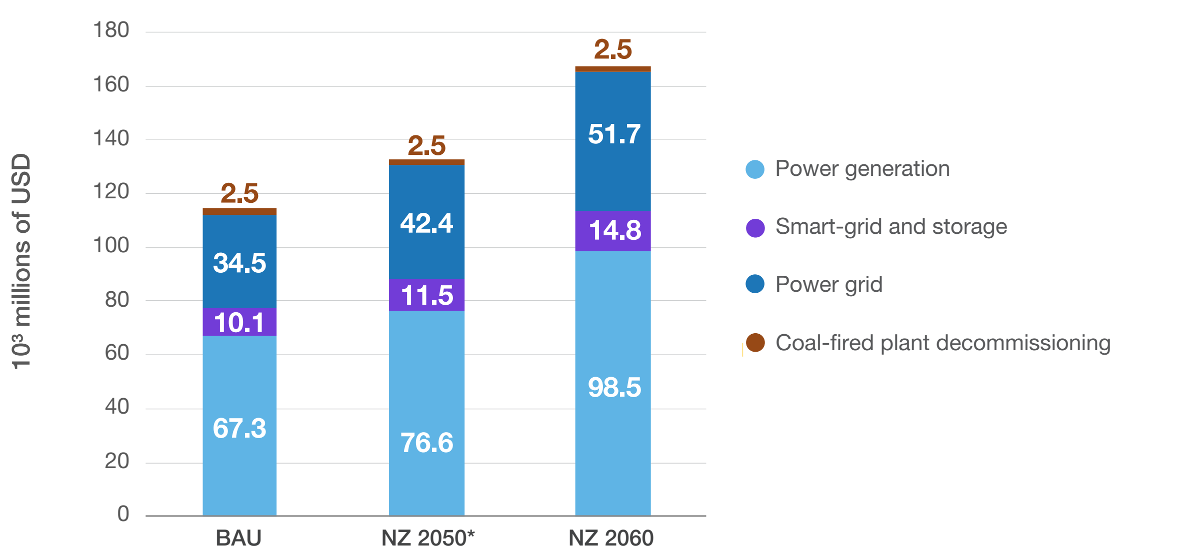
45 See again the *Just Energy Transition / Projection Assumptions* report.

- the estimated investment required for the phase-out of coal-fired plants before the end of their useful life (stranded assets or sunk assets). It was estimated by using 50 % of the CAPEX of a new coal-fired thermal plant published by the NREL[46].

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 some 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 62 Power sector: cumulative investment in the transition period (billions of USD)

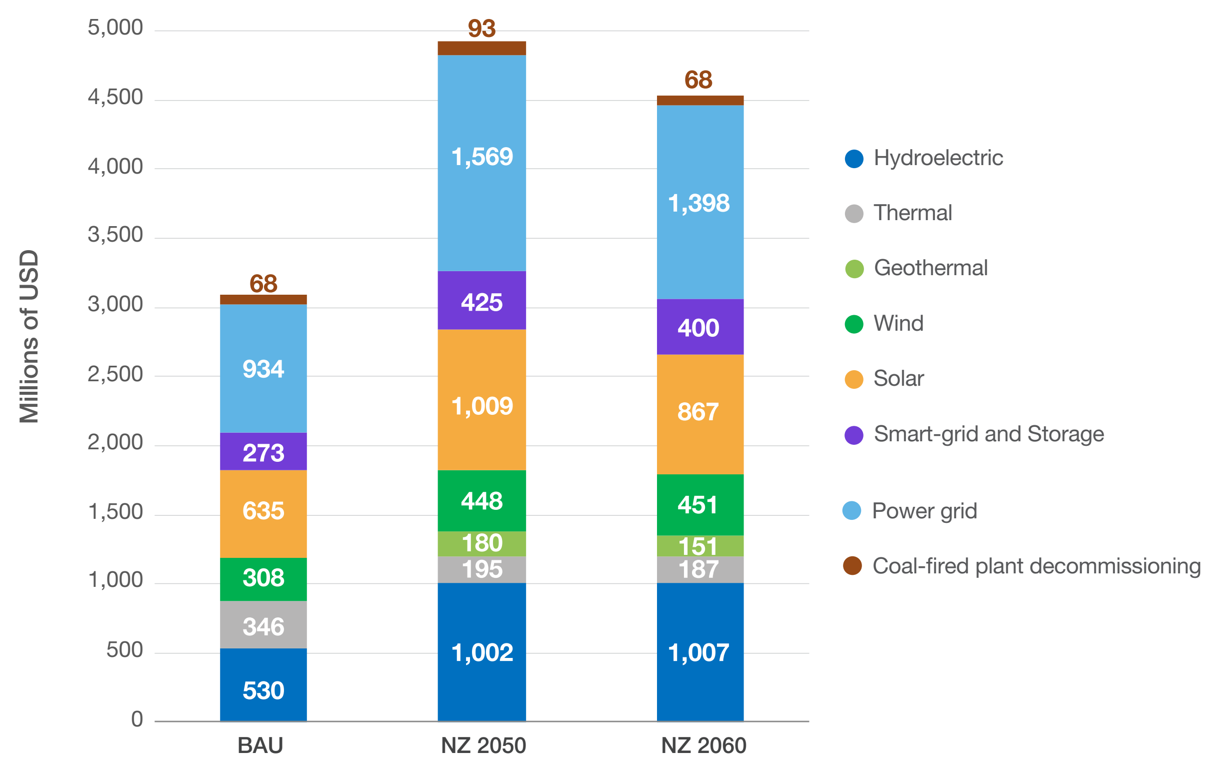


Source: Own preparation. *Investment in the NZ 2050 scenario refers to the period 2024-2050 whereas it refers to the period 2024-2060 in the other scenarios.

46 Table 10, *Just Energy Transition / Projection Assumptions*.

The cumulative investment related to the power sector is approximately USD 114,000 million in the period 2024-2060 for the BAU scenario; USD 124,000 million in the period 2024-2050 for the NZ 2050 scenario; and USD 158,000 million 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.

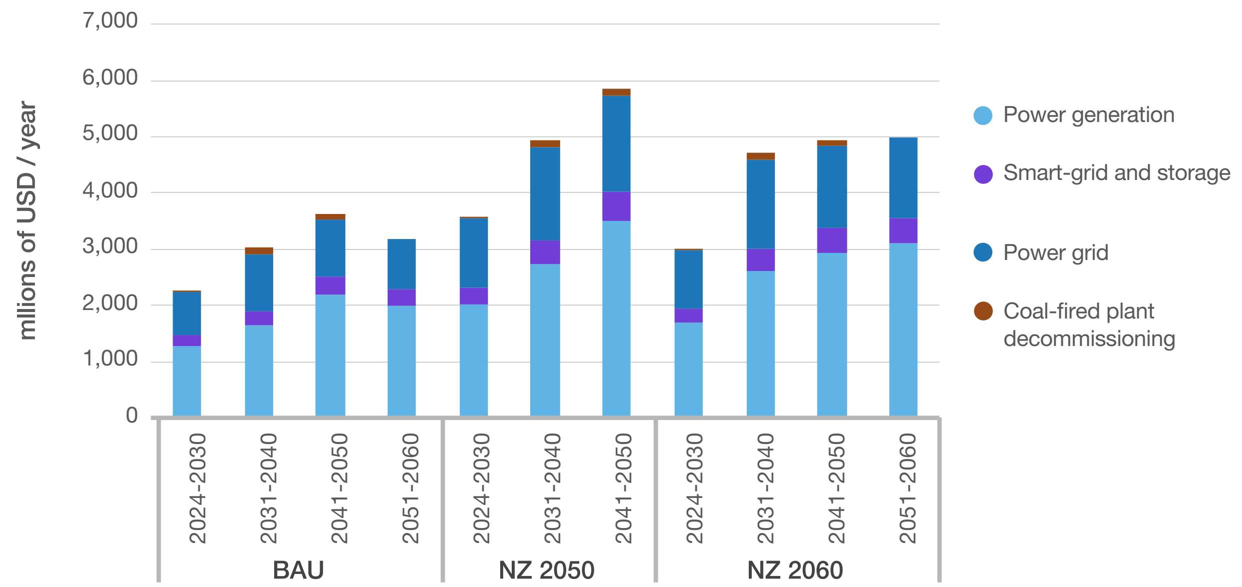
Graphic 63 Power sector: Average annual investment by type (millions of USD)



Source: Own preparation.

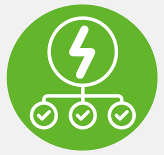
By year (average value), the required investment is higher in the NZ 2050 scenario with USD 4,922 million. The NZ 2060 scenario follows with USD 4,529 million and, finally, the BAU scenario with USD 3,093 million. By technology, the investment in power generation with the largest participation is in 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 64 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 if 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[47] in electric vehicles (EV) and hybrid vechicles (VH) is estimated on the basis of the unitary CAPEX projected by the International Renewable Energy Agency (IRENA), and on the number of new vehicles, as well as the charging stations, based on an estmation of the number of stations required and a unitary cost;
- energy efficiency measures, electrification, use of alternative fuels (hydrogen and its byproducts, 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[48] 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)[49], which is presented as an option for very polluting industrial sectors with higher CO_2 emissions which are difficult to transform.

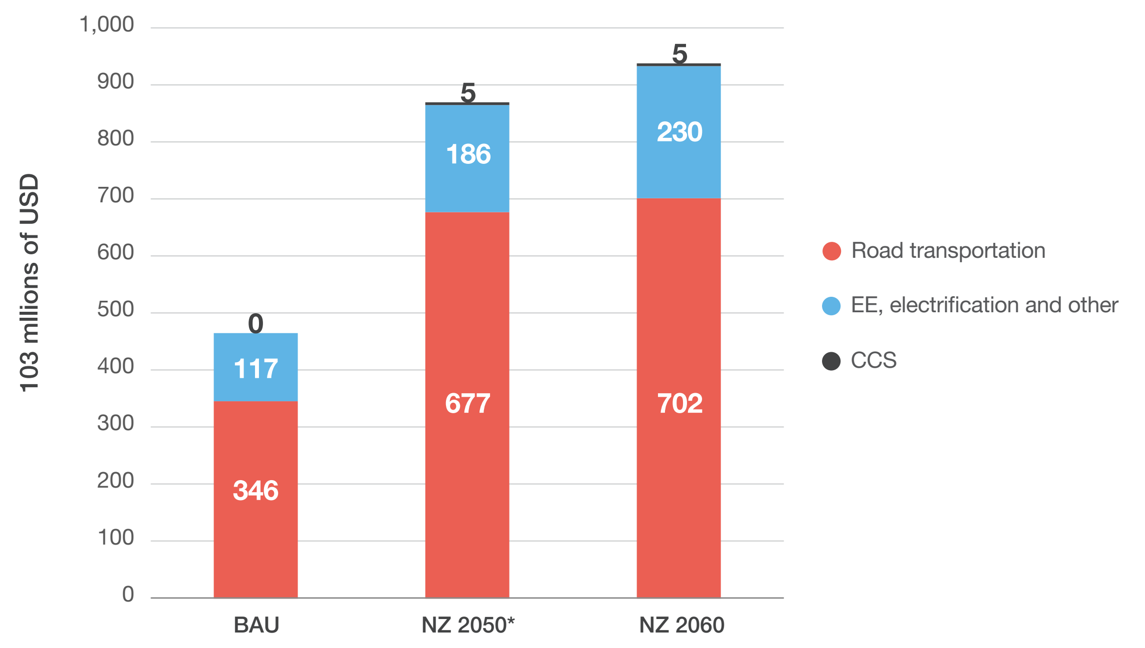
Graphic 65 presents the cumulative investment in the transition period for each scenario.

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

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

49 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 65 ▶ End uses: cumulative investment in the transition period (billions of USD)

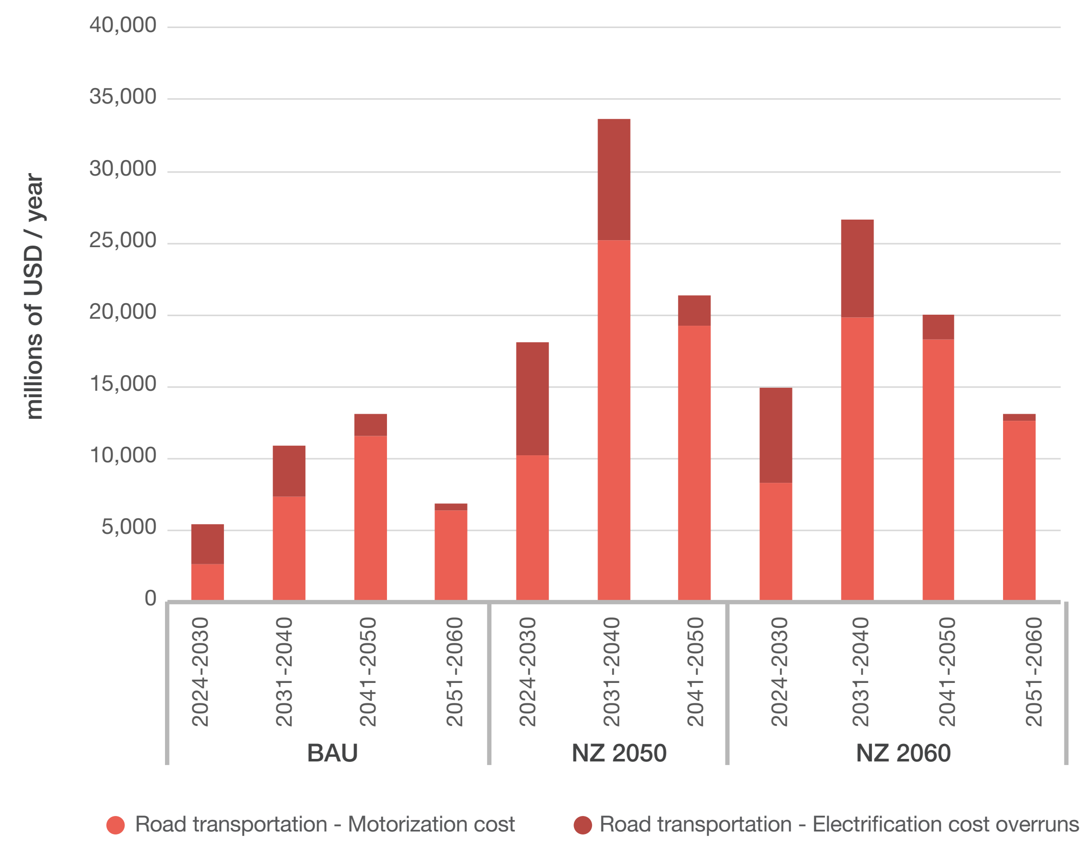


Source: Own preparation. * Investment in the NZ 2050 scenario refers to the period 2024-2050, whereas it refers to the period 2024-2060 in the rest of the scenarios.

The cumulative investment related to end uses is approximately USD 463,000 million in the period 2024-2060 for the BAU scenario; USD 868,000 million in the period 2024-2050 for the NZ 2050 scenario; and USD 963,000 million for the period 2024-2060 for the NZ 2060 scenario. 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 less than half of the investment related to end uses (see Graphics 66 and 67, dark red segment referring to electrification cost overruns).

Graphic 66 illustrates the difference between both concepts for road transportation.

Graphic 66 ▶ Road transportation: annual investment by period (millions of USD/year)



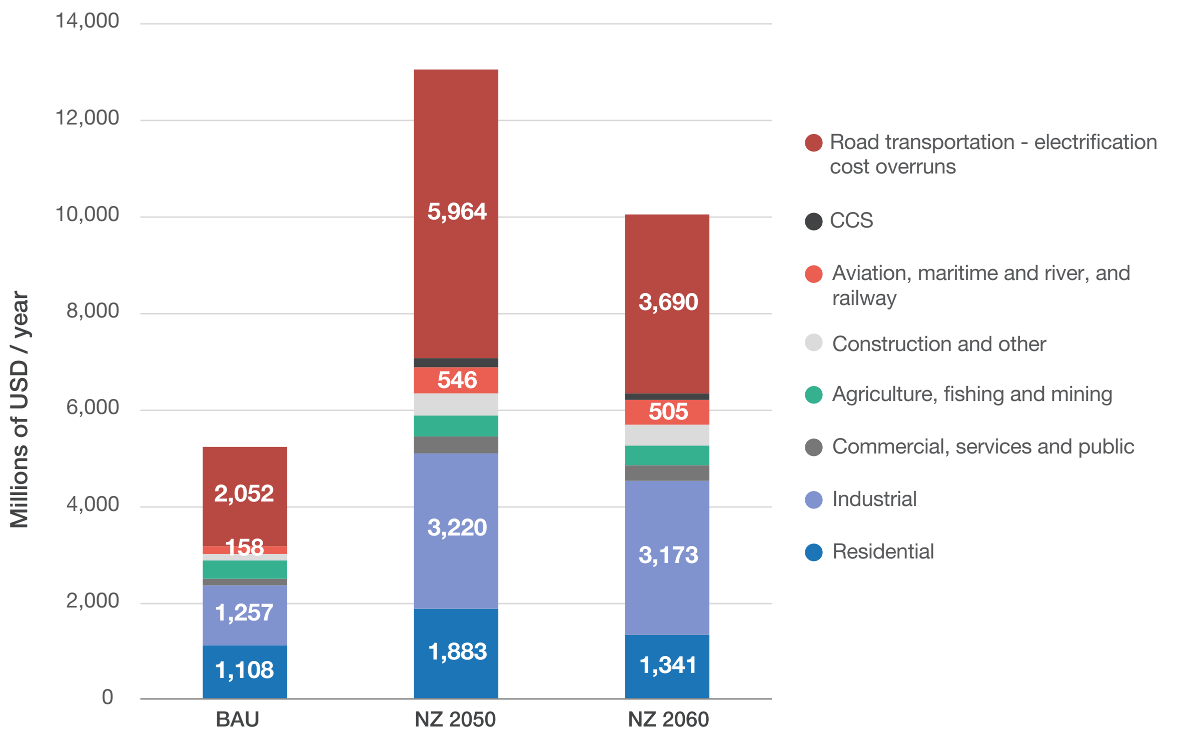
Source: Own preparation.

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

Graphic 67 presents investment by type, without considering the cost of motorization.

Graphic 67 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, and the aviation, maritime/river, and railway sector.

Transition scenarios

> **Among the investments for energy end-uses, road transportation (electric vehicles, hybrids, new vehicles, and charging stations), energy efficiency measures, and fuel substitution in the industrial and residential sectors stand out.**

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 ▶ Indicators by time horizon and scenario

Number	Potential indicators	Unit	2019	BAU 2060	NZ 2050	NZ 2060
E-2.1	Share of renewable energy in total final energy consumption	%	32 %	32 %	67 %	67 %
	Share of renewable energy in power generation	%	86 %	80 %	96 %	96 %
E-2.1bis	Installed renewable energy generation capacity	GW	12.0	50.2	61.5	71.6
E-2.2	Energy intensity measured on the basis of primary energy and GDP	TJ/ MUSD PPP 2017	2.4	1.3	0.9	0.9
E-2.3	Efficiency of energy conversion	%	14 %	50 %	50 %	50 %
	Efficiency of energy distribution	%	84 %	84 %	84 %	84 %
E-2.4	Energy intensity by sector (industrial)	TJ/ MUSD PPP 2017	3.7	3.0	2.3	2.1
	(Agricultural, fishing, and mining)		0.7	0.3	0.3	0.3
	(Services and commercial)		0.2	0.4	0.3	0.3
	(Transportation)		0.7	0.6	0.4	0.3
E-2.5	Energy intensity in the residential sector	TJ/ 1,000 inhabitants	5.1	7.4	5.2	5.8
E-2.6	Penetration of electricity in the transportation sector	%	0.1 %	12 %	45 %	44 %
E-2.7	Penetration of natural gas in the transportation sector	%	3 %	34 %	22 %	22 %
	Penetration of hydrogen in the transportation sector	%	0 %	2 %	14 %	15 %
S-1.4	Energy use per capita	TJ/ 1,000 inhabitants	26.5	49.8	28.1	32.9
A-1.1	GHG emissions per year, energy*	$MtCO_2e$	87	161	36	42

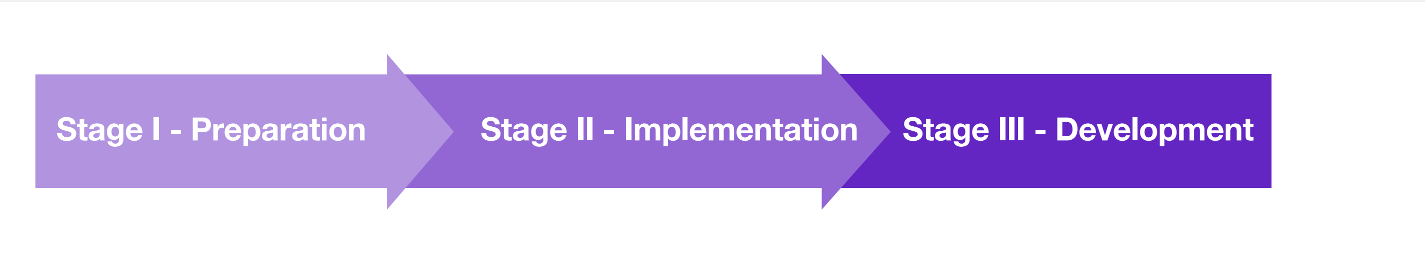
Source: Own preparation. *Fugitive emissions are not included.

1. The environment for the transition

Projections

When analyzing the results of the projections of the energy matrix in Colombia in the long-term, we observe more consumption electrification, a reduction in the demand for liquid fuels (that is, refined hydrocarbons), and a slight 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 68 ▸ Roadmap: stages



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

- the relative inertia of the first years of the period (particularly for power generation and energy infrastructure, projects may take 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.

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.

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 technologies with more CO_2 emissions. 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.

The implications for public policies

Colombia is in the 88th position in the human development index ranking, with a value of 0.752 (high indicator)[50]. 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 commitments 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.

50 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).

Stage I – Preparation

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

1. **Public policies.** Maintain its energy policies aligned and updated to comply with the nationally determined contribution by 2030. In 2021, Colombia presented its National Long-Term Strategy (E2050)[51] to the UNFCCC[52]. The strategy includes different scenarios and pathways towards decarbonization, in line with the net zero emissions target for 2050. In 2023, UPME presented a National Strategic Plan (PEN, in Spanish) updated for the period 2022-2052[53] which contains several scenarios with different pathways towards GHG emissions reduction. There is also progress in terms of hydrogen policies (hydrogen roadmap in Colombia) that may encourage the development of detailed regulations.

   Compliance with the NDC will allow the country to gain access to better financing sources in the future; therefore, countries should recalculate their objectives considering the concept of just energy transition, where the terms to reach a NZ economy and decent standards of living are compatible.

2. **Access.** Reach full electricity coverage and universal access to clean cooking in order to displace firewood (and other inefficient fuels with high CO_2 emissions) in the residential sector.

   These policies should include the replacement of firewood and coal as sources of energy with other cleaner energy sources in rural locations, particularly in non-interconnected areas (ZNI) in Colombia.

51 https://www.ipcc.ch/report/ar6/wg2/. This document defines a long-term vision for the Colombian energy sector and identifies potential pathways to reach net zero emissions in 2050.

52 United Nations Framework Convention on Climate Change.

53 https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN_2020_2050/Actualizacion_PEN_2022-2052_VF.pdf

Roadmap of a just energy transition - Recommendations

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.

   Colombia has energy efficiency programs and plans, as indicated in the diagnosis; therefore, actions are focused on promoting replacement and scrappage programs for cars and equipment in order to phase out of equipment and cars over 20 years old, with low efficiency and high pollution levels. These programs must promote the improvement of construction aspects in existing houses by replacing windows and other equipment.

   The development of programs to facilitate investment in energy efficiency, which imply the adoption of mature technologies in many sectors, is a policy that can be applied quickly to implement the just energy transition in Colombia.

4. **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.

5. **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).

   Within the fiscal incentives, taxes on carbon should be considered, and they should relate to the international prices of carbon credits so that they adequately reflect the mitigation cost[54].

54 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.

Develop regulations to continue fostering policies related to hydrogen and CCUS technologies in order to reduce uncertainty in this business and allow for its development in the long term.

6. **Social aspects**. Propose socio-environmental agreement schemes to make the development of infrastructure using renewable resources viable in certain geographical regions. In this point, we must include the reinforcement of regulations to allow for more development of the renewable energy focusing on socio-environmental aspects, especially in the north of the country (Guajira).

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

8. **Reconversions**. Colombia is an oil, gas, and coal producer and an oil and coal exporter. Reconvert regional economies associated with extractive industries without great social impact requires starting the regional planning processes and the reconversion of local economies with a just energy transition approach at this stage.

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 costs of introducing smart grids in low-consumption demand and promoting it as part of the agenda to facilitate energy efficiency should be analyzed.

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.

Roadmap of a just energy transition - Recommendations

Colombia has had a National Electric Mobility Strategy (*Estrategia Nacional de Movilidad Eléctrica*, ENME)[55] since 2019 and a National Sustainable Transportation Strategy (*Estrategia Nacional de Transporte Sostenible*, ENTS)[56] since 2022, to incentivize the use of zero emission vehicles for both private and public transportation.

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.

11. **Markets**. Develop secondary markets in the power sector. Focus on electricity trading and its financial derivatives (futures, swaps, options, etc.) to allow the residential and commercial segments to select the energy products they want to acquire and allow the industrial sectors to calculate their prices in the very long term.

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.

55 https://archivo.minambiente.gov.co/images/AsuntosambientalesySectorialyUrbana/pdf/Estrategia-Nacional-de-Movilidad-Electrica-enme-minambiente.pdf

56 https://mintransporte.gov.co/publicaciones/10754/transporte-sostenible/

Stage II - Implementation

In the second stage, there will be more investment.

1. **Public policies.** Develop the detailed transition plans to NZ in the planning horizon that is finally defined.

2. **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 carbon taxes should promote this investment.

   Promote equipment and car replacement and scrappage programs, focusing on vehicles (trucks and cars), given the expected advance in EV development and prices.

3. **Subsidies and prices**. Maintain subsidies for people with unfulfilled energy needs and design prices that internalize environmental and remediation costs.

4. **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 units with high CO_2 emissions.

   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.

   Develop detailed regulations to promote policies related to hydrogen and CCUS technologies to reduce uncertainty in such businesses.

5. **Social aspects**. Propose socio-environmental agreement schemes to make the development of hydrogen projects and CCUS technologies viable.

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

7. **Reconversions**. Initiate the financing schemes for the policies defined to reconvert regional economies.

8. **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.

9. **Transportation**. Foster clean technologies in transportation, including electric vehicles and their associated charging infrastructure, and promote freight vehicles running on LNG as transition fuel.

   Implement electric railway transportation to transport cargo and passengers.

10. **New technologies.** Develop concessional financial instruments to implement hydrogen and CCUS technology projects[57].

57 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.

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, banking regulations to promote energy transition, and carbon taxes should foster this investment.

   Promote replacement and scrappage programs for equipment and cars, focusing on all the equipment using liquid fuels.

2. **Subsidies and prices.** Subsidies for people with unfulfilled energy needs should be maintained.

3. **Regulations.** Within the fiscal incentives, carbon taxes should be established with highly prohibitive effects, so as to encourage the scrappage and replacement of such equipment.

4. **Reconversions.** Financially assist those regions that could not develop consistent plans for their reconversion to facilitate new businesses and private undertakings.

5. **Transportation.** Promote clean technologies in transportation, hydrogen, and electricity, 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.

2. 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 from CAF

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Public policies		- Issue detailed plans for the JET.	- Adjust JET plans to the deadlines to meet decent standard of living goals.	
Access	- Continue developing and implementing programs to offer clean solutions by combining LNG and renewable energy in interconnected areas. - Promote international financing schemes to make connection possible (rural electrification). - Achieve universal access to clean cooking and electricity.			
Energy efficiency	- Design, finance and implement replacement policies for home appliances (refrigerators, air conditioning, freezers, etc.). - Design and seek financing to replace old commercial vehicles with very little efficiency. - Promote studies for business reconversion in energy efficiency topics.		- Continue with the replacement policies, including all kinds of home appliances. - Promote plans to replace commercial and private vehicles with low efficiency.	
Energy subsidies	- Analyze the subsidy system, its legal and economic considerations, and propose enhancements so that they do not modify price signals. - Reduce State contributions. - Propose enhancements in the subsidy scheme to improve subsidies between strata.	- Modify the regulation that supports subsidies. - Implement new subsidy mechanisms. - Propose enhancements in the subsidy scheme to improve subsidies between strata.	- Focus the subsidies on people with unfulfilled energy needs.	
Fuel prices	- Analyze the internal price system and propose mechanisms to align prices and costs.	- Modify the regulations by introducing a price mechanism that gradually reflects 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 certificates.	
Public services tariffs	- Propose the regulations required to allow decoupled tariffs for company remuneration.	- Establish decoupled tariffs.	- Internalize investment in mitigation and adaptation in the tariffs.	

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Regulations	- Continue the fiscal and financial incentive policies to promote investment in renewable energy and energy efficiency. - Promote banking regulations that incentivize loans associated with energy transition (renewable sources and transition fuels).		- Promote regulations to favor electric and hybrid vehicles to incentivize the replacement of highly polluting units. - Within the fiscal incentives, carbon taxes should relate to remediation and adaptation costs. - Develop regulations to promote hydrogen and CCUS technology-related policies to reduce the uncertainty in these businesses.	- Within the fiscal incentives, establish taxes on carbon with highly prohibitive effects so as to encourage the scrappage and replacement of this equipment.
Socio-environmental aspects for project development	- Strengthen regulations that allow for greater development of renewable energy focusing on socio-environmental aspects, in particular, in the north of the country (Guajira).			
Transition fuels	- Permit financing and regulation of the gas sector in banking regulations.	- Maintain investment in the gas sector and promote the use of CNG and LNG in transportation as a mechanism to ensure the phase-out of part of the hydrocarbon value chain at the last stage.		
Reconversions	- Initiate studies on the impact of the exploitation of coal, other minerals, and oil on the communities.	- 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 strategic plans to mitigate the impact of the JET on sectors that have not achieved reconversion.
Phase-out of coal-fired plants		- Financing of the phase-out of coal-fired plants. - Establish regulations to phase out the plants as from 2030.	- Promote the replacement of coal in industrial sectors wherever possible.	

Policy	Between 2024 and 2025	Between 2026 and 2030	Between 2031 and 2040	As from 2040
Phase-out of fuel oil-fired plants		- Establish regulations to phase out the fuel oil-fired plants that remain operational.		
Development of smart grids (AMI)	- Analyze the mechanisms to integrate smart grids and international financing to allow for a better administration of the system as a whole.	- Introduce smart metering.		
Integration of renewable energy and storage systems	- Estimate the storage needs in the long term to integrate large amounts of renewable energy as a complement to hydroelectric storage.		- Design mechanisms to remunerate the services provided by storage to facilitate its development.	
Operation of the transmission and distribution grids in a coordinated way		- Develop the mechanisms for the integrated operation 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 in all segments of the economy.		

Works cited

EUROSTAT. (2021). Obtained from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

IEA. (2021). *Net Zero by 2050*.

IEA. (2021). *Net Zero by 2050, A Roadmap for the Global Energy Sector*.

IEA. (2022). *Energy Efficiency 2022*.

International Transport Forum, IADB. (2022). Obtained from https://publications.iadb.org/publications/english/viewer/Decarbonising-Transport-in-Latin-American-Cities-Assessing-Scenarios.pdf

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

UPME. (2019). *Balance de Energía Útil*.

UPME. (2020). *Plan Energético Nacional - La transformación energética que habilita el desarrollo sostenible. Bogotá: UPME*.

UPME, IREES, TEP, Corpoema. (2019). *Primer Balance de Energía Útil para Colombia y Cuantificación de las Pérdidas Energéticas Relacionadas y la Brecha de Eficiencia Energética*.

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