JUST ENERGY TRANSITION

Projection assumptions

IDFC International Development Finance Club FACILITY

CAF DEVELOPMENT BANK OF LATIN AMERICA AND THE CARIBBEAN

Just Energy Transition / Projection assumptions

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List of abbreviations

AFOLU	agriculture, forestry, and other land use
BAU	business as usual
CAGR	compound average growth rate
CAPEX	capital expenditures
CCUS	carbon capture, use, and storage
CEPAL	Economic Commission for Latin America and the Caribbean
CNG	compressed natural gas
EE	energy efficiency
EV	electric vehicles
GDP	gross domestic product
GDPpc	gross domestic product per capita
GHG	greenhouse gases
HDI	human development index
IEA	International Energy Agency
IREES	Institute for Energy Strategies and Resource Efficiency (*Institut für Ressourceneffizienz und Energiestrategien*)
IRENA	International Renewable Energy Agency
ISIC	International Standard Industrial Classification
JET	just energy transition

LEAP	SEI's low emissions analysis platform
LNG	liquefied natural gas
LPG	liquefied petroleum gas
NCRE	non conventional renewable energy
NREL	National Renewable Energy Laboratory
NZ	net zero
OLADE	Latin American Energy Organization
O&M	operation and maintenance
PPP	purchasing power parity
SEI	Stockholm Environment Institute
SHW	sanitary hot water
SieLAC	Energy Information System for Latin America and the Caribbean
TJ	terajoule
UN	United Nations
UNDP	United Nations Development Programme
UPME	Colombia's Energy Mining Planning Unit (*Unidad de Planeamiento Minero Energético de Colombia*)

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Objetives

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 member countries – Latin America and the Caribbean Development Bank – 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 manner;
2. to diagnose the national energy systems – in particular, the electricity ones – (target countries) 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 alternatives for energy transition in the previously defined context.

3. Organization of the Just Energy Transition series

In order to achieve the indicated objectives, the study was carried out 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 by country were organized according to 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.

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

5. Projection assumptions

The objective of this report is to describe the assumptions, criteria, and methodology applied to prepare the energy transition scenarios of the low-emission analysis platform (LEAP) model in more detail.

The report presents the general structure of the model, the scenarios, and the socio-economic variables projection, the assumptions, and the methodological aspects in detail for each demand sector, the projection of the power sector, and the hypotheses used to estimate the required investment for each scenario.

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Methodological section and assumptions

1. Projection modeling

Base year and planning horizon

The base year considered for the projection is 2019. The planning horizon starts in 2019 and ends in 2060.

General description of the model

The LEAP model, developed by the Stockholm Environment Institute (SEI), was used to conduct the study. The LEAP model is a software tool used to analyze energy policies and evaluate climate change mitigation. In this case, it was used to model the energy sector emissions related to burning fuel in each of the analyzed countries.

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

- It starts from the information on 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 reach a total projection, or*
    - *top-down.*

  In this study, bottom-up modeling was selected and the demand was divided into sectors (residential, industrial, transport, etc.) which, in turn, were subdivided into subsectors and energy 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 by using the demands produced with the LEAP model[1].

The modeled demand sectors are projected according to an activity level and an explanatory variable, summarized in Graphic 1 in a simplified manner.

1 In the context of this study, only the LEAP model simulation tools were used. No dispatch results from other programs were incorporated.

Graphic 1 ▶ Sectors, Activity levels, and explanatory variables

Sector	Activity level	Explanatory variable
Residential	Population	Consumption per capita
Road transportation	Target variable, vehicle fleet	Average consumption per vehicle
Non-road transportation	Total GDP	Energy intensity
Industrial	PIB setorial	Energy intensity by subsector and energy use
Commercial, Services, and Public Sector	PIB setorial	Energy intensity
Agricultural, Fishing, Mining, and Construction	Sectoral GDP	Energy intensity

Source: Own preparation.

The gross domestic product (GDP) of the sector 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 caese of passenger transportation and GDP in the case of freight transportation. Non-road transportation is projected on the basis of the global GDP.

The proposed scenarios and the modeling adopted for this study are 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.

2. Scenarios and global framework

Definition of the scenarios

Three scenarios were studied to characterize different pathways towards a just energy transition.

A Business as Usual scenario

The Business as Usual (BAU) scenario represents the expected evolution following the national public policy guidelines and the current trends. In this scenario, the observed and developing policies aimed to reduce emissions are recognized. For instance, progress in the region regarding the following topics is taken into account: introduction of renewable energy (socializing, at first, the higher cost through the wholesale markets and tenders), energy efficiency (by implementing labeling and mimimum energy performance standards (MEPS), the gradual phase-out of coal and fuel oil from energy matrices, and biofuel production for transport, etc.

In this scenario, we will seek to introduce evolution rates that are consistent with the past, especially during the first years of the projection.

B Net Zero 2050 scenario

This scenario establishes the most ambitious time horizon, with immediate compliance with the terms established in Article 4 of the Paris Agreement[2]. It focuses on reducing greenhouse gas (GHG) emissions from the energy sector[3] to a permissible minimum[4], so that the country can manage the absorption of CO_2 in the general balance of the national GHG inventory[5]. The objective of the Net Zero scenario is that GHG emissions be equal to the savings produced by the sinks in every country in the region.

C Net Zero 2060 scenario

In accordance with the Paris Agreement, which states that the emissions balance must be reached in the second half of the century, the Net Zero scenario 2060 (NZ 2060) presents a more realistic time horizon based on the reality of the region, and considers a minimum of 10 years beyond the Net Zero scenario 2050 (NZ 2050). NZ scenario 2060 should allow for the graduality of the necessary adjustments to the regulatory framework and market practices, leveling technology costs, and asset depreciation, among other aspects. According to the projections prepared for GDP growth, the countries are expected to approximate the consumption characteristics and human development index (HDI) required for sustainable development between 2050 and 2070.

2 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".

3 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.

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

5 It is expected that CO2 absorptions result from measures implemented in the agricultural, cattle-raising, forestry, and other land uses (AFOLU) sector or via the adoption of CO2 capture, use, and storage technologies (CCUS).

Like the previous scenario, this one focuses on reducing GHG emissions from the energy sector to a permissible minimum, so that the country can manage the absorption of CO2 in the general balance of the national GHG inventory. The objective of the NZ scenario is that GHG emissions be equal to the savings produced by the sinks in every country in the region.

Projection of socio-economic variables

GDP per capita and GDP

In line with the grounds for a **just energy transition**, the scenarios are accompanied by similar socio-economic development in the region, **reaching sufficient GDP per capita levels to be considered high-income countries.**

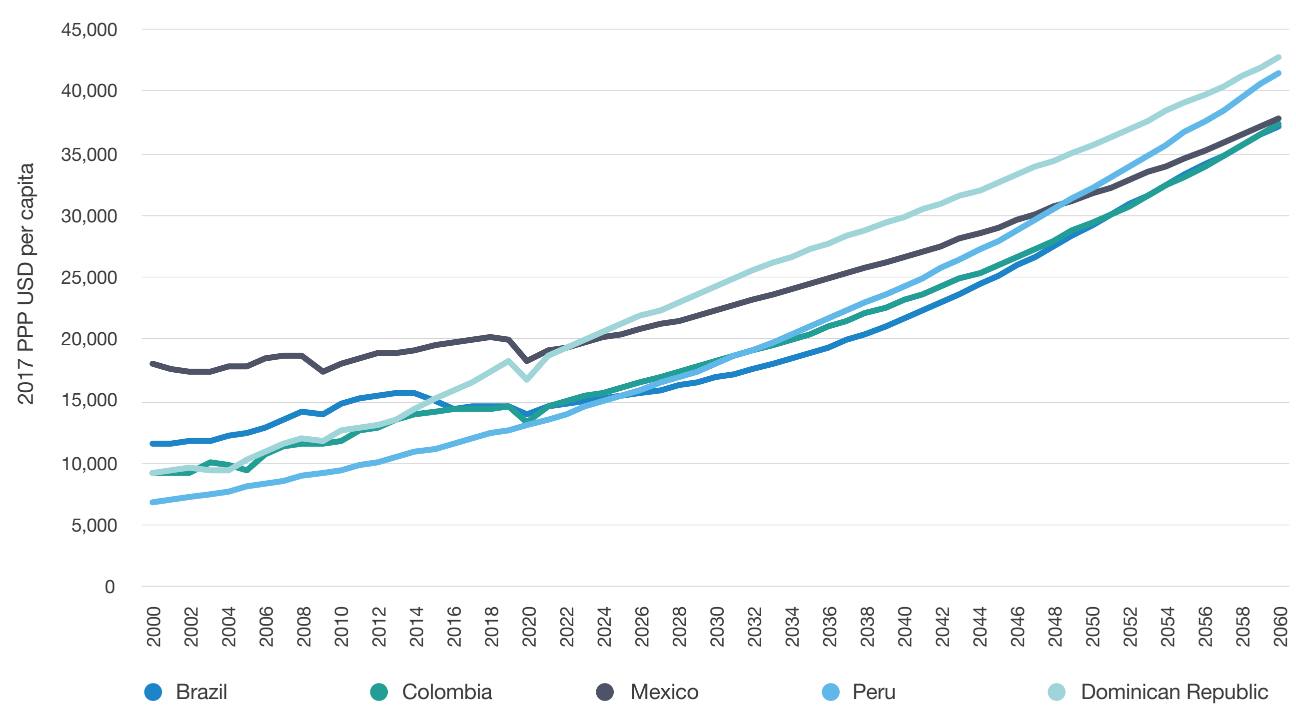
In order to define the GDP per capita target level that is consistent with a decent standard of living, two criteria were considered: HDI and power consumption per capita. Based on these criteria, the following were determined:

- the average GDP of the lower quintile of countries with very high HDI (≥0,8), and
- the average GDP of the lower quintile of countries with power consumption over 5,000 kWh per capita-year. This value is used in energy planning to consider which countries are industrialized and developed.

This data is defined as the reference values that countries must reach to have a decent standard of living. The target GDP per capita (measured in 2017 US dollars (USD) at purchasing power parity (PPP)), according to the first indicator, is USD 21,000, and USD 33,000 for the second indicator. Therefore, this second value was considered the reference value for the objectives set in Article 4 of the Paris Agreement. This value is compatible with a HDI ≥0.8.

The GDP projections were carried out through stochastic models detailed in the Annex. The GDP per capita by country is shown in Graphic 2 and the GDP by country is shown in Table 1:

Graphic 2 Evolution of the GDP per capita by country, 2017 USD per capita at PPP



Source: Own preparation.

Total GDP is calculated based on the GDP per capita and the projection of the population shown in subsection “Population”. Sustained growth of approximately 2% to 3.5% is expected for all the analyzed countries, with differences that reflect the initial GDP per capita level and the recent historical trends.

Table 1 Total GDP projected by country, 2017 USD per capita at PPP and CAGR between 2019 and 2060, %

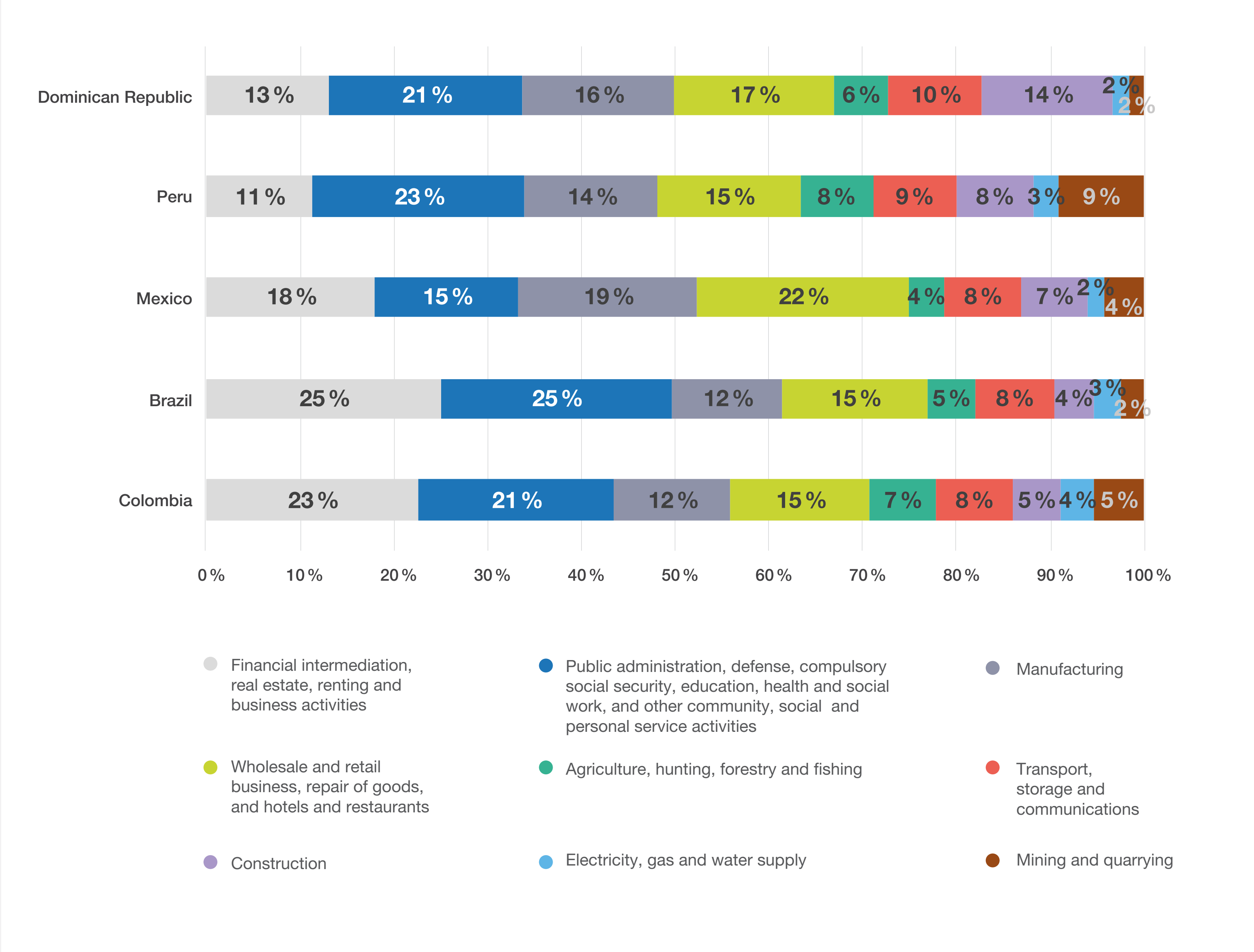
	2019	2030	2040	2050	2060	CAGR period
BRA	3,110,059	3,779,951	4,996,912	6,736,951	8,460,524	2.5 %
COL	733,546	984.85	1,301,385	1,674,808	2,109,590	2.6 %
MEX	2,509,774	3,006,961	3,757,355	4,564,218	5,403,887	1.9 %
PER	418,610	661,382	965,078	1,350,929	1,807,592	3.6 %
RDO	197,736	291,340	379,659	471,112	571,919	2.6 %

Source: Own preparation.

GDP by sector is projected assuming that the share of each sector is maintained pursuant to 2021 values (see Graphic 3). This results in a GDP growth rate by sector equal to the total GDP growth rate[6].

6 This assumption seeks to simplify the simulation work.

Graphic 3 Distribution of GDP by sector and country, %

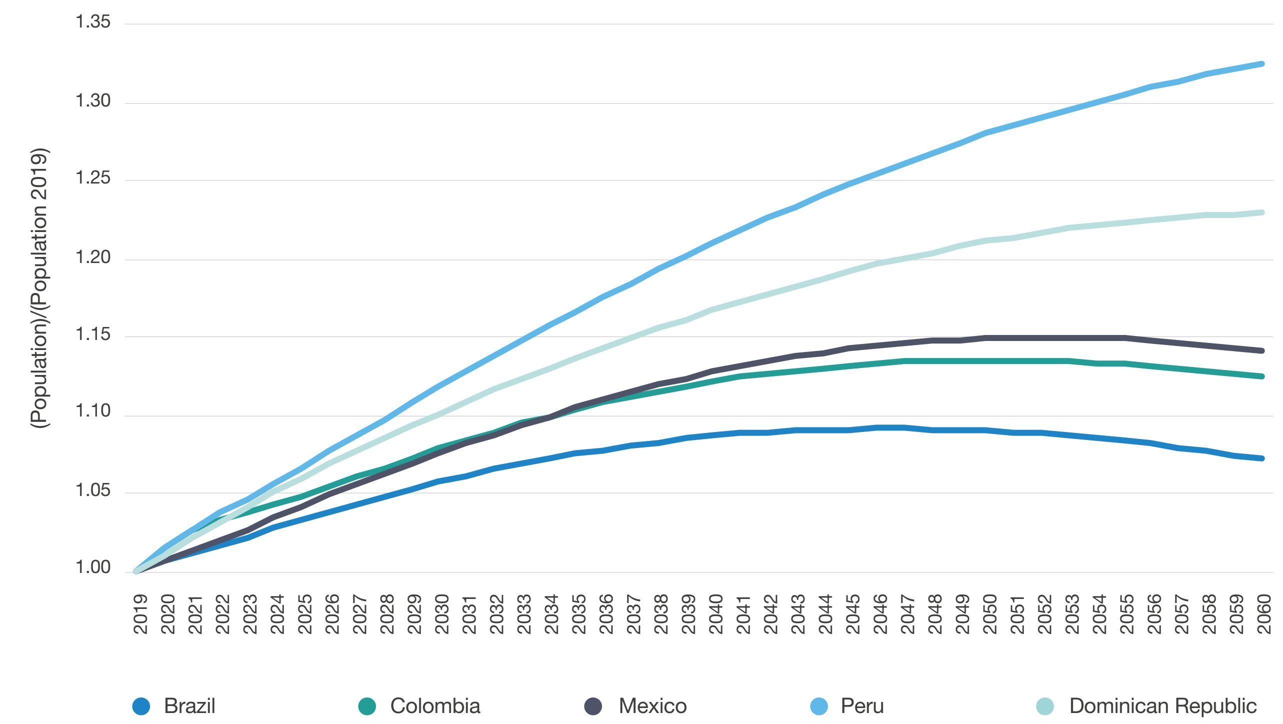


Source: Own preparation based on historical data from CEPAL.

Population

As to the population projection, the projections prepared by the United Nations and CEPAL[7] were used. A deceleration in population growth is expected in the future, with long-term negative growth in Brazil, Colombia, and Mexico. Graphic 4 shows the evolution of the population in each country compared to 2019.

Graphic 4 Evolution of the population by country, base year 2019



Source: Own preparation based on data from CEPAL
https://statistics.cepal.org/portal/cepalstat/dashboard.html?theme=1&lang=es

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

Main assumptions in the energy sector

The general framework of the study covers the definition of assumptions for five countries analyzed in the series. Even though each country has its own characteristics, the study standardized, where possible, the assumptions used, assuming that the countries will undergo similar processes for a just energy transition. The inherent particularities of 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 objectives set in each scenario, the assumptions considered were more ambitious in the case of the NZ scenarios. The main assumptions are based on the following measures.

- **Energy efficiency enhancements.** This is applied in all sectors, with equipment replacements, more thermal efficiency in houses, 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 transfer from freight transportation by truck to the railway system.

- **Fuel substitution**. In most of the sectors, there is a trend towards greater electrification of energy uses, except for industrial uses or subsectors where there are low electrification possibilities. In these cases, the replacement of the most polluting fuels with natural gas or the use of CO2 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, and the phase-out of coal-fired plants and plants running on liquid fuel plants is incentivized. It is important to remember that the composition of power generation 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.

As to the assumptions related to the energy sector, the analyzed bibliography covers both general documents that set guidelines for all the countries and particular ones according to the reality of each of them.

Methodological section and assumptions

3. Demand by sector

Residential sector

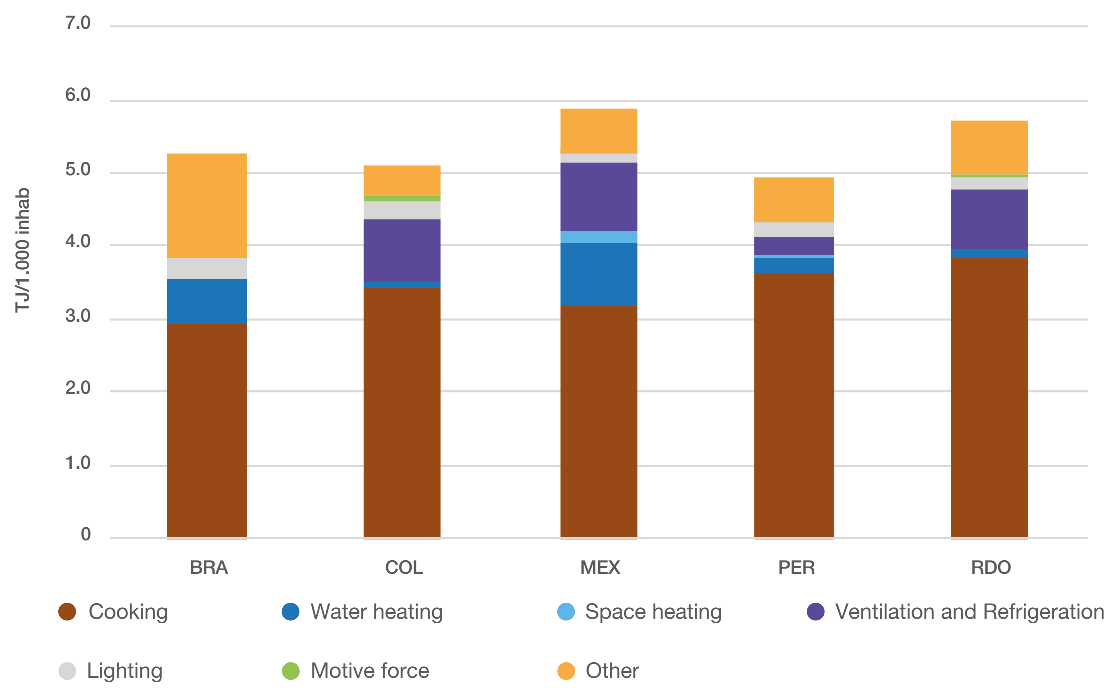
Starting point

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

- **Consumption by energy use.** Residential consumption has two kinds of energy uses[8], heat uses (mostly: cooking, sanitary hot water (SHW), space heating), which use different energy products (fuel, electricity, renewable energy) with substitution potential, and electrical uses (lighting, refrigeration, air conditioning, etc.).

8 It is important to point out that this classification refers to the end use, not the fuel used, and part of the heat use may be supplied with electric power. On the contrary, the so-called “electrical” uses are only supplied by electricity.

Graphic 5 Final unitary energy consumption, by energy use and country, 2019, TJ/1,000 inhabitants



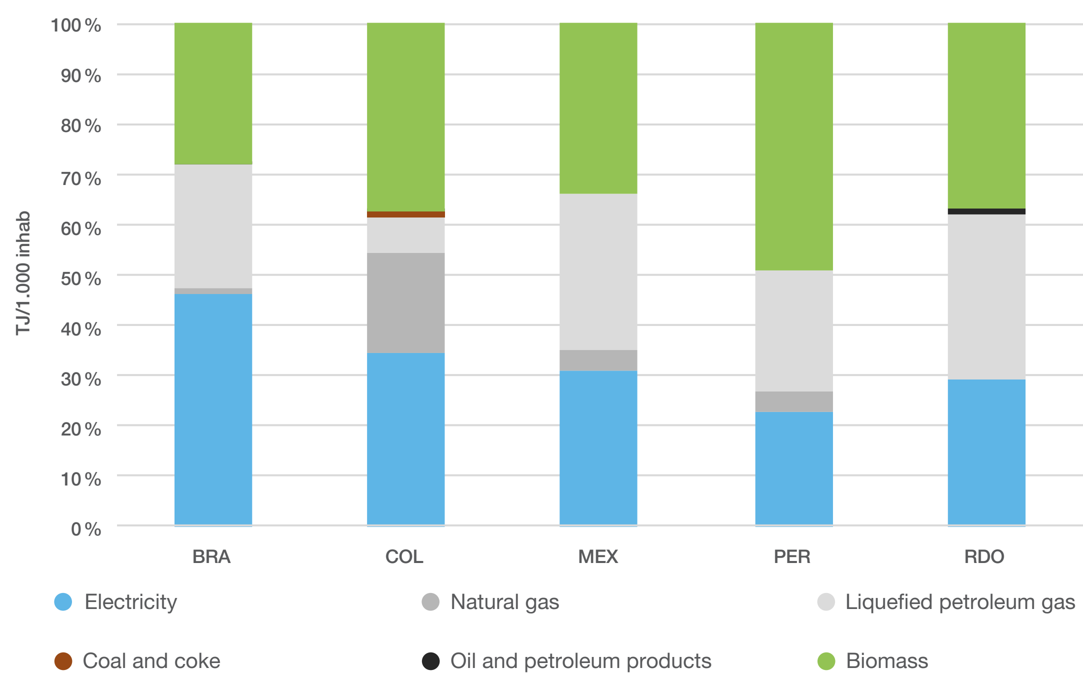
Source: Own preparation based on data from (EPE, 2019), (UPME, 2019), (SENER, 2022), (Engrinter, Mercados Energéticos Consultores, Datum, 2016) and (Fundación Bariloche, 2020).

In the analyzed countries, cooking is the energy use with the greatest final energy consumption in the residential sector, exceeding 50% in all cases, whereas heating and motive power consumptions are much lower. In addition, the use of water heating is not significant in Colombia, Peru, and the Dominican Republic.

Residential energy consumption is between 5 and 6 TJ/1,000 inhabitants in the five countries.

- **Consumption by fuel.** In general, the residential sector shows high consumption of biomass, especially for the cooking use, because of its availability and the development level of the analyzed countries. Even though electric power consumption is rising, it is not the prevailing fuel in the sector.

Graphic 6 Fuel consumption in the residential sector, by country, 2019, %



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

Assumptions

Heat uses and electrical uses, which respond to different historical dynamics and potential future evolution, are analyzed separately[9]. The following subsections describe the projection methodology used in each case. By way of illustration, correlation graphics related to the Colombian case are presented. This process was repeated for each country in the study.

Heat uses

Heat uses, where cooking prevails over water heating and space heating, show great **electrification** potential. The substitution of the use of firewood may lead to great **efficiency** gains[10].

A Cooking

Historical consumption trends are analyzed in terms of useful energy[11] per 1,000 inhabitants, and are used for future projections. Assumptions related to fuel substitution by scenario (which refer to the replacement of firewood with appliances running on electricity or natural gas) are presented.

9 Upon analyzing the elasticity of per capita residential consumption revenue in relation to GDP per capita for each of the countries studied, it is concluded that this is not a reliable metric for projecting residential consumption. It is essential to separately assess heat uses and electrical uses.

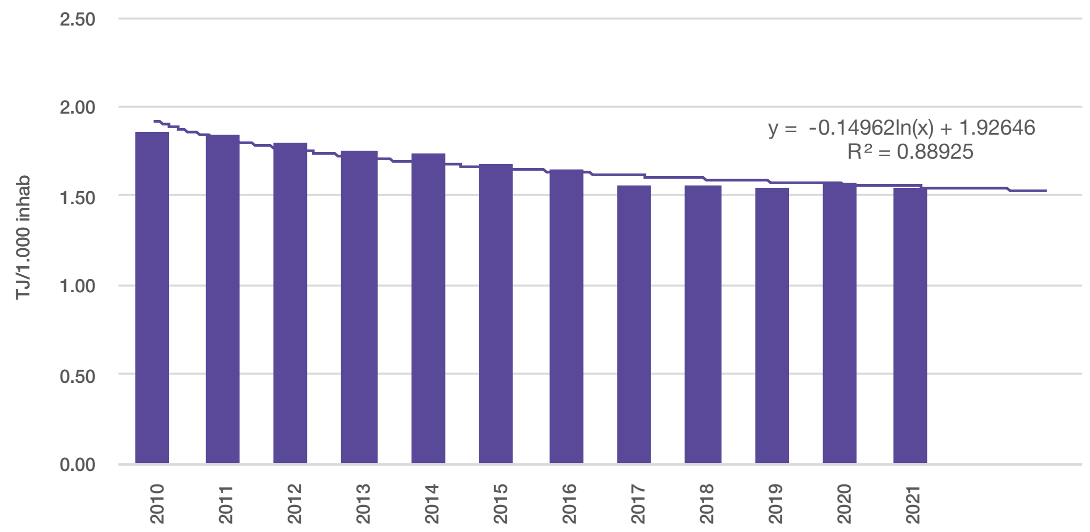
10 Replacement with electric power (or natural gas) produces an increase in the useful energy/final energy relation, which causes a reduction in energy intensity (energy consumption per capita).

11 According to OLADE, IADB, 2017, final energy "is the amount of energy source consumed in each of the economic and social sectors in the country". In addition, useful energy "is the amount of energy actually used to carry out the productive activity of the consuming equipment or appliance, for example, the heat food must absorb to be cooked".

Historical consumption trends in terms of useful energy

Graphic 7 shows the analysis of historical fuel consumption per 1,000 inhabitants for heat uses in Colombia, as well as the projection considered for this case, (see equation).

Graphic 7 Colombia: evolution of useful energy consumption per capita for heat uses, between 2010 and 2021, TJ/1,000 inhabitants



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

The decreasing historical trend shows both the energy efficiency gains of the cooking use (use of more efficient equipment) and the behavior changes (tendency to cook less time) which are expected to continue in the future[12].

Fuel substitution assumptions

The fuel used (substitution effect) will depend both on the country analyzed and on the scenario, and will reach higher electrification levels in NZ scenarios and a trend similar to the historical one in the BAU scenario, as illustrated in Table 2 (targets are expressed in terms of useful energy).

Table 2 Substitution assumptions by fuel, country, and scenario, cooking use

	Country	BAU	NZ 2050	NZ 2060
Firewood	All	Total substitution of firewood in the long term (accelerated substitution for NZ scenarios).		
Electricity	All	2060: low penetration of electricity (≤40%), except for Brazil (50%).	2050 and 2060: mainly electrical (≥80%).	
NG and y LPG	All	2060: high penetration of NG and LPG (≥50%). 50% for Brazil. Only LPG for the Dominican Republic.	2050 and 2060: remaining share. Dominican Republic: only LPG.	

Source: Own preparation.

12 When analyzing the historical trend, it is considered that energy efficiency elements are already incorporated because of the use of more efficient equipment that reduces the final energy demanded. Therefore, no extra assumptions on efficiency were made in the cooking segment.

Methodological section and assumptions

The NZ scenarios propose greater ambition in fuel substitution, mainly through electrification, energy efficiency enhancements, and behavior changes. This implies a significant increase in electricity demand. Non-fossil technologies are key to achieving the low emission levels required.

B Sanitary hot water

Even though it is currently a minor use in Latin America, it is assumed that the increase in purchasing power (GDP per capita) may be accompanied by an increase in sanitary hot water consumption per capita in the future.

In the European Union countries (which, in general, have a similar GDP per capita to the target long-term GDP per capita presented for the three scenarios), energy intensity for sanitary hot water consumption reaches, on average, 3.5 TJ/1,000 inhabitants and is very variable among the different countries. In the five analyzed countries, Brazil and Mexico start with a consumption of under 0.8 TJ/1,000 inhabitants whereas the others start from under 0.2 TJ/1,000 inhabitants. Of the countries in the European Union, the useful energy consumption in Portugal (1.4 TJ/1,000 inhabitants in 2019) is taken as a reference because it is a country with a similar climate to that of the region and it meets the indicators of the target countries defined when estimating the activitiy growth.

In the case of Brazil, Colombia, Peru, and Mexico, for the BAU scenario, we chose to use a target of 75% of the current consumption of useful energy in Portugal for 2060 and the current fuel share is maintained for this energy use. The 20% savings refer to an annual efficiency enhancement of 0.7% compared to the current situation, in line with the range managed by the International Energy Agency (IEA). This energy use is considered to be strongly electrical, as it will develop almost completely.

In addition, for the NZ scenarios, an even greater efficiency enhancement of 50% must be achieved. Fossil fuel consumption in these cases is eliminated, the rest being electrical and solar (60% and 40%, respectively).

On the other hand, in the Dominican Republic, an increase in water heating consumption proportional to the GDP increase was considered on the grounds that greater wealth implies greater comfort; however, this energy use will not be developed at the target countries' level because of the hot climate.

Methodological section and assumptions

C Space heating

Similarly to the previous point, the analyzed countries currently show a much lower space heating consumption (≤0.2 TJ/1,000 inhabitants). In Portugal, the space heating use amounts to 3.7 TJ/1,000 inhabitants in final energy (2.2 TJ/1,000 inhabitants in useful energy). Once again, for Colombia, Peru, and Mexico, a target of 75% of the current consumption in Portugal for 2060 is considered (that is, an annual efficiency enhancement of 0.7% compared to the current situation, in line with the range managed by the IEA). For the NZ scenarios, an even greater efficiency enhancement of 50% must be achieved.

Since it is an energy use to be developed, it is assumed that more competitive technologies in terms of cost will enter the market. Therefore, it is expected that space heating will be mainly electrical, as it is a consumption that will be developed almost from scratch.

Given that a large part of the Brazilian population lives in areas with warmer climate than Portugal, the targets defined for this country are lower than those selected for Colombia, Peru, and Mexico. Finally, the use of space heating is not envisaged for the Dominican Republic on account of its hot weather.

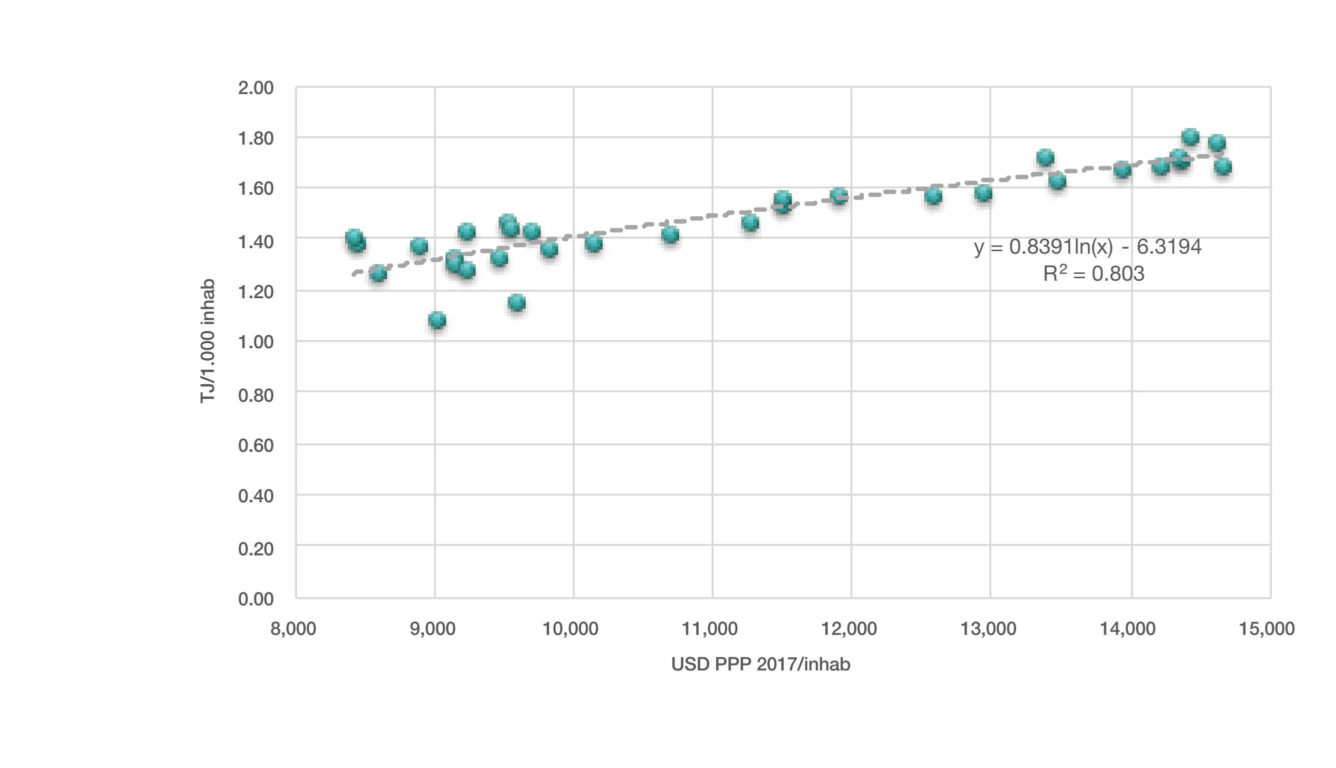
Electrical uses

Electrical uses[13] (lighting, refrigeration, air conditioning, water pumping, etc.) do not show any substitution potential. The future increase in GDP per capita can be accompanied by energy efficiency (EE) but also by additional electric power consumption (acquisition of new house appliances, air conditioning, etc.).

13 The following categories are included in this subsection: electronics, motive force, lighting, other, refrigeration, and television.

In order to project electric consumption, a regression was performed against GDPpc in terms of **final energy**[14], as shown in Graphic 8 for the Colombian case. This historical elasticity reflects the increase in electrical uses as the standard of living increases, and is identical in the three scenarios.

Graphic 8 Colombia: Electricity consumption vs. GDPpc regression, period 1990-2019



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

14 Electrical uses, for which there is no potential replacement with other fuels, must be analyzed in terms of final energy whereas heat uses must be analyzed in terms of useful energy to eliminate the impact of the efficiency of each fuel/process when considering substitutions.

Methodological section and assumptions

On the other hand, energy efficiency assumptions were made by scenario.

i. **BAU scenario.** Between 0.5% and 1.0% p.a. is considered for all uses.

ii. **NZ 2050 and NZ 2060 scenarios.** A greater efficiency enhancement is expected, between 1.0% and 1.5 % to meet the carbon neutrality targets.

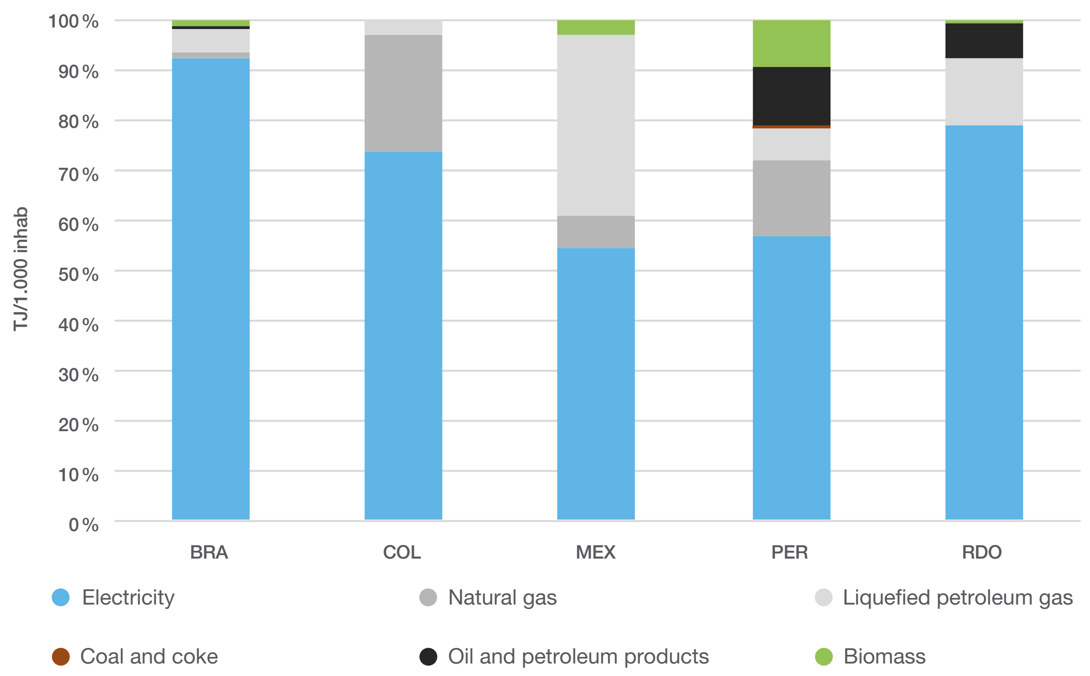
As a reference, according to the IEA (2022), **energy efficiency (EE)** in the residential sector improved by an annual rate of between 1.5% and 2.0% in the period between 2000 and 2015, and only by an annual 0.5% between 2016 and 2020.

Commercial, services, and public sector

Starting point

The commercial, services, and public sector is formed by several subsectors, for example, public administration, hospitals, hotels, and stores. It is often a sector with little weight in terms of energy consumption (≤7% of the total, in 2019) compared to the transportation, industrial, and residential sectors. Graphic 9 shows final consumption by fuel and by country. It is a sector with a large share of electricity.

Graphic 9 Fuel consumption by country, Commercial, services, and public sector, 2019



Source: Own preparation based on data from sieLAC (OLADE) and national energy balances.

Assumptions

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 the 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.

Methodological section and assumptions

For the BAU scenario in all the countries, an annual efficiency enhancement of 1% was considered, as it is assumed that similar enhancements to those detailed in the residential sector are applied, reaching cumulative 34% in the period.

For the NZ 2060 and NZ 2050 scenarios, a greater penetration of electricity is reached at the end of the period. In addition, an annual efficiency enhancement of 1.6% and 2.2%, respectively, was considered, and both scenarios achieved a total energy consumption reduction of 50% at the end of the period due to energy efficiency measures.

Table 3 Main energy transition assumptions by scenario: commercial, services, and public sector

	BAU	NZ 2050	NZ 2060
Energy efficiency	-1% annual (-34 % cumulative to 2060)	-2.2% annual (-50 % cummulative to 2050)	-1.6% annual (-50 % cumulative to 2060)
Substitutions	Slight electrification of the sector	2050 and 2060: electric consumption displaces fossil fuels almost completely.	

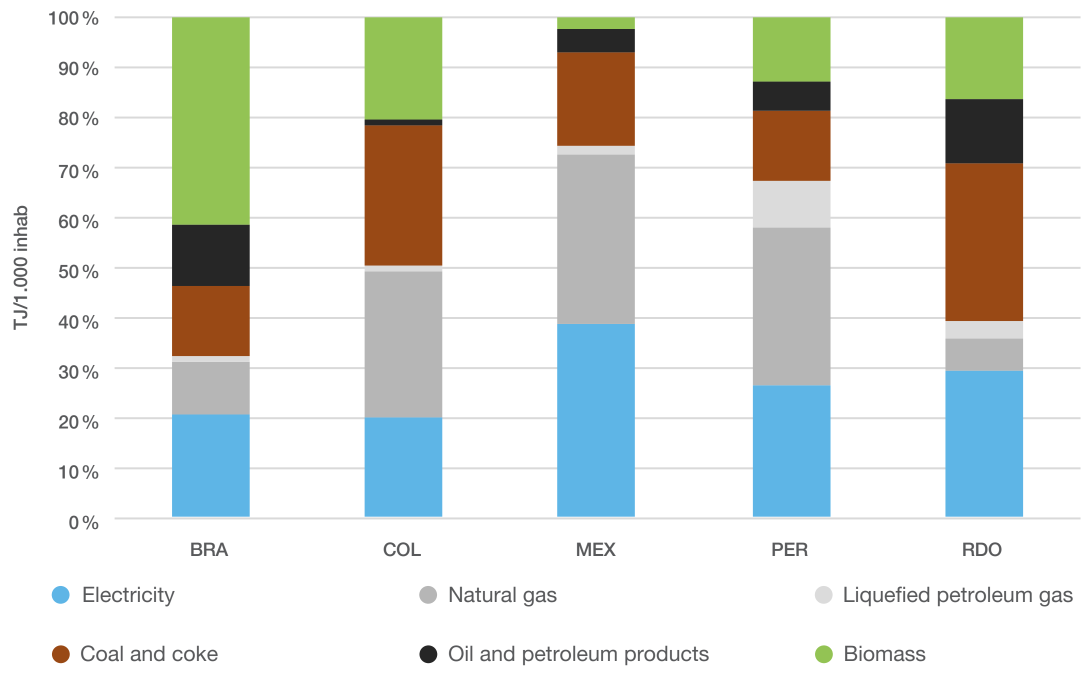
Source: Own preparation.

Industrial sector

Starting point

In all the analyzed countries, the industrial sector has the second largest energy demand after the transport sector. There is often low penetration of electricity, conditioned by various sectors with difficult electrification, such as the steel and cement ndustries.

Graphic 10 Fuel consumption in the industrial sector, by country, 2019



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

Assumptions

Industry was projected with information on energy consumption of 2019 broken down with a digit of the International Standard Industrial Classification (ISIC), additional to that of the sector's GDP, by subsector. In turn, for each industrial subsector, consumption is broken down by end use.

Methodological section and assumptions

Expected GDP growth, together with energy intensity by subsector and use obtained for 2019, are used for the projection of energy consumption, 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[15].

Transition measures focus on **enhancements in terms of efficiency and fuel substitution.** 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.

In the case of fuel substitution, the solar alternative for indirect heating (water heating) and natural gas as coal substitute appear as adequate, in addition to electrification.

In cases where coal cannot be replaced, long-term carbon capture and storage technologies can be considered. Energy efficiency is achieved thanks to the optimization of the use of energy in industrial processes and technological replacement to more recent and efficient appliances and facilities.

It is important to remember that substitution possibilities may vary considerably from one 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 sectors (fewer than 10).

The analysis focused more in detail on the subsectors with greater consumption and their associated uses. The main sectors and uses are often similar in all the analyzed countries. The food, beverage, and tobacco sector is often one of the greatest energy consumers, together with the iron and alloys, non-metal minerals (especially cement) and other industries.

15 This assumption implies that structural changes within the industrial sector are not modeled and the same GDP growth rate is applied in all the subsectors.

In the food, beverages, and tobacco sector, heat (either direct or indirect) is the main energy demand. In general, this energy is supplied through fossil fuel boilers that heat water or generate steam, or through heat transfer from hot combustion gases.

Direct heating is also used in certain applications. This heat is used in several food processing stages, such as pasteurization, sterilization, drying, and cooking, among others. There are electric heating technologies that allow for greater electrification in this subsector.

For the cement and iron and alloys sectors, the replacement of the current fuels (generally solid fuels such as coal and coke) with natural gas was mainly presented, along with a slight increase in the share of electricity (IEA, 2021).

The hypotheses considered by country and by subsector are summarized in Table 4. These assumptions take into account both the particularities of the subsectors and those of the countries.

Table 4 Main energy transition assumptions, by country and scenario, industrial sector

	Country	BAU	NZ 2050	NZ 2060
Energy efficiency	All	Enhancement of energy intensity over useful energy		
		• -0.5% annual • -19% cumulative	• -1% annual • -27% cumulative	• -1% annual • -34% cumulative
Substitutions by country	All	Based on historical trends	• Fuel oil and diesel: total replacement with NG and LPG between 2019 and 2035. • Coal: total or partial replacement with NG and electricity.	
	COL	For industrial subsections with high penetration of coal: • With substitution potential: strong reduction in consumption (greater in NZ) and partial replacement with NG. • With low substitution potential: long-term carbon capture and storage technologies are considered in the NZ scenarios (IEA).		
Substitutions by subsector	Food, beverages, tobacco	Increase in the importance of electricity and solar energy, in line with potential electrification processes in the sector (drying, roasting, etc.)		
	Cement, ceramic	• Cement: most difficult sector to electrify. Partial replacement of coal with gas. • Ceramic: potential conversion to electric kilns.		
	Various industries	Great heterogeneity in this group. Replacement of coal (and biomass) with NG, LPG, and electricity.		
	Iron and alloys	Replacement of current fuels with natural gas and slight increase in the share of electricity.		

Source: Own preparation.

Transportation sector

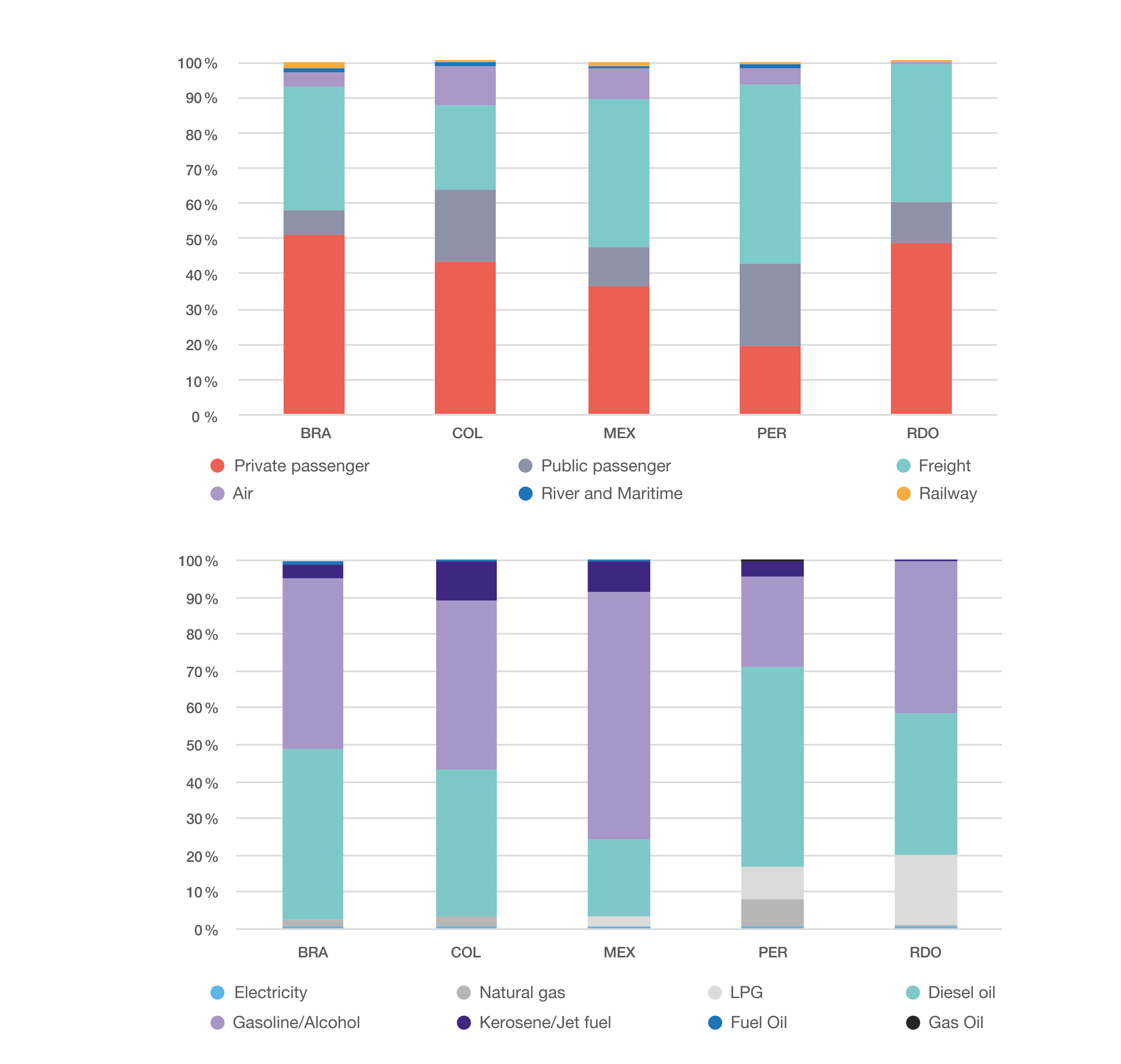
Starting point

The transportation sector is the maximum energy consumer and greenhouse gas emitter in the five countries under analysis. It mainly consumes liquid fuels (diesel, gasoline, etc.). Even though electric vehicle sales have increased in several countries in recent years, these vehicles account for a small portion of final consumption in the analyzed countries.

Road transportation accounts for over 85% of total consumption, led by road passenger transportation (except for Peru, where freight transportation accounts for over 50%).

Methodological section and assumptions

Graphic 11 Energy demand by energy use and by fuel, transportation sector, 2019



Source: Own preparation based on data from sieLAC (OLADE), national energy balances, and useful energy balances.

Assumptions

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).

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; the number of private vehicles is identical in the three scenarios, and
- **average consumption by vehicle** calculated as the average annual distance traveled divided by performance in km by energy unit.

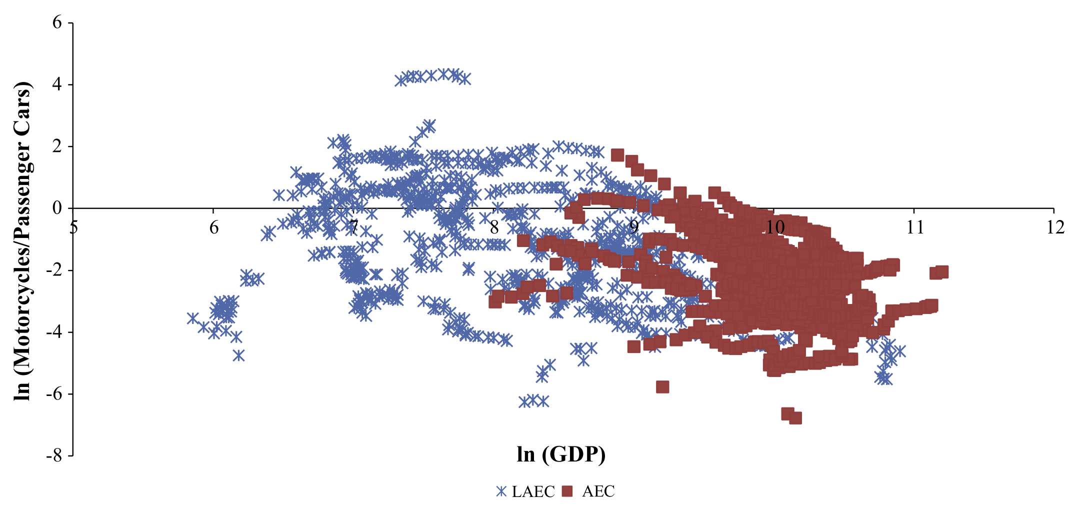
A Projection of the passenger vehicle fleet

i. Private transportation (motorcycles, cars, light trucks)

Given the analysis of correlations between GDP per capita, HDI, and electric consumption (see "Annex. Detailed methodological aspects"), the countries with high development levels were identified. In this way, data was collected on the number of cars and motorcycles per 1,000 inhabitants in developed countries, and an average of 635 units was estimated. Such average was used as a long-term **saturation point** (2060), and projections were made using a logit function 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** were used. They indicate that this relation is shaped like an **inverted "U"**[16], which implies that, at first, the number of motorcycles per 1,000 inhabitants has a positive relationship to GDP per capita until it peaks; from there, as the development level of the countries increases, the number of motorcycles per 1,000 inhabitants starts to fall and the number of cars increases.

Graphic 12 Relation between motorcycle/car ownership rate and GDP per capita



Source: Law, Hamid & Goh (2015).

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

According to Law's analysis (Law, 2015), the motorcycle ownership rate starts to fall from GDP per capita levels between USD 4,000 and USD 6,000 (measured in constant USD of 2011). Since our estimations are based on the GDP/PPP of 2017, the GDPs of the analyzed countries at constant prices were used and their relation to the prices measured at PPP was analyzed. The value estimated by Law equals values of between USD 9,000 and USD 10,000 when the GDP is measured with thPPP of 2017.

Based on the GDP per capita projections by country, the values previously presented were used as a maximum saturation point in the number of motorcycles. In this way, each country has a year and a maximum number of motorcycles reached according to their expected level of development and growth.

ii. Public transportation (bus)

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.

After finding that the saturation point is 8 passenger vehicles per 1,000 inhabitants, such saturation was taken and the number of buses was projected by using an econometric model based on a logit-type equation, and the saturation point was used as a saturation value for the five analyzed countries.

B Energy transition assumptions

The energy transition measures contemplated are:

- **transition in terms of fuel used**/engine type, which depends on the type of vehicle (motorcycles, cars, light trucks, buses) and the scenario. In particular, one of the main options contemplated is the electrification of the vehicle fleet that allows reducing emissions and total consumption (a reduction of 75%-80% consumption by km). Moreover, the use of hybrid vehicles allows for a significant reduction in energy consumption;

- **enhancement of** vehicle **performance** and of the average efficiency of the vehicle fleet as a result of technological progress and/or the reduction in vehicle weight by category; and
- reduction in distances traveled (km/type of vehicle) as a result of the **digitalization** of society (remote work, etc.) and the development of **public transportation**.

C Transition in terms of fuels used

The European Union established an agreement that guarantees that all the cars and light trucks registered in Europe as from 2035 must be environmentally friendly (zero emissions)[17]. Even though the rule does not apply to motorcycles, it is expected that a similar policy will be enforced for this type of vehicles in order to fight climate change. In addition, other countries like India, one of the largest motorcycle markets in the world, has made the first move in this sense[18]. In this context, supposing a similar practice were applied in Latin America as from 2045, it is expected that by 2060 100% of the electric motorcycle fleet will be reached.

As to public passenger transportation, there are several initiatives worldwide to eliminate combustion engine vehicles. The Netherlands, Denmark, and New Zealand lead this movement by setting 100% electric vehicle purchase targets as from 2025 and aiming to reach a fully electric fleet by 2030. In Latin America, Colombia and Chile have proposed that 100% of their acquisitions should be electric as from 2035[19]. In this context, it was projected that, by 2060, in all the scenarios, all buses will be electric and such target will be met in 2040 in the two NZ scenarios in all the countries (Table 5).

17 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6462

18 https://soymotero.net/noticia/a-partir-de-2025-en-india-solo-se-podran-vender-motos-electricas-28858/

19 https://theicct.org/decarbonizing-bus-fleets-global-overview-of-targets-for-phasing-out-combustion-engine-vehicles/

As regards cars, ATVs, and light trucks, it is assumed that it is a more difficult segment to replace. Even though it is expected that sales will be almost completely electric by 2050, it is estimated that their share will be 30% electric and 20% hybrid by 2060 in all the analyzed countries, where the remaining 50% will depend on the availability of resources in each country. In the NZ scenarios, a share of 80% electric and 20% hybrid must be reached by the end of the period.

In the case of Brazil, in line with the energy transition program (CEBRI, 2023), a greater use of biofuels is expected. In the BAU scenario, it is envisaged that 20% of the vehicles will be hybrid, another 20% electric, 20% will use green diesel, and the rest will run on gasoline by 2060. For the NZ scenarios, it was considered that the share will be 20% hybrid, 40% electric, and 40% green diesel by the horizon year.

D Performance enhancement

In order to determine the efficiency of the vehicle fleet, the Energy Efficiency 2022 (IEA) report is considered: "[…] The average annual improvement (reduction) in energy consumed by passenger kilometer traveled (specific fuel consumption) from 2000 to 2020 of cars and light trucks was 1.7%, followed by two- and three-wheelers at 0.8% and buses at 0.8%". In this study, we opted for conservative assumptions in the BAU scenario and an annual enhancement of 0.5% was considered in the km/fuel gallon ratio.

On the other hand, for NZ scenarios, the balance of useful energy of the transport sector was used (Energy Mining Planning Unit, UPME), which specifies the maximum performance reachable by type of vehicle/fuel (best available technologies, BAT). The assumption was that, by the end of the analyzed period, the performance reached in the vehicle fleet will be the best available technology as of today.

E Reduction in distances traveled

Another aspect to consider is the type of transportation used by passengers. In the BAU scenario, light passenger transportation is expected to be replaced by buses and railway transportation. In addition, the digitalization phenomenon generates an extra reduction in private passenger transportation. This reduction reaches 7.5%, 2.5% and 7.5%, respectively. In the NZ scenarios, ambitions in this sense must be doubled. In short, the assumptions were considered in Table 5.

Table 5 Main energy transition assumptions, by country and scenario, passenger transportation

	Country	BAU	NZ 2050	NZ 2060
Car and light truck performance	All	0.5% annual improvement	2.1% annual improvement	1.6% annual improvement
Vehicle fleet substitutions by country	Brazil	Motorcycles and buses: 100% electric (2060). Cars and light trucks (2060): 20% electric, 20% hybrid, 20% synthetic fuel and 40% gasoline.	Motorcycles and buses: 100% electric (2040). Cars and light trucks (2060): 40% electric, 40% synthetic fuels and 20% hybrid.	
	Dominican Republic	Motorcycles and buses: 100% electric (2060). Cars and light trucks (2060): 30% electric, 20% hybrid and 50% fossil fuels, with greater penetration of CNG and LNG.	Motorcycles and buses: 100% electric (2040). Cars and light trucks (2060 RD): 65% electric, 20% hybrid, 5% biodiesel and 10% LPG/CNG	
	Rest	Motorcycles and buses: 100% electric (2060). Cars and light trucks (2060): 30% electric, 20% hybrid and 50% fossil fuels, with greater penetration of CNG and LNG.	Motorcycles and buses: 100% electric (2040). Cars and light trucks (2060): 80% electric and 20% hybrid.	
Average distance traveled annually (reduction to 2060 or 2050)	All	Replaced with buses: -7.5% Railway transport: -2.5% Digitalization: -7.5%	Replaced with buses: -15% Railway transport: -5% Digitalization: -15%	
Public transportation	All	Existing fleet projected on the basis of the historical growth (linear regression). Additional growth in replacement of km traveled by cars and motorcycles. It is assumed that buses will transport 10 times more people simultaneously (UPME). In the case of railway transportation, it is assumed that the energy consumed by passenger-km is 7 times less (French Environment and Energy Management Agency, ADEME) 20% bus CNG in 2030. 100% electric buses in 2050 or 2060.		

Source: Own preparation.

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. In the case of freight transportation, a constant annual average distance traveled by vehicle is expected in the future.

A Projection of the freight vehicle fleet

In order to estimate the future evolution of the freight vehicle fleet, regressions were made between the freight fleet and the GDP of the analyzed countries. High levels of correlation were found between the results, which justifies the selection of such method for the estimation.

Moreover, the freight transportation fleets were projected with the linear regression method using the total GDP (measured at PPP of 2017) as independent variable.

Freight transportation is segmented into two types of trucks: trucks and truck tractors (truck tractors are those used to transport heavy loads; they are sold with separate trailers). Trucks and truck tractors maintain their relative current weight in the projections.

B Energy transition assumptions

The contemplated energy transition measures are:

- **enhancement of vehicle performance;**
- **transition in terms of the fuel used**/type of engine, which depends on the type of vehicle (truck/truck tractor) and the scenario. Transition fuels depend on the time horizon considered: CNG, LNG, electricity (as from 2023) and hydrogen byproducts (as from 2040). Gas (CNG, LNG) plays an important role in the period 2030-2040;
- **logistics enhancement and transfer to railway transportation** (which implies a reduction in the number of vehicles; the annual average distance traveled by trucks and truck tractors remains constant).

The assumptions contemplated are similar between countries, assuming that all the countries reach the same level of economic development and access to technological solutions.

The specific assumptions for Brazil reflect current policies (approach towards the development of green fuels produced from biomass) whereas in the Dominican Republic's shorter distances can allow for more electrification of freight transportation.

A lower penetration of electricity is expected for truck tractors than for trucks, since technological solutions to transport very heavy loads are still being developed and electrification is not always a solution.

Methodological section and assumptions

Table 6 Main energy transition assumptions, by country and scenario, freight transportation

	Country	Type of vehicle	BAU	NZ 2050	NZ 2060
Performance	All		0.2% to 0.5% annual enahncement depending on fuel.	0.4% to 0.5% annual enhancement depending on fuel.	
Logistics and transfer	All		-	Logistics enhancements: 10% trucks and truck tractors. Transfer to railway: 10% of trucks and truck tractors.	
Vehicle fleet substitutions by country	COL, PER, MEX	Trucks	2060: 10% electric, 40% to CNG, and 50 % diesel.	2050 or 2060: 80% electric and 20% to CNG.	
		Truck tractors	2060: 50% LNG and 50% diesel.	2050 or 2060: 60% electric, 30% H_2 (fuel cell), and 10% CNG (diesel in MEX).	
	RDO	Trucks	2060: 30% electric and 70% diesel.	2050 and 2060: 90% electric and 10% diesel.	
		Truck tractors	2060: 10% electric and 90% diesel.	2050 and 2060: 70% electric, 20% H_2 (fuel cell), and 10% diesel.	
	BR	Trucks	2060: 70% diesel and 30% flex fuel.	2050 and 2060: 50% green fuel and 50% electric.	
		Truck tractors	2060: 90% diesel and 10% flex fuel.	2050 and 2060: 20% green fuel, 40 % electric, and 40% H_2 (fuel cell).	

Source: Own preparation.

Air, maritime/river, and railway sector

Energy consumption for the sector was projected based on the global GDP growth and the energy intensity obtained for 2019, for each type of transportation, by source and without making a difference by end use, since the information available does not allow us to separate fleet consumptions (which are the most important) from consumption for other energy uses in terminals, storage, logistics, etc.).

Table 7 shows the assumptions for the air, maritime, and railways sectors applied to all the analyzed countries. They are sectors with more difficult transformations (in particular, the air and maritime/river subsectors are not suitable to be electrified with the technologies currently available, although in the future, new technologies could be developed in some cases).

Some of the energy transition options available to transportation units are synthetic fuels and ammonia (H2 byproducts) or green fuels for Brazil (elaborated from hydrotreatment of vegetable oils, Fischer-Tropsch process, fermenting processes or alcohol oligomerization[20]).

The current fuel share is maintained for the BAU scenario whereas the use of alternative fuels is developed for the NZ scenarios. As a reference, Europe has recently announced new rules that will impose at least 70% green fuels by 2050 in the aviation sector..

20 https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-467/NT_Combustiveis_renovaveis_em_%20motores_ciclo_Diesel.pdf

Methodological section and assumptions

1 2 3 4

Table 7 Main energy transition assumptions by scenario, air, maritime/river, and railway transportation

	BAU	NZ 2050 and NZ 2060
Air	Growth is projected with GDP and 0.95 elasticity. The current fuel share is maintained.	Growth is projected with GDP and 0.90 elasticity. 40% of sustainable aviation fuel is incorporated.
Maritime and river	Growth is projected with GDP and 1.0 elasticity. The current fuel share is maintained.	Growth is projected with GDP and 0.95 elasticity. Penetration of 20% synthetic fuel to replace fossil fuels.
Railway	Growth is projected with GDP and 1.0 elasticity. A substituted passenger demand is incorporated. The current fuel share is maintained.	Growth is projected with GDP and 0.95 elasticity. A substituted truck and passenger demand is incorporated. Total electrification of consumption.

Source: Own preparation.

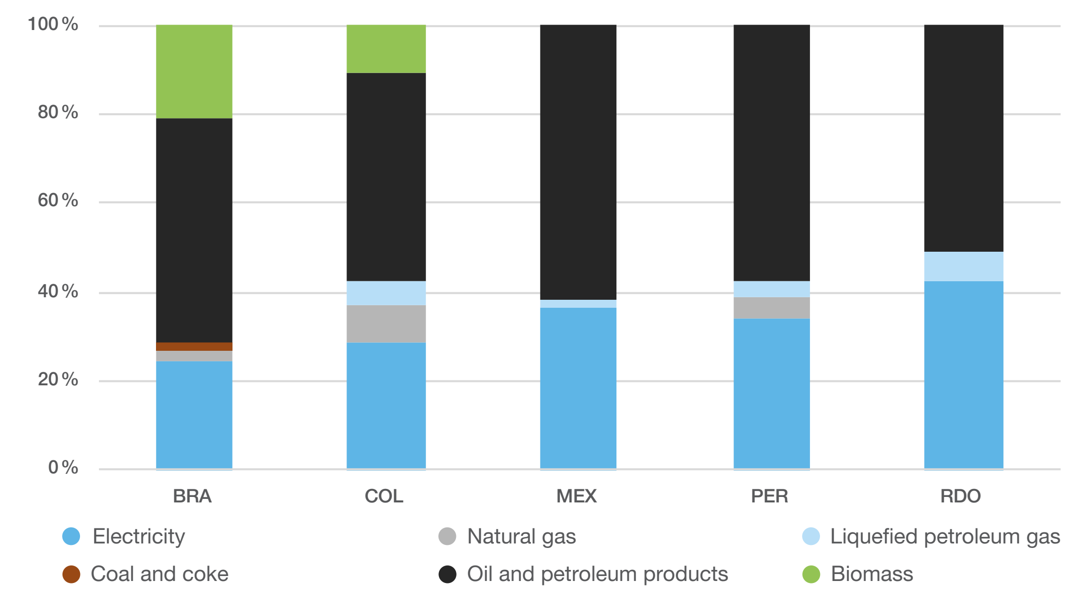
Agricultural, fishing, mining, and construction sector

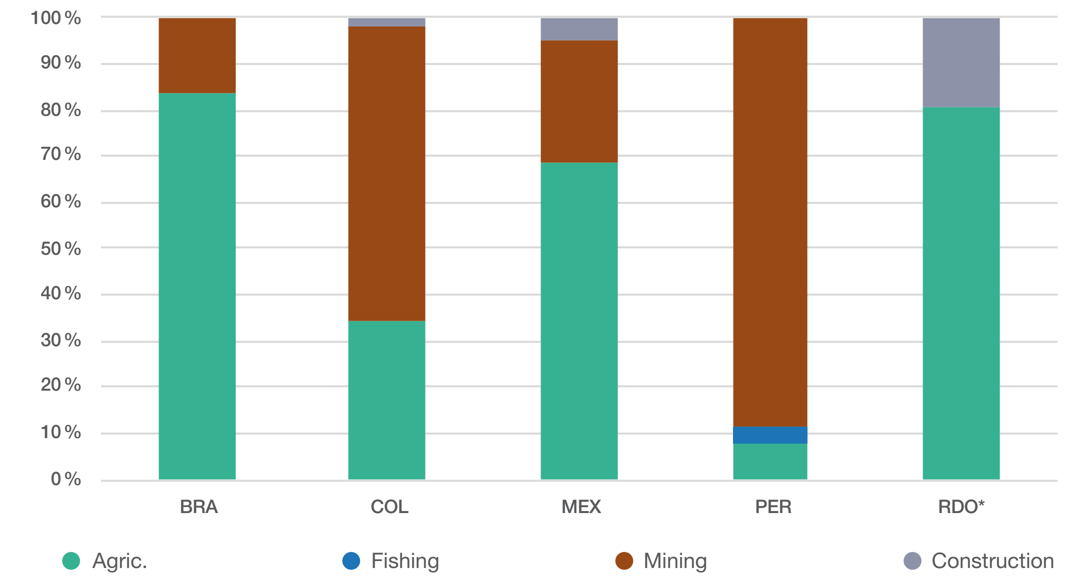
Starting point

The agricultural, fishing, mining and construction sectors, together with the commercial, services, and public sector, represent the sectors with the least energy consumption in the analyzed countries. The electrification of the sector tends to be low, except in Peru, where it exceeds 72% in final energy. Fishing vessels, which represent a very difficult sector to decarbonize, are in this sector. When analyzing the demand by sector, we can see the importance of the agricultural sector, especially in Brazil, Mexico, and the Dominican Republic, whereas Colombia and Peru stand out because of their high consumption related to mining.

The transport sector is the largest energy consumer and greenhouse gas emitter in the five countries studied. To estimate the level of energy consumption in the road transport sector for both passengers and freight, the evolution of the vehicle fleet, the average distance traveled, and the energy consumption per vehicle were estimated. The analysis considers transition actions in terms of fuel substitution, performance improvements, and reductions in distances traveled.

Graphic 13 Consumption by fuel and by subsector in the agricultural, fishing, mining, and construction sector, 2019, %





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

*For the Dominican Republic, there is no distinction between the agricultural, fishing, and mining sectors. For Brazil, Colombia, and Mexico, there is no information on the fishing sector's consumption. In Brazil and Peru, the demand from the construction sector is included in the industrial sector.

Assumptions

Energy consumption for this sector was **projected based on the GDP growth and energy intensity** obtained for 2019, without distinguishing it by end use. The transition measures considered were enhancements in terms of energy efficiency and fuel substitution, depending on the analyzed country and their starting point.

For the BAU scenario, in all the countries, an annual efficiency enhancement of 1% was considered, reaching cumulative 34% in the period.

For the NZ 2060 and NZ 2050 scenarios, more penetration of electricity is achieved at the end of the period. In addition, an annual efficiency enhancement of 1.6% and 2.2%, respectively, was considered, thus achieving a total reduction in energy consumption of 50% due to energy efficiency measures by the end of the period.

Table 8 Main energy transition assumptions by scenario, agricultural, fishing, mining, and construction sector

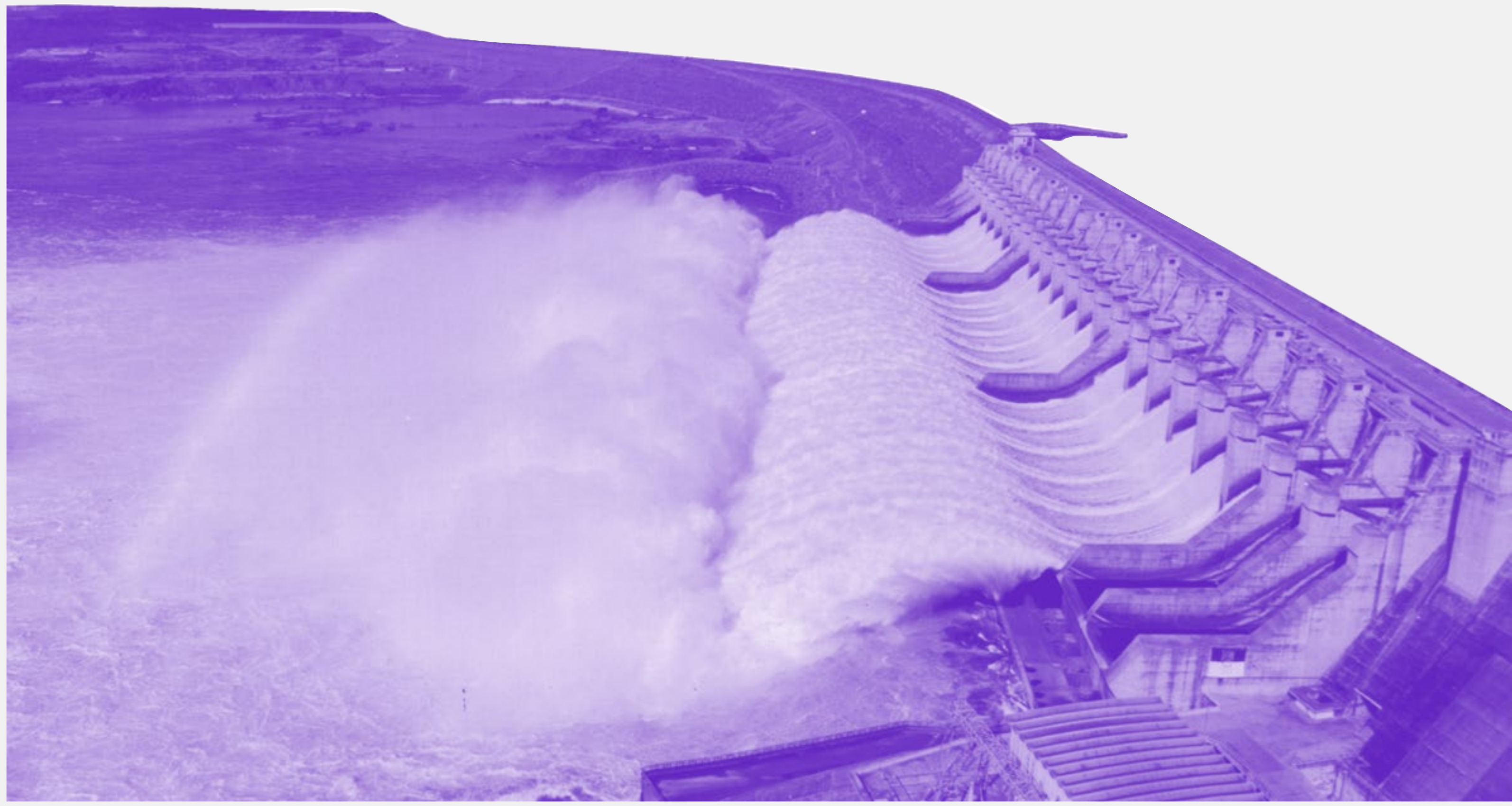
	BAU	NZ 2050	NZ 2060
Energy efficiency	Enhancement in energy intensity over useful energy.		
	-1% annual -34% cumulative	-2.2% annual -50% cumulative to 2050	-1,6 % annual -50 % cumulative to 2060
Substitutions by country (increase in the electrification rate)	Greater electrification in line with historical trends	COL and PER: ≥90% electrification (heavy weight of mining sector). BRA, MEX and RDO: electrification between 60% and 75%. Some subsectors are more difficult to electrify.	

Source: Own preparation.

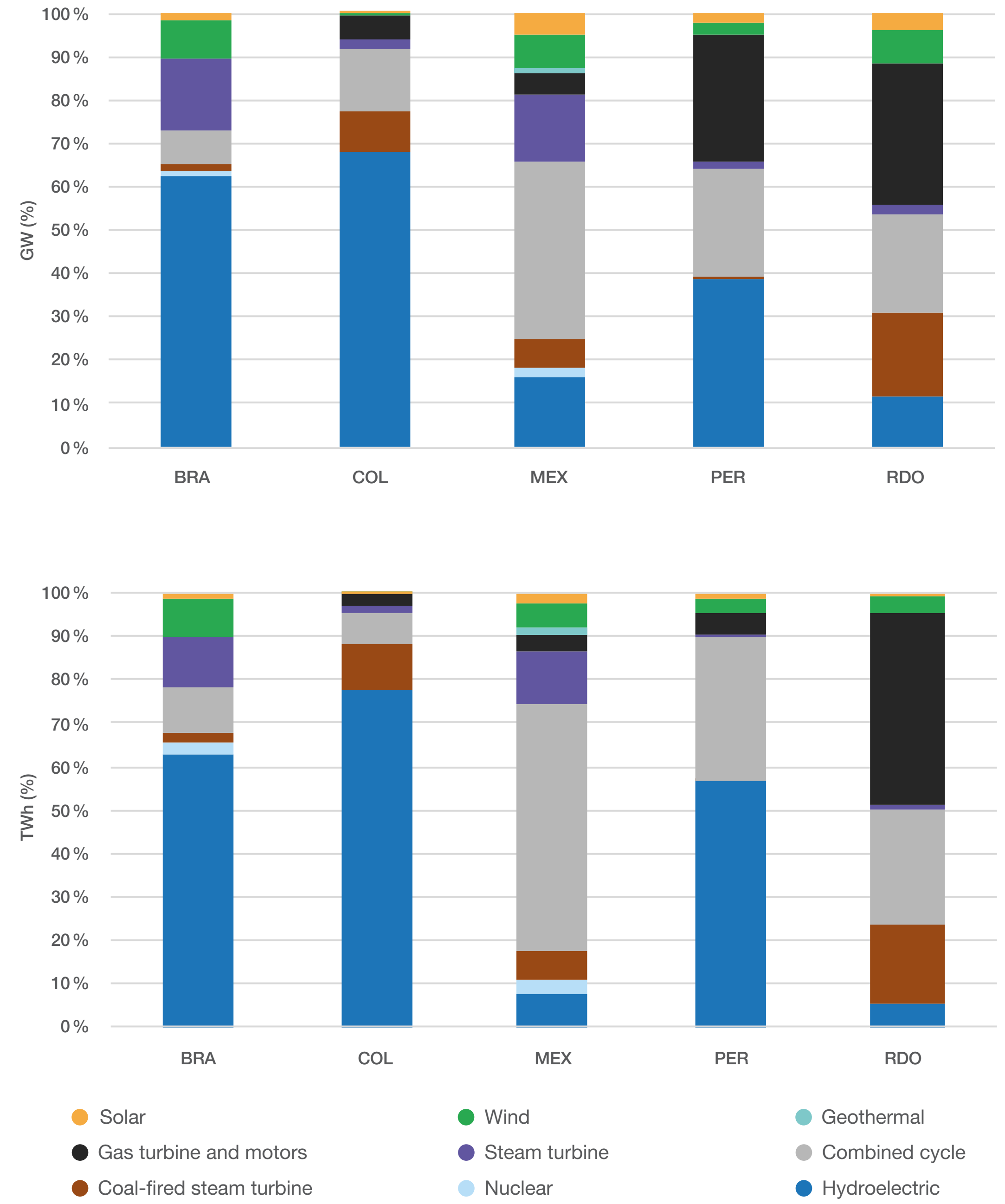
Power sector

Starting point

According to data from 2019, power generation in Brazil, Colombia, and Peru is mainly from hydroelectric sources, whereas in Mexico and Peru there is a large share of gas-based generation. The Dominican Republic, on the other hand, has a combination of generation based on coal, gas, and liquid fuels.



Graphic 14 — Installed capacity and power generation, 2019, %



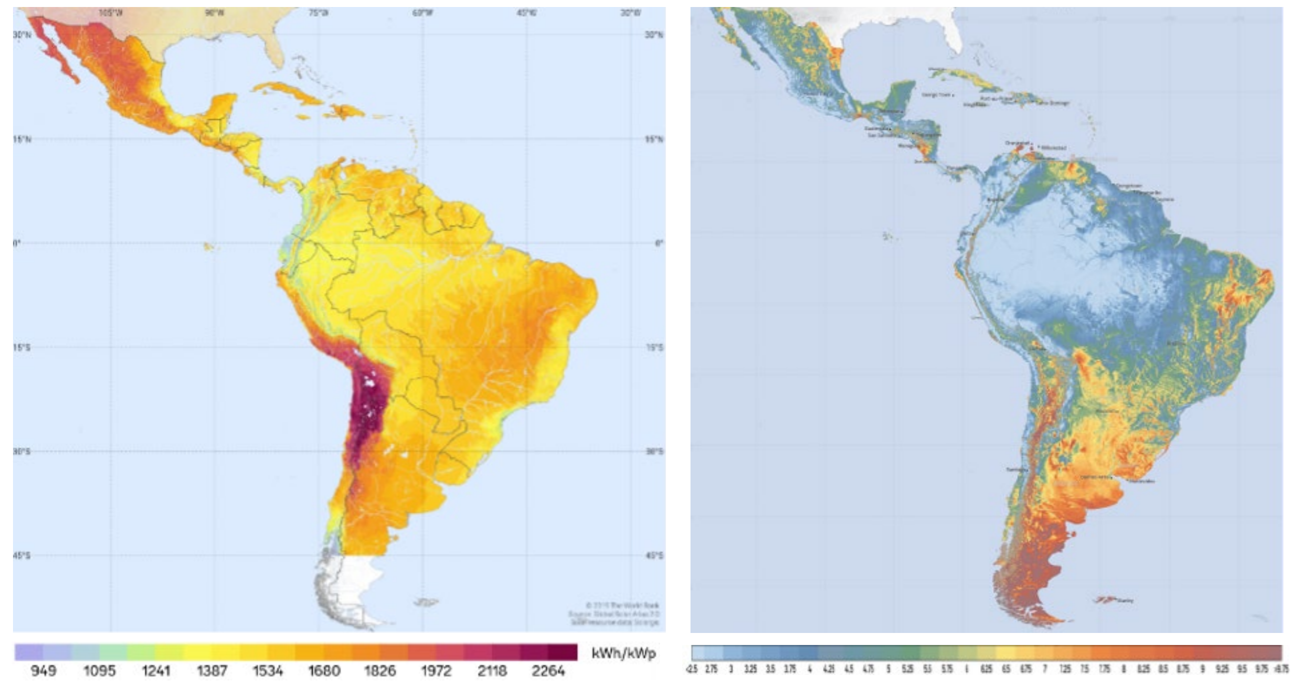
Source: Own preparation based on data from sieLAC, OLADE.

Methodological section and assumptions

1 2 3 4

As to renewable energy, Brazil, Colombia, and Peru stand out for their great hydroelectric potential, Mexico has great solar potential, and the Dominican Republic has limited wind and solar potential due to its land availability (offshore wind may be an interesting option). Graphic 15 shows solar and wind resources in the region.

Graphic 15 — Potential solar resource (kWh/kWp) and mean wind speed at (m/s)



Source: Global Solar Atlas (Banco Mundial)[21] and Atlas eólico mundial (Banco Mundial)[22].

21 Global Solar Atlas, Grupo del Banco Mundial, https://globalsolaratlas.info/download/latin-america-and-caribbean

22 https://s3-eu-west-1.amazonaws.com/globalwindatlas3/HR_posters/ws_LAC.pdf

Methodological section and assumptions

Assumptions

The starting point was the current composition of installed capacity and generation. In the short and medium terms, the development of the power sector considers the projects under construction or the winners of auctions with a great amount of certainty and progress. In the future, the expansion of the generation fleet will depend on:

- the relative competitiveness of the expansion options (it is considered that renewable projects, particularly solar and wind, 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 and which is considered a maximum limit;
- energy policy decisions indicated in the generation expansion plan;
- the local context regarding 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[23] estimation, including losses and own consumption.

23 The analyses are conducted by annual steps. In this context, no precise assessment of the necessary battery capacity was made. On the other hand, 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, nor the related electrical capacity.

The analysis is carried out by annual steps (that is, it is not a thorough hourly simulation exercise but a “high level” estimation, as a first estimation in the context of a long-term energy transition analysis).

Even though flexibility means (storage, demand management) will be necessary in most of the countries to accompany the strong development of non conventional renewable energy (NCRE), no precise assessment of the necessary capacities was made, but a high-level estimation was carried out in the financing chapter[24].

24 Current technologies are not competitive and, as a result of the productivity enhancements expected, it is not possible to establish the degree of penetration they could reach with certainty.

> **Investment assumptions may be sensitive to dynamic signals related to regulatory, market, and financing access solutions that may arise within the horizons of the energy transition.**

4. Investment

The assumptions used to estimate total investment in each just energy transition scenario are shown in this Chapter 4.

This investment refers to the energy transition assumptions presented in previous chapters. In particular, the investment is related to:

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

Investment is calculated by year and the total investment amount as of the first year in which CO_2 emissions are reduced is applied. This is a simplification of the model, as large investment must take place in advance, one to five years before, depending on the construction time or the beginning of the investment in question (hydro plants, for example, are characterized by a construction period of several years).

Power sector

Investment in the power sector includes:

- investment in new power generation plants, in line with the estimated generation expansion;
- investment in infrastructure and flexibility, key to facilitate the integration of intermittent power generation in the electric dispatch, and which includes the concept of smart grids, batteries, and modernization of old hydro plants;
- 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;
- the estimated investment required for the phase-out of coal-fired plants before the end of their useful life (stranded assets).

Power generation: future projects

Financing estimations for power generation were carried out by using the CAPEX prices projected by the National Renewable Energy Laboratory (NREL) for the startup of new facilities, as shown in Table 9:

Table 9 Evolution of CAPEX by technology, USD/kW

CAPEX (USD/kW)	2020	2030	2040	2050	2060
Onshore wind	1,300	1,150	1,025	900	900
Offshore wind	3,573	2,865	2,596	2,434	2,434
Large-scale solar	1,290	1,038	763	632	632
Hydroelectric	2,750	2,750	2,750	2,695	2,695
CCGT	1,200	1,180	1,100	1,015	1,015
GT	1,120	1,050	960	872	872
Geothermal	6,750	5,930	5,420	5,150	5,150
Nuclear	9,450	7,730	7,200	6,670	6,670

Source: Own preparation based on data from the *Annual Technology Baseline* 2023, NREL[25].

These CAPEX were multiplied times the additional MW to be installed in each scenario.

As to solar and wind generation, reinvesment estimated every 20 and 25 years, respectively, was also included to reflect the useful life of these technologies.

25 https://atb.nrel.gov/electricity/2023/technologies

Investment in infrastructure and flexibility

Infrastructure and flexibility costs were considered; they include items like smart grids, batteries, and modernization of old hydro plants, and are estimated at an additonal extra[26] on the investment in power generation considered by scenario.

Transmission and distribution grids

The expected financing in transmission and distribution grids was estimated by using a 16% and 44% percentage, respectively, on the investment calculated in future power generation projects, estimations based on GME and its experts' several decades' experience of working in the power sector. As a result, and in collaboration, a necessary requirement for investment in transmission and distribution grids was obtained, equal to 60% of total investment in power generation.

This need for large investment occurs in a context of very significant growth in power demand, as a consequence of the strong economic development and the electrification of end uses, as well as the growing participation of variable renewable generation in the generation mix, all factors that justify the need for large investment in grids.

It is important to point out that the values estimated herein are net of overhauling and degradation.

26 This generic amount is in line with the amounts of global investment estimated by IRENA in its *World Energy Transitions Outlook 2023: 1.5 °C Pathway report.*

Power generation: decommissioning of coal-fired plants

The estimated investment required for the decommissioning of coal-fired plants before the end of their useful life (stranded assets) was estimated by using 50% of the CAPEX related to a new coal-fired thermal plant published by the NREL, as shown in Table 10:

Table 10 Power generation: decommissioning of coal-fired plants, USD/kW

CAPEX (USD/kW)	2020	2030	2040	2050	2060
Coal	3,550	3,320	3,035	2,750	2,750

Source: Own preparation based on data from *Annual Technology Baseline* 2023, NREL.

Even though the cost of decommissioning coal-fired plants that arrive at the end of their useful lives is much lower, this value is a proxy of the cost overrun related to the anticipated phase-out of the asset as a result of energy transition measures.

End uses

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

- road transportation sector, in which the total investment in electric vehicles (EV) and hybrid vechicles (VH) is estimated, as well as the charging stations;
- energy efficiency measures, electrification, use of alternative fuels (hydrogen and byproducts, among others), and behavior changes with an impact on the end uses sectors, except for road transportation and carbon capture, use, and storage technology (CCUS);
- carbon capture and storage (CCS), which is presented as an option for very polluting industrial sectors that are difficult to transform.

Road transportation

In the first place, the financial effort required for the total investment in a **fleet of electric and hybrid road vehicles**[28] was estimated.

This investment was estimated by using the current prices of electric vehicles (EV) and hybrid vehicles (HV), according to market data as a starting point. To estimate the costs of EVs and HVs of all sizes (light, freight, heavy, motorcycles) in the future, the cost reduction rates estimated by IRENA for light vehicles were used, as all these vehicles[29] will have lower costs in the future on account of the expected reduction in the cost of batteries.

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

28 Investment in vehicles running on CNG or LNG was not considered in the total investment, given the very low impact of these technologies in terms of emission reduction; they participate in the reduction of the costs of using the vehicles (O&M) but not in the energy transition itself.

Table 11 Evolution of the total cost of ownership for electric and hybrid vehicles, USD

Costo total de propiedad	2023	2030	2040	2050	2060
Light, electric, and hybrid vehicles[30]	32,000	26,200	18,900	11,600	11,600
Freight vehicles (trucks and truck tractors)[31]	344,000	281,500	203,300	125,100	125,100
Heavy vehicles (buses, vans, and minibuses)[32]	472,000	386,200	278,900	1,171,600	171,600
Motorcycles	3,000	2,500	1,800	1,100	1,100

Source: Own preparation based on market data.

Once total investment has been calculated, the **cost overrun** is estimated to cover the investment in EV and HV until the costs of electric and fossil vehicles are equal. This calculation allows identifying the weight of having access to a new vehicle ("motorization" effect) and the weight of "electrification" on this total investment in EV and HV in a simplified way. The prices of fossil vehicles come from market data and it is assumed that they will remain constant over time. The costs considered for fossil vehicles are detailed in Table 12.

29 Projections of future prices are available for the other types of EV (trucks, motorcycles, etc.).

30 IRENA: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Innovation_Outlook_EV_smart_charging_2019_ES.pdf?rev=d92189d0969246d79a9f030b8b15a0b4

31 https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf

32 https://blogs.iadb.org/sostenibilidad/es/bogota-es-pionera-en-adquirir-buses-electricos-por-licitacion/

Table 12 Total cost of ownership of fossil vehicles, USD

Total cost of ownership	Between 2023 and 2060
Light fossil vehicles	32,000
Freight vehicles (trucks and truck tractors)	146,000
Heavy vehicles (buses, vans and minibuses)	114,000
Motorcycles	1,600

Source: Own preparation based on market data.

On the other hand, the cost of the necessary investment in **new infrastructure** was calculated, in particular, the construction of charging stations for electric vehicles (EV). According to a study by Deloitte[33], 10 EVs are calculated per non residential charging station (charging station level 2). A cost of USD 1.550 is considered to calculate the necessary investment in charging stations.[34]

33 https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/energy-resources/deloitte-ch-en-eurelectric-connecting-the-dots-study.pdf Such non-residential charging stations are classified as charging station level 2, require 240-volt current, provide a range of up to 25 miles per hour, and can charge the vehicle completely in 8 hours. Most public charging stations are level 2.

34 Own estimate based on NREL and PWC reports.

Energy efficiency, electrification, and use of alternative fuels

This investment covers all energy efificiency actions, 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 CCUS. In particular, the end use sectors considered are: residential; industrial; commercial, services, and public; agricultural, fishing, mining, and construction; and air, maritime, and railway.

In the first place, the savings in emissions resulting from the energy transition measures were estimated for each sector. Thus, GHG emissions related to a “baseline” scenario, which considers the growth in energy demand based on historical variables and socio-economic variables projected, were estimated. This scenario has more emissions than the BAU scenario, as it does not assume any kind of efficiency measures or electrification policies, whereas the BAU scenario considers actions to mitigate GHG emisisons. A posteriori, it also has more emissions than the NZ scenarios. The difference in emissions between each scenario and the “baseline” scenario reflects the environmental impact of the efficiency and electrification measures proposed in each of these scenarios.

Given the great variability of actions and costs related to each of the energy transition assumptions and the interdependence of these actions in terms of impact on the emissions, a proxy was estimated by sector, equal to a CAPEX to invest to reduce emisisons per year. This equivalent CAPEX by sector was estimated on the basis of a study conducted by the Climate Change Committee (CCC)[35].

35 https://www.theccc.org.uk/publication/sixth-carbon-budget/#supporting-information-charts-and-data

Table 13 Equivalent CAPEX by sector, USD/ton CO_2e absorbed-year

Equivalent CAPEX	USD/avoided ton
Industry	2,500
Residential	4,100
Commercial	4,100
Agriculture	1,500
Aviation, maritime and railway	3,500

Source: Estimación propia based on the study *Sixth Carbon Budget*, CCC.

The investment required to cover the reduction in GHG emisisons is calculated by using the incremental annual differences (year N less year N-1) of emissions by sector between the baseline scenario and the other three scenarios (BAU, NZ 2050 and NZ 2060) times the equivalent CAPEX by sector.

Carbon capture, use, and storage

If applicable, depending on the country, estimations of financing in CCUS were made by using the inter-annual difference (year N less year N-1) of the emissions absorbed by industry, times the unitary CAPEX of a project in CCUS capable of storing 1 MtCO2 per year. This unitary cost was estimated at USD 1,000 per absorbed ton of CO_2[36].

36 https://sustainability.crugroup.com/article/carbon-capture-economics-why-usd-200-per-tco2-is-the-crucial-figure

Investments in the electricity sector include the construction of new power plants, infrastructure and flexibility, transmission and distribution networks, as well as the decommissioning of power plants. Regarding end uses, they include energy efficiency measures, electrification, the use of alternative fuels, behavior changes and CCS.

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ANNEX. Detailed methodological aspects

GDP projection

According to the definition of the United Nations Development Programme (UNDP), a country is considered to have very high human development when its HDI is equal to or higher than 0.8[37]. In turn, it is considered that a country has met all its energy needs when it shows energy consumption values of over 5,000 kWh per capita-year[38].

In order to establish a margin of minimum GDP levels that countries must reach in the long term, we use the average GDP of the lower quintile of countries with very high HDI and the average GDP of the lower quintile of countries with power consumption over 5,000 kWh per capita-year. It is concluded that the countries' target GDP per capita to cover their unfulfilled energy needs and to be considered developed is in the range of USD 21,000 to USD 33,000, measured in US dollars of 2017 at PPP.

37 https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

38 GROVER, R. B. *An examination of the narratives about the electricity sector*. Current Science, 2020, vol. 119, n.° 12, p. 1910l

Once this long-term objective had been defined, and for the purpose of conducting the GDP projections, different estimation tools and methodologies were used. These tools and methodologies are detailed below:

A Historical trend: linear regression

GDP projections were made through a linear regression of the data, using the historical trend of the available data of the period 1990-2021 that belongs to the World Bank[39]. Table 14 shows the formulas used in the linear regressions of the countries:

Table 14 Linear regression formulas by country

Country	Linear regression
Colombia	Y=223.7x+7,484.9
Brazil	Y=180.46x+9,926,5
Mexico	Y=141,56x+15,498
Peru	Y=280,46x+3,954
Dominican Republic	Y=392.86x+4,856.1

Source: Own preparation based on data from the World Bank. x: year; Y: GDP.

However, it is neccesary to bear in mind that autoregressive linear regressions have a lot of heteroscedasticity problems when estimating more than 10 years of projections.

39 https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD?locations=BR-CO-MX-PE-DO

Thus, the result fails to reflect the enhancements in the business environment or in the education levels of the last 20 years that should be the basis for the countries' further growth and development.

B Historical trend: logit model

GDP projections were made by means of the logit model, using the historical trend of the available data on the period 1990-2021 that belongs to the World Bank[40].

This way of estimating combines two projection schemes and allows us to simulate the pairing of the countries' GDP towards the developed world. In this case, the United States GDP per capita is used as a saturation point, estimated as of 2100, in which a constant and fixed interannual growth rate of 0.1 is assumed. Such growth rate is the minimum efffective active annual rate (EAR) of the United States in the period 1990-2100, for 2007. The saturation GDP per capita used for the logit model is USD 132,805.

Given the small amount of data available (31 years) and the existing gap between developing countries and the developed world, the countries' projections fail to reach the saturation level.

C Extrapolation of the historical effective rate

In order to extrapolate the historical effective rates, the growth rates of the last 31 years of the period 1990-2021 are used. Table 15 shows the effective historical rates used by country:

40 https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD?locations=BR-CO-MX-PE-DO

Table 15 Effective annual rate between 1990 and 2021 by country

Country	EAR
Colombia	1.80 %
Brazil	1.10 %
Mexico	0.70 %
Peru	2.85 %
Dominican Republic	3.61 %

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

It is important to mention that such parameter does not reflect the changes in the environment in recent years and fails to predict enhancements in the total productivity of the factors in the different countries.

D ARIMA model

Based on the database on GDP per capita in the period 1990-2021, multiple ARIMA projection models are run to year 2060 through an automatic processing system. The system is asked to select the ARIMA model that performs the best adjustment based on Akaike information criterion (AIC),

It is necessary to consider that, given the limited databases available (31 pieces of data), ARIMA models may pose problems in their estimations and cannot observe autocorrelations of more than one period.

In this way, it is expected that the projections of these models will tend to look like the projections made with the extrapolation of the effective rates.

E *Ad hoc* scheme: adjusted logit model

The *ad hoc* scheme, or adjusted logit model (catch up), is a proposal from the consultant that introduces a higher growth rate in the projections assuming an increase in the countries' productivity levels.

Even though this methodology lacks the strict methodological support of the previously mentioned methodologies, the model is based on the need to increase the productivity of developing economies to achieve the target levels.

In addition, it contributes to observing a different scenario and introducing the need to rethink the results obtained by the other scenarios.

F Final comments

For all the methodologies presented above, total GDP estimations were made by adjusting the expected GDP growth per capita according to the expected population growth rates in the countries.

For such purpose, the population estimations and projections published by the Economic Commission for Latin America and the Caribbean (CEPAL)[41] were used.

The total GDPs projected are expressed in millions of 2017 USD measured at PPP.

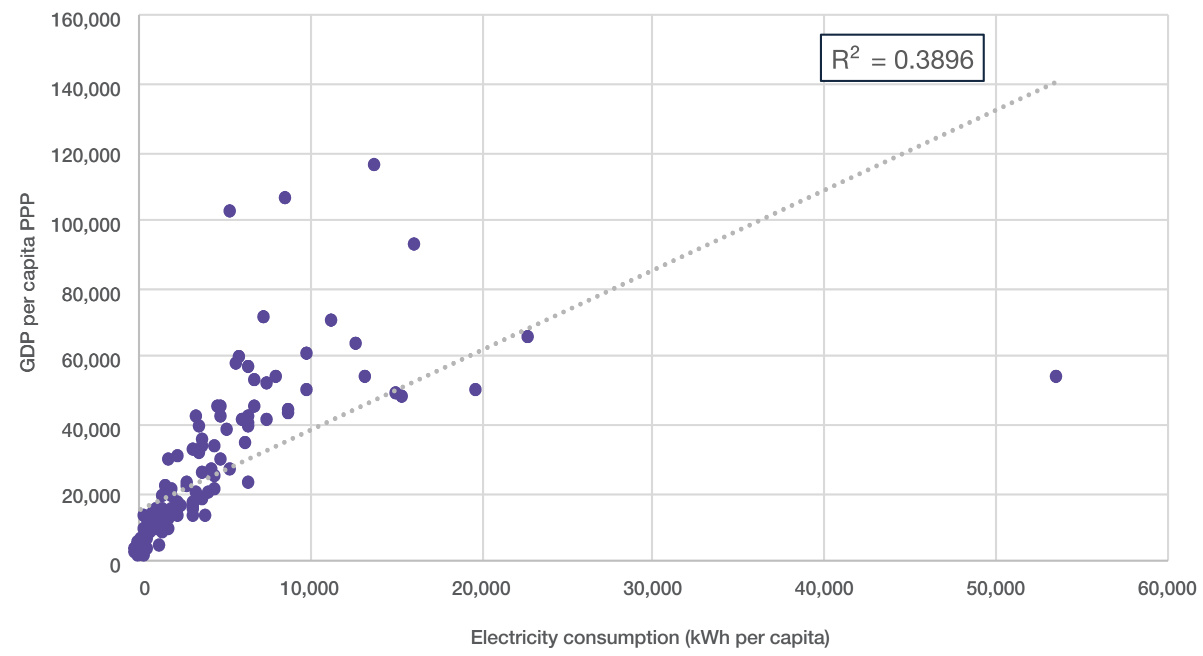
41 https://www.cepal.org/es/subtemas/proyecciones-demograficas/america-latina-caribe-estimaciones-proyecciones-poblacion

Annex

Identification of developed countries

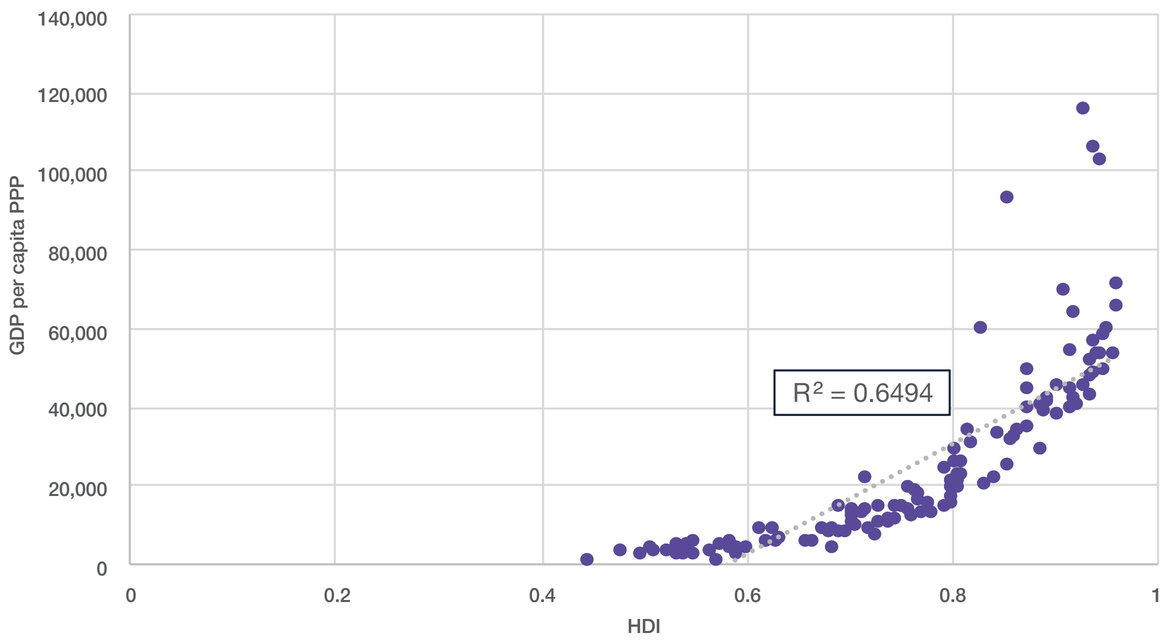
Developed countries were identified in order to use the average vehicle fleets as saturation point in the projections. Therefore, correlations were made between GDP per capita, HDI, and power consumption per capita to validate whether the last two are accurate indicators of the countries' development level. The results are shown in Graphics 16, 17 and 18:

Graphic 16 Comparative data on GDP per capita, power consumption



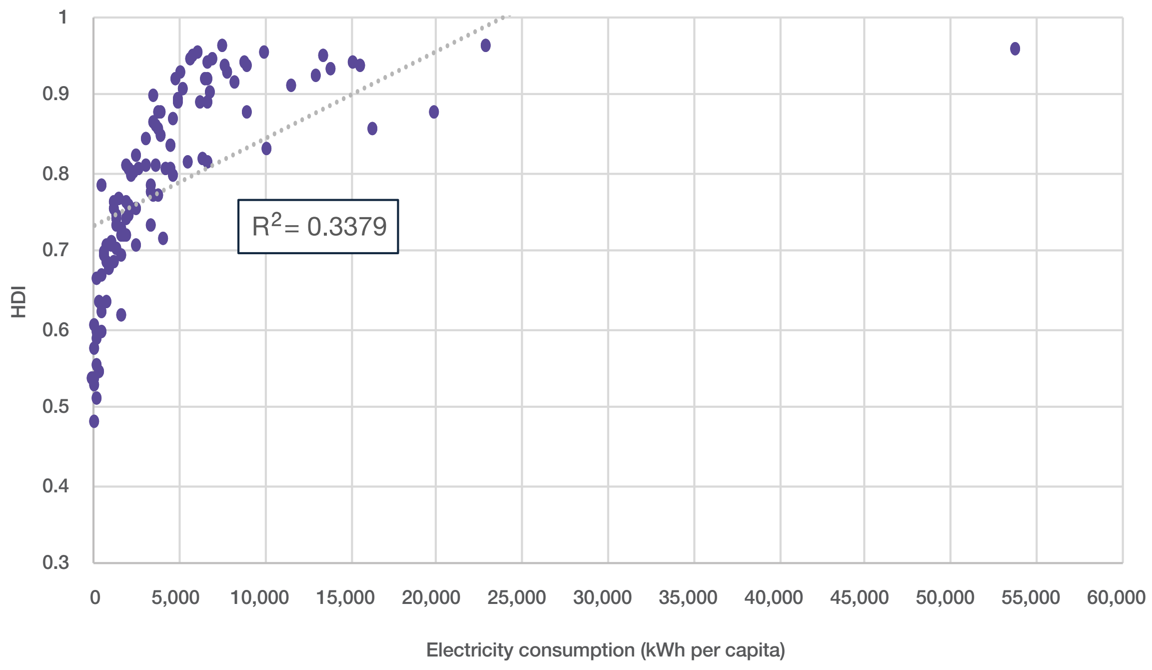
Source: Own preparation based on data from the World Bank.

Graphic 17 Comparative data on GDP per capita, HDI



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

Graphic 18 Comparative data on HDI, power consumption per capita



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

In this way, given the last three graphics and the relations found, it is concluded with certainty that both the human development indices and the power consumption levels per capita are accurate indicators of the countries' development levels measured in GDP per capita.

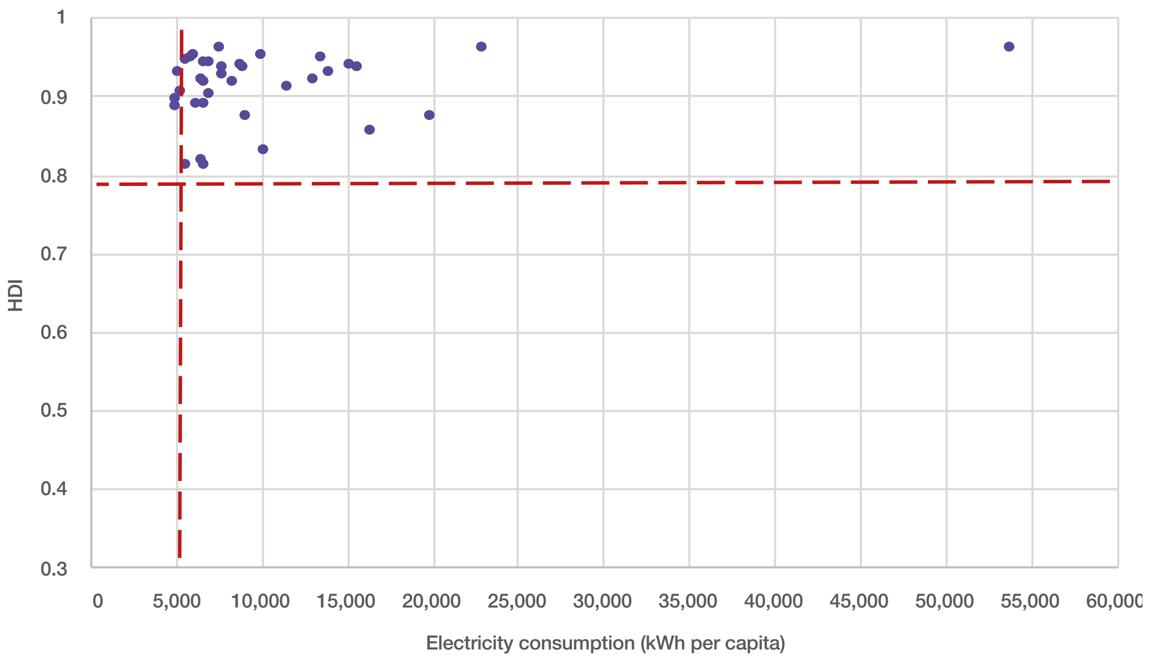
According to the definition of the United Nations Development Programme, a country is considered to have very high human development when its HDI is equal to or higher than 0.8[42]. In turn, a country is considered to have met all its energy needs when it shows power consumption values above 5,000 kWh-year[43].

42 https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

43 GROVER, R. B. *An examination of the narratives about the electricity sector*. Current Science, 2020, vol. 119, no 12, p. 1910

Finally, Graphics 19 and 20 show the data after being previously filtered for power consumptions over 5,000 kWh. It is observed that all those countries with consumption levels higher than the specified one have a very high human development level, that is, a HDI equal to or higher than 0.8.

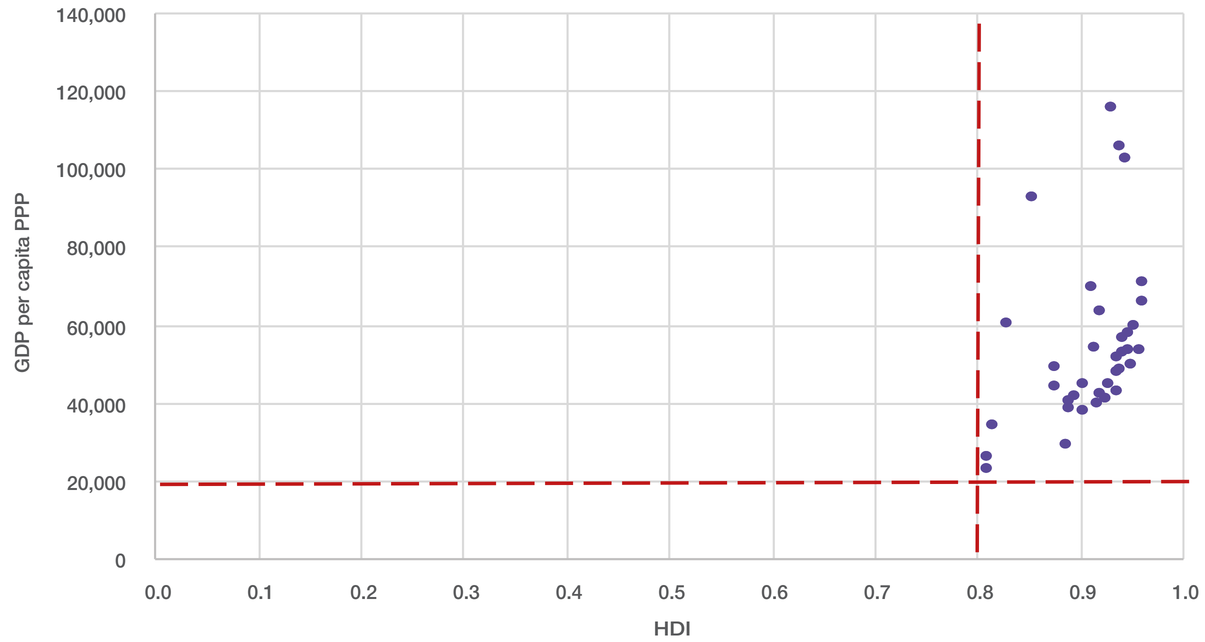
Graphic 19 ▶ Comparative data on HDI, power consumption over 5,000 kWh



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

Annex

Graphic 20 ▶ Comparative data on GDP, HDI (power consumption over 5,000 kWh)



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

It is concluded that all those countries with higher consumption levels than the specified one have a GDP per capita of over USD 20,000 measured in 2017 USD at PPP. In turn, given the conclusions obtained from Graphic 20 above, said countries are considered to have very high human development levels.

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