Report on Economic
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DEVELOPMENT BANK
OF LATIN AMERICA
AND THE CARIBBEAN

Renewed energies

A just energy transition for sustainable development

Executive summary

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Part I
Economic development in times of energy transition

Economic development during the 20th century and the need for a new energy transition

The economic development achieved during the 20th century is undeniable. Over the past 80 years, global per capita output has nearly quintupled. Unfortunately, greenhouse gas (GHG) emissions have multiplied sevenfold.

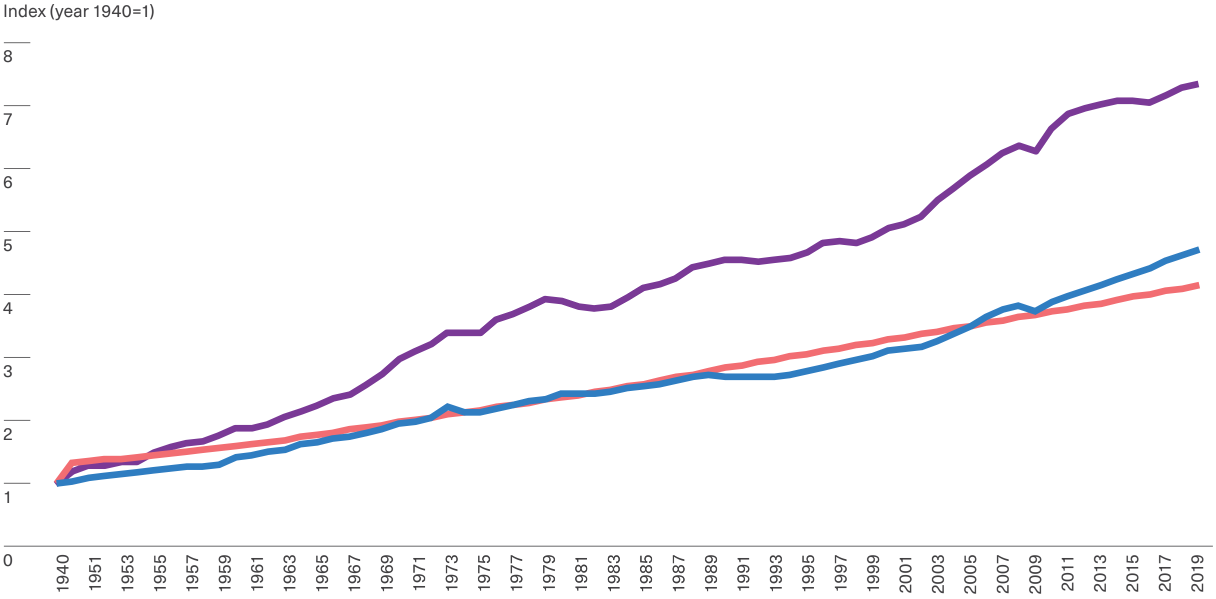
Over the past 80 years, global per capita output has increased nearly fivefold. Unfortunately, greenhouse gas (GHG) emissions have risen sevenfold due to this growth in per capita income and population growth

Energy consumption, primarily from fossil sources, lies at the heart of this growth with increased emissions phenomenon. Since 1850, human activity has emitted over 2,300 gigatonnes of carbon dioxide (CO_2), with 68% originating from the use of energy generated by fossil sources.

This dynamic is unsustainable. Scientific evidence suggests that the excessive accumulation of anthropogenic GHGs is the cause of global warming and that, at current emission rates, there are just over 28 years left to limit the temperature increase to 2 degrees Celsius (°C) compared to the pre-industrial era, or only nine years to the 1.5°C threshold. Global environmental goals, therefore, require an energy transition aimed at reducing emissions.[1] In this context, such a transition emerges as a global imperative to address the environmental crisis and ensure sustainable development.

1 The 2°C threshold is considered by scientists to be a sort of tipping point at which there is a high risk of massive and irreversible damage on a global scale. However, the effects of global warming have already begun, increasing, for example, the frequency and severity of extreme weather events, with significant economic and social costs.

Graph 1
Evolution of global population, GDP per capita, and CO_2



Source: Authors based on World Bank (2023a, 2023c), Bolt and van Zanden (2020), and Friedlingstein et al. (2022).

Certainly, the developed world has had a greater responsibility in these historical emissions, accounting for 45% of them. In contrast, Latin America and the Caribbean (LAC) as a region accounts for only 11%. While this is relevant from an environmental justice perspective, it does not exempt any country or region from making efforts to limit GHG emissions. Given that 75% of current emissions come from low- and middle-income countries, if only the developed world were to adopt climate mitigation measures, it would be insufficient to reach global emission targets.

The developed world has a greater historical responsibility in GHG emissions, as its contribution represents 45% of the total. In contrast, LAC accounts for only 11%

This challenging scenario has led to a global consensus on the need to significantly reduce GHG emissions, especially those originating from energy consumption. The 2015 Paris Agreement is a remarkable milestone for a united response to the climate crisis. Its main achievement has been an almost universal adherence, with 196 countries having signed the treaty, including 33 from Latin America and the Caribbean.

Under the Paris Agreement, each country committed to establish, based on its circumstances and capabilities, mitigation targets to reduce GHG emissions and adaptation goals to the impacts of climate change. These commitments are described in the nationally determined contributions (NDCs).

A review of the most recent NDCs shows that LAC has agreed to reduce its emissions by around 11% by 2030 compared to 2020. This reduction is higher than the global average (less than 1%) but lower than that of North America or the European Union, which reach 37% and 29%, respectively. However, this emission reduction represents mitigation efforts comparable between Latin America and the Caribbean and the developed world when considering population growth rates and closing the existing GDP per capita gaps between both regions.

Specifically, given the projected demographic growth, if the GDP per capita in Latin America and the Caribbean grows by 4% per year, the region must reduce its emissions per GDP by around 5.5% annually, a value similar to the reduction that the European Union must achieve if it grows by 2% (5.24%).

Table 1
Emission commitments established in the NDCs

Region	Number of countries [a/]	Change in GHG emissions 2010-2020 (percentage)	2020 GHG emissions ($MtCO_2e$) [b/]	2030-NDC GHG emissions ($MtCO_2e$) [c/]	Change in GHG emissions 2020-2030 (percentage)
Africa	37	19.2	3,023	3,805	25.9
North America	2	-14.7	6,021	3,766	-37.4
Latin America and the Caribbean	21	-15.5	3,293	2,952	-10.8
Asia (excluding China and India)	19	19.5	5,598	6,081	8.6
China	1	24.4	12,296	12,804	4.1
India	1	22.7	3,167	3,910	23.5
Oceania	6	3.1	703	390	-44.6
European Union	27	-20.1	2,957	2,085	-29.5
Rest of Europe	19	4.9	2,750	3,927	42.8
Total	**133**	**5.7**	**39,807**	**39,720**	**-0.3**

Note: The table presents a measure of the ambition of the NDCs at the regional level. a/ The values by region were obtained from the aggregation of a sample of countries. b/ The level of net emissions in 2020 includes the same sectors covered by the target declared by each country in its NDC for 2030. c/ The net GHG emissions for 2030 were estimated by applying the mitigation target to the declared base emissions level (in base year or business as usual [BAU] scenario). Emissions from the sectors included in the target are considered and, for countries that do not specify sectors, the target is assumed to cover all sectors (including land use, land use change and forestry [LULUCF]). The annex to Chapter 1 (available online) provides more details on the methodology used in the estimates and the countries included in each region.

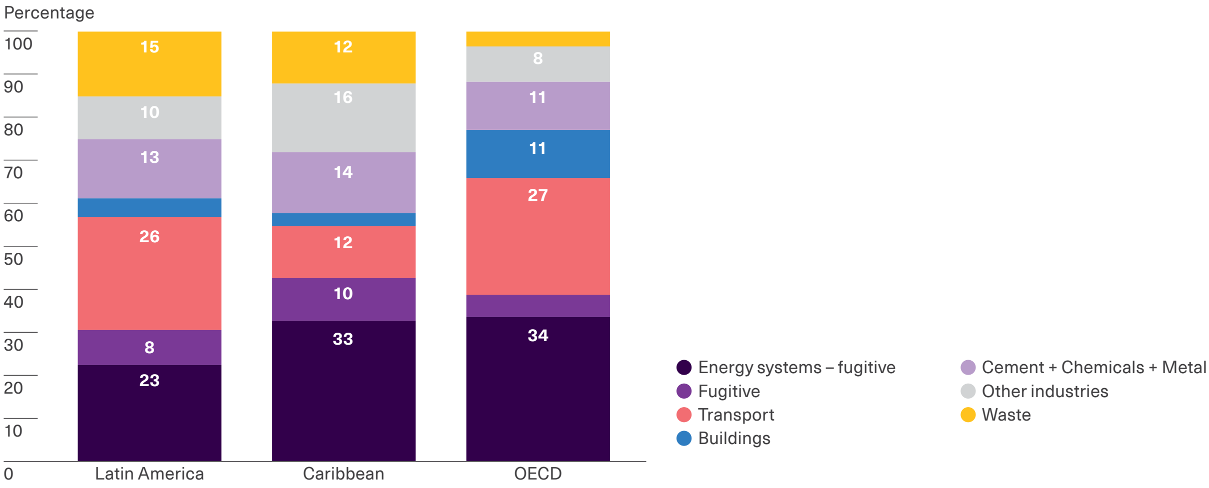
Source: Authors based on Brassiolo et al. (2023), Climate Analytics and New Climate Institute (2023), Climate Watch (2023b, 2023a), Hattori et al. (2022) and UNFCCC Secretariat (2023).

The region's emissions profile

Globally, almost 80% of GHG emissions come from energy-related consumption of fossil fuels and industrial processes (FFIP), while just over 20% come from agriculture, forestry and other land use (AFOLU). In Latin America, the situation is different. In 2019, about 65% of emissions in that region came from the AFOLU sector, a much more significant value than the 14% in the Caribbean or 8% in the Organisation for Economic Co-operation and Development (OECD) countries.[2] This implies that in some Latin American countries, mitigation efforts must be carried out simultaneously in the energy sector and the AFOLU component.

Several conclusions can be drawn by breaking down emissions by FFIP, which are much closer to energy-related emissions (see Graph 2). The first is that emissions associated with buildings, while not negligible, are relatively modest in all regions, even in OECD countries, where their importance is greater due to higher heating needs. Fugitive emissions related to energy production, although also relatively modest, are considerably higher in the region than in the OECD countries, which could indicate that there is room to reduce them. Something similar could be said about waste management, which accounts for 15% of FFIP emissions in Latin America, 12% in the Caribbean, and only 3% in OECD countries.

Graph 2
Total FFIP emissions broken down by sector in 2019



Note: The components of FFIP emissions are described in Table A.1.3 in the annex to Chapter 1 (available online), with a breakdown of the countries included in each group.

Source: Authors based on Minx et al. (2021).

2 The importance of this component has been dropping notably in Latin America and the Caribbean.

Perhaps most notable is the prominence of three sectors: energy systems[3] (excluding fugitive emissions), transport, and industry. In Latin America, transport leads the ranking, accounting for 26% of FFIP emissions; industry is responsible for almost 24%; and energy systems, nearly 23%. The relatively large presence of hydroelectric sources could be behind the relatively lower contribution of this category to emissions in Latin America. In the Caribbean, where there is a greater presence of fossil fuels in the electricity matrix, the energy systems category leads the ranking, with 33% of FFIP emissions, a value similar to that of the OECD. In the Caribbean, industry represents 30% and transport, 12%.

The historical problems of development and the need for a just transition

In addition to its environmental commitments, LAC must address long-standing structural challenges. Two of the most obvious ones are the per capita income gap with the developed world, on the one hand, and poverty and inequality, on the other.

Over the past few decades, the region's GDP per capita has remained 30% below that of the United States. Low output is associated with low productivity and this, in turn, is linked to an excess of small, informal enterprises with low physical, human, and organizational capital. What are the implications of this for the energy transition?

Perhaps the most obvious implication is that the region must achieve economic growth superior to that of developed countries to close the gap. This, coupled with population growth, puts pressure on mitigation efforts to meet a certain emissions target. Productivity gains are key to achieving this growth, but they can also help reduce emissions. On the one hand, higher productivity of businesses translates to higher output per unit of energy, reducing the environmental impact of growth. On the other hand, evidence suggests that, at the business level, productivity correlates positively with energy efficiency levels. This opens the possibility for policies that improve resource allocation among businesses to increase productivity and economic output while reducing energy intensity and emissions.

In addition to its environmental commitments, the region must address long-standing structural challenges: closing the per capita income gap with the developed world, and reducing poverty and inequality

Moreover, energy transition demands transformational processes from companies in the region, which require internal capabilities that many of them may not have, as well as a favorable business environment.

Countries in Latin America and the Caribbean not only have relatively low income per capita but also a high level of income inequalities. Indeed, the region is one of the most unequal in the world and has high levels of poverty. On average, in Latin America, one in three people are poor, and 12 out of every 100 live in extreme poverty (ECLAC, 2022).

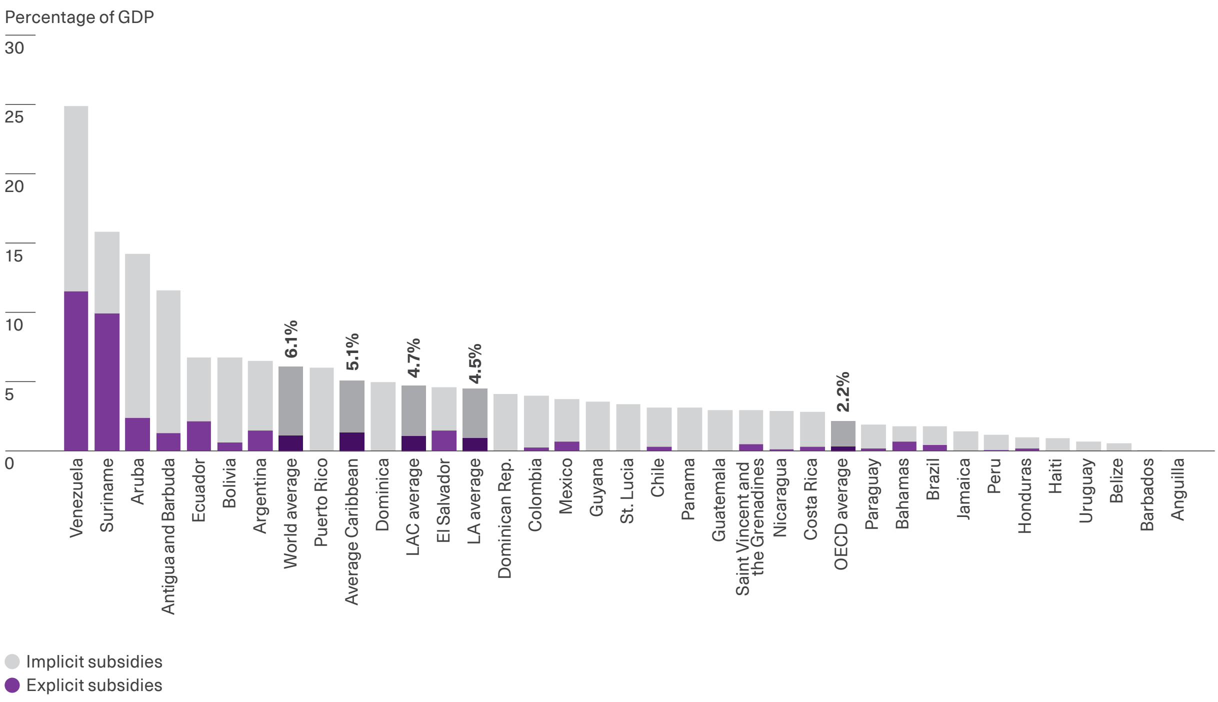
3 Emissions from energy systems typically include those from electricity and heating, fugitive emissions from oil and gas, oil refining, and others (see Table A.1.3 in the annex to Chapter 1, available online). However, Graph 2 separates fugitive emissions from energy emissions to highlight their relative importance in the region.

The levels of poverty and vulnerability of significant segments of the population demand protection against the adverse distributive changes that energy transition may generate. Additionally, they impose restrictions on households' adoption of clean or energy-efficient technologies.

On the energy front, the region also faces pre-existing challenges. Firstly, problems of access to quality energy sources persist, despite the marked progress made. For example, at least 40% of the rural population in Colombia, Honduras, Mexico, Nicaragua, Paraguay, and Peru still cook with firewood. Secondly, there are challenges in terms of the reliability of energy supply. For example, according to data from the World Bank Enterprise Survey (WBES), almost 60% of manufacturing companies report having had two power outages per month, lasting approximately three hours each. In light of this situation, one in three companies in the region considers electricity supply problems a major obstacle to their development. This figure is 40% higher than in the Europe and Central Asia region.

Lastly, another characteristic of the region's energy markets worth highlighting is the presence of energy subsidies. These amount to 4.7% of GDP, a figure that is more than double that of the most developed countries (around 2.2%) (Graph 3). The existence of these subsidies can promote a high demand for fossil fuels, with a consequent impact on emissions.

Graph 3
Fossil fuel subsidies as a share of GDP in selected countries in 2022



Note: Explicit subsidies reflect the under-charging of supply costs, while implicit subsidies add the under-charging of environmental and congestion costs, as well as uncollected consumption taxes.

Source: Authors based on IMF data (2021).

For the region, energy transition cannot take place without taking these realities into account. Its sustainable development certainly requires reducing GHG emissions from energy sources for a more sustainable planet (justice between generations) but, at the same time, closing the existing per capita income gaps with the developed world (justice between countries) and reducing social and energy inequalities (justice between citizens).

Anatomy of decoupling: A conceptual framework

Unlike the countries that developed in the 20th century, Latin America and the Caribbean must achieve development in the context of a global energy transition that seeks to reduce GHG emissions.

Recent history in developed countries suggests that achieving per capita GDP growth while reducing emissions is feasible, a concept known as decoupling. From 2000 to 2019, OECD countries achieved, on average, per capita GDP growth of 1.1% and a reduction in emissions linked to fossil fuels and industrial processes (FFIP) of 0.6%.

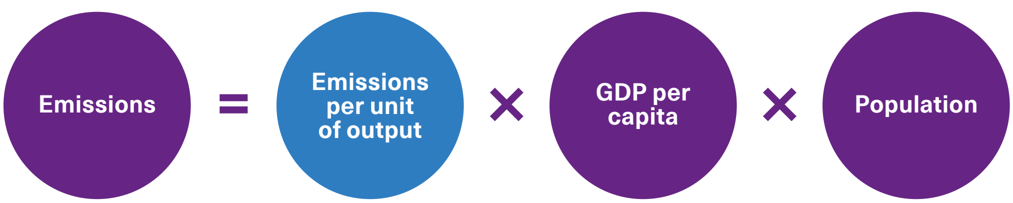
To understand the key to achieving this decoupling, it is useful to start with the Kaya's identity which indicates that a country's emissions can be expressed as the product of three factors: emissions per unit of output, GDP per capita, and population.

The recent history of developed countries suggests that it is feasible to achieve per capita output growth and reduce emissions

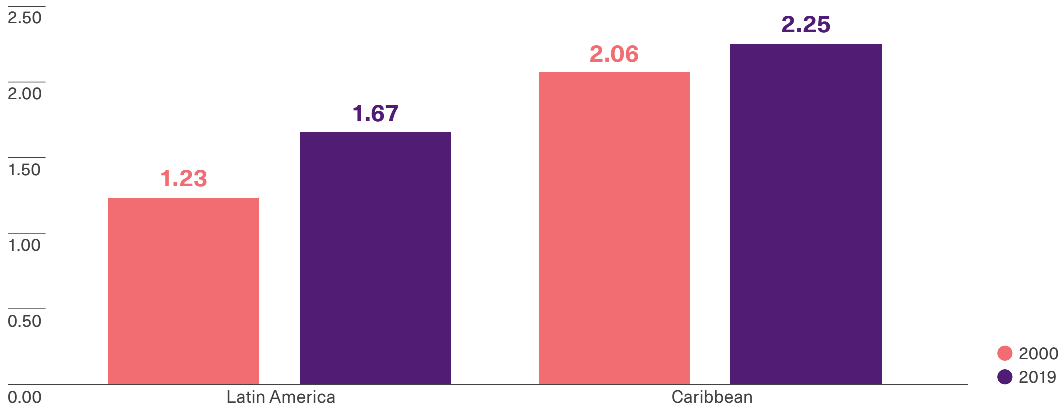
For decoupling to occur, emissions per unit of output must fall sufficiently to more than offset the growth in population and output per capita. In other words, the more emissions per unit of output fall, the smaller the impact of economic and population growth in terms of GHG emissions.

A comparison of FFIP emissions per unit of output shows that there are differences between the region and the developed world. In 2019, these emissions were 2.06 times higher in Latin America and up to 2.25 times higher in the Caribbean than in OECD countries (Graph 4).

Figure 1
Formula to account for emissions and determine decoupling



Graph 4
Emissions from FFIP per unit of output relative to the OECD value in 2000 and 2019



Source: Authors based on Minx et al. (2021) and World Bank (2023b).

Emissions per unit of output, in turn, can be expressed as the multiplication of two well-known factors closely linked to energy policy. The first of these is emissions intensity, given by emissions per unit of energy, and the second is energy intensity, defined as the ratio between the units of energy used and the output obtained.

While it is true that reducing emissions per unit of GDP can be achieved by reducing either emissions intensity or energy intensity, the evidence indicates that the countries that have achieved decoupling in this century have done so by simultaneously cutting both components. The contribution of the decline in energy intensity seems to have played a more important role over the last 20 years. However, the factor associated with emissions intensity has become increasingly more important as the century has progressed, most likely explained by the decline in the cost of non-conventional renewable energy sources (NCRE).

Figure 2
Calculation of emissions per unit of output

How has the region performed in these key factors? During the 21st century, Latin America reduced emissions per unit of output by 0.7% annually, and the Caribbean by 1.9%. This decline has been achieved mainly by reducing energy intensity, which decreased by 0.5% annually in Latin America and 1.8% in the Caribbean.[4] In both subregions, there was also a decrease in emissions intensity, but it was more modest. However, the reduction in emissions per unit of output was not sufficient to offset the combined impact of the growth of the other two components: population and GDP per capita; as a result, emissions increased by 1.7% in Latin America and 1.6% in the Caribbean (Figure 3).

During the 21st century, LAC reduced emissions per unit of output, but not enough to offset the combined impact of population growth and per capita GDP growth

Figure 3
Decomposition of emissions growth between 2000 and 2019

Source: *Authors* based on IEA (2022), World Bank (2023b), Minx et al. (2021) and OLADE (2023a).

4 Emissions relative to GDP depend on factors beyond energy, in particular, the emissions intensity of the economic structure. Therefore, it is possible that changes in the economic structure may affect the trajectory of energy intensity. This has been the case in LAC. Based on a decomposition exercise conducted in this report, it is found that, if the economic structure had not changed, the drop in energy intensity between 2011 and 2017 would have been 20% in Latin America and the Caribbean, more than double that experienced in that period. This role of the structure is consistent with the reduction in the importance of primary sector industries (typically of low energy intensity), combined with the growth of sectors like transport, which are highly energy-intensive.

To grow vigorously and minimize the impact of this growth in terms of GHG emissions, the region must further reduce emissions intensity and energy intensity. This Report on Economic Development (RED) explores energy actions to achieve this on both the energy supply side (part II) and the energy demand side (part III). RED 2024 also analyzes cross-cutting actions, such as carbon capture and storage technologies, the circular economy, and carbon markets and taxes (part IV).

Table 2
Energy strategy to reduce emissions per unit of output

Energy supply	Efficiency of energy systems (Chapter 3)
	Green electrification and energy integration (Chapter 4)
	Promotion of clean fuels and use of gas in the transition (Chapter 5)
Energy demand	Industries: Electrification and decarbonization of industrial processes (Chapter 6)
	Households: Energy efficiency, electrification and closing gaps in access to quality energy (Chapter 7)
	Transportation: Energy efficiency, electrification, promotion of public and active transportation, and the use of clean fuels (Chapter 8).
Cross-cutting energies (Chapter 10)	Capture technology development
	Green financing
	Carbon markets and carbon tax
	Circular economy

Part II
Pillars for a cleaner energy supply

Starting point: The region's energy matrix

Energy-related emissions depend on how energy is produced, both in terms of the mix of inputs to produce it and the efficiency with which energy systems transform these primary inputs into energy vectors: electricity and fuels.

Table 3 presents the aggregate energy matrix of Latin America and the Caribbean for the average of the last five available years, 2017–2021, organized as follows. The left-hand side shows the primary energy inputs and the right-hand side shows the final consumption sectors. The upper panel depicts the electricity submatrix, and the lower panel displays the fuel use submatrix. Finally, the central block indicates amounts related to transformation losses (plus self-consumption), transmission, and distribution.

Total energy consumption in Latin America and the Caribbean is 24.2 exajoules (EJ), of which 20% (4.78 EJ) corresponds to electricity generation. This electrification rate is slightly lower than that of OECD countries (around 22%) and remarkably heterogeneous across countries, ranging from lows of 1% and 7% in Haiti and Guatemala to highs of 26% and 27% in Panama and Suriname, respectively (see panel A of Graph 5).

In the region, 57% of electricity is produced from renewable sources, significantly higher than the world average of 36%

Power generation is estimated at 5.89 EJ. Over half (57%) of this electricity is produced from non-fuel sources, which is significantly higher than the world average (36%). In other words, the region has a relatively clean electricity matrix. Non-conventional renewable energy (NCRE) represents 11% of power generation, similar to the global value, indicating that the advantage in non-fuel generation comes from water resources, from which 80% of electricity from renewable sources is generated. The participation of these sources in electricity generation is heterogeneous among countries. The Caribbean islands show low participation in non-fuel generation, reaching a maximum of 14% in the Dominican Republic. In South America, there is a group of countries with medium progress, where non-fuel generation represents between 30% and 40% of the total, and another group of advanced countries, with values between 74% and 80%. Paraguay stands out because all its generation comes from hydroelectric sources. Most of the Mesoamerican countries show values between 44% and 68%, with the exception of Mexico (23%), on the low end, and Costa Rica (99%), on the high end (see panel B of Graph 5).

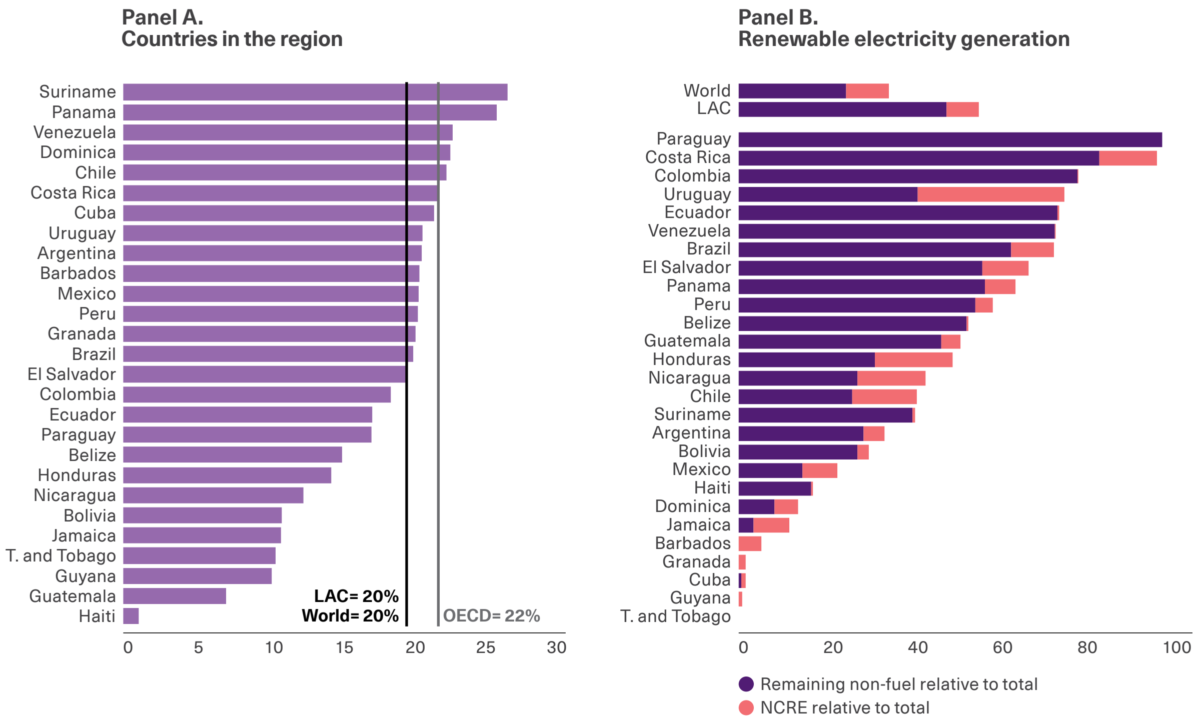
Table 3
Energy matrix of Latin America and the Caribbean in average values for 2017–2021

	Primary energy supply and secondary energy imports (a)		Transformation losses and self-consumption (b)	Power generation (and net power imports) (c)	Transmission and distribution losses (d)	Final consumption (e)	
Non-fuel-based power generation	Hydroenergy	2.70					
	Geothermal	0.19					
	Nuclear	0.39					
	Solar	0.10				Residential	1.38
	Wind	0.33				Agriculture, fishing, and mining	0.41
	Non-fuel-based power subtotal	**3.72**	**0.38**	**3.34**		Commerce	1.01
						Transport	0.02
Fuel-based power generation	Natural gas	3.92				Industry	1.89
	Oil and derivatives	1.25				Construction	0.07
	Coal	0.92				**Power consumption subtotal**	**4.78**
	Biomass	1.10					
	Fuels subtotal	**7.19**		**2.55**			
	Net imports	**0.00**		**0.00**			
Power generation subtotal		**10.91**	**4.64**	**5.89**	**1.10**	**Power consumption**	**4.78**
End use of fuels	Natural gas	5.91				Residential	2.90
	Oil and derivatives	11.91				Agriculture, fishing, and mining	1.04
	Coal	1.00				Commerce	0.36
	Biomass	5.36				Transport	9.34
	Non-energy use of fuels	0.06				Industry	5.64
						Construction	0.13
						Fuel energy consumption	**19.41**
						Non-energy consumption	**1.19**
Fuels subtotal		**24.24**	**3.64**			**Fuel consumption**	**20.60**
Total		**35.15**				**Total consumption**	**25.38**

Note: The table reports the aggregate values of the LAC energy matrix with the latest available data for the period 2017–2021. The matrix shows the inputs for power generation and end-use fuels (column a), power generation (column c) and total consumption, disaggregated by sector and type of use (column e). In the purple area, it is classified (in column a) in "non-fuel imputs for power generation " and "fuel inputs for power generation," which are used for electricity generation corresponding to each type (column b). More details of the calculations can be found in the annex of chapter 3 (available online).

Source: *Authors* based on OLADE data (2023b).

Graph 5
Electrification and renewable generation rate



Note: Panel A presents the electrification rate of LAC by country. This is calculated by aggregating the electricity consumption of all sectors and calculating its share of total energy consumption. Panel B presents the share of non-fuel electricity generation, i.e., the share of non-thermal generation in electricity production and the percentage of this that is obtained from non-conventional renewable energy sources (NCRE), including solar and wind.

Source: *Authors* based on IEA (2021a, 2023d) and OLADE (2023a, 2023b).

The report identifies three areas for action on the supply side to drive the energy transition in the region:

1. **Increase the electrification rate and the participation of non-conventional renewable sources (green electrification).** In the IEA's announced net zero emissions scenario, the electrification rate for the region reaches 41% in 2050. Along with this expansion, there is a significant growth in installed capacity from solar and wind sources, which reach 43% and 19% in 2050, respectively.

2. **Minimize the emissions impact associated with fuel consumption.** Some industrial processes and components of the transport sector are not electrifiable with current technologies. Moreover, the intermittency associated with non-conventional renewable energy sources may require the use of fuels to generate electricity, in order to provide flexibility to power systems and ensure supply security. The issue with current fuels, mainly of fossil origin, is their emissions. Therefore, a second key line of action will be moving toward clean fuels. This may require substituting coal and oil with natural gas in the short run and eventually substituting fossil fuels for low-emission fuels, such as green hydrogen and sustainable biofuels.

3. **Improve the efficiency and operation of energy systems**. Table 3 shows the incidence of losses in the process of production, transformation, and transportation of energy vectors. As observed, the 25.4 EJ of energy consumed is produced from 35.2 EJ of inputs, called primary energy sources.[5] These losses occur in different processes, which include: a) fuel production, b) power generation with fuels, and c) self-consumption, transportation, and distribution of electricity. Part of these losses is related to inefficiencies. Thus, strengthening the efficiency and operation of energy systems represents a third key pillar of a cleaner energy supply.

Energy system improvements

There is considerable heterogeneity among countries in terms of losses resulting from the transformation of primary sources into energy vectors. Although these losses are not always attributable to inefficiency issues, differences between countries can provide indications of potential areas for improvement.

Energy losses during the process of transforming fuels into electricity are on average 56%, plus another 19% on average during the transport and distribution stage

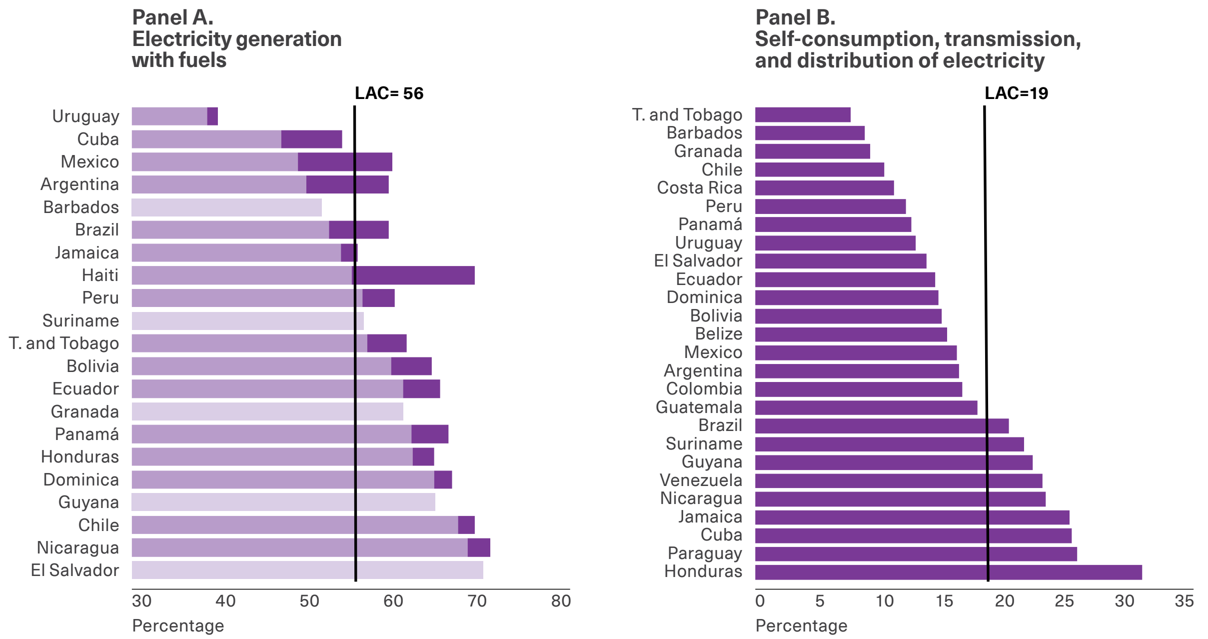
Starting with the electricity vector, Graph 6 shows the losses during the transformation of fuels into electricity (panel A) and during the transport and distribution of electricity (panel B). In the thermal generation phase, these losses average 56%, but can vary from almost 40% to more than 70%. These losses depend on different factors including the type of generators and fuels used, the previous transformations these fuels underwent, and the type and age of the machinery. In the transport and distribution phase, the average losses are 19%. In this dimension, Barbados, Grenada, and Trinidad and Tobago stand out for having the lowest values in the region, as they are equal to or below 10%. On the other end of the spectrum is Honduras, where they reach 33%. These losses are again associated with various factors, including unbilled consumption, but also technical losses linked to the operation of distribution and transmission systems.[6]

Regarding fuel vectors, significant losses have also been identified, averaging 13% in the region. These losses imply the need for more primary fossil inputs per unit of fuel that reaches consumers, which, along with methane emissions linked to the fuel production process, affect emissions. Graph 7 shows the emissions associated with fossil fuels prior to their consumption as a percentage of emissions at the time of use. The latter include emissions associated with energy use in the various stages of primary fuel production and transformation, in addition to fugitive methane emissions from the fossil sector.

5 This is in line with what is observed globally, where energy consumption is estimated at 439 EJ from inputs of 624 EJ (IEA, 2023d).

6 For example, the very voltage at which the transport is carried out, which varies from country to country, influences losses.

Graph 6
Losses in electricity generation, transmission, and distribution processes



Note: The graph reports, in panel A, the proportion of energy losses during the generation process (purple and mauve bars) and transformation (purple bar) of fuels, and in panel B, losses due to self-consumption, transportation, and distribution of electricity.

Source: *Authors* based on OLADE (2023b).

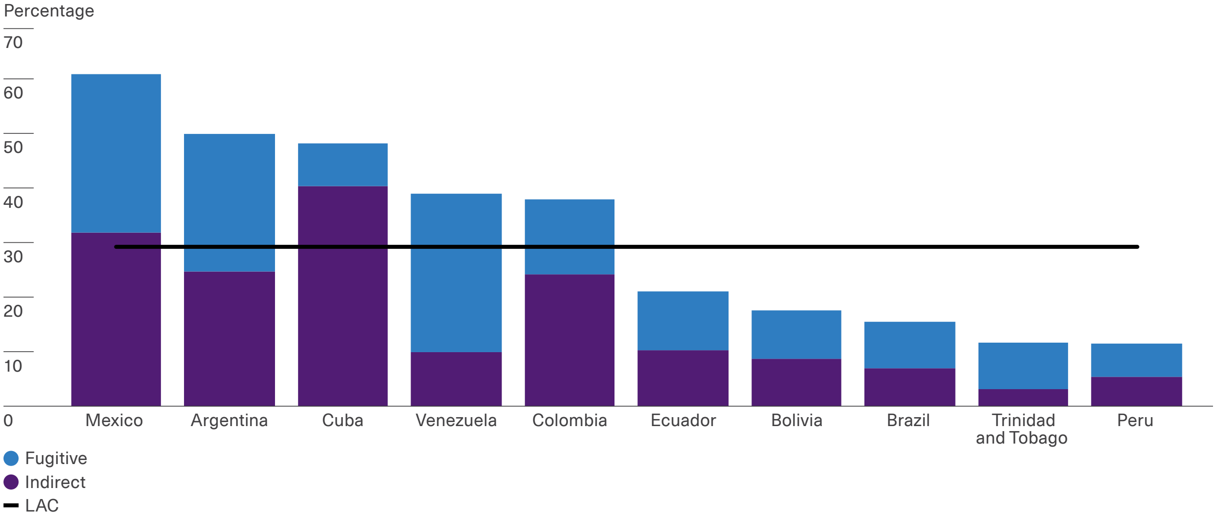
Thus, for the average of the countries shown, for every 100 tons of CO_2 (tCO_2) emitted at the time of consuming fossil fuels, more than 29 additional tCO_2 were previously released during their production and transportation. Most of these were methane emissions generated by venting or flaring unused natural gas or by leaks in the production, transformation, and transportation processes.

Emissions in the production and transportation of fuels can be reduced through the adoption of better equipment and the electrification of fuel production processes. According to the IEA (2023a), the use of more efficient equipment could save around 30% of the energy needed, with corresponding decreases in emissions. However, complete electrification would allow even greater reductions, close to three-quarters of the current emissions from fuel production.

Proper closure of oil and gas fields and coal mines is also crucial for mitigating the environmental impacts of fossil fuel production, especially methane emissions.

The problem with these losses, both electricity and fuel losses, is that they amplify the emissions associated with energy consumption (quantified in Table 4).

Graph 7
Emissions from fossil fuel production and transport as a percentage of total emissions from final product consumption



Note: The graph shows fossil sector emissions from energy use and fugitive methane emissions released in the production, transportation, refining and distribution of coal, gas, oil and oil derivatives, as a percentage of emissions from the consumption of final fuels produced. Emissions from energy use are computed using the corresponding emission factors for each fuel. Total consumption refers to domestic plus external consumption. Countries for which homogeneous information on methane emissions is available are shown.

Source: Authors based on OLADE (2023b) and IEA (2023c).

Table 4
Direct emission factors, with processing and production losses (tCO_2/TJ)

Source	Combustion (a)	(a) + inefficiencies (b)	(b) + fugitive (c)
Natural gas	56	60	74
Mineral coal	95	96	96
Liquefied petroleum gas	63	75	85
Gasoline	69	83	92
Kerosene and turbine fuel	72	85	95
Diesel	74	88	98
Fuel oil	77	92	102
Coke	107	124	125
Charcoal	112	215	-
Biofuels	71	84	-

Note: The table shows direct emissions (taken from the IPCC stationary combustion emissions factors, column a); emissions amplified by losses and inefficiencies in the production, transformation, and transportation processes of these fuels (column b); and global emissions, considering the fugitive emissions that can be attributed to each fuel (column c). The countries for which homogenized information on estimated methane emissions is available are Argentina, Bolivia, Brazil, Colombia, Cuba, Ecuador, Guyana, Mexico, Peru, Paraguay, Trinidad and Tobago, Uruguay, and Venezuela. Based on this set of countries, fugitive emissions per unit of final energy produced are estimated and the result is imputed to the region as a whole. The values are expressed in metric tons of CO_2 equivalent per terajoule (tCO_2e/TJ).

Source: Authors based on IPCC emission factors (2006), IEA (2023c), and OLADE energy matrices (2023b).

Two important messages emerge from this table. First, both inefficiencies and fugitive emissions significantly increase the emissions factor of each of the fuels, although this impact varies depending on the fuel. Second, natural gas has the least impact from combustion, but its emissions factor increases significantly due to fugitive emissions, partially reducing its advantage. For example, emissions from coal combustion per unit of energy delivered are 70% higher than those of natural gas. When losses and fugitive emissions are taken into account, the figure drops to 28%.

Inefficiencies and fugitive emissions increase the emissions factor of fuels, especially natural gas

A similar analysis applies to electricity. Accounting for transmission and distribution losses results in a 23% increase in emissions associated with electricity consumption.

Green electrification

The increase in electricity demand poses capacity challenges for transmission and distribution systems. However, the fact that this increased electrification must be met with a growing share of renewable energy sources imposes additional challenges due to the specific characteristics of these sources.

Challenge 1: How to deal with power system operation intermittency

Electricity demand exhibits significant variability over time. With the integration of renewable energy sources, additional uncertainty is introduced on the supply side. In this context, ensuring continuity of supply requires backup mechanisms which can be provided by some market participants. For example, flexible hydroelectric power plants with storage capacity and open-cycle natural gas-fired thermal power plants can increase or decrease their production quite rapidly (this is not possible with steam turbine plants). Battery storage systems also help smooth out the intermittency effects of these sources. Likewise, energy integration can help address these challenges by incorporating different generation sources (with different randomness between countries), although it currently faces some obstacles (see Box 1).

Box 1
Barriers to energy integration

Energy integration in the region has achieved different levels of progress, but barriers persist that hinder its full development. Among these, three stand out:

- Countries in the region prioritize supply security and self-sufficiency since dependency on others implies strategic risks, especially in contexts of institutional weaknesses that characterize several of them.
- Interconnections require overcoming technical challenges, such as the difference in frequency between countries (for example, between Brazil and its neighbors).
- The lack of regulatory symmetry and stability also plays a crucial role, as the technical requirements of coordinating bodies and the harmonization of energy policies between nations with different regulatory frameworks present additional complexities.

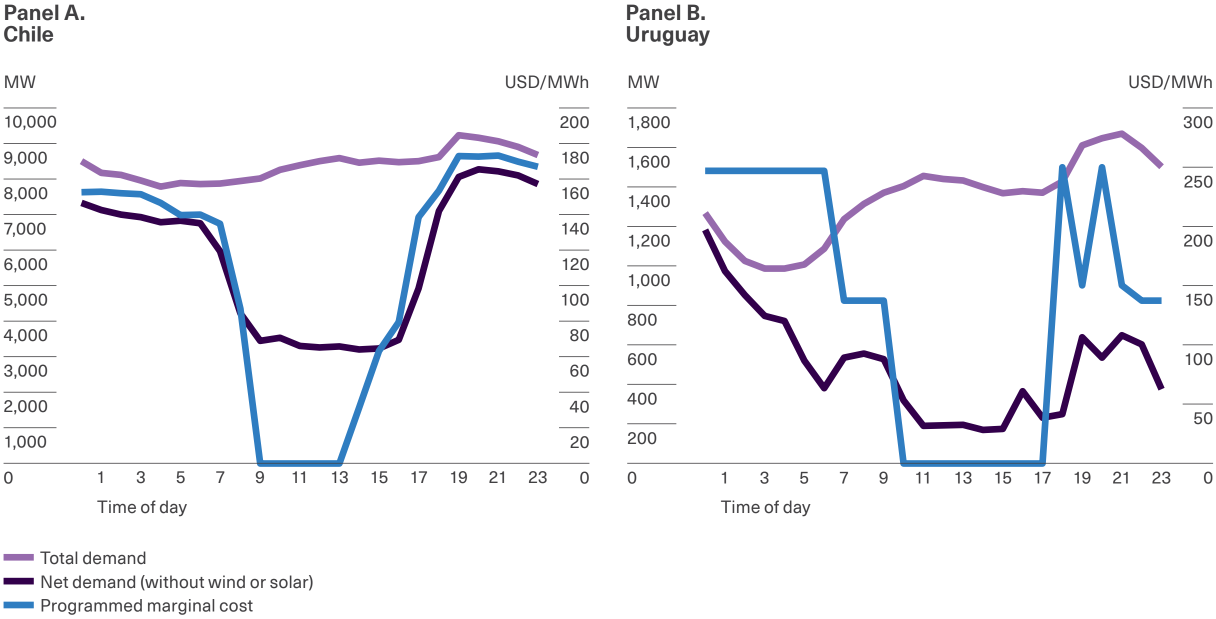
Some power systems may need to maintain dispatchable fossil fuel-based generation capacity for backup and to provide flexibility to the system

Theoretically, continuity of supply could be achieved with non-polluting sources, by incorporating sufficient reserve capacity and diversifying the power matrix. This entails a diverse and balanced mix of generation technologies—solar photovoltaic, solar thermal, wind, hydraulic, etc.— storage technologies—hydraulic, batteries—, and that these sources are sufficiently spread as to be resilient to environmental shocks. However, some systems may need to maintain dispatchable generation capacity[7] based on fossil fuels, for backup and to provide flexibility to the system, especially during the transition. In the long term, maintaining these fossil alternatives may require carbon capture technologies to offset the impact on emissions.

Two illustrative cases are Chile, a country with a relatively large participation of solar energy, and Uruguay, with a considerable relative proportion of wind energy, as shown in Graph 8. The purple line in the panels shows the hourly demand on a typical day; the black line shows the net load curve (net demand from non-dispatchable sources) and the blue line represents the marginal cost. The graph illustrates that, in systems with a high solar generation component (Chile), a duck curve emerges: a distinctive pattern of a lower net load during daytime hours because part of the demand is met by this source. In contrast, when the system incorporates a high proportion of wind power (Uruguay), the net load curve lies below the demand curve, of greater or lesser magnitude, depending on wind conditions (Bothwell and Hobbs, 2017; Muñoz and Mills, 2015).

7 Dispatchable sources are those where the level of output can be administered at will at any time. Thermal and hydropower with storage are two examples. In contrast, solar and wind power are "non-dispatchable," since the level of output depends on the availability of the natural resource and the only decision an operator can make is to dispatch or curtail the power produced.

Graph 8
Total and net load curves of wind and solar generation and marginal cost or spot price



Note: The graph shows the total (load) and net generation curve of wind and solar sources in megawatts (MW) and the marginal cost or spot price in dollars per megawatt per hour (USD/MWh) in each hour of a typical day. Data for Chile are as of April 7, 2023, and for Uruguay, as of April 18, 2023 (in this case generation plus imports, minus exports is reported). Depending on the day, hourly prices can be positive at noon or zero all day.

Source: *Authors* based on data from the National Electric Coordinator (2023), for Chile, and ADME (2023), for Uruguay.

The graph also shows that the marginal cost of generation is affected by this intermittency pattern. Its value is zero at certain times of the day, when demand is satisfied by non-conventional renewable sources and dispatchable sources with zero marginal cost, such as run-of-the-river hydropower. This dynamic clearly demonstrates the potential role of batteries, whose penetration will depend on the net benefit their participation brings to the sector in terms of providing flexibility compared to alternatives like natural gas generation. The intra-day price differential provides a signal about the benefits of storage.[8] Existing models for the development of energy transition scenarios in the electricity sector foresee the incorporation of batteries in practically all countries in the region (MRC Consultants and PSR, forthcoming publication).

Demand-side actions can also address this issue. Currently, the systems have large users that sell response capacity to the system and make it available to the operator. In the future, the presence of dynamic prices could reflect the scarcity of electricity at any given moment, encouraging changes in consumption patterns. These advances are part of sector developments for creating a smart grid.

8 Although the price signals needed to make investment decisions in this technology are long term, short-term prices can give an indication of the benefits of hourly arbitrage. The price differences observed in the examples shown in the report are as high as 180 USD/MWh in Chile and 250 USD/MWh in Uruguay.

Challenge 2: NCRE generation incentives and cost structure

Wind and solar energy are available at no cost, so NCRE technologies operate with variable costs close to zero but relatively high fixed costs. This cost structure of NCRE presents challenges for the operation of the electricity market, especially in the spot market,[9] since a high penetration rate could lead to all demand being covered by NCRE, resulting in spot prices close to zero in the wholesale market.

Obviously, prices close to zero do not encourage the entry of new actors to increase generation capacity. Hence the importance of the supply contract segment, as the remuneration for NCRE generation (and associated services) through contracts is more closely linked to the average generation cost.

Fortunately, the entry of new power suppliers in Latin American and Caribbean countries has typically been done through auctions accompanied by long-term contracts. However, there has not been a widespread practice regarding the mechanism, of which there are several, including energy contracts (which assign the seller the risk of the generated energy), capacity contracts (which are also energy sales contracts but assign the buyer the risk of the energy received) and neutral or technology-specific auctions.[10]

Experts suggest that tariffs should migrate from systems based on volumetric rates to schemes based on fixed charges, without compromising affordability

This cost structure also has implications for tariffs. Experts point out that there should be a migration from systems based on volumetric tariffs, with increasing variable charges per consumption interval,[11] to schemes based on fixed charges.[12] This migration should be done in a way that does not compromise affordability, an issue that could arise when schemes based on uniform fixed charges are in place.

In the face of NCRE penetration, other good practices include time-of-use (TOU) block differentiated pricing schemes, grouping customers according to capacity or load and usage time, and differential treatment of prosumers (Faruqui and Tang, 2021).

These tariff mechanisms have already begun to be used in the region with the implementation of digitization. For example, smart meters with automatic and remote electricity readings have been installed in Paraguay and Peru (ENEL, n.d.; La República, 2023). Furthermore, Brazil, Costa Rica, and Uruguay have implemented programs based on the TOU approach in the residential sector, where adoption by households is voluntary, allowing consumers to choose between this model or a flat rate (Weiss et al., 2022).

9 The market formation that took place in the 1980s and 1990s in Latin America and the Caribbean sought to organize a structure in which generators would transact with distributors and large users for the supply of electricity in a wholesale market consisting of two tranches: supply contracts and the spot market, also known as the immediate delivery market.

10 See Fabra and Montero (2023).

11 These charges may be differentiated, as in the cases of Argentina, Bolivia, El Salvador, Peru, and Uruguay, or undifferentiated, as in Costa Rica, Mexico, and Paraguay. One country that does not charge fixed charges is Colombia.

12 See Navajas (2023).

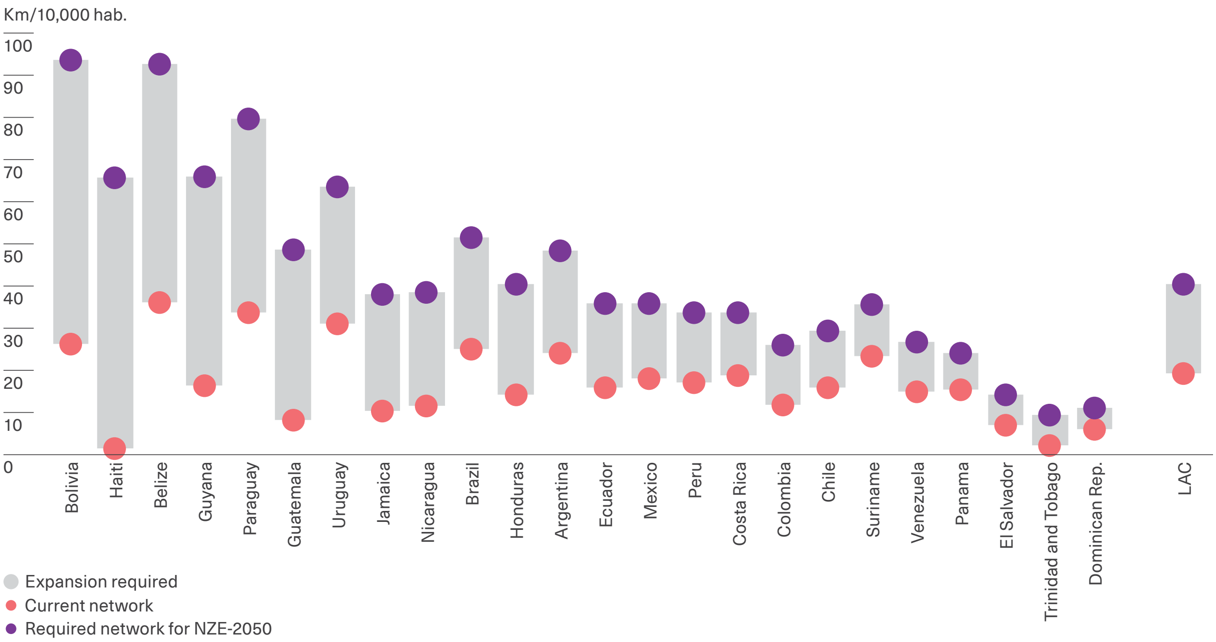
Challenge 3: Transmission and distribution

Electrification not only increases the demand for generation but also for electricity transmission and distribution infrastructure, which must adapt to the qualitative aspects of NCRE generation, including spatial distribution, intermittency, and scale.

The region's transmission network is currently about 20 km per 10,000 inhabitants, but in the net zero emissions (NZE) scenario, this figure needs to more than double by 2050 (Graph 9). Notably, Bolivia, Belize, Haiti, Guatemala, Guyana, and Paraguay face particularly significant needs, with requirements exceeding 40 km per 10,000 inhabitants.

The electricity transmission network in the region is approximately 20 km per 10,000 inhabitants, which needs to more than double in a net zero emissions scenario by 2050

Graph 9
Transmission network extension and required expansion in the NZE scenario for 2050



Note: The graph shows the current length of electricity transmission networks in relation to the population (in kilometers per 10,000 inhabitants). The purple and pink dots show the current and required grid extension under the CEN scenario for 2050 respectively. The gray bar represents the expansion needed to meet consumption requirements under that scenario.

Source: *Authors* based on IEA (2021c) and Ardene et al. (2020).

Box 2
Distributed generation and prosumers

Distributed generation, which involves low-scale production close to the point of consumption, has gained prominence within distribution systems, mainly driven by renewable sources. This trend has enabled the emergence of prosumers—users who both generate and consume energy, depending on their needs.

In the region, distributed generation capacity has grown tremendously to represent 5.1% of total existing generation capacity in 2021, with Brazil playing a significant role in driving this growth. Solar PV accounts for almost 98% of distributed generation installations in the region.

Brazil's experience points to three factors that contributed to its growth: 1) the sharp drop in the real price of PV generation systems in the last five years; 2) the significant increase in electricity tariffs; and 3) the implementation of the energy compensation system that allows the producer or consumer to inject their surplus into the local distributor's grid.

The penetration of distributed generation and prosumers requires regulatory adjustments, particularly in determining how injected flows are remunerated, whether balances accumulate as monetary credit or energy, and whether restrictions are imposed to safeguard distribution networks. These restrictions may include quantitative limitations (maximum capacity panels) or quality limitations (technical procedures for panel installation and use).

There are two main remuneration schemes: net metering and net billing. The former calculates the difference between what is consumed and what is injected into the system per prosumer and charges consumers for the net energy consumed using the tariff price, so that the injection is valued at the same price as consumption. The latter valuates power injections at the wholesale market (spot) price and power consumption at the tariff price.

Expanding the transmission network poses challenges related to finance, land use permits, and concession management. Moreover, NCRE generation brings unique qualitative aspects that may impact transmission and distribution infrastructure needs. For instance, solar and wind generation centers are, on average, 30% and 60% farther from consumption points compared to natural gas generation. Additionally, these technologies operate on a much smaller scale than other forms of generation, and households and businesses can supply energy to the system as prosumers (see Box 2).

The larger needs of electricity injection points due to lower scale, the increased average distance from generation to consumption sites, and the emergence of prosumers may require changes in transmission networks. These changes may include extensions, flexibility for bidirectional operation, and the need for more numerous injection points.

Endowment for clean generation

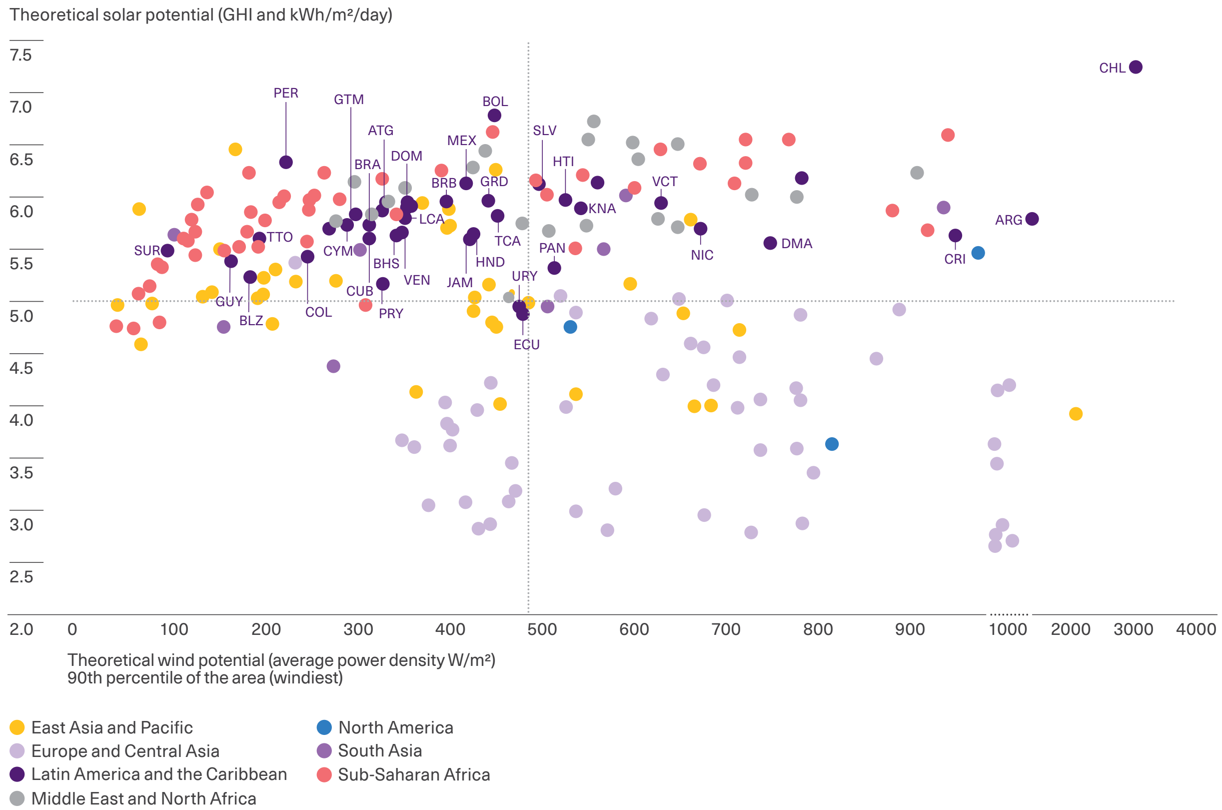
The region benefits from excellent natural conditions to meet the challenges of green electrification. These include water resources, solar irradiation, and wind exposure. However, the endowment of these resources varies across countries and regions.

Currently, the region's hydropower generation capacity reaches 199.5 GW, equivalent to 41% of the total capacity in 2021. However, these developments do not exhaust the exceptional hydropower potential of Latin America and the Caribbean, estimated at 677 GW by the Latin American Energy Organization (OLADE, 2023c). If viable, full utilization of the hydro resource could cover the total expected electricity generation for the NZE-2050 scenario in 17 of the 24 countries analyzed by OLADE (Alarcón, 2018).

Additionally, almost all countries have good solar potential (exceeding the global average), and in some of them, like Bolivia and especially Chile, it is the highest on the planet. Likewise, approximately one-third of the countries have high wind potential, with Argentina, Chile, and Costa Rica standing out (see Graph 10).

Graph 10

Theoretical potential in wind and solar energy



Note: The graph shows the theoretical wind (measured in W/m2) and solar (measured in kWh/m2/day) potential for the 90th percentile of the windiest and most irradiated area, respectively.

Source: Brassiolo et al. (2023).

Penetration of low-emission fuels

The most auspicious energy transition scenarios for Latin America and the Caribbean estimate a target electrification rate of around 50% by 2050. The other half of energy consumption will have to be met mainly by fuels. The problem is that the fuels used today are mostly of fossil origin and are associated with high GHG emissions, among other environmental impacts. The transition therefore implies adopting cleaner fuels.

There are two groups of technological alternatives for obtaining clean fuels to replace fossil fuels: the first consists of fuels of agricultural origin (including biofuels); and the second, hydrogen and its derivatives.

There are two technological alternatives for obtaining clean fuels to replace those of fossil origin: the first consists of biomass-based fuels, and the second consists of hydrogen and its derivatives

Biomass-based fuels and their role in energy transition

Technological advancements have enabled the development of high-quality fuels from the transformation processes of animal and plant-based inputs. These fuels are currently used as substitutes, typically combined with equivalent fossil fuels, with prominent examples being biodiesel and ethanol.

While biomass-based fuels generate CO_2 emissions comparable to their fossil counterparts during combustion, the emitted carbon was previously removed from the atmosphere through photosynthesis.[13] Therefore, if managed sustainably, they can play an important role in the decarbonization of energy uses that require fuels. Under the IEA's Announced Pledges Scenario, their importance in the energy supply should increase by 10 percentage points between 2022 and 2050, to reach 31%.

Biomass-based fuels face challenges associated with the use of land and agricultural inputs like fertilizers, herbicides, and insecticides. This entails greenhouse gas emissions due to increased cultivated land leading to the loss of natural ecosystems, deforestation, and the carbon intensity of agricultural inputs. Additionally, there is an increase in food prices due to competition with food production. Some conditions that mitigate these challenges include increased agricultural productivity, the use of non-food crops, forest waste, agricultural waste, or urban solid waste that would otherwise not be used, as well as production on degraded land unsuitable for food production.

13 Consequently, these fuels would be considered carbon neutral if no inputs (fertilizers, herbicides, etc.) or energy with emissions are used for agricultural production and if the time frame between combustion emissions and subsequent capture for resource renewal is short.

To promote the development of sustainable biomass-based fuels, the IEA proposes a strategy based on three pillars. The first involves adopting regulatory frameworks that establish guidelines for their production with low environmental impact, including sustainable management certification frameworks with independent verification that cover the entire supply and production chain. The second pillar is the adoption of demand policies that aim for specific participation goals for these products. Policies in this direction include setting minimum quantities of these products at fuel pumps.[14] The third pillar corresponds to policies that promote innovation, especially for waste-based fuels, namely wood and paper. Policies along these lines include loan guarantees and mandatory quotas for the use of advanced biofuels.

Hydrogen and its role in the transition

Low-emission hydrogen gas (H_2) represents another clean fuel alternative. Its physicochemical properties give it great versatility as an energy vector, but at the same time, make it difficult to transport and store.

An environmental virtue of hydrogen is that its use does not produce GHG emissions or local pollutants. However, its production can entail emissions depending on the input and the process used to obtain it. In LAC, hydrogen is currently mostly produced from natural gas (76%) and coal (23%). Less than 1% of current hydrogen production comes from plants operating with renewable energy or fossil fuels with carbon capture and storage technologies.

The energy transition demands a significant growth of low- or zero-emission H_2. The alternatives for producing it can be grouped into three categories: 1) integrating carbon capture and storage with production based on fossil fuels (blue H_2); 2) hydrogen production by water electrolysis, with electricity generated from renewable or clean sources (green and yellow H_2); and 3) using inputs from sustainable organic sources, incorporating carbon capture (green H_2).

Low-emission H_2 is expected to play an important role in future energy systems through two avenues. The first is as a complement to the intermittency of NCRE. Temporary and regional surpluses of solar and wind generation can be used to produce hydrogen, store it, and transport it where and when it is needed.[15] The second avenue is replacing fossil fuels to meet energy needs better served by combustion, as in steel industry processes, which require high temperatures, or freight transport.

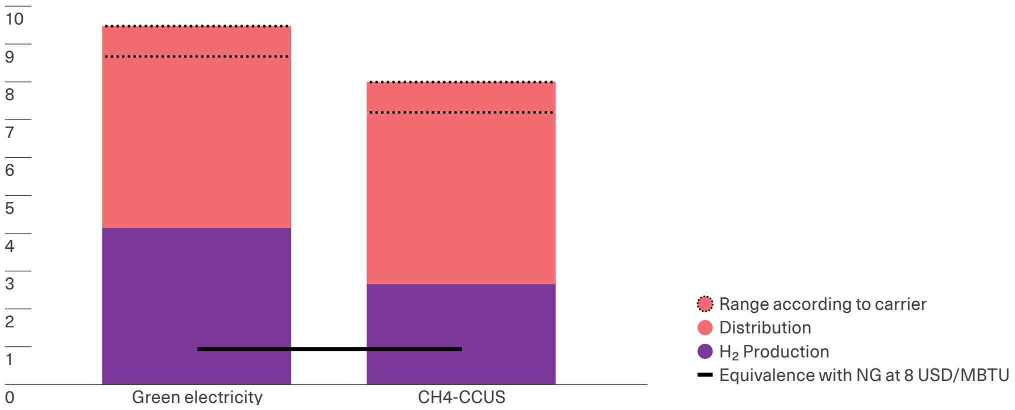
At present, the production of clean H_2 is not very competitive and its distribution is extremely costly (Graph 11). Consequently, for hydrogen to fulfill the roles outlined above, its production must become cheaper, and above all, the barrier of difficulty of transport and storage resulting from its low energy density per unit volume must be overcome.

For hydrogen to replace fossil fuels, its production must be made cheaper, and above all, the barrier of the difficulty of transportation and storage must be reduced

14 Argentina, for example, already has a minimum cut of ethanol in gasoline and biodiesel in diesel of 12% and 5%, respectively (Secretariat of Energy, 2022; Sigaudo, 2019). Brazil, in addition to the adoption of minimum quotas, has the sale of ethanol to the final consumer and the development, by the automotive industry, of vehicles with flexible engines (internal combustion engines that can run on gasoline or alcohol).

15 The production of hydrogen in dedicated (off-grid) wind or solar farms makes it possible to obtain this energy vector on a primary basis.

Graph 11
Estimated costs for hydrogen production, transport, and distribution in the European Union in 2030



Note: The graph shows the estimated costs of domestic production (in purple color) and distribution of hydrogen in the EU in 2030. Shown are costs in dollars per kilogram (USD/kg) of H2 for production from natural gas with carbon capture, use, and storage (CCUS) and green electricity, assuming a natural gas cost of USD 8 per million British thermal units (USD/MBTU) and an electricity cost of USD 47/MWH. The dashed black rectangle indicates the range of transportation and distribution costs between the ammonia, liquid hydrogen, and organic liquid hydrogen carrier transportation alternatives. The horizontal black line indicates the cost equivalence value of hydrogen to natural gas.

Source: *Authors* based on IEA (2019).

Large-scale transport of H_2 is feasible through pipelines. Hydrogen can be injected into natural gas networks in low proportions (up to 3%) without difficulties or requiring modifications to networks or equipment in use, and this amount can be gradually increased with adjustments to the installations. This strategy has the additional advantage of boosting H_2 demand, making it cheaper thanks to economies of scale. Moreover, reallocating natural gas networks for hydrogen transport is a promising and cost-effective long-term alternative. This requires adjustments to existing infrastructure, such as introducing interior coatings in pipelines, internal monitoring of pipeline conditions, and adapting compressors and valves to withstand the higher pressure required for hydrogen transport.

Regarding storage, the alternative for large-scale and long-term storage is geological. Deposits can include underground salt caverns, depleted oil and gas fields, and aquifer caverns. Currently, only salt caverns are a proven solution for hydrogen storage without losses or contamination with impurities, although their geographic availability is limited. For small-scale storage and transport, current options include storing hydrogen in tanks as compressed gas and in cryogenic hydrogen tanks in liquid form.[16]

The low-emission H_2 industry is promising for the region. There are currently outstanding projects, such as those in Argentina (Hychico, in Patagonia), Costa Rica (Astra Rocker), and Chile (Microrred). Chile aims to produce and export the world's most competitive H_2 from renewable electricity by 2030, and many countries in Latin America share the conditions to develop this process. In some of these countries, such as Brazil, existing biofuel and bioelectricity production could also help produce and export H_2.

16 Other storage and transport solutions consist of integrating hydrogen into carrier compounds, such as ammonia, a substance consisting of hydrogen and nitrogen (NH3), or liquid organic carriers.

Gas as a transition fuel

A promising policy space for reducing GHG emissions in the short run is the replacement of coal and petroleum-derived liquid fuels with natural gas.

Natural gas is the hydrocarbon with the lowest CO_2 emissions per unit of delivered energy (see Table 4). Moreover, it produces negligible amounts of sulfur oxides, nitrogen oxides, and fine particulate matter, local pollutants that have harmful impacts on health.

Furthermore, the use of gas in existing equipment designed for other fossil sources is feasible. For example, in the electricity sector, it is possible to adapt coal-fired power plants to operate with natural gas, resulting in capital expenditures up to 30% lower than installing a new plant. The use of gas in vehicles is also a viable option and has already been deployed at scale in the region.

If half of coal and petroleum-derived fuel use in Latin America and the Caribbean were replaced by natural gas, a direct reduction equivalent to 6.5% of the region's emissions would be achieved. However, to enhance the role of gas in decarbonization, it is critical to adopt measures to eliminate fugitive emissions that erode the advantage of this fuel.

If half of coal and petroleum-derived fuel use in Latin America and the Caribbean were replaced by natural gas, a direct reduction equivalent to 6.5% of the region's emissions would be achieved

Trading natural gas through pipelines or in the form of liquefied natural gas to replace coal and oil in the energy matrices of other countries would contribute to reducing emissions in those countries in the short term.[17]

One risk of increasing the participation of natural gas is that further investments in exploration, production and transport infrastructure, and end-use equipment required may delay the speed of convergence toward carbon neutrality. One way to minimize this risk is to develop strategies where natural gas use is a clear temporary step in a strategy toward full decarbonization, by channeling investments to infrastructure and equipment that may be repurposed (e.g., to the hydrogen value-chain) or explicitly pricing-in the costs of early decommissioning.

17 Global coal consumption is still higher than that of natural gas, accounting for 27% of primary energy sources, while in the region it represents only 5% (OLADE, 2023b). However, long-distance natural gas trade requires specific infrastructure and intensive capital for gas liquefaction at origin, maritime transport in specialized vessels, and regasification plants at destination.

Part III
Energy demand and energy transition

Energy transition in hard-to-abate industries

Industry generates 11% of direct emissions and 24% of energy-related emissions in Latin America and the Caribbean. Of these, the cement, steel, and chemical subsectors account for 57%. These three industries have three characteristics that distinguish them: they are essential for modern economies, have high energy intensity, and have limited viable alternatives to decarbonize their production processes in the short term.

Industry generates 24% of energy emissions in Latin America and the Caribbean. Of these, the cement, steel and chemical subsectors account for 57%

The main decarbonization policies for these sectors are presented in Table 5 and are discussed in more detail below.

Table 5
Policies for the decarbonization of industry

Cement	Steel	Chemistry
Use of more modern furnaces	Promotion of the green hydrogen industry and promotion of industrial clusters in areas close to it for the production of steel	Promotion of the green hydrogen industry and development of industrial clusters in areas close to it for the production of chemical products
Adoption of technical standards on cement composition and performance to reduce clinker content	Financing for furnace renovation and other technological improvements	Carbon capture (mature technology in ammonia)
Biomass as fuel and biomass ash as clinker substitute	Circular economy and scrap recovery	Electrification of certain processes (production of plastic pellets)
Circular economy and concrete recycling		Circularity and recycling of plastic, including regulation and taxation of single-use plastics

Cement

The cement sector is characterized by its emissions stemming from high energy consumption, especially in its production process. During production, ash, rock waste, and dust containing air pollutants such as particulate matter ($PM_{2.5}$) and solid waste are produced. The production process also releases nitrogen oxides (NO_x) and sulfur dioxide (SO_2) (Kusuma et al., 2022), air pollutants that break down into $PM_{2.5}$ in the atmosphere. Eighty-six percent of the emissions along the value chain, from quarry extraction to on-site logistics, occur during clinker manufacturing. Of this percentage, 60% comes from the calcination of limestone, which decomposes into calcium oxide and carbon dioxide when burned, while the remaining 40% comes from burning fuels for calcination. All the thermal energy utilized by the sector is allocated to clinker production, with the remaining processes relying mostly on electricity.

The alternative with the greatest decarbonization potential is the reduction of clinker usage in cement production. The main currently viable options to achieve this are fly ash, which arises from coal combustion, and granulated blast furnace slag (GBFS), which is generated as a waste product in blast furnace steel production. Other mitigation strategies for the sector include the use of alternative fuels for combustion and modern kilns. These are rotary kilns with precalciners and suspension preheaters, which are the most efficient solution for reducing emissions. In Latin America and the Caribbean, only 65% of plants use this type of kiln, with an average age of 29 years, higher than the global average of 18 years, indicating room for upgrading and gaining efficiency. Regarding fuel use, biomass is the most efficient and lowest-emission option.

Eighty-six percent of emissions of the entire cement value chain occur in the manufacture of clinker. Of that percentage, 60% comes from the calcination of limestone, while the remaining 40% comes from burning fuels for calcination

Steel

The sector accounts for 20% of energy consumption in industrial sectors globally and 8% of global energy consumption (IEA, 2020). The IEA projects that global steel demand by 2050 will increase by more than one-third from current levels. For this reason, there is tremendous pressure on the sector to decarbonize its production and meet growing demand with a relatively young furnace stock in developing countries.

Ninety-five percent of the sector's emissions occur in the steel production process and the finishing and distribution stages (Zoryk and Sanders, 2023). These emissions are mainly due to high energy consumption, as fossil fuels are the primary source.

Steel production can be carried out mainly via two routes. The most common is the primary route, which accounts for about 70% of global steel production and involves obtaining steel mainly from iron ore, usually using blast furnaces and basic oxygen furnaces. Blast furnaces are fed with iron ore, coke, coal, natural gas, carbon monoxide, and hydrogen to produce molten iron. This is then used in the basic oxygen furnace, along with scrap, to produce steel. An alternative to this process, which currently accounts for only 10% of global primary steel production, is direct iron reduction using natural gas first and then electric arc furnaces. This method is less GHG-intensive and has high decarbonization potential if the electricity used is generated from clean sources, although it has the disadvantage of requiring high-quality iron ore.[18]

The secondary route of steel production uses scrap as the main input and is carried out with an electric arc furnace, whose main source of energy is electricity rather than coal. Although this method emits significantly fewer GHGs, it alone would not be viable to meet the projected increase in iron demand by 2050, as scrap is required for its production.

One thing that sets Latin America and the Caribbean apart from the rest of the world is that both production methods are used in similar proportions. This difference in the greater use of the secondary route and the fact that the region's electricity matrix is relatively clean explains, in part, why emissions per metric ton of steel produced in LAC are lower than the global average. In 2019, these emissions (measured in kg CO_2/t) were 12% lower than in the rest of the world and 25% lower than in China.

In 2019, emissions per metric ton of steel produced were 12% lower than in the rest of the world and 25% lower than in China

Iron production generates other pollutants, including major air pollutants (SO_2, NOx, and $PM_{2.5}$) (IEA, 2020). The production process also contaminates the soil from the release of heavy metals. Most iron emissions are from energy consumption, given the high energy demand of furnaces to reach high temperatures. Therefore, technological solutions that would reduce emissions from this sector are mainly focused on substituting fossil inputs, improving efficiency, electrification, and carbon capture, use, and storage (CCUS).

The technologies that the IEA identifies as currently mature or in the early adoption stage include exhaust gas conversion into fuels, the use of biochar, and direct reduction of iron based on natural gas and electric arcs.

In addition to energy efficiency efforts, contributions from both the supply and demand sides are needed. On the supply side, progress has been observed in zero emissions announcements by major steelmakers. On the demand side, strong growth in demand for green steel has been noted, mainly driven by the transport sector.

The expansion of these green markets, along with announcements of carbon border adjustment mechanisms, reinforces the importance of regional steelmakers positioning themselves first in these markets, establishing themselves as pioneers in emissions-free steel.

Chemicals

The chemical industry encompasses several inputs that are crucial for economies. Among them are ammonia (key for fertilizers), methanol (with multiple uses as a solvent, antifreeze, fuel, or for the production of formaldehyde), and high-value chemicals (HVCs), from which, for example, plastics are derived. This industry is the main consumer of oil and gas as energy inputs and for the production of petrochemicals.

Chemical production and consumption emit GHGs in three ways. First, by using fossil fuels as an input for the manufacture of plastics, pesticides, and other chemicals. Second, by consuming large amounts of energy for the synthesis and processing of the final products. Finally, some of the substances produced are potent greenhouse gases, hydrofluorocarbons, for example, used in refrigerants and aerosols. In the production stage, ammonia is the main emitter

18 With a 100% green electricity matrix, these emissions would represent less than half of the primary process emissions.

of GHGs and the compound with the highest carbon intensity (Pupo and González, 2023). It is followed by methanol, whose production has shown the highest growth within the chemical industry, increasing by more than 20% between 2015 and 2020 (Pupo and González, 2023). Finally, HVCs are the least carbon-intensive.

Ammonia

Ammonia is an important input for fertilizer production and plays a crucial role in food security. This compound also serves as an emissions-free fuel.

The production process of ammonia requires high pressures and temperatures. More than 95% of the energy consumed in this process comes from fossil fuels. Additionally, natural gas is essential for hydrogen (H) synthesis, which is used as a key input in ammonia production. Ammonia production also involves the use of nitric acid (HNO_3), which, when produced, emits two air pollutants: nitric oxide (N_2O), a potent greenhouse gas, and NOx.

Methanol

Methanol production is intensive in the use of fossil fuels and is usually located in countries or regions with advanced petrochemical manufacturing. Methanol is mainly obtained from natural gas (60% of its production). This route is the most efficient given the high methane content in this gas. Almost all the remaining production of methanol (39%) is made from coal. There is a way to produce methanol from renewable sources, but it only represents 1% of production.[19]

High-value chemicals and plastics

High-value chemicals (HVCs) comprise compounds such as ethylene, propylene, benzene, toluene, and xylenes. The demand for these substances is mainly driven by the demand for plastic (Gabrielli et al., 2023). However, GHG emissions from plastic are higher than those from HVCs, given the energy intensity involved in the transformation process of these compounds (Gabrielli et al., 2023).

Plastic emits GHGs at every stage of its production and life cycle. Obtaining plastic resin from fossil fuels accounts for about 60% of the GHG emissions associated with this product, while its conversion into the final good contributes about 30%. The remaining 10% corresponds to emissions in the final stage of the plastic's life, attributed to its handling as waste, mainly occurring when it is incinerated, although there are also emissions related to its decomposition.

Decarbonization measures for the chemical industry

The main decarbonization measures in the chemical sector are carbon capture, use, and storage (CCUS), green hydrogen, electrification of production processes, and substitution of inputs with non-polluting alternatives. Demand-side measures include circularity and policies that limit the use of certain chemical products, like the ban on single-use plastics.

19 In this route, the main inputs are biomass (agricultural or forestry waste), CO_2 captured in other production processes and hydrogen obtained from renewable energy.

The main decarbonization measures in the chemical sector are carbon capture, use, and storage (CCUS), green hydrogen, electrification of production processes, and substitution of inputs with non-polluting alternatives

In the case of ammonia, energy efficiency measures account for 25% of mitigation efforts. These include adopting available advanced technologies, operational improvements, and substituting coal with natural gas or other less carbon-intensive fuels (IEA, 2021b). Carbon capture in the ammonia production process is already common.

For methanol, there are two main pathways for decarbonization in the short term. The first is the production of biomethanol from biomass. The other is green methanol or e-methanol, obtained from bioenergy with carbon capture.

The main measure for plastic in the short term is recycling, which has two main options. The first is mechanical recycling, which involves sorting, washing, grinding, and reprocessing plastic. This route has lower emissions since it mainly uses electricity. The second is chemical recycling, which allows for greater waste recovery but generates higher emissions. Substituting plastics with other materials does not clearly lead to GHG reductions.

Energy transition in the residential sector

Household energy consumption patterns depend on climate, access to different energy sources, income and energy prices, housing characteristics, as well as the price and availability of equipment and appliances for energy use and generation. The interaction of these factors over time, together with a series of historical characteristics of countries and regions, give rise to energy consumption patterns that condition the possibilities of transition. Four stand out.

1. **In Latin America and the Caribbean, the residential sector consumes significantly less energy than in the developed world.**

   Consumption per person in the region was 0.17 tons of oil equivalent (toe) in 2021 (OLADE, 2021). This value was well below the averages for China (0.46 toe), the United States (0.73 toe), and Europe (0.56 toe) (National Bureau of Statistics of China, 2022; EIA, 2020; Eurostat, 2022).

Energy consumption per person in the region is well below values in China, the United States, and Europe

This lower per capita residential consumption is explained by the low need for heating[20] and lower incomes on average in LAC compared to OECD countries. However, this could change as the region grows to close its income gap with the developed world. Also, global warming could increase cooling needs. Ownership of air-conditioning units in the region is expected to rise by almost 20 percentage points by 2050 as a result of the projected evolution of temperatures and incomes, which would increase total residential electricity consumption by 13%. This would also introduce strong seasonal variability, with implications for the required capacities of electricity systems.

20 Only a small group of countries have heating needs, including Argentina, Bolivia, Chile, Ecuador, Peru, and Uruguay. On the other hand, cooling needs are widespread.

2. **Economic growth has brought a cleanup of the household energy matrix in recent decades, but the challenge of excessive biomass use persists.**

   In 1970, firewood was the main source of residential energy in 23 of the 27 countries analyzed, reaching an average of 58% of total residential consumption. In 2021, electricity occupied this slot, with a 38% share, an increase of 30 percentage points compared to 1970 (OLADE, 2021). In general, the use of dirty energy in residential consumption, which includes kerosene in addition to firewood, fell from 82% in 1970 to 36% in 2021.

The use of dirty energy in residential consumption fell from 82% in 1970 to 36% in 2021. However, the role of fuelwood remains important in some countries

Although the role of firewood has decreased in residential consumption in all countries, in some it continues to be the most relevant source, accounting for 61% of total consumption on average. These countries are those with the lowest per capita income (including Guatemala, Haiti, Honduras, and Nicaragua), Chile, where it is used for heating, and Colombia, Paraguay, and Peru, where it is mainly used for cooking.[21] The challenge of transitioning to cleaner cooking sources is particularly relevant in rural areas, where the prevalence of dirty fuels is much higher[22]. On average, the prevalence of biomass in 2021 was 20 percentage points higher and that of gas was 20 percentage points lower in rural areas compared to urban areas.

3. **There has been a notable increase in access to electricity in the region, but there are still access gaps in rural areas of certain countries. Moreover, the informality of connections is a significant problem in urban areas.**

   Thanks to the progress made in recent decades, residential electricity coverage has grown considerably throughout the region, reaching universality in the countries with the highest per capita income. The access gaps that still exist in countries such as Bolivia, Colombia, Ecuador, El Salvador, Panama, and Peru are due to the lag in rural areas (see Graph 12).

   Solar generation is particularly attractive in rural areas where there is no electrical grid, as it allows access to electricity without incurring the cost of extending infrastructure. Initiatives of this kind are abundant in the countries of the region, notably Peru's Massive Photovoltaic Program, which brought electricity to over 200,000 households.

   In urban areas, the challenge of informal connections is relevant and poses two additional problems. On the one hand, informality entails health risks and deficiencies in the power and continuity of the electricity supply. On the other hand, the absence of meters means that the regulatory role of prices in electricity consumption is lost.

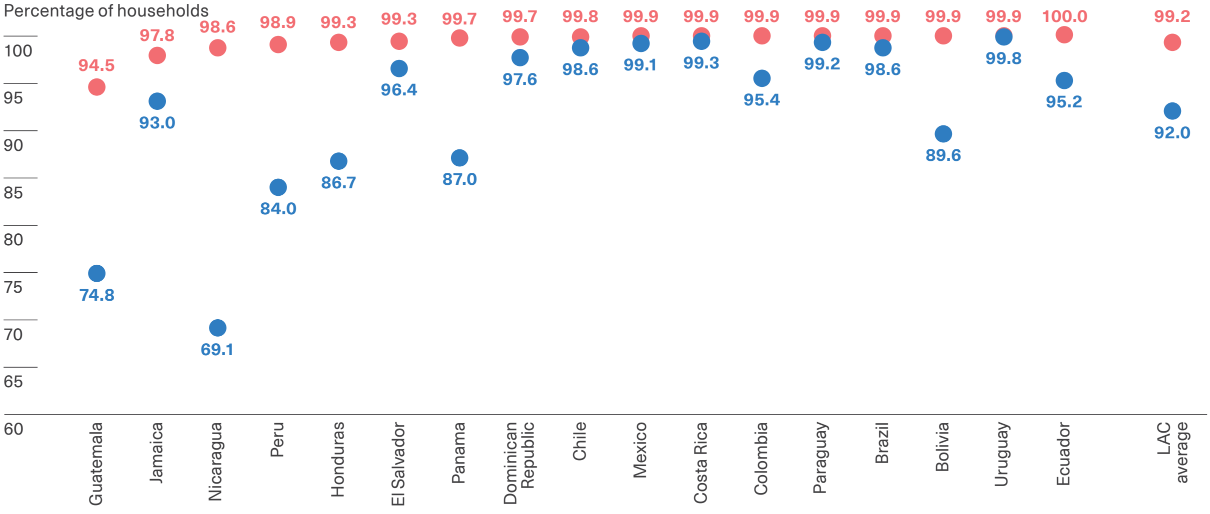
4. **Energy represents an important component of household budgets, especially for the poorest population segments.**

   On average, households spend 6% of their budget on energy, mostly on electricity, exceeding 10% among the poorest in some countries. This may be a challenge for the removal of electricity subsidies, which in some countries in the region (9 out of 32) exceed one point of GDP. Indeed, according to the 2018 edition of the Latinobarometer survey, in the average of 18 countries, 54% of respondents reported having had difficulties at some point in paying their electricity bill.

21 In some countries, such as Guyana, the most prevalent dirty source is kerosene, the consumption of which has also fallen considerably in the region.

22 Verma and Imelda (2023) find that access to clean cooking fuels has significant positive effects on health and labor supply, particularly for women.

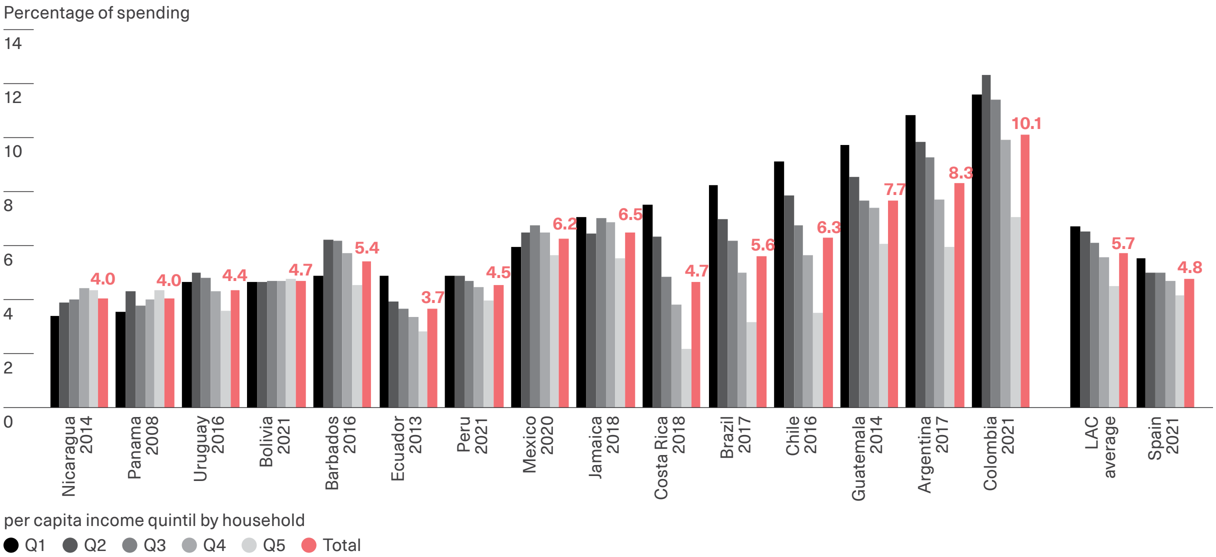
Graph 12
Proportion of households with electricity connection according to area of residence



Note: The variable was constructed from national household surveys.

Source: Puig and Tornarolli (2023).

Graph 13
Percentage of household spending devoted to residential energy consumption



Note: The graph shows the average share of residential energy spending in the household budget by household per capita income quintile in 15 LAC countries, the regional average and Spain. This expenditure does not include fuel consumption for transportation. The data were obtained from national household surveys in the period 2013–2021, with the exception of Panama (year 2008). In some countries, the household survey was conducted over two years. However, due to space constraints, only the data from the first year is shown in the graph. This is the case of Argentina (2017–2018), Brazil (2017–2018), Chile (2016–2017), Costa Rica (2018–2019), Ecuador (2013–2014) and Uruguay (2016–2017).

Source: Puig and Tornarolli (2023).

Policies for energy transition in the residential sector

The analysis above identifies three main challenges for achieving a successful energy transition in residential consumption. The policies for the sector can be formulated based on these challenges (summarized in Table 6).

Table 6
Potential policies for the three main challenges of the energy transition in the residential sector

Challenges	Target	Policies
Biomass cooking and heating	Replace appliances with more efficient or clean energy appliances.	Subsidies and financing for stove and cookstove replacement
		Information campaigns
Increase in electricity demand	Improving the efficiency of appliances and buildings	Subsidies and financing for the replacement of old appliances
		Minimum standards and labeling
		Information campaigns
	Promote more efficient use of electricity	Information campaigns that include consumption comparisons with other households
		Dynamic pricing and no generalized subsidies
		Connection regularization programs
	Generating electricity in homes	Subsidies and financing for the purchase of solar panels targeted to lower-income households
Access to quality electricity for the poorest households	Containing the impact of electricity spending on poor households	Electricity rate subsidies targeted to lower-income households
		Electricity block rate
	Providing access to electricity in rural areas	Subsidies and financing for the purchase of solar panels targeted to lower-income households
	Formalizing irregular connections in urban areas	Electricity rate subsidies targeted to lower-income households
		Electricity block rate
		Connection regularization programs

Challenge 1: Changes in cooking and heating technologies

While switching to electric power is the ideal solution in this area, it requires transmission and distribution networks, which in rural areas of some countries are not always present, and a change of equipment and habits, which can be costly. The option of natural gas has a similar problem. Liquefied petroleum gas, although not environmentally optimal, is much easier to distribute, so it could be considered as a transitional alternative until access to electricity improves.[23]

23 However, it should be considered that part of the emission reduction gains from the use of LPG may be reduced because the distribution of LPG involves transportation that is generally carried out with combustion vehicles.

However, there is room for improvement, maintaining biomass as a source, but taking advantage of the latest advances in its use. For example, in the case of stoves, which are widely used for heating in Chile and Uruguay, those fueled with pellets are more efficient and cleaner in terms of particulate matter production than traditional firewood stoves (Boso et al., 2019).

●●

Informational interventions appear as cost-effective alternatives to reduce residential sector emissions

The low use of these cleaner alternatives may be due to unwillingness to pay or lack of awareness of the health benefits involved. Therefore, two types of strategies can be considered: 1) subsidizing the acquisition of more efficient devices and 2) information and education interventions. These policies are complementary, as subsidies for the adoption of new technologies may not be effective if they are not accompanied by an information and education component (Hanna et al., 2016).

Challenge 2: Promoting energy efficiency in households

Interventions to improve efficiency and promote savings in electricity consumption can be grouped into three categories: 1) improving the efficiency of household appliances and buildings through subsidies or mandatory standards; 2) providing information and education for both the adoption of new, more efficient appliances and the use of existing ones; and 3) modifying the level and structure of energy prices.

The available evidence on subsidies for the acquisition of more efficient equipment shows limited effects, although usually positive depending on the type of appliance and, in some cases, with low cost-effectiveness. Evaluations carried out in Mexico for refrigerators and air conditioners show a reduction in electricity consumption, but at a high cost, estimated at more than USD 500 per ton of CO_2.

Another energy efficiency policy is the improvement of housing envelopes. In the region, there are construction quality deficits, which imply poor thermal insulation conditions of buildings.[24] The two most relevant specific policies for the improvement of housing energy efficiency are the inclusion of minimum standards in building codes and informational campaigns. Given that there are serious housing affordability problems in the region, public policies should be especially careful in evaluating the cost-benefit of energy efficiency interventions in buildings so as not to contribute to this problem.

The adoption of minimum standards in household appliances has more favorable evaluations and has been widely implemented in the world in the last four decades. The region lags behind, especially in water-using appliances, such as washing machines and dishwashers, where standards cover only 20% of consumption, and in appliances with displays, where the coverage is null, in contrast to around 70% for the global average.

Regarding information interventions, there are three main types: household appliance labeling, providing information about one's own and neighbors' electricity consumption levels,[25] and informational campaigns.

As for pricing policies, while the increase in prices can indeed promote efficiency and savings in household electricity consumption, it faces difficulties. First, short-term responses are relatively limited, with reductions of 2% to 4% in consumption for every 10% increase in prices. Second, energy consumption already represents a significant fraction of the household budget for the poorest.

24 Bolivia stands out, where almost half of its population resides in buildings with some type of deficit.

25 One particularly successful method for individual households to provide information about their consumption is by comparing it with the consumption of neighbors with similar characteristics (Allcott, 2011; Ayres et al., 2009; Costa and Kahn, 2013). Evaluation of such an intervention in Quito showed a reduction in average monthly consumption of about 1% (Pellerano et al., 2017).

Moreover, the introduction of dynamic pricing faces the additional obstacle that households have difficulty reacting to tariff schemes that are more efficient but more complex. Furthermore, there is a technological or infrastructure obstacle due to the need to install special meters in households.[26] Also, price increases can reduce informality.

Challenge 3: Improving household access to quality electricity

This challenge involves acting on multiple dimensions. The first one consists of containing the impact of electricity expenditure on household budgets. Two tools can be used for this: targeted subsidies and increasing block electricity tariffs. However, the penetration of renewable energy sources may favor a shift toward tariff schemes with a greater emphasis on the fixed component, which may impact affordability.

The second dimension refers to providing access to electricity for poor households in rural areas. Subsidizing the purchase and installation of solar panels can improve access in these areas.

Lastly, it is necessary to improve irregular connections to electricity grids and thus overcome the access problems they pose. Progress in solutions in this area has two facets. One coincides with the household budget problem, raised in the first dimension, and with the corresponding policy tools. The other facet relates to the infrastructure and management aspect of electricity distribution, as it is necessary to install cables and meters to regularize the situation of neighborhoods that are irregularly connected to the grid.

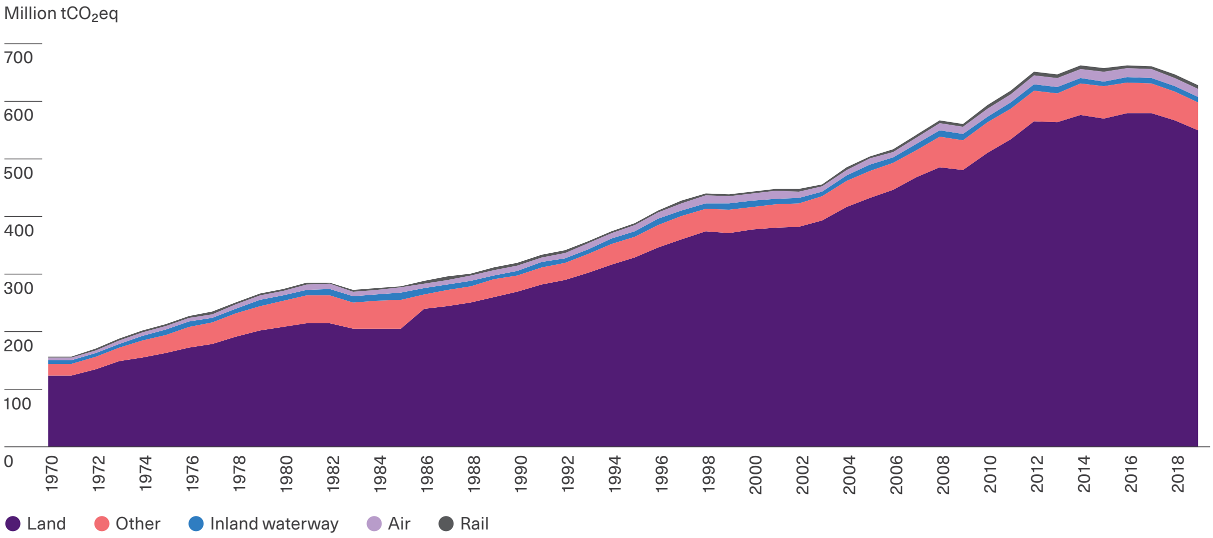
Transportation and energy transition: toward sustainable mobility

The transport sector in Latin America and the Caribbean generates 12% of direct GHG emissions and 25% of energy emissions in the region. Of these emissions, the vast majority are produced by road vehicles. These release 85% of total transport emissions in Latin America and 88% of those in the Caribbean (Minx et al., 2021). Approximately half of these emissions correspond to automobiles and the rest to freight vehicles and buses (Vergara et al., 2021). Road transportation GHG emissions tripled in the last half-century due to the increase in both the number of private automobiles and cargo trucks (Graph 14).

The transport sector in Latin America and the Caribbean generates 25% of the region's energy emissions. Of these emissions, the vast majority are produced by road vehicles

26 Several studies have shown that consumer response to tariff mechanisms designed to improve efficiency does not yield the expected results, among other reasons because of the difficulty in understanding them (see Chapter 7 of the report for more details).

Graph 14
GHG emissions of the transportation sector in Latin America and the Caribbean



Note: The graph shows the evolution of GHG emissions from the transport sector, measured in million tons of carbon dioxide equivalent ($MtCO_2eq$) in LAC over the period 1970–2019, and their distribution by mode of transport. The gases included are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases. The transport sector is divided into land, inland waterway, air, rail, and other (where pipeline transport is included).

Source: Authors based on data from Minx et al (2021).

Table 7
Challenges and policies in the transportation sector for the energy transition

Challenges	Target	Policies
Rising emissions and equity gaps in urban passenger transportation	Increased modal share of public transport	Public transportation infrastructure
		Increased modal share of walking trips
	Lower modal share of individual cars	Safe infrastructure for pedestrians and cyclists
	Menor participación modal del automóvil individual	Congestion, parking, vehicle ownership and gasoline taxes
	Vehicle electrification	Facilitating the development of electric vehicle charging networks through subsidies and regulations
		Reducing emissions from heavy freight transport
Freight transportation emissions on the rise	Reducing emissions from light freight transportation	Fossil fuels taxation
		Increasing property taxes according to the age of the vehicle
		Development of rail infrastructure where it is cost-effective
	Disminuir las emisiones del transporte de carga liviana	Fossil fuels taxation
		Facilitating the development of electric vehicle charging networks through subsidies and regulations
		Financing for fleet renewal

Emission reductions in transportation will be achieved through increased use of the least polluting forms of transport, electrification of engines, and efficiency improvements in internal combustion engines and the logistics chain

An energy transition in the transportation sector that reduces GHG emissions will be achieved through three mechanisms: 1) greater use of the least polluting modes of transport; 2) electrification of engines; and 3) efficiency improvements in both internal combustion engines and the logistics chain. There are different policies to promote these mechanisms, which can be ordered according to whether they involve passenger or freight transport (Table 7).

Transportation of people in cities

Households in large cities in Latin America and the Caribbean spend an average of 1.5 hours daily and 17% of their income on urban travel (Gandelman et al., 2019). This relevance of urban mobility to well-being means that the demands for lower emissions must be considered alongside those for better access to commuting opportunities.

Emissions related to these trips depend on two main factors: mode of transport and distance. Both factors are influenced by urban form (Stocker et al., 2013). Urban forms with higher density imply shorter distances between origins and destinations and, therefore, less energy consumption and emissions. Cities in the region have slightly higher average density levels than European cities and are similar to those in the Middle East and North Africa (Daude et al., 2017). The challenge for the future in this regard is that, as income increases, cities tend to grow more in area than in population (Moreno-Monroy et al., 2021), increasing the distances to be traveled and creating pressure for more car use.

Regarding modes of transport, average energy consumption varies greatly among them, with cars far outstripping the rest, and walking, cycling and the train presenting the lowest energy consumption levels (see Table 8). Regarding the predominant fuel, cars, buses, and BRT rely on fossil fuels, while streetcars, trains, and subways typically run on electricity. Active modes are powered by people. Different combinations of energy quantity and fuel type result in very disparate emissions among the different modes. For example, the emissions per kilometer and passenger of a gasoline-powered car are five times higher than those of a diesel-powered bus and a hundred times higher than those of an electric bus (MOVÉS, 2021).

If urban transport emissions are to be reduced, car usage must be reduced while active modes and public transportation must be increased

Given the differences in energy intensity and fuel usage, individual car usage must be reduced while active modes—walking and cycling—and public transportation must be increased If urban transport emissions are to be reduced. Data from the Urban Mobility Observatory (OMU) suggest that sustainable modes dominate urban passenger transport in Latin America and the Caribbean (see Table 9). One area for reducing emissions in public transport is the electrification of buses. Lastly, a challenge for the region is to ensure that the increase in per capita income does not translate into a greater share of private cars in travel modes.

Table 8
Efficiency and energy consumption of different modes of urban transport

	Car	Bus	Bicycle	BRT	Walking	Tramway	Train/metro
Passengers per hour	2,000	9,000	14,000	17,000	19,000	22,000	80,000
MJ/passenger-km	1.65-2.45	0.32-0.91	0.1	0.24	0.2	0.53-0.65	0.15-0.35
Predominant fuel	Fossil	Fossil	Food	Fossil	Food	Electricity	Electricity
USD/passenger-km infrastructure	2,500-5,000	200-500	50-150	500-600	50-150	2,500-7,000	15,000-60,000

Note: The table shows, for different modes of transportation, the number of passengers that can travel comfortably and safely, taking as a reference European and Asian cities; the energy intensity per passenger-kilometer (measured in megajoules); the infrastructure costs per passenger-kilometer (in dollars); and the predominant type of fuel for its operation. In the case of bus energy intensity, the lowest value corresponds to Austria, while the highest is for Mexico. Originally in euros, the infrastructure cost was expressed in US dollars using the exchange rate in effect in the year to which the data refer (2010).

Source: Figueroa et al. (2014).

Along with urban form, the quality of public transport and its relative price are determinants in travelers' choices and influence modal distribution in cities. Regarding quality, four major issues are low service frequency, the state of public transport fleets, long travel times, and safety deficiencies, which affect women more (Daude et al., 2017). On the other hand, there is room to promote energy transition in transportation through higher gasoline taxes and public transport subsidies.

Regarding private passenger transport, technologies for decarbonization are relatively advanced. The explosive global growth of electric vehicles can be explained by the emergence of more affordable models, overall improvements in their range and performance, and the existence of strong subsidies in some countries.

A fundamental aspect for the adoption of electric vehicles is charging infrastructure. This has emerged as a main constraint hindering faster adoption in developed nations (Climate Group, 2023). However, Latin America and the Caribbean has the advantage that the autonomy of electric vehicles is, in general, sufficient for daily urban use, given that the distances to be covered in the region's cities are not excessive. In addition to the number of chargers, the quality and reliability of these devices are important. The increased use of these chargers can generate congestion not only in the charging devices themselves, but also in the power grid. -An electric car may be more environmentally friendly than a fossil fuel-based car; however, electrification is far from being an integral solution for car-use-related problems. First, it is very costly for the incomes of most households in the region. For the average Latin American and Caribbean household, paying for a fossil fuel car requires 6–14 years of income, while the cheapest electric vehicle requires almost 17 years. The higher price of electric vehicles is mainly due to the cost of their batteries. In addition, there is not a large market for used electric vehicles in Latin America and the Caribbean, which would make them cheaper to purchase. Secondly, their potential to reduce emissions depends on the countries' electricity generation matrix being mostly clean.

Thirdly, electrification does not resolve some negative externalities of car use, such as congestion, whereas others, such as accidents, may even worsen due to the greater weight of electric vehicles.

Despite the advance of electric vehicles, fossil fuel demand for transportation is expected to continue to increase until 2050 in most developing countries, driven to some extent by population growth (IEA, 2023b). Due to this increase in demand, emission reduction will require the use of hybrid vehicles, as they are more efficient than internal combustion vehicles, and the implementation and development of technologies that achieve the same goal, including the use of biofuels, such as bioethanol, biodiesel, and biogas.

Table 9
Modal split in 10 large cities

	Bogotá	Buenos Aires	Mexico City	Curitiba	Montevideo	Panamá	Rio de Janeiro	Salvador de Bahia	São Pablo	Santiago de Chile
Public	**34.2**	**37.8**	**45.5**	**25.2**	**28.4**	**38.1**	**47.3**	**34.9**	**30.9**	**19.8**
Subway/train	0.0	11.2	11.9	0.0	0.0	1.0	6.2	0.0	11.1	5.9
Bus/BRT	34.2	26.6	33.6	25.2	28.4	37.1	41.1	34.9	19.8	13.9
Active	**32.1**	**28.5**	**30.3**	**25.4**	**36.5**	**8.3**	**28.3**	**36.2**	**32.7**	**41.2**
Walking	24.7	24.5	28.5	23.3	34.7	8.1	27.2	35.3	31.8	36.9
Cycling	7.4	3.9	1.8	2.1	1.8	0.2	1.0	0.9	0.9	4.3
Individual motorized vehicles	**24.5**	**31.5**	**23.1**	**49.0**	**35.1**	**45.4**	**23.4**	**22.4**	**30.6**	**33.0**
Car	14.3	26.8	16.9	45.8	31.7	35.2	22.7	19.1	27.0	27.5
Taxi	4.5	1.6	5.3	0.5	1.0	9.3	0.0	1.4	1.1	4.9
Motorcycle	5.7	3.1	1.0	2.7	2.5	0.9	0.7	1.9	2.5	0.6
Others	**9.1**	**2.3**	**1.1**	**0.4**	**0.0**	**8.3**	**1.0**	**6.3**	**5.8**	**6.0**
Year	2019	2018	2017	2017	2016	2014	2011	2012	2017	2012

Note: The table shows the percentage distribution of daily trips by main mode of transport for ten cities in seven LAC countries, for the period 2011–2019 (varies by specific city). The data were obtained from the processing of mobility surveys. The category "Taxi" is not reported for Rio de Janeiro.

Source : Authors based on data from OMU (2023).

Cargo transport

Cargo transport accounts for nearly half of the emissions from land transport globally, despite representing only 8% of vehicles. In LAC, more than 85% of freight transported travels by road and there are some signs of significant inefficiencies in this subsector. On average, a truck in the region travels about 62,000 km per year, 40% less than in the United States and the European Union, and 40% of trips are made with empty trucks, compared to 25% in North America.

The three main technological alternatives for decarbonizing cargo transport include electrification, the use of alternative fuels such as natural gas, green hydrogen, and biofuels, as well as increased utilization of railways.

A truck in Latin America and the Caribbean travels approximately 40% fewer kilometers per year than in the United States and the European Union; in turn, 40% of the trips are made with empty trucks, compared to 25% in North America

Heavy-duty trucks face significant challenges for electrification. One option for these trucks is natural gas, which, although not emission-free, generates fewer GHG emissions than diesel and gasoline and is abundant in Latin America and the Caribbean.

Green hydrogen, while offering zero emissions, greater autonomy, and faster recharging compared to electric trucks, is not yet widely used due to the difficulty and high cost of its production, storage, and distribution (Cantillo, 2023). Biofuels have been an alternative for several years but represent only 4% of the total energy use in this subsector (IEA, 2022).

Rail freight transport consumes, on average, only 15% of the energy used in land freight transport (Gross, 2020). However, the infrastructure for trains is expensive, making this alternative economically viable only when a route reaches a sufficiently high cargo scale.

Urban logistics

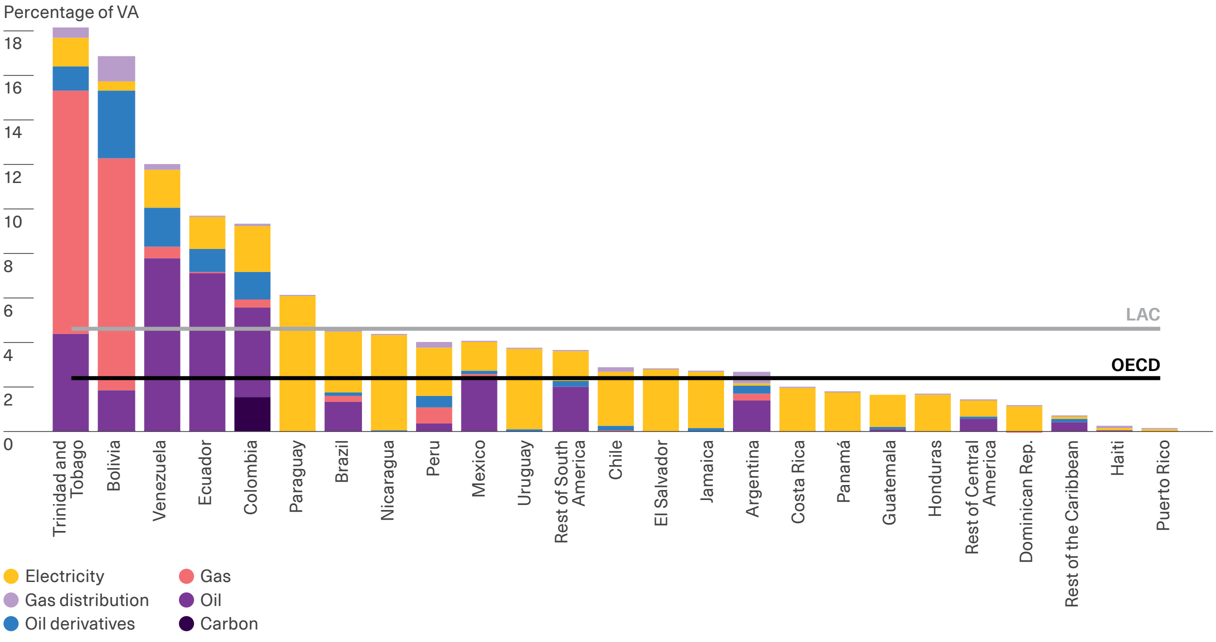
Light-duty vehicles, mainly used for last-mile transport, have significant potential for electrification. These vehicles are leading the decarbonization of cargo transport as they generally travel shorter distances and more frequently.

Urban logistics pose special challenges and opportunities in the context of the energy transition. As for challenges, the greater contribution of trucks to greenhouse gas emissions and other pollutants in urban environments compared to their role in the overall vehicle fleet is also observed in cities. This is due to three factors. The first factor is that freight transportation involves moving more weight than passenger transportation, requiring higher power, which generates more emissions. In this sense, the main opportunities for electrification lie in small and medium-sized vehicles. A second factor is that the higher share of trucks in emissions is mainly due to the fact that the level of use of these vehicles is higher than that of private vehicles, which improves the economic equation for electrification. The third factor is specific to the region and has to do with the greater informality and age of the urban logistics fleet (SPIM-Taryet, 2019).

Part IV
Toward a just transition: Opportunities and challenges

The energy sector has a greater contribution to value added in Latin American and the Caribbean countries than in OECD countries. While in the former region, it provides 4.6% of value added, the share is 2.5% in the latter. These figures hide, however, great heterogeneity in the region. In countries such as Trinidad and Tobago, Bolivia, and Venezuela, the energy sectors account for 18%, 17%, and 12% of value added, respectively; in others, such as Haiti and the Dominican Republic, their contribution is less than 1%. This shows that the aggregate impacts of the transition will be very uneven.

Graph 15
Share of the energy sectors in value added by country



Source: Authors based on Aguiar et al. (2022).

Given the importance of the energy sector in the region, the transition will bring with it a set of challenges in both the macroeconomic and labor spheres. This is due not only to the direct effects on the energy sector but also to important indirect effects through production linkages.

Macroeconomic challenges of the energy transition

The exploitation of fossil resources is associated with two key factors: fiscal and external revenues they generate. Hydrocarbon-producing countries will face a double shock due to a potential reduction in both types of revenues. Countries like Bolivia, Colombia, Trinidad and Tobago, and Venezuela are net energy exporters and these sales represent a significant portion of their total exports of goods and services, as well as important sources of fiscal revenue. This double impact will require a productive and fiscal transformation to adapt the economy to the new context. On the fiscal side, the transition may involve the introduction or redesign of some existing taxes. Of these, a special type are those linked to the environment, such as taxes on fossil energy, transportation or emissions, which serve a dual purpose: to improve revenue collection and promote efficiency by reducing the negative externality generated by emissions.

Hydrocarbon-producing countries will face a double shock due to the potential reduction of fiscal and external revenues

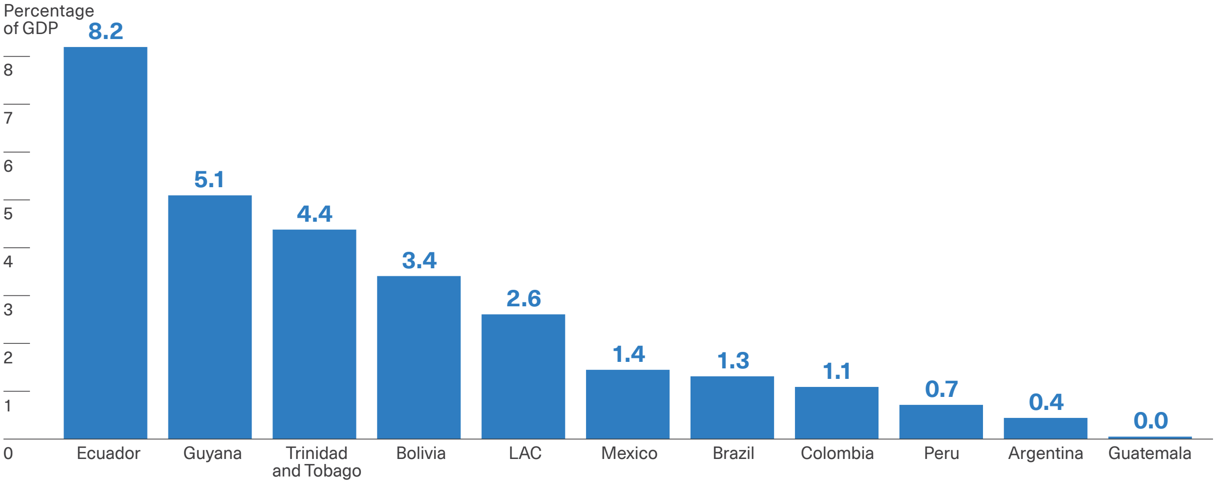
However, the energy transition will not only have an impact on hydrocarbon producers but also on energy importers. Within this group, two sets of countries can be defined. On the one hand, there are energy importers with high potential for energy production from renewable sources, such as Chile. For these countries, a window of opportunity opens up, as they can generate tax revenues by exploiting these resources and, at the same time, reduce energy imports, improving their external accounts. On the other hand, countries with low production potential with renewables may be affected by an increase in the price of energy and a reduction in supply.

In turn, energy is a key input for many sectors of the economy and, therefore, changes in prices can quickly spill over to the rest of the economy. This spillover can come through different channels, such as climateflation, fossilflation, and greenflation.[27] Increased volatility in energy prices, in particular, and the economy in general, presents new challenges for monetary policy.

A crucial component of current monetary policy is clear and precise communication of its expectations, goals, and actions. Increased price volatility, especially if it corresponds to factors that are not under the control of the monetary authority, can affect its credibility and, therefore, the effectiveness of monetary policy. Faced with this, it will be necessary to incorporate these effects and take action to preserve the independence and credibility of the monetary authority while addressing the new price scenarios.

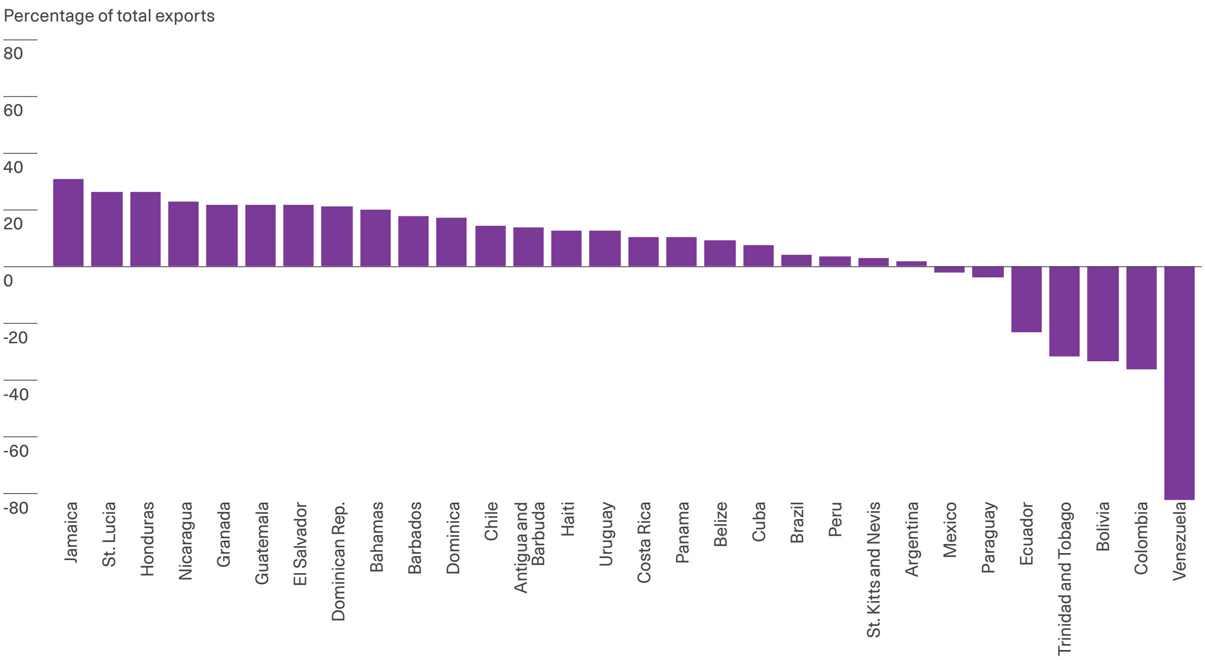
27 Schnabel (2022) defines climateflation as an increase in price levels caused by a higher frequency of extreme weather events and natural disasters, affecting the supply of goods; fossilflation refers to an increase in price levels caused by an increase in the price of fossil fuels; and greenflation refers to an increase in general price levels caused by a rapid growth in the demand for clean energy, putting pressure on the supply of certain inputs, like critical minerals, and resulting in higher prices for these products and, therefore, for energy.

Graph 16
Fiscal revenue generated by the exploitation of fossil resources



Source: Authors based on data from ECLAC (2023).

Graph 17
Average net energy imports as a percentage of total exports of goods and services in the period 2006–20196



Source: Authors based on data from UNCTAD (2021).

Beyond monetary policy, the sustainability of the financial system may be affected. As the economy shifts away from fossil fuel consumption, the capital and reserves associated with fossil fuels may become stranded. This abandonment will affect the economy as a whole, including the financial sector, because many of these assets were used as collateral. The Carbon Tracker Initiative (2017) suggests that between 20% and 30% of the market capitalization of the stock exchanges in London, São Paulo, Moscow, Sydney, and Toronto is related to fossil fuels. The industry linked to these fuels is large enough to cause financial stress if the transition to renewable energy is disorderly and panic erupts in the market (Van Der Ploeg and Rezai, 2020).

This imposes financial regulation challenges in terms of direct resources to finance sustainable projects and to ensure that the energy transition is orderly and with the least possible impact on the financial system's sustainability.

Labor market challenges and opportunities

It is expected that the energy transition will have an impact on employment levels (Saget et al., 2020), as well as on the profile of skills and tasks to be performed (Vona et al., 2018). The process of labor reallocation can be more or less traumatic depending, for example, on how different green jobs and technologies are from the rest of the economy and on the existence of institutions that favor this process.

Most workers are concentrated in non-green occupations. The numbers range from at least 62% in Honduras to over 75% in Uruguay. These high proportions may offer an indication of how large the job reallocation between occupations can be. The immediate question that arises is: how different are green jobs from non-green ones?

Green jobs demand a higher proportion of men and people 31–50 years old. They are more often located in the private sector, in larger companies, and are more likely to be formal, full-time jobs than non-green jobs. They also pay higher wages, demand more skills, and involve a higher intensity of abstract tasks.[28] Job vacancies posted by companies confirm that green jobs require more skills and are better paid (García-Suaza et al., 2023).

Green jobs pay higher wages, demand more skills, and involve a higher intensity of abstract tasks

The energy transition may also affect aggregate employment levels. The limited existing evidence indicates that the effects vary according to the technology and the phase under consideration (construction versus operation and maintenance). For example, Fabra et al. (2023) find significant local employment effects in the case of solar plants in Spain, especially in the construction phase. In contrast, they find no significant effects for wind power plants, either in the construction or maintenance phase. When focusing on local unemployment, the effects are weakened compared to those on employment, even for solar plants. This suggests that local energy companies hire local workers as well as workers from other municipalities. The differences between the local employment multipliers of investments in solar and wind power are explained by the different skills required by each technology, with investments in wind power requiring more specialized workers.

28 In the region, the green job premium is reduced by almost 20% when incorporating controls for job characteristics, firm (especially size), workers' skills, and the level of abstraction of their tasks. However, even incorporating such controls, there is a considerable unexplained wage gap. In contrast, in OECD countries, by introducing these controls, the wage gap between green and non-green jobs disappears.

In the region, specifically in Brazil, wind energy projects are associated with an increase in the number of companies and jobs, as well as in workers' income (Hernández-Cortés and Mathes, 2024).

Looking ahead, under the IEA's Announced Pledges Scenario (2023) for the region, jobs in the energy sector are expected to grow by 15% by 2030 compared to 2022, with a significant part of this increase coming from the clean energy sector, where they will increase from three million to four million jobs. However, to take advantage of these opportunities, institutions must be in place to alleviate the cost for people who lose their jobs and facilitate their reassignment to new jobs.

Table 10
Differences between green and non-green jobs

	Latin America and the Caribbean		OECD	
	Not green	**Green**	**Not green**	**Green**
Man	0.5	0.68	0.42	0.8
Higher education	0.24	0.2	0.4	0.33
Higher education (private employment)	0.16	0.18	0.32	0.31
18–30 years old	0.35	0.3	0.25	0.2
31–50 years old	0.47	0.53	0.48	0.53
Over 50	0.18	0.17	0.25	0.2
Medium or large companies	0.28	0.52	0.38	0.48
Private sector	0.78	0.92	0.71	0.88
Formality	0.63	0.79	0.9	0.93
Full time	0.7	0.87	0.7	0.9
Abstract tasks	-0.09	0.26	-0.09	0.08
Routine tasks	0.11	0.08	0.11	0.13
Numerical skills	0.06	0.15	0.17	0.32
Hourly wage (in log).	1.7	1.91	2.61	2.73

Note: The table reports averages of observable variables for green and non-green jobs, using data from the Programme for the International Assessment of Adult Competencies (PIAAC). Hourly wage calculations exclude Peru due to data unavailability. The list of LAC and OECD countries considered in the table can be found in the annex of Chapter 10 (available online).

Source: Authors based on Allub et al. (2024).

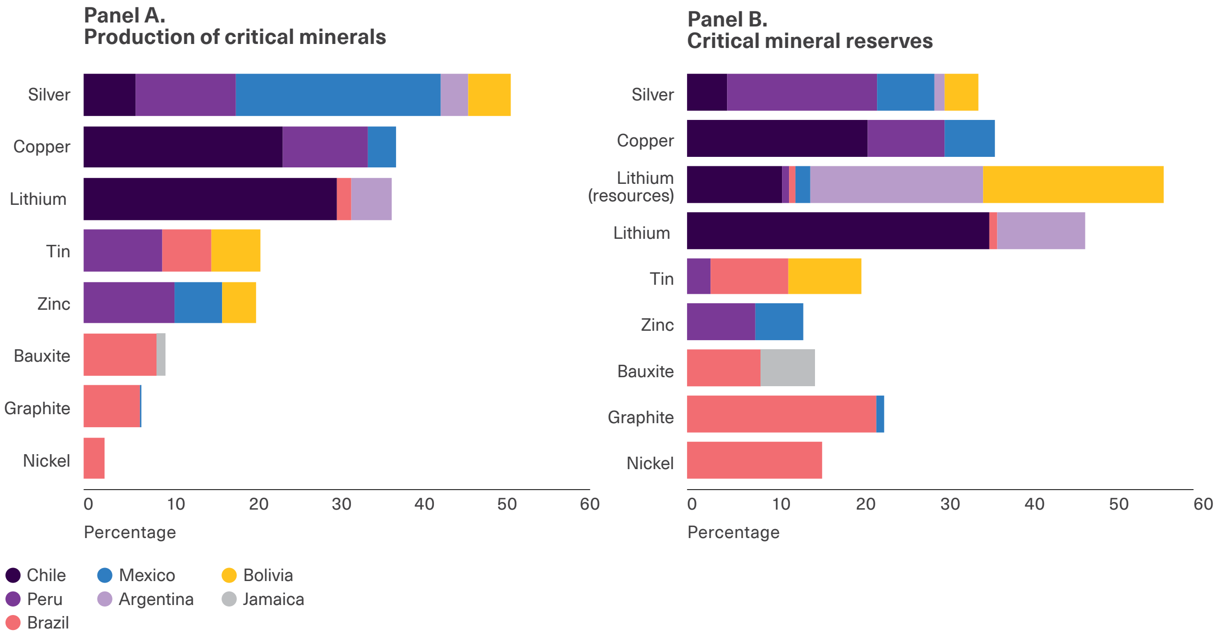
Challenges and opportunities for productive development: Critical minerals and powershoring

The energy transition brings with it a notable increase in demand for critical minerals, like lithium and copper. Certain technologies necessary for the transition, including batteries and electric vehicles, solar, wind, geothermal, or hydroelectric generation sources, or hydrogen production, will require one or more of these minerals for their production and deployment.

This increased demand offers opportunities for several countries in the region that have significant reserves and levels of production of these minerals. For example, silver, lithium and copper reserves in Latin America and the Caribbean exceed 30% of global reserves and production (Graph 18), making the region a key player in the clean energy value chain.

Countries rich in these minerals have the possibility of participating in different stages of the global chain of these technologies, not only as producers, but also by generating jobs and tax revenues in the localities where these resources are found. However, the expansion of mining poses environmental challenges, from the pollution of local watercourses to the loss of biodiversity.

Graph 18
Latin America and the Caribbean's share of critical mineral production and reserves in 2022



Note: A mineral resource is a concentration of minerals that have been identified and measured with reasonable certainty, but whose extraction has not yet been demonstrated to be economically viable. A mineral reserve is a portion of a mineral resource that has been demonstrated to be economically and legally mineable under current socio-economic and operating conditions.

Source: Authors based on U.S. Geological Survey (2023).

The region's great potential to produce clean energy opens another window of opportunity. As the world assigns a social cost to carbon, with mechanisms such as carbon taxes or carbon border adjustments, the carbon footprint of products will become a fundamental part of firms' costs. This will determine location and production patterns to reduce their carbon footprint and thereby gain competitiveness. The broad access to clean energy in Latin America and the Caribbean can therefore become a determining factor in the location and production of companies, attracting investment, a phenomenon known as powershoring.

The region's great potential to produce clean energy is an opportunity to attract investments in energy-intensive sectors

This potential to attract investment will be especially relevant in sectors with high levels of energy intensity and the possibility of being easily traded, for example, aluminum. According to estimates, border adjustment mechanisms to be implemented by the European Union on its imports would imply a tariff of 17% for aluminum from China and more than 40% for aluminum from India, where the energy matrix is less green and does not have developed carbon markets.

In order to take advantage of both opportunities, it will be essential to develop an investment-friendly business environment and ensure that investment is made with the best available practices, guaranteeing environmental care and preservation of local biodiversity so as not to compromise environmental objectives.

A comprehensive agenda for a just energy transition and its political economy challenges

This edition of CAF's Report on Economic Development outlines priority actions related to the energy strategy at length. These include both supply-side (Part II) and demand-side (Part III) actions as well as some cross-cutting policies. Among these cross-cutting policies, the following stand out:

1. **Green financing.** The transition will require significant investments in infrastructure and capital, which will require financial resources. Channeling funds to green projects will be essential to achieve the emissions targets that countries have set themselves and the objectives of climate justice through financing from developed countries. A key ingredient for this is the development of green taxonomies that transparently categorize which projects will be eligible for funding.
2. **Carbon pricing**, including carbon markets and carbon taxes: These policies provide price signals to society to correct the negative externalities generated by carbon emissions, bringing the quantity of emissions closer to the social optimum.
3. **Carbon capture, use, and storage (CCUS) technologies**: Even in the most optimistic decarbonization scenarios, fossil fuels continue to appear as necessary, either as backup for renewable electricity generation or as inputs in industries that are difficult to decarbonize.
4. **Circular economy**: These policies promote recycling and reuse of already produced goods to reduce the need for mineral extraction and production of certain materials, such as plastics or cement.

However, this new energy transition is a complex and transformational phenomenon for the economy as a whole. It must be addressed simultaneously with other non-energy mitigation strategies and concurrently with other development issues in the countries of the region. Consequently, to seize the opportunities and overcome the challenges associated with this transition, the region must manage a range of policies that go beyond the purely energy sector, recognizing the importance of incorporating an agenda of productivity, inclusion and macroeconomic management to achieve sustainable development.

Moreover, the energy transition involves costs and benefits that are not evenly distributed among the various stakeholders, leading to a reconfiguration of interests and powers at both national and global levels. Understanding the challenges of the political economy of this transition is key to advancing the agenda outlined in this report.

An initial source of resistance is social. Global climate objectives imply that the transition must occur relatively quickly. This could entail, at least in its initial stage, higher energy costs compared to current energy alternatives. In other words, in the short term, the transition may generate energy impoverishment as renewable sources may not be available to the necessary extent, and there is potential for fossil fuels to become more expensive due to policies such as carbon taxation.

A second source of resistance arises from the presence of stranded assets and the large losses that their abandonment would imply for economies dependent on fossil energy sources. These losses can also be very unevenly distributed within regions and countries. This is exacerbated for those economies with low potential for renewable energy development and lack of critical minerals.

A third source of resistance relates to the rapid growth in global energy demand. Meeting this demand remains a strategic priority for countries' economies, which may hinder the fulfillment of national and international commitments to cut GHG emissions. This explains why some countries (the United States, China, Germany) are increasing the use of renewable energies while continuing to invest in fossil fuels (Bukowski, 2021).

Each country will experience the energy transition at its own speed, adopting strategies and policies appropriate to its reality and possibilities

The policy agenda described above alleviates these challenges by seeking to improve the trade-offs between emissions and growth, maximizing the opportunities that the energy transition offers the region, and prioritizing citizen protection.

As in other areas of economic policy, there is no single recipe or one-size-fits-all combination of solutions. Each country will experience the energy transition at its own speed, adopting strategies and policies appropriate to its reality and possibilities. But yet taking into consideration how the transition will occur in the rest world, including the developed economies.

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Report on Economic Development 2024.
Renewed energies: A just energy transition for sustainable development.

The preparation of the Report on Economic Development (RED) is the responsibility of the Socioeconomic Research Division of CAF's Department of Knowledge. Lian Allub and Fernando Álvarez oversaw the editing of the report content, with the assistance of Martín Finkelstein. Ana Gerez was responsible for style and editorial corrections.

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Since the beginning of the industrial revolution, economic growth has been closely tied to the increase in greenhouse gas emissions and its consequent impact on climate change. The adverse effects can already be observed, leading to rising temperatures and a greater frequency of extreme weather events, such as floods and droughts. If this process continues, emissions could reach levels inconsistent with life on the planet. One of the main culprits behind the generation of these gases is the consumption of fossil fuels, making energy transition an indispensable imperative for achieving sustainable development.

This report underscores the need for a just energy transition in Latin America and the Caribbean, considering the realities of each country and the need to address, simultaneously, historic development lags, including the gap in per capita GDP compared to the developed world and the region's high levels of poverty and inequality.

On the energy supply side, the report highlights the importance of increasing the presence of renewable energies in energy matrices and replacing fossil fuels with cleaner alternatives, as well as the role that gas can play in the transition. On the demand side, the report explores energy efficiency, changes in behavior and industrial processes (including principles of circular economy), sustainable mobility, and the electrification of industry and household consumption. In the specific case of residential demand, it highlights the need to address targeted problems of access to quality energy.

Finally, the report points out the macroeconomic challenges of this process, as well as the productive development opportunities that the energy transition offers to the region due to its resources and natural advantages.

As a green bank and a bank of sustainable and inclusive development for Latin America and the Caribbean, CAF demonstrates its commitment to the global agenda of just energy transition, promoting projects, initiatives, and knowledge.

Find out more in this video and throughout RED:
América Latina y el Caribe: Somos Energías Renovables (youtube.com)

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