Report on Economic
Development

DEVELOPMENT BANK
OF LATIN AMERICA
AND THE CARIBBEAN

Renewed energies

A just energy transition for sustainable development

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CAF DEVELOPMENT BANK
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Foreword

We live in times marked by unprecedented difficulties—existential and historic challenges whose handling will largely define the future of humanity. Addressing greenhouse gas emissions represents one of the most urgent tasks.

The development model associated with these emissions is unsustainable and is imposing large costs in terms of biodiversity, quality of life and sustainable development for our region and humanity.

Scientists warn that at the current rate of emissions, we have 28 years to limit the temperature increase to 2°C relative to the pre-industrial era, and only nine years to limit it to 1.5°C. This critical evidence has spurred a global consensus—embodied in the Paris Agreement—on the need for a joint response to the climate crisis.

In this context, Latin America and the Caribbean has demonstrated a decisive commitment to the environment: 33 countries in the region have signed this agreement and have pledged to significantly reducing their emissions.

Comparatively, our region makes a minor contribution in terms of emissions but suffers disproportionately from the consequences of the climate crisis. To achieve economic growth with reduced emissions, the region must undertake an energy transition that allows countries to continue producing and consuming energy but limits the emissions generated from fuel use. The experience of developed countries indicates that this path is technologically feasible.

Latin America and the Caribbean must face this transition in the context of actions to reduce its levels of inequality. Despite the valuable progress made, we remain the most unequal region in the world.

The transition, therefore, must also be just. This concept implies justice between countries—recognizing the historical responsibilities of each country in accumulated emissions—and justice among citizens of the same country, ensuring that the costs of the energy transition do not fall on the most vulnerable populations. Similarly, this dimension should extend to justice between generations, so that the costs are distributed over time.

Launching such a complex and necessary process—with a reduced timeframe and a global scenario marked by uncertainty and tensions—demands knowledge, analysis, data, and a comprehensive understanding of the challenge we face.

This report is a meticulous contribution that reflects the role of CAF – the development bank of Latin America and the Caribbean as a generator of knowledge with a strategic vision from the region.

The document rigorously presents how the region has produced and consumed energy over the last 20 years. It also describes the region's opportunities to promote public policies aimed at reducing emissions from both the supply and demand sides of energy sector, while evaluating the fiscal, monetary, external, and productive impacts that the energy transition will impose on the countries of Latin America and the Caribbean.

From the analysis, it is clear that the energy transition will bring challenges and opportunities for the region. Those challenges include a foreseeable restructuring of production and income for hydrocarbon-producing countries as fiscal and external resources will be reduced if the world decreases fossil fuel consumption.

We are a region of solutions, with the capacity to contribute to the global process of energy transition by leveraging opportunities that arise for countries with reserves of critical minerals, such as lithium, copper, or nickel; for countries with gas reserves whose use during the transition would reduce emissions without immediately abandoning fossil fuels; and for countries with the potential for renewable energy production in the relocation of energy-intensive activities (powershoring).

There is no one-size-fits-all recipe for tackling the energy transition. Each country must choose its pace, intensity, and strategy according to its characteristics. For our economies, this transformational process will require an enormous commitment to meet the goals set.

In addition to the efforts of the region's governments, the active participation of individuals and companies in adapting their habits to the new reality, as well as the support of multilateral organizations to guide and assist the countries, will be essential.

It will be a challenging path that will demand bold actions and solid financial muscle to support the actions to be deployed. The financial system, and especially development banking, must be a fundamental ally for this purpose.

CAF has committed to allocating at least 40% of its approvals to green projects, including those that facilitate the energy transition. We are the green bank and the bank of sustainable and inclusive development of the region. With this RED, CAF – the Development Bank of Latin America and the Caribbean – reaffirms its commitment to accompany the region as it successfully faces the challenge of a transition with renewed energy.

Sergio Díaz-Granados
Executive President of CAF – Development Bank of Latin America and the Caribbean

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Abbreviations

AC	Air conditioning
AFOLU	Agriculture, forestry and other land uses
ALACERO	Latin American Steel Association
AMIA	Mexican Association of the Automotive Industry
ANEEL	National Electric Energy Agency of Brazil
BAU	Business as usual
BF-BOF	blast furnace-basic oxygen furnace
BRT	Bus rapid transit
CBAM	Carbon content border adjustment mechanism
CBI	Climate Bonds Initiative
CCA	Chamber of Automotive Commerce
CCUS	Carbon capture, use, and storage
CE	Circular economy
CEDLAS	Center for Distributive, Labor, and Social Studies
CELAC	Community of Latin American and Caribbean States
CH_3OH	Methanol
CH_4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
DANE	National Administrative Department of Statistics (Colombia)
EAF	Electric arc furnace
ECLAC	Economic Commission for Latin America
EJ	Exajoules
EPA	Environmental Protection Agency
ETC	Energy Transitions Commission
EU	European Union
FAO	Food and Agriculture Organization (United Nations)
FICEM	Inter-American Cement Federation
GBFS	Granulated blast furnace slag
GCCA	Global Cement and Concrete Association
GDP	Gross domestic product
GHG	Greenhouse gases
Gj	Gigajoules
GOJI	Greenness of job index
Gt	Gigatonnes
GTAP	Global Trade Analysis Project
GVC	Global value chains
GW	Gigawatts
GWh	Gigawatt-hour
H_2	Hydrogen
HVC	high-value chemicals
IDB	Inter-American Development Bank
IEA	International Energy Agency
ILO	International Labor Organization
IMF	International Monetary Fund

INECC	National Institute of Ecology and Climate Change of Mexico
I-O	Input-output
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LAC	Latin America and the Caribbean
LNG	Liquid methane gas
LPG	Liquefied petroleum gas
LULUCF	Land Use, Land Use Change and Forestry
MADES	Ministry of Environment and Sustainable Development (Paraguay)
MBTU	Million British thermal units
MCTI	Ministry of Science, Technology and Innovation of Brazil
MINAM	Environment Ministry (Peru)
MMA	Ministry of the Environment of Chile
Mt	Megatonnes
MW	Megawatt
MWh	Megawatt per hour
N_2O	Nitric oxide
NCRE	Non-conventional renewable energies
NDC	Nationally determined contributions
NH_3	Ammonia
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen oxides
NZE	Net zero emissions
O*NET	Occupational Information Network
ºC	Celsius degrees
OECD	Organization for Economic Co-operation and Development
OLADE	Latin American Energy Organization
OMU	Urban Mobility Observatory
$PM_{2.5}$	Fine particles
PM	Particulate Matter
PPP	Purchasing power parity
RED	Report on Economic Development
SDGs	Sustainable development goals
SO_2	sulfur dioxide
SO_x	sulfur oxide
SUV	Sport utility vehicle
tCO_2/t	tons of carbon dioxide per ton of output
Tep	tons of oil equivalent
TJ	terajulio
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollars
VA	Value added
WEF	World Energy Forum
WHO	World Health Organization

Introduction

Energy is essential for human activity. Access to new and more convenient energy sources has historically driven global economic and social development, in addition to being the principle that motivated profound changes in the ways energy is obtained and consumed over time. The transition from wood to coal marked a significant milestone in the 19th century in this regard. In the latter half of the 20th century, oil emerged as a primary energy source, and toward the end of that period, the contribution of natural gas significantly increased, thus consolidating the era of fossil fuels. By the end of the last century, fossil sources provided 80 percent of the global energy supply.

Since the Industrial Revolution, the world has witnessed exponential economic growth, partly explained by the expansion of energy sources. However, this process has also left liabilities that compromise the planet's sustainability. Since 1850, human activities have emitted 2,351 gigatonnes of CO2 (GtCO2), nearly 70% of which came from activities with intensive fossil fuel use. Of these emissions, the developed world has been responsible for 45%, while Latin America and the Caribbean has contributed only 11%. This growth also represents a profound incompatibility with maintaining global temperatures at levels viable for life. In this context, it becomes imperative and urgent to ensure an energy transition that is fair and accessible to all

This new energy transition has specific, clear components. The growing importance of electricity from solar and wind sources is one element, but not the only one. Fossil fuels will continue to play a significant role, necessitating cleaner alternatives. In this process, natural gas has the potential to play a key role as the fuel of the transition since it can replace coal and oil to significantly reduce greenhouse gas emissions. In the long term, however, the penetration of low or zero-emission fuels, such as green hydrogen, becomes imperative. From the demand side, energy efficiency and conservation also form an indispensable pillar on the path to decarbonization.

Despite these common factors, each country will experience the energy transition based on its own unique circumstances. This highlights the importance of adopting an approach that is distinctly Latin American and Caribbean, one that considers the specific needs, challenges, and roles each country plays both regionally and globally. The energy transition should be just, promote robust and inclusive economic growth and contribute to narrowing the per capita income gap with the developed world, as well as reducing inequality and poverty.

At the same time, this new energy transition presents opportunities for the region. On one hand, Latin America and the Caribbean has vast potential for generating green electricity. The region's significant hydroelectric capacity is well-known, but potential also exists for wind and solar generation. On the other hand, it possesses extensive reserves of minerals essential for the energy transition, such as lithium and copper. With this potential, adequate financial resources, and appropriate public policies, the region not only has the opportunity to advance toward comprehensive development but also to contribute to meeting the global demand for clean energy required for the planet's sustainability.

At CAF – Development Bank of Latin America and the Caribbean, we are committed to the sustainable development of the countries in the region. This commitment is evident both in the provision of financial resources and our knowledge agenda, which fosters rigorous discussion on the public policies necessary to promote comprehensive regional development.

This edition of the Report on Economic Development (RED) is an essential tool for promoting this dialogue. It analyzes the policies, tools, and measures necessary for countries in Latin America and the Caribbean to advance in a just energy transition, tailored to their realities and without neglecting their other development goals. Our role as a multilateral institution is—and will continue to be—to support and accompany them on this path. I extend my gratitude to all the CAF staff who contributed to this report, especially the Directorate of Socioeconomic Research and Knowledge Management. I would also like to thank all the external collaborators and expert groups from governments, academia, multilateral organizations, and civil society, whose knowledge and suggestions have enriched this publication.

Christian Asinelli
Corporate Vice President of Strategic Programming
at CAF – Development Bank of Latin America and the Caribbean

A new energy transition: Attributes, challenges, and perspectives from Latin America and the Caribbean

- Global warming and the need for a new energy transition
- Pillars and challenges of the energy transition
- Pending development challenges in Latin America and the Caribbean
- Energy resources of Latin America and the Caribbean
- Emissions profile and commitments

1

Key messages

1

Environmental sustainability requires a new energy transition from fossil fuels to renewable sources. Energy consumption is the main contributor to greenhouse gas emissions and, at current rates of emissions, there are only nine years left to limit temperature growth to 1.5°C above pre-industrial levels.

2

The new energy transition is environmentally motivated, but there are also economic incentives at work. Wind and solar generation is currently economically competitive and this will continue to improve. Other drivers of change may be international trade costs or the need to adapt capital to new global production standards.

3

The new energy transition goes beyond the replacement of fossil fuels with solar and wind energy. It also implies an increase in the importance of electricity, a transversal increase in energy efficiency, the development and participation of low- or zero-carbon fuels, as well as carbon capture and storage technologies.

4

The current energy transition will have to overcome several obstacles. One is that the supply of certain key minerals may not keep pace with demand growth. Another potential source of tension is the existence of important assets created for fossil fuel use that are at risk of losing value.

5

The countries of the region have shown their commitment to the environment, declaring, on average, a reduction in GHG emissions of around 11% by 2030 in relation to their 2020 values. This reduction in emissions implies a significant mitigation effort when considering the expected population growth and the need to initiate a process of convergence of per capita income levels with those of developed countries.

6

Each country will experience the energy transition at its own pace depending on its reality. In the region, poverty and the abundance of less dynamic companies must be taken into account, circumstances that can limit the adoption of capital and clean energy practices, either because of financial limitations or because they prioritize other issues over environmental ones. Moreover, energy prices in some countries in the region do not fully internalize environmental costs, which can also act as a disincentive to energy efficiency and decarbonization.

7

The new energy transition brings opportunities for Latin America and the Caribbean (LAC), where there are advantages for generating clean energy and attracting foreign investment (powershoring). The abundance of key minerals is another favorable condition. To take advantage of these opportunities, adequate institutions are required, a pending task in many countries of the region.

8

The new energy transition must be approached in a comprehensive manner from a sustainable development perspective that addresses a triple challenge: reducing inequality and poverty, closing the income gap with the developed world, and protecting the environment. To achieve this, countries will have to manage a range of policies that go beyond the purely energy-related sphere.

A new energy transition: Attributes, challenges, and perspectives from Latin America and the Caribbean[1]

Introduction

Since 1850, human activity has caused the emission of more than 2,300 gigatons of carbon dioxide (CO_2). More than 68% of these emissions came from the use of energy generated by fossil fuels. 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 and only nine years to reach the 1.5°C threshold. Global environmental goals therefore require an energy transition that contributes to reducing emissions.

Energy transition processes are not new. Energy is a fundamental input for the development of human activity and, therefore, since the beginning of time, human beings have sought the most efficient ways of obtaining energy. One of the first major energy transitions was the introduction of coal, which enabled the development of the steam engine and contributed to the first industrial revolution. In the 20th century, first oil and then natural gas replaced coal in production processes and household use. In these cases, the transition was due to purely economic and technological reasons, i.e., the emergence of more efficient alternative sources that displaced or replaced, at least partially, the predominant energy source up to that time.

A distinctive feature of the current energy transition is that it is framed in the context of an environmental concern that has led to the reduction of greenhouse gas (GHG) emissions as a fundamental objective of public policies. This does not mean that the environmental motivation is the only driver; indeed, with the already occurring cheapening of solar and wind technologies, the participation of these renewable sources is expected to occur even in scenarios where environmental consideration is not the priority.

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[1] This chapter was written by Lian Allub and Fernando Álvarez with research assistance from María Pía Brugiafreddo and Martín Finkelstein.

This chapter presents an overview of the energy transition, highlighting the need for a Latin American and Caribbean perspective. The first part discusses the global pillars and challenges of the energy transition and then focuses on the regional situation. It highlights the need for the transition to take place in a context that promotes both economic growth and social development in Latin American and Caribbean countries.

The energy transition to renewable energy sources: Essential attributes

An energy transition implies a structural change in the energy sources used to meet demand. Humanity has experienced several energy transitions throughout its history. In the 19th century, for example, biomass, mainly wood, was replaced by coal. Later, in the second half of the 20th century, the emergence of oil as a leading source became evident. During the last years of the last century, natural gas significantly increased its contribution, consolidating the fossil energy era. At the end of the 1990s, fossil fuels accounted for 80% of the global energy supply, of which 23% came from coal, 36% from oil, and 21% from natural gas, according to data from the International Energy Agency (IEA).

A new energy transition is in full swing. One of its main thrusts is a considerable increase in the share of non-conventional renewable sources, such as solar and wind energy. The essential attributes of this new energy transition are discussed below.

●●

At the end of the 20th century, fossil fuels accounted for 80% of global energy supply

Environmental concern

Complex processes often have different drivers and this energy transition is no exception. A distinctive feature of this new transition is that it is framed in the context of an environmental concern that has led to the reduction of GHG emissions being raised as a public policy objective at the highest level. This does not mean that environmental motivation is the only driver, but it is an important one, at least in its initial phase.

Environmental concerns are well-founded. The average temperature of the Earth's surface during the decade 2011–2020 was 1.1°C higher than in pre-industrial times (1850–1900). The effects of this warming have already begun to be felt, increasing, for example, the frequency and severity of extreme weather events, with significant economic and social costs. However, the worst may be yet to come if the necessary measures are not taken. A continuous increase in the earth's temperature makes the sustainability of the planet unfeasible. Special attention has been paid to the 2°C threshold, considered by scientists as a sort of tipping point, beyond which there is a high risk of massive and irreversible damage on a global scale.

Scientific evidence suggests that this global warming has its origin in anthropogenic GHG emissions, which are largely due to the consumption of energy from fossil fuels. Since 1850, human activity has led to 2,351 gigatons of CO_2 ($GtCO_2$) in emissions, of which more than 68% came from fossil fuel-intensive activities (Brassiolo et al., 2023).

●●

Since 1850, human activity has led to 2,351 gigatons of CO_2 ($GtCO_2$) in emissions, of which more than 68% came from fossil fuel-intensive activities

Certainly, the developed world has had a greater responsibility for these historical emissions, since it has contributed 45% of them. In contrast, Latin America and the Caribbean account for only 11%.[2] These differences in the origin of emissions also coexist with notable disparities in per capita income levels between countries. To close these gaps, the developing world, and Latin America and the Caribbean in particular, must grow faster than developed countries, which is a challenge in a context in which GHG emissions are being reduced. While this is relevant when it comes to introducing elements of fairness, it is also relevant when it comes to introducing elements of equity. in the responsibilities linked to the reduction of emissions, does not exempt any country or region from making the necessary efforts to maintain global temperatures at appropriate levels.[3]

This pressing scenario has led to an important global consensus on the need to significantly reduce GHG emissions, especially those originating from energy consumption.[4] In other words, there is a consensus on the need to accelerate a new global energy transition.

The most notable recent milestone in this crusade for environmental protection is the Paris Agreement signed by the States Parties to the United Nations Framework Convention on Climate Change (UNFCCC). This agreement sets as its central objective "to keep the increase in global average temperature well below 2°C above pre-industrial levels, and to pursue efforts to limit this temperature increase to 1.5°C above pre-industrial levels" (United Nations, 2015, Art. 2, point 1.a). These targets set a greenhouse gas emissions cap equivalent to just over 28 years (at the 2019 pace) to limit the temperature increase to 2°C, and a mere nine years until the 1.5°C threshold is reached (Brassiolo et al., 2023).

●●

At the emissions pace/rate recorded in 2019, there are just over 28 years left to limit the temperxzature increase to 2°C, and only nine years until the 1.5°C threshold is surpassed

The agreement lays out the following timeframe for these efforts and comprehensive development considerations:

> [...Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty (United Nations, 2015, point 1.a of Art. 4).

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[2] Global anthropogenic GHG emissions reached a record high of 59 $GtCO_2$ equivalent in 2019, of which about 10% originated in Latin America and the Caribbean. Most emissions came from developing countries in Asia and the Pacific (44% of the total) and developed countries (23% of the total). The three largest contributors to total emissions in 2019 were China (14.2 $GtCO_2eq$), the United States (6.2 GtCO2eq), and India (3.8 GtCO2eq), which together generated 42% of global emissions that year (Brassiolo et al., 2023).

[3] As highlighted in Chapter 4 of the 2023 Report on Economic Development (RED) (Brassiolo et al., 2023), the principle of common but differentiated responsibilities (CBDR), formalized in the United Nations Framework Convention on Climate Change (UNFCCC), establishes that all countries have responsibility for the challenges of climate change, but not all have equal responsibility. In this sense, it is to be expected that industrialized countries will assume greater obligations in mitigation. However, an exclusive reduction by developed countries alone would be insufficient, given that 75% of current emissions come from middle and low income countries, including 10% generated in Latin America and the Caribbean.

[4] As will be seen below, emissions from agriculture, forestry, and other land use (AFOLU) sectors are significant in some countries in the region. Therefore, they also face the challenge of reducing their non-energy emissions.

Under the Paris Agreement, each country commits to establish, according to its circumstances and capabilities, targets to reduce GHG emissions (mitigation targets) and adapt to the impacts produced by climate change (adaptation targets), as well as to define the measures and actions to achieve these goals. These commitments are described in the Nationally Determined Contributions (NDCs). While the Paris Agreement represents a very important milestone in the global commitment to reduce GHG emissions, it is not without its challenges (see Box 1.1).

Box 1.1

Paris Agreement: Achievements and challenges

The Paris Agreement is a major breakthrough for a joint response to the climate crisis. Its main achievement has been the high level of adherence, with almost all countries participating and proposing national contributions. To date, 196 countries have joined the treaty, of which 33 are from Latin America and the Caribbean.[a]

Its governance model, in which countries propose their own commitments with autonomy and flexibility, has favored this strong adherence. However, it also has implicit weaknesses associated with the lack of a centralized vision of the problem and the absence of mechanisms to ensure compliance with commitments.

The lack of a centralized vision is at odds with the fact that, in order to achieve the objectives of the Paris Agreement, mitigation efforts must be global. In that sense, there is no guarantee that national targets taken together will be sufficient to achieve the global goal.

The most recent review of the NDCs shows that Latin America and the Caribbean is committed to a reduction of around 11% in its emissions by 2030 compared to 2020. This is higher than the global reduction (less than 1%), but lower than the implied reductions for North America and the European Union, of more than 37% and 29%, respectively (see Table 1.3). Unfortunately, according to the Climate Action Tracker, at the time of writing this chapter, only four of the 40 jurisdictions surveyed proposed emissions by 2030 that reflect an effort compatible with the goal of limiting warming to 1.5°C[b] (Climate Analytics and NewClimate Institute, 2022). Moreover, the obligation of member countries is limited to reporting the commitment and complying with certain information and transparency requirements, but there are no formal sanctioning mechanisms in case of non-compliance with the commitments made.

On the other hand, defining emissions at the country level could lead to inefficiencies in the absence of a carbon market. In general, individual strategies do not coincide with the optimal strategy at a more aggregated scale. Energy trading and the possibilities of defining targets at a regional scale could result in better international specialization of production and allocation, in terms of where energy is produced (a simple example of three hypothetical countries is shown in the chapter's annex available online to illustrate this point). The development of a carbon market would also contribute favorably in this regard.

Finally, a weakness of the Agreement is that it does not provide a forum for an explicit and concrete discussion on the global distribution of the emissions reduction effort, an issue that is difficult to address in an absolute manner.

a. Also, according to the most recent edition of the Net Zero Tracker (a platform that monitors compliance with commitments), 150 countries are aiming for net zero emissions in the long term. These countries together account for 92% of output, 88% of emissions and 89% of the population (Lang et al., 2023).

b. The four countries were Bhutan, the Philippines, Norway and the United Kingdom.

Environmental concern has been the original driving force of the energy transition, but this does not mean that technological progress is not playing a primordial role

The fact that environmental concern was the original driver of the energy transition does not mean that technological progress—the usual motivation for transformational phenomena in the economy—is not playing a major and growing role in the future.

On this front, there has undoubtedly been remarkable progress. Perhaps the most notable example is the considerable cheapening of electricity generation from non-conventional renewable sources, especially solar. In 2009, the levelized cost of generating electricity from solar panels was USD 359 per megawatt hour (MWh); in contrast, that of a coal-based power plant was USD 111 per MWh. Ten years later, the numbers are USD 40 and USD 109 respectively.[5] In a decade, solar went from being one of the most expensive sources to becoming the cheapest. This introduces an economic incentive for the incorporation of renewable sources in electricity generation. As will be seen below, even in scenarios where environmental consideration is not a priority, a significant participation of wind and solar sources is expected for economic cost reasons.

Pillars of the energy transition

Global energy transition scenarios are a topic that has received particular attention, with IEA projections being one of the most commonly referenced.[6] This institution proposes three scenarios. The first is the "current policies" scenario, which, as its name suggests, is based on government policies currently in place or under development (and not on commitments made under the NDCs). The second scenario is the "announced commitments" scenario, under which it is assumed that all targets declared by governments are met in full and on schedule, even if there are currently no policies in place to achieve them. Finally, the "net zero emissions by 2050" (NZE) scenario sets out the pathway needed to achieve stabilization of the global temperature increase at 1.5°C, as well as universal access to electricity and modern energy systems by 2030.

In 2022 global emissions were around 37 $GtCO_2$. In the current policy scenario, they decrease to 35 $GtCO_2$ in 2030 and to 30 $GtCO_2$ in 2050. In the announced pledges scenario, emissions fall to 31 $GtCO_2$ in 2030 and then to 12 $GtCO_2$ in 2050. Finally, in the NZE scenario emissions fall to 24 $GtCO_2$ in 2030 and to net zero in 2050 (IEA, 2023n).

How does the energy supply behave in each of these scenarios? Graph 1.1 shows information in this regard, highlighting three aspects.

First, the NZE scenario calls for a reduction in global energy supply from 632 exajoules (EJ) in 2022 to 541 EJ in 2050. In contrast, the current policy scenario maintains historical growth in energy production (up to 725 EJ in 2050).

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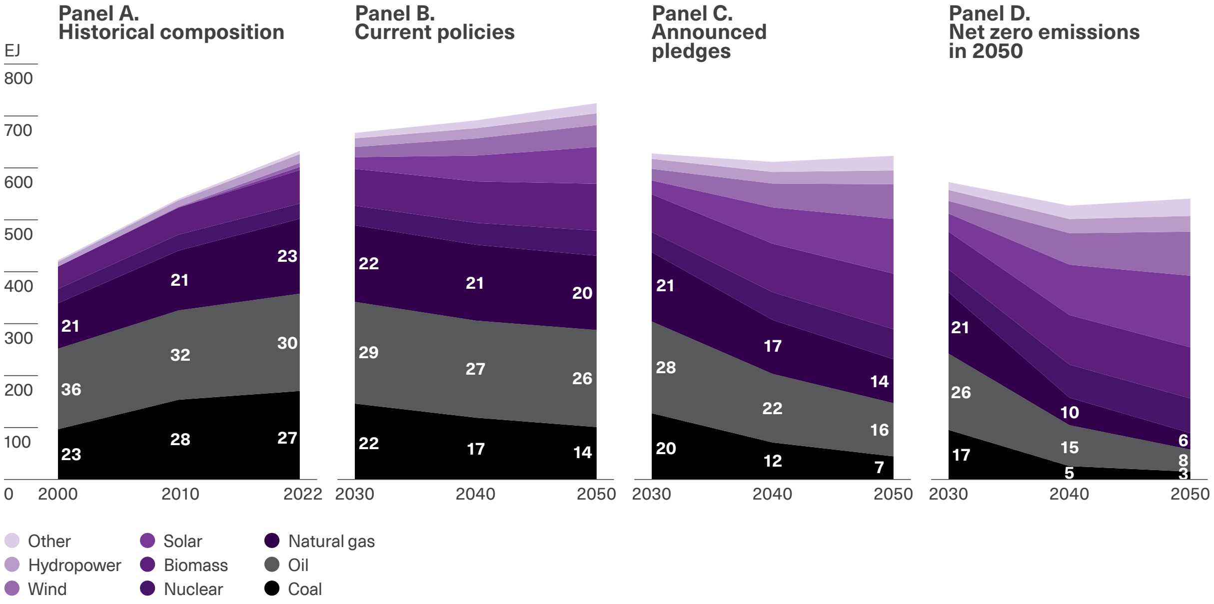
[5] The levelized cost of energy can be thought of as the average price at which the electricity generated by a plant must be sold in order to recover its total costs (construction and operation) over its lifetime. Of course, the costs associated with solar and wind generation vary significantly depending on environmental factors, such as solar irradiance. These results represent average values and do not consider costs associated with dealing with the inherent intermittency of these sources (see Chapter 4).

[6] It is important to keep in mind that these scenarios are not forecasts, but reference frameworks for articulating climate actions that, taken together, are consistent with a climate objective, in this case, net zero emissions. In turn, this zero-emissions target is consistent with the Paris Agreement goal of keeping temperatures below certain critical thresholds (Fankhauser et al., 2022).

Second, the NZE scenario is characterized by a sharp reduction in the absolute and relative levels of fossil energy sources. However, oil, gas, and even coal production do not disappear completely. Specifically, the contribution of coal drops from 27% in 2022 (170 EJ) to 3% (15 EJ) in 2050; that of oil from 30% (187 EJ) to 8% (42 EJ) and that of gas from 23% (145 EJ) to 6% (32 EJ).[7] The presence of fossil fuels in 2050 in the NZE scenario is due, among other reasons, to the intermittency of non-conventional renewable sources and the existence of sectors that are difficult to electrify, such as heavy-duty transport (see Chapter 8) and certain industries, especially those that need to generate high temperatures in their production processes, such as metallurgy (see Chapter 6). This highlights the importance of developing carbon capture technologies or low-emission hydrogen production, which can play a role in meeting the energy demands of industries and processes that are difficult to electrify.

The NZE scenario for 2050 is characterized by a sharp drop in the absolute and relative levels of fossil energy sources. However, the production of oil, gas and even coal will not disappear completely

Graph 1.1
Total energy supply in the world by source



Note: The current policy scenario shows the supply path implied by these policies. The announced pledges scenario assumes that all governments' stated targets are met in full and on schedule, including their long-term zero emissions and energy access targets. The 2050 net-zero emissions scenario charts the way forward to achieve stabilization of global temperature rise at 1.5°C and universal access to electricity and modern energy systems by 2030. The labels indicate the share relative to the total in the year of the change of decade. The biomass category encompasses traditional biomass usage and biomass for sustainable biofuels. In the scenario of zero net emissions, the share of traditional biomass—the first subcategory—decreases from 4% in 2022 to 0% in 2050. Meanwhile, the contribution of the second subcategory, biomass for sustainable biofuels, increases from 7% to 18% between 2022 and 2050 in the same scenario.

Source: Authors based on IEA (2021f, 2023x).

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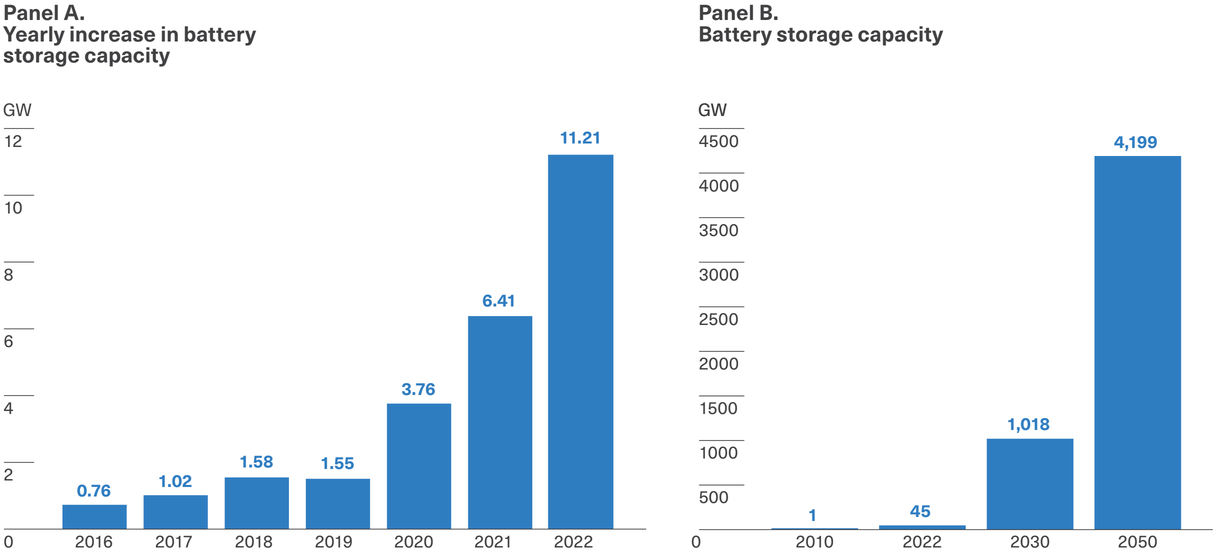
[7] In the current policy scenario, the share of fossil sources also falls (slightly), but not the production in absolute terms of oil and gas, which even increases between 2020 and 2050 (from 173 EJ to 197 EJ and from 137 EJ to 149 EJ, respectively).

Finally, the NZE scenario is characterized by a significant growth in the contribution of non-conventional renewable sources, mainly solar and wind. Solar energy goes from representing 1% (7 EJ) of production in 2022 to 26% (138 EJ) in 2050, while wind energy goes from 1% (8 EJ) to 16% (84 EJ). The participation of solar and wind energy also occurs in the current policy scenario, but at a considerably lower rate, accounting for 16% in total of production in 20250 under this scenario.

The increased generation of energy from these renewable sources, given their intermittency, requires a growth in storage capacity. While electricity storage in batteries has accelerated markedly in recent years (Panel A of Graph 1.2), it is still far from reaching the levels needed to ensure the security of the energy supply, especially on the NZE scenario path with widespread participation of solar and wind sources. Under the NZE scenario, global large-scale battery capacity is expected to reach 1,000 gigawatts (GW) by 2030, 23 times the current capacity (45 GW) (see Panel B of Graph 1.2).

The new energy transition involves much more than replacing fossil fuels with solar and wind energy. Graph 1.3 focuses on four other pillars: electrification; energy efficiency and behavioral changes; the development of low or zero-emission fuels; and the development of carbon capture and storage (CCS) technologies.[8]

Graph 1.2
Growth in global battery storage capacity and projected levels in the net zero emissions scenario



Source: Authors based on IEA (2023b, 2023n).

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[8] Nuclear power is also expected to play a role in the energy transition. As seen in the NZE scenario, the importance of this source more than doubles in relation to its value in 2020. In the case of the region, however, its relevance will be more limited.

The new energy transition is based on these pillars: substitution of fossil fuels with low-emission energy sources; electrification; energy efficiency and behavioral changes; development of low-emission fuels; and development of carbon capture and storage (CCS) technologies

The importance of electricity is growing with the energy transition. Today, electricity covers about 20% of energy demand; under the net zero emissions scenario, electricity is expected to cover 53% (183 EJ) by 2050. Obviously, electrification alone will not reduce emissions to the extent that much of this type of energy is generated from fossil sources. In the NZE scenario, 71% of electricity is expected to be based on solar and wind sources (130 EJ) and 11% on hydropower (20 EJ); in contrast, only about 1% of electricity would come from fossil sources. This green electrification poses major challenges (see Chapter 5).[9]

Energy efficiency and consumer behavioral change is another key component of this transition. As shown, the net zero emissions scenario implies a decrease in energy supply. So as not to compromise economic growth, it is necessary to reduce energy requirements per unit of output, a term known as energy intensity. Based on the NZE scenario, by 2050, the energy intensity of the energy-producing sector would fall to one-third of its current value; that of the transport sector, one-half; that of industry, 44% lower; and that of construction, 38% lower[10] (see Panel B of Graph 1.3).

As seen above, fossil fuel sources do not disappear completely in the NZE scenario. This implies the availability of carbon capture, use, and storage (CCUS) technology. Indeed, it is estimated that around 6 $GtCO_2$ will be captured globally by 2050, 62% of which would come from the use of fossil fuels and industrial processes (see Panel C of Graph 1.3).

Lastly, the development and participation of new fuels, such as low-emission hydrogen and biofuels, will play an important role in the path to a net-zero emissions world. Hydrogen consumption, for example, is expected to quadruple (from 95 million tons in 2022 to more than 400 million tons in 2050). It is also expected to account for 96% of total hydrogen demand in 2050 in the NZE scenario, as it expands to new applications, with a significant presence in transportation and power generation.

All these pillars will play a quantitatively important role in reducing emissions to achieve the NZE scenario, as summarized in Graph 1.4. It shows the contribution of these pillars in terms of these reductions in two different scenarios: the IEA's NZE scenario, which has been referred to in this section, and the zero-emissions scenario of the International Renewable Energy Agency (IRENA). The similarities between the two are evident.[11]

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[9] Electricity use is heavily concentrated in hydrogen production (28%) and in both heavy (26%) and light (20%) industries. In 2050, light transport will account for 9% of electricity consumption and heavy transport for 6%. In terms of the level of importance of electricity as an energy source, the case of light vehicles stands out, a sector in which 77% of energy consumption will come from electricity. These values refer to the NZE scenario for 2050.

[10] As will be seen in Chapter 2, this energy/output ratio at the aggregate level is not only associated with energy efficiency in each of the sectors but also with the economic structure.

[11] There are other scenarios that may put more or less force on these different pillars, but in all cases, they are key building blocks of an energy transition strategy. For example, the Intergovernmental Panel on Climate Change (IPCC) considers a total of 90 scenarios with at least a 50% probability of limiting temperature growth relative to the pre-industrial era by 1.5°C by 2100. The IEA (2021b) compares these scenarios with the zero-emission scenario in terms of the importance of these pillars.

Graph 1.3

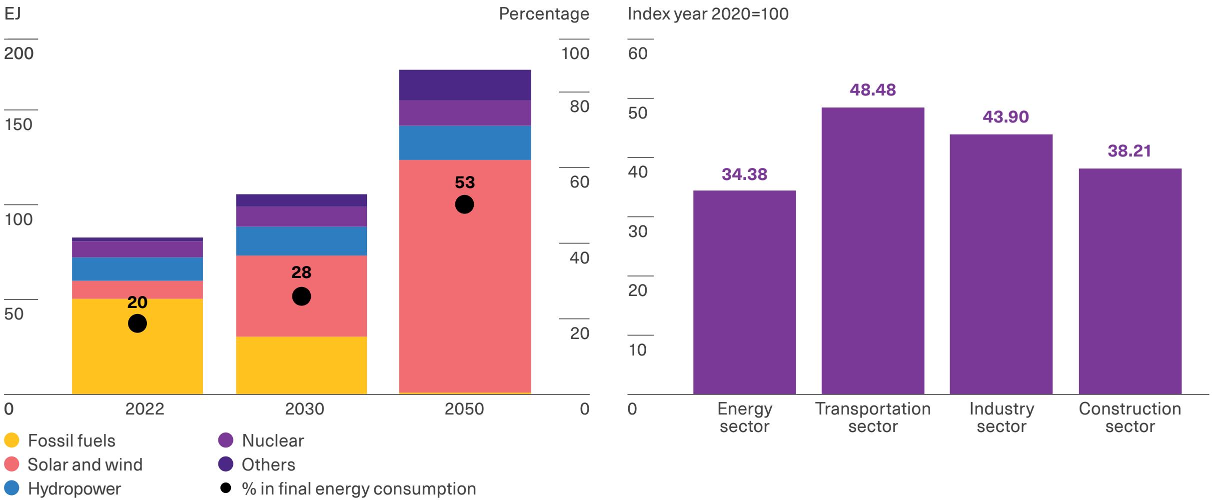
Pillars of the energy transition beyond the participation of renewables

Panel A.
Electrification

Final electricity consumption in net zero emissions scenario by 2050

Panel B.
Efficiency

Energy intensity: Ratio 2050 vs 2020 in the net-zero emissions scenario

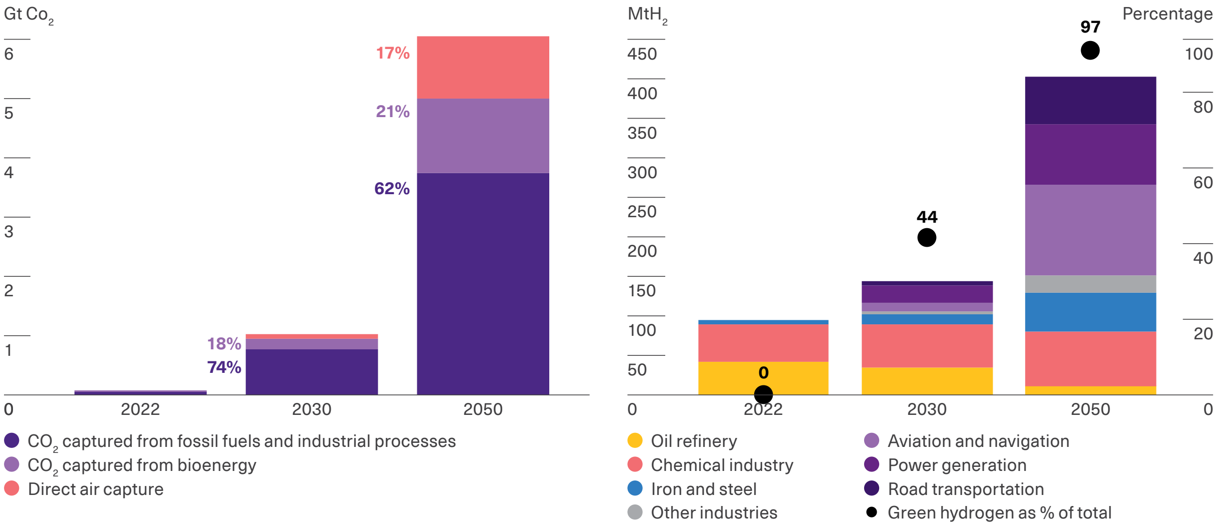


Panel C.
Capture

CO_2 captured globally in the scenario of net-zero emissions by 2050

Panel D.
Green hydrogen

Hydrogen use in net zero scenario

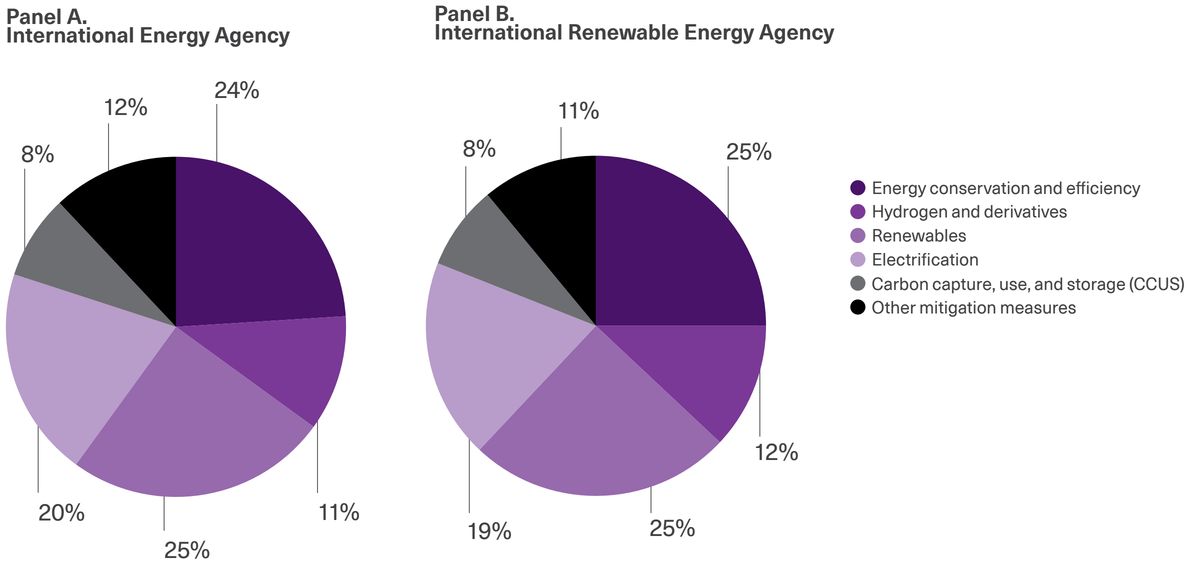


Note: The graph presents the main pillars of the energy transition. Panel A shows, for the NZE scenario, the electricity consumed (measured in exajoules) by type of source used in its generation (on the left axis) and the share of electricity in energy demand (on the right axis). Panel B presents the ratio between 2050 and 2020 of energy intensity by economic sector in the NZE scenario: in the energy sector, energy intensity is measured as the units of energy consumed per unit of output; in the transport sector, as the energy consumed per vehicle kilometer; in industry it is measured as the units of energy per unit of value added; and, finally, in the construction sector, as the energy consumed per square meter per year. Panel C displays the amount of CO2 captured (measured in gigatons) in the NZE scenario. The labels indicate the share of each source in the total CO2 captured. Finally, Panel D shows the hydrogen demand (in million tons) by use or application in the NZE scenario and the share of green hydrogen in the total (on the right axis).

Source: Authors based on IEA (2021f, 2023m, 2023n).

Graph 1.4

Contribution of the pillars to the reduction of CO_2 emissions in the net zero emissions scenario



Note: The graph shows the relative contribution of each of the factors in reducing carbon dioxide emissions under the IEA and IRENA zero-emission scenarios. The category "renewables" refers to the use of renewable energy (wind and solar) for power generation and for direct uses in transportation and heating; "energy conservation and efficiency" includes both behavioral changes, involving reduced energy demand and consumption, and changes in production processes that increase energy efficiency; hydrogen and derivatives" includes synthetic and low-fossil content fuels, such as biofuels (in IEA estimates, hydrogen represents 4% and bioenergy 7%, which are not disaggregated in the IRENA scenario); "capture, use, and storage" includes synthetic and low-fossil content fuels, such as biofuels (in IEA estimates, hydrogen represents 4% and bioenergy 7%, which are not disaggregated in the IRENA scenario). Carbon capture, use, and storage refers to CO2 captured from fossil fuels and industrial processes; "other mitigation measures" refers, in the case of the IEA, to other fuel switching and, in IRENA, to other carbon removal measures, such as direct air capture, soil and ocean carbon capture, afforestation or reforestation, and bioenergy with carbon capture and storage (BECCS).

Source: Authors based on IEA (2023n) and IRENA (2023).

Some challenges on the road to decarbonization

Dependence on accelerated technological progress

The road to a significant reduction in energy-related GHG emissions is not free of challenges. The first has to do with technology. Vigorous progress in various technologies is vital to lay the foundations of the energy transition in a timely manner. While there are already encouraging results on this front, it is also true that much of the road to the NZE scenario is built on technologies that are still under development.[12]

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[12] This includes not only further advances in electricity generation from renewable sources, but also in energy storage technologies; the development of carbon capture and storage technologies; the development and penetration of low-emission fuel in production processes, as well as efficiency improvements and consumer electrification, among others.

According to the IEA, 36% of the emissions reductions by 2070 will stem from technologies currently in the prototype or demonstration phase, and up to 39% from technologies that are in the early adoption phase. In contrast, only 20% of emission reductions would come from mature technologies (IEA, 2020c). Dependence on developing technologies concerns not only the energy-producing sector, but also, very importantly, industry, transport and, to a lesser extent, the residential sector. The public sector plays a key role in promoting this technological progress, providing funds to support research and development activities, facilitating cooperation and coordination between various agents, providing essential public infrastructure, protecting intellectual property and improving financial markets and competition in general, among other instruments.

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By 2070, 36% of emissions reduction will stem from technologies currently in the prototype or demonstration phase, and up to 39% from technologies in the early adoption phase

Fossil assets

A second major challenge is associated with the existence of natural and physical assets linked to fossil energy. One of these assets is the hydrocarbon reserves themselves, which, for many countries in the region, have represented an important source of fiscal and external revenues (see Chapter 9).

Beyond these natural assets, most of the existing physical assets are designed to operate on fossil fuel energy. Fossil-fuel thermoelectric power plants, cement and steel production plants, oil refineries, dispatch plants, pipelines, natural gas distribution networks, as well as the bulk of the transportation fleet, are some of the most relevant examples.

Even if no further investment is made in this type of infrastructure and assets, existing physical capital has usually long useful life horizons, so it will generate emissions for decades. Considering the useful lifetimes and usual operation of this infrastructure and capital assets, it is expected that around 750 $GtCO_2$ will be emitted over the next 50 years. To put this number in perspective, these emissions are more than 30% of the man-made emissions since 1850 (around 2,350 $GtCO_2$) and represent more than 55% of the central estimate of emissions from the "carbon budget"[13] to limit the temperature increase to 2° C (on the order of 1,350 $GtCO_2$).

Existing coal-fired power plants would be responsible for about 44% of these emissions, while other fossil fuel plants would account for more than an additional 10%. The steel and cement industries would contribute just over 8% each. Other industries (including chemicals) would account for just over 9%. Finally, the transportation sector as a whole would account for more than 11% and the residential sector for just over 3% (see Graph 1.5).

While the existence of this infrastructure poses challenges to reducing emissions, there are some strategies to reduce its impact.

The first is the early retirement or repurposing of these assets. At some point in their useful life, these types of plants may not be economically profitable if they require significant maintenance investments, combined with the cheapening of greener technologies or the imposition of certain environmental regulations. It could also happen that some of these assets change their purpose; for example, using gas distribution infrastructure to move hydrogen or reorienting thermal plants more to solve intermittency problems of non-conventional renewable sources than to be the base service.

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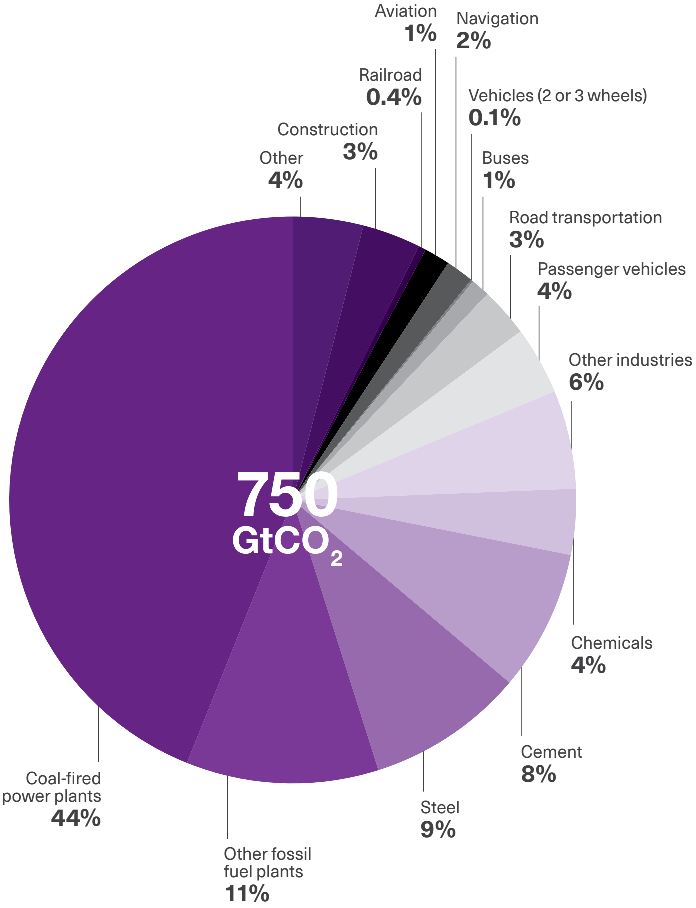
[13] This concept, introduced by the IPCC, refers to the share of emissions that would make it possible to remain below a given temperature.

-A second strategy is modernization or adaptation; for example, providing thermal insulation to existing buildings. This strategy may include the incorporation of carbon capture, use, and storage technologies, which is perhaps one of the most promising.

Finally, fuel switching or blending can also be considered. With small modifications or investments, it is feasible to replace, in certain processes and uses, fuel with high CO_2 content with other fuels or fuel blends with lower CO content. The switch from gasoline to gas vehicles is already a common example. It also seems to be feasible to combine biomass in coal-fired plants or to incorporate hydrogen and biomethane into the gas distribution network to reduce its carbon content.

Graph 1.5
Global CO_2 emissions between 2019 and 2070 from existing infrastructure and assets by subsector



Source: Authors based on IEA (2020c).

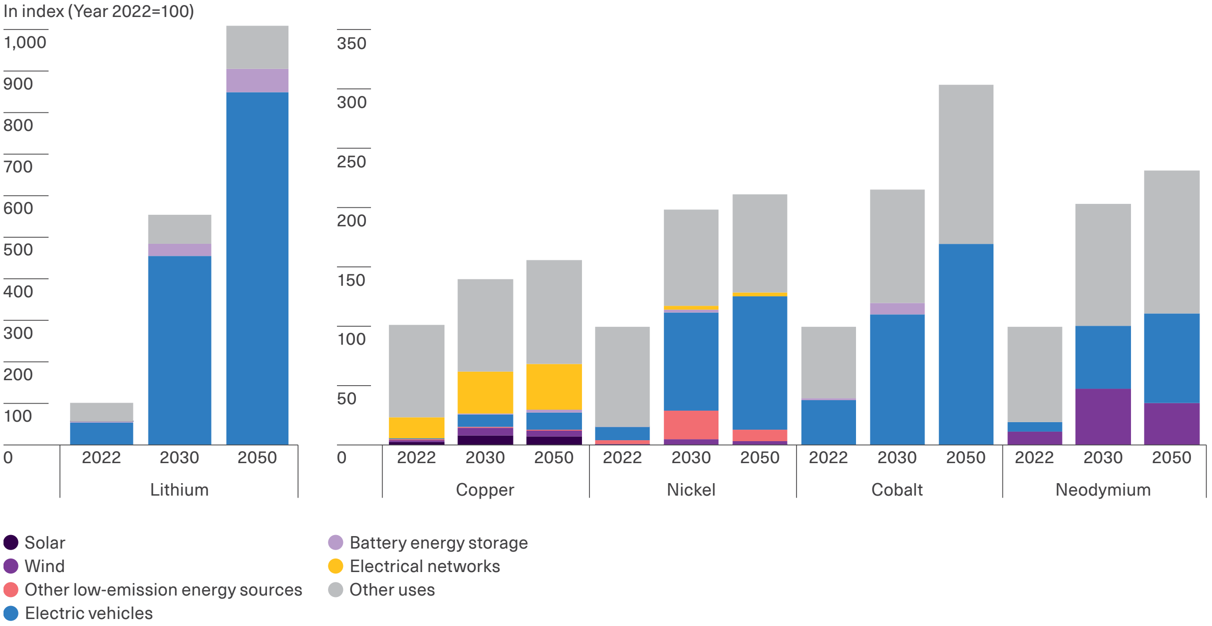
Critical minerals

A third major challenge has to do with the transition's reliance on critical metals. The electrification of the economy and the development of low-emission energy technology require significant quantities of certain minerals, such as copper, cobalt, nickel, and lithium. Demand for these minerals is expected to increase significantly in the coming years. For example, under the NZE scenario, demand for lithium by 2050 is estimated to be more than 10 times its value in 2022 (mainly explained by the need for batteries for the electrification of transport). Demand for other minerals will also grow significantly: cobalt demand will increase by a factor of three, nickel by more than two, and copper by more than 1.5 times (see Graph 1.6).

Some Latin American countries have significant reserves of critical minerals, making the energy transition an opportunity to integrate into these value chains

Some Latin American countries (e.g., Argentina, Bolivia, Chile, and Peru) have significant reserves of these minerals. The energy transition offers these countries an opportunity to integrate into clean energy value chains, boosting their economic development. (This opportunity and the conditions for taking advantage of it are explored in more detail in Chapter 10.)

Graph 1.6
Demand for critical minerals in a net zero emissions scenario



Source: Authors based on IEA (2023e).

However, on the path to accelerated emission reductions, this dependence on certain minerals represents a potential obstacle if supply does not meet demand requirements. Estimates indicate that, although the supply of these minerals appears sufficient for current requirements, in the long term - especially under scenarios of strong emission reductions, such as that of NZE—projected demand could exceed supply given the operational and projected mines (under construction). Consequently, new investments are indispensable to increase the future supply of these products.

Unfortunately, the supply of these minerals has certain characteristics that introduce risks (IEA, 2021g). The first of these is that it is geographically concentrated, which makes supply vulnerable to a number of circumstances, such as political instability or environmental events. For example, around 50% of copper and lithium production is located in areas of high aquifer stress. This introduces additional constraints, as mining competes with other water uses. The second has to do with the long lead times required for the discovery and development of mining projects. It is estimated that the exploration process and feasibility studies can take more than 12 years and the construction phase, an additional four or five years. The investments needed to meet future demand must start now. Lastly, mining activity can also have environmental impacts, including emissions, as it is itself energy intensive. Local environmental impacts (on water quality and consumption and biodiversity, for example) can lead to resistance to the development of these activities (Purdy and Castillo, 2022).

Some strategies can help the reliability of the supply of critical minerals in the medium and long term.[14] First, it is necessary to promote investment and diversification of the new supply, which can be achieved through financial support, simplification of procedures and strengthening of geological survey centers. Secondly, it is necessary to implement good practices to reduce the environmental and social impact of mining activities. A good regulatory system usually encourages the adoption of these good practices. Lastly, recycling will be a key strategy. Estimates suggest that recycling has the potential to cover 20% of the demand for these critical minerals in the next three decades (Simas et al., 2022).

Financing

A cross-cutting obstacle on the road to reducing emissions is the need for vast resources to finance climate change mitigation (and adaptation). Some estimates indicate that until 2050, annual investments (net of the drop in investment in fossil energy) equivalent to 1.3% of global GDP are required worldwide. These requirements imply a threefold increase in investment by 2030 compared to current levels worldwide; in the case of developing countries, they imply a fourfold increase. Seventy-five percent of investment is concentrated in the clean energy generation and distribution sector, with 38% linked to generation, 26% to grids and 6% to storage (ETC, 2023a).

Estimates for less developed countries usually suggest higher needs in terms of GDP. For example, for the period 2015–2030, Rozenberg and Fay (2019) report, for their preferred scenario (ambitious environmental targets with good efficiency performance), investments in electricity systems in the order of 2.2% of GDP and around 1.3% of GDP for emissions reductions in the transport sector.[15] These same authors find for Latin America investment needs of 1.4% of GDP for electricity systems and 2% for transport systems, for a total of 3.4% of GDP in these two components.[16] If investments in other areas are added and the overall structure is maintained, where electricity and transport account for 77% of total investment, investment needs exceed 4% of GDP per year even in the favorable scenario of high energy efficiency.

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[14] Other strategies may be demand-driven. In particular, technological adaptation and material substitution can reduce the demand for critical minerals. Some studies find that these factors would imply a 30% reduction in demand for critical minerals (Simas et al., 2022).

[15] In their scenario of ambitious environmental targets, but low efficiency, investments are 3% and 3.3% respectively.

[16] Necessary investments in transport fall significantly when combined with good urban planning strategies.

In addition to this are the costs derived from the pre-existing social gaps and the social impacts that the energy transition itself may cause. In this regard, Galindo Paliza et al. (2022) report that the costs of facing these social challenges could be between 5% and 11% of GDP.

Energy transition in Latin America and the Caribbean

Each country will experience the energy transition at its own pace, with the emphasis, implications, and perspectives that correspond to its unique reality. Latin American and Caribbean countries have attributes that differentiate them significantly from developed countries and that will condition their transition processes.

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Each country will experience the energy transition at its own pace, with the emphasis, implications, and perspectives that correspond to its unique reality

On the one hand, there are the old development problems: low growth, low productivity, productive informality, and inequality. In energy, there are still gaps to be closed in terms of access and quality and, in some countries, fossil energy subsidies may discourage energy efficiency and the substitution of fossil fuel sources. In terms of emissions, the relative importance of non-energy sources, specifically those associated with the AFOLU sector, stands out. Lastly, there is the issue of natural endowment: some countries have significant wind or solar potential, which gives them the opportunity to attract investment by taking advantage of clean energy (known as powershoring),[17] or significant reserves of minerals needed for the energy transition, while others maintain significant fossil reserves that risk becoming stranded assets.

The historical problems of development

Over the past decades, the region's GDP per capita has been less than 30% of that of the United States. This contrasts with the experience of the Asian "tigers," which have managed to close the gap considerably in 50 years. There is a productivity gap behind this long and persistent lag (Alvarez et al., 2018). This, in turn, is associated with an excess of small and informal business ventures and firms that have a low accumulation of physical, human, and organizational capital.

What implications does this have for the energy transition? Perhaps the most obvious is that, for the region, sustainable development implies reducing the per capita income gap with the developed world, and this can only be achieved with a higher rate of economic growth. This, together with population growth, puts added pressure on emissions and the necessary mitigation efforts to meet a given emissions target (see Chapter 2).

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[17] This term refers to the decentralization of production through the installation of industries in countries close to consumption centers that offer clean, safe, cheap and abundant energy to attract investment.

On the other hand, the energy transition should require transformational processes on the business side, which requires internal capabilities that a significant number of companies may not possess. For example, problems of access to finance may limit investment in green capital or in organizational processes to improve energy efficiency. In addition, some studies suggest that a company's energy consumption is associated with the quality of its management practices (Bloom et al., 2010).

Latin America and the Caribbean not only has a relatively low per capita income, but also a highly inequitable income distribution. Indeed, the region is among the most unequal in the world and still registers significant levels of poverty. On average, one in every three people in Latin America is poor and 12 out of every 100 live in extreme poverty (ECLAC, 2022).

The levels of poverty and vulnerability of large sectors of the population demand protection against the strong distributive changes that the energy transition may generate, and become a challenge in themselves for this transition. On the other hand, both problems impose certain restrictions on the adoption of clean or energy-efficient technologies by households, either because they have limitations to finance these measures or because they do not deem that a priority in the face of improvements in their economic situation.

In line with this last statement, calculations using data from the World Values Survey (WVS) show a positive association between socioeconomic status (proxied by level of education) and the priority given to environmental issues (relative to economic status). Specifically, a person with completed higher education is 10 percentage points more likely to prioritize environmental protection over economic growth than someone with incomplete basic education (after controlling for age and gender).[18]

Pending tasks in energy supply

The discussion on the pending tasks in the field of energy can be framed within the triad of access, quality, and price. In terms of access, the good news is that significant progress has been made so far this century; however, there are still some specific gaps to be closed. In the case of electricity, access is close to universal, except in rural areas of some countries. Access to natural gas networks is more limited (Cont et al., 2022). These energy access gaps translate into practices, such as cooking with firewood, with implications for people's health.

At the beginning of the first decade of the 21st century, considering the simple average of 14 countries, 86.5% of households in Latin America and the Caribbean had electricity connections, with a minimum of 70.5% in Bolivia and a maximum of 99% in Chile. By 2020, the average figure rose to 97%, with a low of 87% in Nicaragua on one end, but virtually universal levels in Argentina, Brazil, Chile, Costa Rica, Mexico, Paraguay, and Uruguay, on the other. However, household surveys indicate that at least 40% of the rural population in Colombia, Honduras, Mexico, Nicaragua, Paraguay, and Peru still cook with firewood (see Chapter 7).

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At least 40% of the rural population in Colombia, Honduras, Mexico, Nicaragua, Paraguay, and Peru still cook with firewood

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[18] Table A.1.1 in the chapter's annex available online provides the details of this statistical exercise.

The challenges in terms of quality are more evident than those of access. For example, Table 1.1 shows this problem for (manufacturing) companies. In general, the situation for the region is similar to that of the world as a whole, but more problematic than for developed countries. Nearly 60% of the companies report having experienced power outages with a frequency of two interruptions per month, each lasting approximately three hours. These outages resulted in losses equivalent to almost 2% of annual sales. Due to this situation, one out of three companies in the region considers electricity supply problems to be a major obstacle. This figure is 40% higher than in the Europe and Central Asia region.

Another characteristic of energy markets that is worth highlighting is the presence of subsidies. Graph 1.7 shows that energy subsidies in the region are equivalent to 4.7% of GDP, a figure that is more than double the values in the more developed countries (around 2.2%).

Energy subsidies in the region amount to 4.7% of GDP, which is more than double that of the most developed countries

The presence of these subsidies can promote a high demand for fossil fuels, with a consequent impact on emissions. In line with these assertions, there is globally a positive association between the amount of subsidies and emissions, both variables measured as a proportion of GDP (see Graph 1.8). These subsidies may therefore be a barrier on the road to reducing emissions.

Table 1.1

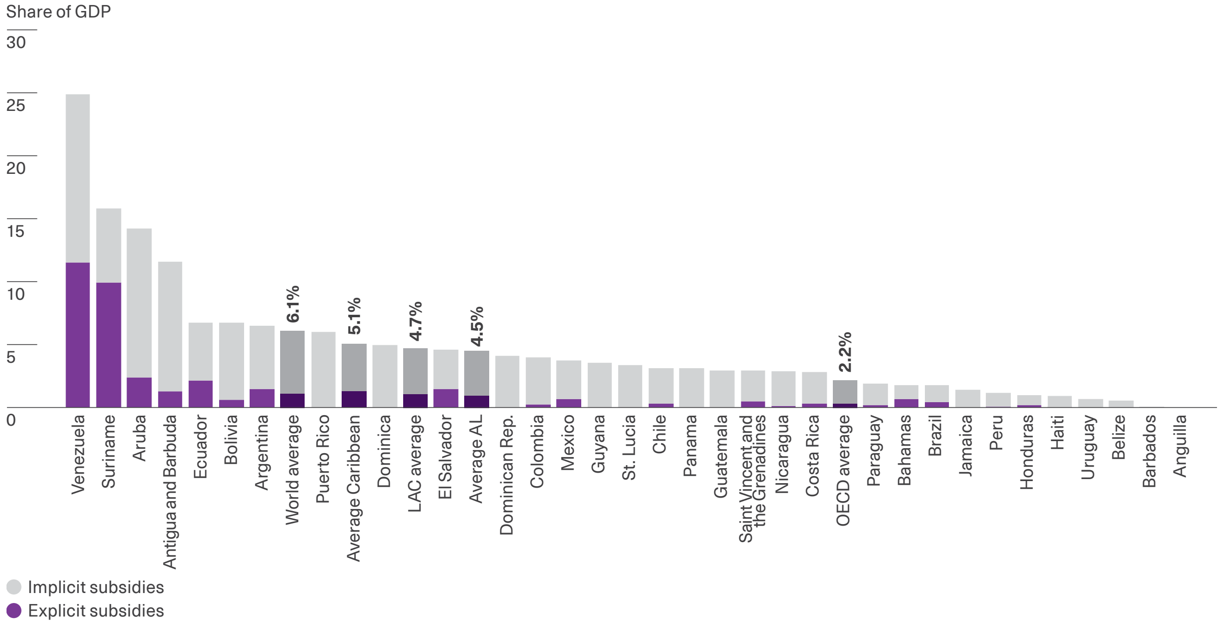
Regional comparison of the quality of electricity service according to companies

	Companies that experienced power outages (percentage)	Power outages in a typical month (quantity)	Average duration of a typical power outage (hours)	Average loss due to power failure (percentage of annual sales)	Companies that consider electricity as the main constraint (percentage)
All economies	49.5	4.6	4	4	30.5
East Asia and Pacific	46.3	4.8	3.6	2.9	17.1
Europe and Central Asia	30.5	0.7	3.1	0.9	24
Latin America and the Caribbean	58.4	1.8	3	1.8	33.5
Middle East and North Africa	35.9	6	4.7	4.3	37
South Asia	53.2	11.7	3.6	8.4	32.1
Sub-Saharan Africa	76.1	8.8	5.6	8.5	40.3

Note: The table shows different indicators of the quality of electricity service according to the results of the World Bank's Enterprise Survey, corresponding to the latest year of the survey in each country. Table A.1.2 in the chapter's annex (available online) presents the same indicators for Latin American and Caribbean countries.

Source: Authors based on World Bank (2023a).

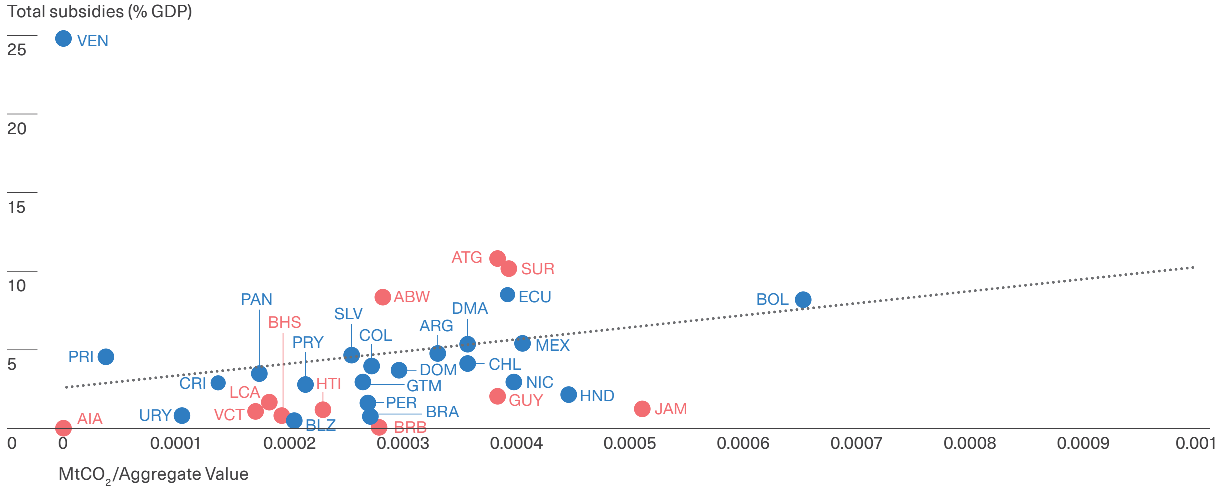
Graph 1.7
Fossil fuel subsidies as a share of GDP in selected countries in 2022



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 (2021).

Graph 1.8
Relationship between fossil fuel subsidies and emissions



Note: Latin American countries are shown in blue on the graph, while Caribbean countries are shown in pink. The list of countries with their corresponding ISO code can be found in the appendix of the chapter available online (Table A.1.3).

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

Natural resource endowment

The energy transition involves gradually abandoning fossil fuels and increasing the electrification of consumption and the generation of electricity from renewable sources, particularly wind and solar. This change affects the demand for natural resources in different ways. On the one hand, the demand for fossil resources will decrease due to the substitution of fossil energy by renewable energy, negatively affecting countries that have reserves of these resources. On the other hand, "green electrification" will increase the demand for certain critical minerals and materials, of which some countries in the region have significant reserves.

Regarding critical minerals, a subject that will be developed in more detail in Chapter 9, the region has significant reserves of lithium (42% of world reserves), particularly in the so-called "lithium triangle": northern Argentina and Chile and southern Bolivia. This mineral is a fundamental component of batteries, which will be extremely necessary as energy storage devices. The region also has 31% of the world's copper reserves, with the largest reserves in Peru and Chile. Copper will be fundamental in the process of electrification of demand due to its excellent conductive properties. The region also has reserves of nickel (17%), cobalt (7%), and rare earth elements (17%), although to a lesser extent. The exploitation of these resources and the possibility of participating in different stages of the value chain related to them offers these countries opportunities to develop productive sectors and generate employment that will help them close the aforementioned per capita income gap with developed countries.

On the other hand, several countries in the region have significant oil and gas reserves and, to a lesser extent, coal reserves. Proven oil reserves would be enough to cover 169 years of current consumption, while gas reserves represent 27 years of current consumption, which highlights the enormous potential for fossil fuel generation in the region. Venezuela, Guyana, Trinidad and Tobago, Ecuador, Bolivia, Colombia, Brazil, Argentina, and Mexico, among others, have oil and gas reserves that are at risk of being underexploited due to the need to move toward a world powered by clean energy sources. [19] This will undoubtedly have an impact on production, employment, exports, and the availability of fiscal resources in these countries, which, in turn, may have consequences for the economy as a whole (see Chapter 9).

Several countries in the region possess significant reserves of oil and gas that are at risk of being underutilized due to the imperative of transitioning toward a world powered by clean energy sources

As for the advantages of renewable energy production, although it is true that water, sun, and wind are available in all countries, the capacity to generate energy from them depends, among other things, on the intensity with which these resources are present. Again, some countries in the region have advantages in this regard.

While Latin America and the Caribbean currently has a high share of hydropower generation, it still has untapped potential in this technology (see Chapter 3). In particular, water availability and topography conditions along the Andes Mountains offer opportunities for the installation of pumped hydropower capacity. These systems use two dams on a watercourse to store surplus electricity in times of abundance and deliver it in times of scarcity. However, hydropower generation is not without environmental costs, often requiring the development of dams that alter natural environments and biodiversity downstream.

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[19] The countries are ordered from highest to lowest considering the years of consumption that their reserves would imply.

With respect to solar generation, the situation is heterogeneous, with countries with high potential, such as Argentina, Chile, or Peru, and others with less, such as the Caribbean islands, partly due to their smaller size, which restricts the space for developing solar parks.

Wind power technology, on the other hand, where again the region has countries with high potential, such as Argentina and Chile, faces more severe space limitations than solar, as wind farms require more land. However, it also offers the possibility of *offshore* wind generation, alleviating this restriction.

An additional challenge imposed by the production of energy from renewables is that, generally, the areas most suitable for generation tend to be far from the centers of consumption. This leads to additional transmission challenges or, directly, transmission inefficiency, which could make them economically unviable.

The composition of total emissions

Globally, almost 80% of GHG emissions come from energy consumption based on fossil fuels and industrial processes (FFIP), while a little more than 20% come from the AFOLU sector. In the region, especially in Latin America and, to a lesser extent, in the Caribbean, things are changing.

These differences are illustrated in Graph 1.9, which summarizes the sectoral composition of emissions in the region and, by way of contrast, in the OECD countries (Table A.1.4 in the annex, available online, presents the information in Latin American and Caribbean countries).[20] Panel A of the graph breaks down total emissions into two categories: AFOLU and FFIP. Panel B breaks down the latter, which are much closer to energy consumption.[21] For a temporal view, the graph contrasts the situation at the beginning of the century with the year 2019.[22]

The graph shows that AFOLU emissions are relatively higher in Latin America than in the Caribbean or OECD countries. In 2019, about 65% of emissions in Latin America came from the AFOLU sector, significantly more than the 14% in the Caribbean or 8% in OECD countries. However, the importance of this component has been falling in the region.

In 2019, about 65% of Latin America's emissions came from the AFOLU sector, a much more significant amount than the 14% in the Caribbean or the 8% in OECD countries

A closer look at FFIP emissions leads to several conclusions. The first is that building-related emissions, although not negligible, are relatively modest in all regions, even in OECD countries, where they are more important, perhaps because of their greater heating needs.[23.] Fugitive emissions related to energy production, although relatively

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[20] Table A.1.5 in the annex shows information on what is included in each category and subcategory of emissions.

[21] Some industrial processes, such as cement production, have emissions associated with them that are not linked to energy consumption. The same is true for waste management processes. However, the energy component is undoubtedly the most important component of FFIP emissions, although the database used here does not allow us to fully separate the energy component from that of industrial processes. In any case, understanding emissions mitigation opportunities in industrial processes is complementary to the analysis of mitigation linked to the energy transition.

[22] For reasons of data availability, the emissions presented in this report are those "production-based", so called because they are imputed to the sector and country of production of the goods and services and not according to where and by whom they are consumed, which is known as "consumption-based emissions". This latter view can provide new insights into the responsibility for emissions.

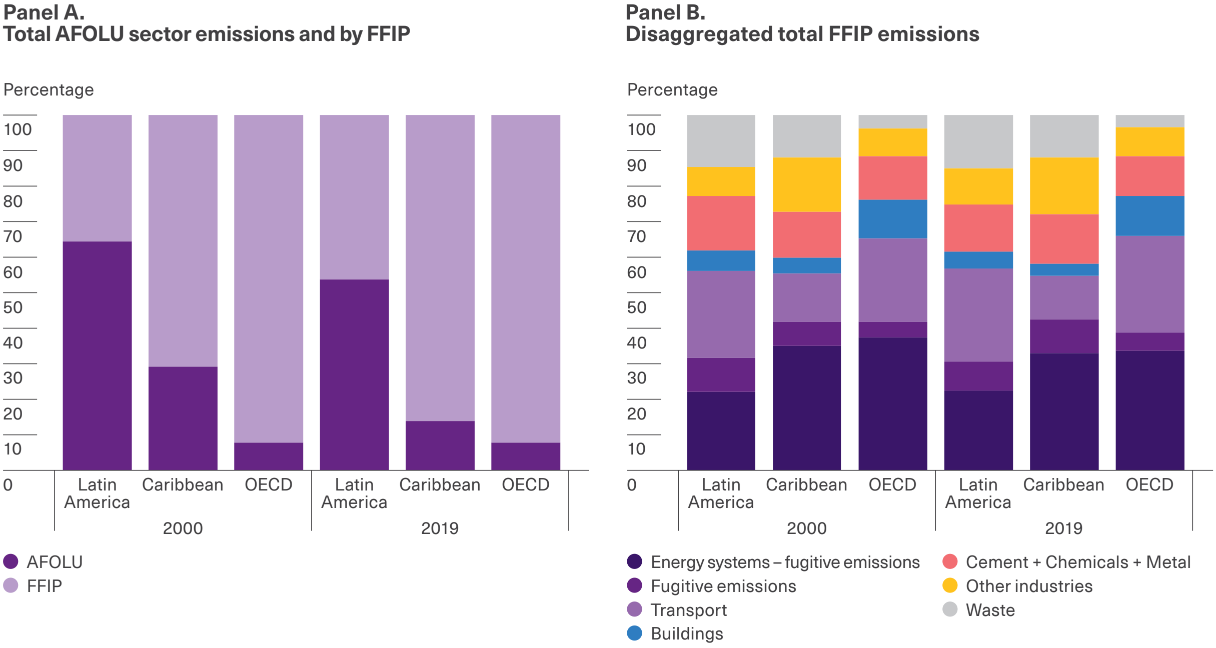
[23] It should be noted that these measurements do not impute emissions from electricity generation and other emissions associated with energy systems to final consumers. Households and businesses are major consumers of electricity and, therefore, part of the emissions associated with it are associated with this consumption. As shown in Chapter 4, 40% of electricity is consumed by industry, 33% by households and 20% by the commercial sector. If these indirect emissions were imputed, emissions from industry and buildings would clearly increase.

modest, are considerably higher in the region than in OECD countries. This could indicate that there is room for reducing emissions in this component. Something similar could be said of the waste management component, which accounts for 15% of FFIP emissions in Latin America, 12% in the Caribbean, and only 3% in OECD countries.

Perhaps the most striking feature of Panel B of the graph is the prominence of the energy systems sector[24] (net of fugitive emissions), transport and industry. In Latin America, transportation leads the ranking, accounting for 26% of FFIP emissions, while industry accounts for almost 24% and energy systems (net of fugitive emissions) for almost 23%. The relatively large presence of hydroelectric sources could be behind the lower contribution of this item to emissions in Latin America. In the Caribbean, where there is a greater presence of fossil fuels in the electricity matrix, energy systems (excluding fugitive emissions) lead the ranking, with 33% of FFIP emissions, a value similar to that of the OECD. In the Caribbean, industries are responsible for 30% and transportation for 12%.

Graph 1.9

Decomposition of emissions in Latin America, the Caribbean and developed countries in 2000 and 2019



Note: AFOLU emissions cover emissions from the agriculture, forestry and other land use sector. The annex to the chapter available online describes the components of emissions by FFIP (Table A.1.5) and provides a list of countries in each group.

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

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[24] Emissions from energy systems include those from the electricity and heating sectors, fugitive oil and gas emissions, oil refining, and other systems (see Table A.1.4 in the annex available online). Graph 1.9 separates fugitive emissions from energy emissions to highlight their relative importance in the region.

Table 1.2
FFIP emissions per unit of output in 2000 and 2019

Country or region	FFIP emissions/GDP		Average annual variation (percentage)
	2000	2019	
Antigua and Barbuda	1.08	1.39	1.33
Argentina	1.20	1.61	1.54
Bahamas	0.81	0.81	0.01
Barbados	0.93	1.19	1.32
Belize	1.05	1.27	1.00
Bolivia	2.14	3.52	2.61
Brazil	1.04	1.45	1.75
Chile	1.34	1.72	1.31
Colombia	1.45	1.68	0.77
Costa Rica	0.57	0.70	1.06
Cuba	1.95	1.42	-1.66
Dominica	0.82	1.44	2.94
Ecuador	1.48	2.10	1.86
El Salvador	1.11	1.45	1.41
Grenada	0.72	0.90	1.16
Guatemala	1.05	1.83	2.90
Guyana	1.53	1.69	0.55
Haiti	0.90	2.42	5.20
Honduras	1.62	2.79	2.88
Jamaica	2.11	2.50	0.89
Mexico	1.50	2.06	1.69
Nicaragua	1.90	2.47	1.38
Panama	0.76	0.80	0.22
Paraguay	0.70	1.21	2.92
Peru	1.15	1.35	0.84
Dominican Republic	1.55	1.50	-0.17
St. Kitts and Nevis	0.71	0.72	0.11
St. Lucia	0.66	0.90	1.64
Saint Vincent and the Grenadines	0.68	0.80	0.86
Suriname	1.55	1.74	0.61
Trinidad and Tobago	5.19	8.27	2.45
Uruguay	0.44	0.83	3.33
Latin America	1.23	1.67	1.59
The Caribbean	2.06	2.25	0.46
Switzerland	0.22	0.22	-0.01
OECD	1.00	1.00	-

Note: The table compares emissions per unit of output for each country or region with respect to the OECD. To do this, first, the ratio between GHG emissions (measured in million tons of CO2 equivalent) and the GDP of each country (in thousands of constant 2010 dollars) was calculated. Secondly, the ratio between the value obtained for each country or region and that of the OECD was calculated. Thus, a value greater (less) than 1 indicates that the country has higher (lower) emissions per USD 1,000 of output compared to the OECD average. The values at the regional level were obtained from the aggregation of emissions and output of a sample of countries that make up the region. The selection of countries for Latin America and the Caribbean and OECD was made to ensure comparability with Table 2.1 and Graph 2.2, respectively (see Chapter 2 of this report). The table also shows how the ratio varied between 2000 and 2019. For this purpose, the average annual (logarithmic) variation for the period was calculated, which is obtained as the difference of the logarithm of the ratio in 2019 and in 2000, divided by the number of years in the period (19). The list of countries that make up each group can be found in the chapter's annex available online.

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

The relatively lower contribution of emissions associated with FFIP, compared to the developed world, might suggest that, in terms of energy use and industrial processes, Latin America and the Caribbean have relatively environmentally friendly practices and technologies. The truth is that, when compared with developed countries, one unit of output in the region is costly in terms of GHG emissions from FFIP (see Table 1.2).

In 2019, the cost of obtaining a unit of output, in terms of FFIP emissions, was 1.67 times higher in Latin America and up to 2.25 times higher in the Caribbean compared to OECD countries. When compared to Switzerland, a leading OECD country, Latin America emits seven times more per unit of output, and the Caribbean nearly 10 times more. More importantly, the gap with developed countries has grown. This does not mean that emissions per unit of output have increased in the region; they have actually fallen, but not at the rate at which they have fallen in developed countries. As will be seen in Chapter 2, a significant decline in emissions per unit of output is the key factor for decoupling.[25]

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In 2019, in terms of FFIP emissions, the cost of obtaining one unit of output was 1.67 times more in Latin America and up to 2.25 times more in the Caribbean than in OECD countries

Where are we going?

As a starting point for a look into the future, this section presents the emission commitments that the countries of the region have expressed in their Nationally Determined Contributions (NDCs). The chapter closes by presenting very concise information on energy scenarios for the region.

Energy commitments

The NDCs are the commitments made by UNFCCC signatory states under the Paris Agreement. At the time of writing this chapter, of the 33 countries in the region that have submitted an NDC to the UNFCCC Secretariat, 21 have an explicit GHG emissions reduction target for 2030.[26] These countries account for more than 80% of the region's current GHG emissions.

As can be seen in Table 1.3, the countries of the region as a whole with explicit emissions targets promise to release a maximum of 2,952 megatons of CO_2 equivalent by 2030,[27] a 10.8% reduction in emissions by this same group of countries in 2020. This drop is higher than the total pledged by countries with explicit targets in their NDCs, but considerably lower than those of developed regions, such as Oceania (44.6%), North America (37.4%), or the European Union (29.5%). Some regions, such as Africa, in contrast, show higher emissions in their NDCs than at present. However, as discussed in Chapter 2, this reduction in emissions contemplates comparable mitigation efforts between the region and the developed world in a just transition context, where a closing of the GDP per capita gap between the region and the richer countries is considered.

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[25] Of course, emissions per unit of output depend on factors beyond the energy sphere and, in particular, on the region's low productivity. Improving the productivity of companies and the economy as a whole would tend to reduce emissions over GDP and would become a key factor in decoupling.

[26] Although member countries of the agreement are required to submit an NDC to the UNFCCC secretariat every five years, they can modify or update their existing NDC at any time to increase the level of ambition of their targets, so the frequency of review and update varies from country to country.

[27] See Table A.1.6 in the chapter's annex available online for more information at the country level.


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The countries in the region have committed to emitting a maximum of 2,952 megatons of CO_2 equivalent by 2030, representing a 10.8% reduction compared to the emissions of this same group of countries in 2020

In addition to these global emissions pledges, most of the countries present specific commitments on energy. These commitments vary widely in nature and include, among others, percentages of electricity generation from renewable sources,[28] policy measures for energy demand management and efficiency, targets for electrification of the vehicle fleet, replacement of fossil fuels with ethanol, reduction of fugitive emissions from the oil and gas subsector, promotion of universal access to appropriate energy sources, and modernization of regulatory frameworks (see Table A.1.7 in the chapter's annex available online).

Table 1.3

GHG emission commitments to 2030

Region	Number of countries a/	Change in GHG emissions 2010–2020 (percentage)	2020 GHG emissions ($MtCO_2eq$) b/	GHG Emissions 2030-NDC ($MtCO_2eq$) 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 countries' NDCs at the regional level. a/ 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 that are covered by the target declared by each country in its NDC for 2030. c/ Net GHG emissions for 2030 were estimated by applying the mitigation target to the declared baseline 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]). See the clarifications to Table 1.3 in the chapter's annex (available online) for 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 (2023a, 2023b), Hattori et al. (2022) and UNFCCC Secretariat (2023).

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[28] Regarding the percentage of electricity generated from renewable sources, the numbers are also varied: in Antigua and Barbuda it is 86%; in Chile, 80%; in Costa Rica, 100%; in Cuba, 24%; in Dominica, 100%; in El Salvador, 80%; in Guatemala, 80%; in Guyana, 100%; in Nicaragua, 60%; in St. Kitts and Nevis, 100%; and in Suriname, 35%.

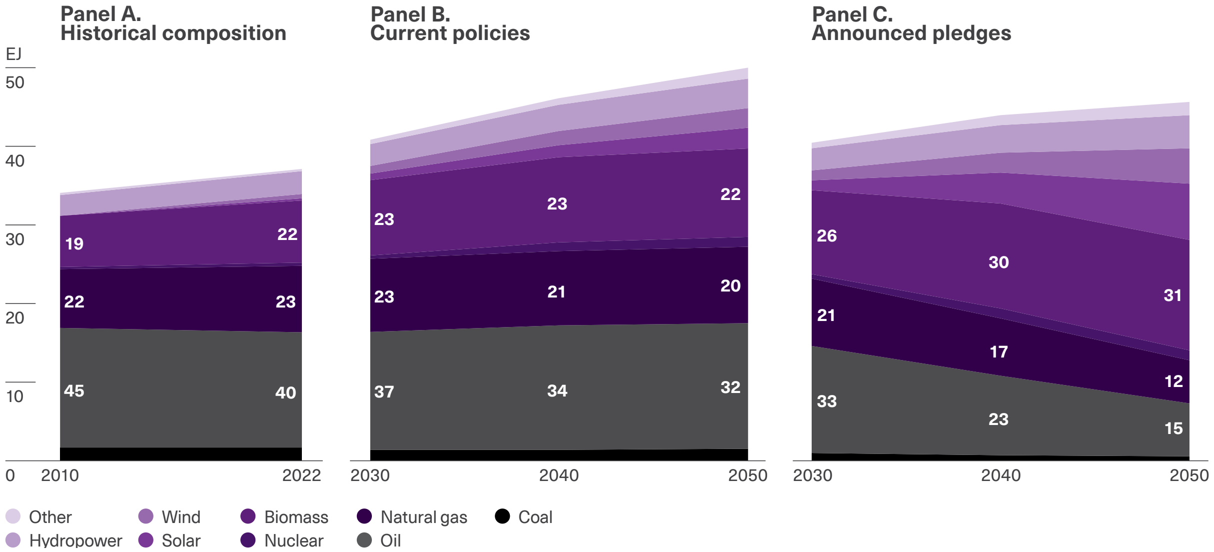
Finally, it should be noted that the NDCs represent commitments set for the year 2030. For a longer time horizon, most of the world's countries are committed to a more ambitious goal: net zero emissions. This implies that mitigation efforts need to be even greater after 2030. Preparing for that future today will be key to achieving a good balance between the benefits and costs of the energy transition.

Some scenarios for the region

Few studies have explored specific energy system scenarios for the countries of Latin America and the Caribbean. This section presents scenarios for the region prepared by the IEA.[29] In particular, the Agency has estimated results for the scenarios of current policies and announced commitments. Graphs 1.10, 1.11, 1.12, and 1.13 reflect information in this regard.

As is the case at the global level, the scenarios indicate a higher participation of non-conventional renewable sources in the current policy scenario, but even more relevant in the case of announced pledges made, where the combined importance of solar and wind power reaches 26%. As at the global level, in the scenario of announced pledges, the share of fossil sources is reduced, but they still have a significant magnitude. Perhaps the biggest differences with respect to the global scenario are the greater weight of biomass for sustainable biofuels in the region (31% in 2050 compared to 16% in the world under the announced commitments scenario) and the lower share of nuclear (Graph 1.10).

Graph 1.10
Total energy supply in Latin America and the Caribbean



Note: The graph shows how energy supply in Latin America and the Caribbean is composed by source today and in the IEA's current policy scenarios and announced pledges. The labels indicate the share of each source relative to the total in each year of the change of decade. The biomass category includes traditional biomass use and biomass for sustainable biofuels. The participation of the former subcategory decreases from 4% in 2022 to 0% in 2050 under the scenario of announced pledges, while the participation of the latter subcategory increases from 18% to 31% between 2022 and 2050 in the same scenario.

Source: Own elaboration based on IEA (2023l).

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[29] An ongoing study, coordinated by the Transportation and Energy Directorate of CAF's Physical Infrastructure and Digital Transformation Division (GIFTD), is developing a comprehensive long-term analysis of the electricity sector in Latin America with a 2050 horizon, including the sector's status, long-term development vision, trends and developments, and investment needs (see MRC Consultants and PSR, forthcoming).

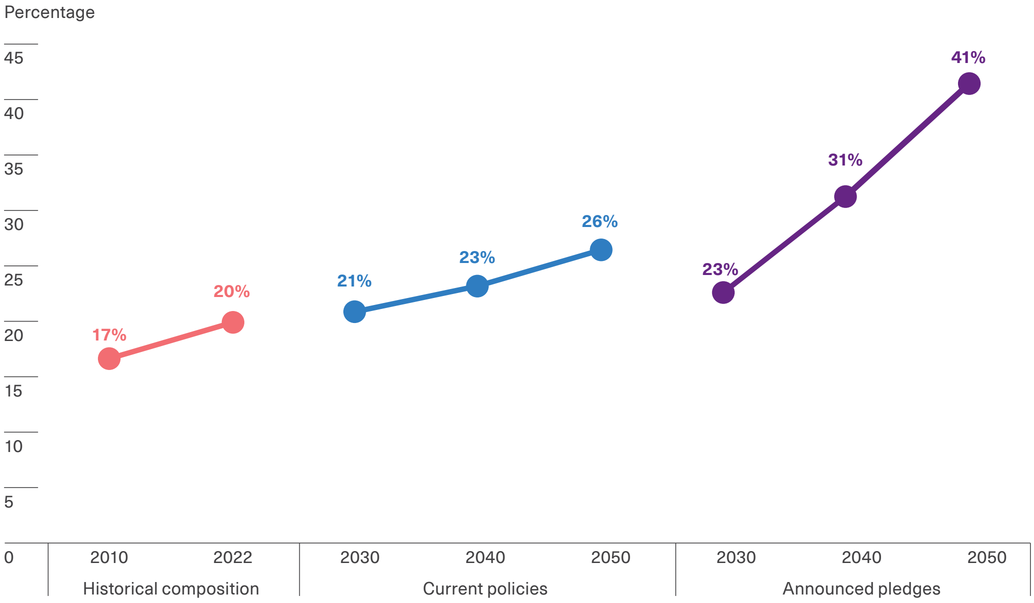
As in the rest of the world, Latin America and the Caribbean are expected to undergo major electrification. Electricity currently satisfies 20% of energy consumption; in the scenario of commitments made, it will satisfy 41% in 2050. Accompanying this expansion, very significant growth is expected in solar and wind power capacity, which will account for 43% and 19% of the total, respectively. This increase in the share of non-conventional renewables, in turn, is accompanied by the usage of batteries, which, under the scenario of announced commitments, will represent 7% of installed capacity in 2050. In this transformation of the electricity matrix, gas and, especially, hydroelectric power are losing relative ground. This does not mean a reduction in capacity; indeed, hydroelectric capacity would increase from 200 GW in 2022 to 310 GW in 2050 under the announced commitments scenario.

Significant electrification is expected in LAC. Today, electricity meets 20% of energy consumption; under the commitments made, it is projected to satisfy 41% by 2050

Finally, the demand for hydrogen (H_2) also expands significantly from 3 megatons (Mt) to 21 Mt, with a notable percentage increase of almost 600%, higher than the growth in global hydrogen demand in this same scenario.

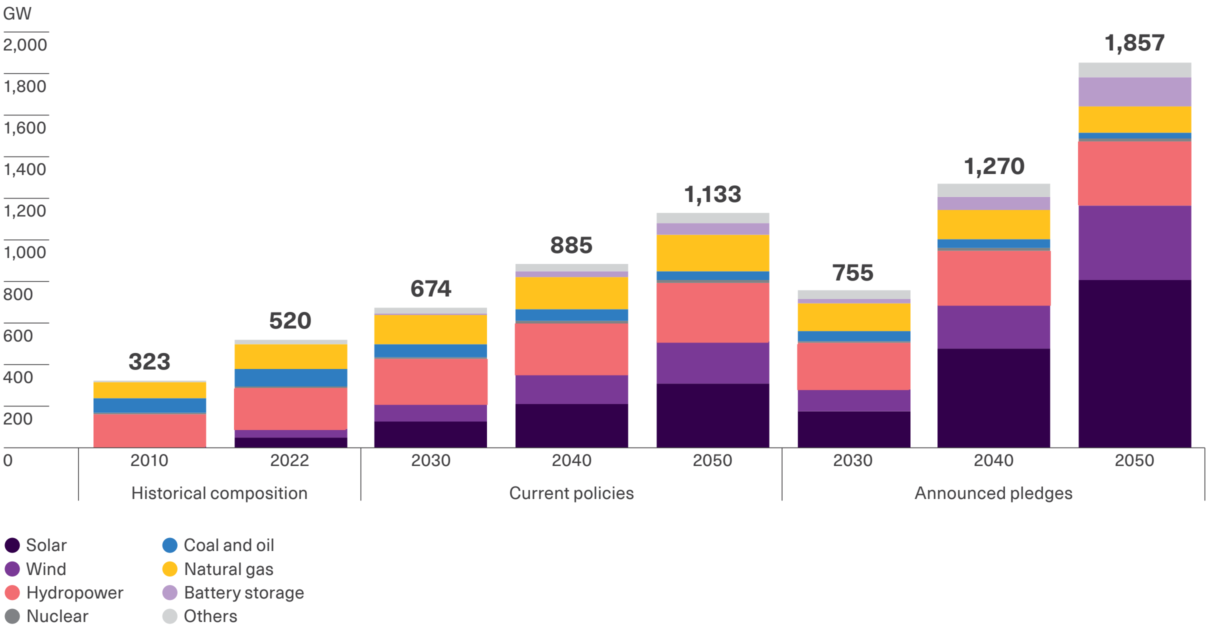
Graph 1.11

Share of electricity in final energy consumption in Latin America and the Caribbean



Source: Authors based on IEA (2023l).

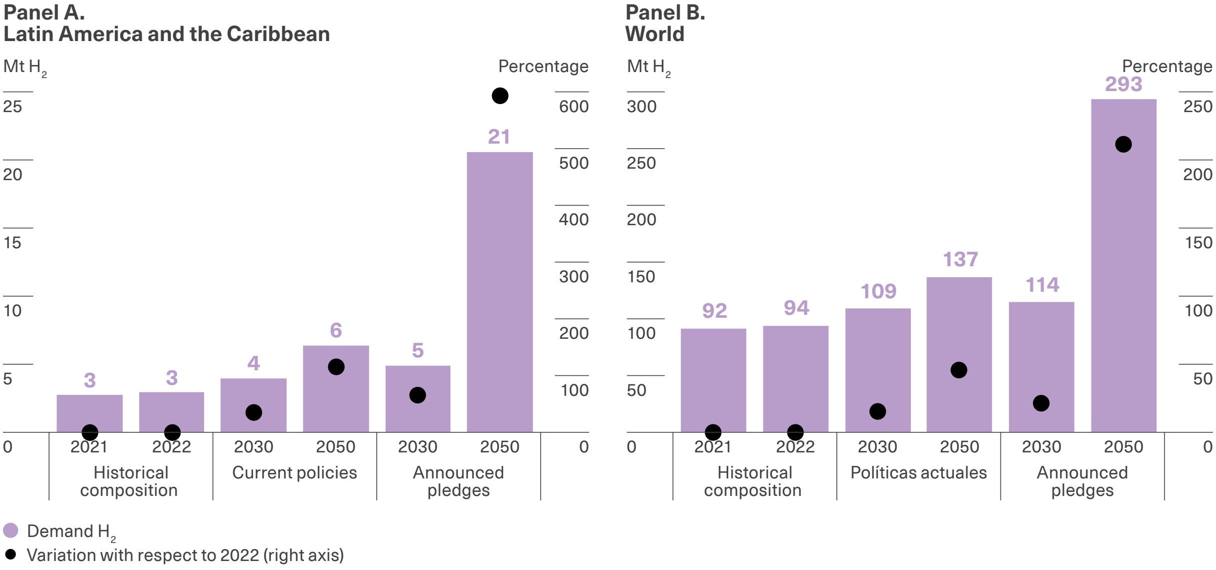
Graph 1.12
Electricity capacity in Latin America and the Caribbean



Note: The graph shows how electricity capacity is composed today and in the IEA's current policy scenarios and commitments. The "other" category includes bioenergy, geothermal energy, marine energy, hydrogen and ammonia.

Source: Authors based on IEA (2023l).

Graph 1.13
Hydrogen demand



Source: Authors based on IEA (2023l).

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The future for Latin America and the Caribbean should be one of economic growth, inclusion, and respect for the environment/environmental stewardship, in which the energy transition strives to achieve principles of justice among countries, among citizens within countries, and across generations

It should be emphasized that these scenarios do not represent forecasts, but rather frameworks for articulating climate actions. It should also be noted that both the scenarios and the actual changes that occur in the energy sphere will depend very much on the conditions of each country. In any case, the future for Latin America and the Caribbean should be one of economic growth, inclusion, and environmental stewardship/respect for the environment. As such, the energy transition must seek principles of justice among countries, among citizens within countries, and across generations. This implies addressing old tasks and facing new challenges (see Chapter 10).

The anatomy of decoupling

- A conceptual framework for decomposing emissions
- An international comparison of decoupling dynamics
- Emission intensity and the energy mix in LAC
- Energy intensity and the role of economic structure

2

Key messages

1

During the 20th century, the economic growth of countries was usually accompanied by an increase in greenhouse gas (GHG) emissions. Sustainable development requires a shift in this historical relationship to ensure growth, while emissions are reduced. The recent experience of developed countries shows that this path is technologically possible.

2

The condition for attaining economic growth while reducing GHG emissions, what is known as decoupling, is to achieve a sufficiently large cutback in emissions per unit of output such that it amply offsets the combined effect of population and per capita GDP growth. During this century, most countries in the region have managed to reduce emissions per unit of output, but not to that extent.

3

According to the climate pledges set out in the Paris Agreement, reflected in the Nationally Determined Contributions (NDCs), by 2030 the total emissions level of Latin America and the Caribbean countries should be approximately 11% lower than in 2020. In order to meet this goal, emissions per unit of output must annually come down by 5.5%, considering the expected population increase and an annual per capita GDP growth of 4%. That reduction is greater than the one observed over the last 10 years in the region, where emissions per unit of output have fallen on average by 2.6% per year.

4

Emissions per unit of GDP are contingent on both energy intensity and emission intensity. Evidence suggests that countries that have achieved successful mitigation conducive to decoupling have generally reduced both variables simultaneously. So far this century, the decline in energy intensity seems to have played a more prominent role; however, the reduction in emission intensity has gained increasing significance. This change is likely explained, among other factors, by the remarkable cost reduction of non-conventional renewable energy sources, enabling an increased share of these renewables in electricity generation.

5

The intensity of emissions related to energy consumption and industrial processes has decreased on average by around 0.24% annually in Latin America and by 0.12% in the Caribbean since the beginning of the 21st century. In contrast, in OECD countries it has fallen by 0.72% per year. The less pronounced decline in the region when compared to the developed world appears to be linked to the lower penetration of non-conventional renewables and the increase of fossil fuels in electricity generation. Fortunately, the increment of fossils was biased toward gas, which has helped reduce the carbon content of thermal power generation.

6

During the 21st century, countries in Latin America have reduced their energy intensity at an annual rate of 0.50%, and those in the Caribbean at 1.76%. Nevertheless, in 2019, the energy intensity of countries in the region was 48% higher than that of OECD countries.

7

The levels of energy intensity vary significantly across and among sectors and subsectors; thus, economic structure influences the overall energy intensity of the economy. Indeed, the shift in the sectoral composition of Latin America and the Caribbean economies in the last decade of the century has somewhat counteracted the progress made in reducing the energy intensity of the different sectors, an achievement that can be partly attributed to energy efficiency gains.

8

A large share of the differences in energy intensity between countries is triggered by variations in economic structure and does not entirely respond to differences in energy efficiency. The fact that the economic structure has implications for aggregate energy intensity does not diminish the importance of energy efficiency. However, it does underline that the challenges of decoupling cannot be assessed without considering the structural transformations of economies.

The anatomy of decoupling[1]

Introduction

Over the last 80 years, global per capita GDP has almost quintupled. Unfortunately, owing in part to this remarkable economic growth, greenhouse gas (GHG) emissions have increased sevenfold. During this period, Latin America and the Caribbean (LAC) has also experienced growth, yet it has not been sufficient to narrow the per capita income gap with advanced countries. To bridge this gap, the region needs to sustain continuous growth at rates higher than those of the developed world. However, this essential process must take place in a different context: that of an energy transition aimed at reducing GHG emissions.

The feasibility of achieving robust economic growth with a simultaneous reduction in emissions, a process known as decoupling, depends on a combination of environmental, technological, regulatory, economic, and even cultural factors. One variable that succinctly captures the impact of all these factors is emissions per unit of output. A country's emissions at a given time can be expressed as the product of three variables: emissions per unit of gross domestic product (GDP), per capita GDP, and population. Consequently, decoupling occurs when emissions per unit of output decrease more than the combined growth in population and per capita GDP. This decline in emissions per unit of output can be achieved either by reducing emission intensity (defined as emissions per unit of energy consumed) or by lowering energy intensity (defined as energy consumed per unit of GDP).

For decoupling to occur, emissions per unit of output must decrease at a higher rate than the combined growth in population and per capita GDP

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[1] This chapter was written by Lian Allub and Fernando Álvarez with research assistance from María Pía Brugiafreddo and Martín Finkelstein.

This chapter adopts an accounting approach to the relationship between emissions growth and economic growth. While the aim of this analysis is not to discuss the policies and institutions that promote decoupling, a topic explored throughout the report, it does provide insight into the scale of the challenge and illustrates the role played by factors such as energy efficiency, economic structure and decarbonization of energy consumption in achieving that disconnection. The chapter focuses on emissions from fossil fuel consumption and industrial processes, which are linked to the main theme of the report: energy transition.

It begins with a review of the aggregate data on emissions and per capita GDP growth. The analysis contrasts the region's experience with that of developed countries and compares the situation at the end of the last century with what occurred in the first two decades of this century. Next, it explores the implicit ambition of the emission mitigation goals pledged by countries of the region for 2030, as outlined in their Nationally Determined Contributions (NDCs). This analysis takes into account the expected demographic growth of LAC countries and different scenarios of per capita GDP increase. The chapter then delves into the experience of those countries that have achieved favorable decoupling so far this century, to assess the relative contribution of reductions in energy intensity and emission intensity in achieving mitigation. Lastly, the chapter focuses on the two determinants of emissions per GDP. It first examines the composition of energy consumption, a determinant of emission intensity, before concluding with an analysis of energy intensity, with a special emphasis on the role played by economic structure.

The challenge of decoupling

The Latin American and Caribbean region faces a triple challenge: narrowing the per capita GDP gap with the developed world, reducing inequality and poverty, and protecting the environment, all within a global context of energy transition.[2] Without downplaying the challenge posed by inclusion and its connection with energy transition, this section is focused on the relationship between GDP growth and emissions.

A key concept in this relationship is so-called decoupling, which occurs when—in a context of per capita GDP growth—a country's emissions do not increase (absolute decoupling) or increase at a slower rate than its per capita GDP (relative decoupling) (Hubacek et al., 2021). This chapter addresses the challenge of decoupling, following the conceptual framework described in Box 2.1.

As explained therein, and as mentioned in the introduction, to achieve decoupling, the decline in emissions per unit of output must exceed the combined growth in population and per capita GDP. This leads to the question: What behavior have these factors displayed over the last century?

[2] The environmental challenge is broader than just climate change mitigation and includes adaptation to the associated risks of climate change and biodiversity loss, and the protection of ecosystems and biodiversity, among other issues. This chapter focuses on the matter of GHG emissions, which is closely linked to the problem of global warming, with a particular emphasis on those emissions produced by fossil fuel consumption and industrial processes. In other words, emissions related to the agricultural, forestry, and other land use (AFOLU) sector are excluded from the analysis, as they have far less to do with the topic of energy transition. As discussed in Chapter One, some countries in the region, such as Brazil, Paraguay or Uruguay, present significant emissions from the AFOLU sector. An analysis of environmental challenges that go beyond energy transition for Latin America and the Caribbean can be found in Brassiolo et al. (2023).

Box 2.1

The anatomy of decoupling: An accounting framework

A country's emissions can be expressed as the product of three terms: emissions per unit of output, per capita GDP, and population.[a] To achieve decoupling, emissions per unit of output must decrease at a higher rate than the combined growth in population and per capita GDP.

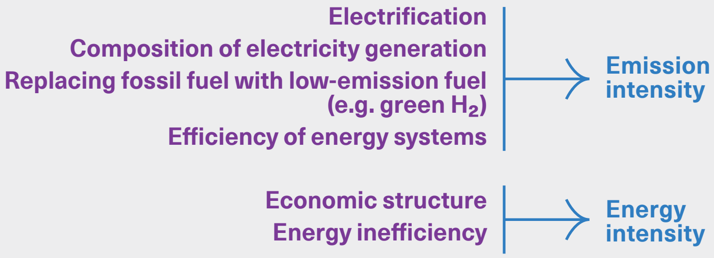
Emissions = Emissions per unit of GDP × GDP per cápita × Population

Emissions per unit of GDP, in turn, can be expressed as the product of two well-known factors linked to energy policy. The first is emission intensity, calculated based on emissions per unit of energy, and the second, energy intensity, defined as the ratio of energy use to GDP. Therefore, a reduction in emissions per unit of output can be achieved either by reducing emission intensity or by decreasing energy intensity.

Emissions per unit of GDP = Emission intensity × Energy intensity

Emission intensity depends on the energy source consumed. The less fossil fuel content in the "energy mix," the more likely emission intensity will decrease. This can be achieved by electrifying fossil fuel-dependent processes (e.g. transportation) and simultaneously increasing the share of renewables in electricity generation. It can also be accomplished by replacing fossil fuel consumption with low or zero-emission fuels, such as green hydrogen, or by improving the efficiency of energy systems.

Meanwhile, a country's energy intensity may be high because its industries have a high energy intensity (relative to the same industries in other countries), or because its economy is focused on industries that are inherently energy-intensive in any country (e.g. transportation). The first component could be associated with the concept of energy inefficiency, and the second, with the role of economic structure.



The accounting approach undertaken in this chapter, while not aimed at discussing policies and institutions that promote economic growth with emission reduction, does provide insight into the scale of the challenge associated with decoupling. It also highlights the role played by factors such as energy efficiency, economic structure, and the decarbonization of energy consumption in achieving decoupling.

[a] This identity applies regardless of whether total emissions or those linked to energy consumption and industrial processes are being discussed, as long as emissions per unit of output are measured in the same terms. Nevertheless, the choice of the emissions component limits the question asked. For example, if emissions linked to fossil fuels and industrial processes (FFIP) are selected, then the question posed is whether it is possible to achieve economic growth while simultaneously reducing energy-related emissions and those associated with such processes.

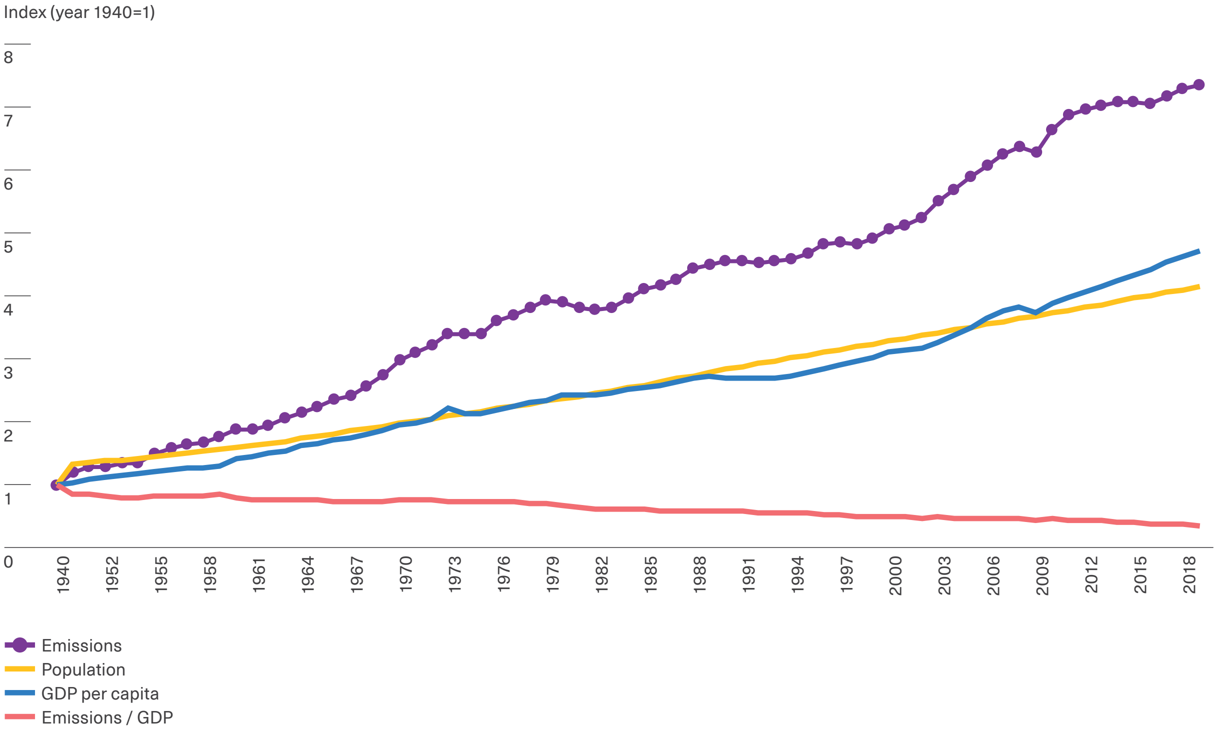
Since 1940, per capita GDP has increased almost fivefold, and population just over fourfold, as shown in Graph 2.1. While global emissions per unit of output have fallen to less than half, this decline has not been sufficient to more than offset the impact of the growth of the other two variables on emissions, which have multiplied by just over seven.

It is useful to revisit the previous discussion with detailed country-level information and a focus on energy and industrial process-related emissions. For this purpose, a comparison is made between the final two decades of the 20th century and the initial two decades of this century. As depicted in Graph 2.2, during the final stage of the last century, economic growth was accompanied by a rise in greenhouse gas emissions, primarily linked to fossil energy consumption and industrial processes. This pattern held not only for most countries in the region, but also for a substantial portion of the most developed countries, with some exceptions such as Germany, Belgium, and France, among others.

Although global emissions per unit of output are now less than half of what they were 80 years ago, this decline has not been sufficient to adequately offset the combined effect of population growth and per capita GDP growth on emissions

Graph 2.1

Evolution of global CO$_2$ emissions and determinant components



Note: The graph shows the evolution of total carbon dioxide emissions and their components from 1940 to 2019. Values are presented as index numbers, with the year 1940 as the baseline (equal to 1). Gross domestic product is measured in constant 2011 dollars (USD). Data for GDP and population were obtained from the World Bank (available from the 1990s and 1960s, respectively). For previous years, both series were estimated based on the annual growth rate implied in the Maddison Database Project data (2020 version).

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

For example, Latin American countries had, on average, a per capita GDP growth rate of 0.3% per year during the last two decades of the 20th century, and an average growth in emissions associated with the use of fossil fuels and industrial processes (FFIP) of around 2.2% per year. The average growth rates of per capita GDP and emissions of Caribbean countries were similar: 1.0% and 2.8% respectively. Lastly, countries in the Organization for Economic Cooperation and Development (OECD) typically experienced relative decoupling, presenting higher per capita GDP growth than the rise in emissions, but were unable to match growth with emission reductions (see Graph 2.2).

How have these variables behaved in the 21st century? Is economic growth possible in the context of this new energy transition?

●●

Latin American and the Caribbean countries exhibit a trend of GDP growth accompanied by increased emissions. In contrast, OECD countries showed a stronger tendency toward achieving absolute decoupling.

During this century, countries in Latin America and the Caribbean have exhibited a trend of GDP growth and increased emissions, except for Barbados, Cuba, and Jamaica, which have achieved slight reductions in emissions. In contrast, the experience of the developed world differs: OECD countries have shown a greater trend to increase their per capita GDP while reducing their emissions, thereby achieving absolute decoupling. Among this group of countries, the average per capita GDP growth rate was 1.1%, while the emissions reduction rate was 0.5%.

These results offer a glimmer of hope and suggest that the technology to achieve absolute decoupling between economic growth and industrial process-related emissions is available worldwide. However, do the Latin American and Caribbean countries have the necessary institutions to achieve this decoupling?

The concept of decoupling does not capture all the information associated with achieving growth while controlling emissions. For example, both Barbados and Denmark experienced absolute decoupling in the first two decades of the 21st century; however, Barbados grew by only 0.14% per year, less than the 0.79% growth achieved by Denmark, while the Caribbean nation's emissions reduction, at 0.57% per year, was lower than the European country's 2.9%. The difference between per capita GDP and emissions growth could be a variable that provides more information and reflects the non-binary nature of mitigation efforts. Henceforth, this variable will be referred to as "mitigation success."

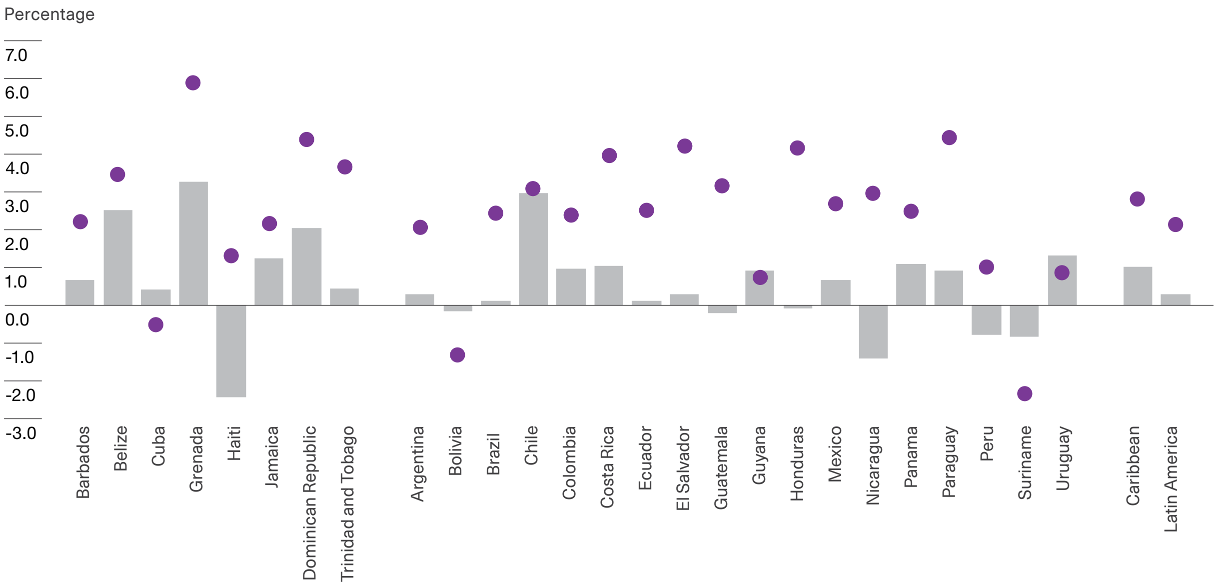
Mitigation success is directly associated with the decline in emissions per unit of output.[3] The key to achieving vigorous growth in per capita GDP while lowering emissions lies in the significant reduction of this variable. The evolution of emissions per unit of output in the region has been favorable, but insufficient to achieve absolute decoupling. During the first two decades of this century, Latin America reduced this factor at an annual rate of 0.74% and the Caribbean at 1.87%. In contrast, OECD countries reduced it at an annual rate of 2.33% (see Table 2.1).

---

[3] Indeed, if growth rates are represented as logarithmic differences, mitigation success minus population growth is exactly equal to the reduction in emissions per unit of output.

Graph 2.2
Per capita GDP growth versus emissions growth

Panel A.
Latin American and Caribbean Countries, 1980–1999



Panel B.
OECD Countries, 1980–1999

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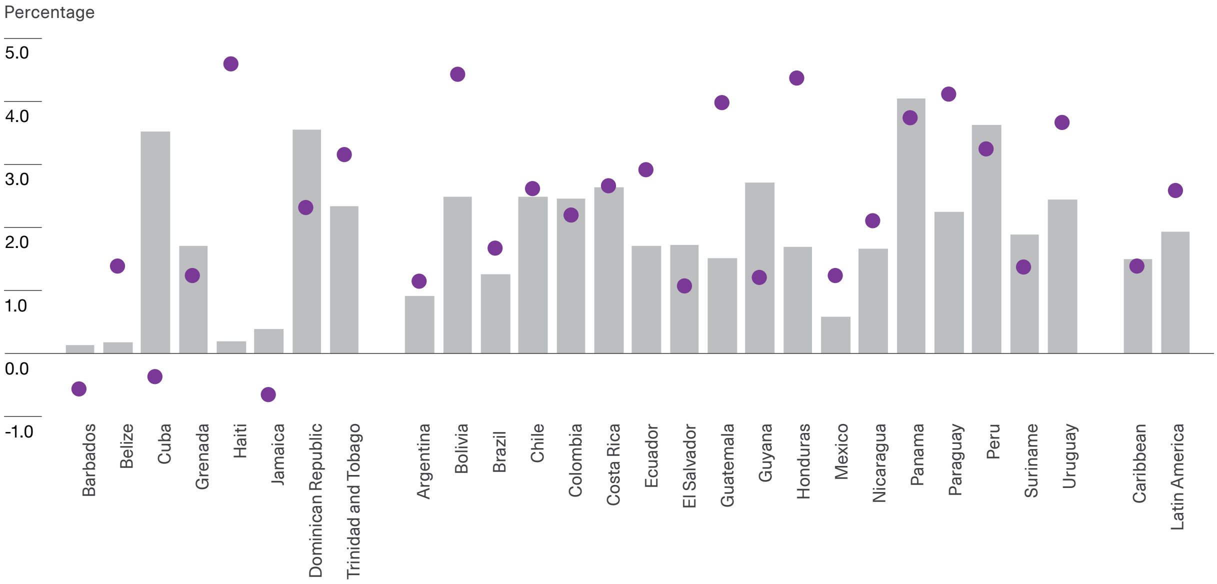
Panel C.
Latin American and Caribbean countries, 2000–2019



Panel D.
OECD countries, 2000–2019

Note: The graphs compare the growth rate of per capita GDP with the growth rates of emissions associated with the use of FFIP. Growth rates represent annualized logarithmic variations. FFIP-related emissions are estimated as the sum of emissions from the following sectors: buildings, energy systems, industry, and transport. The regional average refers to the simple average of the corresponding countries. If emissions and GDP were aggregated at the regional level, instead of being calculated as a simple average of the countries by region, regional growth rates would change, but the message would remain the same: the OECD has been able to decouple in the first two decades of the 21st century, while Latin America and the Caribbean has not.

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

Table 2.1
Emissions per unit of GDP

Country or region	FFIP emissions/GDP (millions of tCO_2eq)		Average annual variation (percentage)
	2000	2019	
Antigua and Barbuda	0.44	0.37	-1.01
Argentina	0.49	0.42	-0.80
Bahamas	0.33	0.21	-2.32
Barbados	0.38	0.31	-1.02
Belize	0.43	0.33	-1.34
Bolivia	0.88	0.92	0.28
Brazil	0.43	0.38	-0.58
Chile	0.55	0.45	-1.02
Colombia	0.59	0.44	-1.57
Costa Rica	0.23	0.18	-1.28
Cuba	0.80	0.37	-4.00
Dominica	0.34	0.38	0.60
Ecuador	0.60	0.55	-0.48
El Salvador	0.45	0.38	-0.93
Grenada	0.29	0.23	-1.17
Guatemala	0.43	0.48	0.57
Guyana	0.62	0.44	-1.78
Haiti	0.37	0.64	2.87
Honduras	0.66	0.73	0.55
Jamaica	0.86	0.66	-1.44
Mexico	0.61	0.54	-0.64
Nicaragua	0.78	0.65	-0.96
Panama	0.31	0.21	-2.11
Paraguay	0.28	0.32	0.58
Peru	0.47	0.35	-1.50
Dominican Republic	0.63	0.39	-2.51
Saint Kitts and Nevis	0.29	0.19	-2.22
Saint Lucia	0.27	0.24	-0.70
Saint Vincent and the Grenadines	0.28	0.21	-1.47
Suriname	0.63	0.46	-1.72
Trinidad and Tobago	2.12	2.17	0.12
Uruguay	0.18	0.22	0.99
Latin America	0.50	0.44	-0.74
Caribbean	0.84	0.59	-1.87
OECD	0.41	0.26	-2.33

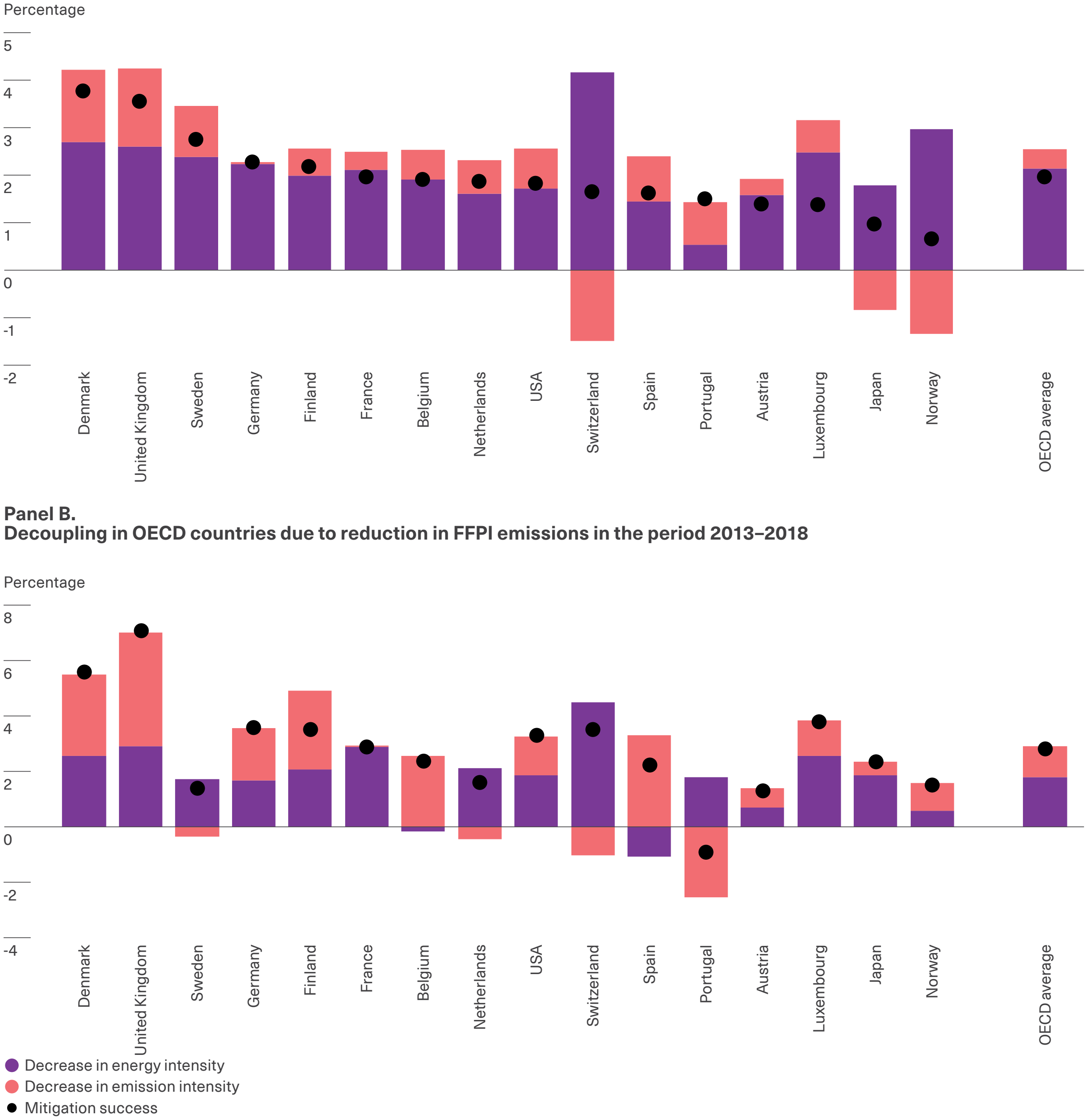
Note: The table shows the FFIP-related GHG emissions generated per USD 1,000 of GDP for each country and region in 2000 and 2019 and their average annual (logarithmic) variation during that period. Emissions are measured in millions of tons of carbon dioxide equivalent ($MtCO_2eq$) and GDP is measured in thousands of constant 2010 US dollars. Logarithmic variation is calculated as the difference in the logarithm of emissions in 2019 and 2000, divided by the number of years in the period (19). The countries of the Community of Latin American and Caribbean States (CELAC) are included, with the exception of Venezuela, for which there is no available GDP data beyond 2014. When taking into consideration Venezuela's GDP (in current 2014 dollars) deflated by the US implicit price index, the emissions per product indicator shows an average annual decrease of 2.7% in the period 2000–2014. The values for each region were obtained by aggregating the emissions and GDP from a sample of countries. The selection of countries for Latin America and the Caribbean was made to ensure comparability with Tables 2.3 and 2.4. The list of countries considered in each region can be consulted in the annex of this chapter available online.

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

Graph 2.3

Mitigation success, reduction in emission intensity and energy intensity

Panel A.
Decoupling in OECD countries due to a reduction in FFIP emissions in the period 2000–2018



Note: The graph presents the growth rate of energy intensity (energy/GDP), the growth rate of emission intensity (emissions/energy), and mitigation success, defined as the difference between the growth rate of GDP per capita and the growth rate of emissions. Emissions refer to the FFPI component, including the following sectors: buildings, energy systems, industry, and transport. Growth rates are expressed as annualized logarithmic variations. The graph only includes OECD countries that experienced absolute decoupling in the period 2000 to 2018, meaning they reduced FFIP emissions while simultaneously growing in terms of per capita GDP.

Source: Authors based on Minx et al. (2021) and data processed by Our World in Data (2023a), obtained from Global Carbon Budget (2023) and Maddison Project Database 2020 (Bolt and van Zanden, 2020).

As mentioned earlier, reducing emissions per unit of output can be achieved by decreasing either emission intensity or energy intensity (see Box 2.1). However, evidence suggests that countries that have achieved (absolute) decoupling this century have done so by reducing both components. The contribution made by the decline in energy intensity appears to have played a more significant role over the last 20 years. Nevertheless, the component associated with emission intensity has gained increasing importance over time, likely due to the decreasing cost of non-conventional renewable energy sources.

These statements are confirmed in Graph 2.3, which shows mitigation success (black dot), the rate of variation in energy intensity (purple bar) and the rate of emission intensity (pink bar) for the countries that achieved decoupling. The graph presents the data for the period 2000–2018 and for the subperiod 2013–2018.

Evidence suggests that the countries that have achieved absolute decoupling in this century have done so by reducing both emissions intensity and energy intensity.

As can be observed in Panel A of the graph, out of the 16 selected OECD countries that achieved absolute decoupling between 2000 and 2018, 13 simultaneously reduced energy intensity and emission intensity. Furthermore, for the period 2000–2018, the average decrease in energy intensity is five times greater than the reduction in the emissions factor. For the period 2013–2018, the average decrease was 1.8 in energy intensity and 1.1 in emission intensity.

Mitigation efforts in the run-up to 2030

As discussed in the previous chapter, as a region, Latin America and the Caribbean has pledged to reduce its total emissions by an average of around 10% by 2030 compared to 2020. At first glance, this percentage might seem modest when compared to the mitigation targets made by the developed world. However, it entails comparable efforts in terms of reducing emissions per unit of output, considering that, to attain the living standards of the developed world, the countries in the region will need to achieve higher per capita GDP growth.

Developing countries, like those in Latin America and the Caribbean, not only tend to have a higher rate of population growth but must also aspire to higher rates of per capita GDP growth than developed countries if they want to close the gap between them. Both factors tend to increase the country's level of emissions and make it more challenging to achieve any emissions target. If these elements are somehow incorporated (see Box 2.2), the levels of effort made by developed countries and those in the region begin to look more similar.

For example, Table 2.2 shows the average annual rate of change in emissions per unit of output needed between 2020 and 2030 to meet the NDC emissions target under various scenarios. The table presents the average values for different regions.[4] Scenario 1 sets the projected population growth rate for each region and a per capita GDP growth rate of zero. In the last two scenarios, the same projected population growth rate is set, but the per capita GDP growth considered is 2% in scenario 2 and 4% in scenario 3.

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[4] Table A.2.1 of the annex of this chapter available online shows the values for Latin American and Caribbean countries.

Box 2.2
A measure of mitigation effort adjusted for expected population and economic growth

At any point in time, a country's emissions (E_t) can be expressed as the product of three variables:

$$E_t = \frac{E_t}{GDP_t} * \frac{GDP_t}{Pop_t} * Pop_t \qquad (1)$$

Where GDP represents the gross domestic product and Pop refers to the population.

If the components of equation (1) are compared at two time points, and G_z denotes the (annualized) rate of change of z between two periods, the expression can be formulated as follows:

$$(1+G_e) = (1+G_{e/GDP}) * (1+G_{GDP/Pop}) * (1+G_{Pop}) \qquad (2)$$

These equations clearly show that as a country's population and GDP increase, emissions are also likely to rise (given $G_{e/GDP}$).

Developing regions can be expected to have a higher rate of population growth and per capita GDP growth than the developed world. Therefore, it may be more challenging in terms of mitigation efforts for a developing country to achieve a given level of emissions reduction than for a developed one.

An alternative measure of mitigation effort is $G_{e/GDP}$, a factor that depends on energy intensity and emission intensity, two key objectives of the mitigation strategy in energy transition.

Consequently, a corrected measure of energy effort is:

$$G_{e/GDP} = \frac{(1+G_e)}{(1+G_{Pop})(1+G_{GDP/Pop})} - 1$$

These measures are presented in Table 2.2 for different economic growth scenarios.

As can be seen under scenario 3, given the expected population growth, if the per capita GDP of Latin America and the Caribbean grows by 4% per year, the region must reduce its emissions per GDP by around 5.5% annually. This estimate is/These estimates are similar to the emission reductions that the European Union should accomplish to meet its NDC if it grows by 2% per year (a year-over-year average decrease in emissions per unit of output of 5.24%).

This 5.5% decrease in emissions per unit of output, which is consistent with the region's mitigation targets and entails a 4% growth in per capita GDP, surpasses the average annual emissions per unit of output decrease (of approximately 2.56%) recorded in the region over the past decade. This underscores the importance of promptly initiating mitigation efforts to reduce emissions per GDP.

Given the expected population growth, if the per capita GDP in Latin America and the Caribbean increases by 4% annually, the region must reduce its emissions per GDP by around 5.5% per year

Table 2.2
Mitigation efforts for 2030 by region

Region	Number of countries	Average annual variation of GHG emissions per GDP in 2010-2020 (percentage)	Average annual variation of GHG emissions per GDP in 2020-2030 (percentage)			GHG emissions 2030 - NDC target ($MtCO_2eq$)
			Scenario 1	Scenario 2	Scenario 3	
Africa	37	-1.04	-0.02	-1.98	-3.87	3,805
North America	2	-3.19	-5.17	-7.03	-8.82	3,766
Latin America and the Caribbean	21	-2.56	-1.72	-3.65	-5.50	2,952
Asia (without China and India)	19	-0.11	0.37	-1.60	-3.49	6,081
China	1	-4.32	0.37	-1.59	-3.49	12,804
India	1	-2.91	1.30	-0.69	-2.60	3,910
Oceania	6	-2.04	-6.62	-8.45	-10.21	390
European Union	27	-2.97	-3.35	-5.24	-7.06	2,085
Rest of Europe	19	-0.76	4.15	2.11	0.15	3,927
Total	**133**	**-1.78**	**-0.70**	**-2.65**	**-4.52**	**39,720**

Note: The table presents the average year-over-year (YoY) change in GHG emissions per unit of product between 2010 and 2020, by country or region, and compares it with the average YoY change rate necessary between 2020 and 2030 to meet the mitigation stated by each country in its NDC, under three different scenarios. Scenario 1 assumes a GDP per capita growth of 0% per year; in scenario 2, GDP per capita increases by 2% per year; and in scenario 3, by 4%. All scenarios take the population growth rate projections of the United Nations. Net GHG emissions (expressed in millions of tons of carbon dioxide equivalent [$MtCO_2eq$]) for 2030 were estimated by applying the countries' unconditional mitigation target to the base emissions level declared in their NDC (in the reference year or the business-as-usual scenario). For countries that do not specify the sectors included in the target, the estimation assumes that the target covers all sectors (including LULUCF), while if countries clarify that the target does not cover LULUCF, emissions without that sector are used. The online appendix of the chapter provides a list of the countries included in each region and reproduces the table on a national scale for the countries of Latin America and the Caribbean.

Source: Authors based on World Bank (2023c, 2023f); Climate Watch (2023b); United Nations (2022); UNFCCC Secretariat (2023) and Brassiolo et al. (2023).

Emission intensity and the energy "mix" in Latin America and the Caribbean

This section provides a diagnosis of the composition of energy consumption and electricity generation. The (energy-related) emissions factor per unit of energy, or emission intensity, tends to decrease as this "energy mix" becomes less fossil fuel-dependent. Observing the evolution of emissions intensity over time is a good starting point for this diagnosis.

In the case of FFIP-related emissions, shown in Table 2.3, emission intensity has decreased in the last two decades at an average annual rate of 0.24% in Latin America and 0.12% in the Caribbean.[5] In comparison, OECD countries achieved a reduction of 0.72%.[6]

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[5] Tables A.2.2 and A.2.3 in the annex of this chapter available online provide information on energy consumption by source of energy for each country in the region. Chile and Uruguay stand out due to their high penetration of non-conventional renewables; however, they do not show a decline in emission intensity but instead exhibit a very slight increase. Similarly, even though Paraguay's electricity matrix is based entirely on hydroelectric power, the country's emissions intensity has increased. The rise in Paraguay's emissions relative to its GDP may be explained by the growing use of oil and its products in its consumption portfolio, which increased from around 30% in 2000 to over 42% in 2019. In the case of Chile, despite the significant penetration of solar and wind energy, generation from fossil plants did not decrease; in fact, coal-based generation increased. In contrast, hydroelectric sources experienced a significant decline. As for Uruguay, the increase in the indicator seems to be linked to the growth of emissions from waste treatment. If these are excluded from the FFIP-related emissions, the indicator shows an annual variation of -0.92% (rather than an increase of 0.21%).

[6] When considering total emissions, the annual decline in emission intensity is around 1.87% in Latin America and 1.20% in the Caribbean. The reductions in total emissions are significantly greater, as a result of the decrease in emissions from the AFOLU sector, combined with the importance of these emissions in the region, as highlighted in Chapter 1.

Table 2.3

Emission intensity

Country or region	FFIP emissions/ Energy		Annual average variation (percentage)
	2000	2019	
Argentina	5.03	4.47	-0.62
Barbados	3.66	3.39	-0.41
Belize	9.70	2.18	-7.86
Bolivia	5.52	5.15	-0.37
Brazil	3.55	3.21	-0.52
Chile	3.64	4.18	0.73
Colombia	4.14	4.45	0.38
Costa Rica	3.12	2.92	-0.35
Cuba	6.07	5.88	-0.17
Ecuador	5.53	4.26	-1.37
El Salvador	4.07	3.29	-1.12
Grenada	3.63	2.82	-1.32
Guatemala	2.58	2.72	0.28
Guyana	2.44	3.11	1.27
Haiti	1.82	2.89	2.44
Honduras	2.81	4.33	2.28
Jamaica	5.36	3.38	-2.43
Mexico	5.66	5.92	0.23
Nicaragua	3.00	3.31	0.51
Panama	3.88	3.57	-0.43
Paraguay	1.60	2.01	1.22
Peru	3.47	3.60	0.19
Dominican Republic	5.12	5.36	0.23
Suriname	3.28	4.08	1.16
Trinidad and Tobago	7.53	7.09	-0.31
Uruguay	2.68	2.79	0.21
Latin America	4.29	4.10	-0.24
Caribbean	5.49	5.37	-0.12
OECD	3.99	3.40	-0.72

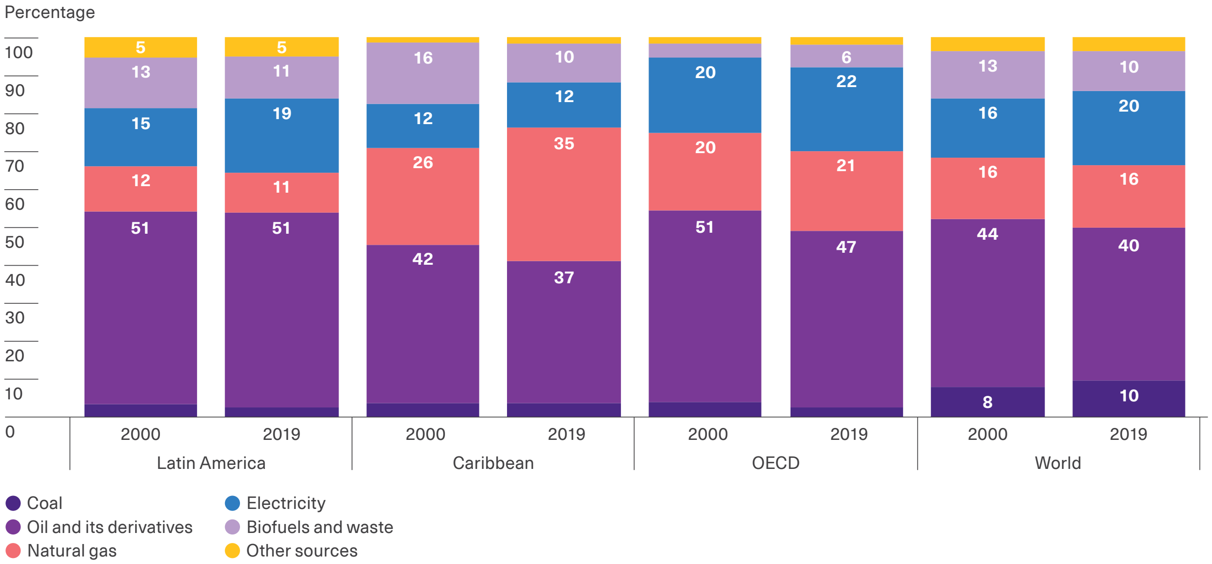
Note: The table shows the FFIP-related GHG emissions generated per unit of energy consumed for each country and region in 2000 and 2019, along with the average annual (logarithmic) variation in that period. Emissions are measured in million tons of carbon dioxide equivalent ($MtCO_2eq$), and energy consumption is measured in million tons of oil equivalent (Mtoe). The logarithmic variation is calculated as the difference between the logarithm of emissions in 2019 and 2000, divided by the number of years in the period (19). The countries included in the table are the CELAC members for which the Latin American Energy Organization (OLADE) has energy consumption information. Regional values were obtained by aggregating emissions and energy consumption data for the constituent countries. The list of countries considered in each region can be consulted in the annex of this chapter available online.

Source: Authors based on IEA (2022d), Minx et al. (2021) and OLADE (2023b).

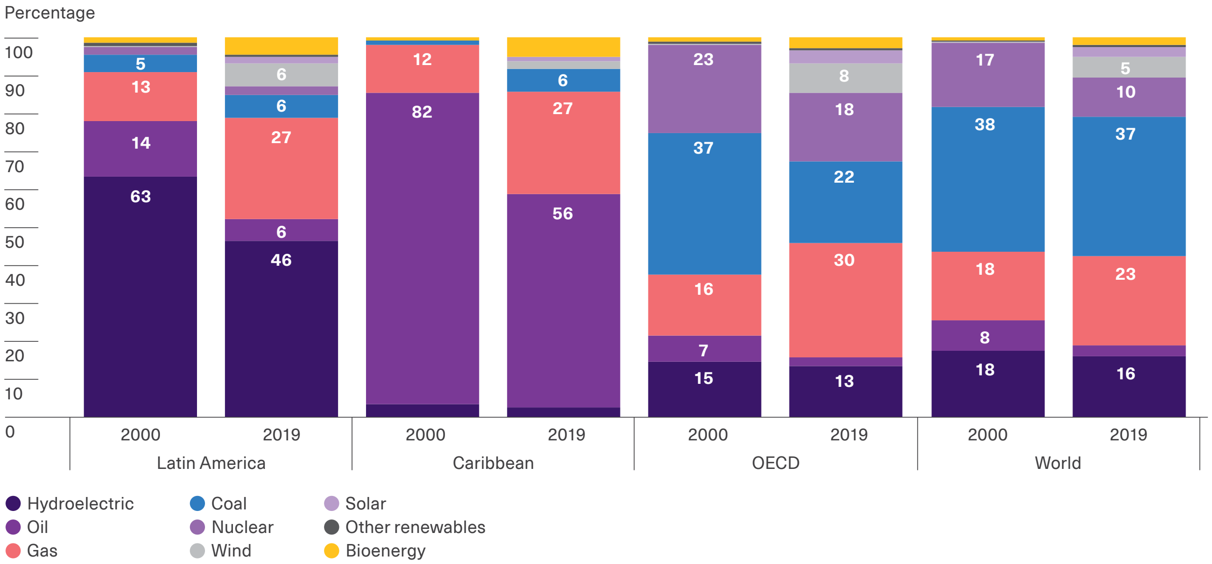
Why was the reduction in emission intensity less pronounced in Latin America than in the developed world? Graph 2.4 provides insights in this regard. Panel A illustrates the evolution of the composition of energy consumption and Panel B shows the evolution of the electricity matrix, which shows the percentage share of different energy sources used in electricity generation.

Graph 2.4
Energy composition of electricity consumption and generation

Panel A.
Final energy consumption



Panel B.
Electricity generation



Note: Panel A shows the share of final energy consumption by source. Data from OECD countries and the world were obtained from the International Energy Agency (IEA). The values for Latin America and the Caribbean were obtained by aggregating the energy consumption in the countries surveyed by OLADE that make up each region. Tables A.2.2. and A.2.3 included in the online annex of this chapter show the energy composition of electricity consumption and generation for each country.

Source: Authors based on IEA (2021e), OLADE (2023e), and data processed by Our World in Data (2023b), based on Ember (2023) and Energy Institute (2023).

Between 2000 and 2019, OECD countries reduced the relative contribution of oil and its derivatives in energy consumption by approximately 4 percentage points. The importance of coal in energy consumption also decreased by an additional percentage point. In turn, electricity and biomass energy consumption increased. In addition, the share of fossil sources in electricity generation went down in developed countries. More precisely, non-renewable thermal generation (coal, oil, and gas) fell by 6 percentage points, a decline accommodated by the increase in non-conventional renewable generation. This combination of the electrification of consumption and the penetration of renewables in electricity generation is crucial in reducing emission intensity. Moreover, the weight of fossil fuels in the electricity matrix not only decreased but also shifted in favor of gas, whose share increased from 16% to 30%. This transition away from coal and oil and towards gas also has a favorable impact on emission intensity.

In Latin America, the importance of electricity also increased, yet, in this case, electricity expansion was not accompanied by decarbonization. On the contrary, non-renewable thermal generation grew by approximately 7 percentage points and there was a more modest deployment of non-conventional renewables. Fortunately, this expansion was heavily skewed towards gas, which likely contributed to the modest decline in emissions. The Caribbean has seen no such electrification of demand, which remains at around 12% of the energy consumed. What can be observed is an increase in the penetration of gas both in electricity generation and energy consumption.

In Latin America, the increased importance of electricity was not accompanied by decarbonization. On the contrary, non-renewable thermal generation grew

In summary, success in reducing emission intensity in OECD countries hinges on growth in the electrification of consumption to the detriment of fossil fuels, the reduction in those energy sources in favor of non-conventional renewables in electricity generation, and, within the fossil energy mix, greater penetration of gas at the expense of coal, oil, and their derivatives. In Latin America and the Caribbean, some of these positive trends have occurred, but not all.

Energy intensity: Efficiency and economic structure

In the first two decades of this century, Latin America reduced its energy consumption per unit of GDP by an average annual rate of approximately 0.50%. This decline is lower than that recorded by the Caribbean and the developed world (1.76% and 1.61% respectively). In 2019, the energy intensity of Latin American and Caribbean countries was 48% higher than that of OECD countries (see Table 2.4). What is behind these shifts and these differences?

As explained in Box 2.1, a country's high energy intensity might respond to the fact that its industries have a higher energy intensity compared to the same industries in other countries. This relates to the concept of energy inefficiency.[7] It may also be the case that the country's economy is focused on industrial activities that are naturally energy-intensive, like transportation. This is connected to the economic structure of the country.

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[7] Although so far this chapter has referred primarily to energy efficiency as a key determinant of energy intensity, in the context of this decomposition, an increase in this variable is associated with a loss of efficiency, which is why it preferred to use the term energy inefficiency.

Table 2.4
Energy intensity

Country or region	Energy intensity		Average annual variation (percentage)
	2000	2019	
Argentina	0.10	0.09	-0.17
Barbados	0.10	0.09	-0.61
Belize	0.04	0.15	6.52
Bolivia	0.16	0.18	0.65
Brazil	0.12	0.12	-0.07
Chile	0.15	0.11	-1.75
Colombia	0.14	0.10	-1.95
Costa Rica	0.07	0.06	-0.93
Cuba	0.13	0.06	-3.83
Ecuador	0.11	0.13	0.89
El Salvador	0.11	0.12	0.19
Grenada	0.08	0.08	0.15
Guatemala	0.17	0.18	0.29
Guyana	0.26	0.14	-3.06
Haiti	0.20	0.22	0.42
Honduras	0.23	0.17	-1.73
Jamaica	0.16	0.19	0.99
Mexico	0.11	0.09	-0.87
Nicaragua	0.26	0.20	-1.47
Panama	0.08	0.06	-1.69
Paraguay	0.18	0.16	-0.63
Peru	0.14	0.10	-1.69
Dominican Republic	0.12	0.07	-2.74
Suriname	0.19	0.11	-2.88
Trinidad and Tobago	0.28	0.31	0.43
Uruguay	0.07	0.08	0.78
Latin America	0.12	0.11	-0.50
Caribbean	0.15	0.11	-1.76
OECD	0.10	0.07	-1.61

Note: The table shows the energy intensity of each country and region in 2000 and 2019, along with the average annual (logarithmic) variation in that period. Energy intensity is calculated as the ratio of final energy consumption (in tons of oil equivalent) to gross domestic product (in constant 2010 US dollars). The logarithmic variation is calculated as the difference between the logarithm of emissions in 2019 and 2000, divided by the number of years in the period (19). The table includes the countries of CELAC for which OLADE has information on energy consumption. The values for each region were obtained by aggregating energy consumption and GDP of the constituent countries. The list of countries considered in each region is available in the annex of this chapter available online.

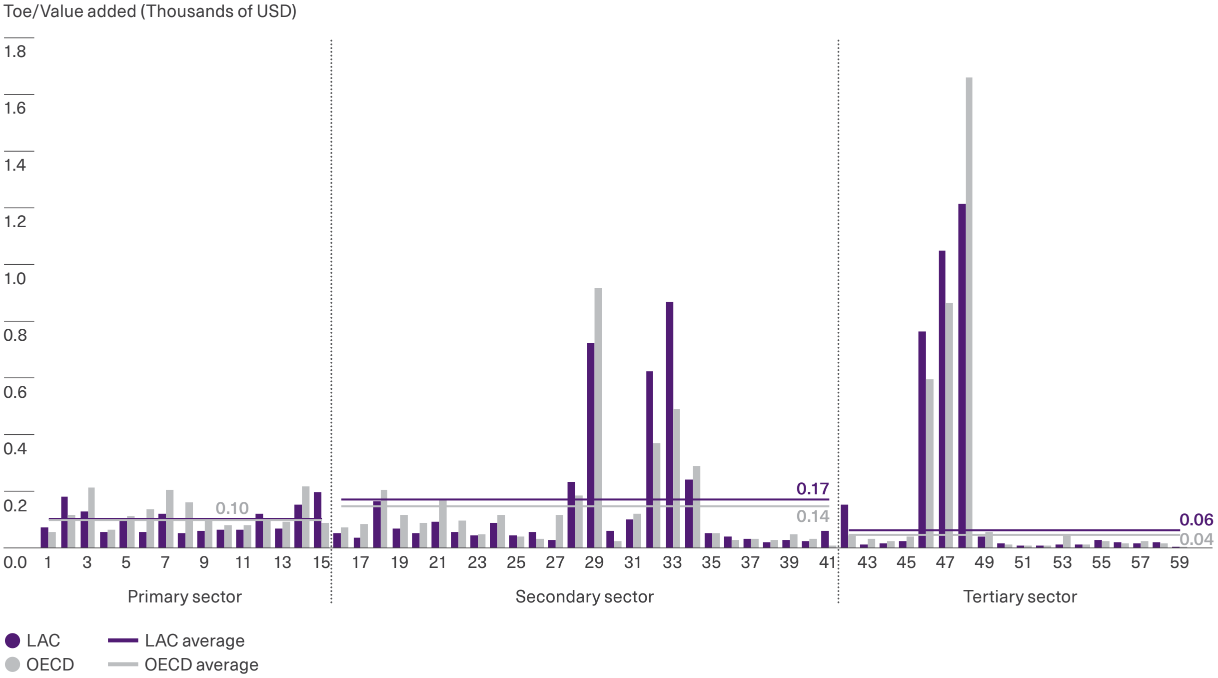
Source: Authors based on IEA (2022d), World Bank (2023c), and OLADE (2023b).

This approach is valuable for comprehending changes over time and explaining differences between countries at a given time. Certainly, the key questions in this regard are: to what degree does the variation in a country's energy intensity over a certain period stem from differences in its energy inefficiency rather than a shift in its economic structure? Likewise, to what extent are the disparities in energy intensity between two countries accounted for by efficiency gaps versus variations in economic structure?

The necessity to incorporate the role of economic structure, rather than just focusing on energy efficiency, into the analysis of energy intensity is supported by three facts (F) that arise when exploring sector-level information.

F1. The first fact is that industries differ in energy intensity. Graph 2.5 depicts the energy intensity constructed from the Global Trade Analysis Project (GTAP) database, following its 2017 version. The graph shows that there are not only differences in the average levels of energy intensity between the primary, secondary, and tertiary sectors but also significant variations between subsectors within these broad sectors. On average, the primary and tertiary sectors have lower energy intensity, while the secondary sector has higher intensity. However, within the tertiary sector, three transportation subsectors—air (bar 48 in the graph), maritime (bar 47), and others (bar 46)—stand out as being among the most energy-intensive in the economy.

Graph 2.5
Average energy intensity by economic sector in Latin America and the Caribbean and in the OECD in 2017



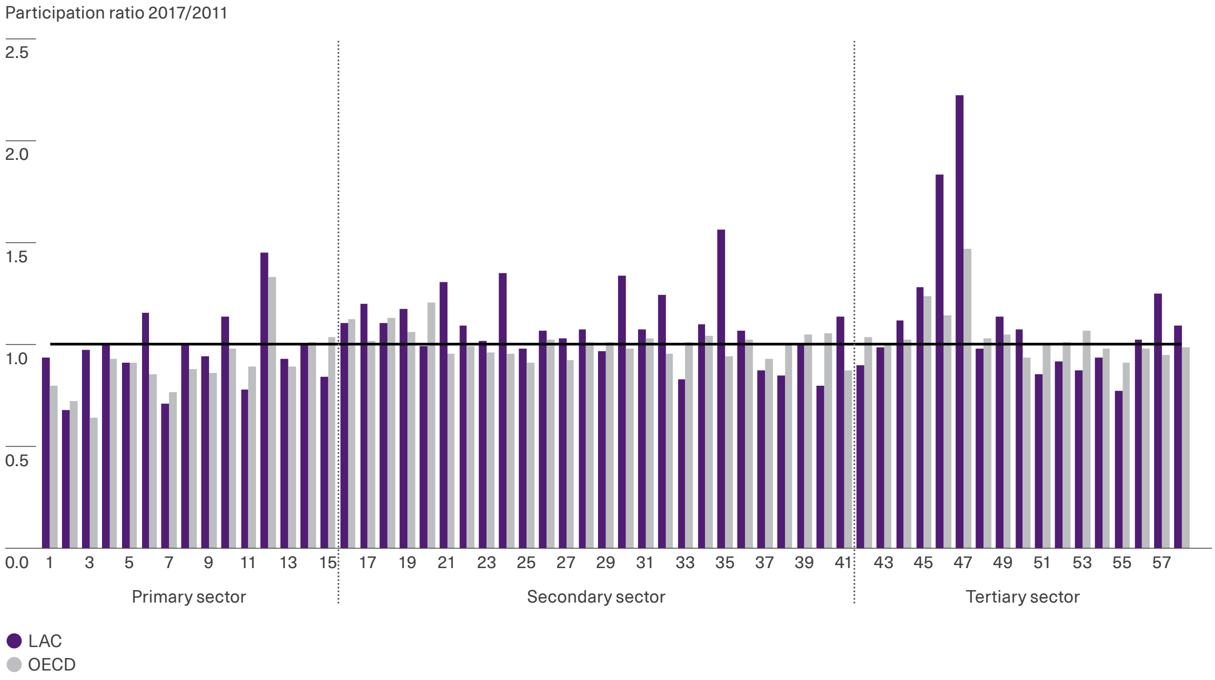
Note: Energy intensity is calculated as the ratio of energy consumption (in tons of oil equivalent) to value added (in thousands of constant 2015 USD). The energy intensity values for each region were obtained by aggregating the energy consumption and value added of a selection of countries. The vertical lines separate the sectors into three main categories: primary, secondary (manufacturing activities), and tertiary (services) sectors. The horizontal lines show the average energy intensity in each of these three broad sectors for both regions. The economic sectors included and the list of countries in each group are detailed in the annex to this chapter available online.

Source: Authors based on World Bank (2023h, 2023i) and Aguiar et al. (2022).

F2. The second fact is that economic structure changes over time. Graph 2.6 shows the ratio of the relative importance of each sector between 2017 and 2011, again using the GTAP. The importance of each sector is measured as the share of the sector´s value added to the total value added of the economy. A number greater than 1 means that the sector grew in importance between 2011 and 2017, while a number less than 1 indicates that its relevance decreased.[8] Broadly speaking, the graph points to a reduction in the importance of most primary sector industries and significant growth in the importance of transportation industries.

Graph 2.6

Change in the importance of economic sectors, 2011–2017



Note: The graph shows how the relative importance of each economic sector changed between 2011 and 2017 in Latin America and the Caribbean and the OECD countries. For this purpose, the ratio of the value added of each sector to the total value added of each region was calculated for the years 2011 and 2017. Next, the ratio between the sectoral share in 2017 and that in 2011 was obtained for each sector and region. The horizontal line shows when this ratio takes the value of 1, indicating that the relative importance of the economic sector did not change between the years in question. The values for each region were obtained by aggregating the value added (sectorial and total) from a selection of countries that make up the region. The vertical lines separate the sectors into three main categories: primary, secondary (manufacturing activities), and tertiary (services). The economic sectors included and the countries that make up each group are detailed in the annex of this chapter available online.

Source: Authors based on World Bank (2023h, 2023i) and Aguiar et al. (2016, 2022).

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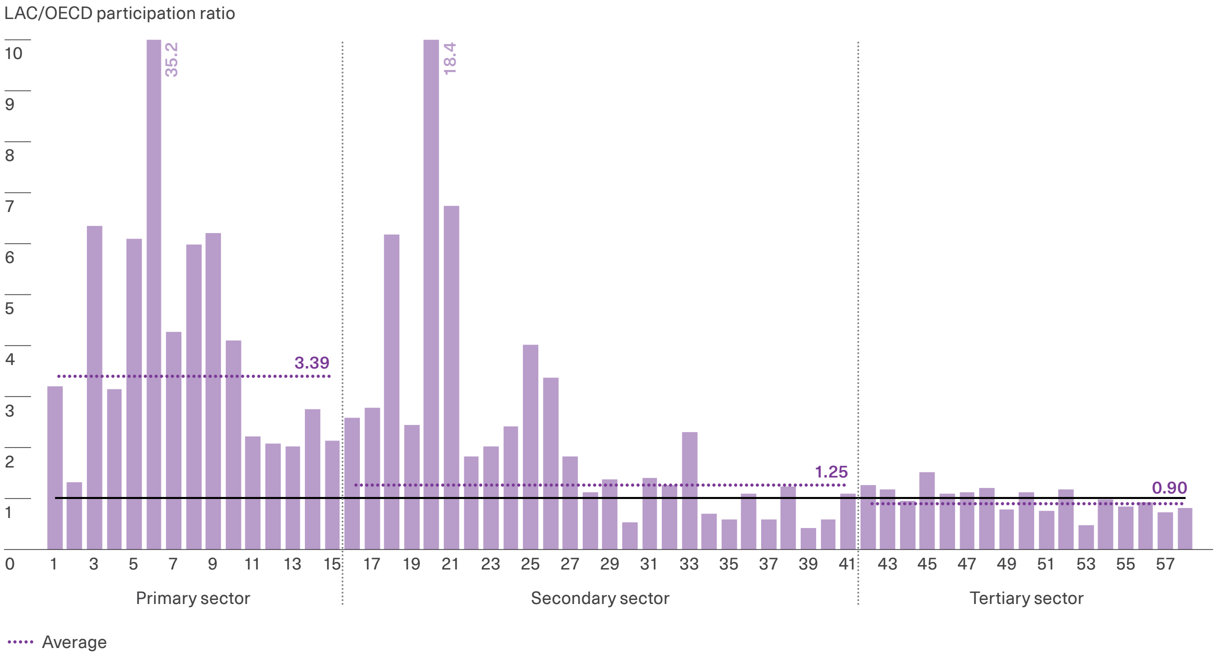
[8] Graph A.2.1 in the annex of this chapter available online shows the level of importance of the sectors.

F3. Finally, economic structure differs between countries. Graph 2.7 compares the importance of each sector in Latin America and the Caribbean and in OECD countries in 2017. In this case, a value greater than 1 means that the sector is relatively more important in Latin America and the Caribbean, while a value less than 1 indicates less relative importance. The most striking aspect is probably the greater importance of primary sector industries within the region, although three industries in the secondary sector also stand out, all linked to food processing: vegetable oil production (bar 18 in the graph), processed rice (bar 20) and sugar production (bar 21).

Graph 2.7

Comparison of the economic structure of Latin America and the Caribbean and the OECD in 2017



Note: The graph compares the economic structure of Latin America and the Caribbean to that of the OECD in 2017. First, the ratio of sectoral value added to total value added in 2017 was calculated for both regions. Then, for each sector, the ratio between the sectoral participation of Latin America and the Caribbean and that of the OECD was obtained. The vertical lines separate the sectors into three main categories: primary, secondary (manufacturing activities), and tertiary (services). The solid horizontal line shows when this ratio takes the value of 1, indicating that the relative importance of the economic sector is the same between regions. The dotted horizontal lines represent the average ratio in each of these three main sectors. The values for each region were obtained by adding the value added (sectorial and total) for a selection of countries. The economic sectors and the countries included in each group are listed in the annex of this chapter available online.

Source: Authors based on World Bank (2023h, 2023i) and Aguiar et al. (2022).

How can the role of energy efficiency be separated from the role of economic structure?

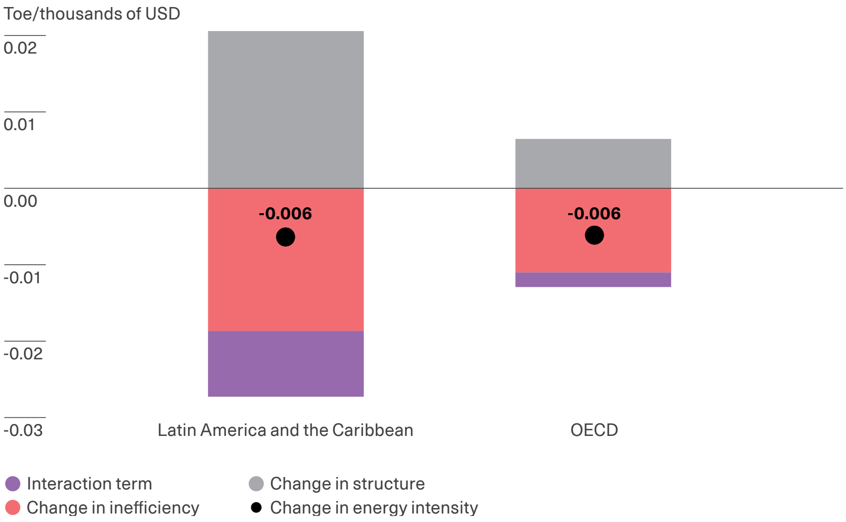
A research study carried out in the context of this report addresses this question for both Latin America and the Caribbean as well as developed countries, by exploring various methods (Allub, Álvarez y Brugiafreddo, 2024). Box 2.3 briefly describes the results of the study, for two of the methods addressed. One of them provides a temporal perspective on the matter (based on Foster et al., 2001). The other one offers a country comparison approach (based on Olley and Pakes, 1996). The decomposition exercises are applied to the GTAP database (2011–2017 waves), which offers information for 65 sectors of the economy. The authors restricted the data to final energy-consuming (but not producing) sectors, obtaining a sample of 59 sectors. For each sector, data includes the value added and units of energy consumed.[9]

Graph 2.8 shows the decomposition from the temporal perspective. Between 2011 and 2017, the energy intensity in Latin America and the Caribbean dropped (represented by a dot on the graph) by 0.006 units of energy per unit of value added (approximately 7%). In the OECD, the figure also corresponds to 0.006 (approximately 9%). However, in both regions, the negative variation in inefficiency (pink bar) is greater than the decrease in aggregate energy intensity (dot), while the effect of the change in economic structure is positive (gray bar). This means that the efficiency gains between 2011 and 2017 in both regions were partially offset by changes in the economic structure.

Decomposition calculations show that if the economic structure of Latin America and the Caribbean had not changed, the drop in energy intensity would have been 20%, more than double the decrease registered

Graph 2.8

Decomposition of changes in energy intensity by region



Note: The graph shows how the variation in energy intensity between 2011 and 2017 can be decomposed into changes in inefficiency, in structure and both effects together based on the GTAP database information. Energy intensity is calculated as the ratio of energy consumption (in tons of oil equivalent) to the added value of the economy (in thousands of constant 2015 dollars). Regional values are obtained by aggregating the energy consumption and value added of the countries within each region. The list of countries considered in each region can be consulted in the annex of this chapter available online.

Source: Allub, Álvarez and Brugiafreddo (2024).

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[9] The GTAP provides information on 19 countries in the region. However, in only 12 of them did the changes and levels of energy intensity match the qualitative patterns of the study period with the source data for Table 2.4. The analysis presented here focuses on these 12. For more details and information on all countries, see Allub, Álvarez, and Brugiafreddo (2024). Graph A.2.5 in the annex of this chapter available online shows the analysis for these seven countries excluded from the analysis in the main text. // GTAP provides valuable information on energy intensity at national levels, including data for 19 countries in LAC. However, the information between 2011 and 2017 for seven of the countries does not align with the patterns observed in Table 2.4. Hence, the analysis in Box 2.3 takes into account the remaining 12 countries, for which data better aligns with the qualitative patterns of the period.

Box 2.3

Methods for decomposing energy intensity into efficiency and economic structure

The energy intensity of a country in period t can be expressed based on the energy intensity of its sectors or industries as follows:

$$IE_t = \sum s_t^e IE_t^e \tag{1}$$

Where s^e represents the fraction of value added in the economy that is explained by the industry *e,* while IE^e corresponds to the energy intensity of this industry.

Based on Foster et al. (2001), the variation in IE in two periods can be written as:

$$\Delta IE_{t,t+1} = \sum s_t^e \Delta IE_{t,t+1}^e + \sum (IE_t^e - IE_t)\Delta s_{t,t+1}^e + \sum \Delta IE_{t,t+1}^e \Delta s_{t,t+1}^e \tag{2}$$

The first term of the equation is the average change in energy intensity at the industry level. The average change is weighted by the sector's share of GDP in the initial period. This term, named **change in energy inefficiency**, captures what the change in aggregate energy intensity would have been if there had been no variation in the economic structure. The second term is called **change in structure**. In this expression, if a sector exhibits higher energy intensity than the economy as a whole, the aggregate energy intensity will rise as the sector's contribution grows. Conversely, when a sector presents lower energy intensity than the aggregate economy, the economy's overall energy intensity will decrease as the sector becomes more important. This term captures the change in aggregate energy intensity if no sector experienced variations in energy intensity. The last term, the **interaction term**, is the change in energy intensity that cannot be attributed exclusively to changes in sectoral energy intensity or changes in economic structure but instead is a result of the interaction between both forces.

Equation (2) is designed to explain changes over time. For cross-sectional information, the decomposition proposed by Olley and Pakes (1996) can be employed. This approach disaggregates the level of energy intensity in an economy at a specific moment into two components, namely:

$$IE_t = \overline{IE_t} + \sum (s_t^e - s)(IE_t^e - \overline{IE_t}) \tag{3}$$

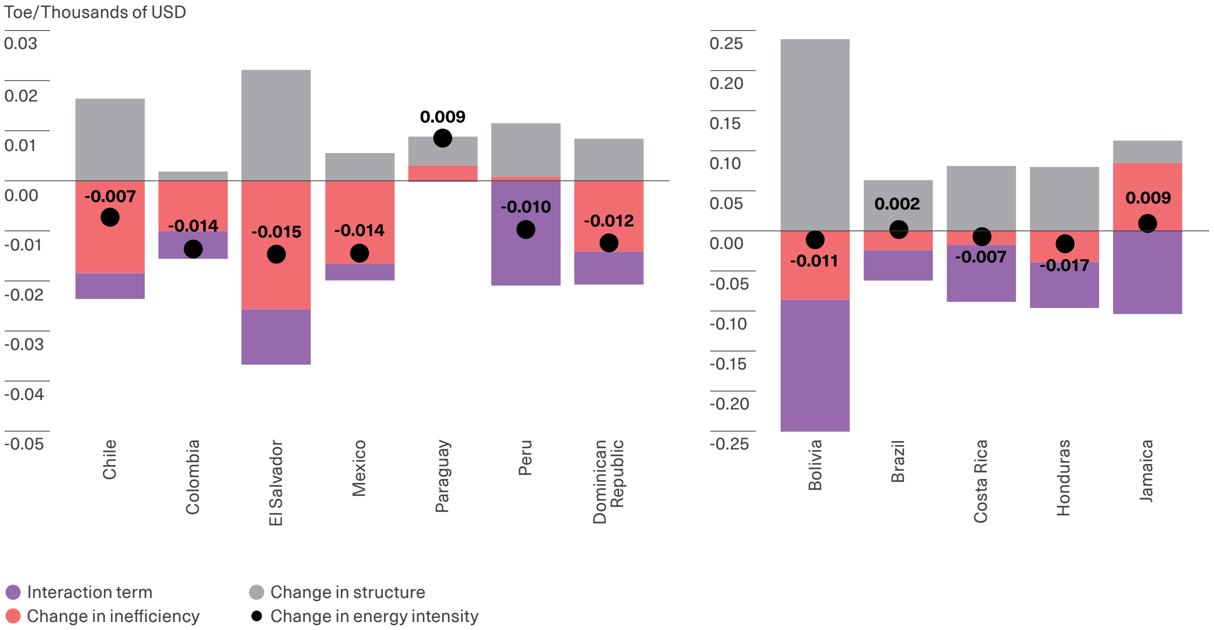
In *e*quation (3), the bars over the variable indicate a simple average. The decomposition divides the aggregate energy intensity into a component that is the simple average of the industries or sectors that make up the economy, which can be associated with the **inefficiency term**, and another linked to the covariance between the size of the sector and its energy intensity. If this second term is positive, it means that larger sectors (measured by their relative contribution to aggregate GDP) tend to have higher energy intensity and vice versa. This is called the **structure term**.

Indeed according to the decomposition calculations, if the economic structure had not changed between 2011 and 2017, the decline in energy intensity would have been 20% in Latin America and the Caribbean, more than double the actual decrease. This role played by the economic structure is consistent with the reduction in the importance of primary sector industries (which are typically low energy intensity), combined with the growth of high energy intensity sectors such as transportation (see Graph 2.6).

Graph 2.9 shows the same information but for several Latin American and Caribbean countries. The sample is divided into two groups based on the range of factor variation. Overall, negative changes are observed in the inefficiency component (pink bar), which are more pronounced than the variations (also usually negative) in the aggregate energy intensity (dot). At the same time, the change in structure (gray bar) is positive, indicating that modifications in the economic structure counterbalanced the energy efficiency gains. In other words, changes in economic structure tended to increase energy intensity, which was partially offset by gains in energy efficiency. Paraguay is an outlier, mainly because it experienced a slight increase in aggregate energy intensity between 2011 and 2017; however, as in the rest of the countries, sectoral reallocation worked against a reduction in aggregate energy intensity.[10]

From the second perspective, the countries in the region are compared to Switzerland as a benchmark, since it leads the ranking of countries with the lowest energy intensity within the OECD. As explained in Box 2.3, the Olley-Pakes decomposition (1996) was used for this purpose. Graph 2.10 shows the aggregate energy intensity (Panel A), the inefficiency component (Panel B), and the structure component (Panel C).

Graph 2.9
Decomposition of changes in energy intensity by country



Note: The graph shows how the variation in energy intensity between 2011 and 2017 is decomposed into changes in inefficiency, structure, and both effects combined, based on GTAP data for a set of 12 countries. Table A.2.2 in the annex of this chapter available online shows the results of the remaining Latin American and Caribbean countries reported by the GTAP but not included in this graph. Energy intensity is calculated as the ratio of energy consumption (in tons of oil equivalent) to the value added of the economy (in thousands of constant 2015 US dollars).

Source: Allub, Álvarez and Brugiafreddo (2024).

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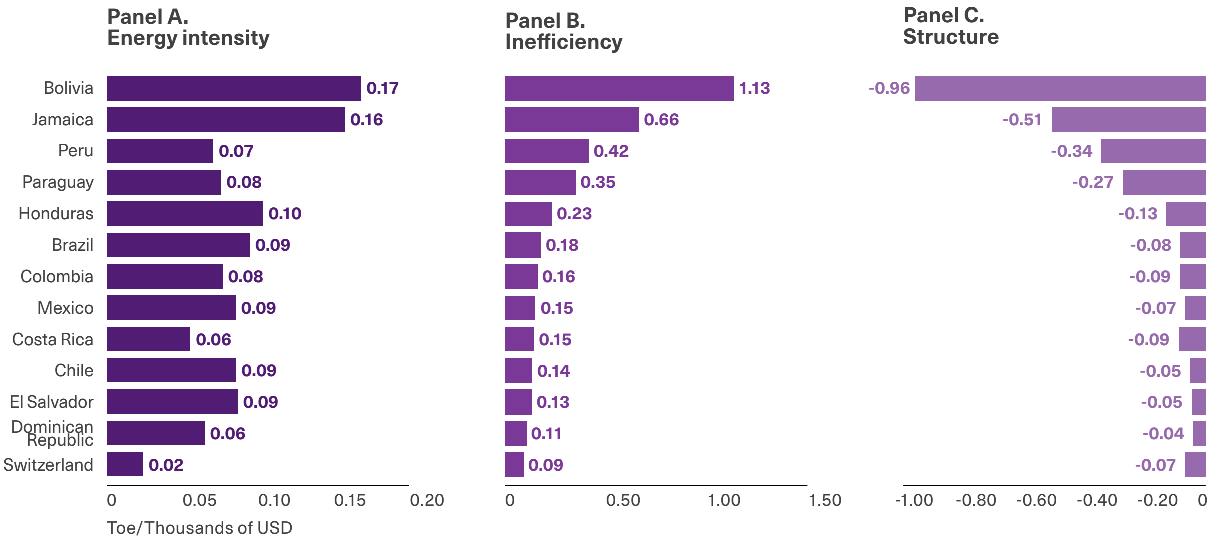
[10] As shown in Table 2.4, energy intensity in Paraguay also fell between 2000 and 2019; however, during the 2011–2017 period specifically, intensity increased.

Graph 2.10

Decomposition of energy intensity in selected Latin American and Caribbean countries and Switzerland



Note: Energy intensity, represented in Panel A, is calculated as the ratio of energy consumption (in tons of oil equivalent) to the value added of the economy (in thousands of constant 2015 US dollars). Panels B and C show the components into which energy intensity is decomposed: inefficiency and structure. The countries were arranged in decreasing order according to their level of energy efficiency. The criteria for selecting the sample of countries analyzed are detailed in the annex of this chapter available online.

Source: Authors based on World Bank (2023h, 2023i) and Aguiar et al. (2022).

The decomposition of the changes suggests that economic structure significantly determines the level of aggregate energy intensity of countries. Specifically, the structure component is negative in all of them, meaning that sectors with a higher share of value added tend to have lower energy intensity. This results in lower energy intensity than in a world where the importance of the sector and its energy intensity are independent.

●●

The decomposition of changes indicates that the economic structure significantly determines the level of energy intensity aggregate of the countries

However, the structure component is more negative in some Latin American and Caribbean countries than in the reference country, Switzerland.[11] This is particularly true for Bolivia, Jamaica, Peru and Paraguay. In these countries, the significant differences in inefficiency with respect to Switzerland do not fully translate into differences in energy intensity, because differences are partly offset due to a structure that is more biased towards less energy-intensive sectors.

Although the results obtained from the decompositions are specific to the period studied, they lead to the conclusion that energy intensity, and therefore energy transition in general, should not be analyzed without taking into consideration the phenomenon of structural transformation of economies. Economic structure affects the level and evolution of energy intensity and, thus, the feasibility of decoupling and mitigation success.

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[11] The greater relative importance of primary sector industries in the region is in line with this conclusion.

Starting point: energy systems of Latin America and the Caribbean

- Required energy attributes
- The makeup of the energy matrix in Latin America and the Caribbean
- The nexus between efficiency and emissions in the energy sector

3

Key messages

1

Energy consumption per capita in Latin America and the Caribbean represents about 65% of the global per capita consumption. Achieving 25.4 exajoules of final energy products in the region requires 35.2 exajoules of inputs.

2

Electricity accounts for just 20% of total energy consumption, while the remaining 80% is supplied by mainly fossil-based fuels.

3

57% of the region's electricity generation comes from non-fuel sources, with a significant predominance of hydropower. Non-conventional renewable energies represent 11%. However, the emission intensity of electricity remains high in some countries, even when compared to the direct use of energy vectors such as natural gas.

4

The emission intensity of energy depends on two elements: the efficiency of energy systems and the combination of primary inputs used to provide energy to end users (the energy mix).

5

Changing the energy mix involves replacing high-emission energy sources, such as fossil fuels, with clean energy. The key enabler for this change is the electrification of consumption, as there are many technologies available for producing electricity with low or zero emissions.

6

The different uses to which it is put require energy to have particular attributes. It is still difficult to use electricity for certain purposes. This is why promoting alternative low-emission fuels is of vital importance.

7

The efficiency of energy systems provides significant scope for public policies on energy, since it makes it possible to reduce emissions in the short and medium term, for as long as fossil energy sources continue to exist. The key parameters in this regard are improving the efficiency of fuel transformation and electricity generation, reducing technical transmission and distribution losses, and eliminating fugitive emissions.

8

Energy vectors undergo various transformation processes from primary source to final consumption, resulting in losses. In addition, the fossil fuel value chain involves fugitive emissions. These two factors amplify GHG emissions from energy consumption and can account for up to 34% of those emissions depending on the type of fuel.

9

GHG emissions from the use of natural gas are the lowest among fossil fuels. At the time of consumption, these emissions are 24% less than those released by diesel and 32% lower than the emissions produced across the entire value chain.

Starting point: energy systems of Latin America and the Caribbean[1]

Introduction

Energy is an essential resource for the well-being and economic progress of society. It plays a crucial role in people's daily lives and the production of goods and services. Households rely on energy for fundamental tasks such as lighting, cooking, regulating building temperatures, and transportation. Furthermore, energy constitutes a central component of the value added to virtually all consumed products.

Despite its importance, energy use is also the main global contributor to the environmental crisis facing humanity, with global warming being its most pressing manifestation. In this context, the energy transition becomes a necessity to tackle this crisis and ensure sustainable development. This process involves a shift in the energy matrix of countries in order to reduce the impact on global warming, by decreasing dependence on fossil fuels and increasing the share of clean and renewable energy sources, such as solar, wind, hydroelectric, and geothermal power, among others.

Energy transition encompasses all actions aimed at lessening the impact of global warming associated with energy consumption. More precisely, it includes all possible measures to reduce the total greenhouse gas (GHG) intensity required by each unit of well-being achieved through energy consumption; for example, the well-being obtained by moderating the temperature of a home with air conditioning. The previous chapter approaches this concept by measuring emissions per unit of gross domestic product (GDP). It then decomposes this measurement into an energy efficiency component (energy per unit of GDP) and an emission intensity component (emissions per unit of energy).

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[1] This chapter was written by Walter Cont and Federico Juncosa with the research assistance from Lautaro Carrizo and Agustín Staudt.

This chapter seeks to analyze the intensity of energy emissions (the second component) by also taking into account two elements. The first is the efficiency of energy systems, which refers to the amount of energy inputs required to deliver a unit of energy to end users. The second is the energy mix, which is to say the combination of inputs (for example, oil, firewood, hydropower) consumed to provide end users with energy. These types of energy inputs, known as primary energy sources, may be associated with different levels of emission intensity, so variations in this mix result in variations in emissions.

Both improvements in the efficiency of energy systems, as well as changes in the combination of energy sources used, play an important role in decarbonization. The desired long-term balance inevitably requires significant changes in the energy mix, moving away from dirty energy towards low-emission sources. In turn, the key enabler of this shift is the electrification of consumption, as there are now many ways to produce electricity from clean sources to replace high-emission ones, which is discussed in depth in Chapter 4. However, this strategy faces challenges in the case of energy needs that are difficult to meet with electricity. Anything beyond the scope of electrification will require low-emission fuel alternatives (see Chapter 5). During transition, it is possible to adopt strategies to change the energy mix, involving the replacement of certain fuels with natural gas, which, as will be seen further on, exhibits a lower environmental impact.

Improvements in the efficiency of energy systems play an important role in reducing their impact on global warming, since the energy losses that occur up to delivery to the end user act as a multiplier of the emissions from the energy consumed. A more efficient use of energy inputs would therefore allow emissions to be reduced in the short and medium term. In this chapter, these energy losses will be estimated using the information available for the countries in the region. This improved use of energy inputs includes the elimination of fugitive emissions associated with the hydrocarbon industry, which, as discussed later, is a substantial contributor to the region's emissions.

Energy use and necessary attributes

Energy has a wide range of uses within society. Each one requires a particular set of attributes in the energy consumed. Energy uses are generally classified into heating (for food preparation and certain industrial processes), cooling, motion (which applies to transportation, but also industrial machinery), lighting, and purely electronic purposes (for communications and computing). They can also be split into three different types of uses depending on where they occur: urban fixed, rural or remote fixed, and mobile.

These uses can be satisfied by means of various energy vectors (or carriers), a term that refers to the medium or substance through which energy is stored, transported, and delivered in a usable form, such as electricity or fuels. Each vector has particular attributes that make it more suitable for certain uses; namely, ease of dispatch, storage, and transportation.[2]

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[2] Dispatch refers to the ease with which energy can be delivered on demand, both in terms of its availability as and when needed, and the required level of power (energy consumed per unit of time). Ease of transportation and storage are associated with energy density in terms of energy contained per unit of volume (volumetric density) and in relation to weight (gravimetric density). Ease of storage also requires that the energy resource be stable and safe under the environmental conditions to which it is subjected at this stage of the process.

Energy serves a wide range of purposes in society, each of which can be met through various energy carriers

Electricity offers a host of advantages for consumption and production. It can be used to meet a whole range of energy needs efficiently and safely. In addition, there are numerous technologies for generating electricity with various inputs. On the flip side, electricity has the highest storage and transportation costs, largely due to the low energy density of current storage media. Almost all electricity is delivered through a continuous connection to transmission and distribution networks. Mobile and remote electricity uses, with no continuous access to the grid, require battery storage, which remains expensive.

The fuels currently in use are also notable for their high energy density and the relative ease with which they can be stored and transported. They are essential in applications that require large amounts of energy in confined spaces or where rapid energy release is needed, such as in air or sea transportation and in certain industrial processes that demand high temperatures. However, their consumption poses significant challenges when it comes to reducing carbon emissions, given that most energy-dense fuels currently come from fossil fuel sources. The transition to low carbon footprint fuels, such as biofuels from sustainable sources or green hydrogen, faces major hurdles in terms of costs, production technologies, and adaptation of existing infrastructure.

Light transportation, which is a mobile use requiring a limited amount of stored energy, can be easily supplied with electricity, taking advantage of the transportation infrastructure present in urban environments for this type of energy and the safe and efficient storage capabilities of batteries. Urban uses do not usually require much storage because they can rely on dense, well-developed distribution networks, which provide a constant and reliable power supply. Grid infrastructure allows energy to be dispatched as needed, thus minimizing the necessity for large-scale storage.

In contrast, for energy uses in remote locations, storage capacity is often a vital attribute, as in the case of mining and agricultural operations. Air transportation is another mobile use that is highly sensitive to energy density by volume and weight. Existing batteries' capacity and energy density impose a technical limitation on the range and charging capacity of electric aircraft, rendering them impractical. Aviation needs energy-dense fuels, such as petroleum derivatives, to meet its range and power requirements.

The fuels currently in use have a high energy density and can be easily stored and transported

Finally, applications involving very high temperatures, such as certain industrial processes, face great technical challenges in using electricity. For example, iron and cement manufacturing processes require temperatures in excess of 1,000°C, more easily achievable through direct combustion. These processes need technological developments that enable high temperature levels to be achieved in a sustainable manner using renewable sources.

The energy matrix in Latin America and the Caribbean

From a schematic perspective, a country's energy system consists of the production of primary energy sources, which goes through various transformation, transportation, and distribution processes. Countries also trade in both primary and intermediate or final energy inputs. The last element consists of the end uses of energy. At each stage, energy is lost, either because it is used for the process itself (useful energy consumed by the energy sector), or because of losses in the form of heat, noise, or leaks, known as rejected energy. The ratio of total consumption to energy inputs used captures the overall efficiency of the system.

Table 3.1 presents the aggregate energy matrix of Latin America and the Caribbean with average values for the last 5 years available, from 2017 to 2021. The matrix breaks down the energy system, from primary energy inputs (Column a) to final energy consumption according to the sector (Column e). The table shows the electricity sub-matrix at the top, highlighting the primary inputs used to generate electricity and distinguishing between generation from fuel and non-fuel sources, as well as electricity consumption by sector. At the bottom, the fuel use sub-matrix is shown, which similarly identifies inputs according to type and consumption according to sector.

Total energy consumption in Latin America and the Caribbean amounts to 24.2 exajoules (EJ) per year, which is equivalent to 36.3 gigajoules (GJ) per capita, approximately 65% of global per capita consumption.[3] 20% of this corresponds to the vector of electricity, while the rest is supplied by fuel energy vectors, such as liquid fuels, firewood, and natural gas. In addition, 1.2 EJ of fuels is consumed for non-energy purposes.

●●

Total energy consumption in Latin America and the Caribbean amounts to 24.2 exajoules (EJ) per year, 20% of which corresponds to electricity and the rest to fuel energy vectors

The 25.4 EJ of final energy products (final energy consumption for energy and non-energy use) is obtained from a set of inputs, known as primary energy sources (Column a of Table 3.1), which add up to 35.2 EJ.[4] The difference between primary energy sources and consumption can be attributed to three factors: 1) the energy input production processes; 2) the transformation processes that energy products go through before reaching end users; and 3) the transportation of these products between the stages of production, transformation, and final use. Each of these stages requires the use of energy and results in energy losses of various kinds. Oil production, for example, consumes energy (generally natural gas) for the pumping that is usually required to pressurize the reservoirs in crude oil extraction and for transporting it through pipelines or other means of land and sea transportation.

Electricity consumption in the region amounts to 4.78 EJ. In turn, the amount of electricity generation has been estimated at 5.89 EJ. The difference between consumption and generation is partly due to self-consumption of electricity, meaning the electricity used in the generation process at power plants, and partly due to the existence of transmission and distribution losses.

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[3] According to information from the IEA (2023x), consumption in Central and South America is 39.7 GJ per capita (excluding Mexico), which is equivalent to 71% of the 55.6 GJ per capita global consumption (IEA, 2023x, Tables A.23 and B.1).

[4] This is in line with what is observed globally, since an energy consumption of 439 EJ is calculated based on inputs estimated at 624 EJ. (IEA, 2023v).

Table 3.1

Energy matrix of Latin America and the Caribbean in average values from 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, it is classified (in Column a) in "non-fuel inputs for power generation " and "fuel inputs for power generation," which are used for electricity generation corresponding to each type (Column b). More details about the calculations can be found in the annex of Chapter 3 (available online).

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

Annual electricity consumption in Latin America and the Caribbean is 4.78 EJ, while generation reaches 5.89 EJ. The difference is due to self-consumption and transmission and distribution losses

Electricity is obtained using various technologies that can be divided into two groups: fuel and non-fuel-based generation. Within non-fuel generation, nuclear is usually regarded as non-renewable because it requires an energy input that is susceptible to depletion: uranium. Although this substance is relatively abundant in the Earth's crust, it is strictly a finite resource that is costly to produce, in terms of both extraction and enrichment, when required, as well as disposal after use.

In addition, fuel-based electricity generation can use inputs from renewable sources, such as firewood or agricultural waste. Fuels of plant and animal origin are renewable, although when burned they produce emissions comparable to those of fossil origin. Nevertheless, under certain conditions, they can be considered low-emission since the carbon released in combustion would have been recently captured from the atmosphere. The emission intensity attributed to them ultimately depends on the sustainability with which their life cycle is managed, as discussed at length in Chapter 5.

Non-fuel-based electricity generation amounts to 3.34 EJ obtained from 3.72 EJ of inputs. The difference arises from losses in the transformation to electricity (for example, heat losses in geothermal and thermonuclear generation) or from unused energy, such as in cases where water is released from hydroelectric dams (for example, due to water level limitations in the dam) without delivering electricity. Within this category, hydropower represents the largest share, accounting for 72% of non-fuel generation inputs and 45% of total electricity generation inputs. Solar and wind generation together make up 12% of total generation, almost double the percentage for nuclear power.

Fuel-based generation represents 43% of the total in the region, which adds up to 2.55 EJ of energy, obtained from 7.19 EJ of fuel energy inputs (natural gas, petroleum derivatives, biomass, and coal). This difference between the primary fuel inputs used and the electricity generated, amounting to 65%, is due to the transformation processes they undergo, which include not only generation losses but also the prior processing to obtain the fuels used as inputs (mainly oil refining to produce liquid fuels) and the losses incurred during transportation of these inputs.

Fuel sources account for 43% of the region's total electricity generation. On average, it takes 2.8 units of primary fuel inputs to produce one unit of electricity from these sources

The left-hand side of Table 3.1 shows the inputs required to obtain the final energy products consumed. Fuel inputs can be divided into two categories: 1) fossil resources, which include natural gas, petroleum and its derivatives, and coal of various types; and 2) fuel inputs derived from organic matter (for example, non-fossilized carbon compounds). These include firewood, charcoal (produced by the incomplete combustion of firewood), biomethane (a gas produced during the fermentation of organic matter), and liquid fuels derived from agricultural products, such as diesel from palm or soybean oil, and ethanol, produced from sugar cane or corn.[5]

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[5] The inputs accounted for correspond to the total supply (domestic production plus net imports) of primary fuels (e.g., petroleum, coal, natural gas, firewood, etc.) plus net imports of secondary fuels (e.g., gasoline and other petroleum derivatives, coke and other coal derivatives, and charcoal).

Within power generation, natural gas accounts for more than half of the energy value of fuel inputs, while petroleum derivatives and coal account for 17% and 13%, respectively. These figures summarize the outcome of the transition process that has taken place over the last 40 years, whereby natural gas has replaced a significant portion of liquid fuels (Cont et al., 2022).

As for final fuel consumption (bottom-right of Table 3.1), this amounts to 19.4 EJ in Latin America and the Caribbean, four times the region's electricity consumption. In addition to energy consumption, primary fuel inputs are used in other production processes (for example, natural gas for producing ammonia or urea, or petroleum derivatives for making plastics), represented here as non-energy consumption, totaling around 1.2 EJ in the region. To produce and distribute these fuels to end users, 24.2 EJ of energy inputs is needed. In other words, 15% of the energy inputs required for final fuel consumption are lost during the transformation processes, mainly associated with oil refining and transportation, while natural gas often experiences losses due to leaks in the systems.[6]

Approximately 15% of the energy inputs needed for final fuel consumption are lost during transformation processes

Key country indicators

By analyzing energy matrices similar to the one presented in Table 3.1 for each of the countries in the region, it is possible to obtain a set of indicators that provide information on their degree of dependence on fossil fuels and conventional energy sources (the rate of electrification of consumption and the share of non-fuel generation). The indicators also provide data on the efficiency of the transformation and transportation processes, from energy inputs to consumption.

Electrification of consumption

Graph 3.1 shows the consumption electrification rate in Latin America and the Caribbean by country and the value for the entire region (Panel A). The rate for Latin America and the Caribbean as a whole is around 20%, a figure equal to the global value and 10% lower than that of the OECD (IEA, 2021f). However, there are significant differences among the countries in the region, ranging from a minimum of 1% and 7% in Haiti and Guatemala to a maximum of 26% and 27% in Panama and Suriname, respectively.

Panel B shows the minimum, average, and maximum electrification rates in countries in Latin America (in purple) and the Caribbean (in blue) by sector. In the aggregate, transportation has the least electrification (virtually nil for Latin America), followed by the industrial, residential, and retail/commercial sectors. In the latter three, however, there are large variations between countries, with a greater dispersion seen in the Caribbean countries as a whole than in Latin America.

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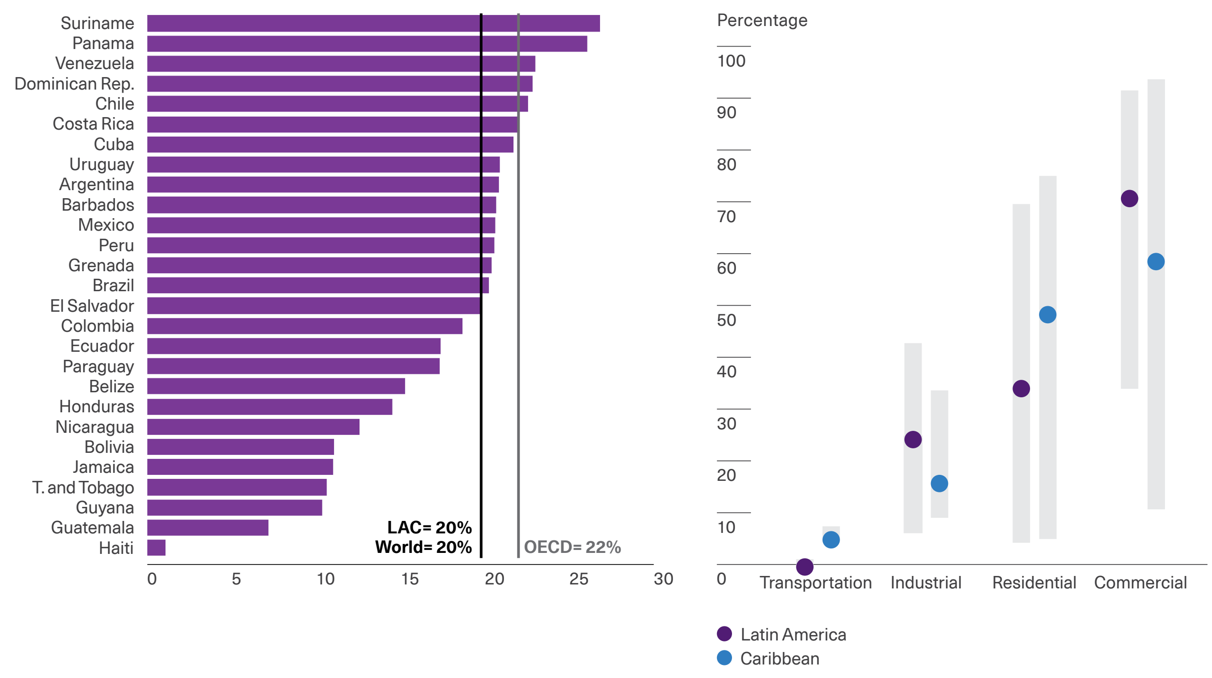
[6] One of the energy uses described in the OLADE energy matrices corresponds to the "own consumption" category. This represents the amount of energy that the energy sector itself needs in order to operate, in other words the energy that is converted into useful energy for some part of the energy supply process, such as oil refining, gas compression, pipeline propulsion, etc. In Table 3.1 these items are subtracted from the energy supply and considered part of the efficiency losses suffered by the energy production system.

Transportation is the sector with the lowest electrification rate in the region, followed by the industrial, residential, and retail sectors

The industrial sector exhibits maximum values of 43% in Latin America (Peru) and 38% in the Caribbean (Dominican Republic), while it registers minimum values of 6% (Belize) in the first sub-region and 5% (Grenada) in the second. The values for the residential sector in Latin America range from 4% (Guatemala) to 69% (Costa Rica), while in the Caribbean they range from 1% (Haiti) to 74% (Trinidad and Tobago). The commercial sector in Latin America has rates of between 34% (Nicaragua) and 92% (Paraguay), while in the Caribbean they lie between 6% (Haiti) and 93% (Trinidad and Tobago).

The electrification patterns observed by sector are partly due to the alignment between energy uses and the properties described in the section entitled "Energy Use and Necessary Attributes," as seen during the consolidation of these sectors. One example is automotive transportation, where electrification has only recently become feasible thanks to the availability of batteries with sufficient capacity.

Graph 3.1
Electrification rate by country and sector



Panel A.
Countries in the region

Panel B.
Maximum, average, and minimum by sector

Note: The graph shows the electrification rate in LAC by country (Panel A) and by sector (Panel B). The latter is calculated as the share of electricity in the sector's consumption relative to the total energy consumption of the respective sector, after converting physical units to calorific units. At the country level, the electricity consumption of all sectors is aggregated and calculated as a proportion of its total energy consumption. The electrification rate for the "world" corresponds to the value for 2021, while for the OECD the value corresponds to 2019.

Source: Authors based on AIE (2021b, 2023v) and OLADE (2023b).

With current technology, electrification may not encounter significant obstacles in the residential and commercial sectors, where fixed energy uses are predominant, especially in urban environments that have access to electrical grids. In the transportation sector, there are increasingly competitive alternative technologies for the electrification of urban transport, while major challenges remain for freight and long-distance transport. The industrial sector shown in Graph 3.1 includes very high temperature energy uses, which are difficult to electrify. In line with this description, the IEA's projected net zero emissions (NZE) scenario sets electrification rates for 2050 at 66% for the building sector (represented here as commercial and residential), and around 44% and 46% for the industry and transportation sectors, respectively (IEA, 2021f).

Non-fuel and non-conventional renewable generation

Graph 3.2 shows the proportion of non-fuel electricity generation and the percentage of this obtained from renewable energy sources, which include solar and wind. Within these dimensions, uneven progress can be seen across the sub-regions, since the island nations of the Caribbean show little participation of non-fuel generation, with the Dominican Republic recording the highest level with 14%. In South America, there is a group of countries that have made medium progress, with a share of between 30% and 40%, and another that has progressed further, with values of 74% to 80%. Paraguay's power generation is 100% hydroelectric, thanks to its 50% stake in the Itaipú Dam—the second largest in the world in terms of annual generation (only surpassed by the Three Gorges Dam in China)—and another 50% in the Yacyretá Dam, which represents nearly three times the country's electricity consumption. Most Mesoamerican countries show values between 44% and 68%, with the exception of Mexico (23%) and Costa Rica (99%). The latter is notable for its large hydroelectric generation capacity (close to three-quarters of its consumption), followed by geothermal and wind energy (close to one-quarter). Four other countries in the region distinguish themselves on account of their active promotion of non-conventional renewable energy (NCRE): Uruguay and Chile (discussed in greater detail in Chapter 4), Honduras, and Nicaragua.

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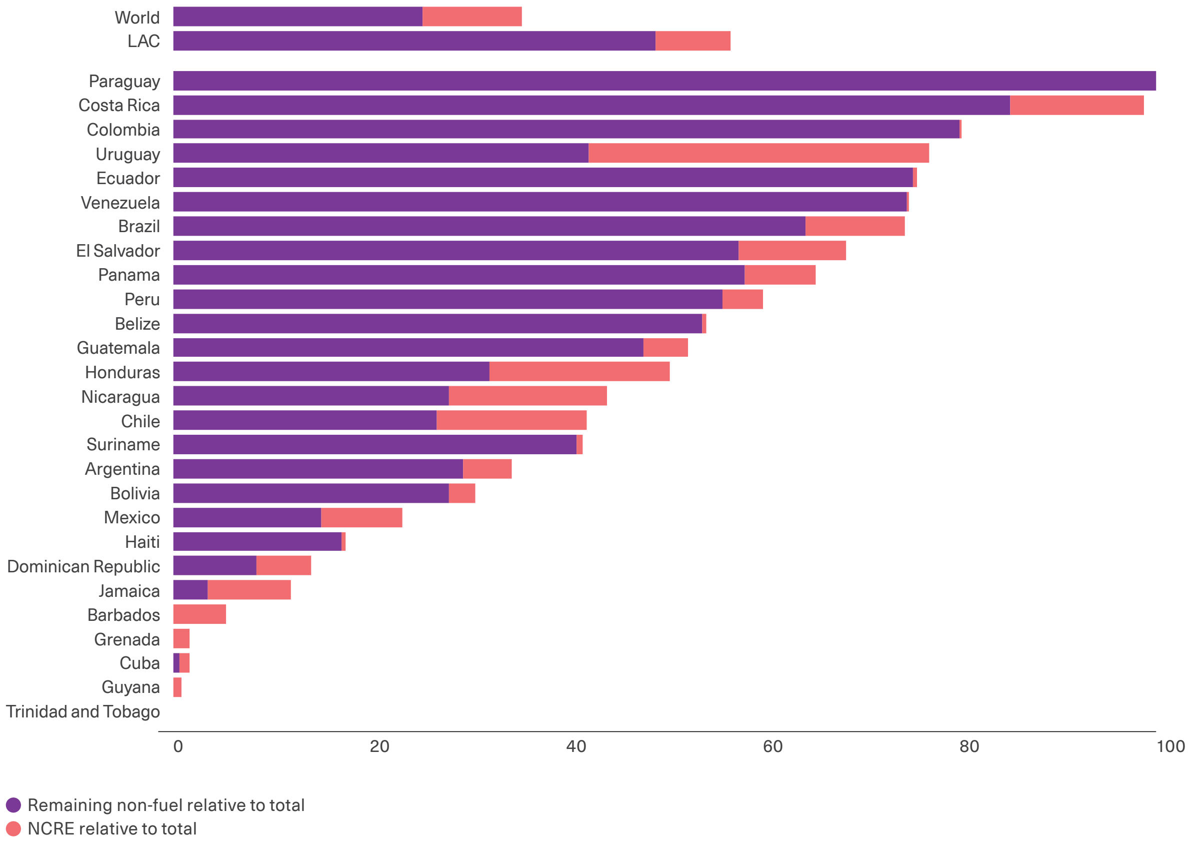
Non-combustible sources account for 57% of electricity generation in Latin America and the Caribbean, with one-fifth of that amount being produced through solar and wind energy

Latin America and the Caribbean as a whole shows a 57% share of non-fuel generation sources (OLADE, 2023b), almost one-fifth of which comes from solar and wind. This is significantly higher than the global figure, which is 36% for non-fuel generation. The region's share of renewable sources in electricity generation is 11%, a value similar to global values, suggesting that the advantage in non-fuel generation stems from efforts that predate the current energy transition agenda, made possible by a significant availability of water resources (IEA, 2021f).

Graph 3.2
Non-fuel generation and NCRE sources



Note: The graph presents the proportion of non-fuel electricity generation, that is, the proportion of non-thermal generation in electricity production and the percentage of that generation obtained from renewable sources, including solar and wind. The "world" values correspond to the year 2021.

Source: Authors based on OLADE (2023a) and IEA (2023v).

Efficiency of energy systems

Another dimension that can be analyzed using energy matrices is the efficiency associated with the various transformation, transportation, and distribution processes that energy products undergo from their primary source to the end users, be they households, companies, or the State. The energy losses in the system are presented below in three stages that are of interest for the energy transition because they increase GHG emissions: 1) losses during fuel production and transformation; 2) losses in electricity generation from fuels, and 3) losses from self-consumption of electricity, transportation and distribution. These three components are displayed by country in Graph 3.3.

Many of the fuels used for final (or intermediate) consumption undergo important transformation processes. Gasoline, diesel, and jet fuel, for example, are obtained by refining petroleum, a process that requires high energy consumption. Ethanol is a liquid fuel of agricultural origin that is increasingly used in transportation in combination with gasoline. Making it involves the cultivation of corn or another agricultural input, milling, fermentation, and distillation. Charcoal production entails the extraction of wood and its subsequent incomplete combustion under low-oxygen conditions. These processes typically require the use of energy and suffer losses in the form of rejected energy.[7]

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Many of the fuels used undergo important transformation processes that involve losses

Panel A of Graph 3.3 shows that, for the region as a whole, approximately 13% of the energy value of the inputs used in the production of end-use fuels is lost.[8] When contrasting countries, significant differences can be seen in these losses, partly associated with the extent to which countries process the fuels they consume internally and partly with the efficiency with which these processes are carried out. Those that experience fewer losses (such as Guatemala and Belize) are the ones that do not have refining capacity and import the final energy products they consume. This is because the transformation loss occurred in the country that produced the derivatives. At the other extreme, Venezuela, Colombia, Mexico, and Argentina are countries with high oil refining capacity and record losses of between 16% and 23%. Meanwhile, Haiti (21%) and Paraguay (17%) have high loss rates in fuel transformation, associated with the high participation of biomass processing (such as firewood and sugarcane).

The process of generating electricity from fuel sources involves first transforming the chemical energy contained in those inputs into heat at the moment of combustion and then into mechanical energy to move the generator. This process inevitably results in energy losses in the form of heat released into the environment. The type of thermal generators used, the type of fuel, the previous transformations undergone by the fuels, and the type and age of the machinery determine the efficiency of this transformation process. Panel B of Graph 3.3 shows the total losses and disaggregation into electricity generation specifically (mauve and violet bars) and the transformation of fuels used for generation (purple bars). The region shows losses of 65%,[9] an estimated 56% of which corresponds to generation. In most countries in the region, generation losses range between 50% and 65%.

The generation, transmission, and distribution of electricity also consume energy and experience losses during transportation, which may be significant. These losses are classified as technical and non-technical. Technical losses are a consequence of the very functioning of the components in transmission and distribution systems, such as the electrical resistance of cables, transformers, etc., and the magnetic fields generated by the flow of current through these components. Non-technical losses are associated with unbilled electricity consumption, which occurs due to registration failures, informal and illegal connections to the electric grid, and unmetered supplies, as seen in some informal settlements (Jiménez Mori et al., 2014). The losses incurred by the region due to consumption by power plants themselves and during transmission and distribution are among the highest in the world, reaching an aggregate of 19% of current electricity generation. With losses equal to or less than 10%, Trinidad and Tobago, Barbados, and Grenada have the lowest levels in the region. At

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7 Chapter 5 describes them in more detail.

8 Fuel transformation losses are approximated by (one minus) the ratio of the sum of the final consumption of fuels and fuels used in electricity generation, in the numerator, to the sum of total primary fuel supply and net imports of secondary fuels, in the denominator. This is equivalent to calculating the ratio of the losses of 3.64 EJ to the primary supply of 24.24 EJ shown in Table 3.1, although the resulting value in the graph and in the table differ because in the latter case the ratio does not include fuels destined for electricity generation. The combination of fuels used in energy generation shows a greater preponderance of natural gas, which does not undergo significant transformation processes, thus resulting in lower transformation losses compared to the total.

9 Calculated by divided the losses of 4.64 EJ in Table 3.1 by 7.19 EJ.

the opposite end of the spectrum is Honduras, with 33% (see Panel C of Graph 3.3).

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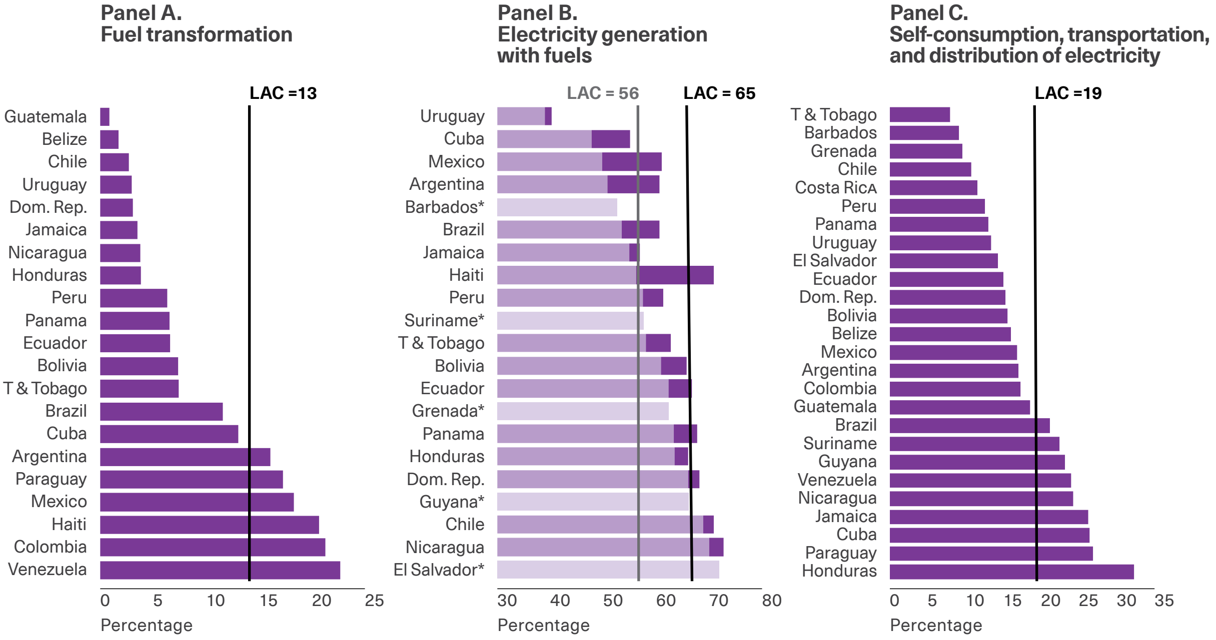
In most countries in the region, fuel generation losses range between 50% and 65%

In summary, although the region has a relatively clean electricity matrix, i.e., with a high share of non-fuel generation (57%, as shown in Table 3.1, compared to the global average of 36%),[10] electricity still represents a smaller share of total energy consumption (approximately 20%, in line with the world average). Direct fuel consumption is four times that of electricity. Furthermore, the electrical systems in the region exhibit significant differences in efficiency and high overall losses, which have important implications for greenhouse gas emissions.

Graph 3.3

Losses in transformation, generation, and transportation processes



Note: The graph shows the proportion of energy input losses at three stages: during the transformation of fuels (Panel A), during the fuel generation process (Panel B), and during the transportation and distribution of electricity (Panel C). Values are presented for LAC countries with available information. Due to limitations in the source data, the following countries are excluded: Barbados, Costa Rica, El Salvador, Guyana, Grenada, and Suriname in Panel A; Belize, Colombia, Costa Rica, Guatemala and Venezuela in Panel B; and Haiti in Panel C. The asterisk indicates that it is not possible to attribute the total losses to either fuel transformation or generation since the information from Panel A is used as an input.

Source: Authors based on OLADE (2023b).

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[10] The calculation is based on IEA data (2023x, Table A3.a).

Emission intensity from energy used by primary source

Burning fuels to meet energy needs contributes to global warming mainly through CO_2 emissions. The various fuels used have disparate impacts on global warming because they have different emissions factors. This concept refers to the amount of CO_2 that is emitted on average for each unit of energy input that is burned.

In addition, energy consumption also leads to methane emissions, another important contributor to global climate change. Oil, gas, and coal production results in varying degrees of methane emissions. These emissions can occur, firstly, in oil fields where natural gas is not harnessed for commercial purposes, and secondly, through fugitive emissions, i.e., losses (accidental leaks and deliberate releases) during the production and transportation of oil and gas.[11] Box 3.1 describes the main greenhouse gases, including the substantial impact of methane emissions on global warming.

The energy matrix of Latin America and the Caribbean presented above shows that the region's energy consumption is lower than the value of energy inputs. These differences between inputs and what reaches the end-use stage have major implications when considering the impact that each energy resource consumed has on global warming: in addition to the direct emissions resulting from the final use of fuels, there are other emissions corresponding to energy losses or uses that occur during the process, from energy inputs to end-use products. Also included are methane emissions due to the non-use of natural gas or fugitive emissions. These are ultimately attributed to the various energy products obtained in an economy.

The energy losses during transformation processes and fugitive emissions have large implications for emissions of the energy consumed

The impact of direct emissions, emissions due to efficiency losses during fuel production, transformation, and transportation processes, and those associated with methane varies according to the composition of the energy inputs consumed, the efficiency of the processes, and the released or fugitive methane.

Table 3.2 presents the emissions factors for end-use fuel energy products in the set of countries of the region. Column (a) displays emissions factors at the time of combustion, as reported by the Intergovernmental Panel on Climate Change (IPCC) for use in GHG emissions inventories. Column (b) shows the increased factor due to efficiency losses from production, transformation, and transportation processes. Column (c) represents the factor with the addition of each country's fugitive methane emissions attributed to the energy production from each source. The calculation methodology adopted is detailed in the annex (available online).

When considering direct emissions, natural gas stands out as having the lowest emissions factor among all fuels, at 56 tCO_2/TJ; this value is half that of charcoal and is 22% lower than the value for diesel. At the other extreme, charcoal is the energy product with the highest emissions resulting from combustion per unit of energy, estimated at 112 $tCO_2/$ TJ, even surpassing those linked to coal by 18%. Liquid fuels are associated with intermediate emissions intensities, ranging from 69 $tCO_2e/$ TJ to 77 $tCO_2e/$ TJ.

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[11] Methane is also produced in the fermentation of organic matter in water reservoirs, which is why it also affects dams built for hydroelectric generation.

Table 3.2

Direct emission factors, with processing and production losses (tCO_2e/TJ)

Source	Combustion (a)	(a)+inefficiencies (b)	(b)+fugitive emissions (c)
Natural gas	56	60	74
Coal	95	96	96
Liquid 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 CO2 equivalent per terajoule (tCO2 e/TJ).

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

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Natural gas has the factor of lowest direct emissions all fuels which is equivalent to the half of that of coal vegetable and 24% lower than diesel

Table 3.2 shows that including indirect emissions, i.e., emissions associated with energy losses and consumption during transformation processes, leads to a significant increase in the emissions factors for the entire region (Column B).[12] The advantage of natural gas in terms of emission intensity is even greater than that offered by the other fuels considered, as the emissions are 32% and 72% lower than for diesel and charcoal, respectively. This is because emissions from petroleum derivatives increase by 19% due to efficiency losses during transformation, while in comparison the emissions factor for natural gas increases by just 7.5%, since it does not undergo major transformations.[13]

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[12] However, this increase depends on the efficiency of the energy systems and varies by country, in line with the patterns discussed in Graph 3.3.

[13] The fuel transformation losses included in Column B act as an emissions multiplier. Petroleum derivatives (gasoline, kerosene, diesel, and fuel oil) share the same multiplier, as a result of taking into account the ratio of refinery inputs and products to the energy consumption of production and transformation.

Box 3.1
Emissions from human activities and the impact of methane

The 2023 Report on Economic Development (RED) (Brassiolo et al., 2023) discusses in depth how various human activities affect the global climate by altering the balance of gases in the atmosphere. A simplified representation might consider carbon dioxide (CO_2), methane (CH_4), and other gases, and three groups of activities. Within the carbon cycle, human activities that produce emissions can be grouped into industrial processes and energy use on the one hand, and land use on the other. In the case of methane, waste management is added to these two groups as a central contributor to emissions associated with human activity.

Globally, the relative contribution of the various gases to climate change in 2019 was about 75% for CO_2, 18% for methane, and 7% for other gases, which include nitrous oxide and fluorinated gases (IPCC, 2022). This relative contribution is expressed as CO_2 equivalent units. Since both the radiative forcing and the atmospheric lifetime of different gases vary, it is necessary to convert the emissions of each gas into their impact on global warming, taking into account a specific timeframe and discount rate.

Energy uses involve CO_2 emissions when carbon-containing compounds are burned, which include all fossil-derived products and fuels of animal or vegetable origin.

In addition, energy sources are also associated with significant methane emissions. During the production and transportation of petroleum, natural gas (methane), and coal, methane is released due to accidental causes (fugitive emissions) or intentional ones (venting or burn on site) when natural gas is not harnessed for commercial ends. Incomplete combustion of moist biomass for energy purposes results in the production and release of methane. Finally, the introduction of water dams for hydroelectric power generation can increase the overall methane and carbon emissions of the affected watershed.

Approximately 60% of annual methane emissions are related to human activity. Energy use and production are responsible for more than one-third of those emissions, the vast majority of which are linked to fossil fuels (93%), while the remainder is associated with biofuels (7% to ethanol, biodiesel, and biogas) (IEA, 2023j).

Finally, Column C of the table presents the total emissions by energy product arising from direct and indirect emissions, including fugitive methane emissions attributed to that fuel. In the group of countries for which estimates of fugitive emissions are available, these represent an additional 9.6 tCO_2e/TJ in the case of petroleum derivatives, 13.2 tCO_2e/TJ for natural gas, and around 1 tCO_2e/TJ for coal. When these fugitive emissions are taken into account, the advantage that natural gas has over other fuels is reduced, although the total emissions are still 25% lower than for diesel.[14] The impact of fugitive emissions in the region is considerable in the case of petroleum and its derivatives and natural gas, while it is lower for coal and its derivatives. As discussed in Chapter 5, reducing fugitive emissions is of central importance for emissions reduction in the short and medium term.

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[14] The fugitive emissions included in Column C are the result of prorating the fugitive emissions estimated by the IEA, corresponding to petroleum, coal and gas, among the total final fuels produced.

Emissions associated with electricity generation

A significant portion of electricity in most countries in the region is generated by thermoelectric power plants that use fuel inputs, thus resulting in GHG emissions. The average emission intensity of each country's electricity can be calculated based on the mix of inputs used, the efficiency of the transformation and transportation processes, and the methane emissions associated with the production of the inputs (petroleum or natural gas).

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The emission intensity of electricity depends on the combination of inputs used, the efficiency of the processes involved, and their fugitive emissions

Graph 3.4 illustrates the emission intensity of the average unit of electricity consumed depending on the country. It shows direct emissions (purple bars)—which include the mix of fuel inputs used and their direct emissions factor (Column A of Table 3.2)—in relation to total generation; energy losses and uses from fuel production, transformation and transport processes (violet bars and Column B of Table 3.2); fugitive emissions attributed to these fuels (blue bars and Column C of Table 3.2); and finally, losses from self-consumption, transport and distribution of electricity (pink bars).

In the aggregate, direct emissions from an average unit of electricity in the region amount to 76.2 tCO_2e/TJ. Accounting for the transformation losses of the fuels required for generation increases emissions to 93.9 tCO_2e/TJ. When fugitive emissions associated with fuel production are also considered, emissions associated with electricity show an additional increase of 14% in comparison to direct emissions, reaching 104.5 tCO_2e/TJ. Finally, factoring in losses from self-consumption, transmission, and distribution of electricity results in an estimated factor of 128.5 tCO_2e/TJ. The graph highlights significant differences in the average electricity emissions among the countries of the region, which can be attributed to the mix of inputs used and the losses from self-consumption, transportation, and distribution of electricity, since, for this exercise, fuel transformation efficiency and fugitive emissions are set at the regional average.[15]

Paraguay, Costa Rica, and Uruguay (in ascending order) show average emission factors close to zero, reflecting a very low or zero share of fuel-based generation. At the other end, Guyana, Nicaragua, and Guatemala show direct emissions per unit of electricity ranging from 190 tCO_2e/TJ to 230 tCO_2e/TJ, which exceed 400 tCO_2e/TJ when all components are included.

●●

The emissions from electricity increase by 23% when transmission and distribution losses are taken into account

Emissions per unit of energy associated with electricity in Latin America and the Caribbean, including all items, are 73% higher than those associated with natural gas (when comparing the 128 tCO_2e/TJ presented in Graph 3.4 with the 74 tCO_2e/TJ from Table 3.2). In addition, they are 39% higher than those for gasoline (amounting to 92 tCO_2e/TJ, as shown in Table 3.2). However, this comparison requires careful consideration of the type of energy use in question.

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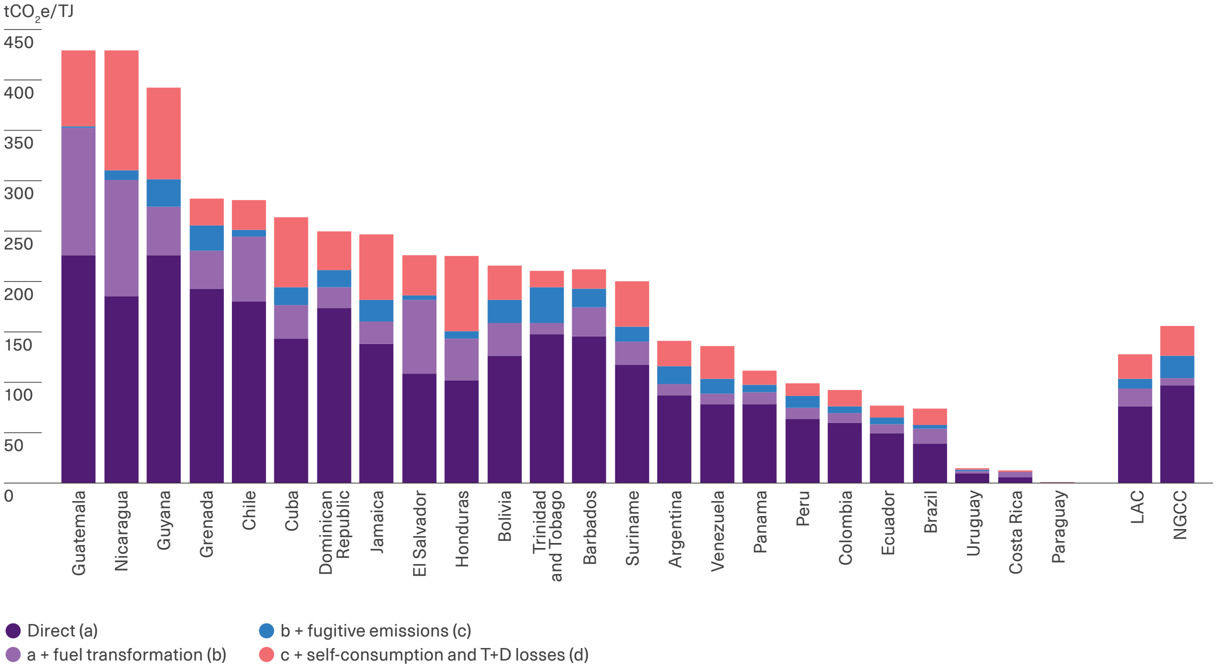
[15] While some countries produce all their fuel inputs, including oil and gas extraction and refining, others import everything they need to generate electricity. Focusing on the electricity sector, the same indirect emissions factors are used and the methane per unit of energy corresponding to the regional aggregate is applied for all countries.

When energy is used to generate heat, as in the case of some industrial processes or residential hot water production, the direct comparison of the emissions involved in the use of electricity, shown in Graph 3.4, with those associated with the use of the various fuels, presented in Table 3.4, is approximately valid. For example, comparable domestic water heating systems show efficiency ratios of between 1.14 and 1.04 when comparing electricity to natural gas or liquefied petroleum gas (LPG). (Keinath and Garimella, 2017). For this example, few countries have an electricity matrix with low enough emissions to ensure that replacing a domestic water heater powered by natural gas or LPG with a similar electric device would result in an overall reduction in emissions.[16]

Graph 3.4
Emissions associated with electricity generation



Note: The graph shows the emission intensity of the average unit of electricity consumed, measured in tons of CO2 equivalent per terajoule, in LAC countries with available information. The purple bars show direct emissions relative to total generation. The violet bars represent energy losses and use during the fuel production, transformation, and transportation processes. The blue bars include fugitive emissions attributed to those fuels. Finally, the pink bars illustrate losses due to self-consumption, transportation, and distribution (T+D) of electricity. Details of the calculation used in each case can be found in the annex available online. The NGCC category represents the theoretical emissions that would result from producing electricity with a natural gas combined cycle plant (using an efficiency parameter of 58%, which is the standard for this technology [IEA, 2020e, p.48]), taking into consideration the natural gas emissions factors corresponding to the aggregate for the region. Extreme values are excluded in the cases of Belize and Haiti.

Source: Authors based on IPCC (2006), OLADE (2023b) and AIE (2020e).

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16 These comparisons depend on the efficiency of the equipment used. In the case of residential air conditioning and water heaters, electric equipment based on heat pumps (the type of system used in air conditioners for cooling or heating) show a much higher coefficient of performance than traditional boilers, although they require a higher initial investment and are not yet available in all markets.

In contrast, for uses relating to propulsion, fuels require an energy conversion from heat to motion, which is subject to significant efficiency losses. For example, the efficiency factor of internal combustion engines used in automobiles ranges between 20% and 30%, while the efficiency factor for electric motors is between 80% and 90%. (Pannone et al., 2017). Therefore, given the ratio of the efficiency of electric motors (90%) to that of internal combustion engines (30%), replacing fuel use with electricity will result in a reduction in emissions as long as the emission factor of electricity is less than three times that of the fuel used, which is the case in most countries in the region.

In short, until electricity generation is 100% green, the electrification of uses will bring reductions in emissions, but these will not be homogeneous, and emissions could even increase depending on the type of use and the efficiency of the equipment employed. This is why advances in the electrification of consumption must be accompanied by increases in clean generation capacity.[17]

Finally, the last bar in Graph 3.4 (NGCC) represents the theoretical emissions that would result from generating electricity with a natural gas combined cycle plant—using an efficiency parameter of 58%, taken from IEA (2020e)—and assuming the natural gas emission factors from the regional aggregate. This would result in direct emissions of 97 tCO_2 for each terajoule of electricity generated and total emissions of 156 tCO_2e per terajoule delivered to end consumers. This hypothetical reference suggests that, in many countries in the region, average generation has a greater impact on emissions than would result from using natural gas with the most efficient technology available—combined cycle—which is an indication of the potential role of natural gas in reducing emissions from the electricity sector. In practice, the specific opportunities for this emissions reduction depend on the feasibility of replacing liquid fuels or coal with natural gas.

Spaces for action on energy systems

The three strategic pillars of energy transition described in this chapter provide a space for action to address the environmental crisis and ensure sustainable development.

●●

Low-emission electricity generation, consumption electrification, and energy sector efficiency are strategic for the energy transition

The first pillar pertains to low-emission electricity generation. The chapter has shown that the region has a relatively clean electricity matrix, with a high proportion of non-fuel generation, amounting to 57%, as seen in Table 3.1, versus 36% globally. However, the emission intensity of electricity in some countries remains high, even when compared to the direct use of fuel vectors such as natural gas.

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[17] Accurately estimating the real impact of electrifying a consumption is a complex task because it depends on the source of electricity generation used to meet that energy need. When the demand for the electricity sector increases, the emissions in the short term correspond to the power plant providing that increase in electricity generation. During peak consumption periods, power plants that cater for marginal consumption will generally be baseload thermal plants with high emissions per unit of energy. However, over time, it is expected that the sector will readjust to the new level of consumption by incorporating lower-cost and lower-emissions generation capacity.

The promotion of solar and wind energy will be key to reducing emissions from the electricity sector, particularly in countries with limited hydropower resources, and to paving the way for electrification of consumption with a reduction in emissions. Chapter 4 describes the existing instruments for promoting non-conventional renewable energy sources and the adaptations required by the electricity sector.

The second pillar is the electrification of consumption. As observed, electricity still represents a smaller portion of total energy consumption (approximately 20%, in line with the global average), while the remainder is met by fuels. Although these low electrification rates have to do in part with the need to match energy uses to suitable vectors, there are already competitive technologies that can achieve significant increases in the share of electricity, particularly in the residential and commercial sector, as well as light transportation. This chapter highlights the importance of evaluating when electrification of consumption is advantageous, as the emission reductions it can achieve vary and may even be negligible, depending on the type of use and the electricity matrix of each country.

The third pillar relates to the efficiency of the energy sector. This chapter describes the various losses in the system associated with the different processes that energy inputs undergo. Fuels, which currently account for 80% of energy consumption, exhibit high emissions that are amplified in the region by energy systems with efficiency losses and fugitive emissions. In addition, the electricity sector also shows high self-consumption, transportation, and distribution losses in comparison to global averages. Policies to improve efficiency in the use of inputs, such as eliminating fugitive emissions and reducing electricity losses, offer promising opportunities for emissions mitigation.

Green electrification

- Description of electrical systems
- Adaptations that systems and mechanisms may require for the incorporation of renewable sources
- Public policies for decarbonization through clean energy sources

4

Key messages

1

The energy transition entails a substantial rise in power consumption and deep decarbonization. The increase in electric energy consumption corresponds to economic development and more availability of electricity. In 2050, the percentage of electricity in the energy matrix will be double what it is today. At the same time, decarbonization requires an increased production of green power to meet the electricity demand and replace fossil energy sources.

2

The growth of the power grid, along with its resource mix, brings three major challenges. First, significant investment is needed to achieve the capacity target, which means incentives and stability to attract the private sector. Second, the most competitive clean energy types are intermittent which means adequate tools are needed to ensure the supply of electricity. Third, the growth of this sector and the incorporation of renewable, distributed electric generation will also require an extended, restructured transmission and distribution infrastructure.

3

Latin America and the Caribbean has relied on middle and long-term contracts accompanied by a spot market for energy trading. Organizing the market in this way has facilitated the use of auctions to initially increase capacity and later incorporate non-conventional renewable energy (NCRE) sources.

4

Investments of around 1% of the GDP annually until 2050 are sorely needed in green power generation in order to work toward net-zero emissions in the region.

5

The cost of electric generation from solar panels and wind turbines is similar to or lower than that of fossil fuels. However, renewable energy is non-dispatchable, i.e., electricity can only be generated when the resource is available. The integration of renewables into energy systems means there are times and places with surplus energy, or a lack thereof, creating challenges for the operations of the power sector.

6

Technology and regulation are the two tools needed to address the operational challenges of a an electrical sector with a high share of non-conventional renewable energy (NCRE) sources. On the technological front, developments include large-scale storage solutions like lithium batteries and hydro-pumping, as well as flexible, low-emission generation methods such as green hydrogen or sustainable biomass. On the regulatory side, measures involve increasing the level of required capacity reserve and ancillary services, as well as enhancing demand response mechanisms.

7

In LAC, there have been several cases in which renewable energies have been rapidly incorporated into the power grid. These include Uruguay (where it accounts for 34.3% of electric generation), Chile (22%), El Salvador (18.6%), Brazil (13.6%), and Argentina (11%). Some countries began incorporating renewables as early as 2010, including Nicaragua and Costa Rica (both at approximately 4% that year). In addition, some countries have been actively working to incorporate distributed generation, which represents 5% of the region's capacity (Brazil accounts for nearly 90%).

8

Transmission and distribution infrastructure will require substantial changes in addition to those described for the other areas of the electricity sector. The size of the current transmission and distribution network, which stands at an estimated 20 kilometers for every 10,000 inhabitants, must double by 2050. For grid operations, the fragmentation of injection points, the increased distance between where energy is generated and where it is consumed, and the presence of prosumers will require changes in terms of extension and flexibility.

9

Latin America and the Caribbean has ample freshwater, solar, and wind resources, though the availability varies between and within areas. The region has one-third of the world's surface runoff, more than all the other continents, yet it leverages only one-third of it. At the same time, it is home to 6% of the world's population. In addition, almost every country in the region is above the global solar power average and 12 countries are above the global median for wind power.

10

Energy integration is the most effective way to ensure continuous electric supply despite the intermittency of renewables. Building stable frameworks for exchanges between countries will be fundamental to leverage existing interconnections and promote new interconnections of different national systems.

Green electrification[1]

Introduction

The energy transition in Latin America and the Caribbean requires an increase in the share of electricity in overall energy consumption and more reliance on low-emission sources in the generation of this electricity. The use of clean sources in generation presents three major challenges.

The first is that unlike baseload resources, which are always available, solar power and wind are intermittent, posing challenges for the electric system. As a result, the system's energy mix must ensure a generation capacity that enables consumption levels and peak demand to be reliably met. The payments that each power plant receives depend on its capacity, so adaptations may be necessary to ensure there are enough plants of each type and that all run optimally. On the other hand, greater intermittency increases the need for tools that give systems the flexibility to avoid power outages. This flexibility can be achieved on the supply side through the use of batteries or other forms of storage. On the demand side, flexibility can come from dynamic pricing that gives adequate signals of grid stress to residential and major consumers.

The second challenge is related to investments in electric generation capacity. This transition will require a higher investment in renewable plants and complementary technologies. This investment has been estimated at between 0.5 and 1% annually of the GDP of countries in the region (MRC Consultants and PSR, forthcoming). Besides replacing existing power plants that rely on fossil fuels, it will be necessary to increase the system's total capacity to meet the higher demand associated with the electrification of the transportation and heating sectors. Therefore, it is important to understand how to provide incentives that will guarantee an increase in the capacity of green power at the pace needed.

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[1] Written by Walter Cont and Federico Juncosa, with research assistance from Lautaro Carrizo and Agustín Staudt.

The third challenge is related to the expansion of the transportation and distribution infrastructure. Along with greater requirements associated with the rise in demand, infrastructure should be adapted to the distinctive characteristics of non-conventional energy sources (solar power, wind, and run-of-river hydroelectricity). The geographical location, size of plants, and variability of renewables all differ.

These changes have implications for oversight of the power service, given that the incorporation of intermittent sources alters the cost structure of the system. This means that the variable costs of electricity are no longer as relevant and the capital costs component rises. At the same time, these variations bring challenges to how different players in the electricity sector are paid under current designs (Fabra, 2021; Fabra et al., 2021; Fabra and Imelda, 2023; Faruqui and Tang, 2021; Ryan, 2021).

This chapter begins with a description of electrical systems and how they can be prepared for the incorporation of renewable energy sources. Next, it delves into the adaptations these systems may require and the mechanisms for incorporating renewables into generation capacity. Given the predicted electrification of demand, electricity consumption could double with regard to current levels in net-zero emission scenarios. This puts a load on the transmission and distribution networks that entails investment, as does non-conventional power generation due to its specific features, particularly, its intermittency. This aspect is analyzed before discussing public policies that could achieve decarbonization through a greater integration of clean energies.

The electricity sector in Latin America and the Caribbean

Sector components

The electricity sector consists of four phases: generation, transmission, distribution, and sales. In each country, the sector may present varying degrees of integration and different participation profiles for public and private actors.

The generation phase consists of a process in which generators are used to transform a primary energy source (associated with an energy input) into electricity. Transmission consists in transporting electricity from the generating sites across a network comprised of medium and high-voltage power lines and transformation stations to cities or hubs with a demand. Distribution consists in transporting electricity from the stations with low, medium, and high-voltage transformers to the consumption points of the end users (homes, businesses, etc.) through a mesh system. Finally, sales involve the management of end users, including meter readings, invoicing, and demand management (forecasting the demand of end users and tariff payments).

The electricity sector consists of four phases: generation, transmission, distribution, and sales

In order to supply electricity to the end user in each country, the institutional arrangements for each of these areas can vary, from market-based approaches to fully centralized ones in which a state-run company owns and manages every stage (the case of Costa Rica, Honduras, and also Paraguay, though its configuration is slightly different.) Others are designed with varying degrees of vertical integration, market concentration, and state ownership.

The market-based arrangement is an illustrative case. Under this arrangement, the sale of wholesale energy—where producers sell energy to distributors or major users—and retail energy—in which resellers sell energy to end users—can be structured as markets with an adequate degree of competition, depending on their size. In contrast, transmission and distribution present some of the features of a natural monopoly in which there is justification for leaving service provision in the hands of a single supplier. In these stages, the institutional arrangement of the typical market involves granting the concession to a private company through an auction, or service provision by a public company that operates under the oversight of a regulatory authority.

In terms of the wholesale market, the most common set-up in the region consists of a wholesale electricity market comprised of distributors, retail resellers, large users on the demand side, and electricity producers on the supply side. It allows for free entry for both suppliers and buyers.

As electricity markets took shape in the 1980s and 1990s in Latin America and the Caribbean, efforts were made to structure it so that the producers dealt directly with distributors and major users for the provision of electricity on a wholesale market that consists of two parts: supply contracts and a spot market.[2] Producers and buyers sign contracts to supply electric energy for a certain period (the term is one element of the contracts and depends on the related asset; it could vary from just a few years to 20 years or more). These contracts lay out the conditions for the provision of the electricity procured. These contracts may be bilateral (between the generator and the distributor or reseller) or arranged as a decentralized system, where the parties set the conditions and prices in a flexible way without the approval of any third parties (as in Argentina, for example, during the period free from interventions). There are also cases of decentralized auctions (for example, in Chile) or centralized auctions in which the energy authority establishes the conditions (the case of Brazil). In all cases, the law establishes that distributors and major users must have contracts covering either all of the estimated demand or a high percentage of it.

The contracts are supplemented with a cash market, which allows demand to be met at every hour not covered by contracts while compensating for any differences between what is agreed to under the contracts and what is delivered. Argentina, Brazil, Chile, Colombia, El Salvador, Mexico, and Panama structure their power generation markets this way, albeit in different formats.

The main role of the market operator[3] consists of determining the order in which producers inject energy (the hour-by-hour supply curve) and release dispatch orders based on the last decision and the demand to be covered.[4] The break-even hourly price is the price or variable cost of the last unit dispatched to meet the hourly demand.[5] The payment depends on existing contracts and the dispatches completed. Thus, in the case of contract dispatches, producers receive a payment equal to the price of the contracts currently in force for the electricity delivered (Figure 4.1, Panel A). For dispatches without a contract or additional power beyond what is stipulated in the contract, the price

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[2] Also known as the immediate delivery market.

[3] The market operator, which is sometimes referred to as the balancing authority, can be a public-private company (with shares owned by different actors from the sector), an independent operator, or the company entrusted with the transmission of the system.

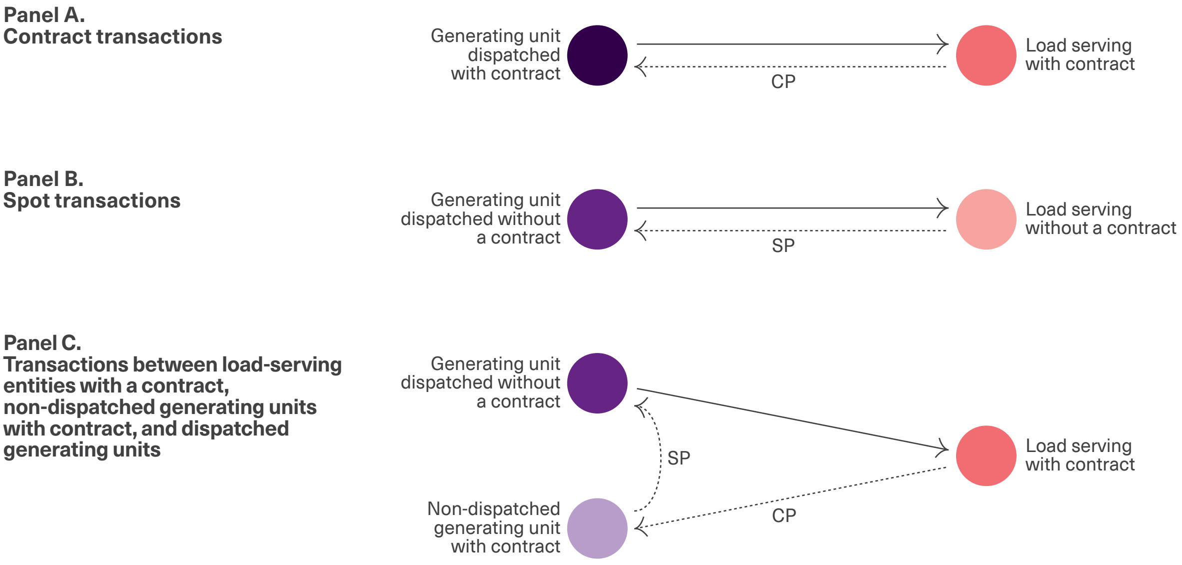
[4] Two different mechanisms are used to determine the order. In some cases (Colombia, for example), the generators lay out offers in price and quantity organized by price, in ascending order). In others, generators inform the operator of their cost structures—fixed and variable costs, fuel consumption by production level—and these are organized by price, in ascending order (Argentina, Chile, and Mexico, for example). Mexico is divided into three non-integrated submarkets: the National Interconnected System (Sistema Interconectado Nacional), Baja California Sur, and Baja California Norte. Baja California Norte is integrated with the California Independent System Operator in the United States, which operates with hourly nodal pricing. There can be differences due to physical constraints, losses, and network congestion.

[5] Argentina is an exceptional case. In 2002, pricing was structured as a supply curve but one based on theoretical supplies calculated by the Dispatch Authority, which ran variable cost simulations lower than actual ones for the thermoelectric generators. In 2011, management of the purchase and sale of energy was further centralized under the Dispatch Authority. Since the value of the energy sold to the distributors was much lower than the cost of generating it (even in the theoretical equation), this produced several deficits. The most important of these deficits was, first, the difference between payment for demand versus theoretical supply, and the difference between the value of the theoretical supply and the real cost of energy generation (higher than the theoretical cost for thermoelectric generation).

is the spot price in force at the time the energy is delivered (Figure 4.1, Panel B).

When a generating unit is not dispatched for the total contracted amount and is instead substituted by another generator, payment is made for the energy not delivered. The amount of said payment is the difference (positive or negative) between the price stated in the contract and the spot price, which compensates whoever delivered the equivalent amount of energy in that generator's place (Figure 4.1, Panel C). The transmission toll that generators must pay is deducted from this price. The toll varies according to the geographical location (node, power station) where the electricity is injected.[6,7] The difference between the spot price (or cost) and the costs of generation of each generating unit dispatched at each moment yields an almost implicit profit for marginal generating units, that is, those that operate with costs lower than the highest dispatch cost.[8] The behavior of spot prices or costs determines investments in new plants and dictates the values of the new contracts signed.

Figure 4.1
Flow of quantities and payments based on dispatch and contract type



Note: The figure shows the flow of energy based on whether or not the generating unit is dispatched and whether the flow is contract-based (CP: contract price) or a spot transaction (SP: spot price). The solid lines represent the flow of energy and the dotted lines represent the flow of money.

Source: Author.

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[6] The form in which financial agreements are implemented in relation to actual dispatches also differs by country.

[7] Another component of the incomes of generators is the power or capacity payment, which is generally determined by the regulator based on the capital cost to meet the peak demand, which is a supplementary income to support expanded capacity. These payments exist in Argentina (they are referred to as available power, though the prices are government-controlled), Chile, and Mexico. See Muñoz et al. (2021) for an analysis of the case of Chile.

[8] In practice, most of the energy of the generating units dispatched is paid under a contract that sets the prices.

Regional electrical generation matrix

In the region, 5.89 exajoules (EJ) are generated annually, of which invoiced energy accounts for 4.78 EJ and 1.1 EJ correspond to transportation and distribution losses, most of which are associated with informal energy uses not carried (19% from generation).

Multiple technologies are used to generate electricity, with characteristics that vary in terms of costs, flexibility, and environmental impact (see Box 4.1 and the Electricity Generation Technologies annex, available online). In terms of regional generation, 57% is produced from non-renewable fuels, 80% of which are hydroelectric.

In the region, 5.89 exajoules (EJ) of electricity are generated annually, of which 4.78 EJ represent invoiced energy and 1.1 EJ are transportation and distribution losses

Box 4.1

Generation technologies and their characteristics

Almost all electricity that is produced and consumed worldwide relies on a mechanical process to power a generator in several different ways. Inside the generator, a magnet circles a coil of wire, generating an electrical current due to the movement of the magnetic field the magnet creates. At the center is a rotor, powered by different sources, which turns along with the magnet.

The different sources used to power a generator can be classified as kinetic or thermal. Thermal generation is achieved through a heat source, i.e., the burning of a fossil or non-fossil fuel such as firewood. Other sources of heat can also be used, such as geothermal, nuclear, and solar energy. Besides electromagnetic induction as described above, the only other type of generators operating at scale are those that rely on solar photovoltaic energy. In this chemical process, electricity is produced when the semiconductor material used in solar panels absorbs the sun’s rays.

The different technologies have three main characteristics: costs and structure, the degree of flexibility in their operations, and their typical environmental impacts. Table 1 outlines these characteristics for a set of relevant technologies. Renewables currently boast low overall costs, comprised almost entirely of the initial capital costs, and virtually no emissions or environmental impact. However, they offer little flexibility in terms of their operations. In contrast, thermal generators produce greenhouse gas (GHG) emissions but can be adapted to varying production levels in response to sudden changes in supply and demand, thus making them highly flexible.

Table 1

Characteristics of the energy generators

Technology	Costs	Environmental impact	Dispatch and flexibility
Internal combustion using natural gas	High: strong variable component due to fuel cost and less efficiency than combined cycle	High emissions due to the use of fossil fuel, though less than other fossil fuels	High efficiency for variable pricing models, typically designed for consumption peaks
Internal combustion using liquid fuels	High: strong variable component due to fuel cost	High GHG emissions due to the use of fossil fuel. Emission of local air contaminants	High efficiency for variable pricing models, typically designed for consumption peaks
Open-cycle natural gas plant	High: strong variable component due to fuel cost and less efficiency than combined cycle	High emissions due to the use of fossil fuel, though less than other fossil fuels	High when generators are optimized for variable loads. Allows for intra-day to multi-annual storage, depending on the reservoir
Reservoir-based hydroelectricity/ hydropower	Moderate: greater capital cost and low variable cost associated with maintenance and the option value of the water used	CO2 emissions due to existing vegetation in the flooded area. Emissions of biomethane in shallow waters	Low flexibility due to the moderate minimum load
Solar thermal	Moderate: no variable component and high capital costs component	Zero emissions in the generation phase. Require a great deal of space	Low flexibility due to the moderate minimum load
Natural gas combined-cycle plant	Moderate: moderate capital costs due to more efficient fuel use and the high initial capital cost	High emissions due to the use of fossil fuel, though less than other plants thanks to high efficiency and the lower emissions of natural gas compared to other fuels	Low flexibility due to the high minimum load and moderate startup times Low flexibility due to the moderate minimum load and lengthy startup times
Coal-powered steam turbine	Low: cost of input is low (without carbon pricing), high capital costs	High GHG emissions due to the use of fossil fuel. Emission of local air contaminants	Low flexibility due to the moderate minimum load and lengthy startup times
Biomass steam generator	Moderate: cost of input is moderate (without carbon pricing), high capital costs	Possible emissions due to land use and indirect deforestation. Emission of local air contaminants	Non-dispatchable
Nuclear energy	Moderate: cost of input is very low, with high initial capital and maintenance costs	Zero emissions in the generation phase. Risks of contamination from radioactivity in the case of accidents. Costly subproduct management	Non-dispatchable
Run-of-river hydroelectricity/ hydropower	Low: no variable costs and low initial investment	Zero emissions, barrier for the movement of fish along the riverbed	Non-dispatchable
Solar photovoltaic	Very low: initial capital is the largest component	Zero emissions in the generation phase. Require a great deal of space	High efficiency for variable pricing models, typically designed for consumption peaks
Wind energy	Very low: initial capital is the largest component	Zero emissions in the generation phase. Possible impact on flying species	High efficiency for variable pricing models, typically designed for consumption peaks

Source: Author based on data from González-Salazar et al. (2018).

The electricity sector's contribution to climate change can mainly be attributed to generation that relies on non-renewable sources. In the region, this represents 2.54 EJ of electricity annually, or 43% of the total for the region. In order to generate this much electricity, 6.85 EJ of primary fuel inputs are needed. The difference between input and output can be attributed to energy losses and consumptions associated with the transformation processes that the production of different fuels requires and the efficiency losses of thermoelectric generation. In this calculation, the energy consumption of the fossil fuel sector is considered part of the input required for electricity generation. At the same time, thermoelectric generation involves high energy losses in the form of heat released into the air.

Our understanding of the other connections between electricity generation and climate change not associated with burning fossil fuels is increasing. On the one hand, the analysis of the full life cycle of each technology reveals all emissions—from the production of primary materials that capital goods require through final disposal. On the other hand, hydroelectric generation can produce carbon dioxide (CO_2) and methane emissions through the decomposition of vegetation in waterlogged soils near dams and the biological activity that occurs in soggy soils and shallow waters along shores. The problem with methane emissions is worsened by frequent changes in water levels that are part of the storage management of a hydroelectric dam.

Enhanced efficiency in fuel-based generation and reduced transportation and distribution losses in electricity allow demand to be addressed with fewer fuel inputs, which means lower costs and emissions. However, a portion of the transportation and distribution losses can correspond to unmetered consumption in the provision of low-income areas. Identifying and quantifying these losses is important to achieve efficiency and enhance supply management, but it may require the incorporation of alternative instruments to reduce regressive distribution, like the use of reduced rate schemes for low-income households (Cont et al., 2021).

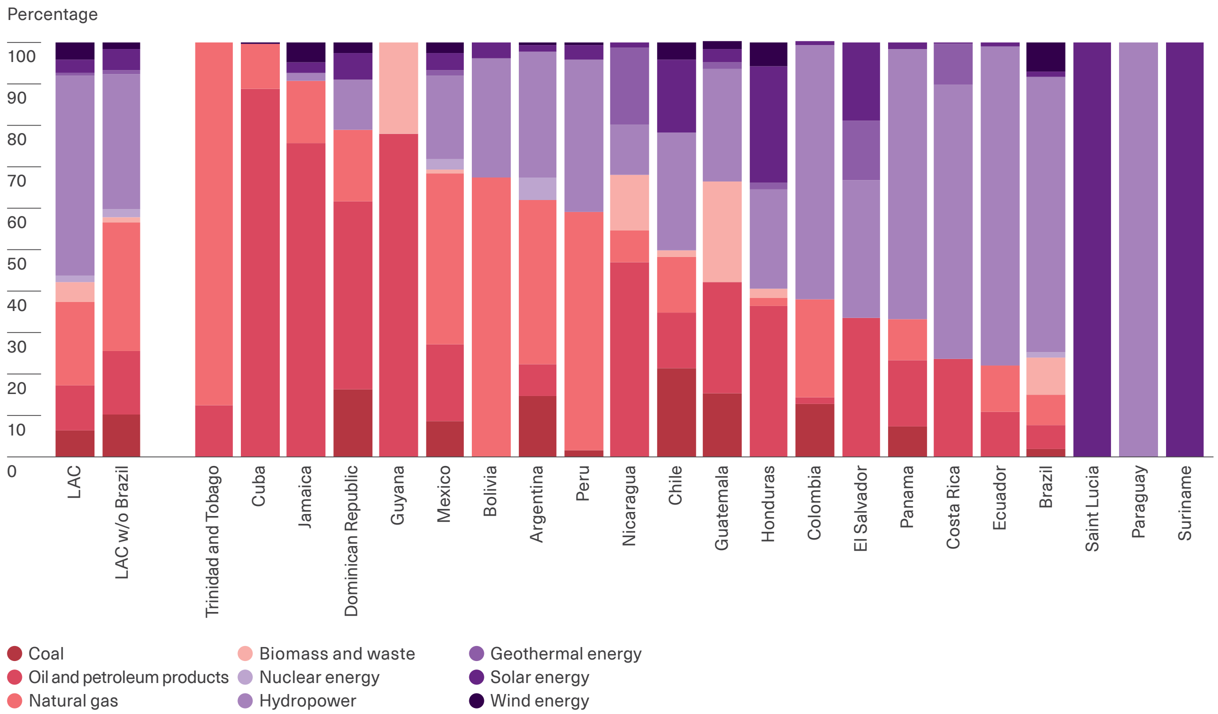
Improved efficiency in thermoelectric generation and the reduction of transportation and distribution losses enable a reduction in fuel use

Graph 4.1 shows the installed generation capacity in LAC by source. In Latin America and the Caribbean as a whole (first bar), hydroelectric plants represent the foremost source at the regional level, reaching 48% of installed capacity. At the same time, the installed capacity of geothermal, solar, and wind energy together represents 8% of the total (this does not include the distributed generation capacity).

Thermoelectric generation from fossil fuels accounts for nearly 38% of the installed generation capacity. The majority of this energy stems from natural gas plants (20%), though coal-burning plants (6.4%) and oil and petroleum products (11%) also account for a good percentage of installed capacity. In addition, electricity generation from biomass and waste accounts for 4.8% of capacity, accounting for 43% of fuel-based generation. Brazil, which mainly relies on hydropower, largely explained the overall capacity. If this country is excluded from the overall capacity, the share of fossil fuel capacity rises to 57%. In addition, the graph indicates that fossil fuels represent the highest share of capacity in the island countries or countries with poorly developed road networks (Trinidad and Tobago, Cuba, Jamaica, Dominican Republic, and Guyana, in ascending order).

Graph 4.1

Installed capacity by country based on main input (2021)



Note: The graph shows the installed generation capacity for the countries of LAC where information is available, organized according to the percentage of the region's total fossil capacity.

Source: Author, based on data from the Global Energy Observatory (2021).

A recent report (González-Mahecha et al., 2019) revealed that the remaining useful life of existing energy plants in Latin America and the Caribbean account for committed emissions[9] of approximately 6.9 gigatons of CO_2 ($GtCO_2$). In addition, if all the plants currently in the planning stage or under construction are approved, completed, and begin operations, this will add another 6.7 $GtCO_2$. This level of committed emissions exceeds the average estimates by the Intergovernmental Panel on Climate Change (IPCC) on cumulative emissions consistent with the remaining carbon budget in the region's energy generation sector to meet climate targets. The study concludes that in order to be aligned with the IPCC's average carbon budgets, it would be necessary to shut down between 10 and 16% of the electric generation plants that run on fossil fuels in the region.

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[9] Davis and Socolow (2014, cited by González-Mahecha et al., 2019) coined the term "committed CO_2 emissions" when discussing the impact of long-term existing infrastructure. It refers to potential emissions from plants already running on fossil fuels and other carbon-intensive equipment during a useful life at typical use levels.

Merit order and load curve

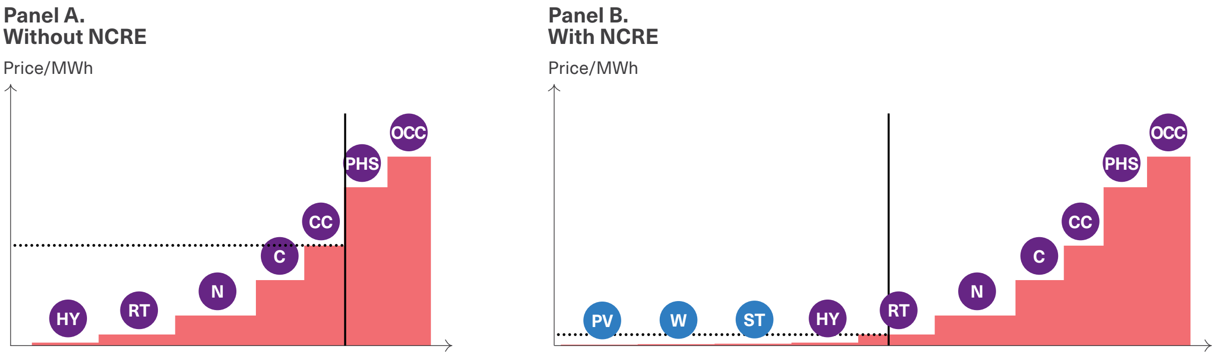
In 2022, energy systems in Latin America and the Caribbean supplied electricity at a rate of 4.8 EJ (or 1.3 million GWh) per year, out of a total consumption of 23.6 EJ. This consumption exhibits significant variability over time, typically showing daily, weekly, and seasonal cycles. The variability in demand includes both predictable components, such as the relationship between demand and ambient temperatures (in addition to seasonal, weekly, and daily cycles), as well as unpredictable components.

To meet demand, systems employ different types of technology (described in Box 4.1 and quantified in Graph 4.1), each with varying levels of dispatch flexibility, variable costs (including startup flexibility, level changes, and shutdowns), and fixed costs relative to production levels. The system operator determines a merit order for these technologies, prioritizing the sequence in which generators are dispatched to meet energy needs, based on available resources and consumption levels at any given moment. According to Guerra et al. (2022), and setting aside NCREs for now, the merit order ranks base hydroelectric power first,[10] followed by nuclear energy, renewable thermal energy, cogeneration, coal, natural gas combined-cycle, pumped hydroelectric storage (PHS), flexible natural gas combined-cycle, and natural gas open-cycle. Consequently, the hourly supply curve in each system is contingent upon resource availability and the mix of technologies deployed (see Graph 4.2, Panel A).

●●

A range of technologies can be used generate electricity, with different features in terms of ease of dispatch, costs, and emissions

Graph 4.2
Order of merit



Note: The graph displays the hourly supply curve and the sources of energy generation in order or merit. Non-conventional renewable energy sources (NCRE), i.e., photovoltaic, wind, and solar thermal energy, are included on Panel B but not on Panel A. PV: photovoltaic; W: wind; ST: solar thermal; HY: hydropower; RT: renewable thermal; N: nuclear; C: coal; CC: combined cycle gas; PHS: Pumped storage hydropower; and OCC: open-cycle gas.

Source: Based on data from Guerra et al. (2022).

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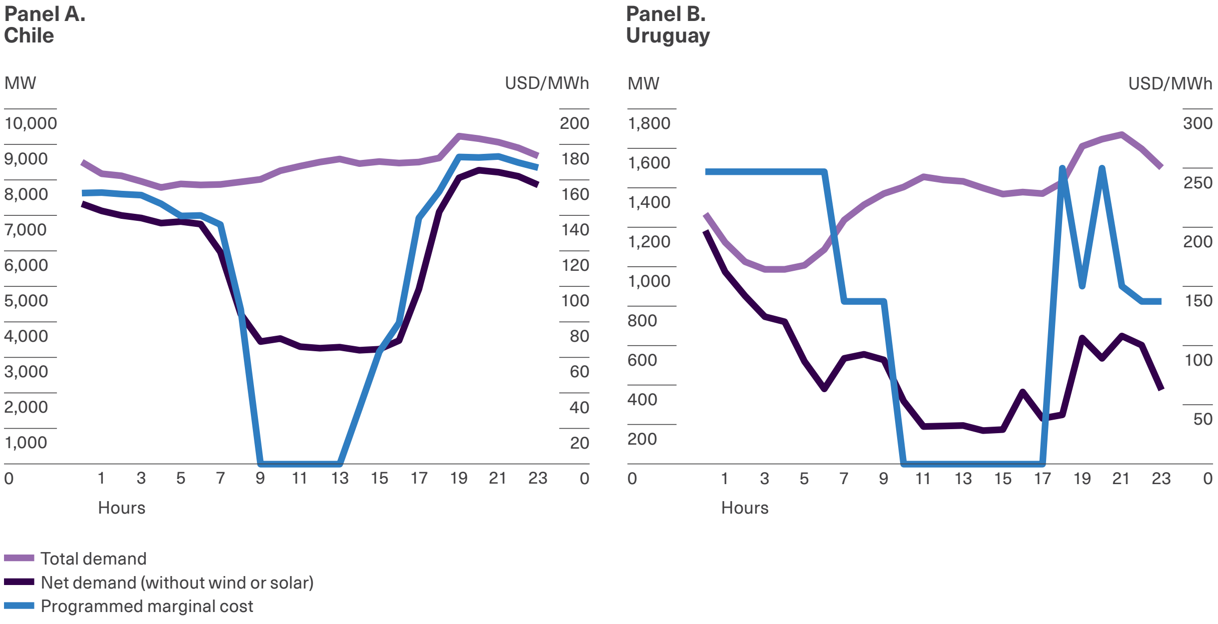
[10] Base load generation refers to large powerplants that can provide blocks of energy at a constant rate with low running costs. This ensures continuous dispatch.

NCRE sources, like generation from renewables like solar power and wind, are characterized by an entirely inelastic demand at a level that is determined randomly and outside the control of the generator based on resource availability and the weather. That is, at each moment, a solar or wind generator will deliver everything produced at any price, as it operates with variable costs near zero. In addition, production quantities vary greatly over time, with predictable and non-predictable components. Solar energy, for example, has a variable component that can be forecast with precision, i.e., solar radiation and the average temperature expected at each place, time of day, and season. It has other more uncertain components, such as concentrated particle suspension and cloud cover that reduces the solar radiation that reaches panels, among others. Thus, when significant quantities of NCRE sources are incorporated, the system's electricity supply curve moves toward the right (see Graph 4.3, Panel B), typically resulting in a reduction of the spot prices or costs. When more renewables are incorporated, there can be periods in which these NCRE sources fully cover demand, which translates into spot costs or prices close to zero on the wholesale market.

As an example, Graph 4.3 shows the hourly demand on a typical day in Chile and Uruguay (purple line). Given the features of each country, the daily demand curve has a peak and a trough, but not necessarily at the same time (in Chile, the peak is at 7 pm while in Uruguay, it comes at 9 pm). In the examples shown, the demand curve in Chile is more stable over the course of the day, while in Uruguay, the intra-day cycles are more pronounced.

Graph 4.3
Total and net load curves for wind and solar generation and marginal cost or spot price



Panel A.
Chile

Panel B.
Uruguay

Note: The graph presents the curve of total demand (load) and net from wind and solar sources in megawatts (MW) and the marginal cost or spot price in dollars per megawatt-hour (USD/MWh) for 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.

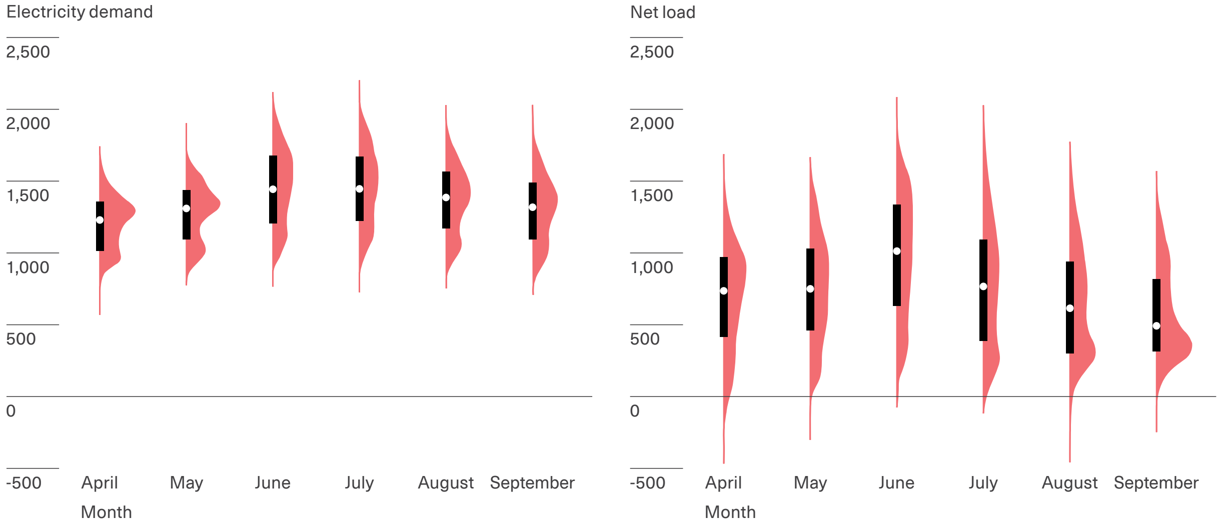
Source: Author based on data from the National Electric Coordinator (2023), for Chile, and ADME (2023), for Uruguay.

On the one hand, over the course of the year, demand has seasonal variations specific to each country. Graph 4.4 shows the behavior of demand during the six months between April and September 2023 in Uruguay. The distributions of hourly demand can be observed for each month and the width of distribution indicates the most frequent demands, which are generally positioned toward the center. The distribution queues reflect the values of peaks and troughs for each month. In addition, the average hourly consumption is illustrated with a white dot. The winter months in the Southern hemisphere are when average consumption is highest and the system's annual peak also occurs in these months.

Graphs 4.3 and 4.4 show some of the operational challenges the electricity sector faces. The sector must have the capacity to supply electricity during annual peaks along with backup capacity to ensure supply, which means the system must maintain idle capacity and cover its costs during troughs. In addition, supply management must ensure an instant response to net demand, given that it must generate each unit of electricity consumed by any piece of equipment connected to the network that is on (like a washing machine), immediately injecting this power to maintain network tension.

The electricity sector should have the capacity to supply electricity during the annual consumption peak and manage supply to respond to net demand instantly

Graph 4.4
Distribution of electricity demand by month (demand and net load) in Uruguay, Apr.–Sep. 2023



Panel A.
Distribution of monthly electricity demand

Panel B.
Distribution of monthly net load

Note: The distribution width indicates the most frequent values. The distribution queues present the highest and lowest values for each month. In addition, the average hourly consumption is illustrated with a white dot.

Source: Author based on data from ADME (2023).

The incorporation of renewable energy sources increases operational challenges because they are non-dispatchable. The only decision an operator can make in this scenario is whether or not to leverage the electricity generated at any given moment, whatever its type. As renewable energy resources are incorporated, the market operator must therefore look at what is known as the net load curve, that is, the net electricity demand that non-dispatchable sources provide at any given moment. The outcome is a significant change in this curve.

In the example of Chile and Uruguay presented in Graph 4.3, the main changes can be seen. On the one hand, in systems with a high solar power component like that of Chile, a duck curve takes shape (the black line on Panel A). This shows a distinctive pattern of a lower net load in daytime hours due to the portion of demand covered by solar power. On the other hand, when the system incorporates a high proportion of wind energy, as is the case of Uruguay, the net load curve shows a vertical shift of the load curve, in descending order, based on wind conditions. This is because output usually fluctuates significantly throughout the day (black line, Panel B). Finally, in both cases, there are lengthy periods in which the marginal system cost is zero, which occurs when the net load is lowest.

Flexible generation and backup services[11]

For the management of reliable, safe electric systems that provide quality service, continuous generation is of the essence. This means meeting a demand that can vary from one moment to the next, taking into account transmission and distribution losses. Levels of availability on the supply side (both programmed and unprogrammed) are another important consideration. The services that guarantee quality, safety, and reliability are referred to as backup services and enable frequency regulation along with short and medium-term immediate reserves. Different market participants can supply these services. For example, hydroelectric plants with storage capacity and open-cycle natural gas power plants can increase or decrease their production quickly, but that is not the case for steam turbines (powered by coal, nuclear energy, or fuels). Some major users can provide these services if they are willing to interrupt their energy use and able to do so in an agile manner when the electric system so requires. Interchanges between countries or neighboring systems can cover demand increases to the extent they have flexible generation capacity. In the medium term, it is necessary to plan for annual reserves that make the system more reliable and, more specifically, can be used for demand peaks.[12]

For the management of reliable, safe electric systems that provide quality service, continuous generation is of the essence

Based on the evidence in other regions and advances reported in international journals, countries have been working to adapt the electric system to enable a high share of renewable energy sources. The intermittency of these resources requires mechanisms that give systems flexibility, especially to accompany demand fluctuations and establish a contingency reserve. This reserve will become increasingly more relevant as the share of NCRE sources rises, thus necessitating a compensation system that provides sufficient incentives (Mercadal, 2023).

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[11] This section draws on data from Joskow (2019); Wolak (2022); Borenstein and Kellogg (2021); Hafner and Luciani (2022); and Fabra (2021).

[12] The system capacity requirements correspond to a calculation of the capacity needed to satisfy demand at every moment (with a low likelihood of a blackout). Wolak (2022) notes that this calculation changes substantially when renewable resources are used. In the example of Uruguay, despite the incorporation of a high proportion of wind energy, the system's capacity diminished only slightly.

In order to increase the share of NCREs, countries must have mechanisms that enable flexible systems

On the one hand, dispatchable generation must be adjusted to the predictable variability component, which is not only associated with energy consumption but also with non-dispatchable generation. In other words, it must meet net demand (black line, Graph 4.3). When the non-dispatchable source is solar, the dispatchable generating unit must be adapted to troughs (in megawatts [MW]) in the morning and peaks during the evening, as observed in the case of Chile (Graph 4.3); in contrast, when the non-dispatchable source is wind, the dispatchable generating unit must be adapted to the frequency and intensity of the wind, as can be observed in the case of Uruguay (Bothwell and Hobbs, 2017; Muñoz and Mills, 2015).

As shown in Graph 4.3, the need for dispatchable power sources during the evening rises by almost 4,800 MW between 4 pm (net generation of 3,475 MW) and 8 pm (net generation of 8,274 MW). The proxy of the hourly spot price published for the Chilean electric system is the marginal dispatched cost, which rises from USD 79.60 per megawatt hour (USD/MWh) to USD 172.90 USD(MWh) (in fact, it is zero from 9 am to 1 pm). In Uruguay, the daily net load curve is less variable, from 351 MW to 525 MW from 4 pm to 8 pm on the day analyzed, with a determined spot price that rises from 0 to 250 USD/MWh (in fact, it is zero from 10 am to 5 pm).

On the other hand, dispatchable generation should be adjusted to the non-predictable component of the variations in electricity consumption and non-dispatchable generation. As a result, requirements for the ancillary services of the electric system increase due to these new sources of unpredictability. The system, then, needs a generation capacity with low capital and start costs; it must also be capable of rapidly responding to dispatch requirements (Joskow, 2019)[13]. In systems that strongly rely on intermittent energy sources, storage at both the system and user level plays a very important role.[14] Specifically, this allows energy to be supplied for hours at low prices (daytime hours, or hours when the wind is strong) and then stored and sold at higher prices during hours when net generation begins to grow (when the sun goes down or the wind abates).

The example in Graph 4.3 illustrates the role batteries can play in softening prices between the increases and decreases in net demand during the 24-hour window. Although the price signals needed to make investment decisions in this technology are long-term, short-term prices can be indicative of the benefits of hourly matching. The price differences that can be observed in the examples included in Graph 4.3 reach USD 180 per megawatt hour in Chile and USD 250 per megawatt hour in Uruguay On the other hand, batteries also provide ancillary services in the medium term (reliable capacity for peak periods) and short term (frequency regulation and others) mentioned earlier. In addition, batteries allow investments in transportation and distribution to be deferred and supply emergency backup, among other benefits (Joskow, 2019). The entry of batteries into the system will depend on the net benefit they contribute in terms of increasing system flexibility compared to other available alternatives, for example, flexible generation from natural gas. Existing models on energy transition scenarios in the electricity sector forecast the incorporation of batteries in practically all the countries in the region (MRC Consultants and PSR, forthcoming).

In a decarbonized market, the additional variability introduced by non-conventional renewable generation can be addressed by incorporating sufficient reserve capacity and maintaining a diversified matrix of available generation technologies (such as photovoltaic solar, solar thermal, wind, and hydro), storage technologies (including hydro, thermal, and batteries), and

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13 In Chile, the ancillary services market began operating in January 2020. On this market, generators can offer primary, secondary, and tertiary reserve services, also with frequency control (competitive and discriminatory auctions), as a supplementary offer to energy markets and capacity (See Muñoz et al., 2021, p. 3). In other countries, like Argentina and Brazil, these services form part of dispatch operations.

14 See the “Batteries and other storage methods” subsection in “Online generation technologies” in the chapter annex available online.

geographical dispersion. during the transition and in the long term, some systems may require dispatchable and flexible generation capacity based on fuels (such as open-cycle natural gas plants and internal combustion generators) to ensure supply and provide system flexibility, particularly in regions with limited hydro resources.[15]

●●

The variability of NCRE can be resolved by integrating capacity sufficient reserve with a matrix diversified generation

Another way to address variability is by reducing peak load requirements through user actions, known as demand response. Currently, systems rely on large users who, by being able to interrupt their consumption, sell response capacity to the system and make it available to the operator. In the future, there will be a need to enhance demand response mechanisms through high-frequency pricing, which sends appropriate signals about electricity scarcity at that moment, prompting consumers to respond and incentivizing changes in consumption patterns. Demand response can also be reinforced by equipment automation (for example, the washing machine starts operating when prices are low, the water heater turns off if prices are high, etc.), to enable these changes and capitalize on these incentives. These advancements are part of the sector's developments.[16] These advances are part of the sector's preparation for creating the smart grid.[17]

Other sources of flexible distributed energy resources (DERs), such as electric vehicles and vehicle-to-grid (V2G) and grid-to-vehicle (G2V) modes may play a greater role in providing these services.

Adapting the electricity sector for the transition

Incentives for incorporating capacity

The integration of NCRE sources has an impact on the returns of other generation sources. Given that they operate with marginal costs equal to zero, they will always deliver all they produce to the market (though what they deliver is limited by demand and the network's infrastructure). In the described generation market framework, the integration of intermittent generation sources results in lower spot market prices and wholesale costs when they are producing. At the same time, higher-cost generation centers are displaced on the supply curve. This results in a reduction in the utilization rate of capital goods for displaced generation centers, affecting their profitability.

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[15] Even as capacity from solar and wind energy is incorporated, these will not necessarily replace the dirtiest types of contamination. For example, some coal plants have higher costs and longer startup times, making them suitable for baseline generation and for continuous operations. Therefore, the incorporation of solar power generation that is available only in daytime can initially replace open-cycle natural gas plants, which are cleaner than coal plants.

[16] The demand response level has been questioned, but some studies point to the idea that consumers respond to price variations (Allcott, 2011a; Andersen et al., 2017; Ito, 2014; Wolak, 2011).

[17] This topic is analyzed in detail in Cont et al. (2021).

Box 4.2
The role of industrial policy in technology adoption

Technology adoption has a learning curve with decreasing costs. The presence of major players accelerates that curve.

In the United States, the 2022 Inflation Reduction Act is one of the most important measures to accelerate the transition toward a clean power matrix. It encourages the incorporation of new clean energy resources to reduce carbon emissions in the country (Bistline, Mehrotra, et al., 2023; EPA, 2023c; Larsen et al., 2022; The White House, 2023). The IRA includes a series of electricity incentives, like tax credits on investments (30% of the cost of installed equipment) and production (USD 27.5/MWh for 10 years) of clean energy resources, tax credits for energy storage and carbon capture, and others for the maintenance of existing nuclear plants. The law offers long-term extensions for tax credits predating the IRA (for example, credits for wind and solar energy), increasing existing tax credits (for example, credits for carbon capture, clean energy investment, and production credits), and other new ones (like support for existing nuclear power plants). The IRA thus includes an ample range of programs that address issues associated with environmental justice and encourage, among others, the use of clean energy, carbon management, electrification, and efficiency measures; the reduction of methane emissions; and support for nationwide supply chains (Bistline, Blanford, et al., 2023).

Studies that assess the impact of the IRA and GHG emissions have shown that this law is fundamental for decarbonization in the United States. According to these studies, by 2035 the law will enable economy-wide emission reductions of between 43–48% compared to 2005, which is 6–11 percentage points lower than without the IRA.(Bistline, Blanford, et al., 2023; Larsen et al., 2022) The authors (2023) estimate that the drop in emissions that the IRA enables will increase over time, leading to a decrease of 43–48% by 2035.

In terms of the electricity sector, its share will be somewhere between 38–80% of emissions reductions in 2030 thanks to the IRA. According to the models, the law will lead to an increase in the use of wind and solar energy, with magnitudes varying substantially. In all the models, the growth rates between 2021 and 2035 oscillate between 10 GW/year and 99 GW/year for wind and solar energy with the IRA (58 GW/year, on average), which means more than double the average of 27 GW/year without the law and exceeds the record of 33 GW of installed capacity in 2021. Additionally, the law is expected to reduce transportation emissions, accelerating electrification. In all the models, electric vehicles will account for between 32–52% of new light-duty vehicles sold in 2030 under the IRA (41% average), compared with 22–43% (31% average) in the reference scenario (Bistline, Blanford, et al., 2023).

As additions and replacements of capacity occur, marginal costs of generation will decrease, making it difficult to obtain quasi-rents as a signal for new capacity entry (in decentralized systems) and rendering it necessary to consider alternative mechanisms.[18] Sometimes, capacity payment mechanisms are incorporated (like in Argentina, although subject to interventions), but they do not necessarily correct the problem (Newbery, 2016).

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[18] An energy market could function if prices reflected shortage conditions at all times. This tends not to happen, particularly when all capacity is being supplied, given that the cap regulators often put on the price is usually lower than the cost of meeting demand. Joskow (2006, 2008) has argued that this restriction generates a problem of lost money and discourages investments in capacity.

Supply auctions are the most widely used mechanism to promote the incorporation of NCRE sources in the region. Brazil, for example, has been holding auctions of this kind for all technologies since the start of the twenty-first century. The accumulated experience in these auctions suggests that these technologies can participate and enter competitively with others, without the need for complementary subsidies, even if they are justified by their positive externalities in terms of accelerating cost reduction due to scale and lower local pollution. In practice, subsidies and other policies to promote clean technologies are frequent (as illustrated by Box 4.2 on recent US industrial policy).

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An auctions is the most common way to promote the incorporation of NCREs in the region

At the global level, there is still no consensus on the best practices for electricity auctions. One unresolved issue is the exposure to price risk that projects could face because fixed-price contracts reduce the project's exposure to the spot market in relation to another model based on sales to that market (Fabra, 2021). In the region, the debate appears to have been settled as fixed-price contracts are largely the norm. In terms of contracts, however, it is not yet possible to identify a trend between energy contracts (in which the seller runs the risks of the energy generated), power or capacity contracts (also energy sales contracts, but the buyer runs the risk of the energy received), or procurement that is either technology-neutral or technology-specific (see Table 4.1).[19]

One more recent development (as seen in Chile) is flexible load time windows. There, due to the variability of solar power, auctions were arranged in time blocks. The same idea could be applied to seasonal auctions in the case of areas dependent on wind power with seasonal wind patterns. Finally, as the market share of renewable energy increases, auctions may need to incorporate plant capacity or energy, a backup source, and network requirements. Ultimately, the generator must meet demand with the various energy sources available while assessing different dimensions to determine whether there is a need for complementary tools to achieve that goal.

Structural changes to the sector and implications for tariffs

Based on the outlook for the electricity sector in terms of generation and infrastructure, the cost levels and structure of electric service provision are likely to change. In terms of generation, the most meaningful change is the reduction of the marginal cost, the result of the growing share renewables are expected to have in the years to come. However, the form of payment for NCRE (via contracts) means that the energy components and associated services are closer to the average NCRE generation cost than to the marginal cost (which can be scaled to the total cost of generation in countries that require contracts to cover all predicted demand).

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[19] In their discussion of the choice between technology-neutral and technology-specific auctions, Fabra and Montero (2023) discuss the trade-off between efficiency (minimum supply costs, innovation, supply security, etc.) and profit extraction (lower extraordinary profits for more efficient technology). This is a common topic in literature that discusses the use of incentives as part of market regulation (Laffont y Tirole, 1993).

Box 4.3
Good practices for electric tariffs and recent trends in LAC

The traditional framework for setting public utility rates is based on the idea that each country, depending on its context and needs, has different (albeit competing) goals. Navajas (2023) discusses these goals and the basic principles for structuring rates: 1) improving cost recovery (to reflect shortage conditions and environmental requirements); 2) moving from volume and rising block charges to schemes with more weight on fixed charges and capacity); 3) promoting micro-metering and offering a menu of options (between stable expenses and real-time prices) to the extent to which it is technologically feasible; 4) addressing affordability through tariff schemes and transfers, and moving toward a lump sum in reduced rate schemes for low-income households like the reform of fixed (differentiated) charges;[a] and 5) revise tax structures at the sector and government levels because they can be onerous, on occasion, and can serve to alleviate the financial burden on low and middle-income users.

Several studies have shown the schemes used in different countries and show the lack of consensus on the best tariff mechanisms to achieve the energy transition (ACER, 2021; Faruqui and Tang, 2021).

The different practices include the use of tariffs that do not incorporate hourly pricing, real-time metering,[b] or other pricing in the middle, like charges differentiated by the demand at a given time of day (also known as time-of-use or TOU). TOU pricing is one of the good practices cited by Faruqui and Tang (2021). Others include customer segmentation based on load capacity and time of use, and differential treatment for prosumers (see the following subsection).

This type of tariff scheme has begun to be used in the region with the increase in digital technology. In Paraguay and Peru, for example, smart meters have been installed that do readings automatically and remotely (ENEL, n.d.; La República, 2023). Other countries like Brazil, Costa Rica, and Uruguay have introduced programs based on TOU tariffs in the residential sector, giving households the option to choose between flat and TOU rates (Weiss et al., 2022).

[a] The IDEAL 2021 report analyzes this as part of the incorporation of digital technologies in the electricity sector (see Cont et al., 2021).

[b] Fabra et al. (2021) suggest that, as a complementary measure to real-time metering, consumers should be kept informed in order for them to react to changes in pricing.

On the other hand, in recent years, some of the processes on the production chain of electrical services at the level of end users have been decentralized through innovative generation and distributed storage. This has largely prevented cross-subsidization between users or different consumer segments (when these are not prohibited by law) and therefore has limited the recovery of the fixed costs of infrastructure (transmission and distribution) through variable energy charges.

As a result , a challenge for the region is how to compensate generators for infrastructure costs when fixed tariffs become the main component of system costs (infrastructure costs are currently included in the fixed and variable components of tariffs). Another challenge is how to migrate from volume-based rates to fixed-rate systems, with variable charges that increase by usage intervals—that can either be differentiated (the case of Argentina, Bolivia, El Salvador, Peru, and Uruguay) or not (Costa Rica, Mexico, and Paraguay)—or systems without any fixed charges (Colombia).[20] At the other extreme, tariff schemes based on uniform fixed charges (the case of Chile), there can be affordability issues, especially for low-income households. There has been no consensus at the regional or international level on how to address this challenge (see Box 4.3).

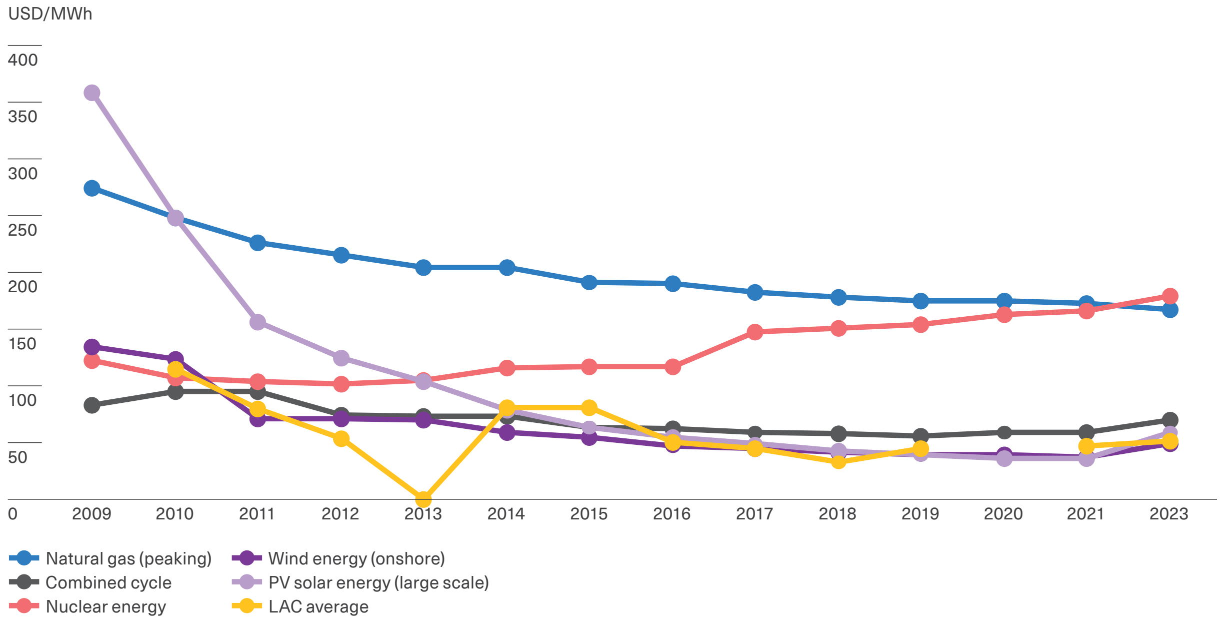
Tariffs must be designed to cover infrastructure costs

Incorporating renewable energy sources

Over the past 15 years , the levelized costs of renewable technologies (especially wind) have fallen, making them competitive with traditional energy sources, especially fossil fuels (Graph 4.5).

Graph 4.5

Levelized cost of electric energy by generation source and average auction price



Note: The graph shows the changes in levelized cost of electricity generation by source globally in USD/MWh for 2009–2023. The levelized cost is the average cost (including fixed and variable components) of generating a unit of electricity. The “natural gas (peaking)” category corresponds to natural gas generators that usually operate during periods of high demand (peak periods). The LAC average is the auction price and has been calculated using the country data presented in Table A.4.1 of the annex (available online).

Source: Author based on Lazard. (2023)

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20 See Navajas (2023).

Over the past 15 years, NCREs have become competitive with generation technologies based on fossil fuels

Non-conventional energy sources have entered the countries of Latin America and the Caribbean in different ways, but typically done through auctions accompanied by long-term contracts. More than a decade ago, when these technologies were not yet competitive (not to mention the need for transmission), these contracts guaranteed a higher price than the market price. The situation has changed as the (average) costs of NCREs have fallen in comparison to those of thermal generation for both peaking plants and combined-cycle plants (Graph 4.5).

However, the mechanisms used in each country vary (Table 4.1). One initial difference has to do with the auctioned product, which can be either power/capacity or the energy generated.[21] A second feature is that multiple technologies are included in the auctions: in Chile, Guatemala, and Mexico, in fact, all technologies compete at an equal level, regardless of whether they are renewable. In other cases, the auctions are technology-specific (Argentina, Brazil, Peru, and Uruguay). Finally, in the case of renewable auctions, some (Argentina and Brazil, for example) discriminate between wind, solar, biomass, etc., while others make no distinction (Colombia).

Table 4.1
Auction type by country

Country	**Product auctioned (a)**	**Technology (b)**	**Differentiated by renewable source (c)**
Argentina	Installed power	Renewable	Yes
Brazil	Installed power	Renewable	Yes
Chile	Energy	No restrictions	No
Colombia	Average annual energy	Renewable	No
Costa Rica	Energy	Renewable	Yes
El Salvador	Capacity	Renewable	Yes
Guatemala	Power	No restrictions	No
Jamaica	Energy	Renewable (that of 2024 will not have restrictions)	Yes
Mexico	Power, energy, and clean energy certified	Clean	No
Panama	Energy, power	Renewable and thermal	Yes
Peru	Energy	Renewable	Yes
Uruguay	Installed power	Renewable	Yes

Note: The table shows the characteristics of energy auctions in the countries of Latin America and the Caribbean based on available information. Column A shows the type of product auctioned (power, energy, or both). Column B details the type of technology to be auctioned, principally whether the country's auction process includes renewable energy sources and, at the same time, whether these are distinguished from other energy sources (Column C).

Source: Author based on Rodríguez Pardina et al. (2022) and sources cited in Table A.4.2 in the chapter annex available online.

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[21] In both cases, energy is delivered. When the auctioned product is power, all the energy that capacity generates is delivered; when it is energy, the generator must draw on other sources to deliver the agreed amount of energy if unable to do so with own capacity. The difference between the two lies in which party assumes the risk of variability in the delivered energy: the buyer (power auction) or the generator (energy auction). In the case of Mexico, clean generation certificates are granted to meet its carbon reduction pledges.

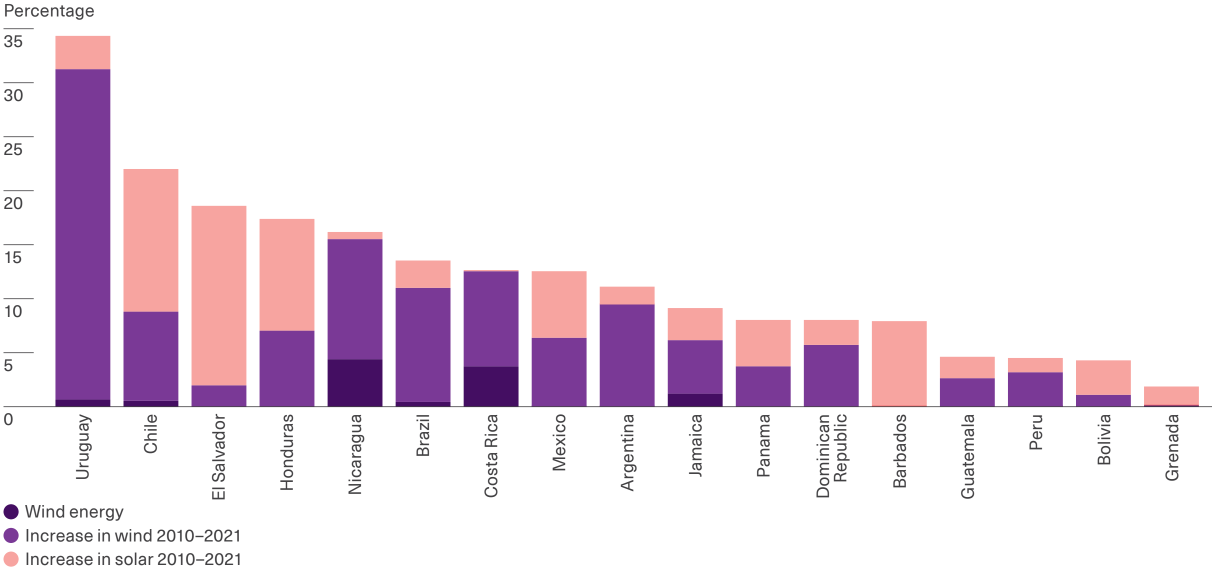
Graph 4.5 shows the changes in price over time for the incorporation of wind and sun sources in auctions between 2009 and 2023 (yellow line) in Latin America and the Caribbean,[22] which are similar to trends worldwide. Brazil has been the most consistent in terms of the auctions held, whereas Argentina, Colombia, and Mexico have made attempts but have not achieved long-term continuity. Uruguay held the majority of its auctions between 2010 and 2012 and these had a major impact on the system in the following years (see Table A.4.2 of the annex available online).

These experiences across the region yielded different shares of wind and solar energy from country to country (Graph 4.6). Uruguay stands out (34.3% in 2021), followed by Chile (22%), El Salvador (18.6%), Brazil (13.6%), and Argentina (11%). Coverage in Nicaragua and Costa Rica stood at around 4% in 2010. In several other countries, efforts have not started or are just beginning (Belize, Colombia, Ecuador, etc.). While Uruguay has concentrated its efforts on wind energy, Chile and El Salvador have focused on solar power. As discussed in the "Order of merit and duck curve" section, this structure has implications for the net demand curve (an unpredictable curve in the first case, duck curves in the others).

Though based on economic conditions, it would appear that the main renewables (wind and solar energy) could enter the electric systems at competitive levelized costs, Graph 5.6 reveals that the evidence has not been consistent and, except in a few cases, there is still a long way to go to meet the increased renewable targets. This applies not only to current demand but also to the demand forecast for 2050 and can be attributed, in part, to regulatory conditions and market design or the non-economic factors cited in previous sections.

Graph 4.6

Share of sun and wind energy in generation, 2010 and 2021



Note: The graph shows the share of wind and solar energy in total generation in two different years in the countries of LAC with available data. In 2010, solar energy did not reach significant magnitudes in the countries shown. Table A.4.1 of the annex available online shows the total values for those same years. The "Incorporation of renewable generation: Experiences of LAC countries" annex offers more details on each country. Countries with a share lower than 2% have been excluded (in descending order: Cuba, Guyana, Belize, Suriname, Haiti, Ecuador, Venezuela, Paraguay, and Trinidad and Tobago).

Source: Author based on data from the OLADE (2023a).

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[22] A breakdown by country can be found on Table A.4.2 in the chapter annex available online.

Distributed generation

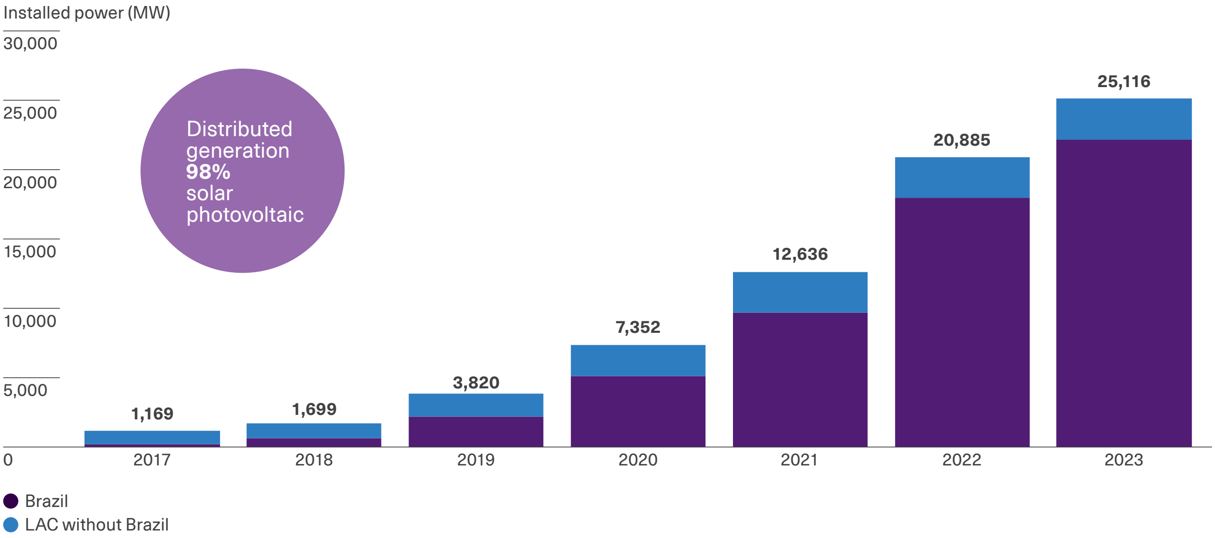
Within distribution systems, the weight of distributed generation—that is, low-scale generation that principally relies on renewables and is close to consumption points—has begun increasing. As part of the energy transition, this trend has been expanding internationally and, more recently, in Latin America and the Caribbean, where new regulatory frameworks and incentives have been introduced to enable these technologies to be integrated into distribution networks by the users.

Regulations related to the integration of distributed generation in electrical systems have to do with payment for the energy flows consumed and the buyback of those delivered to the system. On the one hand, net metering is more attractive for the consumer, since it applies the same price to the injection and consumption of electricity. On the other hand, net invoicing, though less appealing for consumers, gives better signals that this generation source has been introduced and is the suggested mechanism once more advanced stages of maturity are reached (MRC Consultants and PSR, forthcoming). Other challenges include accumulated energy credits and the type of restrictions that users and their technologies face (López Soto et al., 2019)[23].

Within distribution systems, distributed generation from renewable sources is gaining importance

Graph 4.7

Changes to distributed generation capacity in Latin America and the Caribbean over time



Note: The graph shows the values of installed capacity (in MW) of distributed generation in Brazil (up to June 2023, based on the most recent update from ANEEL, Brazil's electricity regulatory authority) and the aggregate value for the rest of LAC countries with available information (up to 2021, according to UNEP). Data from the region correspond to the latest official report from each of the markets included on the graph (Argentina, Brazil, Chile, Colombia, Costa Rica, Guatemala, Mexico, Panama, Puerto Rico, Dominican Republic, and Uruguay).

Source: Author, based on UNEP (2022a) and Perczyk and Rabinovich (2023).

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[23] The "Incorporation of renewable generation: Experiences of LAC countries" annex shows where the region stands with regard to these challenges.

Box 4.4
Distributed generation in Brazil

While in 2021, 71% of electric generation in Brazil came from hydroelectricity, solar energy has grown considerably in recent years through distributed generation, especially in the sphere of distribution for users or producers (residential and business). This rapid growth can be attributed to three main factors that have made these investments highly profitable. The first is the significant drop in the real price of photovoltaic generation systems in the last five years. The second is the significant rise in electricity tariffs. Lastly, the third is the implementation of an energy buyback system under Resolution 482/2012 by Brazil's electricity regulatory authority Agencia Nacional de Energía Eléctrica (ANEEL) (net metering). This resolution, subjected to later modifications, created a prosperous setting for investments in distributed generation (Perczyk and Rabinovich, 2023).

Under the energy buyback system, the producer or consumer returns excess electricity to the local distributor, reducing their net invoice by physically offsetting their own consumption. In addition to the network charges and taxes included on invoices, buyback plans are appealing profit-wise, as noted by Perczyk and Rabinovich (2023). These authors explain that government subsidies have fostered the development of this type of generation in Brazil. The states of Minas Gerais and São Paulo—both market leaders in Brazil—leveraged the exemption from the merchandise circulation and service tax for generated energy and the purchase of equipment needed for micro- and mini-generation (installed power lower than 75 kW and between 75 kW and 1 MW, respectively).

The annual growth of photovoltaic generation in Brazil was 205% for 2016–2020. The installed capacity of distributed generation facilities more than quadrupled between 2020 and mid-2023. It now accounts for 10% of the generation capacity, according to data from ANEEL.

Distributed generation accounts for 5.1% of the region's capacity, almost all of which is photovoltaic solar energy

Graph 4.7 shows how installed capacity in the region has changed over time and reveals the higher efficiency and cost reductions associated with this technology. In particular, it shows the exponential growth in regional capacity through 2021 (the last year in which systematic information for the region is available). This increase is largely explained by Brazil, which has significantly elevated the regional average.

The capacity of distributed generation accounts for 5.1% of the total generation capacity in 2021 (the last year in which systematic information is available for the region). Graph 4.7 also shows that photovoltaic solar energy represents practically 98% of the distributed generation facilities across the region.

Growth of the electricity sector in the energy matrix

All the most ambitious decarbonization plans, like that of the International Energy Agency's Net Zero Emissions by 2050 (NZE-2050) (2021f, 2023n), foresee a substantial increase in the electrification of consumption and renewable generation to meet that demand. They also forecast substantial extensions of electricity transmission and distribution infrastructure networks. Considering the sectorial composition of energy consumption in each country in Latin America and the Caribbean and assuming the same evolution of energy consumption growth and average sectorial electrification rate as the world in the NZE-2050 scenario, aggregate electricity consumption should increase 109% from 4.73 EJ in 2021 to 9.87 EJ in 2050. This reveals significant differences among countries, both regarding generation capacity and network infrastructure.

Green generation's power capacity

In terms of meeting the challenge of the energy transition , Latin America and the Caribbean can leverage its abundance of freshwater, solar, and wind resources, though the availability varies between and within countries.

The region has natural conditions that favor hydroelectric, solar, and wind generation

In the first place, the region has an enormous amount of freshwater resources per capita: with only 12% of the planet's land surface and 6% of the world population, Latin America and the Caribbean are home to one-third of global runoff water (Maldonado and Moreno-Sánchez, 2023).

Currently, the hydropower generation capacity of the region is high at 199.5 GW, which accounts for 41% of total capacity in 2021. After strong growth toward the end of the 1980s, hydropower has again been gathering momentum over the past decade (during this period, capacity increased by one-third). This growth is most evident in Brazil, which boasts 54% of regional capacity and accounts for 62% of the increase in installed capacity in the past decade.

However, the hydropower potential in Latin America and the Caribbean extends far beyond its current use. Based on the region's abundant freshwater resources, the Latin American energy organization OLADE has estimated hydropower capacity at 677 GW (2023d). In keeping with this estimate, the installed capacity in the region stands at 30% of this potential, though it varies greatly between countries: while Panama, Uruguay, and Paraguay make the most of their freshwater resources, other countries like Bolivia and Peru are scarcely using it (Graph 4.8). In fact, if freshwater resources were adequately leveraged, they could cover the generation needs in 17 of the 24 countries analyzed by OLADE (Alarcón, 2018).[24]

It is useful to note that hydroelectric generation emits greenhouse gases due to both the loss of carbon in flooded soil, the vegetation covering that soil, and the emission of methane in shallow waters and along shores.

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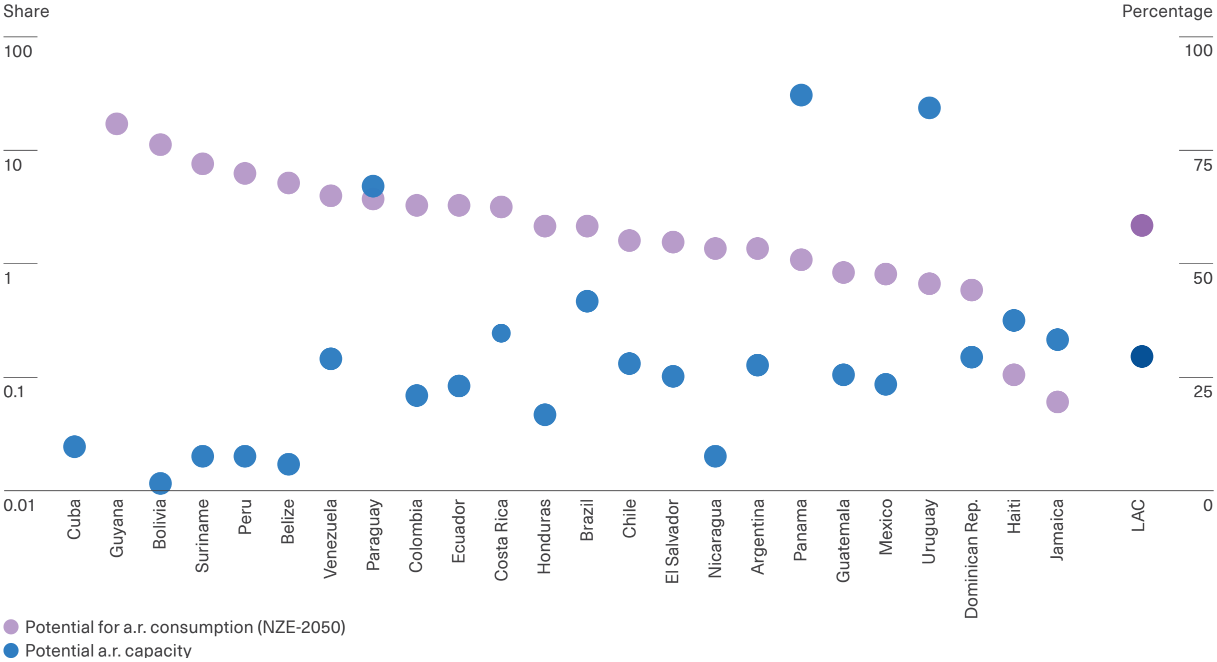
[24] Hydroelectric power capacity is defined as the sum of the installable power in freshwater basins plus the total installed power in existing hydroelectric plants. This power capacity value should be taken only as a reference, as the estimates for some countries may be more precise than others, depending on the type of study and methodology used for the freshwater inventory. On the other hand, the power capacity value does not reflect a viable use value, as it could be subject to technical, economic, environmental, and social restrictions, especially in complex ecosystems like the Amazon rainforest.

Graph 4.8

Hydroelectric power: installed capacity in 2021 and remaining potential by country



Note: The graph shows hydroelectric potential measured in MW for LAC countries with available information. It shows installed capacity in 2021 with respect to the consumption forecast for 2050 according to the Net Zero Emissions Scenario (NZE-2050) and the installed capacity in 2021 with respect to potential. A.r. stands for annual renewable.

Source: Author based on data from OLADE (2023d).

The region also has favorable conditions for solar and wind power. Graph 4.9 illustrates the theoretical potential of wind and solar energy for the countries of Latin America and the Caribbean compared to the rest of the world. In general, practically all the countries in the region have good solar potential (above the world average) while approximately one-third have good wind potential, especially Argentina, Chile, and Costa Rica.

Specifically, the greatest potential for solar energy is found in a vast area centered in the Atacama desert that includes northern Chile, southern Peru, southwest Bolivia, and northwest Argentina. There is also great potential for solar energy in regions within central Mexico and Baja California. On the other hand, parts of LAC boast high wind power density, like the south of Argentina and Chile, the highlands of the Andes up to Bolivia, and some other smaller areas in Costa Rica, Mexico, and Venezuela. In other places in the region, there is potential for offshore wind generation, like certain areas in Argentina, Chile, the Venezuelan and Colombian Caribbean, and, albeit to a lesser extent, in northeast Brazil and the eastern Caribbean.[25] However, the availability of transmission infrastructure (quantity and geographic location) can make it more difficult to leverage this potential.

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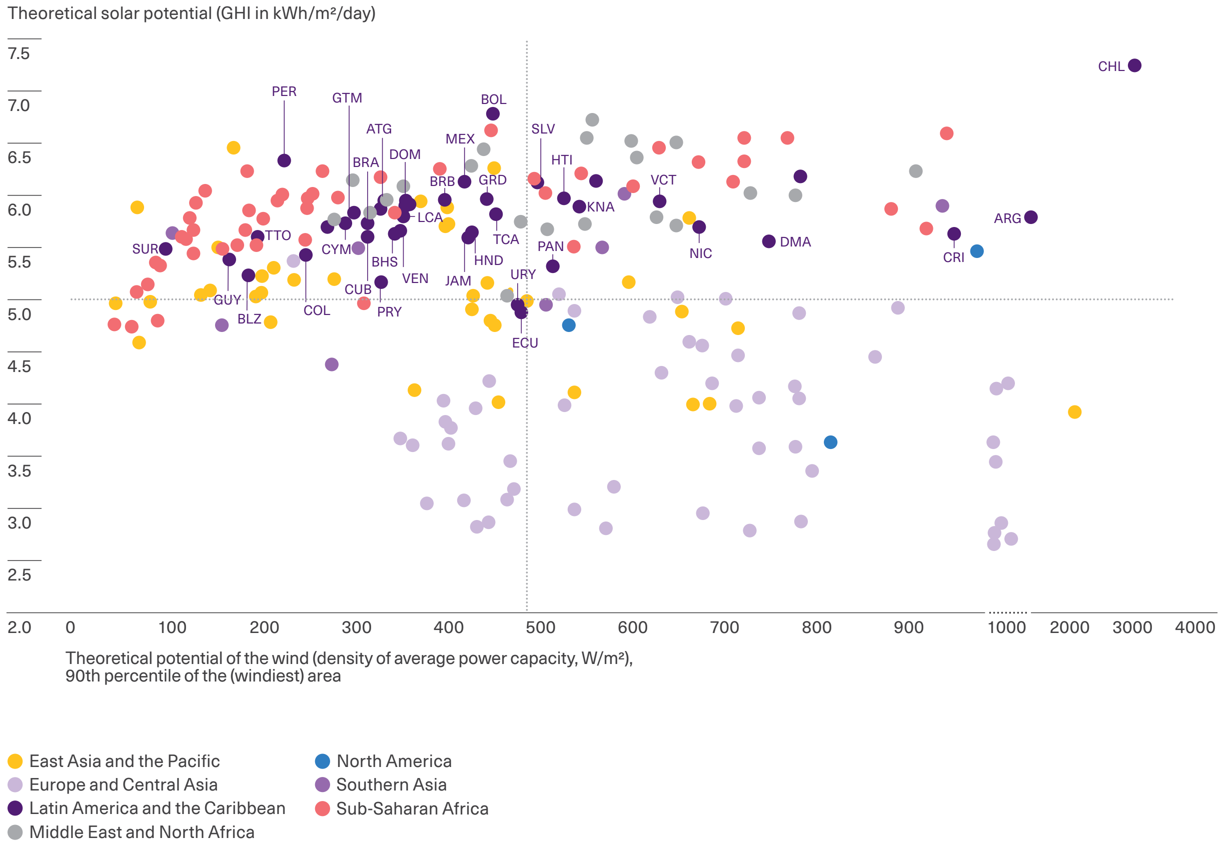
[25] Unlike solar energy, wind generation poses fewer incompatibilities in terms of land use, particularly with regard to farming, which can be done on windy land. The available (exclusive) surface to generate a unit of electricity is lower in the case of solar energy.

Graph 4.9

Theoretical potential of wind and solar energy



Note: The graph shows the theoretical potential of wind (measured in W/m2) for the 90th percentile of the windiest area and solar energy (measured by global horizontal irradiation [GHI] in kWh/m2/day) for the 90th percentile of the sunniest area. The list of LAC countries with the corresponding ISO code can be found in the annex available online.

Source: Brassiolo et al. (2023).

Efficient soil use, among other conditions, will ultimately determine the real generation capacity

Besides the technical potential, the real generation capacity will depend on conditions related to land use efficiency (Hernandez et al., 2014) and the proximity of feasible locations for large-scale solar generation parks to existing transmission networks (which can be improved with investments), among other factors. If it is used to cover the hikes in demand forecast in scenarios like NZE-2050, solar generation could increase land use needs by up to triple the surface currently covered by urban areas. The demand for greater surface area could be a source of conflict with other land uses, especially in countries like El Salvador, Guatemala, Jamaica, and the Dominican Republic (Cont and Juncosa, 2024). For example, a study conducted by MRC Consultants and PSR (forthcoming) on expanded installed capacity scenarios considers a combination of sources that includes offshore wind, which is usually more costly than inland sources in terms of effective generation capacity. In other words, the expansion of solar and wind energy will ultimately depend on the cost conditions and reliability of combined resources.

Transmission infrastructure

Necessary electricity infrastructure for the energy transition

The rise in electricity consumption that is predicted as part of the energy transition has a parallel in the needs associated with transportation and distribution infrastructure. This infrastructure must address the changes expected both quantitatively (the required increase in capacity) and qualitatively as a result of modifications in the electric system (for example, the distribution of energy generated and consumed across time and space).

Transmission networks in the region cover approximately 1.24 million kilometers (km). More than 40% of these power lines are in Brazil and nearly 19% in Mexico. At the same time, when applied proportionally to the infrastructure networks, the 109% rise in electricity consumption under the NZE-2050 scenario described at the beginning of this section translates into approximately 1.34 million km. of new power lines. Upkeep and the need to replace some existing power lines as they reach the end of their useful life before 2050 are additional needs. The IEA estimated that approximately half of the current power lines in the region will have to be replaced by that year.[26]

Graph 4.10 shows the current extension of transmission networks in relation to the population (km/10,000 inhabitants) and what will be needed in 2050 by country. Overall, the region has approximately 20 km/10,000 inhabitants and it will need to double the length of transmission networks by 2050. Of the 25 countries shown on the graph, 13 need to add even more kilometers per capita than the regional average to their transmission network. Bolivia, Haiti, Belize, Guyana, Paraguay, and Guatemala, for example, will all need to add more than 40 km/10,000 inhabitants. This poses significant challenges, including financing, planning, and possible conflicts in the management of land use permits and concessions.

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The increase in estimated electricity consumption during the energy transition correlates with the needs for transportation and distribution infrastructure

The increase in the capacity and transmission lines of the grid must be accompanied by an increase in distribution network capacity. The IEA estimates that developing economies should invest more than USD 10.4 trillion in expanding or repairing electric networks by 2050, including a little under USD 4 trillion in transmission and more than USD 6.4 trillion in distribution. In Latin America and the Caribbean, the additional network needed by 2050 will reach over USD 750 billion in transmission costs (corresponding to the 21 km./10,000 inhabitants required, as shown on the last bar of Graph 4.10) and USD 1.2 trillion in distribution costs, distributed over three decades, equivalent to 1% of the regional GDP.

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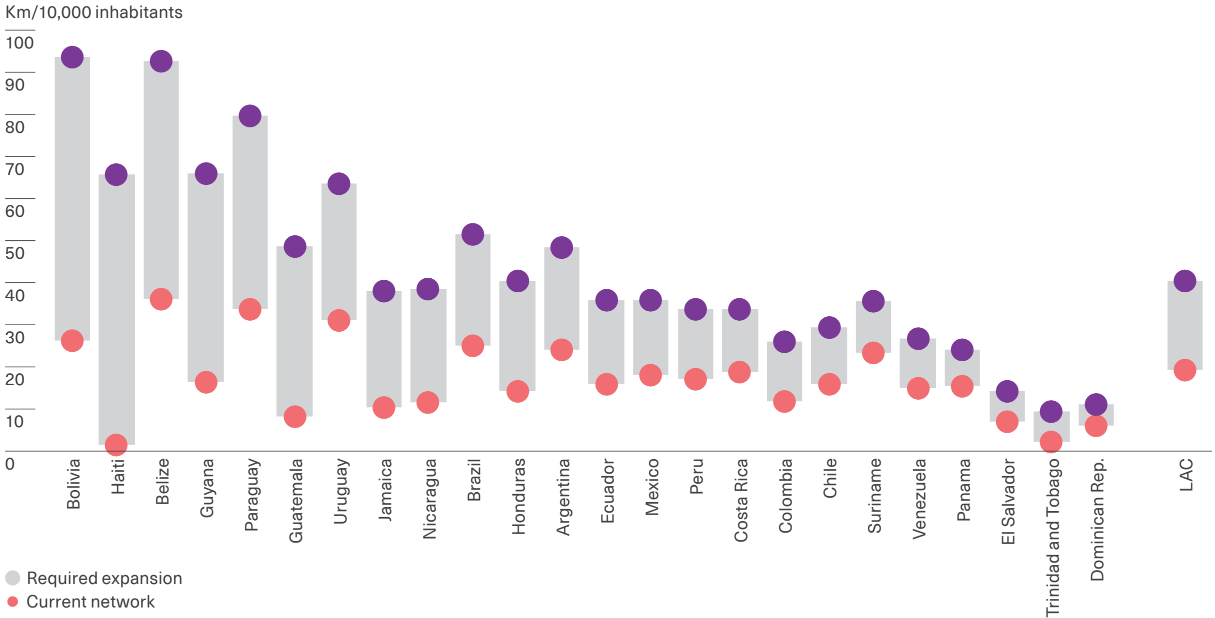
[26] See IEA (2022e, p. 313) for more information about LAC. The group "other emerging markets and developing economies" is comprised almost entirely of countries from the region.

Graph 4.10

Extension of the transmission network and expansion required under the NZE-2050 scenario



Note: The graph presents the current number of kilometers of electric energy transmission lines in relation to population (in kilometers per 10,000 inhabitants). The pink dots represent the current power lines (in kilometers) and the purple dots represent the additional kilometers that will be required under the NZE-2050 scenario. The grey bar shows the number of additional kilometers required to meet the low consumption requirements in this scenario.

Source: Author based on data from the IEA (2021f) and Ardene et al. (2020).

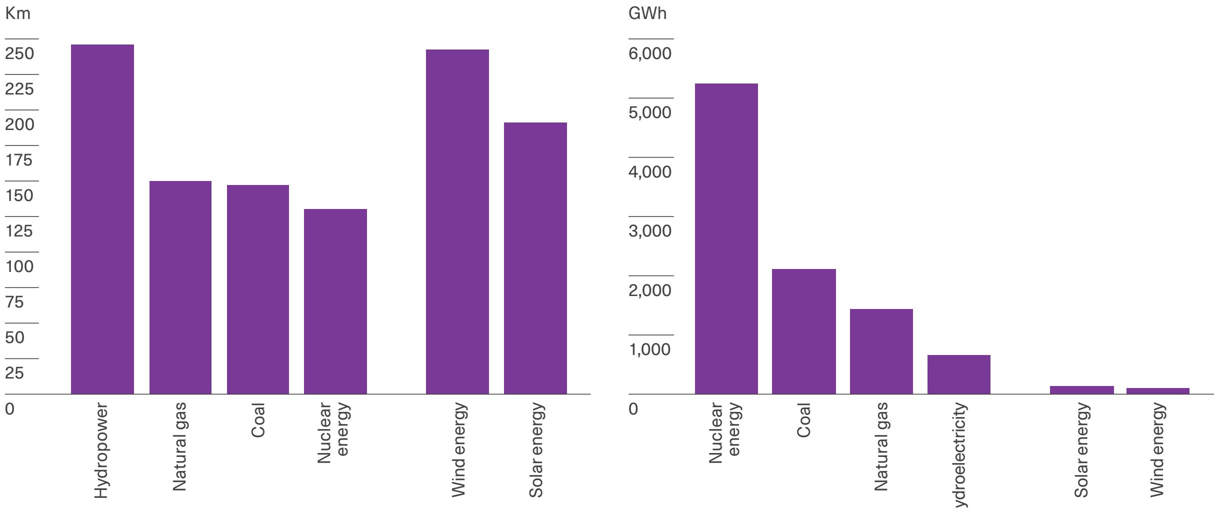
Qualitative changes in electric systems are expected to be part of the energy transition and this could impact infrastructure requirements in unforeseen ways. These changes include greater variations in intra-day and seasonal supply, fragmentation of electricity injection points, an increase in the average distance from the generating site to consumption points, and a reduction of transmission requirements as a result of distributed generation.

Graph 4.11 presents current evidence of two differences between renewable generation and conventional technologies that will affect the structure and necessary transmission infrastructure level. Panel A shows that the solar capacity currently in operation is 30% farther from consumption points on average than natural gas plants and wind capacity, 60% farther. The distance is similar only in the case of hydropower generation (that is, considering the average distance of the MW of installed power capacity by source). On the other hand, Panel B shows the average annual generation obtained for each technology in power plants, showing that the numbers for solar and wind energy are much lower than for the other sources.

This trend of plants located farther from points of consumption and the fragmentation of electricity generation is expected to continue over time. However, as combined generation shifts toward renewable resources, this could bring changes to transmission networks in terms of length, spatial distribution, flexibility for bi-directional operations, and the need for many more injection points.

Graph 4.11

Accumulated distribution of the distance from generating units to closest cities and annual generation by source



Panel A.
Distance to nearest city

Panel B.
Average generation by source

Note: The graph shows the distance from the generating units to the nearest cities. Panel A shows the distance in km according to energy source while Panel B shows the average generation in GWh by source.

Source: Author, based on CAF (2019) and the Global Energy Observatory (2021).

Regulatory aspects of transmission

The relationship between the generators operating on the market, the distributors, and major users depends on the transmission network to supply end users either directly or indirectly through distributors. In general, an independent organization with no ties to any of the market players is entrusted with overseeing these networks in the electric systems of the region (thus avoiding vertical integration). This provides all parties with the same open access and ensures a tariff that reflects the network costs, with fixed components related to the connections and transportation capacity, and a variable component related to the network losses. In cases of dedicated networks, the beneficiaries (major users) are the ones who pay; this is known as dedicated expansion or extension. This has been the case of Chile since 2004 (Serra, 2022).

In any electric system, the expansion of the network yields big benefits, especially when it allows or improves the interconnection between subsystems that are restricted a great part of the time (the case of Argentina in 2006 or Chile in 2017) or when they allow generation resources from different geographical areas or be integrated. The incorporation of new users to the system is one benefit, along with the adaptation of subsystems to an integrated system with a more diverse offer and reduced risk of a cornered market (see Mercadal, 2023).

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The expansion of the transmission network yields significant benefits by enabling the integration of geographically dispersed resources

Historically, the predominant model for expanding networks was centralized planning and decentralized implementation (through calls for tenders), though in some cases, the private sector was involved in both stages, as occurred in Brazil, Chile, Colombia, and Peru.[27] In this context, the countries faced an array of challenges that should be considered in the face of the electricity sector's expected growth. The most common problems have been obtaining rights of way, environmental restrictions in the ecosystems and communities near power lines, and other issues related to easement due to the resistance of local residents to the facilities (the so-called "Backyard Effect"). One interesting case outside LAC is that of the United States, which has multiple regional systems and is facing the same problems mentioned for the countries of Latin America and the Caribbean, In addition to the challenge of coordinating federal, state, and local actors when connecting regional networks,[28] there are concerns associated with the operation of federal systems in the region.

The role of intra-regional integration in the energy transition

The 2021 Report on Economic Development (Sanguinetti et al., 2021) lays out four reasons for the intra-regional integration of electric systems. These are related to the market's scale advantages, the reliability and lower price volatility of a system that combines various generation sources (with different levels of intermittency between countries), and the increase in environmental sustainability that comes with the use of renewable resources at the regional level. The countries of Latin America and the Caribbean have taken advantage of these benefits to different degrees.

Central America has been most successful—particularly Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama—all of which have been part of the Central American Electrical Interconnection System (SIEPAC) since 2014. These six countries are members of the Central American Regional Electric Market, which operates as a seventh market in parallel to the six national systems. The national systems range from vertically integrated monopolies (Costa Rica and Honduras)—with limited entry for private companies—and market systems (El Salvador, Guatemala, Nicaragua, and Panama). However, regional energy transactions in the Central American Regional Electric Market are governed by the operating roles of the system.

●●

Factors like market scale advantages and enhanced environmental sustainability foster the intra-regional integration of electric systems

The electric systems of South America are not physically connected to those of Central America, though there have been projects for interconnection between Panama and Colombia. Geographically, South America could be divided into the Andean subregion and the Southern Cone, yet neither has leveraged the potential for interconnection.

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[27] Argentina is an interesting case that reveals the problems associated with delegating the expansion of network capacity to the private sector. From 1992–2001, a public tender was held to avoid the type of excess (in size and costs) the country had seen in the past when the private sector had been entrusted with expansions. When delays ensued, the government was criticized with leaving this task to the private sector. These delays were attributed to companies leveraging the network without making investments (i.e., free-riding), external issues, the decisions on participants with voting rights, and the transaction costs. Some, however, supported the system, arguing that there was no social justification for the projects that had been delayed. Starting in 2002, the government made the expansion of transmission part of its national plan (see the discussion in Littlechild and Skerk, 2008a, 2008b, 2008c).

[28] See Davis et al. (2023) for a recent discussion of the topic.

In the Andean subregion, counties are interconnected, with interchanges dating back two decades that led to the implementation of the Short-Term Andean Regional Electricity Market. The purpose of the market is to coordinate electricity transactions between Colombia, Ecuador, and Peru, which could be extended in the future to Bolivia and Chile as part of the Andean Electrical Interconnection System (SINEA)(CREG, 2023). In the Southern Cone, most integration experiences have been based on two types of models. The first are binational dams: Itaipú (Brazil and Paraguay), Yacyretá (Argentina and Paraguay), and Salto Grande (Argentina and Uruguay), which have their own rules for the assignment of electrical energy generation. Other interconnections supported by contract schemes involving private actors (Argentina-Chile, Argentina-Brazil, and Argentina-Uruguay) have not proved successful due to a combination of sector-related contingencies, regional macroeconomic problems, and regulations too weak to guarantee a resilient framework. Recently, steps have been taken to create the Southern Energy Integration System between Argentina, Brazil, Chile, and Uruguay.

Despite the steps toward energy integration in Latin America, the region faces multiple barriers to full development. First, the security of supply and self-supply are priorities for the countries in the region, given that dependence on others involves strategic risks, especially given the institutional weakness that characterizes many of these countries. Second, technical challenges must be overcome to achieve interconnections, like the difference in frequency between countries (for example, Brazil and its neighbors). Disparities between countries, combined with a lack of regulatory certainty, also play a crucial role, since the technical demands of coordinating bodies and the harmonization of energy policies between nations with different regulatory frameworks add another layer of complexity. These are indicative of the diverse challenges that must be addressed to advance toward a more efficient, sustainable energy integration in Latin America and the Caribbean.

Space for policies

There is a set of public policies that can help the electricity sector incorporate clean energy and move toward net-zero emissions. As explained in this chapter, challenges include increasing generation capacity with renewable sources to address the growing demand for electricity, replacing fossil fuels, expanding transport and distribution networks in a way that ensures a reliable supply of electricity at competitive prices, and securing the investments that the two previous needs require. The policies, aspects of which have been addressed in this chapter, are summarized below.

In terms of regulations and incentives, it would be important to set minimum NCRE source quotas for distributors and major users that procure co-generation. In order to foster the incorporation of renewable sources, this alternative is currently more common than subsidies. The adoption of quotas has helped drive adoption, promoting the experience and cost reduction that come with economies of scale without any need for tax incentives. Quotas have also forced distributors to do market consultations for the incorporation of renewables by establishing medium and long-term supply contracts.

Centralized auctions are one way of attracting investments and new participants to NCREs. In a centralized auction, a public announcement is made on the total capacity required of multiple load-serving entities on the wholesale market. This promotes the entry of new actors and fosters competition, enabling closing prices that trend downward in each new auction. As in any auction, a succinct definition of the product is key and, for the renewables, there are several alternatives available to adequately segment times and places with shortages and surplus. Auctions can thus be technology-specific (for example, separate auctions for solar energy, wind, etc.) or technology-neutral, i.e., auctions that establish the characteristics of the generation required (for example, hourly blocks).

Adapting this formula correctly must account for both scarcity and abundance conditions, regardless of the form they take. This will be crucial to create the economic incentives for integrating the necessary technologies, especially once NCRE sources dominate the generation matrix and substantial periods of generation surplus occur. At this juncture, the incorporation of storage technologies—like batteries, hydro pumping, and electrolysis capacity for electricity-H2-electricity cycles—will become imperative. Designing technology-neutral auctions, with detailed specifications regarding the sought-after product attributes, can serve as a powerful tool to drive their widespread adoption.

●●

Public policies should focus on increasing renewable generation capacity, expanding transportation networks, and providing necessary investments

The change in the composition of the electric matrix may require pricing changes to cover the costs of incorporating capacity and, at the same time, provide signals of shortage and surplus to households and users in general. In the past, rate charts have usually relied on a small fixed charge component and a larger pricing component based on rising block tariffs. Now, with the incorporation of distributed generation and generation technologies with variable costs near zero, it is necessary to adapt rate charts. As part of this adaptation, the fixed charge component should be larger. It can then be supplemented with dynamic or hourly rates aligned with the system's cost structure; these rates are higher at times when less wind or sun is available. At the same time, higher fixed costs should be supplemented by targeted subsidy schemes to mitigate regressive distributional impacts

Lengthier, denser transmission networks enable change in the electric matrix. Making networks denser will help mitigate the intermittency that characterizes individual generators running on NCRE sources by relying on the combined safety net of diverse technologies located in different regions. In general, government decisions on infrastructure needs are centralized, though the private sector can participate through PPAs and open, transparent calls for tenders. Energy planning is central to this process to anticipate qualitative changes and the shifting supply and demand associated with NCRE sources.

Finally, for many countries in the region—particularly small ones without an array of natural resources to choose from—energy integration is the most effective way to mutually ensure continual electric supply in the face of renewable intermittency. Integration also brings profits associated with the greater scale of the resulting market and increased environmental sustainability to enable the diversification of generation resources. Building stable frameworks for interchange between countries will be fundamental to leverage existing interconnections and promote new projects to connect the electric systems of the different countries.

Promotion of clean fuels

- Why fossil fuels occupy a central place in energy consumption
- Organic fuels and hydrogen and their role in decarbonization
- Emission reductions in the fossil sector

5

Key messages

1

Nearly half of the energy consumption in the region and the world will have to be met by fuels. Therefore, alternatives for producing fuels with low GHG emissions are central to the energy transition.

2

Fuels are likely to maintain a central role in three energy uses: 1) production of very high temperatures in industrial processes; 2) mobile energy uses, especially freight and air transportation; 3) power generation in remote sites lacking alternative resources and as backup in critical situations.

3

The alternatives for producing low-emission fuels come from two groups: hydrogen and its derivatives, and fuels of organic origin. For these alternatives to be carbon neutral, sustainable management of supply chains is required.

4

The reduction of emissions associated with the fossil fuel industry is an area of central importance for the energy transition. This includes the reduction or elimination of fugitive emissions in the production, transportation and transformation of fuels, the substitution of other fossil fuels with natural gas, and the electrification of production processes to reduce the use of fossil fuels at all stages of the value chain.

5

Fuels from organic sources can be allies of decarbonization to the extent that their land use demand is limited and efforts are concentrated on serving uses with few alternatives, such as air and maritime transportation. Diversifying the type of inputs used is critical, for example, by increasing the use of cellulose.

6

Hydrogen can be obtained from fossil inputs, organic inputs and water. Hydrogen produced from fossil or organic inputs can be considered low-emission when it incorporates carbon capture and sequestration and the inputs are obtained in a sustainable manner: no fugitive emissions, in the case of fossil inputs, and no induced deforestation, in the case of organic inputs. Water-based power is low in emissions when the electricity used comes from non-fuel sources.

7

Hydrogen can play an important role in providing flexibility to the energy sector in the face of the high share of intermittent electricity generation sources, such as solar and wind. Surplus energy generated by these renewable sources can be harnessed for hydrogen production and used at the times, places and in the applications that require it most.

8

The production, transportation and transformations that fossil fuels undergo release greenhouse gases due to the energy use required by these processes and the prevalence of fugitive methane emissions. Electrification of processes and elimination of fugitive emissions would significantly reduce the global warming impact associated with the use of fossil fuels.

9

The availability of natural gas resources in Latin America and the Caribbean represents an opportunity to help reduce regional and global emissions by substituting oil and coal derivatives. Key to this is the development of infrastructure for liquefied gas trade and the reduction of fugitive emissions associated with its production and transportation. The strategy for the use of natural gas as a transition fuel in the region must be compatible with the desired emissions trajectories within the framework of the energy transition.

Promotion of clean fuels[1]

Introduction

Given the technologies currently known and their expected evolution, certain energy uses will continue to depend on the use of fuels, even in the most aggressive decarbonization scenarios. The fuels used today are mostly of fossil origin and are associated with high greenhouse gas (GHG) emissions, among other environmental impacts. This chapter discusses the alternatives available for the production of low-emission fuels with the necessary properties to meet these uses.

The most auspicious energy transition scenarios for Latin America and the Caribbean (LAC) estimate a target electrification rate of around 50% by 2050, as shown in Chapter 4. This is equivalent to an annual energy consumption in the region of 12 exajoules (EJ). To eliminate energy-related emissions, almost all of this remainder will have to be met by clean fuels, which can be supplemented, in a small proportion, by heat-bearing energy products (e.g., steam for heating and hot water in remote residential districts).

There are three types of uses in which fuels are likely to maintain a central role in a new balance of zero-emission energy systems.[2] The first is the use of energy to generate heat or meet "thermal demand" in industrial processes because it is very difficult to reach the high temperatures required by some of these processes with electricity. The second is the mobile uses of energy, especially in freight and air transport, since they require an input with a high energy density that existing electrical solutions cannot provide. Energy density here refers to the energy content per unit volume and weight, considering the energy product itself (e.g., gasoline or electricity) and the equipment required for its storage and use (e.g., the fuel tank or battery). The third type is the use of fuels for electricity generation to meet consumption

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[1] This chapter was written by Walter Cont and Federico Juncosa with research assistance from Lautaro Carrizo and Agustín Staudt.

[2] See Chapters 4, 6, and 8 for more details.

in remote locations, devoid of other resources, and to ensure electricity supply in the event of intermittency of non-conventional renewable generation, until competitive alternatives for electricity storage on a sufficient scale become available.

This chapter addresses two groups of alternatives for obtaining clean fuels to replace fossil fuels: the first group consists of hydrogen and its derivatives, and the second group consists of fuels of animal and vegetable origin. In addition, on the road to decarbonization, there are high-impact actions to reduce emissions associated with fossil fuels. These can be classified into two types: 1) actions that improve the efficiency of energy systems, i.e., that reduce the energy inputs needed to produce end-use fuels, in the stages of oil and gas production, transportation and distribution, and oil refining; and 2) actions that reduce the emissions intensity of fuels that are used directly, without changes in efficiency. Policies to upgrade fossil-fuel generation technologies are an example of the former, since they reduce emissions per unit of electricity generated by improving energy efficiency. An example of the latter is the replacement of coal by natural gas, which can reduce emissions without necessarily improving the energy efficiency of the systems. This chapter describes some of the factors that determine dependence on fossil resources, including their high availability, and the technologies that can contribute to the decarbonization of non-electric end uses, their degree of development, and the barriers identified for their expansion. In addition, the role of industry and fossil resources in the energy transition is described.

The current dominance of fossil fuels

Fossil fuels are the source of most of the energy supply in the region and the world, both as inputs in electricity generation and for final uses (IEA, 2023x). In Latin America, fuels of this type represent 14.8 EJ, almost two-thirds of final energy consumption. They are also the source of 19% of the region's electricity generation. Together, final fuel consumption and electricity generation require 23.4 EJ of fossil inputs. In the case of the Caribbean, 72% of final energy consumption and 46% of generation are based on fossil fuels, requiring 1.52 EJ of fossil fuel inputs.[3] This centrality of fossil fuels in current energy systems responds to a set of outstanding attributes of coal, oil and its derivatives, and natural gas.

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Fossil fuels account for almost two-thirds of final energy consumption in the region

The energy density per mass and volume of fossil fuels is high, which facilitates efficient storage and transportation. Products such as gasoline, diesel, and jet fuel, among others, are in liquid form for the temperature and pressure ranges that almost completely cover the atmospheric climatic conditions where the population lives. Coal, on the other hand, can be transported by all modes without requiring insulation and without risk of leakage. Moreover, unlike liquid fuels derived from petroleum, it can be stored indefinitely and exposed to any environmental conditions. The ease of storage and transportation of these fuels, in solid, liquid, or gaseous forms, has been fundamental to their dominance in the energy

[3] Values corresponding to the average from 2017 to 2021, taken from OLADE (2023b).

chain. In addition, the energy delivery capacity of liquid and gaseous fuels (energy delivery rate) is high, allowing their use in a wide range of applications that require it.

Among fossil fuels, natural gas is the one that, at the moment of combustion, generates the least emissions per unit of energy delivered. However, its energy density per unit volume is almost a thousand times lower than that of liquid petroleum derivatives, which makes it a more expensive fuel to transport. The high costs and infrastructure needs required for such transportation have historically meant that natural gas has been consumed close to the point of production. However, interregional trade has been increasing since the 1960s thanks to the development of technologies to transport and store methane gas in liquid form (LNG) and the expansion of the pipeline network. In the latter case, the cost of transportation can reach more than 50% of the total cost along the value chain.

Beyond these positive attributes of fossil fuels, their value chain is of considerable technical and financial complexity.[4] First, there are large upfront costs for oil production, oil and gas transportation, gas distribution, and crude oil refining. Second, a significant part of investors' decisions to incur these costs occur in contexts of very high uncertainty, particularly in the exploration phase for fossil resources. Third, the planning horizons behind these decisions are long: the average payback period for investments in oil production and refining, for example, is around 30 years. Taken as a whole, the total life-cycle costs of the end products in the form of liquid fuels consumed today are far from low.

Behind the current balance of energy systems with high dependence on fossil resources are not only the attributes and cost advantages of these resources; there is also a long experience and decisions of the States to create a fossil industry to meet their energy needs and enhance their development. This experience accumulated at present implies a great strength of coordination of production and consumption, which makes the current balance economically viable, for example, due to the long useful life of the described set of facilities for transportation, storage, and refining already in activity and the establishment of associated productive processes, such as the petrochemical industry.

The combination of these factors (investments already made in operations, infrastructure and equipment, and the current economic viability of the system) has resulted in what is known as the *lock-in* effect, which makes it difficult to abandon these products. The lock-in effect is an incentive for companies to maximize the rate of use of capital goods already installed and in a position to continue operating. At the same time, it represents a challenge for the transition to cleaner energy sources, as it makes decommissioning or retrofitting these facilities economically challenging. Overcoming the inertia of these systems and devaluing existing investments requires careful coordination and planning, with policies and mechanisms that facilitate an orderly transition to a new economic and environmentally sustainable balance. This points to the fact that the transition to a more sustainable energy matrix is not only a matter of financial investment, but also a problem of coordination and long-term planning.

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[4] For more details, see the annex to this chapter available online.

Availability of fossil resources

Latin America and the Caribbean has large quantities of oil and gas resources onshore and on its continental shelf of both conventional and unconventional types. Conventional resources refer to concentrated deposits of oil and natural gas occurring in natural geological traps. Within these, proven reserves in conventional oil or natural gas reservoirs are those estimated in reservoirs whose exploitation is profitable with the current technology and infrastructure available in the country at the time of the evaluation.[5] Unconventional resources, on the other hand, are characterized by being more dispersed, typically mixed in sands or in low permeability soils, which requires the use of more active reservoir stimulation processes for the extraction and separation of impurities for production. Determining the technical and economic feasibility of their exploitation is more complex due to uncertainty about the actual conditions of dispersed reservoirs.

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The region has large quantities of oil and gas resources both onshore and on its continental shelf, including conventional and unconventional sources

Table 5.1 shows oil and natural gas resources in the countries of the region in 2021. It shows a large availability of resources, but unevenly distributed among countries. Of the 27 countries that make up the region, 16 report zero resources. Venezuela alone has almost 90% of proven conventional oil reserves. However, it is facing a steady decline in production, which currently represents a quarter of what it obtained at the beginning of the century. Brazil, Guyana, and Mexico account for 80% of proven conventional oil reserves in Latin America and the Caribbean, excluding Venezuela. The reserves of Argentina, Colombia, and Ecuador together account for 17%.

In terms of technically recoverable unconventional oil resources, Argentina stands out for having approximately 165 EJ, while Bolivia, Brazil, Colombia, and Chile together have resources close to 92 EJ. Technically recoverable unconventional oil reserves in Latin America and the Caribbean, excluding Venezuela, exceed total conventional resources. The total proven and recoverable resources (excluding Venezuela as well) are equivalent to more than 40 years of consumption at the current rate.

In the case of proven natural gas reserves, Venezuela accounts for 68% of the region, while the next seven countries account for 28%, with quite similar shares, ranging from 15 EJ (Argentina) to 9 EJ (Bolivia). Technically recoverable unconventional natural gas resources are almost five times more than conventional resources and are heavily concentrated in Argentina, with 59% of the total, and Venezuela and Brazil, which together account for 30%. Together, the region's proven conventional reserves and technically recoverable unconventional resources represent more than 160 years of consumption at current levels.

The high availability of natural gas resources in the region may represent an opportunity to contribute to the reduction of domestic and global emissions in the short term through the temporary substitution of other more polluting sources on the road to decarbonization. The last section of this chapter discusses the possible risks presented by this use when the incentives to maintain its use in the long term increase.

However, these resources can also represent a significant barrier to reducing emissions associated with energy consumption. This situation particularly affects proven reserves, where exploration costs have generally already been covered and, in many

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[5] Probable reserves are the volumes that could be recovered with a high probability from deposits already discovered when there is a greater development of exploitation technology. There are no exploratory studies for their measurement, but they are estimated based on available information from nearby and similar deposits. Finally, possible reserves are the estimated volumes that could be extracted from reservoirs identified by known formations, with a low level of probability, and which do not yet have exploratory studies.

cases, infrastructure has been built for their exploitation, which has entailed considerable investments. More generally, oil projects in production today have different levels of variable extraction costs. Those with lower costs will be more reluctant to stop production in the face of emission abatement policies, such as carbon pricing and demand reduction. Ultimately, the rate at which fossil exploitation declines will depend to a large extent on the evolution of energy prices and the costs of these projects.

Table 5.1
Oil reserves in 2021 by country

Country	**Oil**				**Natural gas**			
	Conventional reservoirs, proven reserves		**Unconventional reservoirs, recoverable resources**		**Conventional reservoirs, proven reserves**		**Unconventional reservoirs, recoverable resources**	
	EJ	**Years of consumption**	**EJ**	**Years of consumption**	**EJ**	**Years of consumption**	**EJ**	**Years of consumption**
Venezuela	1,857	3,157	82.0	48	207	197	170	179
Brazil	81.6	19	32.4	138	14	10	250	368
Guyana	55.1	1,594			14	341,664		
Mexico	37.4	12			11	3		
Argentina	17.3	18	165	155	15	8	817	1,619
Colombia	11.1	14	41.6	33	3	7	56	26
Ecuador	8.2	16			0	6		
Peru	1.5	3			10	31		
Trinidad and Tobago	1.3	219			11	17		
Bolivia	1.2	8	3.7	1	9	56	37	6
Cuba	0.8	2			3	79		
Suriname	0.5	20						
Guatemala	0.5	3			7	718,663		
Chile	0.1	0	14.1	10	0	1	49	11
Belize	0.0	5						
Barbados	0.0	1			0	5		
TOTAL	2,074	158	365	29	304	31	1,457	133
TOTAL without VEN	217	18.4	283	22	97	9	1,287	123

Note: The table presents proven, probable and possible reserves, expressed in exajoules (EJ), for LAC countries with information available in 2021. Data for unconventional reservoirs correspond to technically recoverable resources. In the case of proven reserves from conventional reservoirs, "years of consumption" represents the availability, measured in years, that such reserves can cover according to the current domestic consumption rate. Does not include unconventional resources not accounted for as reserves. Countries not shown report zero reserves of the resource.

Source: Authors with data from OLADE (2023c) and EIA (2013) for unconventional resources.

The high availability of natural gas resources in the region can contribute to the reduction of domestic and global emissions in the short term

Finally, technological changes may have uncertain effects on the evolution of production, since they can both improve the competitiveness of alternative energies and reduce the production costs of fossil fuels. Thus, in the absence of a boom in low-emission technologies and a global carbon pricing policy, substitution by renewable sources will require decisive policy measures, in the form of environmental regulations, changes in incentives to the private sector through taxes and subsidies, or direct public investment (Borenstein and Kellogg, 2021).

Fuels derived from agricultural, forestry, and waste sources

Fuels derived from animal and vegetable sources are among the oldest energy resources available to humanity. With them, pre-modern societies satisfied their energy needs, for example, for lighting, heating, and food preparation. These fuels include, of course, wood, but also wastes, such as dried dung, and animal by-products, such as whale oil. Today, these traditional uses of animal and plant fuels continue to exist (as documented in Chapter 7), although new high-tech products have been incorporated.

Technological advancements have facilitated the development of high-quality fuels through processes that transform inputs from animal and plant sources. These are widely used today as substitutes, typically blended with equivalent fossil fuels. Two prominent examples are biodiesel (blended with fossil diesel) and ethanol (commonly mixed with gasoline, although in specific countries like Brazil, it is used in its pure form).

Collectively, these products are conventionally referred to as biomass, which includes animal and plant waste and manure. Within biomass, the term traditional biomass is often used to describe raw materials used as fuels without undergoing significant industrial transformation processes (for example, firewood), while biofuels refer to those obtained from animal and plant products subjected to transformation processes. The biodiesel and ethanol produced today are known as first-generation biofuels, a term that denotes their use of traditional food inputs for production. Ethanol is mainly derived from corn starch and sugarcane. Biodiesel is primarily produced from vegetable oils such as soybean, sorghum, or palm oil.

Role of biomass in the energy transition

Biomass can play an important role in the decarbonization of energy uses that require fuel carriers. Chapter 3 shows that, at the time of combustion, these products generate carbon dioxide emissions (CO_2) comparable to their fossil equivalents: charcoal slightly more than coal; biodiesel and ethanol to a similar degree as diesel and gasoline, etc. However, in the case of biomass, all the carbon emitted at the time of combustion must have been removed from the atmosphere shortly before by photosynthesis. These fuels would be considered carbon neutral if inputs (fertilizers, herbicides, etc.) and energy with emissions were not used for agricultural production and transformation to fuels, and if the time scale between combustion emissions and subsequent capture for resource renewal were short.

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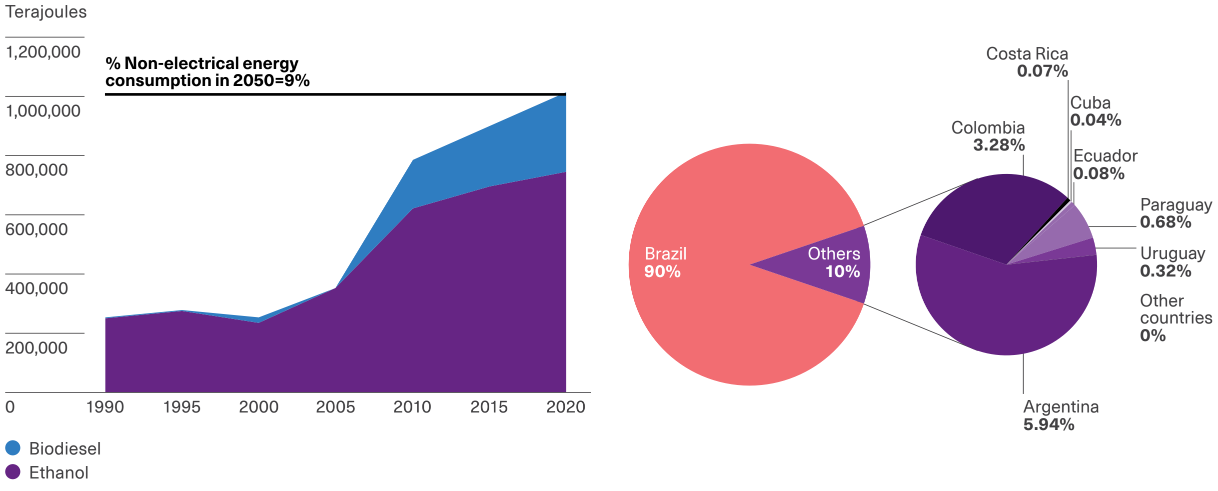
Biomass can play an important role in the decarbonization of fuel-intensive energy uses

Given the agricultural potential of Latin America and the Caribbean, there is already a mature industry surrounding the production of biofuels, supported by active public policies in the form of regulations that impose mandatory minimum blends in liquid fuels and agricultural subsidies. The objectives of these policies go beyond environmental concerns. They also aim to provide price support for agricultural products and reduce fuel imports. Graph 5.1 illustrates the progress in biofuel production in selected countries in the region.

Graph 5.1

Biofuel production in Latin America and the Caribbean



Panel A.
Biofuel production in the period 1990–2020

Panel B.
Composition of biofuel production by country in 2020

Note: The graph shows the evolution of first generation biofuels in panel A and the composition of total first generation biofuels by LAC countries with information available in panel B. Countries without ethanol and biodiesel production were grouped in "rest of countries." The list of countries in this category can be found in the chapter's annex available online.

Source: Authors based on OLADE (2023b).

Allies or obstacles to decarbonization?

First-generation biofuels face a set of environmental challenges that must be resolved if they are to support the energy transition. The problem lies in the fact that they use as input raw materials that compete with food use. In other words, they place an additional demand on land use over and above the demand for food and for materials and fibers consumed in the world. This space requirement manifests itself as an increase in the price of food and an incentive to continue incorporating natural land into agricultural production. The increasing demand for arable land can severely affect the assessment of carbon intensity over the life cycle of biofuels. In fact, integrated assessment models (IAMs) show that, for the case of light transport, the number of hectares of land required to produce sufficient biofuels to travel a given distance with an internal combustion vehicle is approximately ten times the number of hectares of solar panels required to generate the electricity that would be consumed by an equivalent electric-drive vehicle (Van De Ven et al., 2021).

When food inputs used for biofuels are produced on land that was in a natural state, for example, harboring forests, emissions are released due to deforestation and loss of soil carbon. This results in a “carbon debt” that varies according to the ecosystem where this land-use change occurred. This results in a “carbon debt” that varies according to the ecosystem where this land use change occurred. In addition to competition for arable land, biofuels typically require the intensive use of agricultural inputs—fertilizers, herbicides, and insecticides—whose production is carbon-intensive and which are harmful to local air and watersheds. Once the emissions generated by land use change are taken into account, successive crop cycles result in net carbon sequestration during crop growth, followed by a new release through the combustion and use of the biofuels obtained. The replacement of fossil fuels with these products results in avoided emissions that, over time, allow the debt to be canceled.

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When the inputs used to produce biofuels come from former forest areas, emissions are released due to deforestation and loss of carbon in the soil

Fargione et al. (2008) estimate the carbon debt payback time for the various crops used in biofuel production and the ecosystems where they are introduced. Calculations are based on agricultural productivity, carbon content in the ecosystem before land use change, and the fraction of energy production calories relative to co-products (for example, in the case of corn, residues after starch extraction are used for livestock feed). The analysis estimates that the carbon debt payback time for tropical forests exceeds 80 years, reaching highs above 400 years. In the case of grassland and shrubland ecosystems, for example, the payback time ranges from 17 years to 93 years. Lark et al. (2021) study the impact of the Renewable Fuel Standard (RFS) adopted in the United States on GHG emissions. In their work, the authors estimate that the life cycle emissions of corn ethanol over a 30-year horizon are 24% higher than those of gasoline in that country due to changes in land use and the use of nitrogen fertilizers.[6]

Even when it can be determined with certainty that the origin of the inputs used for biofuel production comes from land that was already used for agricultural activities, it is possible that biofuel production may result in land use conversion in other regions within or outside the country under consideration. This is known as indirect land use change. In these cases, establishing the carbon-effectiveness of producing these biofuels has

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[6] Another implication of the carbon debt described above refers to the different temporal profile of emissions in the case of replacing fossil fuels with biofuels. Most of the emissions associated with first-generation biofuels occur at the time of land use change, with deforestation, often carried out by forest fires (Brassiolo et al., 2023). This accentuates the peak of GHG concentration in the atmosphere in the short term and the temporary overheating of the planet.

the added difficulty of requiring the attribution of deforestation and land use change in other regions for this production.

The proportion of agricultural products destined for fuel production is growing rapidly and is now reaching high levels: 35% of corn production in the United States is used to obtain ethanol for integration into the gasoline supply, and 9% in the case of Brazil. These considerations are highly relevant for the region, where alarming deforestation rates are currently observed (Brassiolo et al., 2023). Deforestation explains the distinctive GHG pattern in the region, where 44% of total emissions during the period 2015–2019 came from the agriculture, forestry and land use (ASOUT) sector, well above the 15% global average (Minx et al., 2021).

Adequately assessing the emissions impact of biofuel use is more challenging than for fossil fuels due to the diffuse nature of land use change. It is therefore key for each country to define consistent strategies in the energy and agricultural sectors, and to establish comprehensive spillover regulations and effective implementation to avoid a negative carbon equation when replacing fossil fuels.

Technological alternatives and instruments

Replacing fossil fuels with biofuels can result in reduced emissions when the necessary increase in agricultural production can be achieved through increases in agricultural productivity. In addition, biofuels can be low or zero-emission, particularly in two scenarios: first, when the inputs used come from forestry or agricultural wastes that would otherwise not be used[7]; second, when the inputs are produced on degraded land that cannot be devoted to food production using specific energy crops.

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Replacing fossil fuels with biofuels can reduce emissions if the required agricultural production is achieved through productivity increases

Second-generation or advanced biofuels consist of the use of production processes that allow for the broadening of the types of inputs and are typically focused on the processing of cellulose and woody material. This makes it possible to take advantage of a large part of forestry and agricultural residues, as well as the organic component of urban solid waste. It also enables the use of non-food crops, which can be grown on degraded land with low or no input and irrigation requirements, including herbaceous and woody crops. The former are perennial grasses (i.e., living more than 2 years) that are harvested annually, including switchgrass, miscanthus, bamboo and sweet sorghum. Short-rotation woody crops are fast-growing trees that are harvested 5 to 8 years after planting. These include hybrid poplar and willow and silver maple, among others. Box 5.1 shows the main trajectories of biomass-based fuels, from the type of input used to the transformation process and the fuels produced.

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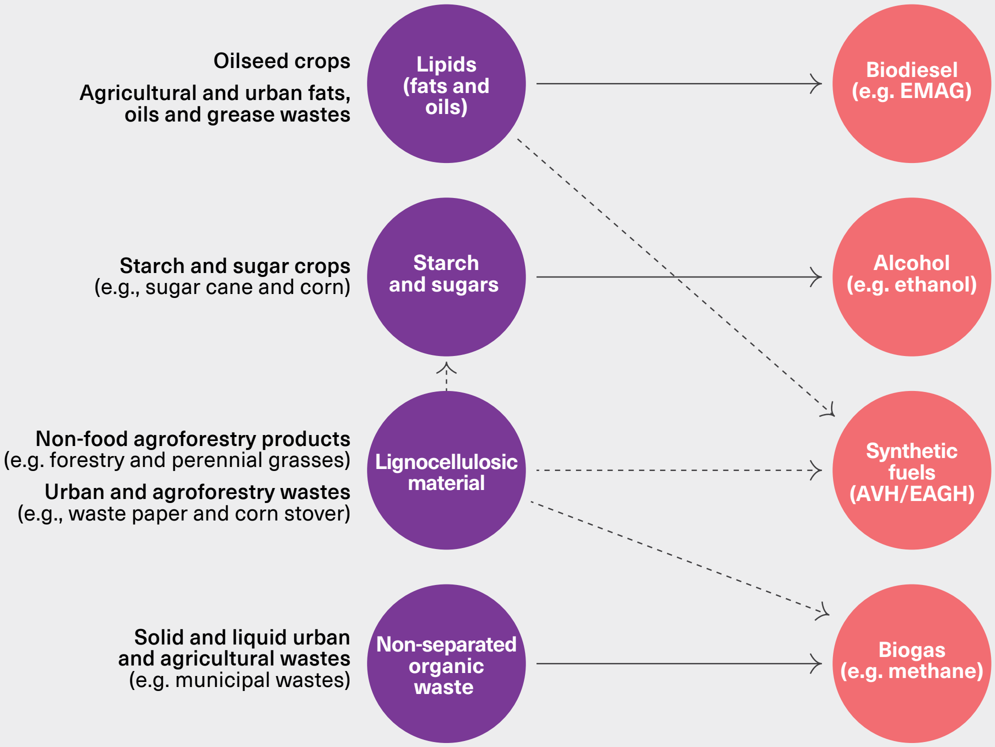
[7] Currently, there is low-emission biodiesel production from previously used food oils. Used vegetable oil can be transformed into biodiesel in a manner similar to the processing of oil crops. However, its availability is limited and requires the establishment of costly recovery networks in the food industry and restaurants.

Box 5.1
From biomass to fuels

There are various alternatives for obtaining fuels from organic inputs, which are summarized in Figure 1. One way of classifying them, relevant to the energy transition, is according to the origin, the type of input and the type of fuel obtained.

The origin of the inputs can be from food crops, non-food agricultural products or wastes. In turn, the type of input can be classified into oils or fats (lipids), sugars and starch, and cellulosic and woody material. Oils and fats can come from crops (mainly soybean, canola and palm oil) or from waste from the food and restaurant industry (such as used oil and animal fat). Sugars come from food crops, such as sugar cane or sugar beet, and starch from corn, sorghum or potatoes. Finally, woody and cellulosic inputs come from agricultural residues (such as sugarcane bagasse), the forestry industry (wood chips and sawdust discarded from sawmills), the paper industry or dedicated crops from pastures and fast-growing forestry.

Figure 1
Main trajectories for the production of fuels from biomass



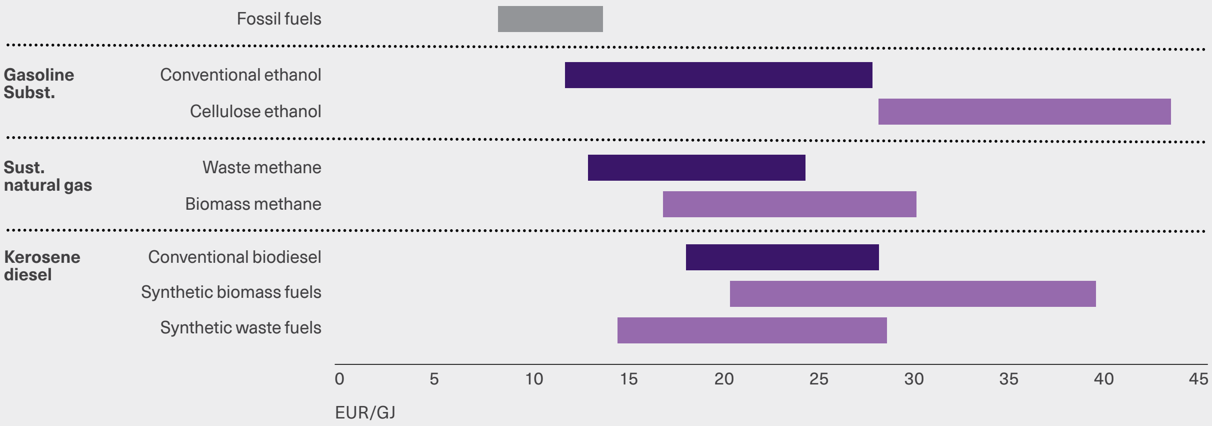
Note: The figure shows the main trajectories for the production of fuels from organic sources, combining the biomass source, the type of input and the final product. Depending on the production process, certain molecules, such as lipids or sugar solutions, are extracted from the feedstock, whereas, in more recent conversion processes, the lignocellulosic material is used directly. EMAG refers to fatty acid methyl ester; AVH/EAGH are hydrotreated vegetable oils, esters and hydroprocessed fatty acids.

Source: Authors based on OECD (2019).

Finally, the type of fuel obtained can be methane or biogas, alcohols, fatty acid esters or biodiesel, and synthetic fuels. A key aspect of the type of fuel is the extent to which it replaces fossil fuels, without requiring replacement or adaptations in equipment. Biomethane, obtained by purifying biogas, completely replaces natural gas. Biodiesel and alcohols, such as ethanol, are used in combination with diesel and gasoline, respectively, without requiring engine modifications, but cannot completely replace them without adaptations. Synthetic fuels are fuels that are chemically equivalent to fossil fuels and therefore serve as direct replacements for them. They are of central importance in cases where there are few viable alternatives, as is the case with aviation turbine fuel.

The production of the various fuels involves varied chemical or biological transformation processes, which result in different production costs. Figure 2 presents estimated ranges of production costs for some of the production trajectories of fuels from organic sources. The fossil fuels as a whole show cost ranges that, in general, are markedly lower than those from organic sources.

Figure 2
Fuels production cost ranges



Note: The figure shows ranges of estimated production costs according to fuel type.
Source: Authors based on IEA (2019).

Among the possible replacements for gasoline, conventional ethanol obtained from food crops such as sugarcane or corn is more economical than that obtained from lignocellulosic material. Among the relevant substitutes for diesel and kerosene, biodiesel is generally more economical than synthetic fuel when both are obtained from food crops, although only the latter is capable of fully replacing fossil fuel and being used in commercial aviation. Synthetic fuel can be cheaper than conventional biodiesel when produced using waste lipids (such as used vegetable oil), although these are limited by a limited supply.

The fuel trajectories—represented by the purple bars in the figure—are central to the decarbonization of fuels, since they either allow for the broadening of the input mix by facilitating the incorporation of sustainable sources, or result in closer substitutes to fossil fuels in energy uses that require certain characteristics.

Source: Authors based on OECD (2019) and IEA (2023k).

The International Energy Agency (IEA) proposes a strategy for sustainable management of biofuel production based on three axes. The first of these consists of the adoption, by the States, of regulatory frameworks for the sustainability of fuels. These establish precise guidelines for the production of low environmental impact and carbon-neutral biofuels, including certification frameworks with independent verification and covering the entire supply and production chain. These frameworks differentiate agricultural fuels from sustainable sources (e.g. without associated deforestation) from other fuels. This is the prerequisite for the adoption of appropriate incentives to enhance their production and achieve significant emission reductions.

The Renewable Energy Directive (RED) adopted by the European Union (EU) is an example of an appropriate regulatory framework. It combines an ambitious target for the share of renewable energies in the energy mix, while incorporating regulations to avoid deforestation associated with these energies inside and outside EU territory. In March 2023, the member countries agreed to raise the target share of renewable energies in final consumption to 42.5% by 2030. In turn, the RED establishes that, in order to achieve this share, the share of energy from food crops can be a maximum of 7 percentage points or 1% more than the level it represented in 2020 in each member country[8] (European Council, 2023; European Parliament, 2023). In the region, Brazil adopted the RenovaBio program, whose main instrument is the establishment of annual national decarbonization targets for the fuel sector, so as to encourage increased production and the share of biofuels in the country's transportation energy matrix (ANP, 2023; BioEconomia, 2020).

The second axis of the IEA strategy is the adoption of biofuels demand policies consistent with the targeted emissions reduction trajectory. Based on regulatory frameworks, concrete targets for the share of sustainable biofuels, along with other carbon-neutral carriers in energy consumption, should be adopted, and command-and-control[9] and incentive policies (carbon pricing, taxes and subsidies) should be put in place to achieve them. Policies that go in this direction and have been widely adopted in the region are the minimum quantities of biofuels at the pumps. Argentina, for example, already has a minimum blend 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.

The third axis corresponds to policies that promote innovation, especially for waste-based biofuels with lower GHG emissions. Achieving the ambitious goal of zero net emissions requires the growth of both waste-based fuels and those from dedicated crops that can be produced on degraded land. Necessary policies include risk mitigation measures such as loan guarantees and mandatory quotas for the use of advanced biofuels. The European Parliament, for example, formally adopted Sustainable Aviation Fuels (SAF) blending targets in July 2022 to expand the market for these products.

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[8] The lower of the two values applies.

[9] This term refers to the adoption and monitoring of laws and regulations that set permissible limits and penalties in case of infringement; therefore, they are based on coercion and sanction mechanisms.

Hydrogen as an energy carrier

Hydrogen gas (H_2) and its derivatives represent another set of low-emission fuel alternatives. Hydrogen gas (hereafter referred to as hydrogen) is composed of two atoms of hydrogen, which is the lightest and most abundant element in the universe. However, it is hardly ever found on Earth as a gas in its natural state but occurs mostly in the form of water (H_2O). It is also a central component of hydrocarbons and organic compounds.

Hydrogen is a versatile energy product that can be used as a fuel or transformed into electricity at the time of use by means of an electrochemical process, through what is known as a fuel cell.[10] Its properties as a fuel are similar to those of natural gas, although it has a somewhat higher combustion temperature (1,085°C versus 1,003°C for methane) and higher flammability (higher rate and thermal range of ignition) (Pacific Northwest National Laboratory, 2023). At standard pressure and temperatures, hydrogen has a very high energy density per unit weight (gravimetric density), more than twice that of natural gas. However, it requires three times the volume of natural gas to hold the same amount of energy. This low density per unit volume makes its transport, storage, and use very challenging. Moreover, as it is the lightest molecule in existence, it is difficult to avoid leaks due to the porosity of transport and storage media.

The great advantage of hydrogen is that it does not emit GHGs when used. In fact, in the absence of impurities in the hydrogen input, its use in fuel cells or its combustion results only in water emissions in the form of steam. It can also emit nitrous oxides, but this is avoidable by controlled combustion standards (Lewis, 2021). In addition to the implications of its use for climate change mitigation, hydrogen does not release local air pollutants associated with burning fossil-based liquid fuels, which are harmful to human health and ecosystems (IEA, 2021c; Popa et al., 2015; Staffell et al., 2019; Wang et al., 2023).

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The great advantage of hydrogen is that it does not emit GHG at the time of use

Hydrogen is currently produced by different processes, depending on the types of compounds used. It can be obtained from water, fossil inputs (hydrocarbons, by definition, are composed of carbon and hydrogen atoms), or organic inputs derived from biomass. Hydrogen is usually characterized by a color depending on the input of origin and the process by which it is obtained (see Box 5.2).

Among the technologies for production from fossil sources are steam reforming, mainly using natural gas as an input (also applied to liquid fuels), and coal gasification. These are the ways of obtaining most of the hydrogen currently produced. Both processes involve the separation of the input into its hydrogen and carbon components, for which high temperatures are needed. In other words, they involve emissions both due to the energy required for the process and the release of the carbon that dissociates from the hydrogen[11] (IEAGHG, 2017).

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[10] The fuel cell is a device that delivers electricity from a chemical reaction, similar to a battery. It differs from a battery in that the fuel cell uses an external supply of reactants (in this case, hydrogen and ambient air), whereas a battery stores all the necessary reactants.

[11] Steam reforming using natural gas can be described in two stages: 1) the production of high-temperature steam, which requires some source of energy; 2) the reforming itself, where a mixture of steam and natural gas is exposed to elevated temperatures. That process causes both hydrogen from water and methane to be released as hydrogen gas (H_2) and oxygen from water to combine with carbon from methane in the form of CO_2. Since the heat source for producing the steam and heating the reformer is typically obtained from fuels, the process involves emissions from combustion and from the reforming itself.

Box 5.2
Classification of hydrogen according to production process

Currently, there are several ways to produce hydrogen, although many of them are far from clean. To help identify the environmental impact associated with the origin of hydrogen, a color classification was adopted (IEA, 2019c).

Table 1
Hydrogen colors

Brown	Coal gasification
Gray	Electrolysis of water powered by fossil generation
	Methane steam reforming
White	by-product of industrial processes
Blue	Coal gasification with CCUS
	Methane Steam Reforming with CCUS
Turquoise	Methane pyrolysis
Yellow	Electrolysis of water powered by nuclear generation
Green	Biogas steam reforming
	Biomass gasification or fermentation
	Electrolysis of water powered by renewable generation

Note: The figure shows the classification of hydrogen types according to their production process or origin. CCUS refers to carbon capture, use, and storage.
Source: Authors based on IEA (2023p, 2023t).

Brown hydrogen comes from the coal gasification process and has the highest GHG emissions associated with it.

Hydrogen produced by steam reforming with natural gas, which currently represents the bulk of hydrogen production (90% of the total produced in Latin America and the Caribbean (IEA, 2023l), and hydrogen generated by electrolysis, using fossil fuels, are considered gray. Both show similar emissions profiles.

Blue refers to hydrogen of fossil origin, but with carbon capture, which significantly reduces its emissions profile.

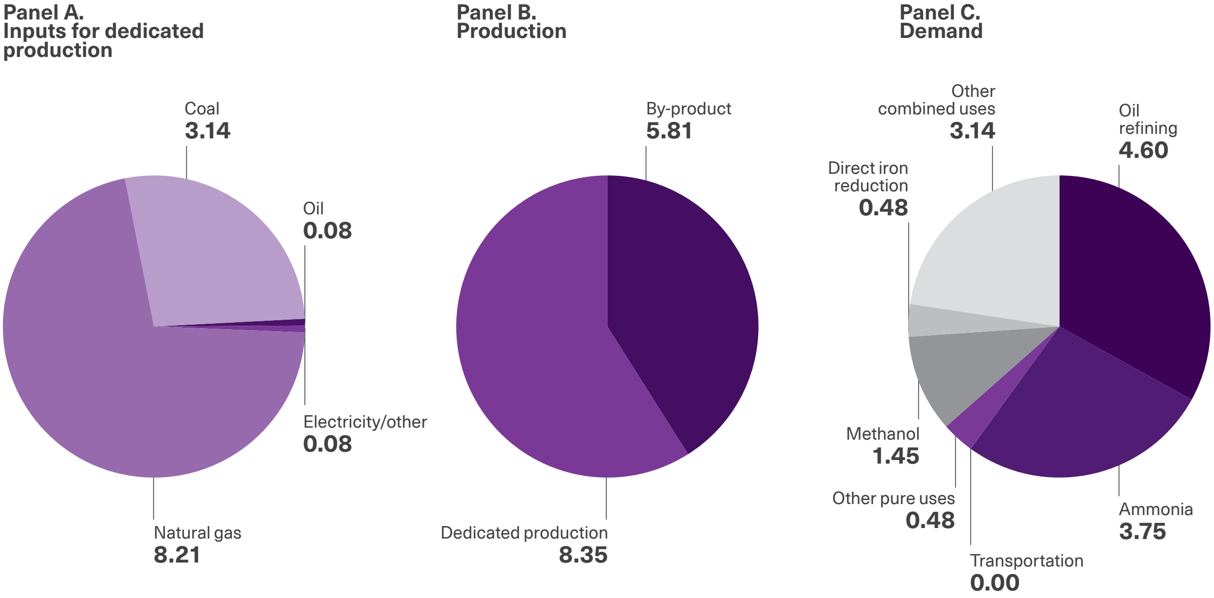
The target is hydrogen obtained as a by-product of industrial processes. This is the case for chlorine production (Bazzanella and Ausfelder, 2017).

Turquoise is obtained through a methane pyrolysis process, in which, although the input is of fossil origin, it does not produce CO_2 emissions, but solid carbon. This by-product shows great stability in oxidation and, therefore, implies long-term carbon sequestration. The input used, however, may be prone to fugitive emissions, which are prevalent in natural gas production and transportation.

Yellow is produced by electrolysis from nuclear generation and, although it does not produce GHG emissions, it is subject to environmental impacts and risks.

Finally, green is the one with the lowest associated environmental impact, since it is produced with electrolysis powered by renewable generation and from organic carbon. In the latter case, the process involves negative emissions when the organic inputs are sustainable (Hafner and Luciani, 2022).

Graph 5.2
Sources and uses of hydrogen



Note: The graph shows the 2019 global hydrogen value chain in exajoules (EJ), from production to demand. The categories indicated in grey refer to uses of hydrogen in combination with other gases, such as carbon monoxide. The category "other pure uses" corresponds to the chemical, metallurgical, electronics and glass industries; the category "other combined uses" includes heat generation from gases derived from steelworks and steam crackers.

Source: Translated from IEA (2019c).

The second alternative is the use of inputs from organic sources. Processes similar to coal gasification and gas reforming or liquid fuels can be applied to the gasification of wood and cellulose from waste or dedicated crops produced on degraded land, as well as to the reforming of biogas produced by waste decomposition. Hydrogen is classified as green when the input is obtained in a sustainable manner (e.g., without deforestation) because the carbon emitted at the time of its production was previously captured by biomass.

The third alternative is the production of hydrogen by electrolysis of water. In this process, water is exposed to an electric field, separating hydrogen from oxygen. This process is emission-free but has a high electricity requirement and considerable energy losses in the transformation from electricity to gas.[12] The source from which the electricity is generated determines whether the hydrogen is accompanied by emissions (e.g., gray hydrogen, when the electricity is generated with fossil fuels) or not (green hydrogen, when the electricity is generated with renewable energies).[13]

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12 If all the hydrogen currently consumed (94 MtH_2) were produced from electrolysis, 1.37 EJ would be required, about 30% of annual LAC electricity generation (IEA, 2019c, 2021c).

13 It also has significant water requirements, at a rate of 9 kilograms (kg) per kg of hydrogen produced. This is important for projects that consider producing it in optimal locations for solar generation, such as deserts, because of their good irradiation and low soil costs. When the water used as an input is not pure, the process tends to produce toxic substances, such as sodium hypochlorite (commonly known as chlorine). To avoid contamination by effluents or emissions, additional processes of prior purification or subsequent separation must be incorporated, which increase production costs.

Hydrogen production and applications have been carried out on a large scale since the 1950s, since its demand was led by the production of ammonia for fertilizer production. In addition to its use for ammonia, the main application of hydrogen is as an input in petroleum refining. The energetic use of hydrogen is also common in the industrial sector, as it is often a by-product in the manufacture of chlorine, sometimes used on site. Currently, dedicated hydrogen production (i.e., not as a by-product) is almost entirely from fossil-based inputs, mainly through the natural gas reforming process and coal gasification. These inputs account for more than 98% of dedicated production and 60% of the total (IEA, 2019c) (see Graph 5.2).

Role of hydrogen in the energy transition

When sourced with low emissions, hydrogen and its derivatives can play an important role in the energy transition, mainly in two dimensions. The first is to provide flexibility in energy supply as the share of solar, wind and other non-conventional renewables increases. These generation sources produce energy when and where the natural resource is present. As their share of electricity generation grows, times and places with surpluses or shortages of electricity generation will become increasingly common. The alternatives for managing the time and geographic location where energy is produced are limited, and there are few options for meeting demand needs.

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Hydrogen and its derivatives can play an important role in providing flexibility in energy supply and replacing fossil fuels

Hydrogen would allow this mismatch between generation and consumption. Temporary surpluses of solar and wind power generation can be used at the same site where the best natural conditions are available to produce hydrogen, store it and transport it to the place and time where its consumption is required.[14] This energy delivery at the time of consumption can occur through electricity generation to be injected into the grid, distribution of hydrogen to end users for instantaneous electricity consumption, such as fuel cell electric vehicles (FCEVs), or maintained as a vector for uses that require combustion (see next dimension).

The second dimension is the replacement of fossil fuels to satisfy energy uses that are better served by combustion, without producing carbon emissions. This is the case for industrial processes that require high thermal demand. Hydrogen can enable decarbonization of steel production, currently responsible for about 9% of global emissions, by allowing the replacement of coal in the direct reduction of iron ore (Kurrer, 2020). In the cement industry, it can help reduce the use of clinker, responsible for most of the emissions from the production process (see Chapter 6). In addition, hydrogen can decarbonize long-distance transport, such as road freight, through the use of fuel cells, and air transport, through hydrogen-derived fuels of higher energy density, including the use of ammonia and synthetic jet fuel (IEA, 2023i; Kapat and Otto, 2022).

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

Alternatives for producing low- or zero-emission hydrogen can be grouped into three: 1) integration of carbon capture and storage with production, i.e., moving from brown or gray hydrogen to blue hydrogen (see Box 5.2); 2) hydrogen production by electrolysis of water with electricity generated from renewable sources (green, yellow hydrogen); and 3) use of inputs from sustainable organic sources, incorporating carbon capture (green hydrogen).

The process of integrating carbon capture and storage into traditional fossil fuel hydrogen production processes has the advantage of building on mature and competitive technologies already deployed at scale. However, carbon capture is still costly and requires transport infrastructure and storage sites for the captured CO_2. In turn, storage is still subject to uncertainties and high costs.

The current cost of hydrogen production by electrolysis exceeds the cost of producing it by methane reforming and coal gasification with carbon capture, even in scenarios of low electricity prices (IEA, 2020). To this must be added that the hydrogen produced must use low-emission electricity, such as solar, wind, or hydropower. This is clearly the case when the installation of the electrolysis plant is done in conjunction with the installation of renewable generation capacity (dedicated plant). When the electrolysis plant is fed from the electricity grid, it is not possible to directly attribute the source used to generate the electricity it consumes. However, it can be considered low in emissions when the marginal electricity generator, the one that is incorporated into the electricity dispatch to meet the increase in consumption at the time, has zero emissions. In fact, as more generation capacity from non-conventional renewable sources is incorporated, there are frequent moments when the production capacity of solar and wind sources exceeds demand.

Finally, technologies that use inputs from sustainable organic sources are promising because such sources involve prior capture of atmospheric carbon. Otherwise, most would have resulted in emissions from the decomposition of organic matter at waste disposal sites. If hydrogen is obtained from sustainable biomass and waste without incorporating carbon capture, the process can be considered carbon neutral, whereas, if it captures carbon, the result is a net absorption of CO_2 from the atmosphere.

These technologies face technical limitations associated with the fact that biomass, the hydrogen-bearing input, is accompanied by multiple compounds and impurities that affect the performance of catalysts and reformers. To date, economic viability depends on low-cost carbon inputs, such as waste, and is therefore limited by the availability of these inputs (IEA, 2020b).

Barriers and solutions[15]

For hydrogen to fulfill the roles required in the context of the energy transition (energy carrier, to decouple production from consumption and as a fuel energy vector capable of high temperatures and industrial processes), first of all, relevant production scales must be achieved from the clean sources discussed above. This requires high investments in electrolysis capacity and, at the same time, entails a high demand for green electricity. In addition, it must overcome the barrier of transportation difficulty that derives from its low energy density per unit volume. This has important implications for the required transport and distribution infrastructure and for the costs to end users.

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[15] Prepared based on ACER (2021) and IEA (2019c, 2020b).

For hydrogen to accompany the energy transition, relevant scales of production from clean sources must be achieved

Similar to natural gas, large-scale transport of hydrogen is feasible through pipelines. This can be done either through the construction of dedicated transportation and distribution networks, the reallocation of existing natural gas networks for hydrogen transportation, or the joint transportation of hydrogen and natural gas. However, pipeline transport of hydrogen presents some difficulties with respect to natural gas because it can reduce the lifetime of steel pipelines. Under certain conditions, hydrogen reacts with steel causing porosity and embrittlement, especially when there are cracks upstream and at pipe joints, which is known as hydrogen embrittlement.

The injection of hydrogen into natural gas networks in low proportions (up to 3%) can be done without difficulties and without requiring modifications in the networks or in the current equipment, and can be increased gradually, accompanied by adjustments (Melaina et al., 2013). In fact, the introduction of hydrogen quotas in gas dispatches is recognized as a valuable policy to boost demand for hydrogen and promote cost reduction through economies of scale. However, this alternative reduces the relative value of hydrogen, since it rules out valuable uses that require high purity, such as in hydrogen fuel cells and for industrial purposes.

On the other hand, the reallocation of natural gas networks for hydrogen transport is recognized as a promising and cost-effective alternative in the long term. This requires adjustments to the existing infrastructure, such as the introduction of interior coatings in gas pipelines, internal monitoring of the state of the pipelines and the adaptation of compressors and valves for the higher pressure required for hydrogen transport, among others. In the short term, this strategy should take advantage of existing redundancies in the natural gas transportation and distribution networks, such as, for example, excess capacity in two parallel pipelines. However, in the long term, the most optimistic hydrogen scenarios estimate that, as an example, in the European Union, the total pipeline network capacity required will be much less than the currently existing natural gas network. This points to efficient infrastructure retrofitting as a promising strategy as the share of natural gas declines in countries that already have transmission networks (Agora Energiewende and AFRY Management Consulting, 2021).

For hydrogen to assume the prominent role of decoupling electricity generation from consumption, large-scale storage solutions with sufficient capacity to mediate temporal and regional mismatches are needed. However, its low volumetric density is a challenge. An alternative for large-scale, long-term hydrogen storage is geological storage. Reservoirs can be subway salt caves, depleted oil and gas fields, and aquifer caverns. Currently, only salt caverns are a proven solution for storing hydrogen without loss or contamination with impurities, although their geographic availability is limited.[16]

Large-scale storage solutions with sufficient capacity are needed to mediate temporary and regional mismatches

Current options for small-scale storage and transport are storage in compressed gas hydrogen tanks and cryogenic liquid hydrogen tanks. Storage in compressed gas is a technically feasible alternative, although, even at elevated pressures of 700 bar (three times the pressure typically used in compressed natural gas systems), the energy density per volume is only about 15% compared to gasoline. Liquefied hydrogen is much denser, but presents major technical challenges because it requires temperatures below -253°C (compared

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[16] These storage sites are well known and currently in use for storing natural gas and crude oil. In fact, they currently account for 7% of the world's natural gas storage capacity (US Department of Transportation, 2021).

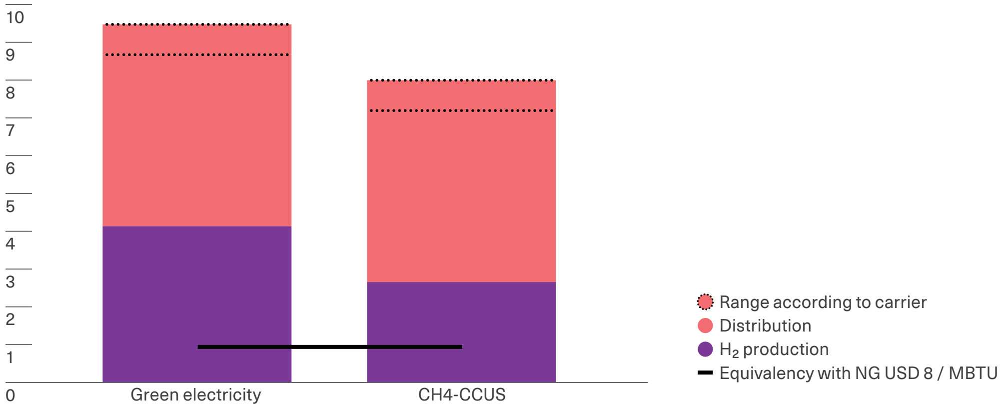
to -162°C for liquefied natural gas). Hydrogen liquefaction is a very energy-intensive process, requiring up to one-third of its energy value in the process. In addition, it requires cryogenic storage tanks with sufficient thermal insulation properties to minimize regasification losses.

Other solutions for storage and transport consist of integrating hydrogen into hydrogen-bearing compounds. One possible hydrogen carrier is ammonia, a substance consisting of hydrogen and nitrogen (NH_3). This input is used for fertilizer production, but is of growing interest as an energy carrier, either for use as a fuel in sectors that are difficult to electrify or as a vehicle for hydrogen, which will later be reconverted into its constituents to recover pure hydrogen. The advantage of ammonia is that it is much easier to liquefy it, which requires cooling it to -33°C, a temperature that is easy to obtain and maintain during transport. However, the process of ammonia production and subsequent reconversion to hydrogen and nitrogen also requires energy: between 7% and 18% of the energy contained in the hydrogen at each stage.

Finally, liquid organic carriers are compounds that can absorb hydrogen (a process called hydrogenation or saturation) and subsequently release it. These carriers offer the advantage of having a high energy density per volume, although it is one-fifth that of gasoline (Giese and Reiff-Stephan, 2021), and being stable in liquid form, without requiring insulation for a wide range of environmental conditions. The disadvantage of organic carriers is that they are generally non-renewable resources of fossil origin, which must return to the hydrogen production site once they deliver hydrogen to the destination, requiring double transport.

Graph 5.3

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



Note: The graph shows estimated domestic production (in purple) and distribution (in pink) costs for hydrogen in the EU in 2030. The costs are shown in dollars per kilogram (USD/kg) of H2 for production from natural gas with CCS and from green electricity, assuming a natural gas cost of USD 8 per million British thermal units (USD/MBTU) and an electricity cost of USD 47 per MWH. The dotted rectangle indicates the range of transport and distribution costs among the alternatives of ammonia transport, liquid hydrogen, and liquid organic hydrogen carrier. The horizontal black line indicates the cost equivalence value of hydrogen with natural gas.

Source: Authors based on IEA (2019c, Figures 31 and 32).

Graph 5.3 presents cost estimates for domestic production, transport, and distribution of hydrogen in the European Union in 2030 (IEA, 2019c). Assuming that the inputs considered cost USD 47 per megawatt hour (USD/MWH) in electricity and USD 8 per million British thermal units (USD/MBTU) in natural gas, natural gas-based production incorporating carbon capture and sequestration shows an estimated cost of USD 2.7/kg, 36% lower than electrolysis. In addition, if the hydrogen is not used near the production site and must go through transportation and retail distribution stages, add USD 4.5 to USD 5.3/kg for the considered alternatives of transportation via hydrogen liquefaction, conversion to ammonia and subsequent reconversion, and use of an organic liquid carrier.

The graph shows with a dotted line the cost equivalence value of hydrogen with natural gas, considering the energy value of both and the aforementioned gas cost of USD 8 per MBTU. Under this comparison, hydrogen is still not very competitive, since, in the most auspicious scenario of use at the production site and with the most economical alternative, it entails costs that are almost three times those of natural gas. However, this analysis is highly dependent on the cost of the inputs used. For example, in the case of being able to take advantage of surplus electricity generation that would otherwise be discarded, electrolysis production could improve the competitiveness of hydrogen substantially and provide flexibility to the sector.

Hydrogen in Latin America and the Caribbean

Currently, hydrogen is produced from natural gas (76%) and coal (almost 23%), so the current processes for obtaining it emit GHGs. Less than 1% of current hydrogen production comes from renewable energy or fossil fuels with plants equipped with carbon capture and storage technologies. By 2019, 90% of the region's hydrogen demand was concentrated in Trinidad and Tobago (more than 40% of the total demand for H_2) and the five largest economies: Argentina, Brazil, Chile, Colombia, and Mexico (Cont et al., 2022).

In the region, less than 1% of current hydrogen production comes from renewable energy sources or from fossil fuels with carbon capture and storage

As mentioned above, green hydrogen generation is currently uncompetitive (Erbach and Jensen, 2021). In Latin American and Caribbean countries, multiple strategies are being developed at the national level,[17] and there is a portfolio of more than 25 projects, several of them at gigawatt scale. Among the largest projects is the Hychico pilot project in Patagonia, Argentina, where some 52 tons of hydrogen per year (tH_2/year) are produced from wind energy. This project has the only H_2 pipeline system in Latin America (2.3 km). The Ad Astra Rocket pilot project in Costa Rica produces about 0.8 tH_2 /year from solar and wind energy. The H_2 is used to power the region's first fuel cell bus, as well as four light fuel cell vehicles. In Chile, the Cerro Pabellón microgrid in the Atacama Desert is a pilot project that uses solar energy to produce 10 tH_2 per year. The project provides manageable electricity from renewable sources to meet the needs of a microgrid serving a community of more than 600 technicians working at a geothermal plant (IEA, 2021c).

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[17] In Chile (already published), Argentina, Bolivia, Brazil, Colombia, Costa Rica, El Salvador, Panama, Paraguay, Trinidad and Tobago and Uruguay (in preparation).

In Chile, H_2 could also offer a viable alternative in segments with very high power and uptime requirements, including heavy mining trucks. For example, Chile's economic development agency Corporación de Fomento de la Producción launched a program in 2017 that sums up its objective right in the name: Development of hydrogen-diesel dual combustion system for mining extraction trucks (OutletMinero, 2017).

In fact, Chile aspires to produce and export the world's most competitive H_2 from renewable electricity by 2030, and many Latin American countries share the conditions to develop such processes. In some of them, such as Brazil, the availability of biogenic carbon from existing biofuel and bioelectricity production facilities could also help to produce and export synthetic fuels, which require both carbon and H_2. Finally, technologies for the production of low-carbon H_2 are under development, which will have to go through learning curves and considerable cost reductions to become competitive.

The fossil fuel industry in the energy transition

Even before a household or business uses a liter of gasoline (or a fossil fuel of any kind), it has already generated substantial GHG emissions. Globally, the production, transport, and processing of oil, gas, and coal releases emissions of approximately 6.5 gigatons of CO_2 equivalent ($GtCO_2$ eq). This represents more than 12% of annual global GHG emissions from all concepts and 17% of the full life-cycle emissions of fossil fuels (IEA, 2023f; ETC, 2023b).

Pre-use fuel emissions come from different sources along the industrial chain. First, oil and gas extraction requires large amounts of energy to power the drilling rigs, pumps, and other equipment used in the process, as well as to provide heat. In turn, most of the oil is refined before use, which requires large amounts of energy. Natural gas is also processed to separate liquids from natural gas and remove impurities. In addition, crude oil, petroleum products, and natural gas are transported, often over long distances, both by pipeline and by ship, another major source of GHG emissions.

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Globally, the production, transport, and processing of oil, gas, and coal account for more than 12% of annual GHG emissions from all sources

Graph 5.4 shows the emissions associated with fossil fuels prior to their consumption, as a percentage of total domestic and external consumption for each country. These include direct emissions associated with energy use in the various stages of production of primary fuels and their transformation and fugitive methane emissions from the fossil sector. Thus, for the average of the countries shown, for every 100 tons of CO_2 (tCO_2) emitted at the moment of consuming fossil fuels, more than 29 additional tCO_2 e were previously generated during production, of which approximately half correspond to methane emissions as a result of venting or flaring of unused natural gas or by leaks in the production, transformation, and transportation processes.

In the IEA's net-zero emissions scenario, the agency projects reductions of 17% in gas and oil consumption and over 50% in associated emissions by 2030. These reductions stem from implementing measures associated with fossil fuel production and transportation. These measures can be grouped into three areas: methane emission reduction, enhanced energy efficiency through equipment improvements, and electrifying energy used in processes.

According to the IEA (2023f), the use of more efficient equipment could save around 30% of the projected energy demand, with equivalent reductions in emissions. However, full electrification would allow even greater emission reductions, close to three-quarters of current production emissions.[18] The IEA estimates that over half of the world's oil and gas production is within 10 km of an electrical grid, and 75% takes place in areas with good wind or solar resources (IEA, 2023f). Consequently, energy at upstream facilities for exploration and production could be supplied by the electricity grid or even generated with clean sources in a decentralized manner for remote sites.

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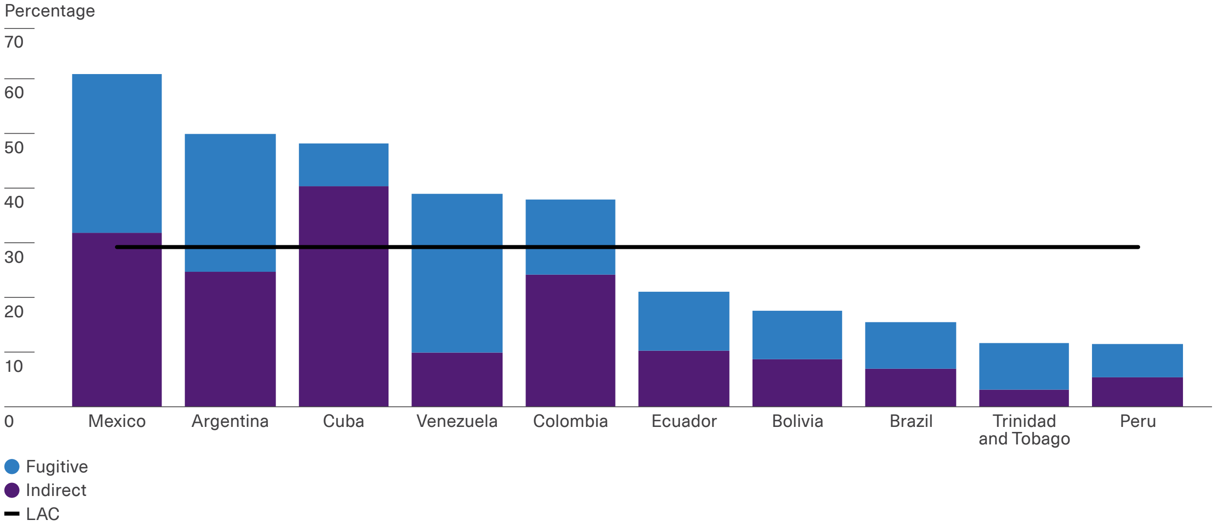
In the IEA's net zero emissions scenario, the agency projects a 17% reduction in gas and oil consumption by 2030, accompanied by a drop of over 50% in associated emissions

Graph 5.4

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 (indirect emissions) and fugitive methane emissions released in the production, transport, refining and distribution of coal, gas, oil and oil derivatives, as a percentage of emissions from 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 (2023j).

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[18] The remainder covers operations that are not feasible for full electrification, including those requiring substantial amounts of heat, and large process emissions (such as facilities for the conversion of coal to liquid fuels). In turn, the authors exclude production that takes place in areas far from grids or with scarce solar or wind resources (IEA, 2023f).

In the case of coal, 85% of the emissions associated with production are fugitive methane emissions and represent 10% of total methane emissions from human activities. These are very difficult to reduce as long as production continues since the process involves extracting, fracturing and separating the material that has methane trapped in it, and hence its release. A key policy area is to eliminate passive methane emissions in mines that cease production, for example, by flooding and sealing subway mines (ETC, 2023b).

Proper disposal of oil and gas fields is also crucial to mitigate the environmental impacts of fossil resource production. If not done properly, abandoned production sites can emit methane and release harmful products into the environment, either because they emerge from the reservoir or because of exposure of remaining production wastes to the environment. The US Environmental Protection Agency estimates that there are about 3.7 million abandoned oil wells (EPA, 2023b), of which approximately 60% do not have sealing treatment to prevent methane spills and, in many cases, do not have well-defined owners. Correct final disposal of these wells has an estimated median cost of more than USD 70,000 per well (Raimi et al., 2021).

The proper disposal of disused fields represents a relevant cost, although often not contemplated in energy transition policies. When fields are abandoned by the operators and it cannot be determined with certainty who were the owners and responsible for the operation (for example, in the case of company closures, bankruptcies, and complex structures involving multiple firms), their decommissioning becomes a costly burden for governments (they are known as orphan assets).

The role of natural gas in the energy transition

The discussion presented in this chapter highlights the significant viability challenges at the required scale that the technological alternatives for decarbonizing fuel demand still pose. At the same time, they remain less cost-competitive compared to the fossil fuels they are supposed to replace. In this context, a promising policy space for short-term emission reduction on the path to decarbonization is the replacement of liquid fuels derived from oil and coal with natural gas.

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A promising policy space for reducing emissions in the short term is the replacement of petroleum and coal-based fuels with natural gas

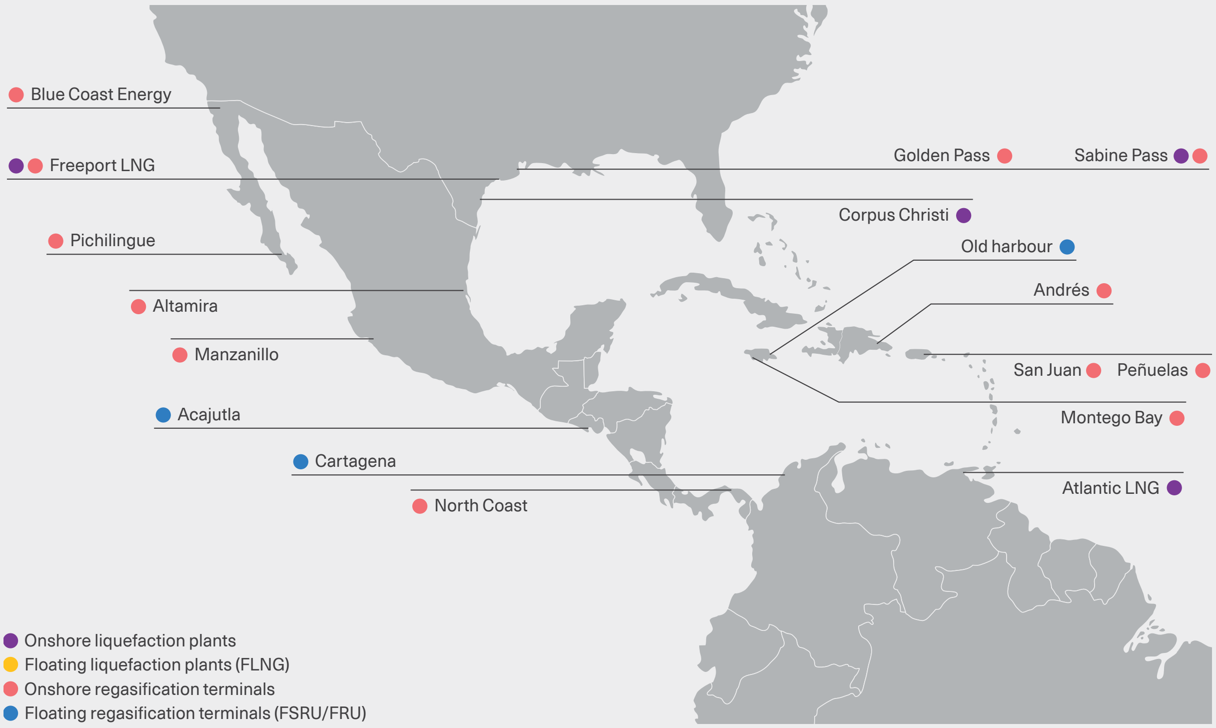
Natural gas is composed mainly of methane, which is the lowest molecular weight hydrocarbon, consisting of one carbon atom and four hydrogen atoms. This low ratio between hydrogen and carbon content means that it is also the hydrocarbon with the lowest CO_2 emissions per unit of energy delivered. In fact, direct emissions associated with natural gas combustion are 56 tCO_2 per terajoule (TJ), 32% lower than diesel combustion and 70% lower than coal (IPCC, 2006). In addition to the emissions generated at the time of consumption, fossil fuels undergo various production processes that involve the use of energy and, consequently, indirect emissions associated with this energy consumption. Finally, their production and transportation are a source of fugitive methane emissions. Considering these indirect emissions, the combustion of natural gas produced in Latin America and the Caribbean is associated with emissions estimated at 75 tCO_2 / TJ, which are 23% lower than those of diesel and 22% lower than those of coal (see Chapter 3). In other words, the use of natural gas, under current production conditions in the region, has less impact on global warming than other fossil fuels.

Box 5.3
The role of small-scale liquefied natural gas for small island developing economies

Long-distance natural gas trade requires specific infrastructure and capital intensive gas liquefaction at origin, maritime transportation in specialized vessels and regasification plants at destination. However, recent technological advances in the natural gas value chain are enabling greatly reduced costs for the establishment of small-scale liquefied gas systems. These advances are particularly promising for meeting the energy needs of island developing countries, such as those in the Caribbean (Perczyk and Rabinovich, 2023). In addition, it would make it possible to meet energy consumption in remote sites with river access that have a lower impact on sites of high ecosystem value, as in the case of settlements in the Amazon basin (Oliveira Barbosa et al., 2023).

The International Gas Union (IGU) defines small-scale liquefaction and regasification plants as those with capacities between 200,000 and 4 million cubic meters per day (m3 /day). This scale allows the distribution and use of LNG to be tailored to the specific needs of smaller markets.

Figure 1
LNG terminals in the Caribbean in 2022



Source: Translated from GIIGNL (2023).

These small-scale value chains exist in two alternatives (Rodríguez Pardina et al., 2022). The first consists of transporting LNG in specialized gas carriers and delivering it in liquid form to small-scale storage and regasification terminals. Among these, floating storage and regasification vessels (FSRUs) are a particularly attractive solution for countries with maritime littorals, as they allow receiving and replenishing LNG without the need to invest in costly long-term gas infrastructure. The second alternative is the distribution of LNG in containers built according to the International Organization for Standardization (ISO) standard. These are specialized tanks with the same dimensions as common shipping containers, allowing the use of existing port and land transport infrastructure. They also require small-scale liquefaction plants close to consumption centers.

These technologies are becoming increasingly important in the Caribbean subregion. For example, AES is developing two projects in the Dominican Republic and Panama. In addition, this company reconfigured in 2015 the terminal for reloading LNG in Santo Domingo, Dominican Republic, for small-scale shipments to nearby Caribbean islands. The initiative is part of a strategy to develop a hub-and-spoke distribution market to supply the Caribbean and Central America. Another example of a similar strategy was implemented at New Fortress Energy's Montego Bay (Jamaica) terminal.

These projects demonstrate how these initiatives can develop regional natural gas markets and exemplify how large LNG cargoes can be redistributed into smaller shipments to nearby markets, fostering new regional demand for this commodity (Rodríguez Pardina et al., 2022).

Natural gas also has other advantages over other fuels in terms of local air pollution because its combustion produces much lower amounts of sulfur oxides, nitrogen oxides, and fine particulate matter than those emitted by other fossil fuels. These pollutants have major impacts on human health: the WHO estimates that the increased exposure to fine particles of 2.5 microns ($PM_{2,5}$) caused by human activities causes more than 4.2 million premature deaths per year, due to the incidence of cardiovascular diseases, respiratory diseases, and cancer (WHO, 2021).

Part of the attractiveness of replacing other fuels with natural gas is that, in many cases, it enables the use of existing equipment with affordable modifications and a smoother transition of the industry, allowing for the prolongation of the life of the technologies and goods in production. For example, the automotive industry in Argentina, Brazil or Peru already has standards for the flexible use of compressed natural gas and gasoline in vehicles. This can facilitate the reduction of emissions where natural gas distribution networks are already in operation and where electricity transmission networks are congested. On the other hand, in the electricity sector, it is possible to modify coal-fired thermoelectric generation plants to run on natural gas, resulting in capital expenditures up to 30% lower than installing a new plant (EIA, 2020c; Siemens Energy, n. d.).

For example, if 50% of the use of coal and oil-based fuels were replaced with natural gas, a reduction of 157 million tCO_2 e/year would be achieved, equivalent to 6.9% of the region's energy-related emissions, which can be higher if measures are taken to reduce or eliminate fugitive emissions.[19]

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[19] The calculation considers direct, indirect and fugitive emissions proportionally (Table 3.2).

If half the use of coal and petroleum-based fuels were replaced by natural gas, the region's energy-related emissions would decrease by 7%

The availability of natural gas resources in some countries in Latin America and the Caribbean and the lower profile of emissions and local pollutants associated with its use may be an opportunity to help reduce emissions in other countries within and outside this region through integration into liquefied natural gas value chains during the transition. Developing production capacity in the region to occupy an export position may allow for some displacement of global coal consumption, which would contribute to reducing emissions in the short term. Global coal consumption is still higher than that of natural gas, accounting for 27% of primary energy sources (171 TJ), while in the region it represents only 5% (1.6 TJ) (OLADE, 2023b). Even a small share in the global replacement of coal by gas would make it possible to monetize regional gas reserves while contributing to global decarbonization in the short term.

Evaluating natural gas-based strategies

Two key aspects for evaluating the extent to which a natural gas project contributes or not to the reduction of energy-related emissions. First, what the additionality of a project is in the short term. Second, how the project alters the trajectories of use of different energy sources in the long term.

The first aspect consists of determining the actual contribution to emissions reduction that a project implies, carefully considering what would happen to that consumption if the project in question did not materialize. For example, a pipeline project that seeks to replace natural gas imports in favor of a domestic source does not contribute to emissions reductions, although it may be valuable for pursuing other fiscal or sectoral objectives. On the other hand, when such an investment replaces the domestic use of fuelwood, it could contribute to emissions reductions. However, the counterfactual scenario should be carefully considered for this assessment. In the event that these households were on the way to electrifying their consumption, the project could no longer be considered as contributing to emissions reduction.

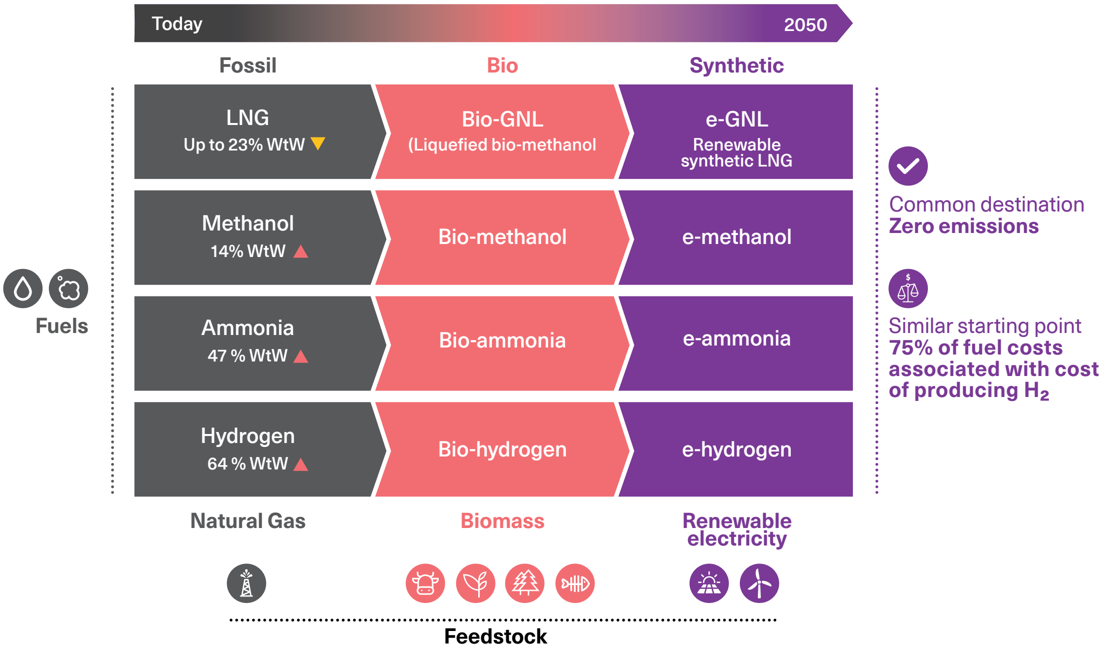
The second aspect concerns how the trajectory of the use of the various energy sources is affected in the long term if gas is promoted in the short term. Although natural gas shows a lower environmental impact than other fuels, it is far from being a carbon-neutral solution. As discussed in the subsection "The current dominance of fossil fuels " both production and equipment investment decisions are likely to further deepen dependence on fossil fuels because of the incentives for the agents involved to extend the use of fuels to the end of the useful life of durable and capital goods.

One way to minimize the risks of the lock-in effect on current decisions is for governments and stakeholders to consider retrofitting equipment for natural gas use as a step in a possible long-term sequence toward decarbonization. Decarbonization paths consider which low-emission energy alternatives are most promising in the long term and the extent to which current alternatives are compatible with that long-term solution.

Two central aspects for evaluating natural gas-based strategies are the additionality of the project in the short term and whether it alters the use of energy sources in the long term

Figure 5.1 presents a schematic example of various decarbonization trajectories mapped out by SEA-LNG, a consortium of gas and shipping companies advocating the adoption of liquefied gas in shipping. This is one of the sectors where fuels are expected to continue to be used in the long term in the absence of disruptive technological advances.

Figure 5.1
Alternative paths for the decarbonization of maritime transport



Note: The figure schematically presents four alternative trajectories for decarbonization of the sector by fuel type with intermediate technological solutions to minimize the lock-in effect. WtW is the acronym for the term "well to wheel," a method to fully and accurately assess the consumption and emissions of an energy source by considering its entire life cycle.

Source: Translated from SEA-LNG (2023).

The framework outlines four alternative pathways for decarbonizing the sector, based on the use of liquefied gas, methanol, ammonia, and hydrogen. Each pathway involves distinct technological solutions, but allows for easy or immediate adaptation between stages within the same pathway, minimizing potential blocking effects. For instance, in the case of liquefied gas, the study suggests that the current adoption of vessels powered by this product, instead of diesel for maritime navigation, could result in emissions up to 23% lower while enabling a direct transition to organically based liquefied gas in the short term and synthetic liquefied gas in the long term.

In conclusion, it is crucial to recognize that halting long-term global warming requires achieving net-zero greenhouse gas emissions globally. This means that any residual use of fossil fuels remaining in the long term, including natural gas, must be effectively offset through carbon capture, use, and storage in other sectors. Therefore, strategies leveraging the attributes of natural gas during the transition to sustainable energy systems must incorporate specific measures to prevent blocking effects that perpetuate dependence on fossil fuels.

The energy transition in hard-to-abate industries

6

Key messages

1

The cement, steel, and chemical industries face significant challenges for carbon reduction due to their strong reliance on fossil fuels and the high emissions associated with their production. Despite these challenges, all three industries are vital to the economy, providing materials that are needed in construction, transportation, agriculture, and a variety of the plastic products people use daily.

2

Given the region's abundant natural resources, Latin America and the Caribbean (LAC) has a strong potential to develop green industries and generate clean energy from renewable sources. To leverage this potential, it is necessary to invest in clean hydrogen, which can be used as a fuel for energy-intensive industries.

3

In just a few years, the region could become a net exporter of steel produced with clean hydrogen, leveraging the goals set on certain markets like the automotive industry, with a zero-emissions target in the short and middle term. In addition, as the hydrogen industry develops, it can be leveraged for the production of fertilizers and plastics with low net emissions.

4

Given the complexities of these hard-to-abate industries, solutions must come from the demand side. Clear examples of this are improvements in the efficiency and use of concrete, greater recovery of steel scrap, the efficient use of fertilizers, and especially, the application of circular economy principles in the use and production of plastic.

5

Carbon neutrality should not be the priority for Latin America and the Caribbean in the short and middle term. Instead, the region should aim to leverage new technologies and markets to improve productivity and be better positioned in segments, in addition to offering carbon rewards.

6

In the cement industry, change could start by replacing coal with biomass whenever possible, given the abundance of this resource in the region.

7

Natural gas will be key in the ammonia industry along with clean hydrogen, enabling the region to benefit from the prevalence of this resource.

8

The emissions of both these industries as well as more energy-efficient ones will be significantly reduced with an increase in renewable generation and with electrification of industries that currently rely on fossil fuels.

9

The importance of carbon capture will increase in the middle and long term as the technology matures and its costs diminish. LAC also has great potential here, as the carbon captured can be reused in the production of ammonia or plastics, injecting it in depleted oil fields or using it for enhanced oil recovery.

The energy transition in hard-to-abate industries[1]

Introduction

The industrial sector generates 11% of direct greenhouse gas (GHG) emissions and 24% of the energy emissions of Latin America and the Caribbean. When the data is broken down by subregions, the number differs in the Caribbean, where industry is responsible for 25% of direct emissions and 28% of energy emissions (Minx et al., 2021).[2] The higher percentages in this subregion can partially be explained by the high industrial emissions of Trinidad and Tobago, a carbon-intensive nation due to its extraction and use of fossil fuels. In terms of industry, just three sectors are responsible for 57% of these direct emissions: the steel, cement, and chemical industries (Minx et al., 2021).

Besides high emissions, these three industries have three things in common.

- They are essential to modern economies. Cement is critical for construction; steel, for diverse industries like construction and transportation; and chemical products, for agriculture and the plastics industry, among others.
- They are carbon-intensive. All three of these industries are energy-intensive as they traditionally rely on fossil fuels to power their production.
- They currently have few viable alternatives to reduce carbon emissions associated with production in the short term.

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[1] This chapter was written by Juan Odriozola with research assistance from Franco Degiuseppe.

[2] The countries that Minx et al. (2021) evaluated in each subregion can be consulted in the annex of this chapter available online..

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Industry is responsible for 11% of direct greenhouse gas emissions and 24% of the energy emissions in Latin America and the Caribbean

Industries that are more energy efficient are mainly characterized by a need for low or medium-temperature processing in their production. Two industries stand out in this regard: food processing, followed by mining. In general, the demand for energy in these sectors is for electricity or fossil fuels for engines or processing machinery and they represent nearly half of the energy demand of the region's industrial sector. Therefore, companies from these sectors should consider the efficiency standards for engines, electrification, the adoption of heat pumps, the use of biofuels, and self-generation to efficiently reduce emissions. Carbon reduction of the electric grid in countries of the region will also have a direct impact on these industries and this will become even more important as these sectors undertake electrification themselves (IEA, 2023l).

The economies of Latin America and the Caribbean have become less complex over time. This has translated into lower energy intensity with respect to the global average. For example, fossil fuels for processes requiring high temperatures represent 50% of industrial energy use in the region, significantly less than the global average of 65%.

This region faces two main obstacles to a rapid energy transition in industry. The first is the high cost of capital: in Brazil and Mexico, for example, the cost of capital was two or three times higher than in China, Europe, or the United States in 2021. The second obstacle is directly related to the first. The costs of financing for the economies of Latin America and the Caribbean are relatively high, a problem associated in part with the region's economic instability. For example, the yield on sovereign Brazilian bonds in the local currency was 12% in 2023, and in Mexico, nearly 9%. This means these bonds yield two or three times more than those of the United States or European countries. Additionally, domestic financial systems are underdeveloped in Latin America and the Caribbean (IEA, 2023l).

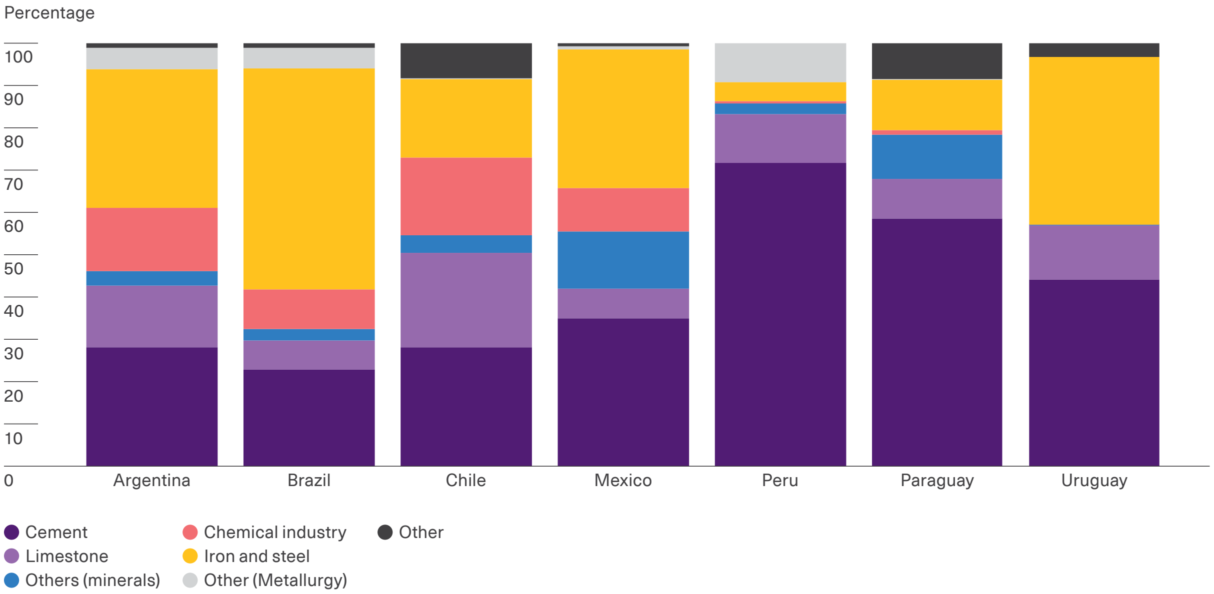
This chapter describes the most important features of industries that face the greatest obstacles to the energy transition, their emission patterns, and viable alternatives for reducing carbon emissions, with a focus on the energy transition. It also explores the technical aspects and specific policies affecting these industries but does not delve into cross-cutting policies like the prices of carbon, given that this is outside the scope of this chapter. Besides a description of the characteristics of the energy-intensive sectors –the cement industry, the steel industry, and the chemical and petrochemical industry– an in-depth analysis of each will be offered.

Description of energy-intensive sectors

Energy-intensive industries are responsible for 13% of energy emissions and 6% of direct emissions in Latin America and the Caribbean. If the two subregions are analyzed separately, direct emissions from energy-intensive industries in Latin America account for approximately 6% of total emissions, while the number in the Caribbean is closer to 12% (Minx et al., 2021). Other sources that consider overall industry emissions report even higher values. According to the United Nations Economic Commission for Europe, these industries account for 25% of greenhouse gas emissions and 66% of those of the industrial sector globally (UNECE, 2021), According to Pupo and González (2023), emissions from these sectors in Latin America and the Caribbean account for 15% of the region's overall emissions and 90% of industrial sector emissions. The numbers for industry are similar to those reported by countries in the region (Pupo and González, 2023) (Graph 6.1).

In terms of the three industries that are the focus here, steel and iron account for 1.7% of direct emissions in LAC and 15% of direct industrial emissions in the region; the cement industry accounts for 1.3% of direct emissions in the region and 12% of industrial emissions; and the chemical industry, 3.4% of direct emissions and 30% of industry-wide emissions (Minx et al., 2021). Graph 6.2 shows the emissions and energy use of these sectors. As can be seen on the graph, ammonia and high-value chemicals (HVC)[3] have the highest energy consumption, requiring 46 gigajoules per product ton (GJ/t) and 80 GJ/t, respectively, and releasing between 1 and 2.4 tons of carbon dioxide per product ton (tCO$_2$/t). Although cement is much less energy-intensive than the other industries considered, 0.6 tCO$_2$ is released for every ton of cement.

Graph 6.1
GHG emissions from industrial processes in select countries of Latin America, 2018



Note: The graph draws on public information from greenhouse gas inventories in the selected countries. The "other" category includes (i) the use of fuels and solvents for non-energy purposes, (ii) the electronics industry, (iii) manufacturing and the use of manufactured products, (iv) the pulp and paper industry, and (v) the food and beverage industry. Category 2F of the 2006 Intergovernmental Panel on Climate Change Guidelines [IPCC, 2006], emissions associated with "substitutes for ozone-depleting substances" has been excluded.

Sources: Mexican Department of the Environment and Sustainable Development (2019); MCTI (2022); MMA (2020); INECC (2018); MADES (2020); MINAM (2020) and the Uruguay Ministry of the Environment (2020).

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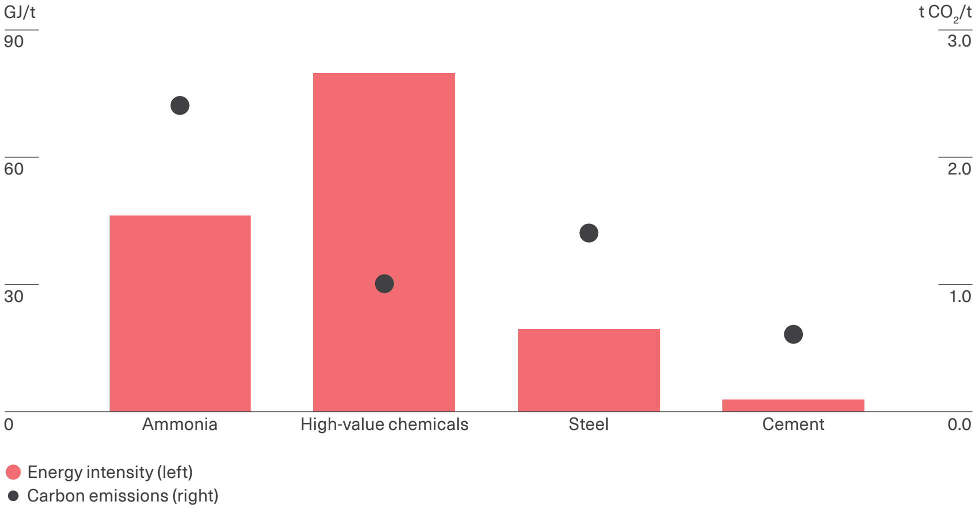
[3] Methanol is not considered here as numbers were not available; however, according to the International Energy Agency (IEA, 2021a), its energy intensity is approximately 40 Gj/t and its carbon emissions, 2.2 tCO$_2$/t.

Graph 6.2
Energy intensity and carbon emissions



Source: Author based on data from IEA (2021a)

Cement, steel, and chemicals are carbon-intensive industries, with limited alternatives for mitigation, yet essential for modern economies

The importance of these industries for economic development can be observed in the evolution of demand for their main products. From 1990–2020, global demand for steel multiplied by 2.5, while the demand for cement and plastics multiplied by over 3.5 (IPCC, 2023). For comparison purposes, GDPs grew by 2.5 times during these same years and the global population, by 1.5 (IPCC, 2023). While manufacturing is not the largest industry in LAC countries, it accounts for 13% of all employment in the region and also 13% of the GDP (ALACERO, 2021). As explained further on, the energy transition represents an opportunity for the development of this industry in the region. Graph 6.3 shows the added value of these three industries together in the countries selected, based on available data. It can be observed that heavy industries have a lower impact in countries like Panama and Uruguay, accounting for less than 3% of value added to the economy, while in Peru, it accounts for nearly 13%.

Finally, with regard to energy intensity, measured as energy use with respect to value added, and carbon intensity, measured as the equivalent quantity of CO_2(Co2eq) over added value,[4] the countries in the region vary significantly. Graph 6.4 shows the carbon and energy intensity for some Latin American and Caribbean countries. As shown on the chart, though there is a positive correlation between these two measurements, countries like Costa Rica, the Dominican Republic, and Uruguay are highly energy-intensive, but their carbon intensity is significantly lower than the main industrial producers like Argentina, Brazil, and Mexico.

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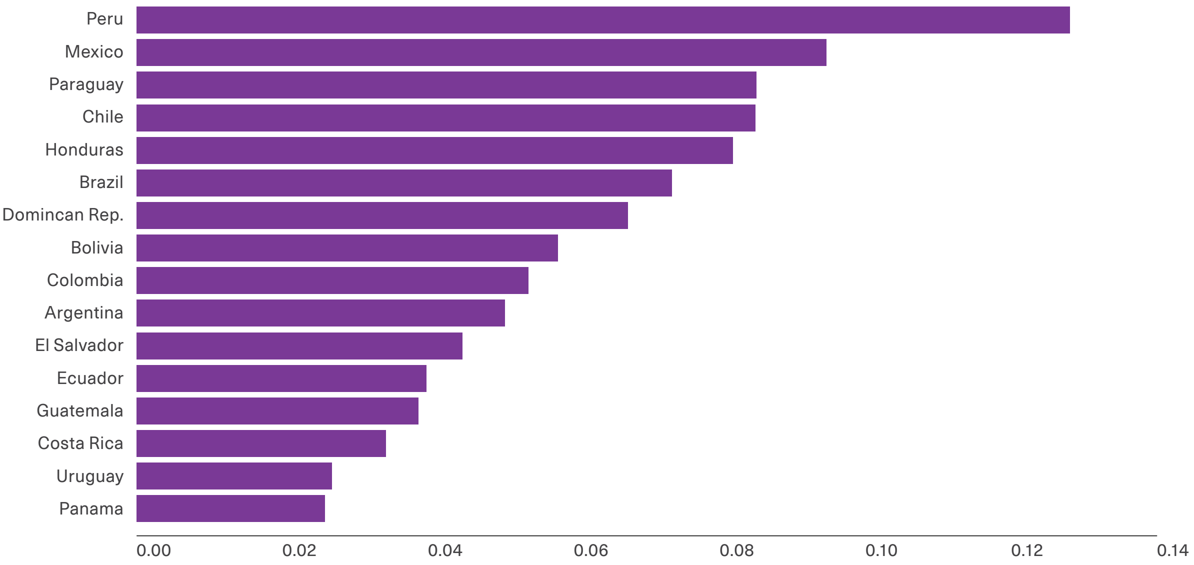
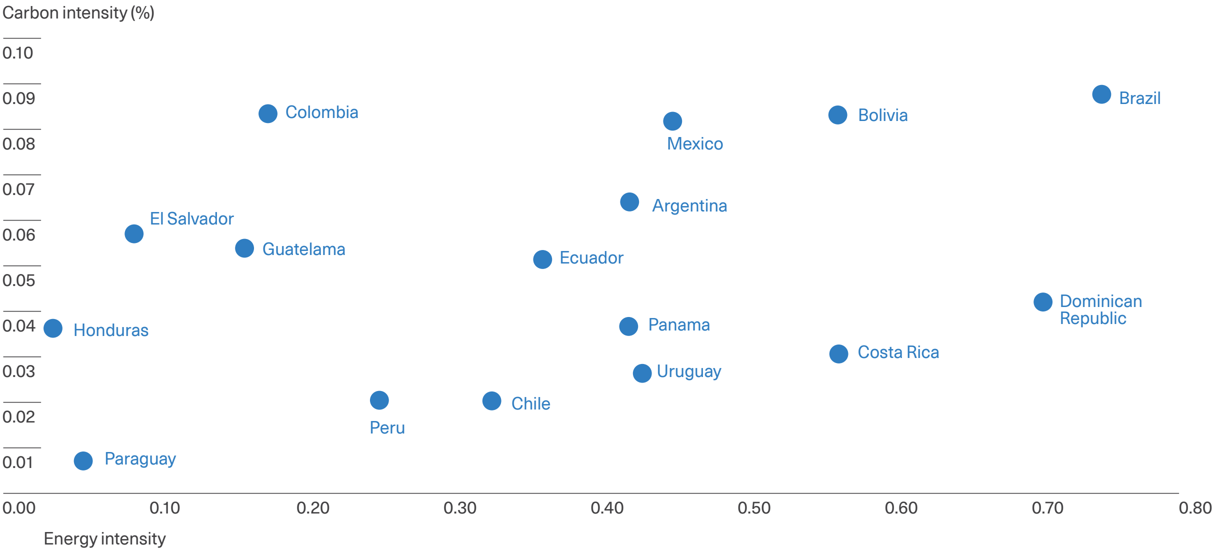
4 CO_2eq is a measure that enables a comparison of total GHG emissions.

Graph 6.3
Proportion of value added by heavy industries to the aggregate value added of LAC countries in 2017



Source: Author based on data from Aguiar et al. (2022).

Graph 6.4
Relation between carbon intensity and energy intensity in the heavy industry of LAC countries in 2017



Source: Author based on data from Aguiar et al. (2022).

Box 6.1

A case of early private investments in energy transitions

The Carrasco International Airport in Montevideo, Uruguay, was a pioneer in the generation of renewable energy. In 2015-2016, major works began at the airport to improve energy efficiency and the sustainability of related infrastructure. In 2018, the ribbon was cut on its solar plant, making it the first airport in Latin America to rely on this renewable energy source. The panels use sun tracking technology, which allows for an increase in energy capture of around 23-24% in comparison to fixed solar panels. In order for the panels to be correctly installed, an investment was made in planning to avoid the interference of glare for landing and departing planes.

Besides this ambitious project, other investments were made in the airport's energy transition: gas boilers were replaced by electric heat pumps; LED lights were installed; and newer model air conditioning fans were installed. Recently, artificial intelligence has been used to modulate the influx of air conditioning ventilation in order to use electricity as efficiently as possible and track the air quality to guarantee quality inside buildings. There was a proposal to expand the solar power station and invest in a wind park off-premises, but Uruguayan legal restrictions prevented this from moving forward.

The airport is certified under ISO 14064-1 and has attained level two of the Airport Carbon Accreditation (ACA) program, in recognition of the quantification and steps taken to reduce greenhouse gas emissions.

The project received support from Uruguay's Commission for the Applications of Investments Act (COMAP), which supports investments and grants exemptions on taxes, tariffs, and duties. This initiative, along with the efficiency enhancements the project attained, allowed a recovery of the total investment in less than four years. It is important to note that the cost of solar panels has fallen drastically since the investment in the airport. This is further evidence that, with adequate planning, regulation, and financial support, private sector projects can drive the energy transition with an eye to enhanced efficiency.

Source: Author based on interviews conducted specifically for this report with Jorge Navarro, engineer and Corporate Management of Airport Infrastructure and Maintenance in Uruguay.

Cement

Cement is second only to water as the world's most consumed product (UNECE, 2021; Zhu et al., 2022) and demand for cement is expected to grow between 12% and 23% by 2050 (IEA, 2018a). At the same time, cement is the industrial product with the highest CO_2 emissions per revenue dollar. For every revenue dollar, 6.9 kilograms (kg) of CO_2 are generated. In comparison, for steel, this ratio is 1.4 kg of CO_2 per dollar, and for chemicals, 0.3 kg of CO_2 per dollar (Czigler et al., 2020). In Latin America and the Caribbean, Argentina, Brazil, Colombia, and Mexico are all large cement producers; together, these four countries account for 75% of regional production. Cement has a low-value ratio in relation to its weight. In other words, its freight cost is high but its storage cost is low (Kusuma et al., 2022). For that reason, most cement is consumed locally, with some exceptions in the Caribbean islands. Therefore, this is an important industry to the construction sector in most of the countries of the region. According to a report by the Inter-American Cement Federation (FICEM, 2019), cement consumption is equal to or less than production in most countries in the region. The main exception is Surinam, where consumption is two to four times greater than production. In Chile, El Salvador, Jamaica, Puerto Rico, and Trinidad and Tobago, domestic cement production accounts for at least 80% of overall consumption.

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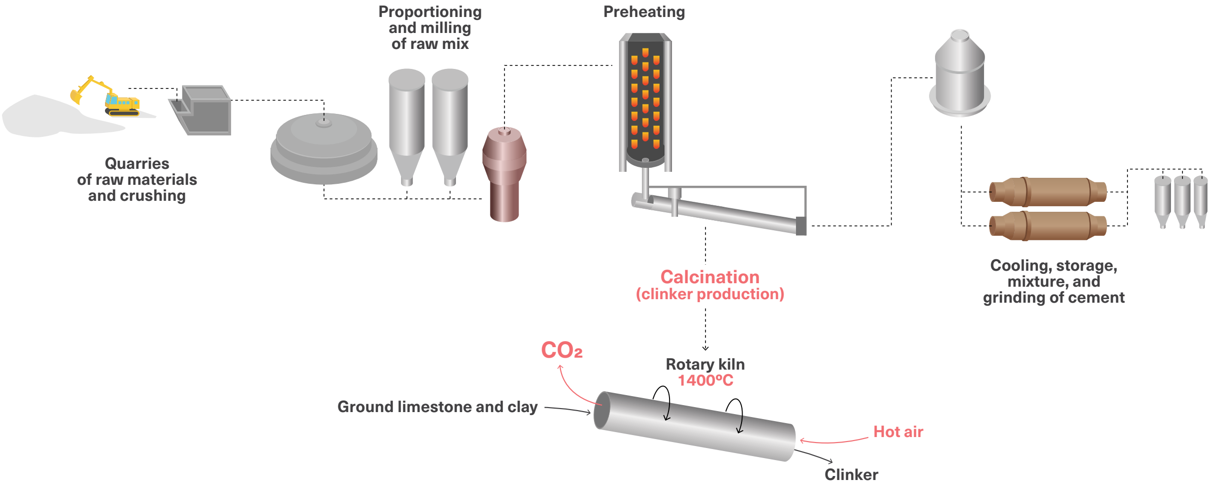
Most of the cement consumed is produced locally, making this industry important to the development of the building sector in most countries in the region

Besides the CO_2 that cement production generates, a range of local pollutants are released during the mining of the main cement inputs and in the production process itself. During cement production, ash and solid wastes are created, along with rock particles and dust, which contain air contaminants like particulate matter (PM).[5] Large quantities of nitrogen oxides (NO_x) and, to a lesser degree, sulfur dioxide (SO_2) are also released during cement production (Kusuma et al., 2022). These air contaminants can affect people's health and break down into $PM_{2.5}$[6] in the atmosphere. In the various stages of cement production, water is used for cleaning systems and mixed with cleaning products and iron particles, among others, that contaminate the water (Adeyanju et al., 2020; Zhu et al., 2022). For this reason, the cement industry needs to invest in efforts to satisfy the expected increase in demand while minimizing environmental harm.

Figure 6.1
Cement production process



Source: Author based on UNECE (2021).

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[5] Particulate matter is a mixture of solid and liquid particles found in the air. Inhaling these particles can cause health problems like asthma and dementia and raise the mortality rate associated with respiratory ailments.

[6] The number refers to the size of the particulates in micrometers. $MP_{2.5}$ is the particulate matter that poses the greatest risks to health.

Box 6.2

A case of private initiatives with demand-driven solutions

RCD Reciclaje is the first processing plant for construction waste in Uruguay. The company's work starts at construction sites, where it classifies waste and transports the clean debris for processing at its plant. Using an electric crusher, this waste is transformed into recycled aggregate, which is employed as a raw material for the manufacturing of different recycled concrete products: ecological pavement, street furniture, and planters, among others. Although the recycled concrete has not yet been used for structure projects, the company is working on a project with the School of Engineering to assess the viability of using this material in such projects. Besides these products, the company offers integral waste management plans aligned with the principles of the circular economy.

The recycling and valorization process has two important impacts on sustainability: first, it allows different types of construction waste to be classified and reduces the quantity of waste that ends up in municipal dumps. Second, it reduces emissions associated with the demand for cement. Though cement is used to produce recycled concrete, the reuse of existing concrete means that fewer raw materials need to be mined, thus reducing the emissions associated with cement production. In addition, the recycling process means less energy is consumed in cement manufacturing with virgin raw materials.

Uruguay's Waste Management Act seeks to prevent and reduce negative impacts in waste generation and management. RCD Reciclaje was distinguished by the Network of Companies for Sustainable Development (DERES) of Uruguay for complying with Sustainable Development Goal 11 on sustainable cities and communities and SDG 12 on sustainable consumption and production. It has also received the “Uruguay Circular” award in the small business category from the Partnership for Action on Green Economy (PAGE), the National Development Agency (ANDE), and the United Nations Industrial Development Organization (UNIDO); and the “Uruguay Natural,” national environmental award from the Ministry of the Environment.

The company currently works in Montevideo and the metropolitan area, though it is evaluating a mobile plant project to expand its geographical reach.

Source: Author based on interviews conducted specifically for this report with Giannina Ceruti, director and co-founder of RCD Reciclaje.

In order to understand how these emissions and damages can be minimized, it is important to understand how cement production works. Cement is made by milling raw materials, mainly limestone and clay, and converting them into powder. Later, the powder is heated in high-temperature kilns (1,450°C), producing cement clinker, which is mixed mainly with gypsum to create the final product. When the entire value chain is analyzed, from quarry to construction logistics, the manufacture of the clinker accounts for 86% of emissions (UNECE, 2021). Of this 86%, 60% comes from the calcination of calcium carbonate ($CaCO_3$). In this process, once the temperature in the kiln rises above 900°C, the calcium carbonate is turned into calcium oxide (CaO), releasing CO_2:

$$CaCO_3 \leftrightarrow CaO + CO_2$$

The remaining 40% is produced by the burning of fuels for the calcination process. Coal is the most commonly used fuel for the production of clinker. The burning of coal produces the highest CO_2 emissions of any fossil fuel. For every ton of cement products, between 700 and 935 kg of CO_2 is released (Bernstein et al., 2007). The range

can be explained by different levels of energy efficiency, the carbon intensity of the fuel utilized, the carbon intensity of the energy used, and the clinker content in the cement.

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The manufacturing of clinker, cement's main input, is responsible for 86% of emissions of the whole cement value chain

Given the pattern of emissions in cement production, the options for mitigation and energy efficiency can be addressed in two different ways. First, energy efficiency policies can lead to a reduction in the burning of fossil fuels and produce cement more efficiently. Second, policies can target a reduction of the direct emissions from the calcination process. These emissions are harder to mitigate, given that they stem from the chemical reaction caused when calcium carbonite is exposed to extremely high temperatures. The main alternative, in this regard, is to reduce the content of clinker in the final product, given that the production of this input is the cause of higher emissions, or use inputs other than clinker.

Technologies for the energy transition

In terms of the energy use of the cement sector, 100% of the thermal energy used in cement products is used to obtain clinker, while the milling and packaging processes mainly rely on electric power (Pupo and González, 2023). These data support the idea that clinker production is where more innovation and improved energy efficiency are needed.

The two main advances to be made in terms of energy efficiency are modern kilns, which have a better ratio of energy consumed versus products obtained, and alternative fuels such as biomass and waste in the burning process (IEA, 2018a). More than 65% of the global production of clinker uses rotary kilns with a precalciner and suspension preheaters (Marmier, 2023), which are the most efficient way to reduce the emissions released during the heating process (Heincke et al., 2023). The precalciner offers the advantage of improving the cement decomposition rate, lowering the thermal charge of the rotary kiln, reducing the size of the kiln, and enabling large-scale production (Zhu et al., 2022). In practice, this translates into lower NO_x emissions and greater recovery of the heat generated, which means lower electric and fuel consumption and consequently, reduced CO_2 emissions. These kilns, accompanied by heat recovery boilers, could decrease energy consumption at plants by two-thirds (IEA, 2018a). In Latin America and the Caribbean, only 65% of plants use precalciners, meaning there is a margin for improvement that could result in fewer emissions and a more energy-efficient process (Kusuma et al., 2022).

The useful life of a cement plant is between 40 and 50 years. The average age of cement plants globally is 18,[7] while it is 29 for Latin America and the Caribbean (Liu et al., 2021). The age of plants is essential for the energy transition. Kilns that have been operating for more than 20 years, which is far from full depreciation, are generally less efficient. Companies will be reluctant to invest in replacing these kilns for energy efficiency when they are so far from full depreciation. Generally, plants at the beginning of their useful life are more efficient. This is the case in the Dominican Republic, where more than 80% of cement production occurs in factories less than 15 years old. Pupo and González (2023), for example, have shown that the energy consumption of cement plants there is significantly

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7 Calculated using data from the Global Infrastructure Emission Database (GID) (http://gidmodel.org.cn/). The average age is calculated based on the plant's capacity. The age of plants is charted in five-year intervals, using the halfway point of the range to calculate the average.

lower than those of the region's largest cement producer, Brazil. According to a report by FICEM (2019), Latin America and the Caribbean are in the process of modernizing their plants.

In terms of fuel use, biomass is the most energy-efficient option with the lowest emissions. While still growing in the forest, wood biomass captures carbon, meaning that the net emissions are significantly lower than the carbon released when that biomass is burned. Other biomass inputs used are agricultural waste and even selected domestic food waste (Mathioudakis et al., 2021). In this regard, Latin America and the Caribbean has great potential due to the natural conditions that enable a stable biomass production chain for this use. Biomass can already be used to replace 20% of cement industry fuels without any capital investments (Rahman et al., 2016), though these fuels require pretreatment due to their moisture level and high oxygen content (Bui et al., 2017; Cortada Mut et al., 2015). Biomass currently accounts for less than 5% of fuel utilized in developing countries, with the exception of Brazil, where it accounts for 40% (IEA, 2018a).

In its Net Zero Emissions by 2050 Scenario (NZE Scenario), the International Energy Agency (IEA) forecasts that the cement industry will require mainly innovative technologies to achieve its goals in this area, among them, carbon capture. The IEA assesses the maturity of technology for its predictions. Besides carbon capture, use, and storage (CCUS), technologies that could moderately improve energy efficiency are electrification through heat generation, heat generation through solar energy, the use of hydrogen, and enhanced efficiency in the grinding process. However, the projected reduction in emissions as a result of these improvements is less than 40% of the emissions that could be mitigated through clinker reduction or carbon capture (IEA, 2018a). Finally, hydrogen is a potential energy substitute that is in the early stage of implementation. The clean hydrogen industry is discussed in Chapter 5, while carbon capture is discussed in greater detail in Chapter 10.

The most promising alternative for lower carbon emissions is reducing the use of clinker for cement production. Clinker (or clinker factor) makes up more than 90% of standard Portland cement, which is used in the United States. In the rest of the world, the clinker content is significantly lower. In Latin America and the Caribbean, the clinker factor is 71%, though in countries with high cement production, like Argentina and Brazil, the clinker factor is under 70%. In its NZE scenarios, the IEA proposes that the clinker content of cement fall to 60% by 2050. Early resistance to cement compression lessens as clinker contents are reduced. In other words, to reach the 60% goal, alternative inputs to clinker must be used.

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Using biomass for heat generation and biomass ash as a substitute for clinker holds significant potential for decarbonization in Latin America and the Caribbean

The main options currently viable for reducing the clinker factor are fly ash, produced when coal is burned, and granulated blast furnace slag (GBFS), a waste product of steel produced in a blast furnace. This input is currently viable and there are already regulations in place that allow cement comprised of 95% GBFS to be produced in Europe (IEA, 2018a). In terms of fly ash, cement can contain between 25-35% of this material (IEA, 2018b). As can be seen, the two most viable options are those that utilize waste from carbon-intensive processes. The hope is that the availability of both these waste materials shrinks in the long term (Kusuma et al., 2022) due to reduced use of coal and tech advances in the steel industry, which will be discussed in the next section.

Other options include natural pozzolans obtained from volcanic ash or rock sediment, biomass ash, or silica fume. However, these materials are not widely available and are also in demand for other industries. Calcium carbonate is another substitute but it requires sophisticated measures in production and use (ECRA, 2017). Biomass ash is an alternative that can supplement the use of biomass as a fuel substitute but it has a high environmental impact (Teixeira et al., 2016). The sources of biomass ash can be forest and demolition wood, straw, sewage and paper sludge, manure, and agricultural waste (Kusuma et al., 2022). Although this ash can be used to replace up to 80% of cement clinker (Campos Teixeira et al., 2020), some studies have shown that this route requires more water and a longer prep time (Khalil et al., 2014; Medina et al., 2017). Because biomass ash can later be used as a replacement for clinker, the use of biomass for heat generation offers great potential as the region pushes to reduce its emissions.

Policies to achieve emissions reduction in the cement industry

There is limited information on the economic viability of options to reduce emissions in the cement sector, especially for Latin America and the Caribbean. Globally, Heincke et al. (2023) have shown how replacing clinker with ash and waste products and increasing the quantity of biomass used as fuel would result in a negative net cost per ton of reduced carbon. A study for the United States shows that the production of cement from calcined kaolin clay can increase net profits by 20%, reducing emissions by 37% (Khung y Crete, 2022). The study also shows how production with GBFS and fly ash can increase net profits by around 7%, while the reduction in emissions would be between 43% (GBFS) and 27% (fly ash). In another study in the United States, Shwekat and Wu (2018) noted that if the social cost of carbon, the harm to natural resources, and air pollution are considered in the cost-benefit analysis, a cement comprised of around 20% fly ash could result in a negative production cost, mainly owed to the environmental impacts of substituting this material in cement production. However, the IEA et al. (2023) revealed that, in general, low-emission technologies are, in the case of cement, 75% more expensive than traditional production.

In the case of concrete, Khan et al. (2020) have shown that in India, the cost of production of green concrete (i.e., cement made with 50% fly ash) is 10% lower than that of traditional concrete, though the properties of both types are comparable. Gallardo and Elevado (2017) noted that cement made of 75% fly ash improves the quality of concrete, reducing the emissions associated with the use of concrete and lowering production costs by up to 12.5%.

In order to analyze the sector-wide policies that should be supported in Latin America and the Caribbean, it is important to view the cement sector and construction in the context of the region. In LAC, 20% of the urban population lives in slums, where houses rely on a great amount of low-quality materials (Villagrán-Zaccardi et al., 2022). These houses are made of concrete with a high context of cement mix, which is not only inefficient but also creates a greater carbon footprint. At the same time, the region has taken steps toward reducing carbon emissions by decreasing the amount of clinker in cement and adopting state-of-the-art kilns. At the same time, the availability of the main clinker substitutes like slag and fly ash has fallen in the region (Villagrán-Zaccardi et al., 2022). The other main step toward reducing carbon emissions, carbon capture, is a technology that is currently too expensive for the region. Finally, construction is a sector largely characterized by lax compliance, and technical regulations and building standards are often lacking.

Table 6.1

Policies for the cement industry

Challenge	Goal	Policies
Increased demand for cement and high carbon intensity associated with the direct emissions of clinker production	Reduced use of clinker	Education about the efficient use of concrete
		Adoption of technical regulations on the composition and performance of cement
		Promotion of circular economy principles and concrete recycling
	Replacement of clinker with alternative inputs	Investments in connections between biomass producers and cement plants to foster increased use of biomass as an energy source and clinker substitute

As a result, in terms of policy, there are three main focuses to reduce emissions in the cement sector in Latin America and the Caribbean. The first is fostering the use of biomass as a fuel and biomass ash as a clinker substitute. To achieve this, adequate infrastructure is needed to transport materials between cement plants and biomass sources. In addition, it could be useful for such infrastructure to be located in industrial areas; among other benefits, this could reduce shipping costs. The role of farmers in the region and the concentration of the population in a handful of urban centers facilitate the pickup of organic waste and should be leveraged. The second focus lies in further improving efficiency in the use of cement. To achieve this goal, training is needed, as are new technical regulations, building codes, and initiatives to promote compliance in the sector. Finally, with regard to the two policies cited above, waste circularity should be promoted, reusing concrete and industrial wastes for burning and improving efficiency in the use of cement and concrete. It is useful to note that, given the lax compliance of the sector, the fact that a great part of cement is supplied locally, along with the low-profit margins and high competition in this sector, could hinder regulations such as carbon pricing for this industry. This is because law compliance will prevent the application and adequate oversight of this tax, while actors in compliance will be severely affected by the policy, creating an unfair disadvantage in an already competitive sector.

> **The main mitigation policies in the cement sector should focus on circular economy principles, the adoption of technical regulations, and the replacement of clinker with alternative inputs**

In Latin America and the Caribbean, FICEM is an organization that represents cement producers, organizations, and associations in the region, Spain, and Portugal. Part of FICEM's mission is to encourage sustainable development in the cement industry. FICEM is a member of the Global Cement and Concrete Association (GCCA) and is following the association's roadmap for carbon-neutral cement and concrete by 2050 (GCCA, 2021). Ten countries in the region already have FICEM roadmaps[8] to reduce emissions in cement production: Argentina, Chile, Colombia, Costa Rica, Guatemala, Honduras, Mexico, Panama, Peru, and the Dominican Republic. Additionally, Brazil has drafted its own. Together, these countries are responsible for 90% of the cement produced in the region (GCCA, 2021). These documents reveal that

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[8] A roadmap is a document or strategic plan laying out the steps or key milestones necessary to achieve a specific goal.

the region is working to modernize this sector and reduce emissions, mainly by decreasing the clinker factor and upgrading kilns. However, there is room for improvement in four key aspects. The first and most important is continuing to reduce the clinker factor; the second is to continue upgrading kilns; the third is to increase the rate of substitution for fossil fuels; and the fourth, to reduce emissions for power generation or encourage self-generation with clean energies in cases where this proves efficient (GCCA, 2021).

Iron and steel

Globally, the steel sector is the main industrial consumer of coal. Coal accounts for 75% of the steel sector's energy demand and 25% of its global emissions (IEA, 2020d). In the region, for example, the Brazilian iron and steel industry uses more than 72% of all charcoal produced in the country. Brazil is the largest producer of charcoal worldwide (van Dam et al., 2017). The steel made in Latin America and the Caribbean accounts for 4% of global production. Brazil and Mexico are the two largest producers, accounting for 84% of the region's steel, followed by Argentina (8%), Peru, Colombia, and Chile (2% each) (ALACERO, 2022).

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The steel sector is the main industrial consumer of coal, an input used to generate high temperatures

Steel is the third most abundant bulk material, exceeded only by cement and wood, and it is highly durable, resistant, recyclable, and low-cost (AIE, 2020d). Nearly 50% of the steel produced is used in construction. The second and third consumers of steel are the automobile industry and mechanical equipment (17% each), while metal products account for 12% of steel use (ALACERO, 2022). The production capacity of raw steel has doubled in the past 20 years, and 85% of this growth took place in developing countries, mainly China (IEA, 2020d). The strong rise in the steel demand led to larger fleets of steel furnaces. Given that the useful life of these facilities is an estimated 20-24 years, the rapid growth of steel plants poses a quandary. On average, these newer furnaces have been in use for 13 years. If they are used until the end of their useful life, the emissions of these furnaces could exhaust most of the carbon budget for the steel industry (IEA, 2020d). If not used to maximum capacity, the sector will have an enormous fleet of idle furnaces. At the same time, the IEA estimates that the global steel demand will rise by more than one-third compared to its current levels by 2050. For that reason, the sector is under great pressure to reduce its production emissions and meet the growing demand with a relatively young fleet of furnaces in developing countries.

In terms of the sector's carbon emissions, the production, finishing, and distribution of steel accounts for 95% (Zoryk and Sanders, 2023). These emissions are mainly attributed to high energy consumption, as fossil fuels are the main source used. The sector accounts for 20% of the energy used by industry globally and 8% of all energy use worldwide (IEA, 2020d). Steel can be produced in two ways. The most common is primary steelmaking, which accounts for 70% of global production and involves obtaining steel mainly from iron ore. Generally, a blast furnace-basic oxygen furnace (BF-BOF) is used. In this process, the blast furnaces are fed with iron ore, coke, coal, natural gas, carbon monoxide, and hydrogen to produce molten iron. Limestone and dolomite are added to control impurities in the process. A ton of molten iron produced with this method requires nearly 15 GJ of energy and generates, on average, 2.2 tons of CO_2 (IEA, 2020d). The molten iron is later used in the blast furnace steel mill with scrap to produce the steel.

All the raw materials utilized in iron production are carbon-intensive. The extraction of iron ore accounts for 4% of the emissions of the product's entire value chain (Zoryk and Sanders, 2023). These emissions can be reduced mainly through electrification and through renewable electricity supply. However, mineral ore must be prepared before it is used. This involves heat and pressure and requires coal, coke, natural gas, and electricity. The coal and natural gas used for the processing of the iron ore and the iron production itself are both fossil fuels with high carbon emissions. Coal, however, is a more carbon-intensive fuel, as it produces twice the amount of CO_2 as natural gas (EPA, 2009). Coke is a reducing agent with a high carbon content that is produced through coal combustion. This accounts for nearly 16% of global carbon utilization. Carbon monoxide and hydrogen, both of which are used in this method, are carbon-intensive, as they are mainly produced from coal and coke. Finally, limestone and dolomite release CO_2 as they burn, as explained in the manufacture of cement.

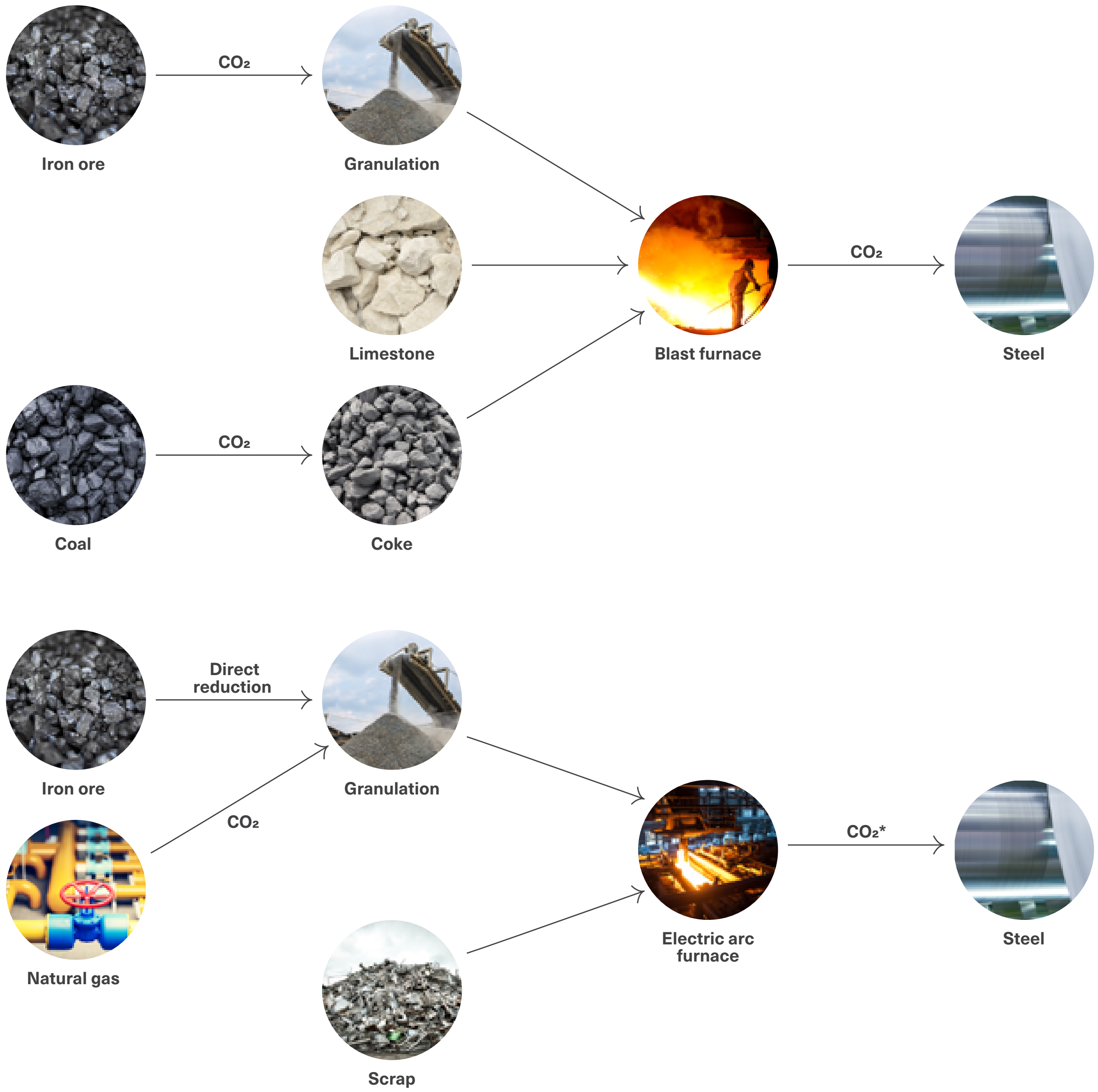
An alternative to this process, which currently accounts for only 10% of primary steelmaking, is direct reduction of iron (DRI), using first natural gas, and later, electric arc furnaces (EAF). The three main differences between this process and the previous one are that it requires high-quality iron ore; hydrogen, as a reducing agent (which is generated using natural gas instead of coke); and a great amount of energy, mainly electricity and natural gas (IEA, 2020d). This method is less GHG-intense, principally because it uses little or no coal or coke, and has a high potential for carbon emissions reduction if clean energy is used. If the carbon intensity of electricity generation is taken as a global parameter, this route currently involves, on average, 1.4 tCO_2 emissions per ton of raw iron, of which 0.4 tCO can principally be attributed to secondary emissions from the electricity used. This is a little under two-thirds of the emissions released using the BF-BOF. With a 100% green power grid, these emissions would be less than half compared to primary steelmaking that relies on BF-BOF. The scarcity of high-quality mineral ore is the main limitation to broader use of this route (Zoryk and Sanders, 2023). Only 4% of the mineral ore available worldwide is adequate for DRI (Nicholas and Basirat, 2022), and Brazil is the world's main supplier of this mineral (Franklin Templeton, 2023).

Secondary steelmaking involves producing steel mainly from scrap and is done in electric arc furnaces, which are powered by electricity instead of coal. In this method, the iron ore in a solid state is reduced using natural gas derivatives, instead of smelting it in the furnaces. Although this method releases significantly less GHG, it is not a viable route to satisfy the estimated spike in the demand for iron by 2050, given that it requires scrap for its production. Therefore, primary steelmaking will be necessary for the initial manufacture of steel using mineral ore (Blank, 2019). Annually, nearly 700 million tons (Mt) of scrap are used in this route, while 1,870 Mt tons of raw steel are produced each year.

The use of electric furnaces in steel production in Latin America and the Caribbean is higher than the global average

One thing that sets Latin America and the Caribbean apart from the rest of the world is its use of both production methods to similar degrees. In Brazil, primary steelmaking is predominant, accounting for nearly 75% of production, a number similar to the world average. In Mexico, however, secondary steelmaking accounts for over 80% of production. In the rest of the region, the secondary route is also more prevalent (Pupo and González, 2023). This predominance of the secondary route and the fact that the electric grid in Latin America and the Caribbean is relatively clean explain, in part, why the emissions per ton of steel are lower in the region than the global average. In 2010, emissions in steel production (measured in kg of CO_2/t) were 12% lower than in the rest of the world and 25% lower than in China, the world's largest iron producer, with more than 50% of total production (ALACERO 2021).

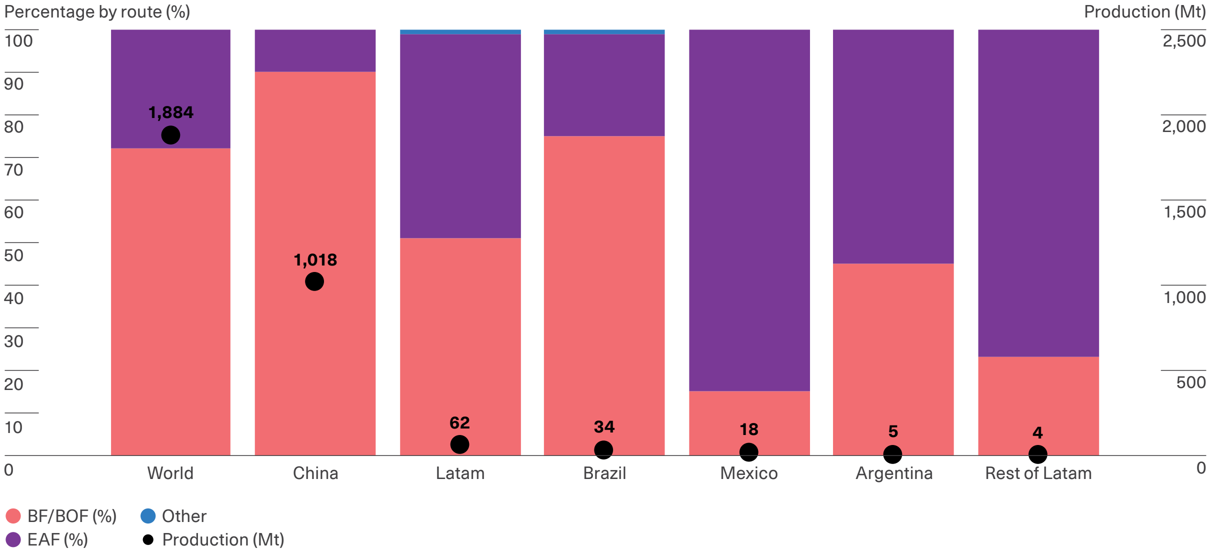
Figure 6.2
Steel production process



* The intensity of emissions from the process will depend on the intensity of emissions from the electrical grid.

Source: Author.

Graph 6.5
Production of raw steel by method



Source: Author based on data from Pupo and González (2023).

Besides its high CO_2 emissions, iron production produces other contaminants, including the main air contaminants (SO_2, NO_X, and $MP_{2.5}$) (IEA, 2020d). By releasing heavy metals, the manufacturing process also contaminates the soil (Khudhur et al., 2018; Yang et al., 2018). One of the co-products of steel manufacturing, slag, is also a contaminant. Every ton of steel made in primary steelmaking results in 400 kg of slag, while the electric arc furnace method produces around half of this co-product (World Steel Association, 2018). Handling slag involves safety risks and storage is costly. However, the product is frequently used as fertilizer and can replace clinker in cement production (IEA, 2018a).

Technologies for the energy transition

Unlike cement emissions, most iron emissions are attributable to energy consumption, given that the furnaces need a great deal of power to reach high temperatures. Therefore, tech solutions to reduce emissions in this sector are mainly focused on the substitution of fossil inputs, improved efficiency, electrification, and carbon capture through use or storage.

In its NZE by 2050 scenarios, the IEA estimates that it will be necessary to reduce the use of coal in this sector by 40% and double the use of electric energy. In order to achieve that, it is necessary to increase the proportion of secondary steelmaking. Another reason that the IEA projects such a large rise in the use of electricity is the replacement of coal with clean hydrogen; according to the agency, 30% of the electricity used will go to clean hydrogen production. Given its rich natural resources, Latin America and the Caribbean has great potential for the production of clean hydrogen and electricity from renewable sources. At the same time, the region does not have a great demand for iron on the global market, meaning that in the near future, it could become a net exporter of low-emission iron produced through the secondary route (IEA, 2020a). This requires investments in primary steelmaking manufacturing plants with electrolytic hydrogen production. In countries with large natural gas reserves, this resource could be considered a short-term alternative.

As mentioned earlier, the new blast furnaces are more energy efficient. China, for example, has strongly invested in the production of cement with highly efficient blast furnaces and has shut down old steel mills, many of which were antiquated, inefficient, and, in some cases, illegal (IEA, 2020a). This can be seen when looking at the average age of furnaces worldwide. In the case of China, the average age of the furnace fleet is 16 years; in Latin America and the Caribbean, the average is 28; the global average, 25. These fleets are relatively young in comparison with those of developing countries. In the United States, the average age of furnaces is 35, and in Western Europe, 41 (Wang et al., 2019). There are two interesting facts behind these numbers. The first is that, given that the useful life of furnaces is approximately 20-25 years, the age at which its refractory coating can be replaced (IEA, 2020a), this equipment is being used far beyond its useful life worldwide, leading to inefficiencies in steel production. Second, the age of furnaces in Latin America and the Caribbean is lower than those of developed countries, which explains, in part, the region's higher energy efficiency in steel production (Pupo and González, 2023).

The technologies that the IEA considers mature or in stages of early adoption include turning exhaust gas into fuel, the use of biocarbon, and direct reduction of iron using natural gas and arc furnaces. DRI has the greatest potential for mitigation (IEA, 2020a). The technologies not yet viable for implementation—but with high mitigation potential—are smelting with carbon capture and utilization or storage and direct reduction through electrolytic hydrogen. However, these techniques will not be available until 2030 at the earliest.

One innovative alternative is HRBRIT, a system to manufacture iron that relies on hydrogen. This technology allows for primary steelmaking fossil-free, using electric arc furnaces and hydrogen produced through the electrolysis of water.

Technology solutions that enable a reduction of emissions in this sector are mainly concentrated on replacing fossil inputs, improving efficiency, electrification, and carbon capture through use or storage

Finally, besides the energy efficiency efforts, efforts must be made on the supply and demand side. On the supply side, progress has been made in recent years, with major steelmakers announcing zero emissions; however, the companies that have made these announcements accounted for just 8% of global steel production in 2019 (Blank, 2019). In Latin America, the Latin American Steel Association (ALACERO) promotes the sustainability and profitability of the sector. This organization helps organize industry-wide efforts and represents the sector in its dealings with international organizations. In 2022, ALACERO published the first consolidated sustainability report in Latin America's steel sector.

The private sector has also undertaken several important initiatives. At its plant in Argentina, the company Ternium holds the record for replacing charcoal with natural gas as a reducing agent. It struck an agreement to take advantage of biomethane from a landfill in the town of Seropédica for its plant in Brazil. At its plants in Guerrero and Puebla, Mexico, Ternium captures CO_2 from the iron ore reduction process and gives it other uses, for example, in the beverage industry (ALACERO, 2021). Gerdau, a Brazilian company, uses charcoal for its steel production. The biomass utilized to produce the charcoal is, in turn, produced by a firm certified with the Forest Stewardship Council (FSC). In Ouro Branco, Gerdau has also taken major steps toward energy efficiency by combining different fuel sources and improving its energy management. At its plant in Várzea do Lopes, the company began using trucks that run on natural gas and electric buses (ALACERO, 2021).

On the demand side, there has been significant growth for “green” steel, or steel free from emissions, especially in the transportation sector. In May 2023, 48 agreements had been signed to supply green or emissions-free steel, 21 of which involved transportation companies (Roca, 2023). Globally, initiatives include Steel Zero, started in 2022 by the Climate Group, and First Movers Coalition (FMC), started in 2021, establish markets for the sale of innovative clean technologies. Steel Zero promotes the use of green steel, encouraging companies to come on board so that 50% of steel demand is for green steel, with a target of reaching 100% by 2050. According to the FMC, at least 10% of the demand for steel in 2030 will be for an emissions-free product. In the case of China, Baosteel is a company that produces the same amount of steel as India, the world’s second-largest producer (IEA et al., 2023). In 2022, Baosteel reached an agreement with Mercedes-Benz to gradually reduce emissions by between 50 and 80% starting in 2026, and ultimately ensure that 95% of its steel is emissions-free (SteelOrbis, 2022).

In general, emissions-free steel is priced higher, but because of the increase in demand for it, there is also an opportunity for growth in this market in the short term (Zoryk and Sanders, 2023). The expansion of these green markets, along with announcements of carbon border adjustment mechanisms, reinforce the importance of the region’s steelmakers gaining a foothold on these markets to establish themselves as pioneers in emissions-free steel.

Policies to achieve emissions reductions in the steel industry

The main obstacle to a rapid reduction in steel industry emissions is the high cost of mitigation policies in a market this competitive. The low maturity level of some technologies means that those that are currently viable are high-cost, while the implementation of the alternatives is still not feasible.

The cost of investment in a low-CO_2 global production is estimated at somewhere between USD 600-800 million per year. If the investment were spent on reconditioning the current furnace fleet, an alternative that involves no emissions reduction, the cost would be approximately one-third of that (MPP, 2021). On the other hand, an investment in a factory for the production of green steel is 90% more expensive than that of a new conventional plant (MPP, 2022). Not only is the cost of renovating prohibitive but, as mentioned earlier, capital investments in the steel industry are made approximately every 20 years, so in many cases, this would limit the investment to refurbishing plants that are far from the end of their useful life (MPP, 2022).

The companies that act first on the green steel market will be able to leverage the new markets mentioned above, like the growing demand for green steel in the automotive industry. However, acting first also means hefty investments and higher input costs. The cost of production is closely tied to the price of energy inputs. Considering the principal alternatives for reducing carbon emissions, the production cost for every ton of steel could be 15-40% higher than it is in the current primary route (MPP, 2021). Higher costs mean that green steel comes with a premium. Therefore, growth in the demand for low-carbon steel will be critical, so that the difference in prices between traditional steel and green steel does not represent a competitive disadvantage for the actors who take the initiative in this market.

In the long term, the hope is that this premium will fall as demand for green inputs expands, not only in transportation, but also in construction and the manufacturing industry. Bloomberg NEF estimated the cost per ton of steel for the main traditional routes and for hydrogen methods that rely on natural gas and electrolysis, as well as carbon capture and storage. According to these estimates

for 2021, the three green routes are, on average, 40% more expensive than traditional routes, but by 2050, green steel production will cost 5% less than traditional production (Roca, 2023).

Governments and multilateral organizations should be focused on overcoming the barriers to reduced carbon emissions and fostering opportunities to achieve reduction. One of these policies is to support investments in green steel factories and in the necessary inputs for low-CO_2 steel production. The construction of modern plants requires hefty investments, as do hydrogen production and carbon capture. This support can come in the form of loans, credit guarantees, or even subsidies. National or regional policies to foster green hydrogen will aid in the transition of the steel sector. It will also be necessary for governments to continue working to reduce the carbon emissions of the power grid.

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Latin America and the Caribbean has the potential to become a net exporter of green steel

In the short term, the premium for green steel and the existence of markets for this product will be the main drivers for the industry. Beyond the private sector initiatives cited above, it could be in the interest of both local governments as well as development banks to foster the creation of these markets and bring down the costs of green steel (IEA, 2020a; MPP, 2021).

Table 6.2
Policies for the steel industry

Challenge	Goal	Policies
Increase in the demand for steel and high consumption of fossil fuels as an energy source	Development of a green steel industry	Support for the development of a green hydrogen industry
		Financing assistance for new furnaces
		Support for industrial hubs where steel can be produced near the green hydrogen production sites
	Improved efficiency in primary steel production	Financial assistance for the adoption of the best technology available
	Increase in secondary steel production	Investment in education and equipment for greater scrap recovery

Chemical industry

The chemical industry is more complex than that of cement and steel, given that it encompasses several inputs that are very important to economies. Some of these include ammonia (key for fertilizers), methanol (used as a solvent, antifreeze, fuel, or for formaldehyde production), and high-value chemicals (HVCs) used to make, for example, plastics. This industry is the main consumer of oil and gas for energy inputs and for the production of petrochemicals, making it, in turn, the industry with the highest energy consumption. The petrochemical industry stands out from the steel and cement industries in two important ways. First, the petrochemical industry uses much less coal, and second, a great part of the carbon content of inputs is stored in the final product and only released if these are burned or decomposed.

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The chemical industry is the main consumer of oil and gas as an energy input

In the production and consumption of chemicals, GHGs are generated in three ways. First, fossil fuels are used as inputs for the production of plastics, pesticides, and other chemicals: for example, natural gas is the main raw material for ammonia synthesis. Second, a great amount of energy is needed for the synthesis and manufacture of the final products of the chemical industry. Finally, some of the substances it produces are powerful greenhouse gases such as hydrofluorocarbons, which are used in refrigeration and aerosols.

In the production stage, ammonia is the main emitter of GHG and the most carbon-intensive compound (Pupo and González, 2023). Methanol is second and its production has grown significantly in the chemical industry, rising more than 20% between 2015 and 2020 (Pupo and González, 2023). Finally, HVCs are less carbon-intensive, releasing approximately one ton of Co_2eq for every ton produced, less than half the carbon intensity of the other two chemical inputs (Pupo and González, 2023).

Ammonia (NH_3)

Ammonia is an important input for fertilizer production and plays a critical role in food security (FAO, 2022). Nearly 70% of the ammonia produced is used for fertilizers and the rest goes into plastics, explosives, and synthetic fibers (IEA, 2021a). It is estimated that half of all food produced worldwide depends on these fertilizers (Gabrielli et al., 2023). Therefore, based on estimated population growth and the development of emerging economies, the demand for fertilizers (and with it, that of ammonia) is expected to rise.

This compound can also be used as an emissions-free fuel.[9] Though there are limits to its use, mainly in terms of its distribution and the adaptability of vehicles, its applicability is more feasible in the ocean shipping industry, given the infrastructure available for the transportation and distribution of ammonia at ports (Krantz et al., 2020). This could lead to a greater demand for ammonia, in addition to the increase expected for food production.

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[9] The chemical formula of ammonia is NH_3 and thus, no CO_2 is produced when this compound is used as fuel.

In ammonia production, fossil fuels account for more than 95% of energy consumption due to the high pressure and temperatures it requires (Pupo y González, 2023). Additionally, natural gas, which is mainly comprised of methane (CH_4), is essential for the synthesis of hydrogen (H), which is a key input for ammonia production. It is important to emphasize that when hydrogen is used as an input, ammonia production does not emit CO_2 during synthesis. However, nitric acid (HNO_3) is used in ammonia production. When nitric acid is produced, it releases nitric oxide (N_2O), a powerful greenhouse gas, as well as NOx, both of which are air contaminants (IPCC, 2006). Ammonia can also undergo a process known as cracking, which generates hydrogen and nitrogen (Pupo and González, 2023). The hydrogen produced is increasingly finding use as a fuel in both industry and potentially, in heavy-duty transport.

Methanol (CH_3OH)

In the past decade, methanol is the compound that has seen the highest production growth (6.5% per year) (IEA, 2021a). This growth can be attributed to its many uses, mainly in fuels (30%) but also in the manufacture of plastics, acetic acid, formaldehyde, and other chemical products like HVCs (Pupo and González, 2023). The production of methanol is carbon-intensive, due to the use of fossil fuels, and is generally limited to countries or regions with advanced petrochemical manufacturing. In Latin America and the Caribbean, Trinidad and Tobago stood out as the global leader and main exporter of methanol in 2021. That year, the country exported nearly four billion kilograms of methanol, 15% of the world's production (Report Linker, 2023).

The main input for methanol is natural gas (60% of its production). This is the most efficient route, given the high content of methanol in this gas. Almost all the other methanol produced is made from coal (39%). In this process, the burning of the coal produces synthesis gas, which is converted to methanol. This method is being discontinued because of its high GHG emissions (Pupo and González, 2023). Finally, there is a form of production that relies on renewable resources, but it represents just 1% of all methanol produced. The main inputs for this route are biomass (farming and forest waste), the CO_2 captured in other production, and the hydrogen obtained with renewable energy (Pupo and González, 2023).

High-value chemicals (HVCs) and plastics

High-value chemicals include compounds like ethylene, propylene, benzene, toluene, and xylene. The demand for these substances is mainly driven by that of plastics (Gabrielli et al., 2023). However, the GHG emissions for plastics are higher than those of HVS, given the amount of energy required to transform these compounds into plastic (Gabrielli et al., 2023). At the same time, since the 1980s plastic has been the most in-demand bulk product and also boasts the highest increase in demand.

Plastic emits GHG in every stage of production and across its useful life. The production of plastic resin from fossil fuels represents nearly 60% of GHG emissions associated with this product, while the conversion of the plastic in the final product contributes nearly 30% of emissions. This can be attributed to the high amount of energy this process requires. Finally, the remaining 10% corresponds to end-of-life emissions related to its disposal. These are mainly attributed to the burning of plastics, though the decomposition of plastics also generates emissions (OECD, 2022; Zheng and Suh, 2019). These estimates do not include fugitive emissions or those of poorly managed plastics, which continue releasing CO_2 as they decompose or when they are burned (OECD, 2022; Zheng and Suh, 2019). As they decompose, plastics generate microplastics, contaminants that can potentially harm people's health and ecosystems but also contribute to climate change. Recent evidence suggests that microplastics can interfere with the ocean's carbon uptake and capture (Shen et al., 2020). In parts of the Arctic free of any human activity, microplastics are causing more rapid global warming, absorbing light and reducing snow albedo (Bergmann et al., 2022; Emberson-Marl et al., 2023; Lusher et al., 2015).

Although the sector stands out in terms of energy consumption and the subsequent GHG emissions, its environmental impact causes the greatest harm. In industry, the chemical sector is the second in terms of air contaminant emissions, responsible for nearly one-third of SO_2 emissions and nearly one-fifth of NO_X and $MP_{2.5}$ emissions (IEA, 2018b).

Yet in terms of environmental impact, water contamination by chemical products is perhaps the most severe. According to Jambeck et al. (2015), an estimated 5–13 Mt of plastics entered the ocean in 2010, causing different types of damage. For example, polyurethanes can cause marine eutrophication,[10] seriously affecting aquatic ecosystems, while polyvinyl chlorides (better known as PVC) are cancerous for humans and, when ingested by fish or filtered into drinking water systems, end up being ingested by humans (OECD, 2022).

The main problem with plastics is environmental contamination. Ten percent of plastic emissions are released in the final stage of its useful life

Technologies and policies to achieve emissions reductions in the chemical industry

Policies to reduce carbon emissions in the chemical industry should include measures on the supply and demand side. Although this is also true for the cement and steel industry, it is even more pressing for the chemical sector for two main reasons. The first is because globally, the demand for chemical products will continue growing as the world advances toward 2050, as these are mainly used as inputs for goods in high demand. The second is that, as already explained, most of the production of these compounds relies on fossil fuels and there are not enough alternatives to achieve net-zero carbon emissions in the short term.

In this regard, the main measures for reducing emissions are closely tied to the energy transition. These are carbon capture, utilization, and storage; green hydrogen; electrification of production; and the substitution of inputs for others that are contaminant-free. In terms of measures on the demand side, circular waste management could prove important, along with policies that limit the use of chemical products such as single-use plastics. This section presents solutions specifically for ammonia, methanol, HVCs, and plastics, with a focus on the energy transition. Chapter 5 discusses the green hydrogen industry, while Chapter 10 goes into greater detail about carbon capture.

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[10] Marine eutrophication is a process in which too many nutrients accumulate in a body of water, generating excess growth of plants and algae in estuaries and coastal waters. This vegetation absorbs oxygen from the water, which can kill fish and seagrass and harm essential marine habitats (NOAA, s.d.).

Great progress has been made on ammonia. In terms of the IEA's NZE scenarios, energy efficiency measures account for 25% of mitigation efforts and most of these efforts will be made before 2030. These include the adoption of available advanced technologies, operational improvements, and, importantly, the replacement of coal with natural gas or other less carbon-intensive fuels (IEA, 2021d). At the same time, carbon capture is already common in ammonia production, which requires the separation of the CO_2 from the hydrogen (IEA, 2021d). The carbon captured is used with ammonia to produce urea, an input mainly used in fertilizers, though also in some animal feed supplements and plastic production. However, not all the CO_2 that is generated gets captured; part is released into the atmosphere. In addition, a portion of the CO_2 captured and utilized in urea production ends up being released when the final product is used. The quantity of CO_2 that is captured and stored can be increased, though this requires additional investments for the capture and transportation of the CO_2 to warehouses (IEA, 2021d). Other efforts with significant potential are improvements to energy efficiency. Kermeli et al. (2017) showed how process control software investments at an Australian plant led to increased ammonia production along with reductions in CO_2 emissions in just six months. On the demand side, the efficient use of fertilizers is key for the reduction of both ammonia demand and the environmental damage caused by nitrogen pollution (Smith and Martino, 2007).

In the case of methanol, there are two principal pathways to reducing carbon emissions in the short term. The first is the production of biomethanol, i.e., methanol produced from biomass. Biomethanol can be used as a fuel. It reduces N_2O emissions by 80%, CO_2 emissions by 90%, and SO_2 emissions by 100%, besides improving the energy efficiency of fuel use when combined with diesel or natural gas (Deka et al., 2022). This fuel can be produced from forest or farming waste and municipal and industrial waste as well (IRENA, 2021). Another alternative is green methanol or e-methanol, which is made from bioenergy with carbon capture and storage (BECCS) and green hydrogen (IRENA, 2021). The main limitations of both alternatives are production costs, though e-methanol is significantly more expensive. Currently, less than 0.2 Mt of renewable methanol is produced each year, mainly in the form of biomethanol (IRENA, 2021).

Plastics, on the other hand, have more alternatives. In the short term, the foremost alternative is recycling, as this would reduce primary plastics production and emissions in the disposal stage. However, there are GHG emissions during the recycling process due to the decomposition of plastic and the energy the process requires. There are two main types of plastics recycling. The first is mechanical recycling, the most well-known method, which requires sorting, washing, grinding, and compounding the plastic. This route involves fewer emissions since mainly electricity is used. However, the recovery rate of the plastic is lower, as not all the waste gets reused. In the case, for example, of plastic bottles, an increase in mechanical recycling could reduce emissions by 9-14% (Gracida-Alvarez et al., 2023). The alternative is chemical recycling, which allows for greater waste recovery but also generates more emissions. Gracida-Álvarez et al. (2023) estimate that an increase in the chemical recycling of plastic bottles would not yield net reductions in GHG emissions. One potential use for recycled plastic is burning it for energy use; although this alternative could reduce the burning of other fossil fuels for energy, it also generates GHGs (Shen et al., 2020).

Replacing plastics with other materials is an option, though it is not clear this would lead to a reduction in GHG emissions. In some cases, plastic inputs enable emissions reduction. This is the case of the automotive industry, as plastics allow for lighter, more energy-efficient vehicles (IPCC, 2023). Stefanini et al. (2021) compared the impact of glass and plastic bottles on GHG emissions, water consumption, and toxicity, among other impacts, and concluded that polyethylene terephthalate (PET) plastics contaminate the least, not considering the impact in terms of water contamination. Civancik-Uslu et al. (2019) showed that, in the case of bags, there is an inverse relationship between the impact on waste and the environmental impact. For example, single-use plastic bags are more likely to end up as waste than paper bags, but this relationship is inverted if CO_2 emissions are considered. Finally, Helmcke et al. (2022) analyzed the impact of 14 plastic

products comparing them with the best non-plastic alternative. Their analysis reveals that 13 of the 14 plastic products have lower CO_2 emissions than their non-plastic alternative and that there are few plastic alternatives for certain products, such as packaging, the largest source of global waste (Rosenboom et al., 2022). It is important to clarify that this impact is linked to use. Single-use products have greater environmental impacts, mainly as potential waste (UNEP, 2020b).

Another alternative to plastic is bioplastics, although the Organization for Economic Co-operation and Development (OECD, 2022) has estimated that these will account for only 0.5% of plastics in 2060. The main input for bioplastics is readily fermentable sugar like sugarcane, corn, and edible vegetable oils. The clear disadvantage of these products is that they require large swaths of cropland, which competes with food production and has potential carbon emissions due to land use. Producing bioplastics is also more expensive than traditional plastics (Rosenboom et al., 2022). The advantage of bioplastics is that they have a smaller carbon footprint, with a potential reduction of GHGs of 25% in comparison to current emissions. Additionally, they are biodegradable in some cases and can be integrated into existing recycling infrastructure (Rosenboom et al., 2022).

When powered by clean energy, electrification has great potential for certain processes, like the conversion of plastic resin into the final product and recycling. Zheng and Suh (2019) showed that globally, in a scenario of 100% renewable energy by 2050, the emissions of both plastics made from fossil fuels and bioplastics could be reduced by half, in comparison with a scenario in which the energy grid does not undergo changes until that year.

Green hydrogen and carbon capture will be critical technologies for all chemical industries

Finally, green hydrogen and carbon capture will be critical to reduce carbon emissions in this sector. Green hydrogen can be used to replace fossil fuels and as input for certain chemical products like methanol, BTX,[11] and ethylene-propylene. (Pupo and González, 2023) In the case of ammonia, for example, nearly 80% of the emissions from production come from obtaining hydrogen (Lee et al., 2022). If this is replaced by emissions-free hydrogen, the production of this chemical has enormous potential. This also creates an opportunity for ammonia manufacturers, given that there could be synergies between the production of this compound and green hydrogen. In the case of carbon capture, the IEA estimates that this technology will account for close to 40% of GHG mitigation by 2050 but, as mentioned in earlier sections, it is not yet mature enough and the main limitation is its high cost.

In Latin America and the Caribbean, Trinidad and Tobago stands out in the chemical sector, accounting for nearly 66% of the region's ammonia production and 52% of its methanol production. This is because the country is home to one of the world's leading natural gas processing facilities and it utilizes more than 30% of its capacity for ammonia and methanol processing (Pupo and González, 2023). Trinidad and Tobago has taken steps toward reducing its carbon emissions with the NewGen project, whose goal is to have the largest low-carbon content hydrogen production plant in the world. Once completed, it has the potential to supply 20% of the hydrogen for the largest ammonia production plant (CariGreen, 2022; Jugessur et al., 2022). Besides green hydrogen production, Trinidad and Tobago also has great potential for reducing carbon emissions thanks to its reserves of natural gas –a key input for the energy transition– and its installed capacity for the extraction and sale of natural gas. Additionally, it could become a key player in the hydrogen market given its role as a net

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[11] BTX is a mixture of aromatic hydrocarbons: benzene, toluene, and three xylene isomers.

exporter of ammonia and methanol, its investment in offshore wind energy, and its investment in green hydrogen production (Jugessur et al., 2022).

Other initiatives for green ammonia and hydrogen production can be found in Paraguay, with an investment by ATOME. This project aims to supply the agriculture and fertilizer markets in Paraguay and turn the country into a net exporter of green fertilizers. The first plant is expected to be operational in 2025, and the second in 2027 or 2028.

Table 6.3
Policies for the chemical industry

Challenge	Goal	Policies
Increase in the demand for chemicals and high use of fossil fuels as production inputs and energy source	Development and fertilizers and synthetic fuels produced from green hydrogen	Support for the development of a green hydrogen industry
		Greater carbon capture in processes involving mature technology, such as ammonia production
		Support for industrial hubs where chemicals can be produced near the green hydrogen production sites
	Reduction of emissions and plastic contamination	Greater investments in education on the importance of circular plastics
		Regulation and taxes on single-use plastics
		Electrification of plastic pellet production and the final product

Technologies of the future: Opportunities for the region

As shown in this chapter, one of the main limitations to adopting mature technologies is the high cost. Carbon-intensive industries are highly competitive and without the existence of markets with green premiums for low-carbon products, these industries could lose their advantage if they choose to adopt such technologies. Part of this logic can be explained by the lack of internalization of the environmental costs of industrial production. A carbon price that internalizes these emissions would even out the costs and make some of the technologies mentioned in this chapter economically feasible (Rissman et al., 2020).

However, short-term efforts in Latin America and the Caribbean should not aim for net-zero emissions of these industries, which often involve difficult obstacles and, in some cases, high implementation costs. Instead, the region should leverage opportunities that offer efficiency improvement margins and allow their industries to be modernized with a sustainable horizon. Some of the short-term measures that point in this direction include the adoption of new efficient furnaces in the cement and steel industry; the replacement of fossil fuels with biomass; and initiatives that promote the conscientious use of fertilizers, cement, or plastic products. At the same time, there are niches where the region can grow strong and build future markets where it can compete. These include green hydrogen production, the production of fertilizers using green hydrogen and existing capture processes, and the production of green steel, which already has a market (the automotive market) that pays high premiums for these products.

Although putting a price on carbon would boost all of the subsectors of the green industry, this alone is not enough to justify the introduction of a carbon pricing system in the region, given that industry is not one of the main sectors in terms of either added value or GHG emissions. The main priority for countries in the region should be to modernize industrial sectors to increase their production capacity, leveraging the rapid development of tech improvements described in this chapter. In this regard, governments should focus their efforts on policies that contribute to compliance in these sectors; foster the adoption of the best technologies available, either through access to financing or subsidies; and build awareness about the efficient use of industrial inputs. Although the main objective of these policies is not the energy transition, they would foster the development of the industrial sector in the region and, as a positive externality, reduce GHG emissions and industrial waste.

Figure 6.3
Advances in strategies to support green hydrogen

Source: Author based on data from Pupo and González (2023).

Latin America and the Caribbean has great potential to generate renewable energy and green hydrogen for ammonia projects with carbon capture; to transition to a use of lower-carbon-content fuels, like natural gas and biomass; and eventually, to use depleted gas and oil fields for capture and storage projects. The Intergovernmental Panel on Climate Change (IPCC, 2023) has emphasized that the geographical distribution of industries can be redirected toward regions with abundant renewable resources, carbon capture and storage capacity, and the potential for green hydrogen production: all conditions Latin America and the Caribbean meets. This would require the introduction of policies that help build the necessary infrastructure (electric grid, road, rail, and port) but also promote industrial hubs that enable synergies between sectors, such as access to biomass and green hydrogen and adequate shipping infrastructure. At the same time, it is essential to support industries where green markets are developing.

For example, an economic outlook for Brazil shows that the right support for green investments could modernize and reduce carbon emissions of the country's manufacturing industry, which would increase projected growth by 0.42% and reduce CO_2 emissions by 14.5% (Gramkow and Anger-Kraavi, 2019). The IEA (2023l) has emphasized the region's abundant renewable resources, especially in Argentina, Brazil, Colombia, and Chile, noting their potential as major producers of low-cost, low-emission hydrogen, and fuels, which in turn could strengthen the iron and steel and chemical industry. The cost of producing steel and conventional ammonia in Latin America and the Caribbean is similar to that of advanced economies but higher than in developing countries of Asia. However, when hydrogen is used, the production costs of these two inputs are lower than they would be in developing Asian countries and developed economies (IEA, 2023l).

Latin America and the Caribbean has great potential to generate renewable energy and green hydrogen ad eventually, to use depleted gas and oil fields for carbon capture and storage

The region has already made progress toward this. Figure 6.3 shows advances in strategies to support green hydrogen. Six countries are already producing green hydrogen and have other projects in the developmental phase. At the same time, three more countries in the region have announced hydrogen production projects. Besides these nine countries, Panama and Ecuador have strategies for green hydrogen development but have not yet announced specific projects (Pupo and González, 2023).

Energy transition in the residential sector

- Residential energy consumption patterns in the region
- Building insulation and energy consumption
- Energy transition policies for the residential sector
- The challenges of residential electrification

7

Key messages

1

Per capita energy consumption in the residential sector in Latin America and the Caribbean is several times lower than that of China, Europe, and the United States and, overall, is below that of countries with similar income levels. This is due to a combination of mostly warm climates and medium income levels. While the warm climate limits heating consumption needs, which are the main source of consumption and emissions in the residential sector in developed countries, medium incomes limit overall energy consumption.

2

The current state and future evolution of income and climate define two of the three key challenges of energy transition in the residential sector in Latin America and the Caribbean: replacing biomass with cleaner energies and increasing the provision of household appliances.

3

The still high consumption of biomass in the region is not only a challenge in terms of emissions but also in terms of health. In five of the poorest countries, at least 30% of households use firewood as the main cooking fuel. Biomass is also the main input, along with gas, to meet heating needs in higher-income and colder-climate countries.

4

The progressive increase in the use of household appliances, particularly air conditioning, will result in a substantial increase in the level, seasonality, and daily variation of electricity consumption. The connection of households to electricity grids does not pose a major obstacle to this expansion of electricity consumption, as it is universal, except in rural areas of a few countries.

5

The combination of medium incomes with the high structural inequality characteristic of the region poses an additional challenge to the transition. It pertains to the poorest households' access to energy. In most countries, these households already spend more than 5% of their income on electricity expenses, limiting their ability to electrify more of their consumption or cope with higher prices. Additionally, many low-income households in rural areas still do not have access to electricity grids, and in urban areas, they are informally connected, implying deficiencies in quality and health risks.

6

There is a series of proven effective policies to improve the efficiency of electricity consumption in a way that contains the increase in its demand. These include promoting, on one hand, the efficiency of electrical appliances and building envelopes through labeling practices and minimum construction and manufacturing standards, and on the other hand, encouraging more efficient electricity consumption behaviors through informative tools and more sophisticated pricing schemes.

7

Household solar electricity self-generation is a promising path to reduce CO_2 emissions and improve access to energy, especially in rural areas where electricity distribution costs are higher. Subsidies for panel adoption should be targeted to avoid being regressive, as higher-income households have more incentives to install them due to their higher electricity consumption.

Energy transition in the residential sector[1]

Introduction

Household energy consumption is a key input for peoples' well-being. Households use energy for cooking and refrigerating food, operating a variety of appliances, and, depending on the region's climate, for heating or cooling their homes. Final energy consumption derived from all residential uses accounts for nearly a quarter of total consumption in 27 countries in Latin America and the Caribbean (LAC) (OLADE, 2021b) on average. In addition to the positive impacts of different energy uses on well-being, the use of dirty energy sources, such as firewood for cooking or heating, has well-documented negative impacts on health and requires greater effort and time dedication.

Given the relevance of residential sector energy consumption to total consumption, the climate imperative to reduce greenhouse gas (GHG) emissions also applies to this sector. The total CO_2 emissions generated directly by households in these 27 countries in 2021 accounted for 5.6% of total emissions from energy systems, buildings, industries, and transportation, as well as waste management (Minx et al., 2021). This regional proportion is lower than the global average, which stands at 7.7% and does not include emissions associated with the generation of electricity used by households, which more than double direct emissions worldwide.

The challenges of energy transition in the residential sector include improving access to energy as a key ingredient of household well-being and the necessary reduction of emissions. The combination of both dimensions is clearly reflected in the seventh United Nations Sustainable Development Goal (SDG 7), which sets the target of "ensuring access to affordable, reliable, sustainable, and modern energy." This dimension emphasizes that access involves affordability and the quality of the energy consumed. The quality of residential energy consumption refers to both

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[1] This chapter was written by Guillermo Alves with research assistance from Facundo Lurgo.

the continuity of supply, in terms of it not suffering interruptions, and the use of modern energies, which refers to the use of clean energies.

As seen in this report, the climate motivation for energy transition entails advancing both energy consumption efficiency improvement and electrification. Households can achieve higher levels of energy efficiency by using appliances with improvements in this technical ratio and by using thermal insulation in their homes. As for electrification, this chapter shows that there is ample room in the region to electrify residential consumption, but that margin appears substantially more limited than in higher-income countries worldwide. The chapter also explains that households can contribute to electrification by generating electricity with solar panels installed in their homes. This technology has special potential to improve electricity access in rural areas, where households still lack connection to electricity distribution networks.

In the case of residential consumption, the two margins of efficiency and electrification, which are cross-cutting in the report, are linked to behavior changes that reduce energy consumption. Another behavioral mechanism is energy saving. Two classic examples are turning off lights in spaces where they are not needed and moderating temperatures of heating and cooling systems.

The type and amount of energy consumed in households depend on four main factors. The first is climate, which plays a fundamental role in the region. This chapter shows that in regions with cold winters, room heating and hot water are the main uses, accounting for more than half of total energy consumption, while in warm areas, the main use is food cooking. The second factor is household access to energy sources, which determines the type of energy they consume. The use of electricity and natural gas requires connection to grids; the use of liquefied petroleum gas (LPG) requires proximity to the distribution network; and the use of biomass for cooking and heating is cheaper when there is a nearby forest with a readily available source of firewood. The third factor is household income, as it delimits the type and quantity of energy consumed, mainly through its impact on the quality and quantity of appliances that the household can purchase. Lastly, the price of appliances and energy sources determines the purchasing power of that income in terms of energy consumption and, through this channel, the type and amount of energy consumed by the household.

The interaction of these four factors over time, along with a series of historical characteristics of countries and regions, shapes cultural patterns of energy consumption that condition the possibilities of energy transition. For example, the availability of forests and low incomes make biomass cooking practices deeply rooted in the culture.

Another characteristic of residential energy consumption that conditions transition possibilities is the extensive useful life of certain goods. This is the case of homes, whose structures endure for decades or centuries, and which, as will be seen, influence the efficiency of energy consumption dedicated to meeting heating and cooling needs. Likewise, several of the main household appliances, such as stoves and refrigerators, condition the type and efficiency of the energy consumed and have very long useful lives, making their replacement necessarily gradual.

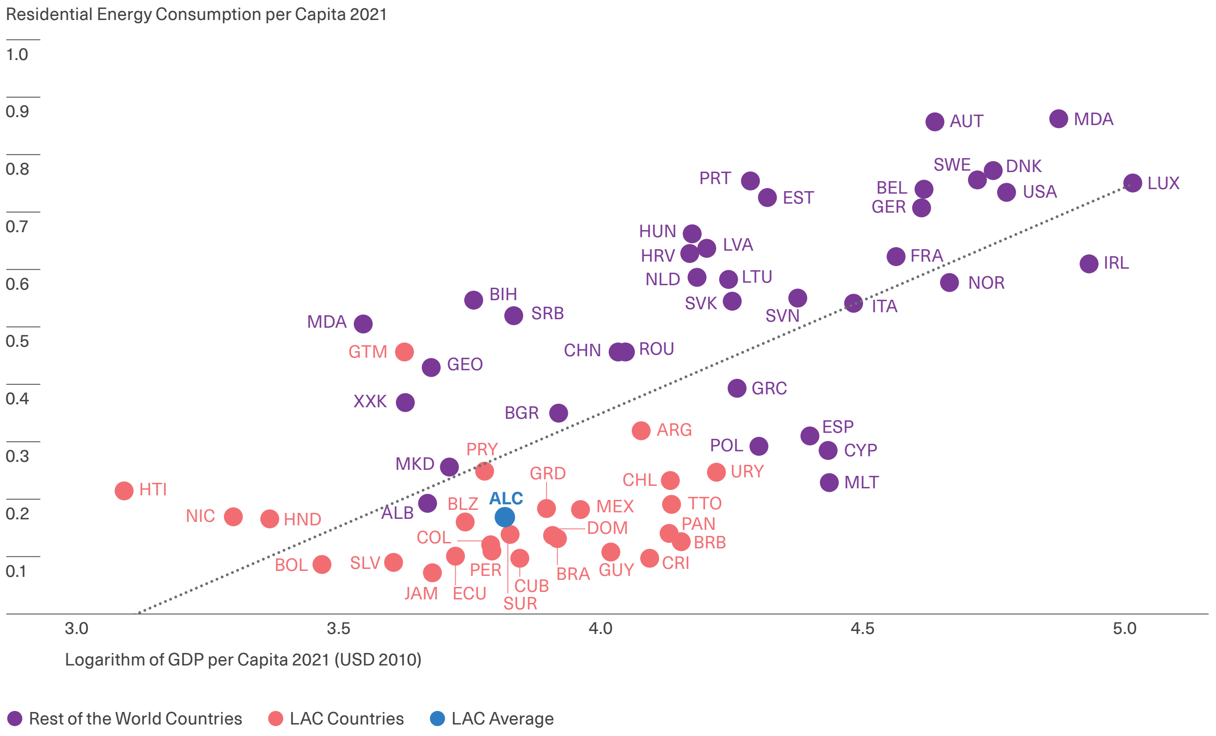
Patterns of residential energy consumption in the region

How much and what type of energy do households consume?

The simple average of residential energy consumption per person in 27 countries in Latin America and the Caribbean was 0.17 tons of oil equivalent (toe) in 2021 (OLADE, 2021b). This value was well below the averages of China (0.46 toe), the United States (0.73 toe), and Europe (0.56 toe) (National Bureau of Statistics of China, 2022; EIA, 2020d; Eurostat, 2022). As shown in Graph 7.1, the level of residential consumption varies widely among countries in the region, ranging from a minimum of 0.07 toe in Jamaica to a maximum of 0.46 toe in Guatemala. The graph reveals a strong positive correlation between the country's income level and total per capita residential energy consumption. Likewise, the fact that countries in Latin America and the Caribbean (in pink) are mostly below the dotted line confirms the idea that the region has relatively low residential energy consumption for its income level.

Graph 7.1

Residential energy consumption per capita and GDP per capita in 2021



Note: The graph presents per capita residential energy consumption and the logarithm of GDP per capita (in constant 2010 US dollars) in 26 countries in LAC, 36 in Europe, China, and the United States. Energy consumption is measured in tons of oil equivalent (toe). For visualization purposes, Finland is not included due to its high per capita consumption value. The dotted line represents an estimated regression of the values on the vertical axis against those on the horizontal axis. Countries are identified by their ISO code. The list of countries in each group are listed in the chapter's annex available online.

Source: Authors based on data from OLADE (2021b), Eurostat (2022), ECLAC (2023), and World Bank (2023d).

The increase in household income is associated not only with higher consumption but also with the substitution of dirty energy for clean energy. These forces are behind the radical change in the energy basket composition of households in LAC over the last five decades. While in 1970, firewood was the main source of residential energy in 23 of the 27 countries, accounting for an average of 58% of total residential consumption, in 2021, electricity occupied this place, with a 38% share, increasing by 30 percentage points compared to 1970 (OLADE, 2021b). As will be discussed below, this increase in the importance of electricity was possible due to a significant expansion of household access to electrical grids.

●●

The low need for heating and medium incomes explain why per capita residential energy consumption in Latin America and the Caribbean is substantially lower than that of developed countries

In addition to electrification, the decrease in kerosene use, which went from 17.5% in 1970 to 1.4% in 2021, and the increase in LPG, which went from 6.2% to 20.9% in the same period, also contributed to making the energy matrix of households in LAC much cleaner over the last half-century. According to the classification of the World Health Organization (WHO), discussed in Box 7.1, the use of dirty energy in residential consumption decreased from 82% in 1970 to 36% in 2021.[2]

Comparing the current residential energy matrix in LAC with that of developed countries, electricity has ten percentage points less participation than in the United States and ten points more than the European average (IEA, 2022b; Eurostat, 2022). The major difference with the developed world lies in the lesser role of natural gas, which, at 5%, is well below the 46% in the United States and the 34% in the European average, as well as the greater relevance of firewood, which reaches 30%, while it is nonexistent in the United States and around 17% in Europe.

While the substitution of dirty energy for clean energy at the residential level in the last 50 years occurred in all countries in Latin America and the Caribbean, there is still significant heterogeneity in household consumption sources and, therefore, in the challenges of this transition for this sector. Graph 7.2 presents this information for 27 countries in the region in 2021 and suggests three groups based on the main source of residential energy consumption.

Although the role of firewood in residential consumption has dropped in all countries, in a first group it is still the most prevalent source, accounting for 61% of total consumption on average. This group includes countries with lower 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. While globally this pattern of a heavier reliance on firewood is characteristic of countries with very low income levels, it is also observed in Eastern European countries, which must meet significant heating needs with medium income levels. This is the case in Bosnia-Herzegovina, Croatia, Estonia, Montenegro, and Romania, which have a firewood share of at least 40% of total residential consumption (Eurostat, 2022).

In a second group, the predominant source is gas, with a 51% average share, including natural gas and liquefied petroleum gas (LPG). The countries in this group are Belize, Bolivia, Ecuador, El Salvador, and Mexico, where LPG predominates, and Argentina, where natural gas prevails. This group presents the most balanced situation among the different sources, with electricity reaching an average of 31% and firewood, 16%. This type of combination of sources, with gas dominance, electricity in second place, and firewood in third position, is also observed in the European average and particularly in Germany, Finland, and Italy.

In a third group of countries, electricity is the main source, with an average participation of 54%. This group includes the countries with the

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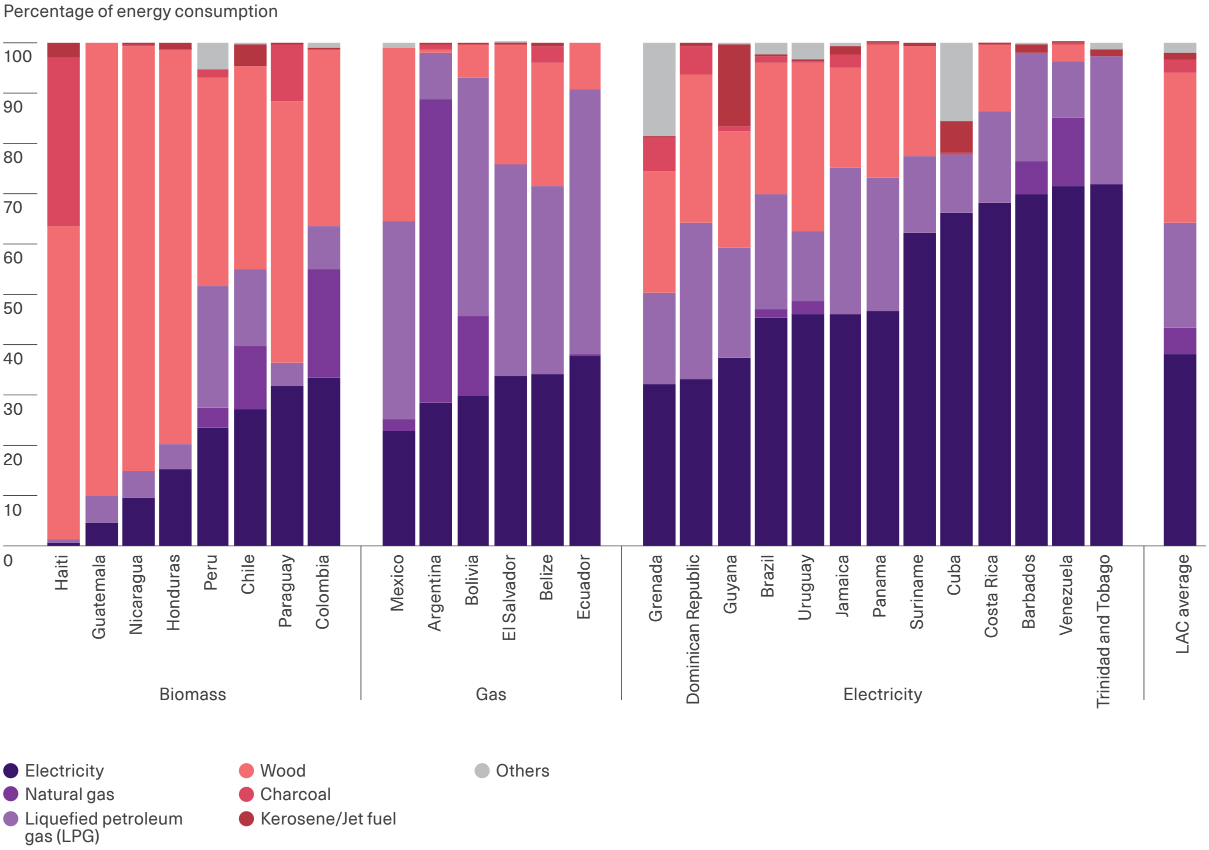
[2] Graph A.7.1 in the chapter's annex available online depicts the evolution of the relative use of different energy sources between 1970 and 2021 by country.

highest per capita income in Central America and the Caribbean, including Barbados, Costa Rica, Grenada, Panama, the Dominican Republic, and Trinidad and Tobago, as well as Brazil, Guyana, Suriname, Uruguay, and Venezuela. The high participation of electricity in these countries is similar to that observed in the United States and in European countries with a greater emphasis on electricity, such as Bulgaria, Spain, Portugal, and Sweden (IEA, 2022b; Eurostat, 2022). This third group differs from the United States and several of those European countries due to the low or nonexistent participation of natural gas (2% on average) and the greater relevance of LPG (21% on average) and firewood (17%).

The first challenge of the energy transition in the residential sector of the region is to replace the consumption of firewood with cleaner sources, whether for cooking or heating

Graph 7.2

Distribution of residential energy consumption by source in 2021



Note: The graph displays the percentage distribution of residential energy consumption by source for 27 countries and the LAC average in the year 2021. Three groups of countries are identified based on the predominant energy source, from least to cleanest: biomass (wood and charcoal), gas (natural and liquefied petroleum gas), and electricity.

Source: Authors based on data from OLADE (2021b).

The use of firewood varies in importance among the three groups, but it is relevant in almost all countries, and its substitution by cleaner sources constitutes the first of the three main challenges of the residential energy sector's transition in the region. From a climate perspective, the absolute magnitude of this consumption is important. In 2021, the countries that consumed the most firewood (more than 200 kilograms per capita [kg/cap.]) were, ranked from highest to lowest, Guatemala, Nicaragua, Honduras, Paraguay, Haiti, Uruguay, and Chile. In Colombia, Brazil, the Dominican Republic, Peru, Grenada, and Mexico, this consumption was at an intermediate level, between 100 and 200 kg/cap., and in the rest of the countries, it was less than 100 kg/cap.[3]

How do households in the region consume energy?

Households use energy to cook food, heat water and spaces, cool and light environments, preserve food, wash clothes, and operate a variety of appliances. Climate is the primary determinant of which of these uses predominates. In warm regions, it is primarily used for cooking, accounting for over 50% of total energy consumption, while in regions with cold winters, space heating predominates (Bouille et al., 2021; ECLAC, 2016; Contreras et al., 2022).[4] Although these regions differ in whether cooking or heating is the primary use, they both define the first of the three key challenges in the energy transition in the region's residential sector, which involves substituting biomass with cleaner sources.

The operation of appliances and lighting ranks second in importance in warm countries and third, behind water heating, in those with cold winters. As discussed below, the use of air conditioning for environmental cooling still plays a relatively minor role in all countries, although its adoption is increasing and is expected to continue rising due to global warming and increasing household incomes. The increase in the level, seasonality, and variability of electricity demand throughout the day, driven by the growing ownership and use of appliances, including air conditioners, constitutes the second of the three main challenges facing the residential sector in the region during the energy transition.

Cooking as the predominant use and the challenge of adopting clean energy

The predominance of cooking as the primary use of energy in the residential sector in most LAC countries is due to its fundamental nature in terms of human needs and the fact that incomes are still too low to extend other uses. Additionally, its requirement to generate heat makes it a particularly intense energy use: cooking with electricity for three hours a day consumes two and a half times more energy than a refrigerator that is operational all day (Wright et al., 2020). This ratio is even higher when using other energy sources for cooking: more than ten times if using a modern wood stove and more than twenty times if cooking over an open fire in the traditional way.

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[3] Graph A.7.2 in this chapter's annex available online presents these results in greater detail.

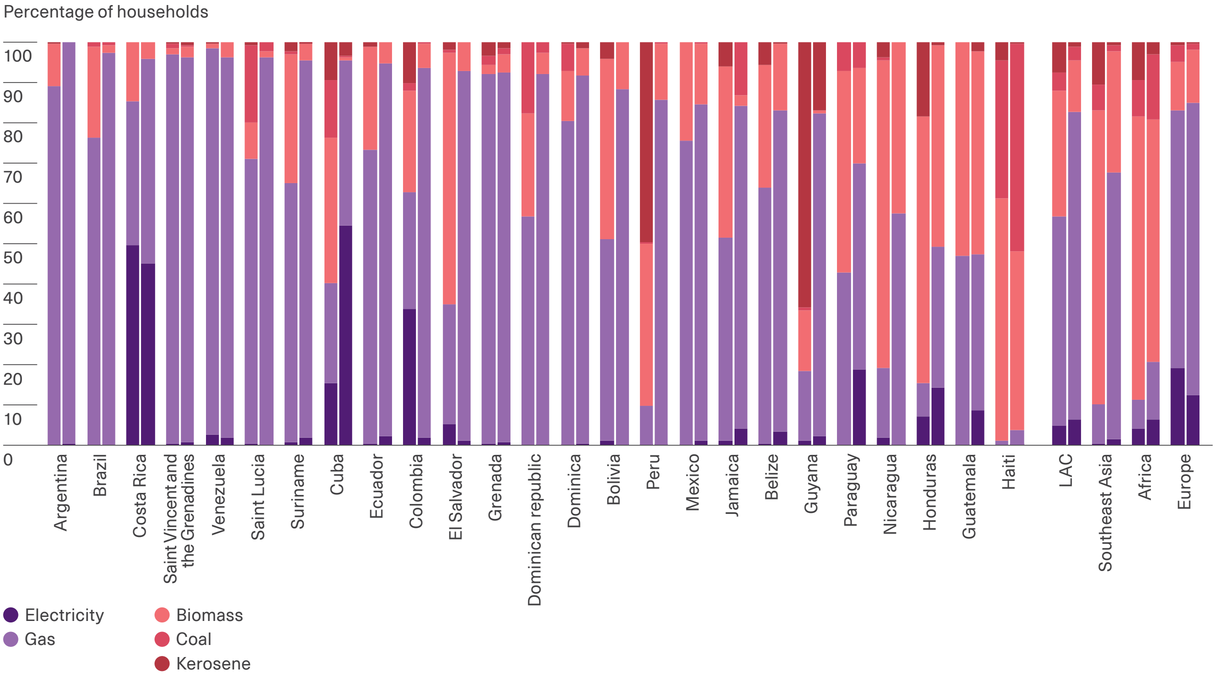
[4] The ECLAC (2016) report provides data on the distribution of consumption according to final use for only seven countries (Argentina, Brazil, Chile, El Salvador, Paraguay, the Dominican Republic, and Uruguay). In Brazil, El Salvador, and the Dominican Republic, cooking is the primary use, accounting for over 50% of the energy consumed. The climatic similarities between most LAC countries and the three latter countries lead to the inference that cooking is indeed the primary use in the majority of them. Argentina, Chile, and Uruguay, countries with cold winters, have final use consumption patterns quite similar to those in Europe with comparable heating needs, although with a higher proportion dedicated to heating water in all three and to cooking in Argentina and Uruguay.

The type of energy used for cooking varies considerably between countries and between rural and urban areas in Latin America and the Caribbean. This explains many of the differences between countries in total consumption (Graph 7.1) and in the composition of the residential energy matrix (Graph 7.2) and, therefore, in the direct emissions of households. The use of dirty energy for cooking has negative health impacts, which are addressed in Box 7.1.

Graph 7.3 shows the proportion of households in each country according to the main source of energy used for cooking in 1990 and 2021. In the latter year, gas was the main source in all countries except Guatemala, Haiti, and Honduras, reaching 76% in the regional average. This average is very similar to Europe, with the difference that natural gas predominates there, while LPG prevails in LAC. Biomass occupied a distant second place in 2021, at 13%, similar to the European average and well below the averages of Africa and Southeast Asia. Electricity is the third energy source used for cooking, at 7% in the simple regional average.

Graph 7.3

Main energy source used for cooking in 1990 and 2021



Note: The graph displays the distribution of households in 25 LAC countries according to the main fuel used for cooking in the years 1990 (first vertical bar) and 2021 (second vertical bar), as well as the regional average in LAC, Europe, Southeast Asia, and Africa. Clean energy sources (electricity and gas) are highlighted in dark purple and light purple, while dirtier energy sources in terms of emissions (biomass, coal, and kerosene) are shown in various shades of red. The countries comprising the regions of Africa, Europe, and Southeast Asia can be found in the chapter's annex available online.

Source: Authors, based on data from WHO (2021).

Box 7.1

Use of dirty energy and health

The use of traditional, solid, or "dirty" fuels to meet household energy needs create indoor air pollution posing a negative impact on health (Gordon et al., 2014; Lee et al., 2020). This occurs due to the generation of toxic gases, such as carbon monoxide, and particulate matter (PM). The negative impacts consist of a higher incidence of respiratory diseases and, to a lesser extent, cardiovascular diseases (Po et al., 2011).

The WHO considers fuels dirty if they exceed certain critical thresholds for emissions of fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO). Clean fuels for cooking include solar energy, electricity, biogas, natural gas and liquefied petroleum gas, and alcohol-based fuels, including ethanol. In the case of biomass, the cooking or heating device used must meet very high quality standards to be considered clean.

The direct negative effects of using dirty energy within the household primarily affect women and children (Po et al., 2011). Women are more exposed than men to pollutants because they spend more time doing unpaid household work, particularly in cooking tasks where exposure is more direct. Children are particularly affected due to the time they spend with their mothers, who are primarily responsible for their care, and because their respiratory systems are still developing.

●●

In the residential sector of most countries, energy is primarily used for cooking food, with liquefied petroleum gas (propane) being °the most common fuel

The high incidence of dirty cooking fuels poses a serious challenge in Haiti, where biomass and charcoal combined exceed 90%; in Guatemala, Honduras, and Nicaragua, where the proportion of households cooking with biomass exceeds 40%; and, to a lesser extent, in Belize, Guyana, and Paraguay, where the incidence of dirty energy for cooking ranges between 15% and 25%.[5] The challenge of transitioning to cleaner sources for cooking is especially relevant in rural areas, where the incidence of dirty fuels is much higher. On average across countries, the incidence of biomass in 2021 was 20 percentage points higher and that of gas 20 points lower in rural areas than in urban areas.[6]

Given the relevance of electricity for energy transition, it is worth assessing whether this form of energy is relevant for cooking in any country in the region. Costa Rica and Cuba stand out as the only countries where at least half of households use electricity for this activity. It is also relatively important in Paraguay, where approximately one in five households use it. The relevance of this energy source in cooking in these countries could indicate a possible path of replacing biomass with electricity. Furthermore, while liquefied petroleum gas is considered a clean energy source, its carbon footprint is higher than that of electricity, especially when considering that propane tanks are transported by vehicles powered by internal combustion engines.

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[5] While biomass is the main dirty source in Belize and Paraguay, it is kerosene in Guyana.

[6] Graph A.7.3 in this chapter's annex available online presents the differences between rural and urban areas broken down by country.

Energy consumption and temperature: Clean hot water and room heating and cooling

Temperature is the fundamental determinant of the quantity, source, and seasonality of energy consumption in the residential sector worldwide. In Europe, space heating accounts for nearly two-thirds of household energy consumption on average and is the most intensive use of fossil fuels (Eurostat, 2022). In contrast, in Latin America and the Caribbean, the warm climate limits the need for space heating, while room cooling becomes more relevant, constituting a non-intensive use of fossil fuels. In addition to heating and cooling spaces, hot water for sanitary purposes is another fundamental use linked to temperature, being the second most important in Argentina, Chile, Mexico, and Uruguay (Bouille et al., 2021; ECLAC, 2016; Contreras et al., 2022).

A common measure of thermal needs for spaces is heating and cooling degree days for a city, region, or country in a year. Calculating heating degree days starts by defining a reference temperature below which a home needs to be heated. Then, for each day of the year, the difference between that reference and the average temperature of that day is taken. Finally, these differences are added together for all days of the year. The calculation for cooling degree days is similar but uses the difference between the average temperature of a day and a reference temperature above which it is necessary to cool the home.

●●

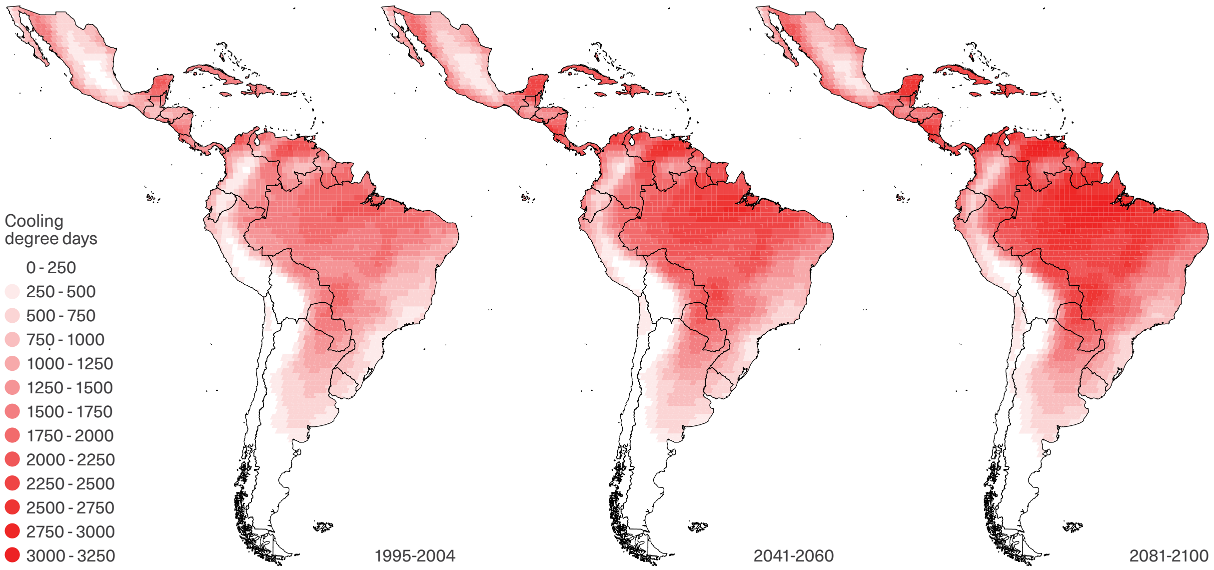
The region's climate implies that the need for cooling spaces far surpasses that for heating. This trend will be exacerbated by global warming

Figure 7.1 presents maps with heating and cooling degree days for Latin America and the Caribbean, using 17.5 degrees Celsius (°C) as the reference for the former and 22°C for the latter. The maps in Figure 7.1 are based on observed temperatures from 1995 to 2014 and projected temperatures for two future periods: 2041–2060 and 2081–2100. Alves and Lurgo (2023) provide the exact methodology used to develop these maps, along with a more detailed analysis. The heating degree days map shows a value of zero for populations in Central America, the Caribbean, and northern South America. These values increase as areas move away from the Equator and are high in the Andean regions.

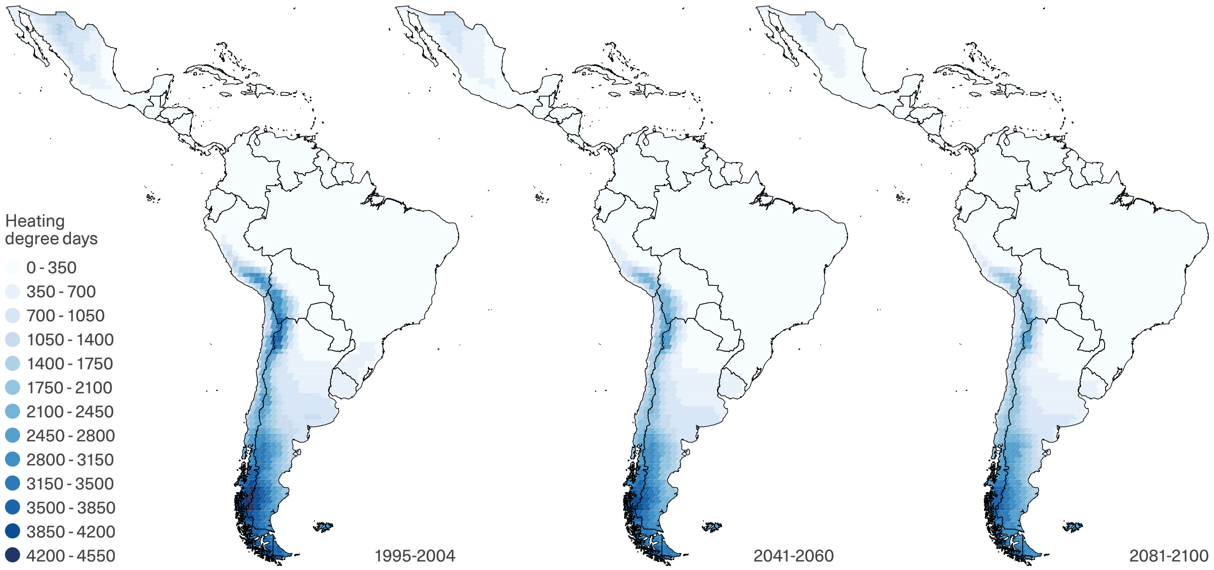
Considering the data from Figure 7.1 and the spatial distribution of the population within each country, three groups of countries can be formed based on their population's heating needs: nonexistent, limited to certain areas, and majority (Alves and Lurgo, 2023). The group with nonexistent needs has fewer than 10 heating degree days per year for the average household and includes Caribbean countries, Central American countries except Guatemala and Costa Rica, and Venezuela. The group with needs limited to certain areas has fewer than 500 degree days for the average household and includes, in order of decreasing degree days, Costa Rica, Guatemala, Brazil, Paraguay, Colombia, and Mexico. In the latter two countries, due to mountainous terrain, at least 10% of the respective populations reside in areas with over 1,000 degree days. The group with the highest heating needs includes Peru, Ecuador, Uruguay, and Argentina, where households have between 500 and 1,000 degree days on average; Bolivia, with an average of around 1,400; and Chile, with 1,900. In relation to European countries, Bolivia's average is similar to that of Spain and Portugal, and Chile's is comparable to Croatia and France (IEA, 2023s). Furthermore, the wide latitudinal range covered by Argentina and Chile's territories and the presence of populations in very high-altitude areas in Bolivia, Ecuador, and Peru mean that a significant portion of households in these countries have heating needs much higher than the average. At least 25% of the population in Bolivia and Chile and 10% in Ecuador and Peru reside in areas with at least 2,000 degree days. In an extreme case, 10% of Bolivia's population exceeds 3,400 degree days, a magnitude comparable to the average in Denmark or the Czech Republic.

Figure 7.1
Thermal needs in homes in Latin America and the Caribbean

Panel A.
Cooling needs



Panel B.
Heating needs



Note: The base temperatures for calculating degree days are 22°C in Panel A and 15.5°C in Panel B. The map was created from a layer provided by the IPCC, with a resolution of 1°x1°, using QGIS software. The data are derived from various climate models for the current period (1995–2014) and future projections based on the IPCC's SSP2-4.5 scenario for the medium term (2041-2060) and long term (2081–2100). See Alves and Lurgo (2023) for more details on data acquisition and processing.

Source: Alves and Lurgo (2023) based on data from IPCC (2021).

In the few LAC countries where heating needs exist, they are covered in very different ways, and in some cases with quite extreme use of sources compared to others outside the region. Of the 28 countries worldwide for which the International Energy Agency (IEA) has data, Chile has the highest proportion of households using biomass as their main source, at 60%, while in Argentina the vast majority use natural gas, with over 90% (IEA, 2022a). Although with a lesser incidence than in Chile, wood is also predominant in Uruguay, where 42% of households used it as their main source in 2022 (National Institute of Statistics, Uruguay, 2022). Finally, while Bolivia is the second country in the region in terms of heating needs according to degree days faced by the average household, there is no information on how households meet these needs.

In addition to room heating, low temperatures create the need for clean hot water. This is the second residential energy use, after heating, in Argentina, Chile, Mexico, and Uruguay (ECLAC, 2016; Contreras et al., 2022). The source used to heat water varies greatly between these countries. While liquefied petroleum gas predominates in Chile and Mexico, natural gas predominates in Argentina, and electricity in Uruguay (Gil, 2021; In-Data and CDT, 2019; National Institute of Statistics, Uruguay, 2022).

Some data suggest that there is an underutilized potential for solar water heaters in the region, as the installed area is low compared to European countries with similar solar irradiation. Although needs vary because comparable European countries have colder climates, the differences are notable. The installed area is 18m^2 per 1,000 households (m^2/1000) in Chile and Uruguay, considerably low compared to 440 m^2/1,000 in Greece and 870 m^2/1,000 in Cyprus (ECLAC et al., 2023). The situation is different in Barbados, where 38% of households had one of these heaters in 2016 (Puig and Tornarolli, 2023).

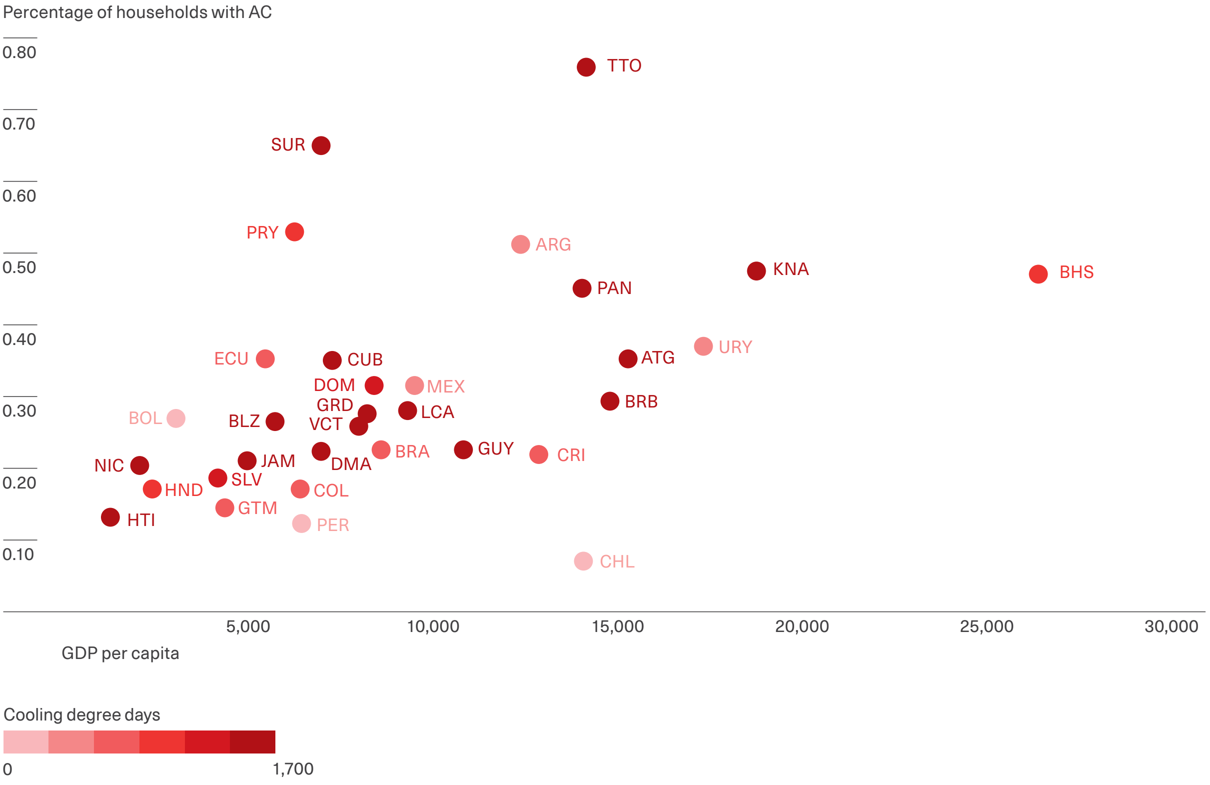
The counterpart to the relatively low heating needs in the region is the widespread need for room cooling. This can be quantified using the population distribution according to cooling degree days calculated in Alves and Lurgo (2023). The countries with the most extreme cooling needs, where the average household faces more than 1,500 degree days per year, are, in descending order, Nicaragua, Trinidad and Tobago, Suriname, Barbados, Jamaica, Belize, Saint Vincent and the Grenadines, Saint Lucia, Grenada, Haiti, Dominica, and Cuba. A second group also has significant cooling needs, between 1,000 and 1,500 degree days, and includes, in the same order, Saint Kitts and Nevis, Antigua and Barbuda, Panama, Guyana, El Salvador, Venezuela, the Dominican Republic, the Bahamas, and Paraguay. With values between 500 and 1,000 degree-days for their average household, are, from highest to lowest, Honduras, Brazil, Costa Rica, Guatemala, Colombia, and Ecuador. Finally, Mexico, Argentina, Uruguay, Bolivia, Peru, and Chile have fewer than 500 degree days. Part of the population of several countries in the last two groups has substantially higher cooling needs than the average: at least 25% of the inhabitants of Argentina, Ecuador, Guatemala, Mexico, and Uruguay have more than 500 degree days, and the same proportion of Brazil, Colombia, Costa Rica, and Honduras face at least 1,000 degree days.

The main method to meet room cooling needs is the use of air conditioning (AC) units. These devices operate on electricity, so they do not directly generate emissions, but they do indirectly contribute to emissions if the electricity generation matrix is not clean. In addition to cooling rooms, certain AC units can be used for heating, making them particularly attractive for reducing emissions generated by the use of fossil fuels for heating homes.

Graph 7.4 presents an estimate of the proportion of households with AC units in each country, calculated by Alves and Lurgo (2023), and its relationship with GDP per capita, as well as cooling needs measured by degree days, with darker shades indicating higher values. On average across countries, less than a third of households have AC units, so the adoption of these devices is still relatively limited in the region, especially considering the intense room cooling needs documented in Figure 7.1.

Graph 7.4

Income level, cooling needs, and estimated proportion of households with air conditioning



Note: The graph shows the positive correlation between the GDP per capita in 2021 (in constant 2010 US dollars) and the estimated percentage of households that own at least one air conditioning unit. The latter variable is predicted using a logistic regression estimated with household survey data from Argentina and Brazil for the period 2017–2018. The predictive variables in this regression are GDP per capita and cooling degree days. The color of each point is determined based on the average cooling degree days weighted by population, with a base temperature of 22°C. The color scale is defined based on six equal intervals with a range of 283. The minimum corresponds to Chile (37) and the maximum to Nicaragua (1,668). See Alves and Lurgo (2023) for more details on the construction and estimation of the model. The ISO country codes can be found in the chapter's annex available online.

Source: Authors based on data from Alves and Lurgo (2023) and World Bank (2023d).

The positive correlation between AC ownership and income in Graph 7.4 suggests that the fundamental reason behind the low adoption of these units is due to low household incomes. For example, Trinidad and Tobago and Nicaragua have a very similar number of cooling degree days, but the GDP per capita of the former country is nearly seven times that of the latter, and AC ownership differs by more than 50 percentage points in favor of the former. Cooling needs also play a role and explain, for example, an even greater difference between Trinidad and Tobago and Chile, despite both countries having similar GDP per capita. The same strong correlation between AC ownership and income is observed when comparing households with different economic levels within the same country. AC ownership in Barbados, Ecuador, El Salvador, Honduras, and Jamaica is at least 10 times higher in households of the highest income quintile than in those of the lowest income quintile (Puig and Tornarolli, 2023). Another variable that correlates with AC ownership is the price of electricity. Several countries that have high AC ownership for their income level also have historically low electricity prices. This is the case for Argentina and Paraguay.

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Global warming and the future increase in household incomes will significantly raise the demand for electricity for household appliances, primarily refrigerators, washing machines, and air conditioners

AC units already have a significant share in residential energy consumption, and this will only increase with economic growth and global warming. In Mexico, the use of air conditioning already accounts for 30% of electricity consumption and 7% of total energy consumption (Contreras et al., 2022). In the Dominican Republic, these magnitudes are 17% and 6%, respectively (Ministry of Energy and Mines and Bariloche Foundation, 2020). As a reference framework for how much this consumption could increase in the future, in the southern United States, where high incomes and temperatures combine, over 90% of households have AC units, and their use represents at least 30% of total electricity consumption (EIA, 2020d). Box 7.2 shows that AC ownership would increase by nearly 20 percentage points by 2050 as a result of the expected evolution in temperatures and incomes, which would increase total residential electricity consumption by 13%.

In addition to increasing total electricity consumption, the use of AC units for cooling increases the variation in demand between months of the year and throughout the day based on temperature. This has significant implications for countries' electricity generation capacity, which must have the necessary power to cover the hottest moments of the day. In the southern United States, where, as seen, the use of AC units is widespread, these devices cause a peak in electricity consumption in the summer afternoons that exceeds by 50% the consumption registered during off-peak hours, which occur during the early morning (EIA, 2020b).

Appliances and lighting

Of all appliances, those used for food preservation consume the most electricity in the region. They account for approximately 30% of residential electricity consumption in the Dominican Republic (Ministry of Energy and Mines and Bariloche Foundation, 2020) and 20% in Mexico (Contreras et al, 2022).

Panel A of Graph 7.5 presents the average proportion of households with a refrigerator (purple dots) and within each income quintile (gray dots) in 12 countries in the region. The ownership of this appliance in Latin America and the Caribbean is far from universal, being below 70% in Bolivia, Guatemala, Nicaragua, and Peru, which constitutes a very relevant well-being deficit. This proportion increases significantly with the household income level, up to approximately USD 500 per capita per month, and reaches levels of universality as it approaches USD 1,000 per capita.

Box 7.2

Cooling and heating demand and temperature projections

Using the intermediate emissions scenario (SSP2-4.5) from the Intergovernmental Panel on Climate Change (IPCC) as a reference, it is possible to calculate the amount of cooling and heating degree days in the various countries of the region for 2040 (short term), between 2041 and 2060 (medium term), and between 2081 and 2100 (long term). Alves and Lurgo (2023) conduct this exercise under the assumption that the relative distribution of the population within countries remains the same as the current one.

This exercise quantifies the decrease in heating needs and the increase in cooling needs in the region due to global warming. The simple average of heating degree days in the group of countries with the highest current needs, including Argentina, Bolivia, Chile, Ecuador, Peru, and Uruguay, will decrease from around 1,000 currently to 900, 820, and 740 in the short, medium, and long term, respectively. The increase in cooling degree days would be much more pronounced. The group of 21 countries with the highest cooling needs would increase their degree days from approximately 1,500 currently to 1,750, 1,900, and 2,200 in the short, medium, and long term.

The pronounced increase in ambient cooling needs, together with the long-term growth in household income, will strongly impact the demand for electricity for air conditioning. Extending the current patterns observed in Argentina and Brazil to the rest of the countries, the average ownership of air conditioning units in the region would currently be around one-third. Assuming that household incomes will increase similarly in the coming decades as observed in the last two, such ownership would increase by almost twenty percentage points, reaching approximately half of households by 2050. This increase would imply a rise in electricity demand of 6% by 2030 and 13% by 2050 (Alves and Lurgo, 2023).

Table 1

Estimates and projections of air conditioning (AC) penetration in households

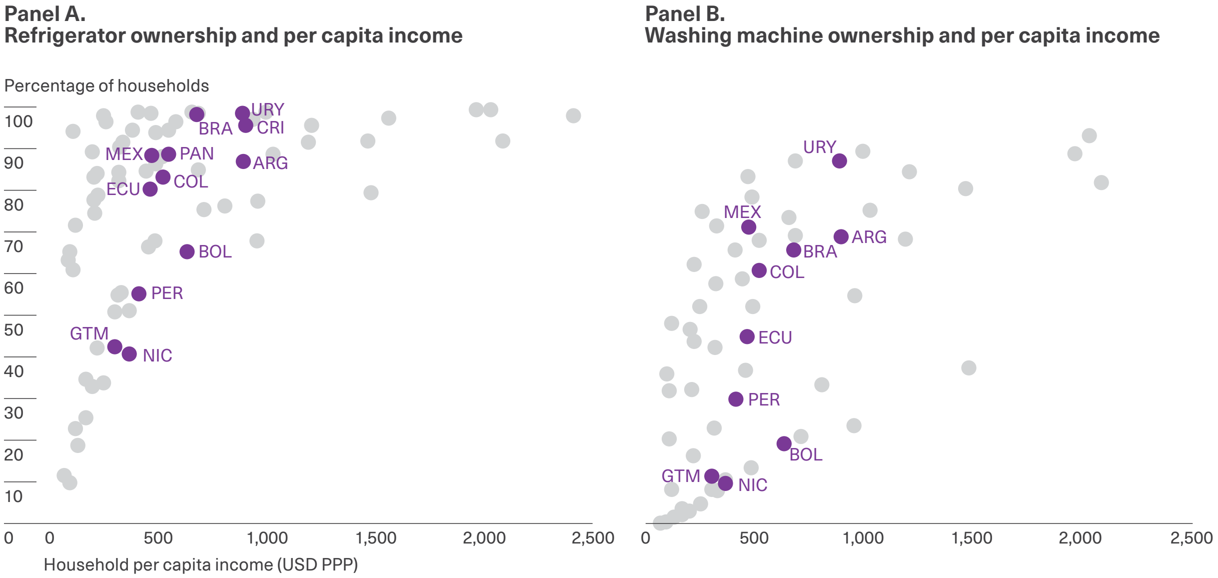
	Current		**2030**		**2050**	
	Households with AC (%)	**Average units per household**	**Households with AC (%)**	**Average units per household**	**Households with AC (%)**	**Average units per household**
LAC	31	1.4	39	1.4	48	1.5
South America	32	1.3	39	1.3	50	1.4
Central America and Mexico	24	1.3	34	1.4	43	1.5
Caribbean	34	1.4	41	1.5	50	1.6

Note: The table shows estimates of the percentage of households with at least one air conditioning unit and the average number of units for those households that have at least one. These variables are predicted with a two-stage Hurdle counting model, which includes GDP per capita and cooling degree days as explanatory variables and considers electricity price, estimated from household surveys in Argentina and Brazil in the period 2017–2018. Refer to Alves and Lurgo (2023) for more details on the construction and estimation of the model. The list of countries included in each subregion can be found in the chapter's annex available online.

Source: Authors based on data from Alves and Lurgo (2023).

Graph 7.5

Relationship between refrigerator and washing machine ownership and income level



Panel A.
Refrigerator ownership and per capita income

Panel B.
Washing machine ownership and per capita income

Note: The graph displays the correlation between ownership of basic household appliances and household per capita income converted to US dollars adjusted for purchasing power parity (PPP). Each point represents an income quintile of a specific country, with national averages highlighted in red. Ownership data were obtained from household surveys conducted in 12 countries between 2013 and 2021, with the exception of Panama (year 2008). Income was adjusted using the PPP factor corresponding to the period of each survey. The ISO country code and the survey year for each country can be found in the appendix of the online chapter. Table A.7.1 in the chapter's annex available online presents the survey year for each country.

Source: Authors, based on data from Puig and Tornarolli (2023), CEDLAS and World Bank (2022, 2023b).

Washing machines are generally the second most relevant appliance in terms of electricity consumption (Contreras et al., 2022; Ministry of Energy and Mines and Bariloche Foundation, 2020). Panel B of Graph 7.5 shows a positive relationship between ownership of a washing machine and income, but with a more gradual pattern than refrigerators. Additionally, there is a noticeable increase in adoption when income exceeds USD 500 per capita per month. Therefore, the acquisition of washing machines will be another significant addition to residential electricity demand in the region in the coming decades as household incomes continue to rise.

A third very relevant use of electricity, both for its impact on well-being and its consumption, is household lighting. Technological progress has introduced new lamps that are significantly more efficient than previous ones, thereby reducing electricity consumption. LED (light-emitting diode) lamps use 90% less electricity and last 25 times longer than traditional incandescent lamps (US Department of Energy, n.d.). While these two characteristics of savings and longevity make it economically advantageous to switch from traditional lamps to LED ones, their higher cost may restrict adoption by households. As will be seen later, this lack of adoption can be a focus of public policy action.

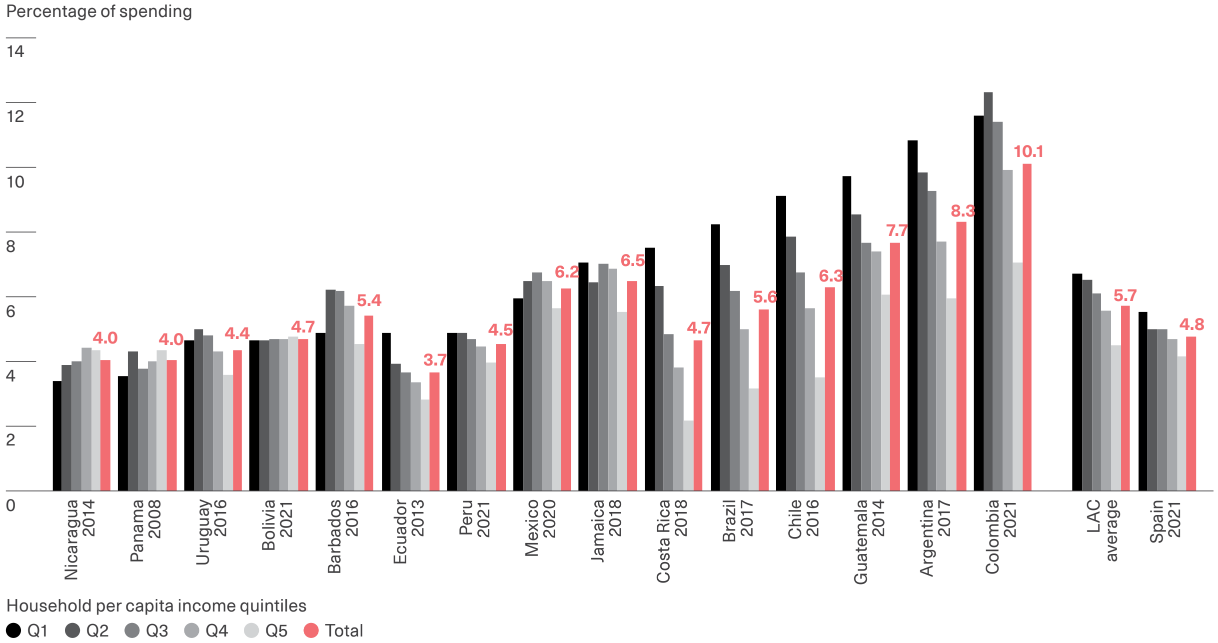
How much do households spend on electricity?

Household expenditure on residential energy consumption is a highly relevant category in household budgets in LAC. Therefore, any potential changes in energy prices during the transition will impact family finances. Graph 7.6 presents the proportion of residential energy expenditure to total household expenditure in each country in specific years when national statistical institutes conducted surveys on the subject. This residential use excludes the cost of energy consumption for transportation, analyzed in Chapter 8. In most countries in the region (and in Spain), this proportion ranges between 4% and 5% of total expenditure, but in Argentina, Colombia, and Guatemala, it is higher, exceeding 7%. The graph also shows that in most countries, this proportion tends to decrease with household income. This implies that energy is a necessary good and that the impacts of potential price changes resulting from the energy transition will be more intense for poorer households.

On average, households spend 6% of their budget on energy, mostly on electricity, exceeding 10% among the poorest in several countries

Graph 7.6

Percentage of household expenditure dedicated to residential energy consumption



Note: The graph shows the average weight 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 y Tornarolli (2023).

Box 7.3

How does electricity consumption respond to changes in price?

There is ample evidence that households respond to an increase in energy prices (electricity or gas) by consuming less, and that this response is greater in the medium and long term than in the short term (Espey and Espey, 2004; Labandeira et al., 2017). In the short term, the number of appliances remains relatively fixed, and the behavioral response is limited to changes in their usage. As time passes, households react to prices by modifying the number of appliances in the home, leading to substantially greater variations in consumption.

The responses of energy consumption to prices also vary significantly depending on the country and household income. Generally, studies available for Latin America and the Caribbean indicate that a 10% increase in electricity prices reduces residential consumption by between 2% and 4% in the short term and between 4% and 6% in the long term (Espey and Espey, 2004; Labandeira et al., 2017; Marques et al., 2022; Moshiri and Martínez Santillán, 2018; Zabaloy and Viego, 2022).[a] These magnitudes imply that price increases have little effectiveness in reducing consumption in the short term and, instead, strongly impact household budgets.

[a] Zabaloy and Viego (2022) and Marques et al. (2022) report short-term elasticities between 0.2 and 0.47 for Latin America and 0.36 for the Caribbean; Labandeira et al. (2017) estimate this elasticity at 0.25 for developing countries, and Moshiri and Martínez Santillán (2018) calculate it to be 0.35 for Mexico. In general, the evidence suggests that short-term elasticity is higher in Latin America and the Caribbean than in developed countries. For the long term, estimates, considering the same set of studies except for the last one, range between 0.25 and 0.33, 0.42, and 0.59, respectively.

Puig and Tornarolli (2023) show that the composition of spending on electricity in terms of energy sources aligns with consumption data by source presented in Graph 7.2. In the group of countries with the highest incidence of electricity in residential energy consumption—including Barbados, Brazil, Costa Rica, Jamaica, Panama, and Uruguay—on average, three-quarters of energy expenditure is on electricity. In Argentina, Bolivia, Ecuador, and Mexico, which form a group where gas predominates, this source accounts for one-third of total expenditure, with electricity around 60%. Lastly, in Chile, Colombia, Guatemala, Nicaragua, and Peru, countries with a high incidence of biomass, the proportion of electricity consumption is on average slightly less than 50%. The incidence of electricity in this latter group shows that it has a significant weight in household spending even in countries with a less electrified basket.

The proportion of energy expenditure in the household budget allows for an approximation of the impact that potential price increases have on household welfare, assuming that the quantity consumed remains constant.[7] Considering an expenditure of 10% on energy, similar to the average Colombian household in Graph 7.6, a 20% increase in prices reduces well-being to the same extent as a 2% decrease in household income. Similar impacts are observed in households in the lowest quintile of the population in Argentina, Brazil, Chile, and Guatemala.

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[7] As shown in Box 7.3, the demand response to price changes is relatively limited in the short term (Coady et al., 2015). However, as explained in the box, the price elasticity of energy demand is not zero. Therefore, these welfare impacts should be understood as very short-term and represent a ceiling in relation to long-term impacts. There is also an indirect impact through the increase in prices of non-energy goods that use energy as input for their production.

The state and challenges of electrification

Residential electricity access: connection and prices

Access to electricity entails well-being gains, and a fundamental aspect of this access is connection to electricity distribution networks. Panel A of Graph 7.7 shows that residential electricity coverage is universal in the countries with the highest per capita income in Latin America and the Caribbean, including Argentina, Brazil, Chile, Costa Rica, Mexico, Paraguay, the Dominican Republic, and Uruguay. A second group of countries has slightly lower coverage levels than the first but still very high, reaching between 94% and 99% of households. This group, which needs to make a relatively small effort to achieve universality, consists of (sorted from lowest to highest connection rate) Jamaica, Peru, Panama, Bolivia, Barbados, El Salvador, Ecuador, and Colombia. Finally, Guatemala and Nicaragua stand out for having substantially lower levels of electricity connection than the rest, with around 85% of households having electricity in their homes, although their data are the least updated.[8]

The current panorama of widespread electricity connection in the region is the result of significant progress made in recent decades (Puig and Tornarolli, 2023). Of the countries with universal coverage today, only Argentina, Chile, Costa Rica, and Uruguay had attained it at the beginning of the century. Colombia, Ecuador, and El Salvador increased the proportion of connected households by more than ten percentage points during the same period and are very close to achieving universality. Progress was even more notable in Bolivia, Honduras, and Peru, with increases of more than twenty percentage points so far this century.

Panel B of Graph 7.7 shows that the lack of universality of electricity connection in Bolivia, Colombia, Ecuador, El Salvador, Panama, and Peru is due to a lag in rural areas. In these areas, distribution costs are higher due to lower population density, compounded by challenging geography with regions of jungles and mountains. In the context of the energy transition, the obstacles posed by these higher distribution costs can be addressed with the installation of solar panels in each household, an aspect that will be analyzed later in this chapter.

Electricity grid connection is universal in urban areas, thanks to significant advancements in recent decades, but connectivity gaps still persist in rural areas

While the region is very advanced in terms of household connection to electricity networks, this does not guarantee access, which also depends on price. Survey data suggest that there are indeed access challenges in terms of households' ability to afford electricity expenses. According to the 2018 edition of the Latinobarometer survey, in the simple average of 18 countries, 54% of respondents reported having had difficulties paying the electricity bill at some point (Latinobarometer Corporation, 2020).

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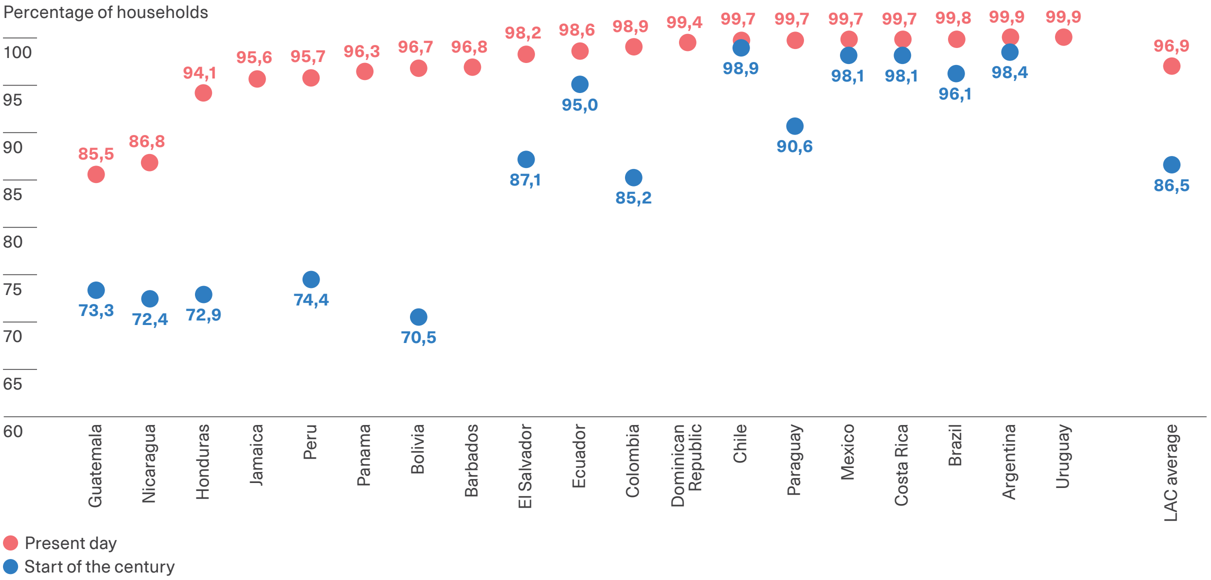
[8] Table A.7.1 in this chapter's annex available online shows the year corresponding to each indicator in Graph 7.7.

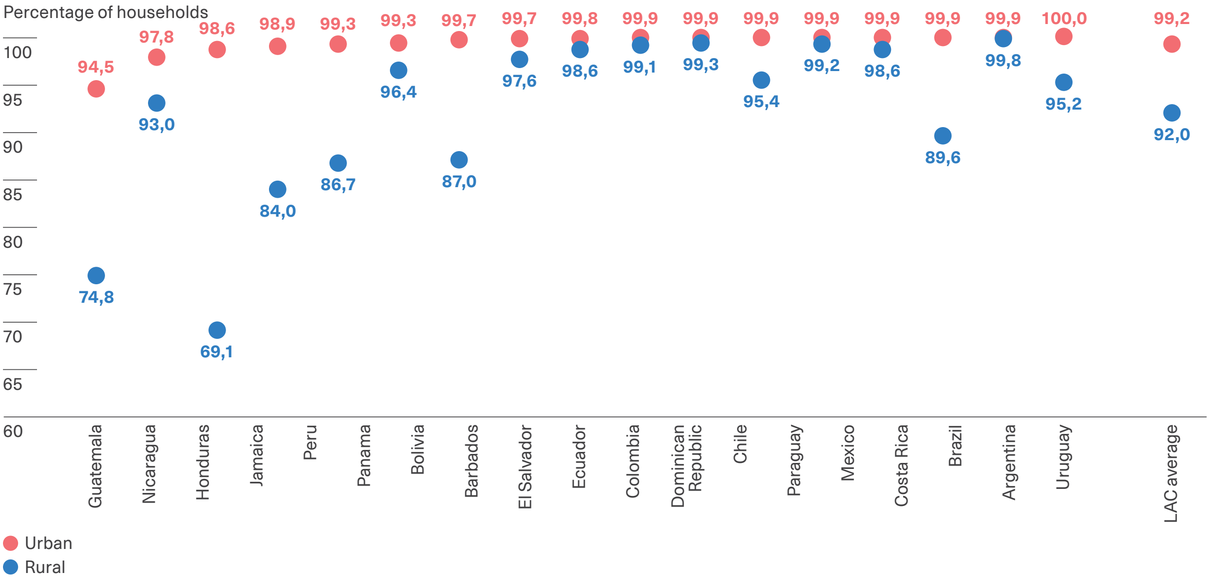
Graph 7.7

Electricity connection status in Latin America and the Caribbean

Panel A.
Evolution of the proportion of households connected to the service in the last 20 years



Panel B.
Proportion of households with service connection in rural and urban areas today



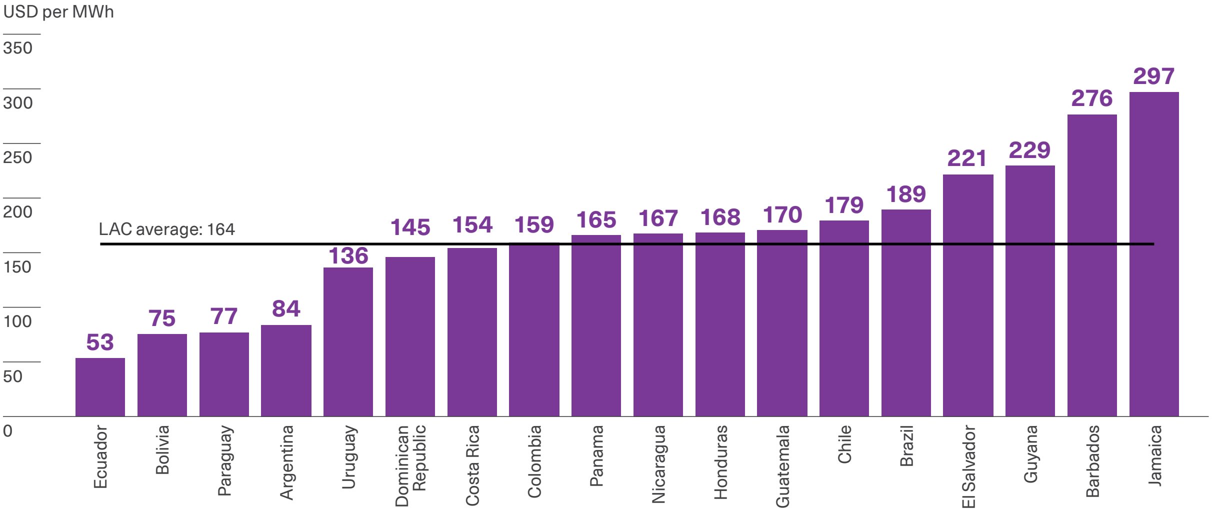
Note: The graph shows the percentage of households with access to electricity service in 19 countries and the LAC average. Panel A displays the evolution of this indicator between the present period (2014–2021) and the early century (2000–2005), while Panel B presents the current data distinguishing between urban and rural areas. The variable was constructed from national household surveys. Table A.7.1 in the chapter's annex available online provides the survey year for each country.

Source: Puig and Tornarolli (2023).

Graph 7.8 presents the average prices per country of residential electricity for the period 2014–2020. The extended period over which these data are collected enables an approximation of the structural level of prices, a factor relevant for household appliance purchasing decisions, which primarily determine their levels of electricity consumption. The graph reveals enormous differences between countries, which can be grouped into three sets. A first group has the highest prices, above USD 200 per megawatt-hour (MWh), and is composed (from lower to higher price) of El Salvador, Guyana, Barbados, and Jamaica. A second, larger group has prices close to the regional average, ranging between USD 140 and USD 190 per MWh. Finally, Ecuador, Bolivia, Paraguay, and Argentina have very low prices, around half of the regional average. These enormous differences in retail prices are explained, on the one hand, by dissimilar generation costs and, on the other hand, by different levels of taxes and subsidies in the various stages of electricity production and distribution.

Subsidies to residential electricity prices have historically been very common in the region. Between 2011 and 2013, they averaged around 0.8% of GDP for 32 countries in Latin America and the Caribbean (Di Bella et al., 2015). Table A.7.1 in the annex (available online) shows that this average concealed very different realities. Of those 32 countries, 11, primarily including high-income nations that do not export oil, either have no subsidies or subsidize to a maximum of 0.1% of GDP, while nine subsidize by at least 1 percentage point of GDP. Of the total electricity subsidies, approximately half were directed to the residential sector (Marchán et al., 2017). Beyond the general subsidy to prices, in most countries, there is also a social tariff component, which uses the amount of electricity consumed as a targeting mechanism. The general (non-targeted) component of these subsidies is key to explaining the low prices observed in Graph 7.7 in Argentina, Bolivia, and Ecuador, three countries where such aid exceeded the regional average between 2008 and 2014 (Sanin, 2019).

Graph 7.8
Average residential electricity prices in 2014–2020



Note: The graph shows the average price paid by consumers (in current US dollars per MWh) in 18 countries and the LAC average for the period 2014–2020. The average price for the countries considered is 164 USD/MWh. The variable was constructed using billing and sales volume data. The final price includes national taxes.

Source: Authors based on data from OLADE (2021a).

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In several countries, there are significant subsidies for electricity prices. These could be targeted toward low-income households to improve efficiency and access

An important phenomenon in the region is the non-payment of the electricity bill due to informal connections. This phenomenon is closely linked to informal settlements, although not exclusively. In Argentina, data from the national registry of popular neighborhoods indicate that only 31% of nearly 1.2 million families residing in these areas have a connection to the electricity grid with an individual meter and individual billing (Ministry of Social Development, n.d.). Of the remaining 69%, less than 1% are not connected to the grid, so the vast majority access electricity irregularly. In Brazil, data processing from the 2010 population census indicates that 3.7% of households reported not having an exclusive or shared meter in their electricity connection.

In addition to the dimension of the hidden subsidy that informal connections may have, they have two other characteristics that are relevant to the energy transition. First, from an access perspective, informality, in general, is associated with deficiencies in the quality of the connection, both in terms of supply continuity and power and the existence of health risks. Second, the absence of a meter means losing the regulatory role that prices play in electricity consumption.

Self-generation electricity through solar panels in households

The installation of solar panels is a tool to reduce CO_2 emissions associated with electricity generation. When households adopt this technology, they also indirectly contribute to reducing emissions by limiting losses that occur in the electricity distribution stage. Beyond its social benefits, one advantage of households adopting solar panels is that it allows them to save on electricity service payments and associated taxes and even earn money by supplying energy to the grid when possible. Globally, in 2022, 17% of total solar-generated electricity came from the residential sector, and it is projected to grow by over 60% between 2022 and 2024 (IEA, 2023o).

Promoting the adoption of this technology by households is particularly attractive in rural areas where there is no electricity grid, as it allows access to electricity without incurring the costs of extending infrastructure. Initiatives of this kind are abundant in the region, with a special mention of Peru's Mass Photovoltaic Program, which brought electricity to over 200,000 households (Bejarano et al., 2023).

While, in principle, the installation of panels could reduce the extraction of electricity from the grid by a similar amount to the household's consumption before installing the device, this is not usually the case due to the existence of a rebound effect (Beppler et al., 2023; Deng & Newton, 2017; Qiu et al., 2019). For the case of Uruguay, D'Agosti and Danza (2023) find that households react to the panel installation by increasing their electricity consumption by around 20%. Another interesting aspect of Uruguay's case, studied by D'Agosti and Danza (2023), is the combination of panel installation with the existence of net metering technology, which allows households to sell energy to the grid in addition to buying it. This led households to react to panel installation by injecting electricity into the grid, with an average of 1,600 kWh per month.

A limitation of subsidies for panel adoption is that they tend to be regressive, as wealthier households will have greater incentives to adopt this technology due to their higher electricity consumption (Feger et al., 2022). For this reason, a more effective alternative to promoting panel installation in higher-income households is to create schemes that increase electricity prices as household consumption increases (Feger et al., 2022).

The current profitability of installing panels on rooftops is associated with a significant drop in equipment and installation costs, which decreased by over 80% in the last decade (IEA, 2023o). However, there are still barriers to adoption, mainly regulatory, financial, and informational, so there is ample room for initiatives from both the public and private sectors to promote greater implementation in the region in the coming years. Regarding regulations, these include pricing schemes and smart meters, interventions in city building codes to facilitate panel adoption on the roofs of new buildings, and informational campaigns to make households aware of the opportunities associated with this technology.

The faster advancement of solar panel use in the residential sector also requires that the prices of these products continue their downward trend, which was interrupted between 2020 and 2024 due to increased material prices and transportation costs resulting from the COVID-19 pandemic. On the other hand, the reliance on solar light to generate electricity inherent in this technology necessitates improvements in storage and grid interconnection technologies.

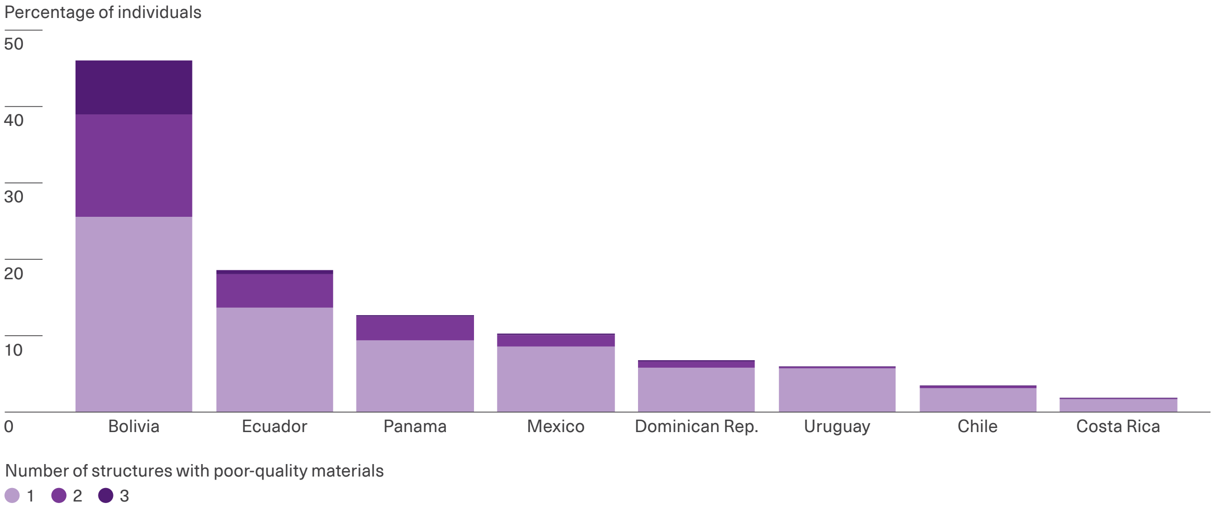
Insulation of buildings and energy consumption

Given the current and future relevance of heating and cooling needs in households, thermal insulation of buildings becomes crucial to reduce or contain the increase in energy consumption. While this chapter focuses on residential buildings, thermal insulation is also relevant for office and commercial buildings.

Building envelopes are the structures that separate the interior from the exterior and provide thermal insulation, as well as visual and sound protection. These envelopes mainly include walls, roofs, and windows. Their efficiency as thermal insulators influences the energy consumption and thermal comfort of the people dwelling in them. The impact of differences in envelope efficiency on energy consumption can be significant. In Great Britain, for example, there are building efficiency certificates ranging from A, for the most efficient, to G, for the least efficient. It has been estimated that buildings in Category G can consume up to three times more energy than those in Category A for the same level of thermal comfort in the home (IEA, 2022a).

In the region, there are deficiencies in housing quality, which include poor insulation conditions in buildings. Graph 7.9 provides an approximation of the most extreme insulation deficits considering the materials of roofs, floors, and walls of homes. Of the eight countries with census data collected after 2010, Bolivia stands out, where almost half of its population resides in buildings that have a deficit in at least one of these three components. This is particularly concerning given that Bolivia has one of the highest heating needs in the region. These needs are also relevant in Chile and Uruguay, where a smaller but significant proportion of the population lives in buildings with poor materials in one of these key structures. Within the group of countries with widespread cooling needs, between 10% and 20% of the population in Ecuador, Mexico, and Panama lack some of these materials, while in the Dominican Republic, this proportion rises to 7%.

Graph 7.9
Population with at least one dwelling structure made from poor-quality materials (floors, roof, walls)



Note: The graph depicts the percentage of people living in homes where roofs, floors, or walls are constructed with poor-quality materials. Data were obtained from national censuses for eight countries in LAC during the period 2010–2017. The definition of poor construction materials follows the methodology proposed by ECLAC (2001) for identifying unmet basic needs (UBN) and includes materials such as dirt, straw, cardboard, waste material, mud, bamboo, and palm, among others.

Source: Authors based on data from the Minnesota Population Center (2020) and ECLAC (2001).

The two most relevant specific policies for improving the energy efficiency of housing are the inclusion of minimum standards in building codes and informational interventions. Regarding minimum standards, these include regulations on building envelopes, as well as heating, cooling, lighting, and ventilation systems, which are particularly relevant for multi-story buildings' energy consumption. Data from the United Nations and the IEA indicate that the adoption of minimum efficiency standards is lagging in the region, but many countries are in the process of establishing them (IEA, 2022a; UNEP, 2022b). Out of a total of 33 countries, only Chile, Colombia, and Jamaica have mandatory standards. Argentina, Brazil, and Mexico have available standards, although not mandatory, while 11 have codes under development, and the rest have no information available.

The quality of building envelopes can be difficult for homebuyers or renters to verify, decreasing incentives for owners to invest in improvements. Public policies can address this by creating quality certificates for building envelopes and making them available or even mandatory. There is evidence, based on price comparisons of certified and uncertified homes in developed countries, that households value this information (Brounen and Kok, 2011; Kahn and Kok, 2014).

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Deficiencies in housing construction materials reduce the efficiency of energy consumption for climate control

A specific justification for public policies to promote improvements in building thermal insulation arises from the lack of alignment between the incentives for improvement that property owners and tenants have (Gerarden et al., 2017). In rental contracts, tenants often pay for electricity consumption, while owners control construction efficiency aspects. If these aspects are difficult to observe, they will not be incorporated into the housing price, and the owner will have no incentive to improve energy efficiency in the building. Hancevic and Sandoval (2023) provide evidence in favor of this hypothesis for Mexico. These authors find that appliances provided by homeowners in rented homes in Mexico, such as air conditioners and water heaters, are less efficient than those in owner-occupied homes. Conversely, they do not observe efficiency differences in appliances not provided by owners in rented homes, such as washing machines.

Given serious housing affordability issues in the region, public policies must be especially careful in evaluating the cost-benefit of energy efficiency interventions in buildings to avoid contributing to this problem (Daude et al., 2017). The limited available evidence supports this cautious approach, showing that the cost-benefit analysis of the actual effects of interventions is often less auspicious than indicated in ex-ante technical assessments (Christensen et al., 2023; Davis et al., 2020; Fowlie et al., 2018).[9] There are two reasons for this disconnection between ex-ante evaluations and real policy impacts. First, these evaluations sometimes completely omit intervention costs and focus only on the reduction in energy consumption generated. Second, these evaluations do not consider household behavioral reactions to the intervention; for example, a post-intervention evaluation in Mexico found that improving thermal insulation in homes did not result in changes in temperature or electricity consumption because households kept windows open on hot days (Davis et al., 2020).

Energy transition policies in the residential sector

Reducing CO_2 emissions through the use of cleaner energy sources, more efficient appliances, and energy-saving practices generates social benefits beyond private ones, motivating the implementation of policies that promote it. In addition to environmental reasons, two other key factors justify not only the intervention of public policies but also their successful design. On one hand, as explained in Box 7.4, the complexity of decisions associated with energy-efficient consumption and credit access constraints may prevent households from increasing the efficiency of their residential consumption even when it would be beneficial to them in private terms (Allcott and Mullainathan, 2010; Fowlie and Meeks, 2021).[10] On the other hand, there are equity considerations. The monetary costs of adoption may be too high for low-income households, and within this group, younger members and women are disproportionately affected by health damages and the higher burden of effort associated with the use of dirty energies.

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[9] Davis et al. (2020) found that a housing insulation improvement intervention in a warm area of northern Mexico had no effect on electricity consumption or technical comfort, despite ex-ante technical calculations indicating a 25% savings in electricity consumption. Similarly, Fowlie et al. (2018) studied a massive, but low-adoption, program for thermal insulation improvement in homes in the United States and found a negative cost-benefit relationship ex-post for households, despite ex-ante technical studies indicating otherwise. Christensen et al. (2023) have also reported recent evidence of serious overestimations ex-ante of energy savings in another building insulation improvement program in the United States.

[10] This does not imply that unrealized private benefits always exist. There is abundant evidence from contexts where this is true (e.g., Berkouwer and Dean (2022)) as well as from others where it is not (Fowlie et al. (2018)). Allcott and Greenstone (2012) and Gerarden et al. (2017) evaluate the available evidence regarding the existence of these unrealized private benefits and discuss their causes and implications for public policy.

Box 7.4

Why might households not implement energy efficiency measures that would improve their well-being?

Evidence suggests that households often fail to adopt energy efficiency technologies and practices even when they would provide them with private benefits, and they do not respond to energy prices in the most beneficial way for their interests (Bensch et al., 2015; Berkouwer and Dean, 2022). To analyze how public policies can help households make better energy consumption decisions that are also socially beneficial, it is useful to identify three deficiencies underlying this issue: access to credit, access to information, and decision-making.

The lack of access to credit is a barrier to the adoption of efficient technologies in various contexts, and recent evidence suggests it is also a problem for energy consumption (Bensch et al., 2015; Berkouwer and Dean, 2022). The deficit in access to credit is particularly relevant in middle-income settings with high inequality in the region, where credit markets are less developed, and poorer households lack collateral and stable formal incomes.

Regarding information problems, advancements in residential energy consumption efficiency are associated with new technologies that households may not be aware of and may find costly to learn about. Given the public good nature of information, it may be insufficiently provided, leading to low adoption rates of more efficient technologies.

As for decision-making, evidence from behavioral economics shows that issues with temporal inconsistency, lack of attention to details, and difficulty processing complex calculations can lead households to not adopt technologies and practices that would be best suited to their budget. In the case of acquiring new equipment to reduce energy expenditure, temporal inconsistency and difficulty in calculating future savings may lead to non-adoption. Concerning electricity consumption, households may not accurately record how much they consume and at what time of day, two crucial aspects for designing efficient tariffs.

Given the description provided in the section "Patterns of residential energy consumption in the region" in this chapter, public policies for energy transition aimed at this sector can be framed around the three main challenges identified. Table 7.1 summarizes these challenges, the objectives of the policies to address them, and specific policy measures. The following subsections delve into more detail about these three elements.

Before reviewing the available evidence regarding the effectiveness of different policies, it is crucial to note that there is a significant knowledge gap regarding the impact of energy efficiency programs in developing countries (Fowlie and Meeks, 2021). Just as funds are allocated to develop technologies, governments should allocate resources to evaluate scalable policies experimentally (Allcott and Mullainathan, 2010). This is especially relevant since ex-ante evaluations of policies often ignore behavioral reactions and implementation aspects, thus strongly overestimating gains (Davis et al., 2020; Fowlie et al., 2018).

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The lack of information, difficulties in accessing credit, and the complexity of energy consumption decisions motivate and provide the framework for public policies in the residential sector

Table 7.1
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: Reduce the use of biomass for cooking and heating

The most basic intervention to improve energy efficiency in biomass cooking and heating in the region involves maintaining the use of this energy source while improving existing technologies. For example, in the case of stoves, pellet-fueled stoves are more efficient and cleaner in terms of particulate matter production than traditional wood-burning stoves, and pellets also take up less space (Boso et al., 2019).

Evidence shows that the willingness to pay for cleaner cooking methods is very low among households that traditionally cook with biomass, which are generally residents of rural areas with very low incomes (Berkouwer and Dean, 2022). This implies that pricing policies such as carbon taxes would not be effective in improving adoption and would have a strong regressive bias. In this context, two types of alternative strategies can be considered. On the one hand, partially or fully subsidizing the acquisition of more efficient

appliances; on the other hand, implementing information and education interventions that affect behavior without requiring an economic transfer to the household.

Subsidies for the acquisition of such equipment have the advantage of being effective in addressing a variety of reasons why households do not adopt socially more efficient technologies. This includes issues associated with poverty and credit constraints, which are very relevant in the developing world (Berkouwer and Dean, 2022), but also information problems that lead households to underestimate the private returns of investments in efficiency (Allcott et al., 2015). Given the credit access issues highlighted in Table 7.1, subsidies in equipment acquisition credit programs could stipulate lower interest rates and longer terms.

The main disadvantage of subsidies is their fiscal cost, which highlights the importance of carefully targeting subsidies, directing them to households where a greater impact on behavior is expected while avoiding benefiting those with higher incomes (Allcott et al., 2015). Information and education measures are not effective in addressing poverty and credit problems, but generally, their cost is much lower due to the absence of a transfer and lower logistical costs. Available evidence suggests that there is significant room for complementarity between information and subsidies. In particular, subsidies for the adoption of new technologies may not be effective if not accompanied by an information and education component (Hanna et al., 2016).

Overall, policies promoting the adoption of more efficient stoves have been effective in reducing emissions and biomass consumption in households receiving the equipment, but they have faced issues of low adoption and maintenance (World Bank, n.d.; Beltramo et al., 2023; Berkouwer and Dean, 2022; Hanna et al., 2016). Given these implementation problems and the fact that even when stoves and heaters are well used, they continue to generate emissions, their replacement with cleaner technologies such as LPG and electricity could be considered (Beltramo et al., 2023).

Challenge 2: Increase in the demand for electricity

Interventions to improve efficiency and promote savings in electricity consumption can be grouped into three categories. First, improve the efficiency of electrical appliances through subsidies or mandatory standards. Second, provide information and other behavioral interventions both for the adoption of more efficient appliances and for the use of existing appliances. Third, modify the level and structure of energy prices.

Available evidence on subsidies for the acquisition of more efficient equipment shows limited effects on refrigerators and air conditioners, but positive and significant effects on lamps (Allcott et al., 2015; Carranza and Meeks, 2021; Davis et al., 2014; Iimi et al., 2019). Davis et al. (2014) studied a program to replace these two appliances in Mexico and found that replacing refrigerators effectively reduced total household electricity consumption by 8%, a considerable amount. However, this program constitutes an additional example of discrepancies between actual impacts and ex-ante evaluations, which in this case predicted an effect four times greater than the actual one. The results of the same program were worse regarding the replacement of air conditioning units, which led to an increase in electricity consumption. This was due to a typical “rebound effect,” whereby households reacted to the greater efficiency of the equipment by increasing their usage. The overall evaluation of replacing both appliances showed that it was a very expensive way to reduce emissions, costing over USD 500 per ton of CO_2.

appliance labeling existed in most countries in Latin America and the Caribbean, except Bolivia (Ravillard et al., 2019).[12]

The challenge of increasing electricity demand must be addressed through improvements in appliance efficiency, housing materials, and behaviors

Adoption of minimum standards, on the other hand, has received more favorable evaluations and has been widely implemented worldwide over the last four decades (Saunders et al., 2021). According to data from the IEA, minimum standards coverage in the region exceeded 90% of refrigerator consumption in 2022, placing it above the global average, but is lagging in other appliances (IEA, 2022a). In lighting and room cooling, the region is slightly below the global average, with less than 70% of consumption subject to minimum standards. The greatest challenges are in water-using appliances, such as washing machines and dishwashers, where standards cover only 20% of consumption, and especially in appliances with screens, where minimum standards coverage in the region would be zero, compared to around 70% for the global average.

The complexity associated with energy efficiency technologies and the high potential cost of subsidies reinforce the attractiveness of informational and behavioral interventions. These have been widely implemented worldwide in recent decades with favorable evidence regarding their effectiveness. There are three main types of interventions: appliance labeling, provision of information on one's own electricity consumption and that of one's neighbors, and informational campaigns.[11]

Appliance labeling policies involve requiring sellers to place a standardized label on appliances describing their level of energy efficiency. Impact evaluations indicate that these policies are effective in improving consumers' valuation of more efficient appliances (Andor and Fels, 2018). In 2023,

Regarding the provision of information on electricity consumption levels, households traditionally received information at the end of the month, with no more details than total consumption quantity and cost. Technological advances have made it possible to improve the level of information households receive. On the one hand, several randomized experiments have shown that providing real-time consumption information leads to decreases in consumption (Houde et al., 2013). This requires the ability to measure consumption in real time, thus requiring investments in smart meters. On the other hand, a particularly successful form of providing information about a single household's consumption is to compare it with the consumption of neighbors with similar characteristics (Allcott, 2011b; Ayres et al., 2009; Costa and Kahn, 2013). An evaluation of such an intervention in Quito showed a reduction in average monthly consumption of around 1% (Pellerano et al., 2017). Although the effects of these interventions are usually small, their implementation cost is minimal, making the cost-benefit balance highly favorable (Andor and Fels, 2018).

Informational campaigns aim to draw households' attention to relevant aspects of their consumption. One such typical aspect is the temperature at which cooling or heating appliances and systems are set. Technical calculations indicate that just a one-degree difference, higher for cooling or lower for heating, can decrease consumption by up to 20% (Gil, 2021).

Regarding price policies, as seen in Box 7.3, household consumption responds to changes in that value. Therefore, higher prices can promote efficiency and savings in electricity usage. However, there are three significant obstacles

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[11] Another behavioral intervention that has shown cost-benefit relationships in some contexts involves households making commitments to reduce their energy consumption (Harding and Hsiaw, 2014). The evidence supporting this type of tool is less abundant than the three mentioned in the main text (Andor and Fels, 2018).

[12] Ravillard et al. (2019) state that by 2017, all countries had labeling except Bolivia, El Salvador, and the Dominican Republic. However, it has been verified that the latter two countries adopted it subsequently. A study by the Ministry of Energy (2019) confirmed that Bolivia had not adopted it and indicated that labeling existed in Peru and Paraguay but was not mandatory.

on the path of increasing energy prices. First, the same box showed that short-term responses are relatively limited, with reductions of 2% to 4% in consumption for every 10% increase in prices. Second, as seen in the subsection "How much do households spend on their residential energy consumption?", those with lower incomes allocate a significant portion to energy, so price increases strongly impact their budget. Third, households have difficulty reacting to tariff models that are more efficient but more complex.

One way in which price design can, in theory, contribute to the more socially efficient use of energy is by varying prices according to the time of day. In the context of energy transition, the variability in the generation potential of renewable sources, such as wind and solar, means that the costs of producing electricity can differ significantly throughout the day. Thus, prices can incentivize consumers to use their appliances during hours when there is greater availability of renewable electricity and minimize the social costs of electricity generation (Fabra et al., 2021). In practice, the implementation of dynamic pricing is not usually observed in a "pure" form, in the sense that prices reflect real-time costs, but rather, they are often implemented in bands associated with periods of lower and higher aggregate consumption. As a result, typically, the variable tariff will be higher during peak hours, which usually occur in the late afternoon and evening, and lower during off-peak hours in the early morning. However, the implementation of dynamic pricing faces the same three difficulties mentioned in the previous paragraph, along with a technological or infrastructure obstacle.[13] Traditional, older residential consumption meters do not record the time of day when consumption occurs. Therefore, billing consumption according to dynamic prices requires the installation of smart meters. Additionally, in a "pure" dynamic pricing scheme, consumers ideally need access to real-time information to react to price changes.

Challenge 3: Improve the poorest households' access to electricity

The challenge for improving access to quality electricity for poor households involves acting on multiple dimensions. Three of them are highlighted in Table 7.1. The first was discussed in the section "How much do households spend on their residential energy consumption?" and consists of containing the impact of electricity expenses on the household budget. To advance toward this goal, two main tools can be used. On one hand, there are targeted subsidies, consisting of reducing the electricity tariff for households with lower incomes. On the other hand, there is the design of increasing electricity tariffs in blocks, which implies that the price of electricity increases discreetly with the amount consumed. Beyond these two specific actions, measures that make appliances and buildings more efficient also serve to reduce the impact of electricity expenses on the poorest households.

Subsidies targeted at low-income households, expanding access in rural areas, and formalizing informal connections are key to improving equitable access to electricity

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[13] Fabra et al. (2021) found that Spanish consumers did not respond on average to dynamic pricing, and Cahana et al. (2022) suggested that lower-income households would be relatively more adversely affected by the introduction of dynamic pricing. Other studies, while not focusing on dynamic pricing, have explored related aspects, revealing that consumers do not respond to more sophisticated tariff schemes in a manner that would generate greater social efficiency. Shaffer (2020) demonstrates that households in Canada do not comprehend non-linear prices because they believe the marginal price applies to all consumption. This observed behavior implies a welfare loss equivalent to 10% of annual electricity consumption. Similarly, Ito (2014) finds that consumers in California respond to average rather than marginal prices.

The second dimension refers to providing access to electricity for poor households in rural areas. As seen in the section “Access to electricity at the residential level: connection and prices,” access to electricity in rural areas of several countries is far from universal. Likewise, in the section “Self-generation of electricity in households through solar panels,” it was discussed how subsidies for the acquisition and installation of these devices can improve access in such areas.

Lastly, in the section on the amount of resources that households dedicate to energy, the phenomenon of irregular connections to electricity networks and the access problems they pose were presented. Progress in addressing this problem has two aspects. One coincides with the budgetary problem, raised in the first of the three dimensions, and with the corresponding policy tools. The other aspect is related to infrastructure and management of electricity distribution, as it is necessary to install cables and meters to regularize neighborhoods that are irregularly connected to the grid.

Transportation and energy transition: Toward sustainable mobility

- Energy efficiency and electrification in land transport
- Energy transition in urban mobility
- Sustainable transportation policies
- How to decarbonize freight transportation

8

Key messages

1

Transportation in Latin America and the Caribbean accounts for 12% of total direct greenhouse gas emissions and 25% of energy emissions, with nearly 90% stemming from land vehicles. While per capita emissions are notably lower than those of developed nations, they have surged in recent decades due to the proliferation of private and freight vehicles.

2

Significant technological advances have enabled the electrification of private vehicles, yet their adoption in the region remains limited due to high acquisition costs. Promoting private vehicle electrification through purchase subsidies appears unsuitable due to fiscal implications, regressive tendencies, and limited impact on new vehicle adoption.

3

The large-scale electrification of heavy freight transport remains costly, prompting emissions reduction efforts to focus on enhancing efficiency and increasing the utilization of alternative fuels like biofuels. While freight rail transport boasts lower emissions, its economic feasibility necessitates a scale that justifies its operation.

4

Light-duty transport, particularly in urban logistics, holds significant potential for decarbonization through electrification. The economic viability of electrification is notable due to its lower power requirements compared to heavy freight transport, with intensive usage expediting investment recovery. However, challenges arise from the high level of informality and fragmentation within the sector, hindering progress toward electrification.

5

Although two-thirds of trips in the region's major cities are made using sustainable transportation modes, private vehicles remain the primary contributors to emissions. Decreasing their usage in favor of public transport and active modes not only mitigates greenhouse gas emissions but also reduces particulate matter emissions, noise pollution, congestion, and accidents. Some of these costs are not mitigated and may even worsen with car electrification, further justifying the avoidance of subsidies for their acquisition.

6

The energy transition offers an opportunity for bus electrification, already well underway in various cities across the region. While the operating costs of electric buses are lower than those of internal combustion engines, their initial purchase price remains high, necessitating subsidies and financing to ensure the financial sustainability and affordability of urban public transport systems.

Transportation and energy transition: Toward sustainable mobility[1]

Introduction

The transportation sector in Latin America and the Caribbean (LAC) contributes to 12% of direct greenhouse gas (GHG) emissions and 25% of energy emissions in the region. Per capita emissions are around one ton of carbon dioxide equivalent per year (tCO_2 eq/cap/yr), which is 15% below the global average, nearly half that of Europe, and five times less than the United States (Minx et al., 2021). The majority of emissions in the region stem from land vehicles, accounting for 85% of total transportation emissions in Latin America and 88% in the Caribbean (Minx et al., 2021). Roughly half of these emissions originate from automobiles, with the remainder attributed to cargo vehicles and buses (Vergara et al., 2021).

Direct emissions from transportation stem from the use of fossil fuels to power vehicle engines. The urgency of addressing climate change and ongoing technological advancements necessitate an energy transition within the sector to mitigate these emissions. This transition will be facilitated through three mechanisms, outlined below and presented in depth in this chapter.

First, different forms of transportation generate different levels of emissions. Therefore, the energy transition involves making greater use of the least polluting forms. Changing the way people move around cities is, in fact, the key to such a transition in these areas, since walking, cycling, and mass public transportation generate substantially fewer emissions than fossil fuel-powered automobiles. In freight transport, in certain contexts, it may be economically viable to replace truck trips with rail transfers.

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[1] This chapter was written by Guillermo Alves and Juan Odriozola with research assistance from Facundo Lurgo and Franco Degiuseppe.

Second, technological advancements have rendered engine electrification economically viable in many scenarios, with cheaper batteries playing a crucial role in this progress. Typically, the economic calculus for electric vehicles entails higher acquisition costs but lower usage costs compared to conventional vehicles. Consequently, the cost-effectiveness of vehicle electrification increases with usage, particularly in frequently utilized vehicles like taxis, urban buses, and last-mile freight transport. However, higher acquisition costs present a financing challenge. In urban mass transit, this challenge has been tackled through institutional innovations that facilitate financing via the separation of bus ownership and management.

Third, even if combustion engine vehicles are retained, significant emission reduction opportunities exist through enhancing engine efficiency and, in freight transport, optimizing the logistics chain to minimize truck circulation with idle capacity. Decreasing emissions from combustion engines involves strategies like reducing vehicle age to enhance efficiency and employing fuels with lower emissions than gasoline, such as biofuels, natural gas, and hydrogen.

●●

12% of direct greenhouse gas emissions and 25% of energy emissions in Latin America and the Caribbean are generated by the transportation sector

Transportation, energy consumption, and emissions

Petroleum derivatives are one of the primary energy inputs in Latin America and the Caribbean. Transportation is responsible for more than two-thirds of the total use of these products. Graph 8.1 shows the enormous growth in GHG emissions generated by land transport in the region. These emissions tripled in the last half-century due to the increase in both the number of private cars and freight trucks. The former grew by more than 60% between 2005 and 2015 (Rivas et al., 2019) and in 2019 almost one out of every three households owned, on average, at least one automobile in the region (Puig and Tornarolli, 2023).

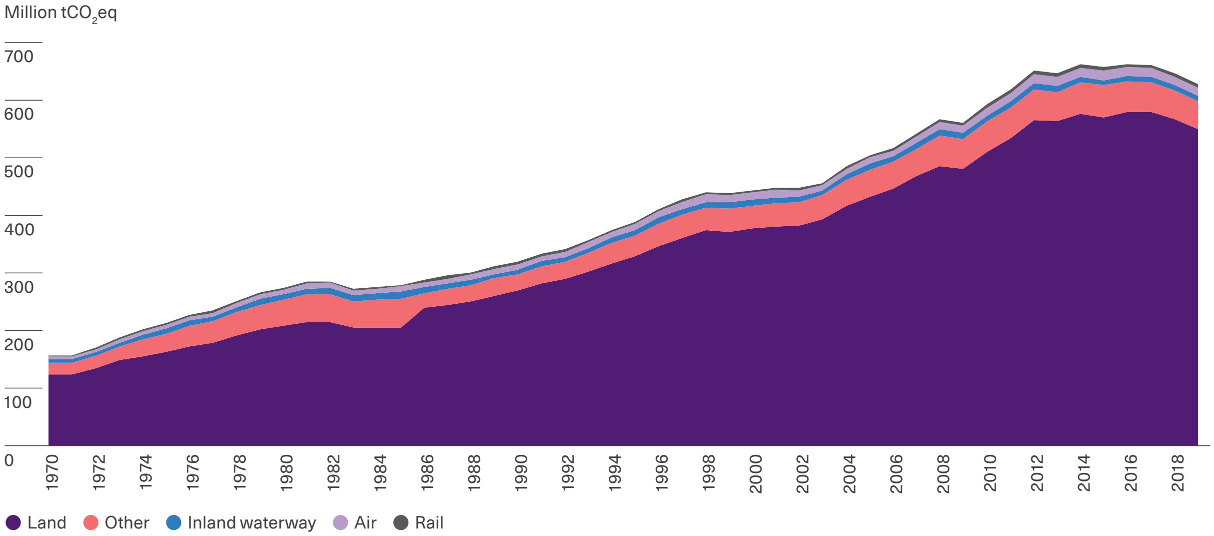
●●

Nearly 90% of transport emissions are from land vehicles with combustion engines, equally distributed between freight and passenger transport

Graph 8.2 shows the proportion of households in 18 countries with at least one automobile, as well as the share among those with the lowest and highest incomes. It shows that countries with higher per capita income have higher car ownership and that, within each country, car ownership increases with the level of household income. Compared to developed countries, average car ownership in Latin America and the Caribbean is considerably lower. For example, in the United States, more than 90% of households own at least one vehicle (U.S. Census Bureau, 2022). In the European Union (EU), the figure is 87% (Vega-Gonzalo et al., 2023) and in the United Kingdom, it is 78% (Department for Transport, 2022). Latin America and the Caribbean has the highest growth of private vehicles globally, and their number is projected to triple by 2050 (SLOCAT, n. d.; Yáñez-Pagans et al., 2018).

Graph 8.1

GHG emissions from the transportation sector in Latin America and the Caribbean

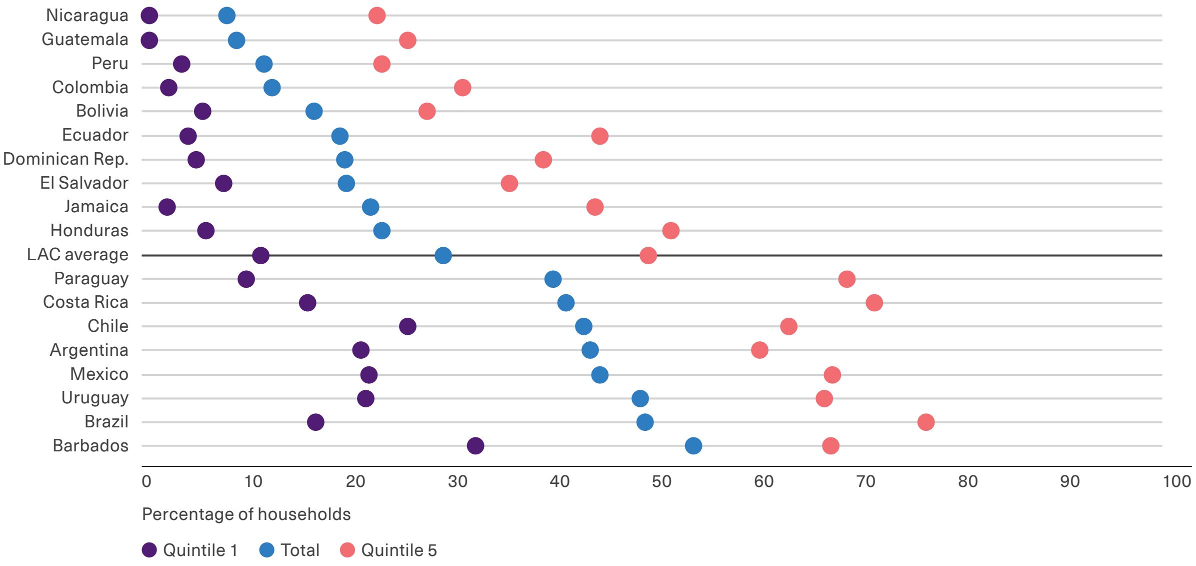


Note: The graph shows the evolution of GHG emissions from the transport sector, measured in million tons of carbon dioxide equivalent ($MtCO_2eq$) in LAC over the period 1970–2019, and their distribution by mode of transport. The gases included are carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O) 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).

Graph 8.2

Percentage of households with at least one automobile



Note: The graph shows the percentage of households with at least one car in LAC countries and, within each country, ownership according to the household's position in the per capita income distribution. The data is the most recent available from household surveys for the period 2014–2021. Table A.8.1 in the chapter annex available online shows the year the survey was conducted in each country.

Source: Authors based on data from Puig and Tornarolli (2023).

The number of freight vehicles has also grown significantly in the region, with an annual rate of between 5% and 7% in the period 2005–2015 in most countries. These growth rates imply that this number will double within 10 to 14 years (Barbero et al., 2020).

Almost all fuels used in transportation in Latin America and the Caribbean are petroleum derivatives, with gasoline in first place (69%), followed by diesel (28%) and then kerosene and aviation fuel (3%). From 1970 to 2019, gasoline consumption for transportation increased by an average of more than 2.5% annually, while diesel consumption grew by an average of 4% annually (OLADE, 2021b). Although, as will be seen below, there has been progress toward transport electrification, this trend is still insignificant compared to the growth in the number of internal combustion vehicles in the region.

Given the significance of land transportation use and emissions in the region, as well as its decarbonization potential compared to air and maritime transport, the following sections focus on describing the state of technology in the sector and the opportunities and barriers to making it more sustainable.

Energy efficiency, costs, and electrification in land transport

Electric vehicles

Private passenger transportation is relatively advanced in terms of technologies that enable its decarbonization. Of the 50 components of the energy systems that the International Energy Agency (IEA) considers critical for the energy transition, only three are sufficiently advanced to achieve the net-zero emissions scenario, and electric vehicles are one of them. Sales of these vehicles have shown steady exponential growth worldwide over the last few years (IEA, 2023q).

●●

Electric vehicles use advanced technology. The recent exponential growth in their sales shows substantial progress toward achieving a net-zero emissions scenario

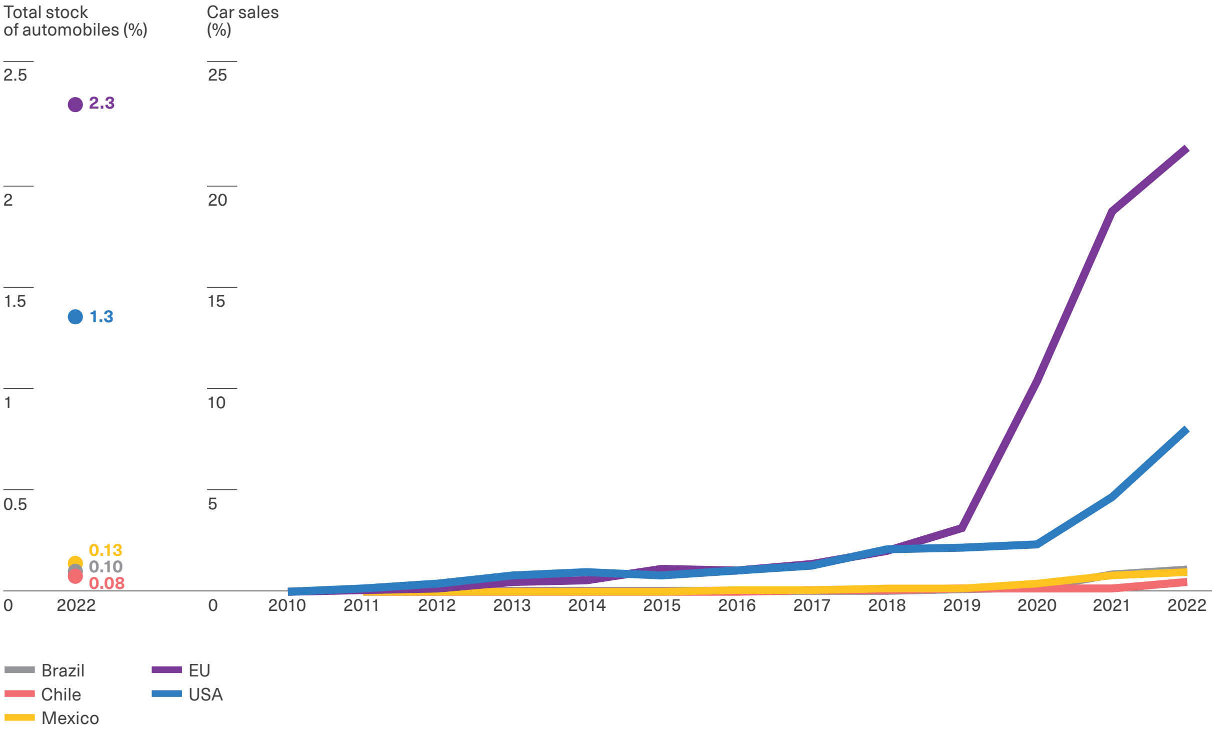
Graph 8.3 illustrates the proportion of electric vehicles in total sales (left axis) and total stock (right axis) in the European Union, the United States, and three Latin American countries with available data. In developed countries, where the relative cost barrier is lower and tax incentives for the purchase of electric vehicles are common, sales penetration is much higher than in Latin America, where stock is less than 0.15% of total sales in any of the three countries, despite existing acquisition incentives in Brazil and Mexico (AMIA, 2022; Mobility Portal, 2023).

Part of the problem hindering the expansion of electric vehicles in Latin America and the Caribbean is that, as a new segment, there isn't a large market for used vehicles in comparison to the fossil fuel segment. Between 2015 and 2020, about 2 million used light-duty vehicles were exported to the region, accounting for almost 10% of the global used vehicle fleet (IEA, 2023l). These vehicles accounted for at least 70% of sales in Argentina, Brazil, Colombia, and Peru (AAP, 2022; Andemos, 2022; CCA, 2023; Fenabrave, 2022). The importance of these secondary markets can also be seen in the age of urban private vehicles, which in Latin America and the Caribbean is around 14 years, while in Europe it is approximately 11 years, and in the United States around 12 years. When examining the largest vehicle fleets in Latin America, Brazil stands out with a low average for the region, which is comparable to the European average. In contrast, Mexico and Colombia surpass the regional average, with their vehicle fleets averaging close to 17 years in age.[2] Another factor limiting the population's purchasing capacity is the absence of secondary markets in the electric vehicle segment, where vehicles are typically offered at more affordable prices.

The explosive global growth of electric vehicles is attributable to the emergence of more affordable models, improvements in their overall range and performance, and the existence of heavy subsidies in some countries. Despite this, prices remain high compared to fossil fuel models, restricting the rapid expansion of sales in low-income countries and less developed financial markets.

Graph 8.3

Penetration of electric vehicles in Latin America and the Caribbean



Note: The graph shows the percentage of electric car sales relative to total car sales between 2010 and 2022 (left axis) and the percentage of electric car stock relative to total stock in 2022 (right axis) in Brazil, Chile, Mexico, the United States and the average of the 27 EU countries. Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are included.

Source: Authors based on data from IEA (2023h).

[2] Table A.8.2 in the Annex, available online, shows the average age of the vehicle fleet in Latin American countries and the sources of that information.

Table 8.1 compares prices for a group of internal combustion, electric, and hybrid cars based on data from ten countries in the region.[3] From the data, four key observations emerge, suggesting that electric vehicles are significantly more expensive. First, one of the best-selling hybrid models in Latin America and the Caribbean in 2023, the Toyota Cross, has an acquisition cost 20% higher than the same fossil-fuel model. Second, this model is cheaper than all the electric vehicles surveyed, except the BYD Dolphin, a compact car with half the range. Third, electric models are priced much higher than their fossil-fuel counterparts. For instance, a comparison between similar models from the same manufacturer, such as the Nissan Leaf and Sentra, reveals a 60% price differential, with the electric variant being costlier than the combustion model. Comparing the most economical models, the electric car is priced 175% higher than the fossil-fuel model. When comparing mid-priced models, electric cars are 40% more expensive than fossil-fuel models. Lastly, the electric models with the longest ranges are the most expensive among those listed in the table.

These high costs limit the purchase of electric vehicles by low- and middle-income households. The last column of Table 8.1 shows, on average for the region, how many years of income it would take a household in the middle of each country's income distribution to purchase each of the models. While fossil fuel cars require between 6 and 14 years of income, the cheapest electric car requires almost 17 years. Mid-range electric models, such as the BYD Yuan Plus, require an additional 6 years of income compared to a mid-range fossil fuel model, such as the Renault KWID. Higher-end electrics, such as the BYD Han or the Tesla Model S, require 40 or more years of median income to pay off in full.

High acquisition costs and lack of robust aftermarket pose significant barriers to electric vehicle adoption in Latin America and the Caribbean

The primary factor contributing to the higher cost of electric vehicles is the cost of their batteries. Lithium-ion (Li-ion) batteries, known for their superior efficiency, reduced weight, and greater capacity, are the most prevalent (IEA, 2023c). Given the pivotal role of these batteries in electric vehicles, there is growing concern regarding the availability and cost of the minerals essential for their production, particularly lithium. Although the IEA anticipates that the installed battery production capacity will meet the targets of the zero-emission scenario, there has been a notable increase in the prices of minerals required for their manufacture, notably lithium and nickel, from 2020 to 2023 (IEA, 2023a). Between January 2021 and the corresponding month in 2023, the price of lithium surged nearly ninefold. Subsequently, there was a significant decline in the latter half of 2023, stabilizing in January 2024 at a level akin to the 2021 average. The volatility in lithium prices and its availability has spurred vigorous efforts to develop batteries with reduced dependence on lithium. This has led to the establishment of a supply chain for sodium-ion (Na-ion) batteries, which do not require lithium for their development. While Na-ion batteries are relatively cheaper than Li-ion batteries, they have lower energy density (IEA, 2023h). Energy density refers to the energy that is stored and delivered in kilowatt-hours, thus the lower density results in reduced autonomy.

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[3] The choice of models was made using the following criteria. First, the authors sought to identify the best-selling electric or hybrid models in the selected countries, determining it was the Toyota Corolla Cross non-plug-in hybrid; then its fossil-fuel-powered model was taken as a frame of reference. Nissan models were then selected as they have a presence in most of the selected countries and have both types of vehicles, which facilitates the comparison. Next, a list of the electric and fossil models that are in the lowest and average price range for these countries was compiled. From there, the BYD Dolphin and Renault KWID were selected as the most economical models, and the BYD Yuan Plus and Volkswagen Taos as models with prices in the mid-range. Finally, the BYD Han was selected as a high-end model with a presence in the region and compared with a high-end electric reference model, such as the Tesla Model S.

Table 8.1
Average retail prices of automobiles in 10 countries in 2023

Model	Technology	Average price (USD)	Autonomy (km)	DC charging time (min)	Years to acquire with median income
Toyota Corolla Cross	Non-plug-in hybrid	38,476	732	-	17.2
Toyota Corolla Cross	Fossil	32,489	562	-	14.5
Nissan Leaf	Plug-in hybrid	46,362	298	143	20.8
Nissan Sentra	Fossil	28,449	541	-	12.8
BYD Dolphin	Electric	37,166	387	64	16.6
Renault KWID	Fossil	13,495	582	-	6.0
BYD Yuan Plus	Electric	48,554	451	43	21.7
Volkswagen Taos	Fossil	34,442	555	-	15.4
BYD Han	Electric	87,766	551	45	39.3
Tesla Model S	Electric	109,000	637	75	48.8

Note: The table shows the average retail price for a selection of hybrid, electric, and internal combustion vehicles in the SUV, sedan, and compact segments in mid-2023. To calculate the range of fossil-fuel vehicles, the authors used fuel-tank size with the yield per liter of fuel. The values in the last column result from dividing the average price by the median monthly per capita household income in each country. DC stands for direct current for battery recharging. Details on participating countries, exchange rates used and models available in each country can be found in Tables A.8.3 and A.8.4 of the chapter annex available online.

Source: Authors based on data from CEDLAS and World Bank (2022), central banks, and official dealerships in each country.

Despite electric vehicles' higher initial purchase cost compared to internal combustion vehicles, their operational expenses are generally lower due to the lower cost of electricity relative to fossil fuels. However, two constraints hinder the realization of this advantage in increased sales. On the one hand, the acquisition cost is a strong signal to consumers. Furthermore, consumers must perform relatively complex and uncertain calculations to quantify this advantage. This analysis involves factoring in numerous variables, such as annual mileage, the comparative prices of gasoline and electricity, the presence of subsidies or taxes, vehicle size, energy efficiency, maintenance costs, insurance expenses, and even disparities in the temperatures and road conditions to which vehicles are exposed.

As an example of the heterogeneity that exists in the comparison of total ownership costs[4] between electric and combustion vehicles, Burnham et al. (2021) find that such costs for small electric utility vehicles in the United States surpass those of internal combustion vehicles, with non-plug-in hybrids emerging as the least expensive. Conversely, Hao et al. (2020) show that electric vehicles in China generally have a lower total cost. Moreover, they predict that this differential will become even more advantageous by 2025, fueled by anticipated enhancements in battery performance and charging infrastructure.

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[4] The total cost of ownership evaluates all the costs of acquiring, owning and operating an asset or resource throughout its life cycle.

Box 8.1

Life-cycle emissions from private vehicles

Discussions around the impact of vehicle electrification typically focus on emissions avoidance, given that they do not rely on fossil fuels. However, the emissions profiles of the two vehicle types—electric versus internal combustion—differ not only during operation but also throughout their manufacturing and end-of-life management processes, including their components.

Manufacturing batteries for electric vehicles is a process with a significant carbon footprint, as they are responsible for between 40% and 60% of the emissions associated with the production of electric vehicles. Overall, the total emissions resulting from the manufacture of electric vehicles are approximately twice those of internal combustion vehicles (EPA, 2023a; Linder et al., 2023). This substantial difference primarily arises from the energy-intensive nature of mining lithium, nickel, cobalt, manganese, and graphite required for battery production, as well as the manufacturing processes themselves. Importantly, the emissions intensity of this process hinges on the energy sources utilized during the extraction and production phases. For instance, electric vehicles manufactured in Sweden exhibit a carbon footprint of less than half that of those produced in China (Linder et al., 2023). Moreover, apart from its larger carbon footprint, this process has more significant environmental impacts due to various forms of local pollution associated with mining activities and its substantial water consumption (Crawford, 2022).

During the operational phase, electric vehicles do not emit GHGs directly; however, their carbon intensity depends on how the electricity they are powered with is generated. In extreme cases, a vehicle that is recharged with coal-fired electricity will have higher emissions than an internal combustion vehicle, whereas, if this electricity is generated from entirely renewable sources, such as solar or wind, emissions will be zero.

The U.S. Department of Energy estimated emissions from the use of different types of vehicles by state using 2022 data (U.S. Department of Energy, 2022a). In states such as Washington, where hydropower accounts for nearly 70% of the electricity mix, electric vehicle use accounts for 5% of the emissions of an internal combustion vehicle. In contrast, in the state of Utah, where 57% of electricity is generated by coal, these vehicles emit 37% of what would be emitted by a fossil-fueled vehicle.

Hall and Lutsey (2018) and Bieker (2021) jointly consider emissions from manufacture and use in different countries. Their findings reveal that electric vehicles consistently yield lower total emissions compared to internal combustion vehicles. Remarkably, this conclusion holds true even for India, which boasts the largest carbon footprint in electricity generation among the countries scrutinized.

Finally, the disposal or recycling of the battery when it reaches the end of its life presents an additional environmental challenge. Inadequate treatment of depleted batteries leads to soil, air, and water pollution, and threatens human health. In turn, decomposing lithium batteries present a risk of explosion and fire (Mrozik et al., 2021). Currently, the most frequent disposal method is landfilling, although recycling and recovery of the minerals they contain is showing an increasing trend (Mrozik et al., 2021). An increase in the recovery rate of these minerals is also important for the reduction of emissions during the manufacturing process. Estimates show that lithium, copper, nickel, and cobalt recovered in the European Union can supply between 5.2 % and 11.3 % of its estimated demand for new minerals (Kastanaki and Giannis, 2023).

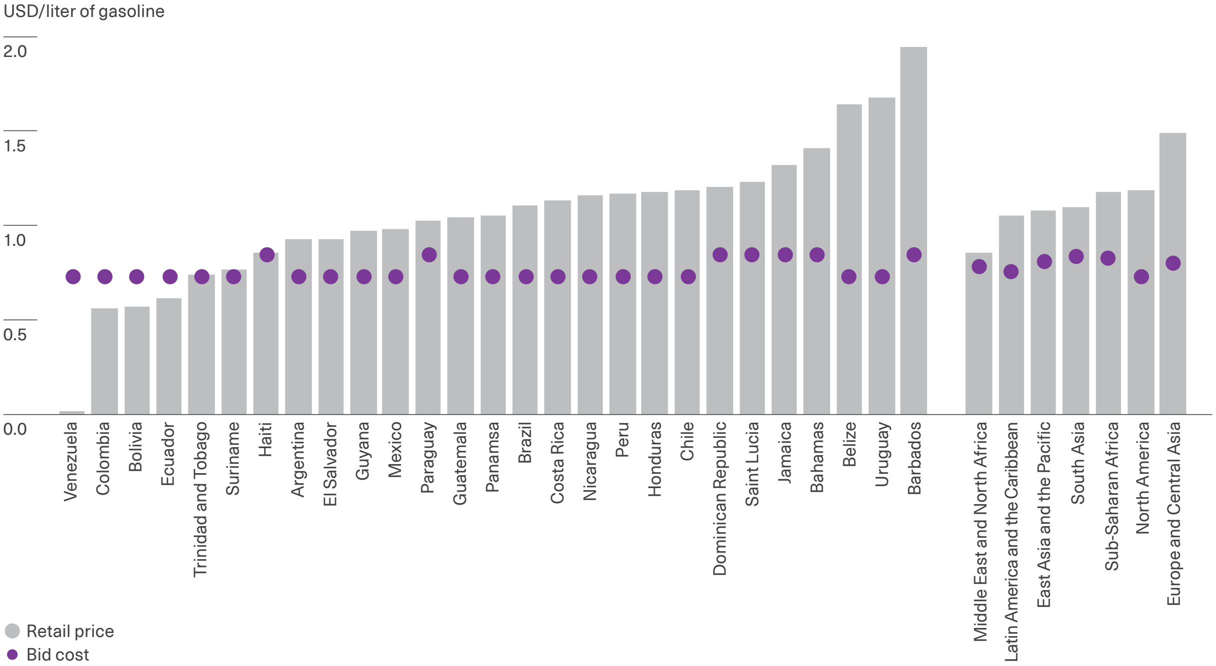
Gas prices in most countries in the region do not reflect the high social costs of pollution, global warming and accidents resulting from automobile use

Gasoline and electricity prices are fundamental factors in the analysis of the total cost of ownership. Graph 8.4 illustrates production costs and retail gasoline prices in USD for 2022 across 34 countries in Latin America and the Caribbean, as well as the average for these countries and six other regions. Given that the production cost of gasoline remains relatively consistent across countries, disparities in final retail prices predominantly stem from variations in tax and subsidy policies (Parry et al., 2021). In 2022, only Bolivia, Colombia, Ecuador, and Venezuela exhibited retail prices lower than supply costs. Thus, in the remaining countries, excluding the social costs associated with gasoline use, taxes rather than subsidies prevail.

The variations in taxes and subsidies between countries contribute to a significant disparity in gasoline prices, with peaks exceeding 150% observed in Barbados, Belize, and Uruguay. When compared to other regions, Latin America and the Caribbean exhibit average retail prices akin to those of East and South Asia, standing approximately 20% higher than those of the Middle East and slightly below the average prices of Sub-Saharan Africa and North America. Notably, Europe boasts the highest average retail price, hovering around USD 1.5 per liter.

Graph 8.4

Gasoline retail costs and prices including taxes per liter in 2022



Note: The graph shows the cost and retail price (including taxes and subsidies) of gasoline per liter, in constant 2021 dollars, for 27 LAC countries and regional averages for the rest of the world in 2022. The countries that make up each region can be found in the Chapter Annex available online. A similar graph for diesel can also be found in the Annex.

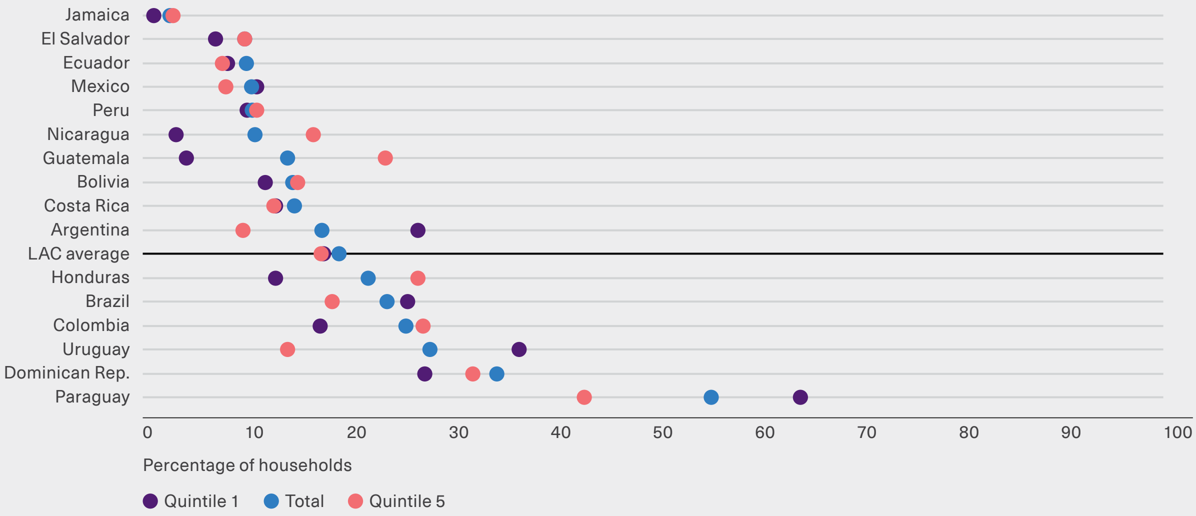
Source: Authors based on data from Black et al. (2023).

Box 8.2
Energy transition in two- and three-wheeled vehicles

Two- and three-wheeled vehicles are the easiest to electrify due to the smaller size of their batteries, which means less impact on weight, cost, and energy needed to recharge them (IEA, 2023h). Electric motorcycles not only emit up to 55 times less than those that use gasoline but also reduce noise and air pollution (MOVÉS, 2021). Their primary disadvantage, independent of the fuel source, is damage due to accidents. Addressing this issue requires active prevention and control policies.

Graph 1 shows the number of households with at least one motorcycle. Comparing this data with Graph 8.2 reveals that the countries with the highest number of motorcycles, such as Paraguay, the Dominican Republic, Colombia, and Honduras (in descending order), have a relatively lower number of automobiles. Furthermore, in the Dominican Republic, Colombia, and Honduras, lower-income households own more motorcycles. This is attributed to the substantially lower cost of motorcycles compared to automobiles, albeit with far fewer features and amenities.

Graph 1
Percentage of households with at least one motorcycle



Note: The graph shows the average percentage of households with at least one motorcycle broken down by their position in their country's per capita income distribution. This is the most recent data available from household surveys for the period 2014-2021. The exact year of each survey can be found in Table A.8.1 in the Chapter Annex available online.

Source: Authors based on data from Puig and Tornarolli (2023).

The use of motorcycles for the delivery of food, pharmaceuticals, and packages has experienced substantial growth in recent years, particularly during the COVID-19 pandemic. Given the intensive nature of this activity in terms of kilometers traveled, there is an increasing desirability for their electrification.

The price of gasoline across the region inadequately accounts for the significant social costs linked to negative externalities, including pollution, climate change, and traffic accidents stemming from automobile use. To adequately address these externalities, gasoline prices should ideally align with the European average (Parry et al., 2021). In densely populated cities, including several of the most prominent ones in Latin America and the Caribbean, gasoline prices should be even higher to encompass the elevated social cost of congestion. Parry and Timilsina (2010) estimated that in Mexico City alone, the price of gasoline in 2005 should have been 16 times higher to comprehensively account for all these externalities.

Recharging infrastructure

In developed countries, a significant obstacle to the more widespread adoption of electric vehicles is the inadequate charging infrastructure (Climate Group, 2023). While most electric vehicle charging occurs at home (IEA, 2019a), achieving performance and accessibility parity with internal combustion vehicles necessitates the establishment of a charging infrastructure comparable to the extensive networks of fossil fuel refueling stations. This deficiency in charging infrastructure contributes to what is known as “range anxiety,” which denotes the apprehension of running out of battery charge before reaching the intended destination (Noel et al., 2019; Pevec et al., 2019; Shrestha et al., 2022).

Latin America and the Caribbean enjoys the advantage that the range of electric vehicles typically meets the needs of daily urban commuting, as the distances within their cities are generally not excessive (Gómez Gélvez and Mojica, 2016; Kenworthy and Laube, 2002). Moreover, the region has made strides in the installation of charging stations and intends to further invest in this infrastructure both within and outside urban areas.

In 2022, the Costa Rican Electric Mobility Association (ASOMOVE) spearheaded the Central American Electric Route, featuring a caravan that traveled through the national capitals from Guatemala to Panama, passing through El Salvador, Honduras, Nicaragua, and Costa Rica. This caravan took advantage of existing recharging points and installed new fast and semi-fast chargers that made it possible to connect the six capitals (Máñez Gomis et al., 2021). Building upon this initiative, the Latin American Association for Sustainable Mobility (ALAMOS) is working to create five routes to connect 15 countries in the region. In addition to the one already mentioned, plans include the Andean route, running through Colombia, Ecuador, Peru, and Panama; the northern route, which would connect the Central American route with Mexico; the Southern Cone route, between Chile, Argentina, Uruguay, Brazil, and Paraguay; and, finally, the Caribbean route, which for the moment includes the Dominican Republic and Puerto Rico. These routes will be key to electromobility and to reduce range anxiety in the region.

Figure 8.1 shows the installed and projected chargers by country and the electro-corridors that are already in operation. Despite the relatively low penetration of electric vehicle sales, countries are making strides in developing charging infrastructure. However, further concerted efforts from both the public and private sectors will be necessary to accelerate progress.

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The charging infrastructure electrical has been growing by public and private investments, although it will be necessary to deploy more efforts focused on quality and reliability of these devices

The advancement in the promotion of electric vehicle policies has spurred private interest in the installation and management of chargers. Volvo, in collaboration with Evergo, has announced plans to install 2,295 chargers by 2025 (Evergo, 2023), while Porsche announced 550, although these will be exclusive to its vehicles (Porsche, 2022).

Figure 8.1
Shippers by country and electro-corridors in Latin America and the Caribbean

Argentina
1 Province of San Luis
2 Retiro (CABA) - Cariló (Atlantic Coast)

Uruguay
3 Colonia - Punta del Este

Chile
4 Marbella - Termuco
5 Termuco - Chiloé - Coyhaique - Aysén

Brazil
6 Río de Janeiro - São Paulo
7 Salvador (Bahía) - Natal (Rio Grande do Norte)

Colombia
8 Coffee-growing region: Caldas - Risaralda - Quindío

Panama
9 Colón-Chiriquí

Costa Rica
10 Fortuna, Monteverde, Nosara, Miravalles, Bahía Ballena, Río Cuarto

Panama and Costa Rica
11 San José - Panama City

Mexico
12 Potosí - Mexico City - Puebla

Pan American Corridor
13 Connects 11 countries from Ushuaia (ARG) to Ensenada (MEX)

Central American Electricity Corridor
14 Guatemala City (GUA) - San Salvador (SAL) - Tegucigalpa (HON) - Managua (NIC) - San José (CR) - David (PAN) - Panama City (PAN)

Note: The figure shows the map of electric vehicle chargers installed by country in LAC (purple ovals) and the electro-corridors in operation (pink lines). Corridor 13 is not represented on the map because it covers 196 chargers in 11 countries. For the exact source of information for each country and details on the electro-corridors, please refer to Tables A.8.5 and A.8.6 in the annex available online.

Source: Authors based on data from Liborio (2023), Electromaps (2023), Venditti (2023), Diario Sustentable (2023) and Instituto Mexicano del Transporte (2022).

In addition to the growth of the charger fleet, the quality and reliability of these devices are paramount, especially as the penetration of electric vehicles rises. The increased use of these chargers can generate congestion not only at the charging stations but also within the power grid. This problem can be mitigated with smart chargers, strategically locating charging stations at points where peak demand does not strain the grid, integrating solar panels into charging infrastructure, and digital tools that enable coordination between the grid and users (IRENA, 2019b). For instance, the chargers announced by Volvo and Evergo enable users to schedule charges via an app, thereby reserving spaces at these stations. Furthermore, dynamic tariffs could help prevent grid overload during peak demand periods (IRENA, 2019b). The specific requirements of each city will vary based on electricity consumption patterns, the availability of charging infrastructure at residences and workplaces, and population densities.

Improvements in the efficiency of internal combustion vehicles

Despite the advancement of electric vehicles, the demand for fossil fuels for transportation is projected to persistently increase through 2050 in most developing countries, partly driven by population growth (IEA, 2023c). Consequently, reducing emissions will necessitate the implementation and development of technologies aimed at enhancing the efficiency of internal combustion vehicles. McKinsey & Company (2009) identifies several mature advancements in internal combustion engines that could enhance fuel efficiency while remaining cost-effective. For instance, utilizing smaller engines alone could boost efficiency by 12%, while the implementation of tire pressure monitoring systems could provide an additional 1% improvement. However, data from the IEA (2019a) indicates a deceleration in the progress of fuel efficiency for cars and light trucks, with an average improvement of 0.8% per year between 2017 and 2019, compared to a 2.6% yearly improvement observed between 2010 and 2015.

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The demand for fossil fuels for transportation in developing countries is expected to rise until 2050. Improving the efficiency of internal combustion vehicles will be crucial in this scenario

A major constraint to efforts to improve vehicle efficiency is the growing demand for larger units. Seventeen percent of vehicles sold in 2010 worldwide were sport utility vehicles (SUVs), while this segment accounted for 46 percent of sales in 2021. These vehicles are larger and offer less energy efficiency than compacts. The increase in demand for SUVs has been responsible for 40 % of the slowdown in the aforementioned efficiency improvements (IEA, 2019a).

Another alternative for reducing emissions in internal combustion vehicles is the use of biofuels, such as bioethanol, biodiesel, and biogas. Bioethanol is the most widely used and can be produced from different raw materials, such as corn, wheat, and sugar cane. The major limitation to the use of biofuels is the amount of land required for cultivation (Brassiolo et al., 2023). If this is not done in a sustainable manner, a change in land use or displacement of agricultural production may not offset the reductions in emissions from the use of biofuels (McKinsey & Company, 2009; OECD, 2019). Brazil stands out as a leader in the region in its biofuel usage for transportation and as the second-largest producer of biofuels in the world (IEA, 2023c). Between 2010 and 2022, Brazil invested nearly USD 35 billion, surpassed only by the United States (IEA, 2023u). It has incorporated biofuels into its long-term energy strategy, with a current resolution permitting the blending of up to 12% biodiesel with diesel, aiming to raise this to 15% by 2026 (Ministério de Minas e Energia, 2023). Additionally, its strategy includes provisions for blending up to 27% ethanol in fuels, alongside financial incentives and vehicle standards (IEA, 2023c). Sugarcane serves as the primary feedstock for biofuel production in Brazil, yielding biofuels with lower carbon intensity and reduced emissions per gigajoule (GJ) compared to diesel and gasoline (OECD, 2019). Several other countries in the region, including Argentina, Colombia, Peru, and Uruguay, have also set targets for blending biofuels with fossil fuels (IEA, 2023l).

Finally, hybrid vehicles stand out as a great improvement in efficiency over internal combustion vehicles. Hybrids come in two main variants: plug-in electric and non-plug-in. The plug-in electric variant shares similar limitations with electric vehicles, notably their higher cost. On the other hand, the non-plug-in variant doesn't require charging infrastructure, as the electric battery recharges while the vehicle is in motion, primarily relying on fossil fuel energy. The non-plug-in hybrids are more prevalent due to their lower cost and offer efficiency improvements ranging between 23% and 49% compared to fossil fuel vehicles (CER, 2021; U.S. Department of Energy, 2022a).

Freight transportation

Freight transport constitutes approximately half of global road transport emissions, despite representing only 8% of vehicles (IEA, 2023r). Progress toward decarbonization within this sub-sector lags significantly behind that of electric cars, with the IEA indicating that it is not on track to achieve zero emissions (IEA, 2023q). Unlike electric cars, where achieving targets is deemed feasible by the IEA with a projected sales share growth of 14% in 2022 and 67% by 2030, fossil fuels are expected to still account for over 80% of energy consumption in freight transport by 2030.

In Latin America and the Caribbean, over 85% of freight is transported by road, revealing notable inefficiencies within the sub-sector. On average, trucks in the region travel approximately 62,000 km per year, which is 40% less than counterparts in the United States and the European Union. Additionally, around 40% of truck trips are conducted with empty loads, a stark contrast to the 25% observed in North America (Barbero et al., 2020; Calatayud and Montes, 2021). The road network across the region suffers from inadequate coverage, quality, capacity, and connectivity. Approximately 20% of the primary roads are in poor condition, and most countries lack a fully paved network of first-order roads. This deficiency could lead to a doubling of fuel consumption and emissions compared to roads in good condition (Cantillo, 2023). Addressing these issues could enhance the productivity of the sector and the road network, enabling the transportation of the same load with fewer trips and consequently reducing emissions.

How to decarbonize freight transportation?

The three primary technological alternatives for decarbonizing freight transportation include electrification, the use of alternative fuels such as natural gas, green hydrogen, and biofuels, as well as the increased utilization of rail.

When evaluating the electrification of freight transport, it's essential to differentiate between heavy and light freight. Heavy-duty transport presents the most significant challenge. While electric trucks are beginning to see adoption, heavy vehicles are considerably expensive, and their availability is limited (Cantillo, 2023). Additionally, the extra weight of batteries for heavy and medium electric trucks poses challenges in terms of road impact and the substantial energy requirements for fast charging (Gross, 2020). Fast chargers may strain the electric grid, particularly in isolated areas with infrastructure deficiencies and grids not designed to handle such demand levels (Gross, 2020).

Light-duty vehicles, primarily utilized for last-mile transport, exhibit significant potential for electrification. These trucks are at the forefront of freight transport decarbonization, largely due to their shorter travel distances and higher frequency, as well as their smaller size, which alleviates the limitations faced by heavy vehicles (Gross, 2020). As we will explore further, last-mile transport plays a particularly crucial role in urban areas.

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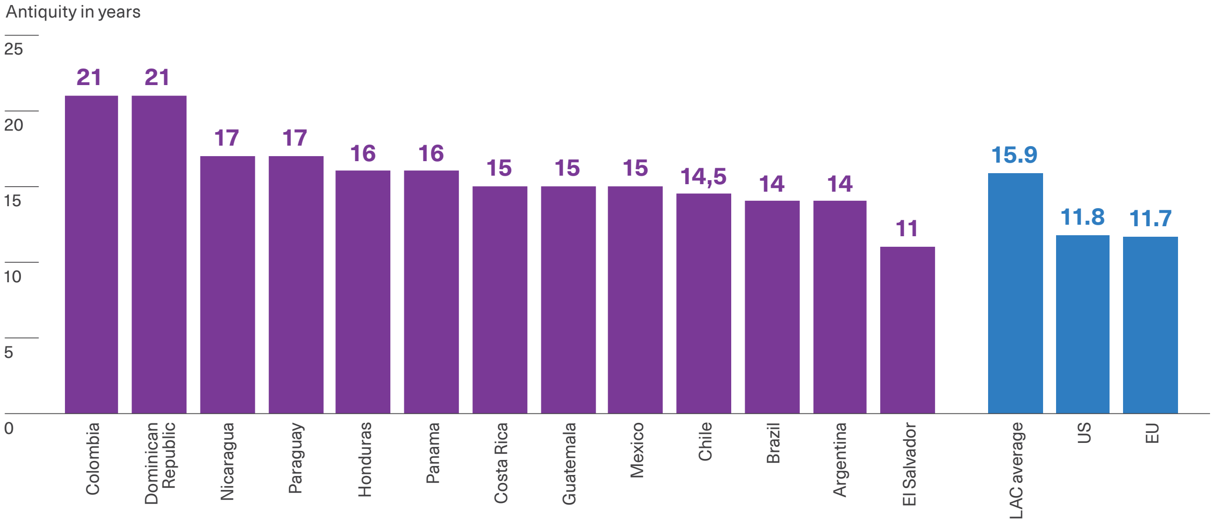
Key options for reducing emissions from freight transport include electrification of light-duty vehicles, use of alternative fuels and leveraging rail, where the scale justifies the investment

A characteristic of the freight transportation fleet in Latin America and the Caribbean, a significant contributor to emissions, is its advanced age compared to developed countries (Barbero and Guerrero, 2017; Calatayud and Montes, 2021; Cantillo, 2023). Graph 8.5 compares the average age of trucks, showing that in some Latin American and Caribbean countries, trucks are on average five years older than those in the United States and the European Union (Cantillo, 2023). Additionally, the ownership structure of the vehicle fleet is highly fragmented, with a vast majority of small truck owners and few large companies (Barbero and Guerrero, 2017; Cantillo, 2023). While this does not significantly differ from what is observed in the United States (ATA, 2023), it poses a challenge for fleet modernization as long as electric truck prices remain high. Typically, these small companies have fewer resources, further extending the lifespan of trucks and limiting their ability to reduce emissions or transition to electric fleets, while larger companies operate newer fleets and integrate information technology into their processes (Barbero et al., 2020).

Graph 8.5
Average age of freight vehicles in Latin America and the Caribbean



Note: The graph shows the average age, measured in years, of the freight transportation fleet for 13 LAC countries, the US, and the EU between 2012 and 2019.

Source: Cantillo (2023).

While natural gas isn't emission-free, it serves as a promising transition fuel due to its lower greenhouse gas (GHG) emissions compared to diesel and gasoline, and its abundance in Latin America and the Caribbean. Freight vehicles powered by natural gas, particularly liquefied natural gas (LNG) trucks, are viable options for long-distance travel and for fleets accessing fuel centrally, thanks to reliable supply infrastructure (U.S. Department of Energy, 2022b). Despite the resource's abundance and widespread urban infrastructure, intercity trucks may encounter fueling challenges due to a lack of supply infrastructure (Thiruvengadam et al., 2018). Natural gas vehicles address this by allowing fuel storage within the truck, extending its range, albeit at the expense of added weight and reduced carrying capacity.

In addition to existing medium- and heavy-duty natural gas trucks, diesel-powered trucks can be retrofitted to utilize natural gas, either as the primary or supplementary fuel (U.S. Department of Energy, 2022b). Proper maintenance is essential to ensure emission reductions from these vehicles by preventing fugitive methane and tailpipe emissions (Thiruvengadam et al., 2018). Observations of increased natural gas usage for transportation have been noted in natural gas-producing countries like Argentina, Bolivia, Mexico, and Venezuela. Furthermore, Colombia passed a law in 2021 to promote the widespread adoption of natural gas-powered cargo vehicles (Acevedo et al., 2023).

Despite its zero emissions, longer range, and quicker refueling compared to electric trucks, green hydrogen remains underutilized primarily due to the challenges and high costs associated with its production, storage, and distribution (Cantillo, 2023). Regarding biofuels, although they have been available as an alternative for several years, they only account for 4% of the total energy use in this subsector (IEA, 2022c). This limited adoption is primarily attributed to the constrained supply of these fuels and, in the case of freight transport, the inconvenience of having to retrofit trucks to accommodate them (Cantillo, 2023).

Rail freight transport presents an appealing option for emissions reduction. On average, trains consume only 15% of the energy used in land freight transport (Gross, 2020). However, the infrastructure costs associated with rail are considerable, making it economically viable only when routes achieve a sufficiently high freight scale. Even in such cases, the potential for decarbonization is limited if trucks intervene before or after rail transport, providing flexibility and establishing a multimodal approach (IEA, 2019d). In Latin America and the Caribbean, Argentina, Brazil, and Colombia boast some heavily utilized rail networks. Recent investments in rail transportation have primarily targeted freight, with freight per kilometer experiencing a 127% growth between 2000 and 2016 (IEA, 2019d).

Challenges and opportunities in urban logistics

The rapid urbanization in Latin America and the Caribbean, coupled with higher per capita income in large cities compared to rural areas, results in the vast majority of goods consumption occurring in urban spaces (Alves, 2021; Daude et al., 2017). These goods must be transported within cities to their points of sale or final consumption, a process known as urban logistics. The efficiency of this process has implications for productivity and welfare in cities (Alves and Lopez, 2021). Urban logistics poses special challenges and opportunities in the context of the energy transition.

In terms of challenges, the higher share of trucks in GHG emissions and other pollutants in urban environments compared to their proportion in the total vehicle fleet, observed in general goods transport, is also evident in cities. In Bogota, for instance, freight vehicles generated 43% of emissions in 2020 with only 5% of the fleet, while in Mexico City, they accounted for 71% of $PM_{2,5}$

emissions (SPIM-Taryet, 2019). This higher share is due to the conjunction of three factors, which are also key to understanding the opportunities and challenges of the energy transition in the sector.

The first factor underlying this emissions ratio is that transporting goods involves moving more weight than transporting people and this requires more power, resulting in increased emissions. Although the weight of goods transported in urban areas is less than that on highways, the higher power demand can pose a barrier to the electrification of vehicles that carry heavier loads in cities. Consequently, the primary opportunities for electrification lie in small and medium-sized vehicles.

While this first factor poses limitations on electrification, a second factor offers more optimism. The elevated proportion of emissions from trucks compared to the fleet is mainly attributed to their higher usage compared to private vehicles. As demonstrated earlier, this increased usage enhances the economic viability of electrification. Therefore, particularly for small and medium urban logistics vehicles, significant opportunities exist to pursue this transition.

The third factor contributing to the higher proportion of emissions is region-specific and has to do with the greater informality and age of the urban logistics fleet, a trend previously observed in trucks in general (SPIM-Taryet, 2019). This is partially linked to the sector's low barriers to entry, allowing individuals with older vehicles to transport goods without requiring special permits or significant initial investments. This scenario poses another challenge for electrification because, while it may be economically profitable for small and medium-sized vehicles, providers of such services may not have access to credit to cover the high costs of acquiring electric vehicles.

Mobility of people in cities

People's mobility in cities is a central aspect of their well-being. Households in large cities in Latin America and the Caribbean spend on average 1.5 hours per day and 17% of their income on urban travel (Gandelman et al., 2019). Given the importance of urban mobility for overall well-being, initiatives to lower emissions must be integrated with efforts to enhance access to mobility opportunities. Interestingly, public policies aimed at achieving more equitable mobility are not at odds with emissions reduction strategies; rather, they are highly complementary.

The energy consumption and emissions associated with people's travel within cities are influenced by two main factors: the mode of transport and the distance traveled. Longer distances not only result in increased energy consumption and emissions directly but also indirectly diminish the viability of sustainable transportation modes, such as walking, cycling, and mass public transit.

Modal split, energy consumption, and emissions

Table 8.2 illustrates the energy consumption per passenger and kilometer as well as the primary fuel type for seven modes of transport, encapsulating the core challenges of urban mobility in the energy transition. Energy consumption varies significantly across modes of transport, with automobiles consuming substantially more energy compared to walking, cycling, and rail. For instance, transporting a passenger for one kilometer in a car consumes at least twice as much energy as a bus, 15 times more than a bicycle, and 8 times more than bus rapid transit (BRT). Moreover, cars predominantly rely on fossil fuels, whereas streetcars, trains, and subways are typically powered by electricity, and active modes are propelled by human effort. These disparities in energy consumption and fuel type result in markedly different emissions profiles. For instance, emissions per passenger kilometer of a gasoline-powered car are five times higher than those of a diesel-powered bus and 100 times higher than those of an electric bus (Movés, 2021).

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Urban emissions per passenger differ greatly by mode of transport. Reducing them requires more mobility by walking, cycling and public transport and less in automobiles

Table 8.2
Efficiency and energy consumption of different means of urban transport

	Automobile	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	2500–5000	200–500	50–150	500–600	50–150	2500–7000	15,000–60,000

Note: The table shows the capacity for comfortable and safe passenger travel across various modes of transport, referencing European and Asian cities. It includes the energy intensity per passenger-kilometer (measured in megajoules), infrastructure costs per passenger-kilometer (in dollars), and the predominant fuel type for each mode of operation. Notably, the energy intensity of buses varies from the lowest in Austria to the highest in Mexico. Infrastructure costs, initially in euros, have been converted to dollars using the exchange rate applicable to the year of the data (2010).

Source: Figueroa et al. (2014).

The variations in energy intensity and fuel usage underscore the necessity of decreasing emissions from urban transport by reducing reliance on individual cars and promoting active modes such as walking and cycling, along with public transportation. However, it's important to note that Table 8.2 does not account for the growing potential of electrification due to technological advancements, which could mitigate emissions from fossil fuel-based modes. Despite this potential, there are three reasons why policies should still aim to reduce the modal share of individual cars. First, as discussed in this chapter, electrifying cars is costly for most households in the region. Second, as detailed elsewhere in this report, the effectiveness of emission reduction through electrification hinges on the cleanliness of the countries' electricity generation matrices. Finally, certain negative externalities of car usage are not only unresolved but exacerbated by electrification, as shown in Box 8.3.

Another advantage of active modes, as shown in Table 8.2, is their lower infrastructure provision costs. Unlike individual cars, which necessitate infrastructure with higher economic expenses, the construction-related emissions associated with such infrastructure are not accounted for in the energy consumption figures presented in the table (Brassiolo et al., 2023). Moreover, active modes and public transport occupy less urban space compared to individual cars. The increased space usage by car lanes correlates with reduced green space in cities (Conwell et al., 2023), imposing both environmental and welfare costs.

Given the significance of modal distribution in urban passenger transport emissions, it bears reflection on the prevailing distribution in the region's cities. Table 8.3 offers insights from the Urban Mobility Observatory (OMU), an initiative spearheaded by the Inter-American Development Bank (IDB) and CAF (Development Bank of Latin America and the Caribbean), based on the proportion of trips by mode of transport in the latest available origin-destination survey in ten cities in the region. The data reveals that in most cities, individual private transport accounts for between one-fifth and one-third of total trips, a trend commonly observed in European and East Asian cities (Land Transport Authority, 2011). This suggests that sustainable modes hold substantial dominance in urban passenger transport across the region, a crucial factor for understanding the comparatively lower emissions levels. However, two cities, Curitiba and Panama, deviate from this pattern, with nearly half of their trips undertaken via individual motor vehicles. Despite this, their figures still pale in comparison to U.S. cities, where car travel constitutes over three-quarters of all trips (Land Transport Authority, 2011).

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The total number of trips made on public transport and active modes is twice as high as those made by car in the region's main cities

Among active modes, walking trips significantly outnumber those made by bicycle. Bogota stands out as the city with the highest proportion of bicycle trips, followed by Santiago de Chile and Buenos Aires. This surge in cycling coincides with the expansion of dedicated infrastructure in these cities. For instance, in Buenos Aires, the network of bicycle paths grew from 30 to 300 kilometers between 2009 and 2023, with the proportion of trips increasing from 0.4% to 7% of the total (Government of the City of Buenos Aires, 2023). Despite these strides, there remains ample room for bicycle usage to expand across the region, thereby contributing to lower-emission transport. Household survey data from nine countries, analyzed by Puig and Tornarolli (2023), indicate that only one in five households owns at least one bicycle.

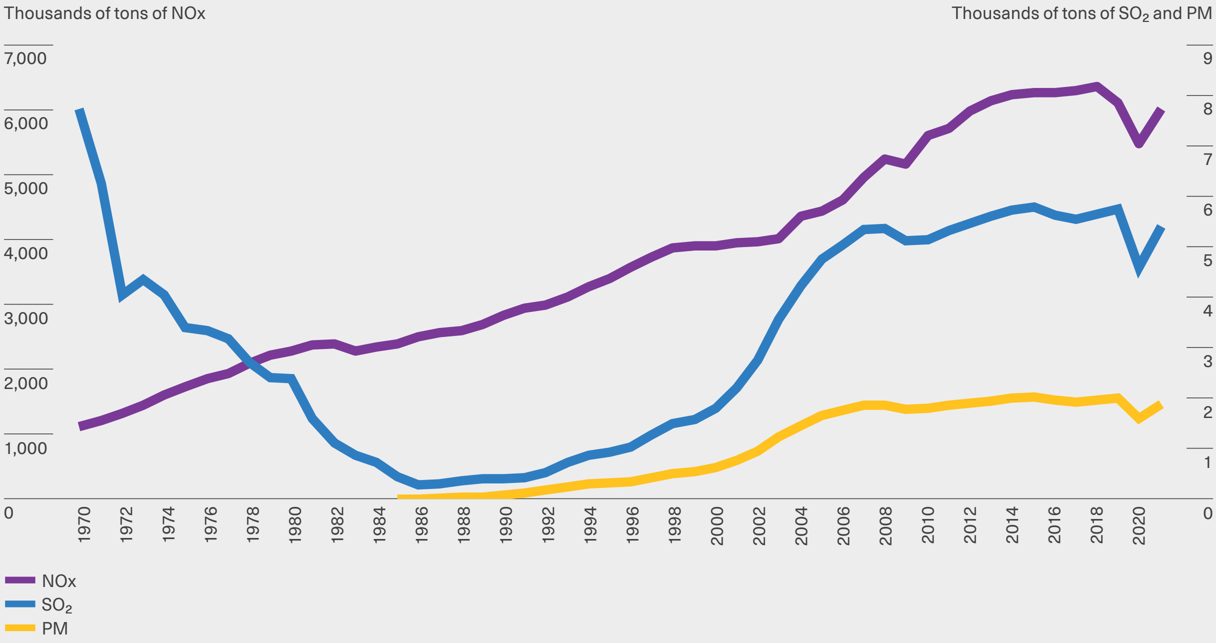
Box 8.3
Do the social costs of private car use disappear with electrification?

Automobile use has several social costs. In the case of combustion vehicles, these costs include GHG emissions and other air pollutants, as well as noise pollution. These costs disappear with the electrification of vehicles.

Air pollutants emitted by internal combustion vehicles that have negative health effects include mainly nitrous oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM). Both NO_x and SO_2 also react with other compounds in the atmosphere to form PM. These particulate materials have shown the greatest negative impacts on health and mortality (Di et al., 2017; Green and Sanchez, 2013; Krewski et al., 2009; Lepeule et al., 2012). The graph shows how in the last 35 years these pollutants have grown significantly in the region, along with the increase in the number of vehicles.

Other social costs of individual cars not only persist but may be exacerbated with the electrification of vehicles. For instance, the rise in travel times due to increased road congestion remains consistent irrespective of engine type. In addition, the heavier weight of electric vehicles, attributed to their large batteries, heightens the risk of accidents and contributes to the emission of particulate matter from tire wear. Furthermore, congestion costs and those linked to the increased weight of electric vehicles might escalate if the lower operating costs incentivize greater usage.

Graph 1
Emissions of polluting substances from the transport sector in Latin America and the Caribbean



Note: The graph shows the evolution of transport emissions in LAC, measured in thousands of tons of nitrogen oxides (NO_x, left axis), sulfur dioxide (SO_2), and particulate matter (PM), the latter represented on the right axis. The period considered is 1970–2021. The aggregation was obtained from individual data from 27 countries in the region.

Source: Authors based on OLADE data (2021b).

Table 8.3

Modal split in 10 large cities

	Bogotá	Buenos Aires	Mexico City	Curitiba	Montevideo	Panama	Rio de Janeiro	Salvador de Bahia	São Paulo	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
Bicycle	7.4	3.9	1.8	2.1	1.8	0.2	1.0	0.9	0.9	4.3
Individual motorized	**24.5**	**3.5**	**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
Cab	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 in 10 cities in 7 LAC countries, for the period 2011-2019 (varies by specific city). The data were obtained from the processing of mobility surveys. The category "cab" is not reported for Rio de Janeiro.

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

Buses play a predominant role in public transport in the region. This is especially true in smaller cities, such as Curitiba, Montevideo, and Salvador de Bahia, which do not have subways, and in Bogotá, which does not yet have an urban train but has plans to build its first line. Even in cities with subways, the number of trips in this mode is substantially lower than those made by bus. Box 8.4 shows that buses have significant potential for electrification and that several cities in the region have made progress in this regard.

Among the modes of private motorized transport, automobiles largely predominate over motorcycles and taxis. Motorcycles play a significant role in Bogota, accounting for approximately 6% of trips, while taxis exceed 5% in Mexico City and Panama. Taxis represent a mode with considerable potential for electrification due to their intensive use, which helps to amortize capital more rapidly. The City of Montevideo has made strides in converting combustion engine taxis to electric, reaching 200 units by 2024, constituting about 7% of the fleet (Intendencia Montevideo, 2023).

Buses play a predominant role in urban mobility in the region. Its electrification results economically viable, but requires financing and subsidies due to its high cost

Data on public and private transport expenditure by income quintile presented for twelve countries by Gandelman et al. (2019) suggest a very disparate modal split between higher and lower-income households. While in the poorest quintile public transport expenditure is more than triple that of private transport expenditure, in the richest quintile private transport expenditure exceeds public transport expenditure by more than seven times. These spending patterns imply that improvements in the quality and availability of public transport benefit lower-income households to a greater extent, demonstrating the inclusive nature of strategies to promote sustainable mobility.

Box 8.4
Electrification of urban buses

Urban passenger buses possess three characteristics that make them particularly attractive for electrification (Correa et al., 2019; Feng and Figliozzi, 2013; Hellgren, 2007). First, buses have significantly higher utilization rates compared to cars, meaning they are in operation for longer periods, thereby maximizing the fuel savings that come with electrification and enhancing the economic viability of adopting electric buses. Second, unlike intercity buses, urban buses typically cover relatively short distances, making it feasible for them to complete their routes on a single battery charge. Third, the mechanics of electric buses are simpler compared to diesel-fueled buses, resulting in lower maintenance costs.

These advantages have led to a rapid adoption of electric buses to replace those powered by fossil fuels in recent years. According to data from the digital platform ebusradar.org, by the end of 2023, there were already more than 5,000 electric buses in the region, representing a stock growth of more than seven times compared to 2017. About four-fifths of these buses are battery-powered; the rest are trolleybuses powered by electricity cables running along their route. This growth has been concentrated in very few cities. Forty percent of the bus fleet in Santiago de Chile is made up of electric vehicles, while in Bogotá it reaches 30%, and in Mexico City, 10%. Santiago and Bogotá have the largest electric bus fleets in the world outside China (Ramos, 2023).

Beyond its advantages, the electrification of buses faces some challenges. On the one hand, although their higher intensity of use makes them profitable due to savings in fuel costs, their acquisition cost is higher than that of conventional buses, posing a financing challenge. An innovative solution to address this financial challenge in the region has been to separate the ownership of electric buses from their operation (Becerra and Galarza, 2022). Although this alternative solves the financing problem, covering this cost requires subsidies to prevent a negative impact on fares (Ramos, 2023). On the other hand, charging electric batteries poses two additional obstacles. One is that new space and infrastructure is needed to charge the buses. The other is that vehicles must remain parked while their batteries are being charged, resulting in lower utilization and a higher number of units needed to cover a given route with the same frequency. Finally, the environmental benefits of bus electrification depend on how clean the electricity matrix is, so the timing of its adoption must be adapted to the electricity generation trajectories of each country (Ramos, 2023).

While modal split data indicate a predominance of sustainable modes in the region currently, there remains a significant challenge to curb the proliferation of automobiles and their associated emissions and negative externalities in the future. This challenge is closely tied to rising household incomes. A 10% increase in income leads to a 4% growth in car ownership within one year and a 10% increase over five years (Goodwin et al., 2004).

Urban layout and transportation in the city

The shape of a city impacts energy consumption and transportation emissions through two mechanisms: the distances traveled and the transportation modes chosen (Stocker et al., 2013). The key behind both mechanisms lies in the fact that city shape determines the distance between trip origins, typically residences, and destinations, such as work, educational facilities, and retail. The first mechanism refers to the fact that longer distances between origins and main destinations will mean longer trips, which will generate more energy consumption and emissions (Glaeser and Kahn, 2010). The second mechanism refers to the fact that these longer distances make the use of sustainable transportation modes less viable (Ahlfeldt and Pietrostefani, 2019). Walking is possible for short distances and cycling for medium distances, but these modalities lose their appeal when distances are long. Also, if the origins and destinations of trips are widely dispersed, it can make the operation of mass public transport unfeasible.

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Dense cities with less sprawl reduce emissions by prioritising public transport and promoting walking and cycling for shorter distances

The significance of urban layout to energy consumption in urban transport can be illustrated by comparing the average energy consumption and urban layout in cities in the United States, Europe, and Japan. While these are countries with relatively similar per capita incomes, their urban transport energy consumption and city shapes are very different. Per capita energy use in urban transport in U.S. cities is three times higher than in Europe and Japan (Figueroa et al., 2014) and the median density of European cities is 15% higher than in the United States.

Density and accessibility serve as fundamental metrics for delineating urban form. Higher values in these metrics suggest shorter distances between origins and destinations, consequently resulting in reduced energy consumption and emissions as a consequence of the aforementioned mechanisms. Density pertains to the ratio between a city's population and its geographical extent. The 2017 Report on Economic Development (RED) by CAF initiated an examination of the extent and density of Latin American and Caribbean cities relative to other regions (Daude et al., 2017), further elaborated by subsequent authors (Ch et al., 2021). The analysis revealed that cities in the region exhibit average density levels slightly surpassing those of European cities and comparable to those of the Middle East and North Africa. These levels notably exceed those observed in cities in Canada and the United States, yet fall below the maximum density levels observed in South and East Asia. A correlation analysis conducted for 27 Latin American cities demonstrates that, when comparing cities of equal size, a 10% increase in density results in a 1.7% reduction in travel time via public transport and a 1.2% reduction in travel time via private transport.[5]

Historically, a negative correlation has been noted between a country's per capita income and the density of its cities. As income levels rise, cities tend to expand more in geographical size than in population (Moreno-Monroy et al., 2021). This phenomenon can be attributed to an increase in the number of households relative to the population, alongside a demand for larger residences, coupled with an ability to afford higher commuting costs. The correlation between per capita income and density presents a forthcoming challenge for the region, as rising income levels in the ensuing decades may exert pressure on the territorial expansion of cities and the prevalence of automobile usage. Consequently, while in other developing regions, urbanization is the primary driver of increased urban transport emissions, in

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[5] Data obtained through a regression that uses the average travel time to the city center by car and bus, according to the OMU, and the density calculated with the FUAS base (Moreno-Monroy et al., 2021). The regression controls for the population of the metropolitan area, also taken from the FUAS base.

Latin America and the Caribbean—a region already significantly urbanized relative to its per capita income levels—the predominant factor could be the expansion of urban areas.

Accessibility refers to the number and quality of destinations that can be reached in a city in a given time, considering the equity in such access among people living there (Daude et al., 2017; Hernandez and Hansz, 2021; Vanoli and Anapolsky, 2023). Conwell et al. (2023) show strong differences in accessibility to the city center by car relative to public transport between Europe and the United States, which is associated with the opposite modal split patterns mentioned above.

The role of public transportation prices

The prices of the different modes of transport are determinants of the choices made by individuals and influence the modal split in cities. A summary of the evidence (predominantly for developed countries) indicates that a 10% increase in the price of gasoline generates a decrease in vehicle traffic and the number of vehicles of about 1% within one year and 2.5% of traffic and 3% of the number of vehicles within 5 years (Goodwin et al., 2004). The responses to changes in the price of public transport suggest that a 10% increase in fare leads to a decrease in demand ranging from 2% to 4% (Davis, 2021; Holmgren, 2007). The evidence is not conclusive regarding the relationship between public transport use and changes in household income. On the other hand, it is indisputable that increases in gasoline prices increase the use of public transportation, although the magnitude of this relationship is very heterogeneous in the available studies. This positive causality between gasoline prices and the use of public transportation is consistent with the fact that people are substituting private automobiles for public transportation.

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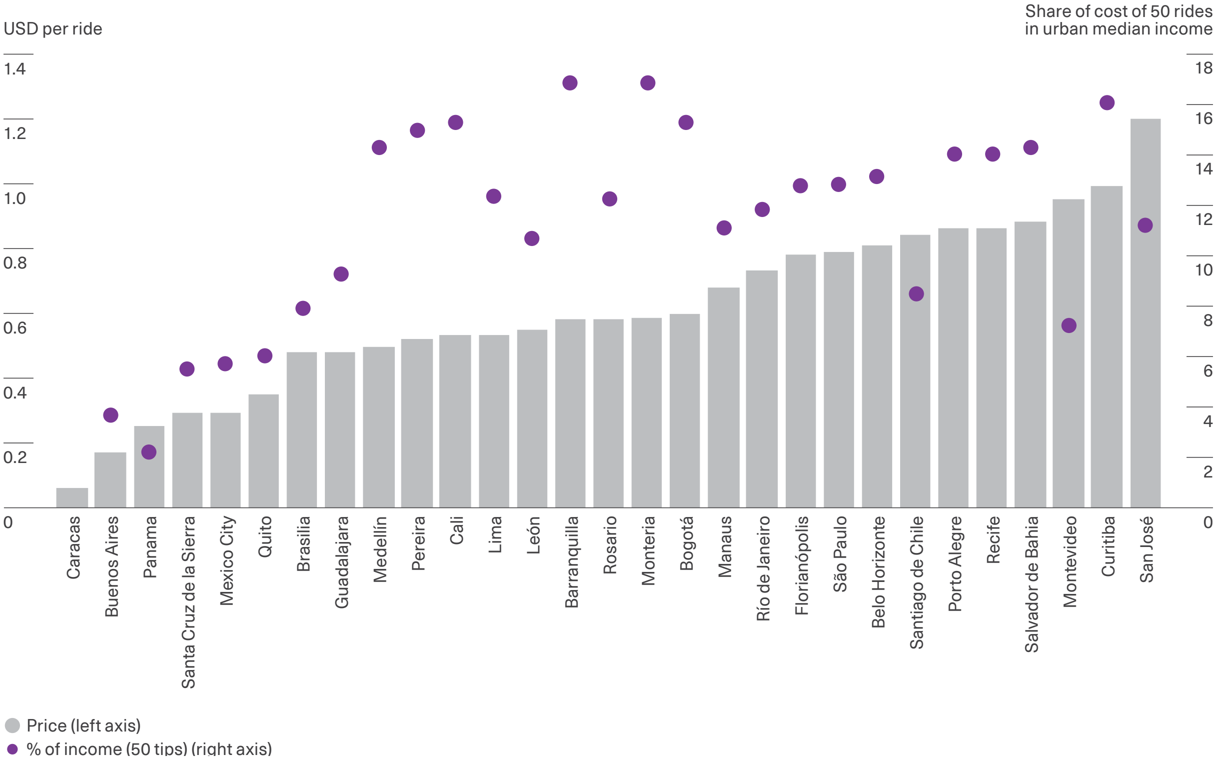
In several countries in the region there is room to promote the energy transition in transportation through higher taxes on gasoline and subsidies for public transportation

Graph 8.6 presents bus travel prices compiled by the SMO for 29 large cities in the region. Prices are expressed in current U.S. dollars as a proportion of the average per capita household income of the country to which the city belongs. This data provides a measure of the affordability of that mode of transport and suggests two broad groups of cities. On the one hand, there are those with relatively more affordable public transport, where the cost of 50 trips is less than 10% of household per capita income. In a second, larger group of cities, the cost of such trips exceeds 10% of household income, with values predominantly between 13% and 15%. This second group includes all Colombian and Brazilian cities except the capital. The substantial expenditure in this second group makes Latin America and the Caribbean the region with the highest proportion of urban household expenditure allocated to transport (Gandelman et al., 2019), which compromises the welfare of people with lower incomes and is a hindrance to increasing the role of sustainable urban transport.

The joint analysis of the affordability data in Graph 8.6 with the subsidy information collected by the SMO for the years 2021 and 2022 shows that bus systems in the first group of cities receive significant subsidies and that these are much lower in the cities of the second group. The cities in the first group, with the largest role of subsidies, are Buenos Aires, where the amount of subsidies was more than twice the revenue, and Mexico City, where they represented 120% of the revenue from ticket sales. In the first group of cities with more affordable public transport, the public transport systems of Panama and Santiago de Chile had one unit of subsidy for each unit of revenue. In the second group, the association between low subsidies and less affordability can be illustrated by Rio de Janeiro, where the subsidy is zero, Porto Alegre, where it accounts for only 14% of revenue, and Medellin and Barranquilla, where it accounts for less than 5% of revenue.

Graph 8.6
Prices for a single bus ride on public transport and the cost of 50 rides relative to monthly per capita household income in 2022



Note: The graph shows the average price (in US dollars) of a bus ride and the weight of a 50-ride package over the average per capita household income in urban households (in percent) for 29 cities in 12 LAC countries, in the year 2022. Incomes correspond to the average for the country and not for the city. The "bus" category was obtained by averaging data referring to urban buses, BRT (Bus Rapid Transit), shuttles, and vans.

Source: Authors based on data from OMU (2023) and CEDLAS and World Bank (2022).

Of course, subsidies alone do not explain differences in affordability between cities. There are also efficiency disparities, linked to various technical parameters of transportation systems, such as vehicle capacity, fuel costs, and wage levels. Urban form—density and sprawl—as well as a country's per capita income also play a role.

Considering both gasoline and public transportation prices reveals significant room for adjusting prices across most cities and countries. This could incentivize the use of public transportation over private vehicles, leading to improved social and environmental outcomes. The following section, which focuses on policy lessons in the transport sector during the energy transition, delves into more concrete tools for addressing these price discrepancies.

Sustainable transportation policies in the energy transition

Table 8.4 summarizes the main objectives and policy tools in relation to the two primary challenges posed in this chapter: 1) reducing emissions from urban mobility of people and improving equity in this area; and 2) reducing growing emissions from freight transport.

Table 8.4
Challenges and policies in energy transition in the transportation sector

Challenges	Target	Policies
Rising emissions and equity gaps in urban passenger transportation	Increased modal share of public transportation	Public transportation infrastructure
		Public transportation subsidies with targeted demand component
	Increased modal share of walking trips	Safe infrastructure for pedestrians and cyclists
	Lower modal share of the individual car	Congestion, parking, vehicle ownership, and gasoline taxes
	Vehicle electrification	Facilitating the development of freight networks through subsidies and regulations
		Subsidies for bus and taxi fleet replacement
Freight transportation emissions on the rise	Reducing emissions from heavy freight transport	Fossil fuel taxes
		Increasing property taxes according to the age of the vehicle
		Development of rail infrastructure when cost-effective
	Reducing emissions from light freight transport	Fossil fuel taxes
		Facilitating the development of freight networks through subsidies and regulations
		Financing for fleet renewal

In urban mobility, policies should prioritize sustainable transportation. This approach is crucial for reducing GHG emissions and enhancing well-being levels and equity in Latin American and Caribbean cities. Adding elements of promoting vehicle electrification to this agenda is essential, with a focus on bus and taxi fleets, while refraining from subsidizing the acquisition of private cars.

The primary goal of the urban energy transition is to bolster public transportation systems. These systems' features should align with city sizes. In larger cities, mass transit plays a pivotal role, necessitating investment in rail infrastructure, whether subway or above ground. However, as depicted in Table 8.1, such infrastructure comes with a high cost, making it less appealing for medium-sized cities. In such cases, Bus Rapid Transit (BRT) offers a mass transit alternative requiring fewer investments, a realm where the region has been a global pioneer, with over 60 cities equipped with this system (BRT Data, 2023). As illustrated in Table 8.2, buses hold a significant modal share in the region. Additionally, Box 8.4 highlights their substantial potential for electrification, including vehicles in the BRT mode, albeit facing notable challenges.

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The key to the energy transition in urban mobility is not the electrification of automobiles, but a greater role for walking, cycling and public transport

Apart from investments in road and vehicle infrastructure, robust public transport systems necessitate adequate regulation, minimum quality standards, mode integration, and operational subsidies. These subsidies, typically substantial, are justified for three primary reasons (Adler and van Ommeren, 2016; Anderson, 2014; Basso and Silva, 2014; Parry and Small, 2009). Firstly, without subsidies, the system would likely be too small, as costs per passenger decrease with increased ridership, and network size enhances passenger value. Secondly, subsidies reduce transport costs, discouraging individual car usage. Thirdly, public transport is predominantly utilized by lower-income households, hence subsidies promote equity, especially when targeted effectively, leveraging card and smartphone payment technologies (Gandelman et al., 2019; Serebrisky et al., 2009). As discussed in Box 8.4, subsidies are crucial for urban bus electrification to prevent fare hikes required for financing.

The second objective of urban mobility policies is to encourage active transport modes. A crucial aspect of this is providing infrastructure that shields pedestrians and cyclists from automobiles. Successful networks for bicycles and micro-mobility should possess three attributes: extensive coverage throughout the city, connectivity between various areas, and physical separation from car and pedestrian pathways to safeguard users (Reich, 2022). Beyond safe infrastructure, ensuring safety from crime and harassment, particularly for women, plays a pivotal role in promoting active mobility in the region (Allen et al., 2019).

The third objective is to deter individual car usage, achievable through various tools such as taxes, bans, or restrictions targeting ownership, circulation, or parking. Some cities, including Santiago de Chile (since 1986), Mexico City (since 1989), São Paulo (since 1996), Bogotá (since 1998), Medellín (since 2005), San José de Costa Rica (since 2005), and Quito (since 2010), have implemented bans on certain days based on vehicle registration, though these have often proven ineffective, leading to increased car purchases (Gallego et al., 2013). Alternatively, more effective approaches include restricting circulation to the most polluting vehicles, such as the oldest ones, or limiting car usage in specific areas and times. For instance, Bogotá introduced the "*pico y placa solidario*" program in 2020, allowing drivers to avoid peak hour circulation restrictions in downtown areas by purchasing a permit or by transporting at least three people in their vehicle.[6] Montero et al. (2022) show that this resulted in a significant improvement in welfare in the city.

Taxes on gasoline, car ownership, and parking play crucial roles in alleviating congestion and reducing emissions. In most countries across the region, there's significant potential to raise gasoline prices to account for the social costs of car usage. Vehicle ownership taxes, ideally, should be higher for vehicles with higher emissions. Moreover, parking prices should, at the very least, reflect the valuable alternative social uses of urban space. Evidence suggests that parking prices, especially with parking meters in regional cities, are often too low, frequently much lower than public transport fares, indicating ample room for greater utilization of this tool (Rivas et al., 2019).

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[6] Policies of restricting use on certain roads depending on the number of occupants have proven to be effective in decreasing congestion in the case of Jakarta (Hanna et al., 2017).

The fourth objective entails the electrification of urban transport, which involves two types of policies. Firstly, there are those aimed at reducing acquisition costs of electric vehicles for private use, typically through tax reductions or subsidies. However, these measures are discouraged due to their fiscal cost and regressive nature. Secondly, policies can focus on reducing usage costs by promoting the expansion of charging infrastructure, particularly by ensuring nationwide coverage. Experiences from the United States and Norway regarding subsidies for charging infrastructure indicate that they have twice the impact on electric vehicle adoption compared to subsidies of the same amount directed toward purchases. This effect is particularly significant in the initial stages of vehicle electrification when charging infrastructure is limited, but its impact diminishes over time (Li et al., 2017; Springel, 2021).

In line with the above, the challenge of reducing emissions in freight transport requires a different approach for light-duty and heavy transportation. Given that electrification remains impractical for heavy transport at present, policies should prioritize enhancing the overall energy efficiency of the logistics process. This can be achieved by introducing taxes and eliminating subsidies for fossil fuels, implementing vehicle ownership taxes that discourage older vehicles, and developing supplementary rail infrastructure alongside trucks when cost-benefit analysis warrants it.

Electrification priorities are in urban buses and light-duty or last-mile freight transportation

In light-duty transportation, opportunities for electrification should be encouraged through fossil fuel taxes and the expansion of recharging infrastructure. Additionally, exploring special credit programs for fleet electrification, particularly in cities with elevated air pollution costs and numerous small urban logistics companies, could be beneficial.

Macroeconomic impacts of the energy transition

- The importance of the energy sector and its sub-sectors in the region's value added
- Energy and its input-output relationships
- Fiscal effects and external impacts of the energy transition
- Monetary policy and financial regulation responses to the transition

9

Key messages

1

Energy sectors have a greater share in the GDP in the countries of Latin America and the Caribbean (LAC) than in developed countries. However, much of this difference is attributed to the production of hydrocarbons, in particular, oil in Venezuela, Colombia and Ecuador, and gas in Bolivia and Trinidad and Tobago.

2

The energy transition may result in stranded assets, particularly in hydrocarbon-producing countries. Scenarios consistent with a 2°C increase in global temperature would imply leaving 40% of oil reserves and 50% of gas and coal reserves in South and Central America unburned.

3

Some countries in the region possess significant reserves of certain critical minerals, which will need to be exploited for the energy transition. Chile and Peru have copper reserves; Argentina, Bolivia, and Chile have lithium; Mexico and Peru have silver; and Brazil and Colombia have nickel.

4

Hydrocarbon revenues constitute a substantial portion of fiscal revenues in some countries in the region. For example, in Ecuador, these revenues surpass 8% of GDP, and in Guyana and Trinidad and Tobago, they exceed 5% of GDP. Across the region, these revenues represent more than 4% of GDP.

5

Latin America and the Caribbean includes both net energy importer and exporter countries, and the energy transition will impact them very differently. In net exporter countries such as Bolivia, Colombia, and Venezuela, the transition to a green economy may require a productive reconfiguration to offset the reduction in exports of energy resources.

6

The energy transition may require the attention of financial regulators for several reasons, including the need to address potential impacts on financial stability stemming from changes in asset valuation and increased price volatility, especially in the energy sector, due to the effects of climate change and efforts to transition to a cleaner energy mix.

Macroeconomic impacts of the energy transition[1]

Introduction

The new energy transition will impact the economy as a whole. In macroeconomic terms, it may impact fiscal and external balances as well as pricing and the stability of the financial system, issues which will be discussed in this chapter. At the structural level, it may lead to a shift with implications for the labor market and productive development, aspects that are analyzed in Chapter 10.

In Latin America and the Caribbean there are hydrocarbon-producing countries that export and derive fiscal revenue from these resources. An energy transition involving a significant reduction in the consumption of these energy sources will undoubtedly impact the economies of the region. On one hand, it will compromise the availability of resources for implementing public policies, while on the other, it will potentially leave a set of stranded assets, which will require a productive, fiscal, and financial reconfiguration.

Beyond the fiscal and external effects, the energy sector is linked to other sectors of the economy. Changes in the participation of each of these sectors therefore have effects on production, prices, and employment at an aggregate level. Effects on energy prices and their associated inputs, as well as on the valuation of assets related to the energy sector, may require adjustments to monetary policy and financial regulations to address these changes.

This chapter describes the share of the energy sectors in production and their linkages. It also discusses the potential problem of stranded assets, fiscal and external revenues from the energy and mining sectors, and, finally, the challenges arising from the transition in terms of monetary policies and financial regulation.

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[1] This chapter was written by Lian Allub and Fernando Álvarez with research assistance from Lorenzo Perrotta, María Pía Brugiafreddo, and Martín Finkelstein.

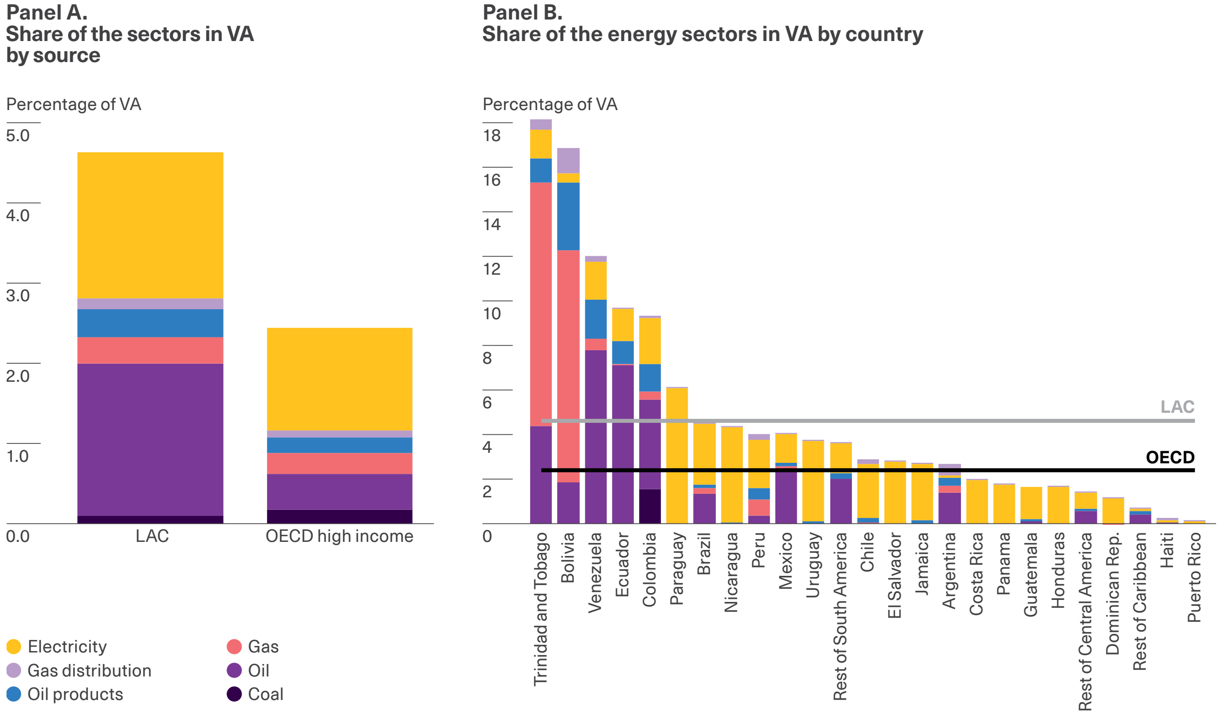
Share of energy sectors in production

A first step to understanding the impact the energy transition will have on the economies of the region is to understand the energy sector's contribution to the value added of the economy. In Latin America and the Caribbean (LAC), the entire sector contributes approximately 4.6% of the value added (VA), compared with the countries of the Organization for Economic Cooperation and Development (OECD), where it provides less than 2.5%. If electricity is omitted, the differences do not change substantially. Energy sectors represent 2.8% of the VA in LAC and approximately 1% in the OECD. This already gives an initial indication that the shift away from fossil fuels will be more challenging in Latin America and the Caribbean due to the abundance of resources and their contribution to the economy.

The energy sectors contribute approximately 4.6% of value added in Latin America and the Caribbean, versus less than 2.5% in OECD countries

Graph 9.1

Share of energy sectors in value added, for the OECD and Latin America and the Caribbean



Panel A.
Share of the sectors in VA by source

Panel B.
Share of the energy sectors in VA by country

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

Certainly, there are considerable disparities across the region in terms of the share of the energy sectors in the VA, especially with regard to hydrocarbons. Hydrocarbon-related sectors —such as oil, gas, and coal extraction, oil production, and gas distribution— represent more than 15% of VA in Trinidad and Tobago and Bolivia, and more than 9% of VA in Venezuela, Ecuador, and Colombia (by order of importance of the sector). Colombia presents a unique case because coal, one of the most polluting hydrocarbons, makes up about 1.5% of the country´s VA, and thus should be among the first to be abandoned. However, discontinuing the use of this resource could have significant impacts on the economy.[2]

The energy industry composition also varies among the main hydrocarbon-producing countries of the region. While in Trinidad and Tobago and Bolivia, the gas industry makes the greatest contribution to the value added, in Venezuela, Ecuador, and Colombia the greatest contribution comes from oil. Finally, Paraguay is a noteworthy case, where the electric power industry contributes nearly 7% of the country's VA. The high share of this industry in Paraguay stems from its hydropower generation potential, facilitating a clean energy mix. In those countries where the hydrocarbon energy sector does not make a significant contribution to the VA, the energy transition will have minimal or no direct impacts on fiscal accounts. Nevertheless, those countries will have to rely on imports to meet their remaining energy demand, that is, the portion of the demand that cannot be supplied by their own energy sectors.

Given the significant share of the energy sectors in the region's value added, the energy transition is likely to have a substantial negative impact on the countries' income as they phase out the use of fossil fuels. These stranded assets may take the form of unexploited reserves or partially depreciated physical capital.

Stranded assets

Stranded or abandoned assets are assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities (Caldecott et al., 2013). These assets are tied to sunk costs, including all their key characteristics (recoverability, transferability, longevity, and financing needs). They are assets that, at some time prior to the end of their useful life (as assumed at the investment decision point), are no longer able to yield an economic return (i.e., meet the expected return on investment) as a result of the changes associated with the energy transition to a low-carbon economy (Carbon Tracker Initiative, 2017b). However, the status of stranded assets also depends on the technology that exists at each moment in time. For example, the development of carbon capture technologies or the possibility of using another type of fuel in thermal plants could enable assets that would currently be considered stranded due to their high emission levels, no longer be considered as such and continue to operate.

Stranded assets are those that, at some point before the end of their useful life, no longer yield economic returns due to changes associated with the energy transition

A distinction must be made between stranded resources (resources that are underutilized) and stranded assets (an asset that is losing or has already lost value). For example, oil resources can become stranded if they cannot be used. However, the investments (assets) that were made to extract

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[2] Brazil and Mexico are two of the major oil producers in the region in absolute terms. However, due to their large manufacturing industries, the share of hydrocarbons in the value added is not as substantial as in the other countries mentioned.

those resources (e.g. an oil refinery or a pipeline) become stranded if production has to be stopped (Bos and Gupta, 2019).

Fossil resources tend to be concentrated among a handful of countries, many of which are medium- or low-income countries, some of which, as mentioned, can be found in the LAC region. This means that conventional climate policies aimed at phasing out fossil energy sources will impact them to a greater extent. In this respect, Mercure et al. (2018) estimate a future loss of global wealth that ranges between USD 1-4 trillion, with significant distributional impacts (an excessive burden on net exporters and benefits for net importers). While hydrocarbon-producing economies will be directly impacted, the rest of the economies may also experience these effects through the productive linkages related to hydrocarbon production, whether as suppliers of inputs for the fossil industry or as users of fossil energy in the production process, for example, in thermal power generators or energy-intensive industries (Ansari et al., 2019; Campiglio et al., 2017).

In this respect, some recent estimates suggest that, to avoid reaching intolerable levels of climate change, between 60% and 80% of publicly traded fossil fuel reserves must remain undeveloped.[3] This implies a loss of USD 28 trillion in revenue for the fossil fuel industry over the next two decades (Carbon Tracker Initiative, 2013; Kepler Cheuvreux, 2014). McGlade and Ekins (2015)[4] estimate that one-third of global oil reserves, half of global gas reserves, and more than four-fifths of global coal reserves would have to remain undeveloped to ensure the increase in global temperature does not exceed 2°C compared to pre-industrial levels (Curtin et al., 2019; Van Der Ploeg and Rezai, 2020). Table 9.1 shows the estimated reserves for each resource that should remain unburned by region.

One-third of the world's oil reserves, half of its gas reserves, and more than four-fifths of its coal reserves would have to remain untapped to keep global temperature rise below 2°C

The Latin America and the Caribbean region has significant oil and gas reserves, which makes it especially vulnerable to changes in environmental regulations that promote phasing out the use of fossil resources.

As previously mentioned, the fossil sectors contribute significant value added in certain countries of the region, and are highly important in terms of their fiscal revenues and foreign currency generation. Given the uneven distribution of these resources across the region, where oil and gas reserves are concentrated in Venezuela and most coal reserves are located in Colombia and Brazil (Caldecott et al., 2016), unequal impacts between countries can be expected.

Following up on the exercise above, McGlade and Ekins (2015) estimate that, in Central and South America, 42% of oil, 56% of gas, and 73% of coal reserves will be 'unburnable' before 2050, in a scenario where there is no widespread deployment of carbon capture, use, and storage (CCUS) technologies. Should these technologies be implemented, the percentages of unburnable reserves would reduce to 39%, 53%, and 51%, respectively. This is comparable to the percentages calculated at the global scale, where 35% of oil, 52% of gas, and 88% of coal should remain unburned if CCUS is unavailable. In a scenario with CCUS technology, these figures would be 33%, 49%, and 82%, respectively. This suggests that Central and South America have slightly higher percentages of unburnable oil and gas reserves than the rest of the world, and relatively fewer unburnable coal reserves.

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[3] For more details on the oil and gas reserves that could remain undeveloped in the region, see Chapter 5.

[4] The authors use the differences in extraction and production costs and the carbon intensities of different types of oil, gas, and coal worldwide. In addition, they break down carbon budgets by region and fuel type by calculating the socially-optimal distribution of stranded carbon assets across regions and carbon assets.

Table 9.1
Unburned fossil fuel reserves compatible with a 2°C temperature increase through the deployment of CCS technologies

Region	Oil	Gas	Coal
Middle East	38%	61%	99%
OECD Pacific	37%	56%	93%
Canada	74%	25%	75%
China and India	25%	63%	66%
Central and South America	39%	53%	51%
Africa	21%	33%	85%
Europe	20%	11%	78%
United States	6%	4%	92%

Source: Data from McGlade and Ekins (2015).

Lastly, it is worth mentioning that stranded fossil fuel assets could also have a profound effect on the labor and social dynamics of local communities in Latin America and the Caribbean. Entire regions and, therefore, entire communities depend on the fossil fuel extractive industries in much of Latin America and, to a much lesser extent, in the Caribbean (with the exception of Trinidad and Tobago). Consequently, governments will have to carefully manage any transition and stranding of assets in order to ensure manpower needs are met and to avoid significant disruptions (Caldecott et al., 2016).

Input-output relationships of the energy sectors

In addition to the direct contributions energy sectors make to the value added of the economy, they are also demanding users of inputs for their own production. At the same time, the energy they produce is an input for other sectors. Input-output (I-O) analysis quantifies the importance of different sectors as input users (backward linkage multipliers) or as input suppliers to other sectors (forward linkage multipliers). Both types of multipliers can be classified as Type I and Type II. Type I multipliers include the direct impacts on the sector as well as the indirect impacts arising from the production linkages. Type II multipliers expand upon Type I multipliers, incorporating the induced effects by households' response to these changes.[5]

In the I-O analysis, the electricity sector, taken from the Global Trade Analysis Project: Version 11 (Aguiar et al., 2022), is disaggregated by generation Source: coal, gas, oil, wind, solar, hydroelectric, and nuclear. The hydrocarbon and mining extractive sectors include coal, natural gas extraction and distribution, oil, metal ore mining, and other mining and quarrying.

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[5] A brief description of input-output matrix analysis and the calculation of Type I and II multipliers can be found in the annex of this chapter, available online.

Table 9.2 shows the Type I and II backward linkage (BL) multipliers for each of these sectors in Latin America and the Caribbean (regional aggregate). While the Type I multipliers for sectors associated with fossil fuel generation sources are greater than those for renewable generation sectors, the pattern reverses once the induced effects are accounted for, as renewable electricity generation sectors show higher BL multipliers. This analysis suggests that, once household effects are factored in, renewable sectors have a greater impact on the economy than the fossil fuel sectors. Turning to the extractive sectors, the table shows Type I multipliers are in line for the fossil fuel-related sectors and the Type II multipliers are in line with renewable sectors. It should be noted that these multipliers are measured in terms of value added. Their impact in terms of employment may differ, depending on the degree to which these technologies are labor- or capital-intensive (see Chapter 10).

That said, the values of these multipliers vary greatly by country. Graph 9.2 shows the values of the Type I and II backward linkage multipliers by sector, normalized by the value of the economy average (the values by country are shown in Table A.9.1 of the annex). In this case, values greater than 1 imply the sector has stronger backward linkages than the economy average, while values less than 1 indicate weaker backward linkages than the economy average. The renewable sectors have lower Type I backward linkage multipliers than the economy average. Conversely, within fossil energy sectors, coal and oil have a significant share of the distribution, showing values greater than 1, indicating their stronger backward linkages. Regarding Type II multipliers, i.e. those that capture the effects induced by household consumption, in general, all sectors present multipliers lower than the economy average. However, the distribution of Type II multipliers in the renewable sectors clusters around the average, while in the fossil fuel and nuclear sectors, the distribution is predominantly lower than the economy-wide average.

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Once induced effects are accounted for, renewable electricity generation sectors have a greater impact on the economy than their fossil-fuel-based counterparts

Table 9.2

Backward linkage multipliers of production in Latin America and the Caribbean by source of electricity generation and by extractive sector

Electricity generation sectors														Extractive sectors								Economy average	
Coal		Gas		Oil		Wind		Solar		Hydroelectric		Nuclear		Coal		Oil		Gas extraction and distribution		Mining			
BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2	BL1	BL2
1.5	3.5	1.6	3.3	2.3	4.2	1.3	4.4	1.2	4.4	1.2	4.4	1.4	4.4	1.4	4.4	1.4	4.4	1.5	4.2	1.7	4.6	1.5	4.2

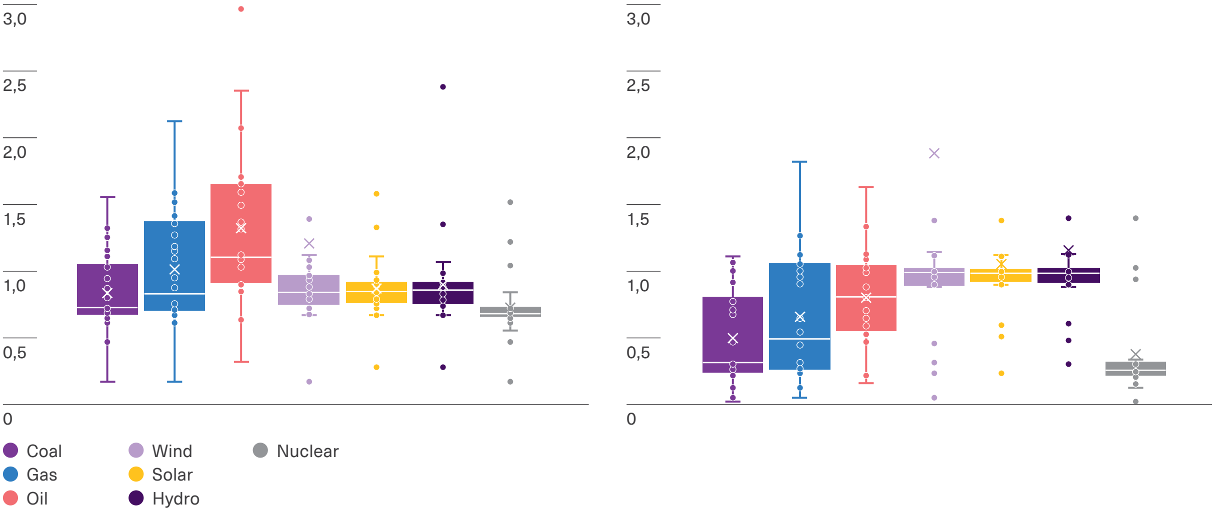
Note: BL stands for backwards linkage.

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

The extractive sectors and energy as a whole exhibit less dispersion of the Type I and II multipliers compared to the electricity sectors, and, in both cases, they are very similar to those of the economy average. In summary, although energy sectors play an essential role as inputs for the rest of the economy, do not seem to have particularly strong backward linkages.

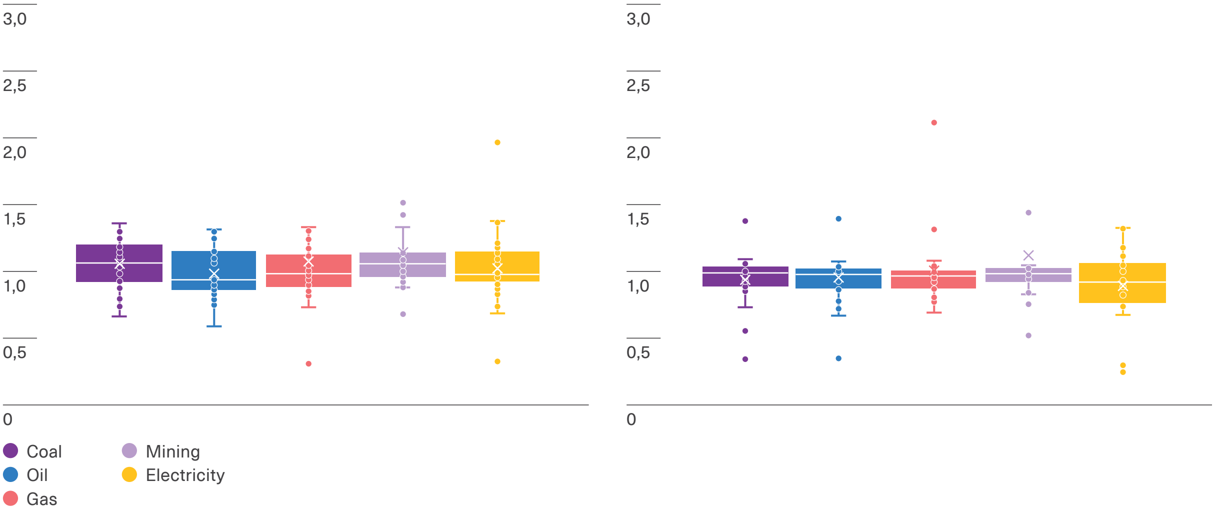
Graph 9.2

Backward linkage multipliers of energy sectors by type and sector



Panel A.
Type I multipliers for electricity generation sectors

Panel B.
Type II multipliers for electricity generation sectors



Panel C.
Type I multipliers for extractive sectors

Panel D.
Type II multipliers for extractive sectors

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

Input-output analysis also allows us to simulate the impact of a positive or negative shock in a specific sector of the economy. Box 9.1 shows the results of simulating the projected variation in the different energy sectors when transitioning to a net-zero emissions (NZE) scenario.

The technology with the lowest capital cost to install a 100 MW plant is wind (1.36 USD/MW), followed by solar (2.19 USD/MW) and geothermal (2.51 USD/MW)

This input-output matrix analysis does not consider the investment required to deploy the technology. As shown throughout this report, the expansion of renewable energy generation necessary to meet the committed goals requires that the generation capacity from these renewable sources increases. This will involve the construction of both onshore and offshore wind farms, solar farms, and other investments. Table 9.3 shows the breakdown by sector of capital expenditures for the installation of a 100-megawatt (MW) plant and the operating and maintenance costs for different sources of electricity generation. As shown in the table, the technology with the lowest capital cost per MW is wind (USD 1.36/MW), followed by solar (USD 2.19/ MW) and geothermal (USD 2.51/MW). It is important to note that, unlike fossil fuel-fired power plants, where the input for generation can be transported, the output of these plants will depend on the availability and intensity of the specific natural resource.

On the other hand, resuming the previous input-output analyses, each of these technologies also requires inputs from other sectors for their installation and operation. In terms of the installation expenditures (CAPEX), construction and the machinery and equipment sectors are one of the largest inputs. Furthermore, some of the technologies have specific requirements that are not relevant to the others. For example, nuclear generation requires inputs from mineral production and the computer and electronics industry, while wind power requires rubber and plastic products. In sum, deploying these generation sources will, through their production linkages, have direct and indirect impacts on the economy as a whole.

With respect to the maintenance and operational expenditures (OPEX), more sectors are generally involved than those regarding installation costs. Machinery and equipment and construction sectors also account for the main OPEX costs. Exceptions to the above are solar energy, where the machinery and equipment sector has minimal participation, and hydroelectric and biomass, where the construction sector contributes little to operating costs. On the other hand, the business services sector has a significant participation in all of the energy sources, in contrast to its low participation in the installation process.

All of this indicates that the installation, operation, and maintenance of renewable energy generation technologies can become drivers of employment and production, not only in the sector itself, but also in the other linked sectors, such as those of the suppliers providing the inputs.[6]

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[6] Chapter 10 discusses the effects of foreign direct investment on employment in Brazil and the installation and operation of solar and wind farms in Spain.

Box 9.1
Aggregate impacts of transitioning to a net-zero emissions scenario

Input-output matrices can be useful for simulating the aggregate annualized effects of the change in production for the main energy sectors associated with the transition to a net zero emissions (NZE) scenario. This box first presents the results of a simulating the changes implied by the NZE targets of each sector independently. Next, it shows the total result obtained from adding these individual changes. Despite this exercise does not consider possible substitutions between inputs (assuming a perfect complements production function), it can provide an initial approximation for inferring the relative importance of the direct, indirect and induced effects. Table 1 shows the assumptions and the results of the simulation.

The simulation exercise suggests a 0.34% decline in the region's annual GDP. As abovementioned, this exercise assumes that the proportion in which each input is used will not be substituted. Consequently, these results may be considered as the worst-case scenario for the GDP decrease. Induced effects explain most of the changes, which underscores the importance of considering all effects, not just the direct ones, in order to understand the impact that the energy transition will have on the economy.

Table 1
Simulated scenarios and input-output model results for Latin America and the Caribbean

		NZE scenario		Unchanged scenario	
		Change in production by 2050	**Annual change in production**	**Change in production by 2050**	**Annual change in production**
Extractive sectors	Coal	-94.92%	-2.50%	-44.07%	-1.36%
	Oil	-18.75%	-0.64%	56.25%	1.67%
	Natural gas extraction and distribution	-37.91%	-1.20%	3.92%	0.14%
	Refined petroleum products	-40.91%	-1.28%	0.00%	0.00%
	Electricity	182.97%	3.93%	89.10%	2.39%

		Annual change in GDP			
		Direct	**Indirect**	**Induced**	**Total**
Extractive sectors	Coal	0.00%	0.00%	0.00%	-0.01%
	Oil	-0.06%	-0.02%	-0.19%	-0.28%
	Natural gas extraction and distribution	-0.01%	0.00%	-0.03%	-0.04%
	Refined petroleum products	-0.04%	-0.04%	-0.09%	-0.16%
Electricity generation sectors	Nuclear	0.00%	0.00%	0.00%	0.00%
	Coal	0.00%	0.00%	0.01%	0.01%
	Gas	0.01%	0.01%	0.02%	0.04%
	Wind	0.00%	0.00%	0.00%	0.00%
	Hydroelectric	0.01%	0.00%	0.04%	0.06%
	Oil	0.00%	0.00%	0.02%	0.02%
	Other	0.00%	0.00%	0.01%	0.01%
	Solar	0.00%	0.00%	0.00%	0.00%
	TOTAL	**-0.08%**	**-0.05%**	**-0.21%**	**-0.34%**

Source: Authors based on IEA (2023x) and Aguiar et al. (2022).

Table 9.3
Sectoral breakdown of capital, operational and maintenance expenditures by sector of activity and source of electricity generation for the installation of a 100 MW power plant

Sector	Wind		Solar		Hydroelectric		Geothermal		Biomass		Nuclear
	CAPEX	**OPEX**	**CAPEX**	**OPEX**	**CAPEX**	**OPEX**	**CAPEX**	**OPEX**	**CAPEX**	**OPEX**	**CAPEX**
Mining and quarrying	-	-	-	-	-	-	17.5%	7.5%	-	-	1.5%
Rubber and plastic products	9.7%	4.8%	-	-	-	-	-	-	-	-	-
Mineral products	-	3.2%	-	3.4%	-	-	-	-	-	-	7.5%
Basic metals and metal products	8.0%	15.0%	9.3%	19.9%	2.0%	9.0%	16.0%	-	3.3%	-	6.0%
Computer and electronic products	-	1.0%	-	11.2%	-	-	-	-	-	-	8.0%
Electrical machinery	9.0%	16.9%	14.3%	17.0%	5.0%	14.5%	5.0%	7.5%	8.3%	5.0%	12.0%
Machinery and equipment	34.7%	23.5%	37.7%	6.5%	23.0%	21.0%	33.5%	22.5%	31.7%	15.0%	28.0%
Motor vehicles and parts	-	-	-	-	-	-	-	-	-	-	-
Construction	17.3%	20.9%	13.3%	16.2%	60.0%	9.0%	20.0%	22.5%	26.7%	-	25.0%
Commerce	-	-	-	-	-	-	-	-	10.0%	30.0%	-
Hospitality and restaurant services	1.0%	0.3%	-	-	-	-	-	-	-	-	-
Transportation	1.0%	0.7%	0.3%	-	0.5%	-	-	-	13.7%	40.0%	-
Financial services	6.0%	2.8%	17.0%	10.0%	1.3%	10.0%	1.5%	10.0%	0.3%	-	2.0%
Insurance	-	0.5%	-	-	-	-	-	-	-	-	-
Real estate services	11.7%	-	7.3%	-	0.8%	-	3.3%	-	4.7%	-	-
Business services	1.7%	10.4%	0.7%	15.8%	3.8%	36.5%	3.3%	30.0%	1.3%	10.0%	10.0%
Public administration	-	-	-	-	3.8%	-	-	-	-	-	-
CAPEX Cost (tUSD/MW)	1.36		2.19		3.51		2.51		3.93		7.44
OPEX Cost (% of investment cost)	4.0%		1.0%		4.0%		3.7%		7.0%		1.8%

Note: Costs are expressed as a percentage of total CAPEX and OPEX for each source. Total CAPEX is expressed in thousands of dollars per megawatt (tUSD/MW).

Source: Authors based on Tourkolias and Mirasgedis (2011), Markaki et al. (2013), EIA (2020a), Garret (2017) and Pollin et al. (2015).

Participation of the mining sector in production and potential positive impacts from the use of critical minerals

Clean energy production and consumption require the development of a value chain to generate and provide this energy, with the mining sector playing a fundamental role.

As discussed in Chapter 1 of this report, one of the challenges of the energy transition is ensuring the two green energy value chains —energy and the technology needed for its production and consumption— are secure, resilient and sustainable.

Security refers to ensuring there is an adequate, reliable, and uninterrupted supply of inputs. The green energy technology value chain is generally more concentrated than the supply of fossil fuels, which poses a potential threat to its security. The Russian invasion of Ukraine underscored the importance of this issue, as countries were forced to reconfigure their energy mix to replace gas imports from Russia.

Resilience refers to the capacity to address and mitigate the shocks that can compromise the value chains of energy systems. Shocks that result in shortages or sudden price increases for key inputs or components of green energy technologies may impact planned decarbonization timelines and lead to increased costs.

Lastly, sustainability is associated with the need to reduce emissions, not only in energy production but also throughout the entire production chain. This includes mineral extraction as well as the processing of the materials and inputs needed to produce clean energy technologies.

Latin America and the Caribbean can leverage its status as a peaceful region to become an ally in the green energy value chain, especially given its reserves of certain critical minerals.

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Latin America and the Caribbean can leverage its status as a peaceful region to become an ally in the green energy value chain, especially given its reserves of certain critical minerals

The minerals and materials needed for the energy transition

The IEA report Energy Technology Perspectives 2023 (2023g) outlines a group of minerals and materials that will lead the energy transition. They include copper, lithium, nickel, cobalt, neodymium, and silver found in mines or deposits. These minerals need to be processed to achieve the desired chemical compositions or alloys and transformed into critical materials. Polysilicon is another sought-after material.[7] In addition, there are bulk metals that will be essential for the transition, such as iron (for steel production) and aluminum found in deposits, as well as bulk materials like cement, steel, aluminum, and plastic.[8]

It is clear that the value chain for these inputs consists of at least two stages: extraction, which is dependent on the reserves available in each country; and the processing and production of materials from the extracted minerals. Latin America and the Caribbean possess globally significant reserves of lithium, copper, nickel, and silver, although their participation in the extraction of these minerals varies greatly. Participation is high in terms of lithium, copper, and silver, while it is lower for nickel, as indicated in Graph 9.3.[9] In terms of production, the region has a considerably high share of lithium, copper, and silver production; a somewhat lower share of zinc and tin production; and minimal production of bauxite, graphite and nickel.

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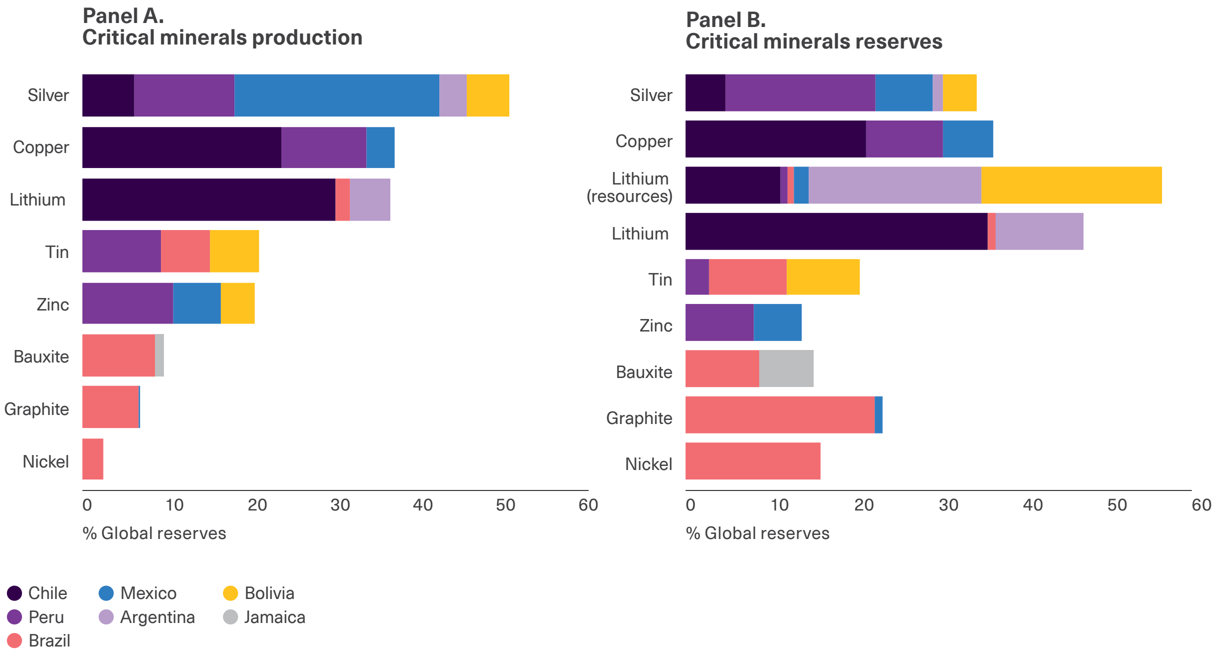
[7] Critical minerals include copper, lithium and its components, nickel and its components, cobalt and its components, neodymium, and polysilicon.

[8] This highlights the need to decarbonize these industries. As seen in Chapter 6, there are priority challenges that must be addressed in the decarbonization of these sectors.

[9] The region also has significant reserves of neodymium, but does not participate in its extraction.

Graph 9.3
Participation of Latin America and the Caribbean in the production and reserves of critical minerals in 2022



Note: A mineral resource is a concentration of minerals that has been identified and measured with reasonable certainty, but whose extraction has not yet been shown to be economically viable. A mineral reserve is a portion of a mineral resource that has been proven to be economically viable and legally extractable under current socioeconomic and operating conditions.

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

Demand for critical minerals and technologies for the energy transition

The IEA classifies the demand for certain critical minerals for a set of clean energy technologies as high, medium, or low. Table 9.4 provides a summary of the level of demand for each mineral by the technologies needed for the transition. Within this group, copper is a critical mineral in almost all technologies, with medium to high demand. Nickel is another mineral with a similar demand across several technologies. Moreover, electric vehicles and battery technologies have high demand for all the minerals considered, while other technologies, such as photovoltaic solar panels, hydroelectric power and electricity grids, only have a medium to high demand for copper.

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Copper and nickel are medium to high demand minerals in most green technologies. Electric vehicles and batteries will demand high levels of several critical minerals

Table 9.4
Demand for critical minerals by technology type

	Copper	Cobalt	Nickel	Lithium	Rare earth elements
Solar photovoltaic panels	🟥	🟩	🟩	🟩	🟩
Wind	🟥	🟩	🟨	🟩	🟥
Hydro	🟨	🟩	🟩	🟩	🟩
Concentrated solar thermal energy	🟨	🟩	🟨	🟩	🟩
Bioenergy	🟥	🟩	🟩	🟩	🟩
Geothermal	🟩	🟩	🟥	🟩	🟩
Nuclear	🟨	🟩	🟨	🟩	🟩
Electricity networks	🟥	🟩	🟩	🟩	🟩
Electric vehicles and battery storage	🟥	🟥	🟥	🟥	🟥
Hydrogen	🟩	🟩	🟥	🟩	🟨

Mineral demand
🟢 Low
🟡 Medium
🔴 High

Source: Own elaboration based on IEA (2021g).

Latin America and the Caribbean boast two of the most important copper-producing countries: Chile and Peru. The rising demand for these minerals, driven by the main technologies for clean energy production, may present new opportunities for these countries, as it may potentially lead to higher prices of these resources.

The region also has a substantial share of lithium reserves. One of the world's largest reserves of the mineral is located in the so-called lithium triangle, which spans the borders between Argentina, Bolivia, and Chile. In addition to extracting lithium, the region also has the capacity to process it.

The region also has a significant share of global nickel reserves (17%), although production is limited and accounts for less than 5% of total global production.

Developing the value chains for these resources could represent investment, production and employment opportunities for some countries in the region. However, these minerals are found in very specific locations. Graph 9.3 shows that Peru and Chile are the main actors in the production of these minerals, along with Mexico (silver in particular) and, to a lesser extent, Argentina and Brazil (different minerals).
The share in production of other countries in Latin America and the Caribbean is relatively minor.

The energy transition and fiscal balances

The energy transition will impact the fiscal balances of countries in terms of both revenue and expenditures. On the one hand, the transition will reduce fiscal revenues, especially in hydrocarbon-producing countries that derive economic resources from royalties, income taxes, and other instruments. On the other hand, as shown in Chapter 1, many countries in the region provide energy consumption subsidies, either directly or, more commonly, indirectly. Moving forward in the transition with a new scheme involving fewer subsidies could imply lower expenditures (in the case of direct subsidies) or greater revenues (with the elimination of indirect subsidies), and thereby have a positive effect on fiscal revenue.[10]

On the expenditure side, it is also possible that during the transition the prices of certain fuels or key inputs (such as critical minerals) for energy production may increase. This would result in higher energy prices and negatively impact household budgets. Such an impact will require the State to aid the most vulnerable households, which, as shown in Chapter 7, are those that allocate a larger portion of household income to paying for energy. Providing assistance will in turn increase public expenditure.

On the other hand, the energy transition will demand investments in infrastructure for generation, transportation, and distribution. While these can be partially borne by the private sector, the public sector will undoubtedly need to accompany it.

The speed at which the transition is carried out may also impact public finances. Speeding up the transition may require state subsidy programs to promote the supply of green energy —such as reducing taxes or granting subsidies for investment in low-emission energy generation, such as solar or wind power— as well as the storage technologies that will be necessary, such as batteries. Similarly, it will be required to boost the demand for replacing assets with clean energy or more energy-efficient options, such as incentives for purchasing electric vehicles or replacing outdated appliances with low-consumption models. Distributed generation could also be encouraged, for example, through installations of solar panels in homes. All of these incentives involve state expenditures that will increase government spending.

As discussed in Chapter 10, the transition will also involve a shift in the demand for the skills required in the labor market. Governments will need to act to reduce the impact of changes in the workforce, which will need to acquire different skills. Such actions could include, for example, providing training programs for those displaced from their jobs.

Finally, the transition will require infrastructure to be adapted, and not just that of the energy sectors, but also that related to urban and interurban transportation systems, as well as public buildings such as schools and hospitals. For example, cities may need to be redesigned to be more public transportation-friendly, or schools upgraded to be more energy efficient. These types of measures will require varying degrees of expenditures, depending on the intensity and extent to which the state decides to engage in reducing energy emissions.

Unfortunately, it is very difficult to estimate the extent of these changes in the total spending. Undoubtedly, these matters must be considered when quantifying the impact of the energy transition on fiscal accounts. They shall also be considered when choosing the most suitable strategy and speed for implementing the transition, so as not to jeopardize the fiscal sustainability and development objectives of the countries in the region.[11]

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[10] The concept of indirect subsidies is closely tied to a carbon tax; that is, to linking the payment for goods to the associated externalities of emissions generated to produce that good. Chapter 10 details the instruments available for internalizing this externality.

[11] One program aimed at supporting the energy transition and combating climate change is the Inflation Reduction Act (IRA) of the United States. Different organizations estimate this legislation would cost between USD 780 billion and USD 1.2 trillion in fiscal incentives, tax relief, and other fiscal measures.

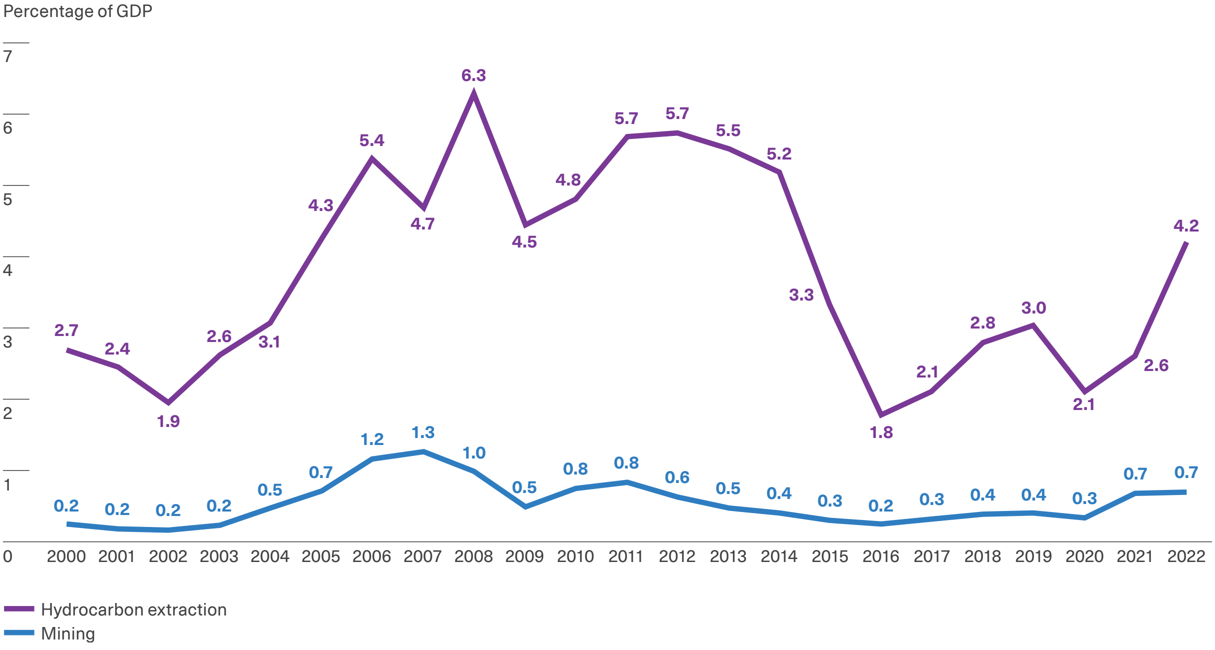
Share of the hydrocarbons and mining sectors in fiscal revenue

Most of the hydrocarbon-producing countries in the region generate fiscal revenue from the exploitation of these products, whether through bonuses, royalties, income taxes, or other revenue-raising instruments. The transition from hydrocarbon-based energy generation to clean sources may thus imply significant losses of fiscal revenue for some countries.

Graph 9.4 shows the revenue generated in the main producing countries from their hydrocarbon and mining operations as a percentage of GDP from 2000 to 2022. Fiscal revenues increased significantly in the early 2000s, reaching 6.3% of GDP for hydrocarbons and 1.3% of GDP for mining. However, starting in 2008 for mining and 2015 for oil, these resources began to decline in terms of their share of GDP. The slight improvement observed between 2017 and 2019 was interrupted by the COVID-19 pandemic. However, in 2021 the trend began to reverse and, one year later, hydrocarbons reached a share of 4.2% of GDP, approaching the values of the commodities supercycle.[12]

Graph 9.4

Share of fiscal revenues from hydrocarbon and mining in total GDP between 2000 and 2022



Source: Authors based on OECD et al. (2023)

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[12] Total revenue in 2021 for the LAC countries for which information on fiscal revenues from hydrocarbons and mining extraction is available was 17.6% and 17.9% of GDP, respectively. Fiscal revenues from hydrocarbon and mining extraction represented an average of 13.1% and 4% of total fiscal revenues, respectively.

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Fiscal revenues for hydrocarbons and mining in Latin America and the Caribbean reached in 2022 4.2% and 0.7% of GDP, respectively

Although mining is a polluting activity, it is also an essential activity for countries to reach their decarbonization targets, as previously shown. Even though the demand for these resources will increase due to electrification and the development of the technologies needed for the energy transition, copper extraction and processing already generates substantial fiscal revenues. while Lithium is instead, an emerging industry with great potential.

In terms of the mining sector's contribution to fiscal revenue, Chile and Peru are the countries in the region where it has the highest share, reaching 3 points of GDP and 1.7 points of GDP, respectively. Bolivia's fiscal revenues from mining account for 1 point of GDP, while these same revenues in Brazil, Nicaragua and Dominican Republic account for around 0.5 points of GDP. Considering the effects of the transition, Argentina, Bolivia, and Chile have the potential to increase their fiscal revenues from mining through lithium exploitation, while Chile and Peru will be able to continue to exploit copper, Mexico, silver, and Brazil, bauxite, nickel and graphite.

Revenue schemes from natural resource exploitation

Extractive industries, such as fossil fuels and mining, present certain features, that can influence the optimal approach to revenue collection from them, as detailed by the IMF (2012). On one hand, these industries can potentially generate substantial income and, therefore, comprise an attractive tax base. At the same time, high degrees of uncertainty about price trajectories affect the estimates of the profitability of exploiting these resources. There may be information asymmetries between the private and the public sectors regarding the costs and benefits of exploiting a resource, which makes it difficult to optimize the revenue collection from its exploitation. These investments entail high sunk costs, which can create time-inconsistency problems and tampering governments' incentives to design and adhere to optimal policies. Ownership is another distinctive feature. In general, the entities involved are either multinational companies or state-owned enterprises. In the case of the former, fiscal problems may arise since these companies may have more experience in tax avoidance and may be sensitive about the distribution of resource revenues with local citizens. In the case of the latter, efficiency problems in exploitation that reduce the potential revenues from the resource may arise. Another potential issue is the concentration of suppliers. These markets typically have few actors, which leads to monopolistic profits and, therefore, requires advanced regulation. Finally, determining the optimal exploitation path may be challenging, given that the opportunity cost of today's exploitation is future exploitation.

Energy generation from renewable sources shares some characteristics with the exploitation of fossil resources, such as the uncertainty about price trajectories and the high sunk costs the investments entail. However, there are other features they do not share, such as the best exploitation path, which may impact the optimal tax collection framework for each source.

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Optimal tax revenue collection for energy generation from renewable sources may differ from fossil fuel-based energy frameworks

Governments usually determine goals for the revenue collection of fossil resources exploitation that may be shared with tax collection from energy production of renewable sources. A first principle would be to maximize the net present value (NPV) for the government, this estimate takes into consideration who bears the risks of resource exploitation. A relevant dimension to bear in mind when maximizing the NPV is the timing of revenue collection. Governments with limited access to credit, or that are shortsighted or impatient,[13] may prioritize revenue collection at the early stage of the project. However, deferring collection can reduce the perceived risk for the investor, and thus reduce the expected return required to exploit the resource. Another principle is the progressive nature of the instrument; that is, revenue collection should increase when profits, due to price increases or cost reductions, also increase. The government should also seek to introduce as few distortions as possible into the production process, so as not to affect the potential output. Likewise, it should ensure there are adequate incentives for investment, which will increase the chances of extracting the highest return on the resource. Finally, it should consider minimizing the risk of investment, as well as the administrative burdens and risks.

The most commonly used fiscal instruments for revenue collection from extractive industries are: bonuses, which establish one-time payments triggered by certain events; royalties (on gross revenues), which generate public revenues from the start of production, though these can render the extraction of some natural deposits unreasonable because they increase project costs; corporate income taxes (CIT) and variable income tax (VIT), which must be applied to ensure that capital is equally taxed to other sectors; and the natural resources revenue tax (NRRT). Unlike CIT, which can discourage investment due to its taxing of all resource returns, NRRT only taxes profits, that is, the return after deducting costs and the minimum return on investment required by the investor. Finally, another instrument is state participation, which is used in many countries to ensure the state has an additional benefit (beyond tax revenues) in profitable projects.[14]

As shown in Graph 9.5, countries rich in fossil resources currently derive their fiscal resources from two main types of instruments: 1) taxes on income, profits and capital gains; and 2) revenues from ownership interests, such as royalties or dividends from state-owned enterprises.

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Countries rich in fossil resources primarily derive their fiscal resources through taxes on income, profits, and capital gains, or through revenues from ownership interests, such as royalties or dividends from state-owned enterprises

In addition to a decrease in revenue flow due to the reduced exploitation and use of fossil resources, the energy transition may result in fiscal costs due to contract breaches if the timing or feasibility of exploiting resources changes. All of this must be duly considered when measuring the fiscal impact of the transition.

Furthermore, while it will be possible to derive fiscal revenues from renewable generation, the same instruments used with fossil resources — such as royalties and bonuses— will likely not apply. Revenue could come from income taxes and surface rental payments, which may at least partially offset the drop in revenue collections from fossil fuels. In some countries, revenues may be improved through the application of higher taxes to mining activities, especially those associated with critical minerals.

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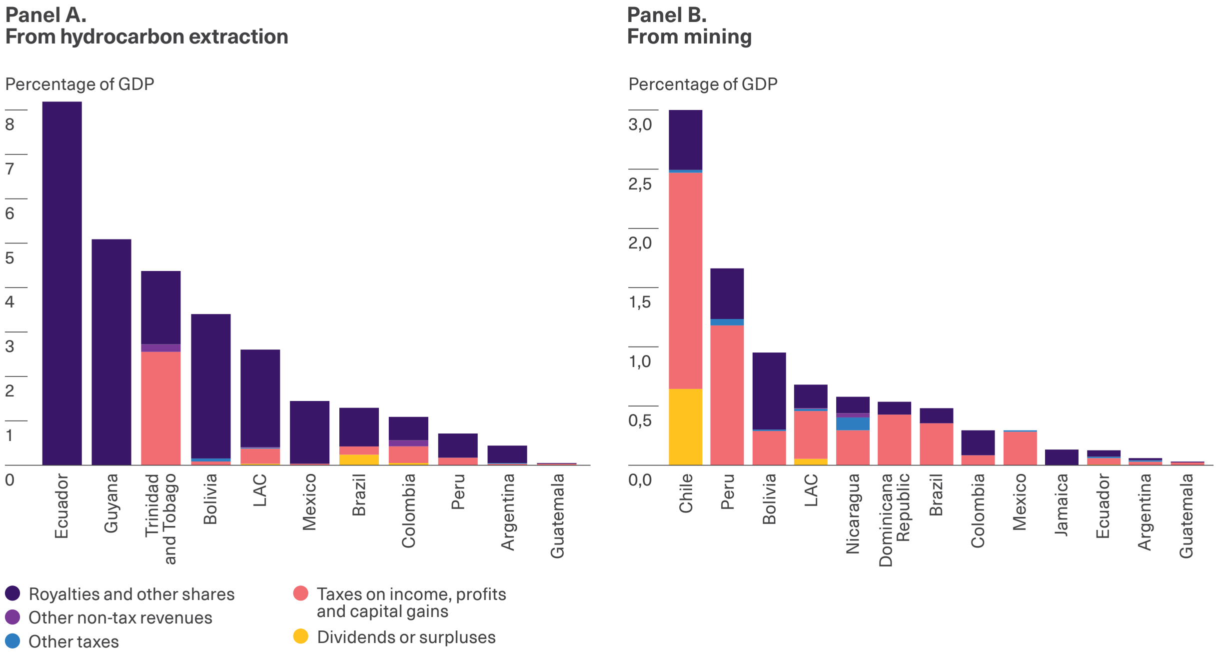
[13] Impatience can arise from typical political economy problems, such as when the current government places more value on the revenues that can be collected during its term in office over the fiscal revenues of future governments.

[14] Table A.9.2. in the appendix, available online, provides a brief summary of how each instrument relates to each objective.

Graph 9.5
Revenue from natural resource exploitation by type of instrument



Source: Authors based on ECLAC data (2023).

Distribution of hydrocarbon revenue at the subnational level

Although resource endowments are usually discussed at the country level or even at broader regional levels, natural resources tend to be concentrated in specific locations within a territory. This uneven geographical distribution impacts revenue collection and allocation, which depends, among other issues, on the political organization of a territory; that is, whether it consists of unitary states or federations. The loss of revenues from the abandonment of fossil resources, and the increase in revenues due to the exploitation of mineral resources or from taxes related to environmental policies —such as carbon tax— could have disparate effects on cities, countries, and regions, which, in turn, could influence the level of support or opposition to proceeding with the energy transition.

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Natural resources tend to be concentrated in specific locations within a territory. This unequal distribution affects how revenue is collected and distributed among jurisdictions

Allocation and distribution schemes of revenues from non-renewable natural resource exploitation include:

- Tax disaggregation (distributing the tax bases to different levels of government, allocating royalties to subnational entities and income tax to the central government).

- Concurrent taxation (the same taxable base is shared by different levels of government).
- Revenue sharing.
- Intergovernmental transfer systems.

A wide variety of distribution schemes for these revenues exist in the region. Table 9.5 presents a summary of the legal frameworks that govern the distribution of these fiscal resources. It is worth noting that most legal frameworks in South America contemplate the distribution of resources among producing regions, but very few consider compensation payments to non-producing regions. At the same time, the table confirms the preceding discussion regarding the methods of revenue collection, showing the vast majority comes from royalties.

In South America, most legal frameworks contemplate the distribution of resources to producing regions, with very few considering payments to non-producing regions

The fact that different South American countries do not consider distributing revenues among non-producing regions may pose a political economy problem for the transition, since those potentially harmed by the phase-out of fossil fuels will be concentrated, which could facilitate joint actions to block potential proposals.

Table 9.5
Distribution of fiscal resources from extractive industries by level of government

Country	Sector	Ownership of resources	Constitutional provision on distribution	Distributed revenue	Computation of taxable revenues	Distribution to producing regions	Compensation to other regions	CAPEX restrictions	Current expenditure allowed?
Argentina	Hydrocarbons	Nation/ provinces	No	Royalties	12% of production value	Yes (provinces collect)	No	Not specified	Not specified
	Mining	Nation/ provinces	No	Royalties	12% of production value	Yes (provinces collect)	No	No	Yes
Bolivia	Hydrocarbons	The People of Bolivia	Yes	Royalties and DHT	18% and 32% of production value	Yes	No	Yes (minimum 85%)	Yes (maximum 15%)
	Mining		No	Royalties	1% to 7% of gross sales value	Yes	No	Yes	No
Brazil	Hydrocarbons	Federal government	Yes	Royalties	10% of production value	Yes	Yes	Yes	No
	Mining	Federal government	Yes	Royalties (FCME)	0.2% to 3% of net sales value	Yes	No	Yes	No
Chile	Mining	State	No	Patent and sales tax	0.5% to 5% of sales value	No	No	Not specified	Not specified
Colombia	Hydrocarbons	State	Yes	Royalties	5% to 25% of production value	Yes	Yes	Yes	5% in OPEX of the project funded with royalties
	Mining	State	Yes	Royalties	1% to 12% of pithead value	Yes	Yes		

Continued on the next page →

Country	Sector	Ownership of resources	Constitutional provision on distribution	Distributed revenue	Computation of taxable revenues	Distribution to producing regions	Compensation to other regions	CAPEX restrictions	Current expenditure allowed?
Ecuador	Hydrocarbons	State	Yes	Royalties	12.5% to 18% of production value and rate	Yes (minimum)	No	N.D.	N.D.
	Mining	State	No	Royalties	3% of production value	Yes	No		
Mexico	Hydrocarbons	Nation	No	All fiscal revenues		Yes	Yes [a]	N.D.	N.D.
	Mining	Nation	No	All fiscal revenues		Yes [b]	No		
Peru [c]	Hydrocarbons	Nation	No	Royalties, fund, and income tax [d]	Royalties 5% to 37% of production value, 50% IT	Yes	No	N.D.	N.D.
	Mining	Nation	No	Royalties, fund, and income tax	Royalties 1% to 3% of gross sales, 50% IT	Yes	No	Yes	No
Trinidad & Tobago	Hydrocarbons	State	No	Royalties	12.5% on offshore sales	No	No	N.D.	N.D.
Venezuela	Hydrocarbons	Republic	Yes	Royalties and percentage of the national budget	20% to 30% of production value	Yes (minimum)	Yes	Not specified	Not specified

Note: a/ Regions have access to fiscal resources through the Fiscal Coordination Law; b/ Includes states and municipalities; c/ Subnational governments receive 50% of the revenues collected from income tax of producing companies; d/ The distribution of mining, gas, and oil royalties is as follows: 10% is allocated to the municipalities where the concession is located, 25% to the municipalities in the provinces hosting the concession, 40% to the municipalities in the departments where the concession is located, and 25% to the regional governments where the natural resource is exploited, with 20% of this portion being transferred to national universities within their jurisdiction. DHT, direct hydrocarbon tax; FCME, financial compensation for mineral exploitation; IT, income tax; and N.D., no data.

Source: ECLAC (2014).

Environmental tax revenues

Pursuing climate targets brings certain opportunities for revenue collection, primarily through taxes on fossil fuels and emissions. These taxes aim to incorporate the negative externalities generated by GHG emissions into prices. The taxes are based on a physical unit (or approximation thereof) of something that has been proven to be harmful to the environment. There are four categories of environmental tax revenues:

- Energy. Taxes on energy products (e.g., fossil fuels), including those used in transportation, which also includes carbon taxes.
- Transportation. Import duties or sales tax on transport equipment, taxes on the ownership, registration or use of motor vehicles, and other transport-related taxes.
- Pollution. Taxes on the emission of various gases —sulfur oxide (SOx), nitrogen oxide (NO_x), chlorofluorocarbons (CFCs), and others— wastewater disposal, packaging, solid waste, and other waste-related taxes.
- Resources. Taxes on water extraction, forestry, hunting and fishing products, mining royalties, and excavation taxes.

Graph 9.6 shows the use of these taxes in the region and the OECD average. Taxes on energy predominate, followed, to a lesser extent, by transportation in Latin America and the Caribbean. The rest of the categories account for relatively small percentages. The trend is the same in the average of OECD countries. The graph shows that some countries generate significant revenues from these concepts. For instance, they represent about 3% of GDP in Guyana, and about 2% of GDP in Honduras. Implementing environment-related taxes is crucial for economic agents to internalize the costs of the environmental externalities they generate. It also contributes to mitigating the drop in fiscal revenues due to the reduced exploitation of fossil resources.

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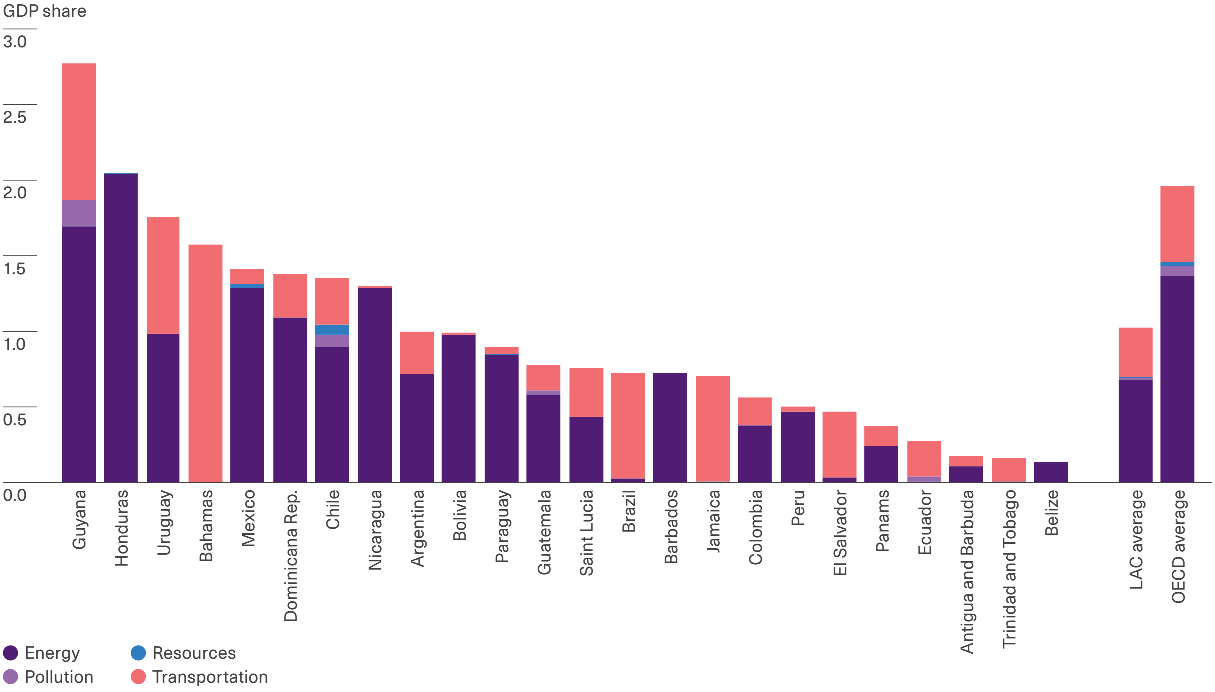
Environment-related taxes can be useful to internalize the costs of environmental externalities and mitigate the drop in tax revenues

Graph 9.6
Environmental taxes



Note: The LAC average represents the unweighted average of 24 countries in the region. Cuba, Costa Rica, and Venezuela are not included due to data availability issues. The graph does not include revenue from the special consumption taxes in Jamaica that apply to petroleum products (estimated to have exceeded 2% of GDP in 2018) due to unavailable data. The calculation of the OECD average includes Chile, Colombia, and Mexico.

Source: OECD et al. (2022).

Fiscal revenues during the transition

Titelman et al. (2022) analyze the fiscal impacts of the energy transition in a business-as-usual (BAU) scenario and in a net-zero emissions (NZE) scenario in six countries of the region: Bolivia, Brazil, Colombia, Ecuador, Mexico, and Trinidad and Tobago. In the BAU scenario, the authors find that there would not be a substantial decline in hydrocarbon revenues, partly because the decrease in the production of these goods would not be very significant. However, in the NZE scenario, there would be a sharper decline in fiscal revenues from hydrocarbons. Part of that drop could be offset by higher carbon taxes, although the study shows that, except in Brazil and Colombia, increasing revenues through those taxes does not fully compensate for the decrease resulting from lower hydrocarbon production. The difference in fiscal revenues from this latter concept between the NZE scenario and the BAU scenario is 6% of GDP in Ecuador, 5% of GDP in Trinidad and Tobago, 3% of GDP in Mexico, and 2% of GDP in Bolivia. In the NZE scenario, in addition to the decrease in revenue there will be increased spending on assistance to vulnerable sectors due to the introduction of the carbon tax. The aggregate effect on the fiscal balance when considering these expenses is negative for all countries.

The energy transition and net energy exports

As explained throughout this report, energy is a key input for both production and household consumption. Therefore, it is not surprising that it also plays a predominant role in trade. Since energy availability is highly dependent on the natural resource endowments of countries, they tend to be either producers of energy goods and, therefore net energy exporters, or net energy importers.

Graph 9.7 depicts net energy imports as a percentage of total exports of goods and services. As the graph shows, most countries in Latin America and the Caribbean are net energy importers. Within this group, Jamaica, Saint Lucia, and Honduras stand out, as their net energy imports represent more than 25% of goods and services exports. On the other hand, there are countries in Latin America and the Caribbean with very significant hydrocarbon production. Venezuela stands out among them, with net energy exports that account for more than 80% of total exports of goods and services. In Colombia, Bolivia, Trinidad and Tobago, and Ecuador, energy exports exceed 20% of total exports of goods and services. Finally, Paraguay, which, although lacks hydrocarbon resources, exports significant amounts of electricity to Argentina and Brazil from the two hydroelectric power plants it has with these countries, Yacyretá and Itaipú.

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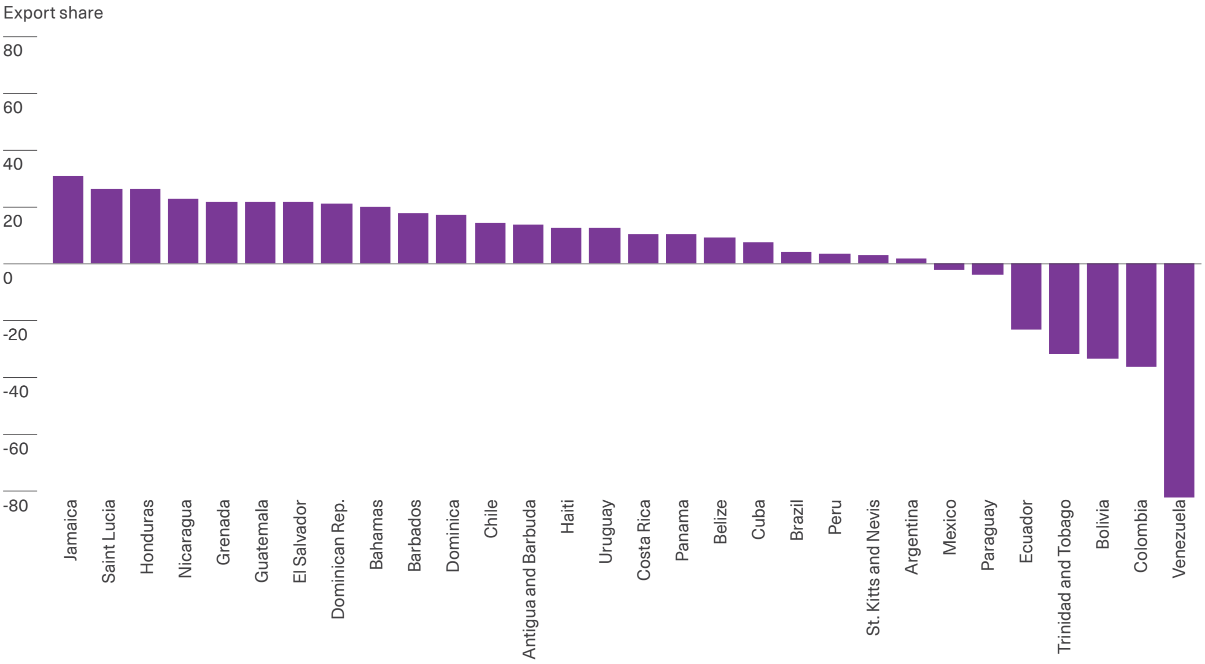
Latin America and the Caribbean includes major hydrocarbon producers like Venezuela, whose net energy exports account for more than 80% of total exports of goods and services

Beyond their current dependence on the energy sector, whether as net importers or net exporters, the energy transition will impose heterogeneous challenges for the countries of the region. On the one hand, hydrocarbon exporters will need to diversify their export mix. Cases like Venezuela will undoubtedly face challenges in their productive reconfiguration. On the other hand, current net energy importer countries such as Jamaica or Chile may be positively affected if their renewable energy-based generation capacity increases, or if the price of hydrocarbons falls due to lower global demand.

A key question today is the extent to which renewable energy trading gan go beyond border interconnections. Currently, energy trade is dominated by exports of oil, coal, and liquefied petroleum gas (LPG). Hydrocarbons allow a separation of production and consumption, with trade playing a central role in matching supply and demand. At least for now, renewable energy lacks this characteristic, and the technology for storing it remains costly, so energy production and consumption must be located in a limited environment where the transmission technology allows for their connection. Green hydrogen and batteries are some of the technologies that could potentially enable trade in renewable energy in the future, which would allow renewable energy to become a basic commodity.

Graph 9.7
Average net energy imports as a percentage of total goods and services in the period 2006-2019



Note: Guyana was not included in the table due to structural changes in the sector from 2020.
Source: Authors based on UNCTAD (2021).

The energy transition, financial regulation and monetary policy

The energy transition and prices

The energy transition and climate change could impact aggregate price levels through different mechanisms.[15] Three of these mechanisms can be defined according to the descriptions used by Isabel Schnabel (2022): First, there is climateflation, which refers to general price increases due to the rise in the occurrence of extreme weather events and the number of natural disasters. These can compromise the supply of goods, such as food, leading to increases in inflation in countries. The resilience and adaptation of infrastructure and productive capital can help mitigate the effect of these events on production, capital depreciation and, consequently, price levels.

●●

Central banks should take into account new scenarios with higher volatility in energy prices when designing and communicating monetary policy

The second mechanism is fossilflation, or the increase in inflation driven by the rise in the price of fossil fuels. Policies such as carbon pricing or the reduced availability of funds for investments in fossil energy can result in higher financing costs. In turn, this can lead to higher prices of fossil fuels, which will be reflected in energy prices, at least in the short and medium run, until it becomes feasible to replace it with clean energy production. Likewise, if companies in the hydrocarbons sector anticipate lower demand and higher costs, they may halt exploration projects for new reserves, as well as cut back on technological improvements to make them more efficient.

The last of these mechanisms is greenflation. In the short run, if companies begin to transition away from fossil fuel consumption in favor of clean energy, demand for the latter will increase, along with the demand for the inputs needed for its production, such as certain critical minerals or materials. This may result in restricted supply, leading to upward pressure on prices and consequently impacting energy prices. Nevertheless, since these technologies have very low marginal production costs, in the medium and long run energy prices are expected to fall compared to scenarios where fossil fuels play a more predominant role.

When designing and communicating monetary policy, central banks must consider these scenarios with high volatility in energy prices. Given that the clear and appropriate communication of central bank actions is fundamental to monetary policy, it is important that such communication warns of the transient impacts of short-term energy price volatility on inflation rates. In connection with the above, designing inflation measures that exclude these prices will be likely necessary. This approach would allow for greater internal control and stability of economic policy objectives and would prevent from undermining the credibility of communications regarding inflation commitments.

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[15] The mechanisms discussed in this section are all associated with changes in relative prices. However, they can also impact general price levels because of the important role of energy as a key input in production processes, and therefore could trigger inertial processes. Nevertheless, they differ from traditional inflationary processes originating, for example, from the monetization of recurring fiscal deficits.

Role of monetary and financial policy

As discussed, the energy transition will have fiscal and external impacts and could affect prices in the energy and related sectors, such as critical minerals. This will occur through different mechanisms, such as increased prices for energy generation inputs, falling marginal costs of renewable source-based generation, or the reduction in the investment and supply of fossil fuel energies. Given the central role energy plays in the productive structure, all of this could affect the levels and volatility of prices in the economy in general. In addition to the impact on prices, there could be other potential effects in other aspects of the financial sector.

According to Carney (2015), climate change can affect financial stability through three broad channels. First, there are the physical risks that impact insurance liabilities and the value of financial assets that arise due to climate- and weather-related events. Second, there are the liability risks, which are the future impacts that could arise if those affected by climate events seek compensation from those they hold responsible for such events. And finally, there are the transition risks, which are the financial risks that could result from the process of adjustment towards a low-carbon economy. The speed and extent to which these risks occur could play a decisive role in the financial stability of the economy. Early policies that anticipate these risks can therefore contribute to preserving stability.

Stranded assets, as mentioned on several occasions, are a underlying risk of the energy transition. These assets could impact financial stability if they affect the value of the collateral available to banks and, consequently, the access to credit by fossil energy companies.

The portfolios of the major coal, oil, and gas companies are not diversified and are susceptible to significant sell-offs if investors decide to divest from them. Including the reserves held by sovereign states, up to 80% of the declared reserves owned by the world's largest fossil fuel companies and their investors could be stranded. The Carbon Tracker Initiative (2017a) suggests that between 20% and 30% of the market capitalization of the London, Sao Paulo, Moscow, Sydney, and Toronto stock exchanges is related to fossil fuels. The fossil fuel industry is large enough to trigger a financial crisis if the renewable energy transition is disorderly and the market panics (Van Der Ploeg and Rezai, 2020).

If the transition to a low carbon economy occurs belatedly and the shift is abrupt, it could affect systemic financial risk through two channels: 1) the macroeconomic impact of the sudden changes in energy use, and 2) the rapid revaluation of carbon-intensive assets. A sudden transition to low carbon emissions could result in a restricted energy supply and increased costs, which would adversely affect economic activity. Furthermore, financial institutions could be affected by their exposure to carbon-intensive assets, which, in turn, could have implications for financial stability and require a redesign of the regulations in this area.[16]

●●

Whatever role central banks ultimately assume in responding to climate change, they should seek to maintain their independence and credibility so as not to undermine their mandate to preserve price stability and the sustainability of the financial system

In summary, climate change and the energy transition may have significant impacts on price levels and the stability of the financial system. How central banks should react to these circumstances is a subject of continued debate. In any case, their actions to mitigate the harmful effects of climate and energy events on the rest of the economy should be carried out without compromising their independence or their primary objective, which is the stability of prices and the financial system as a whole.[17]

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[16] For a more detailed discussion, see Caldecott et al. (2016) and European Systemic Risk Board (2016).

[17] See Cabrales et al. (2022a, 2022b, 2022c), Cochrane (2020) and Weidmann (2019) for a discussion of the role that central banks should play.

The multiple macroeconomic challenges of the transition

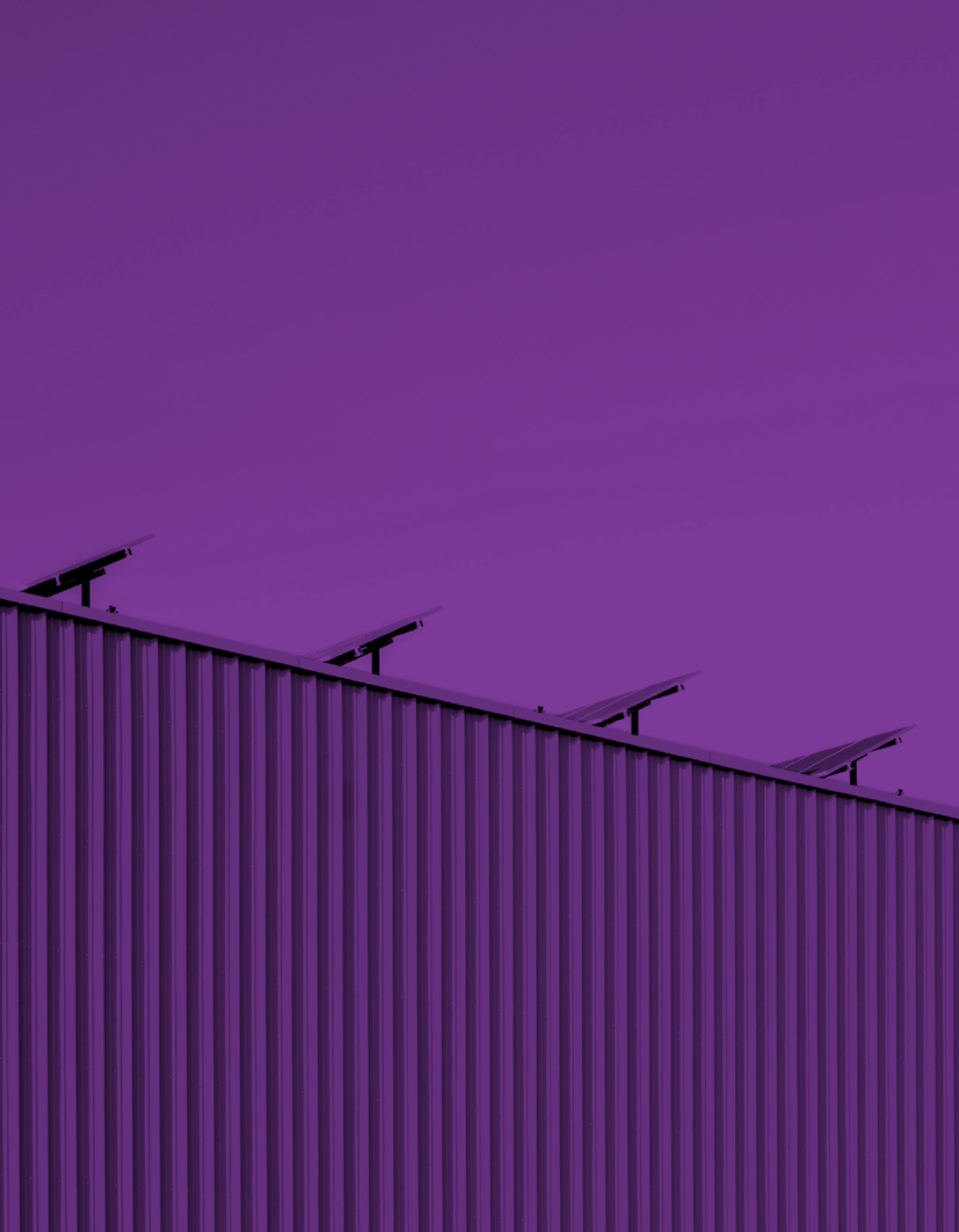
This chapter has analyzed the exposure of the region's economies to the energy transition across several dimensions. The analysis has made clear that some economies will be negatively impacted by the energy transition, particularly those that are net producers and exporters of hydrocarbons, such as Bolivia, Ecuador, Trinidad and Tobago, and Venezuela. In these economies, a decrease in demand for hydrocarbons will affect its fiscal and external accounts, and require a productive reconfiguration.

Then there are the economies that produce hydrocarbons but do not derive significant fiscal and external revenues from these sources, such as Argentina, Brazil, Colombia, Mexico, and Peru.

Finally, there are the non-hydrocarbon-producing economies, which can be divided into two groups. First, there are the countries with a high potential for renewable energy production. The transition may be beneficial to these countries, as long as they can reduce their energy imports and replace them with domestic energy production, as exemplified by Chile. However, the second group includes countries, such as many of the Caribbean islands, where the current energy supply depends largely on energy imports and the potential for renewable energy production is not as high. For these economies, the energy transition may bring supply constraints or price increases.

Beyond energy production, the chapter also discussed the important role the extraction of certain critical minerals will have in the transition. There are opportunities to obtain export and fiscal revenues from the exploitation of these minerals, which could offset the decline in revenues from hydrocarbons in countries such as Argentina, Bolivia, Brazil, or Mexico, and provide opportunities to increase tax revenue in countries like Chile or Jamaica.

In summary, the energy transition will impact countries' fiscal and external accounts, as well as price stability, in different ways depending on their position in the hydrocarbon supply chain, their renewable generation potential, and their endowment of critical minerals. Each country will need to analyze the dimensions that will affect it the most, to outline its strategy for the energy transition.



The path to a just transition: Opportunities and challenges of the energy transition

- The triple challenge to achieve a just energy transition: grow, include and reduce emissions
- Productive opportunities from the energy transition
- The labor market in the face of the energy transition: importance of green jobs and their skills demanded
- Cross-cutting policies for the energy transition
- Agenda for a just energy transition

10

Key messages

1

The developing world, particularly Latin America and the Caribbean, faces a triple challenge: achieve considerable and sustainable income growth; reduce emission levels; and decrease inequality. While all countries must contribute to efforts to reduce energy emissions, the speed and strategies for doing so will be specific to each country.

2

Energy transition must be intergenerationally just because today's emissions affect the well-being of future generations; internationally, given the historical disparities in emissions among countries and significant per capita income gaps; and domestically, as the transition may disproportionately impact vulnerable populations within a country.

3

Energy transition will entail a shift of workers from sectors and occupations with declining demand to those with increasing demand. This significant labor market realignment poses an additional challenge: green occupations appear to have different characteristics, particularly requiring more skills and abstract tasks, requiring active labor policies to facilitate the transition.

4

Green jobs pay higher wages. In OECD countries, this wage premium disappears when considering the characteristics of companies and employees (including their skills); in contrast, in Latin America and the Caribbean, it remains when accounting for these factors.

5

The most energy-efficient companies are also the most productive, serving as an ally in achieving the goal of economic growth with emission reduction.

6

Informality, a scourge in the region, could potentially hinder emission reduction if it becomes a refuge to evade environmental regulations.

7

The region's potential to produce clean, cheap, and stable energy can become an ally for powershoring, attracting investments seeking to meet environmental commitments.

8

Four cross-cutting policies are needed for the energy transition: green financing; carbon markets and carbon taxes; carbon capture and use technologies; and the circular economy.

9

The political economy of the energy transition will entail both geopolitical challenges for control of the supply chain of green technologies, and domestic challenges within countries to equitably distribute the efforts and costs of carrying it out.

The path to a just transition: Opportunities and challenges of the energy transition[1]

Introduction

Underdevelopment is a multi-causal, complex, and persistent phenomenon. Over the past 100 years, many developing countries have failed to converge with the living standards of more advanced countries, and Latin America and the Caribbean is no exception.

Global transformations are perceived as windows of opportunity to leap toward desired development. However, they can also impose challenges and additional constraints that make achieving historic development goals more difficult. What is certain is that this new energy transition brings opportunities and challenges for the region. To ensure that this global transformation brings Latin American and Caribbean countries closer to sustainable development, it is essential to be prepared and to have the necessary institutional framework and environment to fully exploit opportunities and overcome challenges.

The first part of the chapter examines the need for the energy transition to be approached from a perspective beyond the energy sector, with a broad vision of sustainable development and justice. It explores aspects related to the labor market on one hand, and productive development on the other, highlighting the opportunities that clean energy offerings from countries, known as powershoring, could offer to the region.

The second part focuses on four cross-cutting policies to address environmental concerns in the context of the energy transition: green financing; carbon markets and carbon taxes; carbon capture and use (CCS) technologies; and the circular economy. The chapter concludes with a consolidated presentation of the main policy instruments and key messages throughout the report to promote a just transition, highlighting the political economy challenges that may arise.

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[1] This chapter was written by Lian Allub and Fernando Álvarez with research assistance from Lorenzo Perrotta, María Pía Brugiafreddo, and Martín Finkelstein.

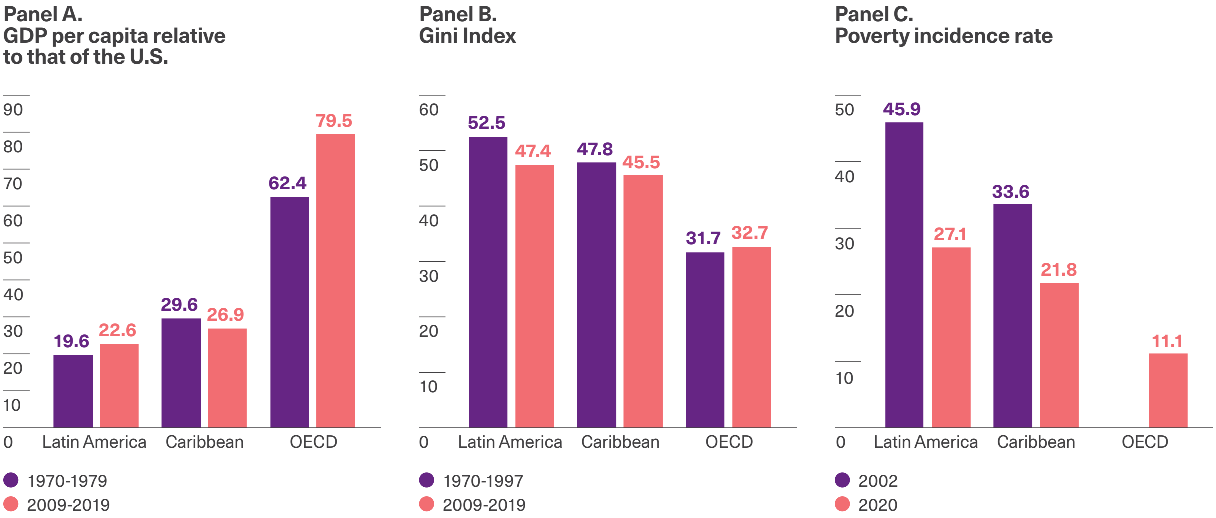
Just transition and the triple challenge

Underdevelopment has clear and multiple manifestations. Economically, it is usually represented by low per capita income and, socially, by high levels of poverty or significant inequality, usually measured by the Gini coefficient. Unfortunately, underdevelopment is also a difficult condition to overcome, as the history of Latin America and the Caribbean confirms.

Graph 10.1 presents three development indicators: per capita gross domestic product (GDP) relative to the United States (Panel A), the Gini index (Panel B), and the proportion of the population living below the poverty line (Panel C). In 1970, Latin America's per capita GDP was approximately 20% of that recorded in the United States, and the Caribbean's was 30%. Over the past decade, these values had barely changed, meaning that in 50 years, the region hasn't managed to close that gap. Inequality and poverty indicators have declined significantly over the last 40 years, especially during the 21st century and up to the coronavirus disease pandemic (COVID-19). Nevertheless, today, around 3 out of every 10 Latin Americans and Caribbeans live in poverty and the degree of inequality in income distribution in the region is significantly higher than in developed countries.

Underdevelopment is a challenging condition to overcome. This is evident in the region's failure to close the development gaps compared to richer countries

Graph 10.1
Development indicators



Note: GDP per capita (panel A) is calculated as a percentage of US GDP per capita (adjusted to purchasing power parity), comparing the average of the 1970s with the average of the period from 2009 to 2019. The Gini index (panel B) measures the extent to which the distribution of income among individuals or households within an economy departs from a perfectly equal distribution (an index of 0 represents perfect equity while one of 100 represents perfect inequity). Given that the first year for which statistical information on the Gini index is available differs between countries, the first year of each country's series between 1970 and 1997 was taken and its average was compared with the average for the period 2009–2019. The poverty incidence rate (panel C) shows the percentage of the population living below the national poverty line. In this case, information is available practically only for countries in Latin America and the Caribbean as of 2002. The values at the regional level were obtained as the simple average of the countries that make up the region. Table A.10.1 in the chapter's annex available online shows the values of the development indicators by country.

Source: Authors based on World Bank (2024), ECLAC (2022), Feenstra et al. (2015) and OECD (2024).

Box 10.1
Energy communities

Energy communities are legal entities formed by members who generate, market, and consume their own energy. The creation of these groups makes it possible to take advantage of renewable resources in the localities where the latter are located and to activate citizen participation in energy production and energy efficiency. These clusters, which are seen as another tool in the energy transition and contribute to local development, can be formed with different structures, for example, among neighbors or with other communities, even with external local entities, such as companies or public administrations.

The constitution of energy communities represents a new way of approaching the generation and distribution of electricity, emphasizing sustainability and the benefit of its members. In this way, they play a central and active role in the energy transition, turning citizens into a channel for collective action. Their main activities include the generation, supply, consumption, storage and distribution of energy from renewable sources. They also provide energy efficiency and electric mobility services. Environmental, economic and social benefits are derived from these energy benefits.

In the self-consumption energy community, the neighbors approve and contract the installation to produce electricity and distribute it among the households that make up the community, i.e., they generate the electricity that they themselves consume. Local energy communities are non-profit organizations committed to acquiring sustainable and environmentally responsible habits. To this end, they generate and market energy and seek to benefit their neighbors and members by reducing energy costs.

At the European level, energy communities have been legally recognized within the Clean energy for all Europeans package and, at the national level, they are covered by the legislation of Germany, Denmark, France, Poland and the United Kingdom. Outside Europe, they have also been recognized in the US and Canada. In Latin America, the figure is very little developed, despite the fact that the International Renewable Energy Agency (IRENA) has highlighted the renewable potential of the region and, in particular, that of energy communities to produce sustainable electricity in the most isolated areas.

The energy transition in the region cannot occur if countries turn their backs on these realities. A just transition demands reducing greenhouse gas (GHG) emissions from energy sources for a more sustainable planet (justice among generations) while simultaneously closing the existing per capita income gaps with the developed world (justice among countries) and reducing social and energy inequalities (justice among citizens).

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A just transition requires reducing greenhouse gas emissions while simultaneously closing the per capita income gaps with the developed world and reducing social inequalities among citizens

Box 10.2

Energy transition, local pollution, and human capital

The implementation of energy efficiency technologies and electricity generation from renewable sources can displace GHG emissions, providing climate benefits. At the same time, it can result in significant benefits for well-being and public health. This is because energy generation from fossil fuels, especially through coal combustion, releases large amounts of local air pollutants (sulfur dioxide, nitrogen oxides, and particulate matter), which have associated adverse effects on human health.

In this regard, an expansion of renewable energy generation capacity, allowing for displacement of thermal energy generation, would bring social benefits through improvements in local air quality and subsequent effects on a country's morbidity.

Quantifying these social benefits is a complex task due to the difficulty of estimating causal effects and because such benefits vary substantially with geographical location and technology type (Buonocore et al., 2016). However, several studies have explored this issue, generally finding that the additional health benefits offset much of the cost of mitigation or even outweigh the climate benefits (Sergi et al., 2020).

The analyses focus on the relationship between reduced fossil fuel generation and various health-related variables. For example, Casey, Gemmill et al. (2018) find that the displacement of coal and oil power plants led to improvements in fertility rates in California, while Casey, Karasek et al. (2018) observe a decrease in the number of preterm births. In turn, Fell and Morrill (2023) show how increased wind power generation and the resulting decrease in fossil fuel generation in Texas result in fewer emergency room visits across the state.

Despite growing efforts to estimate the social benefits of the energy transition, analysis of the impact of pollution on health in developing economies is still limited. In this context, Rivera et al. (2021) provide evidence for Chile by analyzing the effects of expansion in solar energy generation capacity, finding that it displaces fossil fuel generation and reduces hospital admissions, especially those associated with respiratory diseases.

In addition to health improvements, renewable energy generation has benefits in other social dimensions, such as education. Research conducted in the context of this report estimates the effect of improvements in local air quality on school attendance and academic performance of students that live near thermal plants. Preliminary results indicate that the presence of these thermal plants is associated with declines in both attendance and academic performance (Rivera, 2024).

Understanding the magnitude of the benefits of renewable energy in human health and other social dimensions allows for a cost-benefit analysis of the energy transition, crucial for the optimal design of energy and environmental policy.

Box 10.3
Energy transition, mining development, and community resistance

Zero net emissions (NZE) agendas will require the large-scale deployment of renewable energy technologies to eliminate emissions from power generation and to decarbonize the manufacturing and transportation sectors, which are currently highly dependent on coal, oil, and gas.

However, little attention has been paid to the supply chain that makes these technologies possible. The beginning of that supply chain, i.e., the sourcing of metals and minerals, is fraught with a number of challenges. The mining of deposits carries with it a number of climatic and environmental implications. In addition, the extraction, refining and consumption of these products require enormous amounts of energy.

The environmental impacts of mining include the creation of sinkholes, erosion and contamination of soil and ground and surface water. Mining consumes a large amount of resources (e.g. water in lithium mining), which diverts or hinders local people's access to resources. Finally, mining risks associated with biodiversity include habitat loss and fragmentation, alteration of migratory species, introduction of invasive species, and reduction of endangered species.

Beyond the economic and environmental costs of the renewable energy supply chain, the deployment of these technologies in some cases faces social barriers due to community opposition to renewable energy projects in their area. This phenomenon, known as "not in my backyard" (NIMBY), in which citizens organize to oppose the installation of renewable energy projects in their area, has succeeded in stopping mining projects, such as those in Colón, Panama, and Chubut, Argentina, as well as renewable energy projects, such as those in Arras and Normandy, France.

There are benefits of renewable energy that NIMBY groups might ignore, such as reduced electricity rates, more infrastructure for the local area, compatibility with agriculture and livestock, improved air quality, lower GHG emissions, and direct job creation. Project acceptance is likely to be related to, among other things, economic impact, participation in permitting, and full transparency in communication.

The stance of the World Economic Forum (WEF) clearly reflects this vision, defining an effective energy transition as a timely transition toward a more:

> [...] inclusive, sustainable, affordable, and secure energy system that provides solutions to global energy-related challenges, for business and society, without compromising the balance of the energy triangle [security and access; environmental sustainability; and economic development and growth] (WEF, 2021).

As mentioned in previous chapters, one of the current gaps is access to the system, particularly in rural areas of some countries. Civil society has undertaken certain actions to foster this access, encouraging the generation of this energy to be renewable. Energy communities are an example of this type of initiative (see Box 10.1).

To meet these challenges, policymakers must understand how the energy transition impacts the economy as a whole and, in particular, the instances or dimensions that affect growth and inclusion.

This part of the chapter explores the implications of the energy transition in two key instances of sustainable development: its effect on the labor market and the relationship between energy efficiency and productive efficiency. Boxes 10.2 and 10.3 complement the discussion of the impact of the energy transition on household well-being and development. The first highlights favorable "local" impacts on human capital as a result of replacing thermal plants with renewable plants. The second addresses challenges related to the potential adverse environmental impacts of mining development, as well as the resistance of community groups to the local deployment of energy transition projects.

Energy transition and the labor market

Transformative phenomena, including this energy transition, may imply changes in the labor market, both in employment levels (Saget et al., 2020) and in the demand for skills and in the composition of tasks that different occupations require (Vona et al., 2018).[2] T his process of labor reallocation may be more or less traumatic depending, for example, on how different green jobs and technologies are from the rest of the economy and, of course, on the existence of institutions that support such labor market realignment.

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This energy transition may entail changes in the labor market, affecting both employment levels and the demand for skills, as well as the composition of tasks required by different occupations

Size of the green labor market

A starting point in analyzing the employment impacts of the energy transition is to measure the size of green jobs. A first challenge in this regard is what counts as green jobs and what does not.[3] The answer will depend in part on the focus of each study and the availability of data. This section uses the classification developed by the O*NET occupational information network in the context of the U.S. labor market, described in more detail in Box 10.4.

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[2] For several years now, the economic literature has been concerned with various disruptive effects on labor markets, from trade liberalization and the relocation of production from developed countries to emerging economies (mainly China and Asia-Pacific countries) to the phenomena of automation and the effects of the telework pandemic. A feature of recent work is that, based on the O*NET (Occupation Information Network) database, each occupation is assigned the percentage of knowledge, skills and tasks required to perform it.

[3] There is no single definition of green jobs in the literature. For example, García Suaza et al. (2023) include in that qualification those occupations whose tasks contribute to the transition toward more sustainable and environmentally friendly technologies. The magnitude of the greenness of occupations is given by an index that weights the proportion of green tasks with respect to total tasks (GOJI). Allub, Álvarez, Bonavida et al. (2024) define green occupations as jobs that will see an increase in demand as a result of the transition to a greener economy, regardless of their contribution to reducing emissions.

Box 10.4
Green jobs according to O*NET

The O*NET network identifies green occupations as those for which demand is increasing or will increase due to the energy transition and divides them into three groups:

1. **Green New and Emerging Occupations:** These arise from the transition to a new economy and can either be entirely new or evolve from modifications to existing occupations.

2. **Green Enhanced Skills Occupations:** These occupations see changes in tasks, skills, or knowledge requirements as a result of the shift to a green economy.

3. **Green Increased Demand Occupations:** These existing occupations become more sought after in a low-emission economy but undergo no significant changes in tasks. They provide support to the green economy without necessarily involving green tasks.

In other words, an occupation is considered green, either because it did not exist before (e.g., solar panel technicians), because it is an occupation that will have to be adapted to meet new demands (e.g., architects who will have to adapt buildings to make them sustainable) or because demand will increase for the occupation due to the green transition but will not entail any significant changes in the job tasks (e.g., electronic technicians, whose number will grow with the electrification of energy demand).

The majority of workers are concentrated in non-green occupations, which represent between approximately 62% of the total in Honduras and 74% in Uruguay

Based on this classification and the processing of household surveys in the region, De la Vega et al. (2024) have developed an analysis of the share of green jobs in the labor markets of Latin America and the Caribbean in the context of this report. Graph 10.2 shows the fraction of employment in three categories, according to the level of greenness, in selected countries in the region. The main takeaway is that most workers are concentrated in non-green occupations. The share of non-green jobs ranges from around 62% in Honduras to over 75% in Uruguay. Also, the size of the purely green sector ranges from 6% in Panama and Uruguay to 12.3% in Peru.[4]

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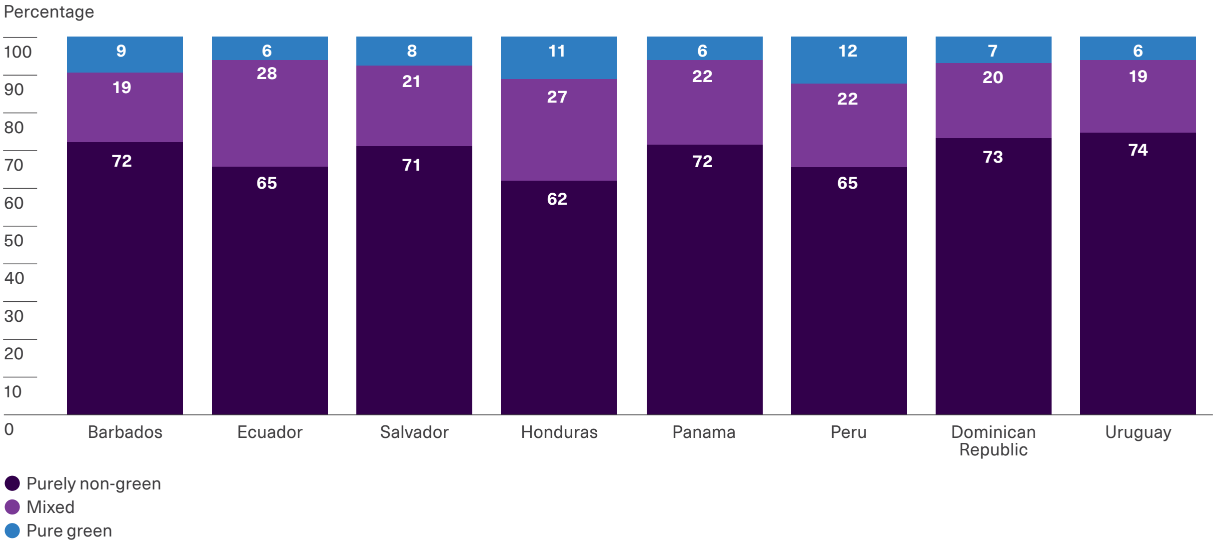
[4] The graph is restricted to countries that have a four-digit disaggregation of occupations. When considering two-digit disaggregations of occupations, the proportion of occupations in mixed or ambiguous categories grows considerably, as can be seen in Graph A.10.1 in the chapter's annex available online. The information in the annex suggests that, most probably, the range for the fraction of green and non-green jobs obtained for the eight countries for which four-digit disaggregation is available would be extrapolated to the rest of the countries for which only two-digit information is available.

Graph 10.2

Size of the green sector in selected countries



Note: Household surveys present employment definitions using two or four-digit codes, while O*NET uses eight digits. Consequently, when looking for equivalences, it may happen that the same category in household surveys includes some occupations in O*NET that are defined as green and others that are not. Different categorizations of greenness are obtained from the processed household surveys: purely green occupations (O*NET considers all sub-occupations within this category as green); purely non-green occupations (O*NET considers all sub-occupations in the non-green category) and some ambiguous or mixed occupations (which O*NET classifies as green in some cases and not in others).

Source: Authors based on De la Vega et al. (2024).

Characterization of green occupations

The question immediately arises: how different are green jobs from non-green jobs? A dimension of special interest in this regard has to do with the profile of skills and tasks required. In this line, Allub, Alvarez, Bonavida et al. (2024) explore differences between green and non-green jobs in some dimensions, using the database of the Programme for the International Assessment of Adult Competencies (PIAAC), a survey conducted in more than 40 countries that seeks to measure cognitive and work-related competencies.

The PIAAC, unlike other sources of information, like household surveys, makes it possible to elucidate the type of skills and task content of green jobs compared to non-green jobs.[5] In addition, it has the advantage of having a homogenized questionnaire, which allows comparisons between countries. However, a substantial disadvantage for the purposes of the report is that the data available for Latin America and the Caribbean is limited to only four countries: Chile, Ecuador, Mexico, and Peru.

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[5] See Allub, Alvarez, Bonavida et al. (2024) for more information on what skills and occupational task content can be built with the PIAAC.

Table 10.1 compares green and non-green jobs using PIAAC data for LAC and OECD countries with available information. As a first conclusion, it can be noted that there is evidence of gender gaps: on average, the number of men in green jobs in the region's countries is 68%, compared to 50% on average in non-green jobs. In addition, green jobs show a higher incidence among people in the age range of 31 to 50, while those categorized as non-green have a higher proportion of people with higher education, except in private sector jobs.

Regarding the characteristics of companies and jobs, green jobs are more frequently found in the private sector and in larger firms. Additionally, they are more likely to be formal and full-time positions compared to non-green jobs.

In terms of aptitudes, people working in green jobs have, on average, higher scores in numerical or mathematical aptitudes and, in the case of OECD countries, they score higher in reading aptitudes. It is also found/ that the intensity of abstract tasks is higher in green jobs, while the weight of routine tasks is lower. Based on these factors, it can be inferred that green jobs would have a lower risk of being affected by possible automation processes. Another conclusion is that the energy transition could demand greater cognitive aptitudes to carry out more abstract and less routine tasks.

Table 10.1
Differences between green and non-green jobs

	Latin America and the Caribbean		**OECD**	
	No Green	**Green**	**No Green**	**Green**
Man	50%	68%	42%	80%
Higher education	24%	20%	40%	33%
Higher education (private sector employment)	16%	18%	32%	31%
18–30 years	35%	30%	25%	20%
31–50 years	47%	53%	48%	53%
Over 50 years old	18%	17%	25%	20%
Medium or large companies	28%	52%	38%	48%
Private sector	78%	92%	71%	88%
Formal job	63%	79%	90%	93%
Full time	70%	87%	70%	90%
Abstract tasks	-9%	26%	-9%	8%
Routine tasks	11%	8%	11%	13%
Numerical skills	6%	15%	17%	32%
Reading skills	8%	5%	16%	26%
Hourly wage log.	1.7	1.91	2.61	2.73

Note: The table reports percentages of observable variables for green and non-green jobs, using PIAAC data. The list of countries included in each group can be found in the chapter's annex available online. Also reported are the averages of the logarithm of the hourly wage, calculated from the reported monthly wage and extrapolating the number of weekly hours worked. The natural logarithm is calculated on this quotient.

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

The energy transition may demand greater cognitive aptitudes to perform more abstract and less routine tasks

In terms of wages, the results show that green jobs tend to be better paid.[6] However, as Table 10.1 shows, they also tend to demand more skills, be concentrated in larger companies, be formal jobs, and have a higher intensity of abstract tasks. All this may explain the differences in wages between green and non-green jobs. In Allub, Alvarez, Bonavida et al. (2024), a statistical exercise is carried out to discount the influence of these factors on wages. Table 10.2 shows the results for the region and OECD countries.

Table 10.2
Wage differentials according to level of greenness of jobs

Greenness (Latin America)	0.21***	0.21***	0.19***	0.20***	0.19***	0.18***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Greenness (OECD)	0.12***	0.05***	0.03**	0.02*	0.02	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Basic controls	No	Yes	Yes	Yes	Yes	Yes
Company size	No	No	Yes	Yes	Yes	Yes
Formality + full time	No	No	No	Yes	Yes	Yes
Skills	No	No	No	No	Yes	Yes
Abstract tasks	No	No	No	No	No	Yes

Note: The table reports wage differences using the natural logarithm of the hourly wage as the dependent variable. The basic set of controls includes education of the respondent and his/her parents, and gender and age of the respondent. Firm size is a variable divided into six categories: self-employed; between one and 10 employees; between 11 and 50 employees; between 51 and 250 employees; between 251 and 1000 employees or more than 1000 employees. Formality in employment and full-time work are represented by dichotomous variables. The skills variable corresponds to an index that captures numerical skills, while the abstract tasks variable corresponds to an index that captures intensity of these tasks in employment. The number of observations was 4,408 for Latin America and 28,276 for the OECD. The asterisks denote statistically significant coefficients with * p < 10%; ** p < 5%, and *** p < 1%. The list of countries included in each group can be found in the chapter's annex available online.

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

In Latin America, the wage gap is reduced by almost 20% when incorporating controls for job characteristics, firm (especially size), worker skills, and level of task abstraction. However, even incorporating such controls, a considerable unexplained wage gap is still reported. In contrast, in OECD countries, when introducing the same scaling of controls, the wage gap between green and non-green jobs is reduced to the point of being statistically non-significant.

Another interesting perspective can be gained by analyzing job vacancies advertised by companies. The results of a recent study developed especially for this report confirm that green jobs demand more skills and pay better salaries (Box 10.5).

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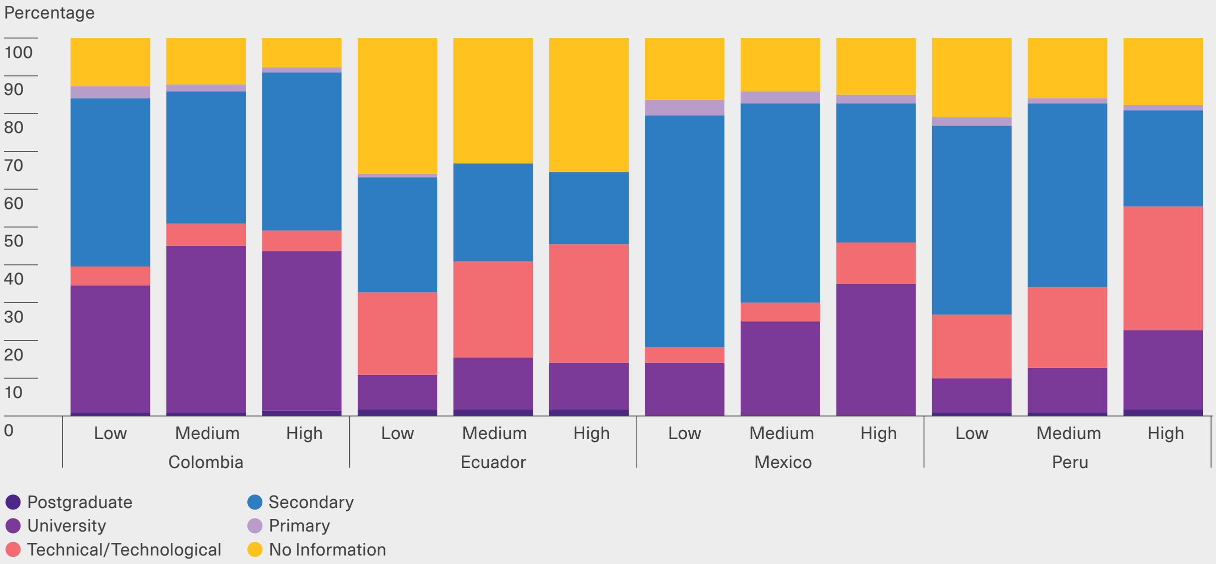
[6] The salary information available in the PIAAC does not contain data for Peru.

Box 10.5
What do job vacancies tell us?

In a paper prepared for this report, García Suaza et al. (2023) explore vacancy information from online job sites. The authors focus on four Latin American countries (Colombia, Ecuador, Mexico, and Peru). The qualification of occupations into more or less green jobs is performed through a two-step procedure. First, the "free" text from published vacancies is processed and the job to which the vacancy refers is identified. Second, a greenness score is computed for each occupation, following the criteria incorporated by the work of Lobsiger and Rutzer (2021). These authors determine for each occupation a greenness score GOJI (*greenness of job index*) dividing jobs into three categories: high green potential jobs (GOJI>=0.7), medium green potential jobs (0.3<GOJI<0.7), and low green potential jobs (GOJI<=0.3).

The authors point out that the highest green potential indexes are found in managerial and professional positions, while the lowest indexes correspond to administrative support positions. They also find that in all countries, with the exception of Ecuador, the proportion of vacancies requiring a university education increases as the greenness index of occupations increases (see Graph 1).

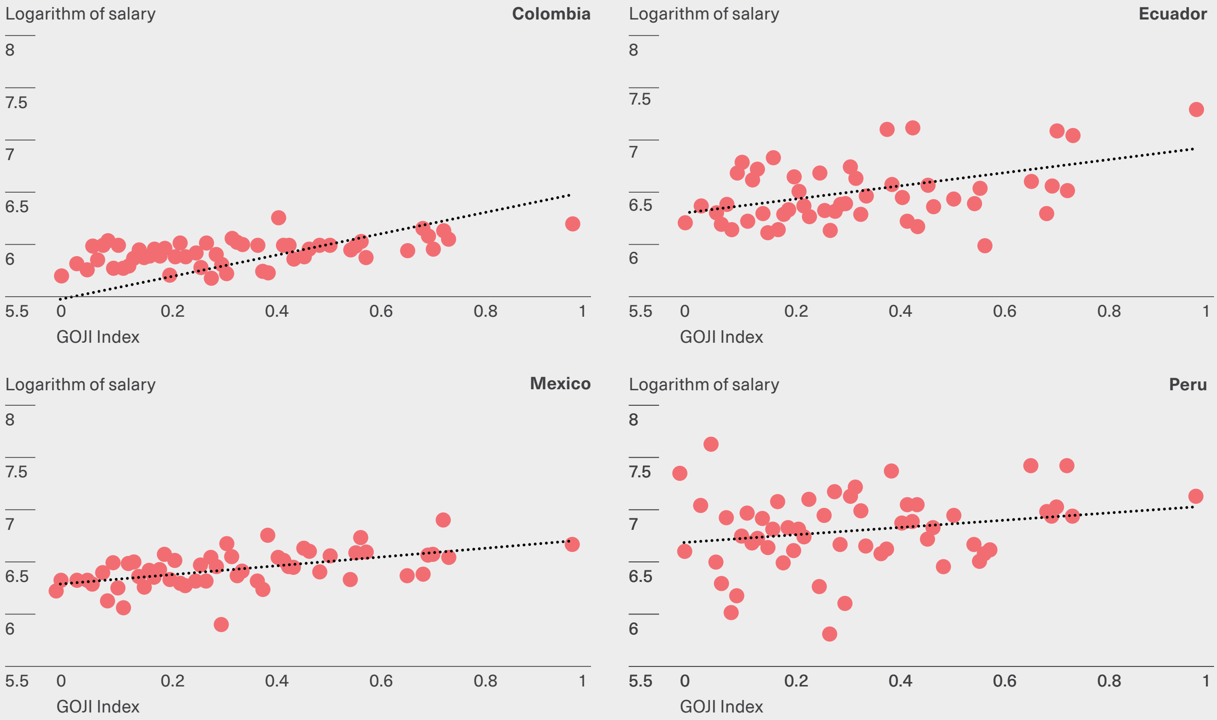
Graph 1
Distribution of educational level according to degree of greenness



Source: García Suaza et al. (2023).

The analysis also indicates a positive association between wages and the level of greenness of the occupation in the four countries studied (see Graph 2). Workers with high green potential are also those who earn higher incomes.

Graph 2
Wages and greenness index



Source: García Suaza et al. (2023).

Energy generation technologies and their impact on employment

The energy transition may not only change the structure of occupations, the profile of skills required and wage dispersion, but may also affect aggregate employment levels. Certainly, some industries linked to fossil energy will contract as a result of the energy transition and others, such as those linked to clean energy value chains, will expand. The net effect is, *a priori*, ambiguous, so its calculation becomes an empirical question.

A starting point is to contrast the multiplier effects of the use of these two types of energy technology. Garret-Peltier (2017) summarizes the evidence found in different research articles regarding the multiplier effect on the employment of the main sources of energy generation, separating the effects into direct and indirect.

Table 10.3 suggests that industries linked to the clean energy and energy efficiency value chain have a higher employment multiplier than those tied to the fossil fuel chain. This is true both for jobs directly created by those sectors, as well as those that have arisen indirectly from the effects of input-output relationships.

Table 10.3

Employment multipliers: Fossil energy vs. clean and efficient energy

	Direct EFT jobs per USD 1M	Indirect EFT jobs per USD 1M	Total EFT jobs per USD 1M
Wind	4.06	3.46	7.52
Solar	4.26	2.98	7.24
Bioenergy	5.22	2.44	7.65
Geothermal	4.67	2.73	7.4
Hydroelectric	4.55	2.98	7.53
Average renewable energy	4.50	2.99	7.49
Thermal with oil and gas	0.7	1.49	2.2
Coal-fired thermal	1.18	1.92	3.1
Average fossil energy	0.94	1.71	2.65
Average difference: renewable energies - fossil energies	3.56	1.28	4.84

Note: Employed full-time (EFT) designates full-time jobs created per million dollars (USD) of renewable energy demand.

Source: Authors based on Garret-Peltier (2017).

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Industries linked to the clean energy and energy efficiency value chain have a higher employment multiplier than those tied to the fossil fuel chain

The empirical literature studying the employment impacts of renewable penetration is still evolving. There is evidence suggesting that the effects vary greatly depending on the technology and phase under consideration (construction vs. maintenance). For instance, Fabra et al. (2023) examine the case of Spain. The authors find significant effects on local employment in the case of solar plants, especially during the construction phase. In contrast, they find no significant effects in the case of wind power plants, neither during construction nor maintenance stages. When focusing on local unemployment, the effects weaken compared to employment, even for solar plants. This suggests that local energy companies hire both local workers and those from other municipalities.

An article by Hernández-Cortés and Mathes (2024), developed in the context of this report, studies the case of Brazil. The authors analyze the impact of the development of renewable energy projects on formal employment in the country. They found that wind energy projects have positive and significant impacts on employment. Wind energy projects are associated with increases in the number of companies by 14.8%, jobs by 15.9%, and workers' income by 18.4%. The workers who benefit most are those under 45 years of age and those in jobs related to electricity, construction, or transportation. Conversely, the authors do not find significant differences when analyzing the effects of solar energy projects, although they acknowledge that this could be due to the insufficiently representative sample of projects included in the study.

Looking ahead, the scenarios suggest a significant increase in energy jobs in the region (IEA, 2023l). Specifically, in the announced pledges scenario (APS), energy sector jobs in the region are expected to increase by 15% by 2030 compared to 2022. The report notes that a significant portion of the increase will come from the clean energy sector, rising from 3 million to 4 million jobs. The critical minerals sector will also play a significant role, especially in countries where they are abundant, such as Chile. Finally, even the fossil sector will see a moderate increase in employment over this period, although in the longer term, it should decrease significantly as economies move toward zero emissions.

While it seems undeniable that the energy transition can bring significant job creation to the region, institutions supporting labor reallocation are needed to seize the opportunities it offers (see Box 10.6).

Box 10.6

Labor policies for job reallocation

The energy transition implies major changes in the labor market, with new skill demands and a general reconfiguration of the way of working. It therefore imposes the challenge of developing adequate skills for the new jobs that arise and adapting existing ones. In this sense, investment in training and skills development that meets the new labor market requirements plays a critical role not only in enabling the green transition, but also in making it a just transition that ensures social inclusion and decent work.

Addressing the challenge of labor market reconfiguration requires planning labor retraining policies in an integrated manner with environmental policies and regulations. While these strategies may vary across countries, depending on national context and policy priorities, the International Labour Organization identifies certain key factors for advancing a just transition to environmentally sustainable economies (ILO, 2019, 2022):

- Policy coherence. Labor market policies should be planned in coordination with broader environmental and climate policies.

- Social dialogue. The joint participation of all key actors is important: governments (creating the conditions and investing in education and training), employers (training their staff) and workforces (actively participating in continuous learning opportunities). Educational and training institutions, as well as civil society actors, will also have an important role to play in providing demand-driven training.

- Ability to anticipate the demand for skills. It is important to have mechanisms that provide information on the supply and demand of skills required in green jobs in order to assess existing and future skills gaps. Examples of institutional mechanisms in this area include France’s National Observatory of Green Economy Jobs and Occupations (ONEMEV, for its acronym in French) and Costa Rica’s National Learning Institute (INA, for its acronym in Spanish).

- Technical and vocational training system. To close skills gaps and improve the potential of individual skills, new educational and vocational training policies are needed. It is also necessary to develop new national education programs or adapt existing ones, focusing them on the skills needed in new occupations.

- Development of soft skills. In addition to technical skills, specific to an occupation, the acquisition of so-called soft skills favors the just energy transition by improving the ability to adapt to changes in the work environment.

Energy transition and opportunities for productive development

Achieving sustained and vigorous growth should be a top and urgent priority for countries in Latin America and the Caribbean. To accomplish this, it is crucial to achieve productivity gains, which also serve as an environmental ally. Higher business productivity translates into higher output per unit of energy, reducing the environmental impact of economic growth. Furthermore, there is the possibility that policies improving resource allocation among companies could increase productivity while simultaneously reducing energy intensity and emissions.

On the other hand, given the region's potential to produce clean energy, this new energy transition opens a window of opportunity for the region to gain competitiveness, attract foreign investment, and increase its international integration.

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Given the region's potential to produce clean energy, this new energy transition opens a window of opportunity to attract foreign investment and increase international integration

Factor allocation and the relationship between productivity and energy intensity

There is evidence that the productivity lag of developing countries is partly explained because inputs for production are not allocated where they have the highest return (Hsieh and Klenow, 2009; Restuccia and Rogerson, 2008). This inefficiency in allocation can occur in any factor, including energy.[7]

Improving allocative efficiency involves moving resources from less efficient to more efficient companies. This transfer makes it possible to increase a country's production and, therefore, reduce its energy intensity. The potential for a double bonus (productive and environmental) from better resource allocation is strengthened as companies that are more efficient in managing capital and labor are also energy-efficient, as suggested by the evidence.[8] For example, a statistical analysis for Colombia, based on the Annual Survey of Manufactures (ASM), shows that the most productive firms have lower energy intensity, as do larger companies (see Table 10.4). This is important for the region, given its high proportion of small, informal, and low-productivity businesses, which, according to the results, would unfavorably affect an economy's energy intensity.[9]

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[7] A study on South Korea finds that distortions in the energy market (linked to price interventions by the government) have promoted inefficient energy allocations, which, in turn, has negatively affected the productivity of the country's manufacturing sector between 2000 and 2014 (Choi, 2020).

[8] See Yépez et al. (2021) for evidence at the sector level in Brazil, Chile, Mexico and Peru; and Cantore et al. (2016), for evidence based on the World Bank Enterprise Survey (WBES).

[9] The relationship between size and energy intensity is also found in Montalbano and Nenci (2019) based on the WBES. The authors find that micro firms (with less than 10 permanent workers) register, on average, higher energy intensity than the other firms in the sample and have the highest degree of heterogeneity. Firms in the medium category (with a number of permanent workers in the range 50–250) have energy intensity levels comparable to those of larger companies (more than 250 permanent workers) and a significantly lower degree of heterogeneity.

Table 10.4

Productivity and firm characteristics in Colombia

	Intensity 1	Intensity 2
Productivity	-0.13 ***	-0.11 ***
	(-17.17)	(-14.8)
Small	-0.05*	-0.04
	(-2.16)	(-1.78)
Medium	-0.13 ***	-0.09 ***
	(-6.89)	(-4.30)
Large	-0.06 **	-0.11 ***
	(-2.92)	(-4.76)
Remarks	22,231	22,220

Note: Years 2018 to 2020. Intensity 1: Electric power/value added. Intensity 2: Total energy expenditure/value added. Small firm is 10 to 20 employees; medium, 20 to 100 employees; and large, more than 100 employees. Productivity is obtained from the ratio of value added to employment. Survey wave fixed effects and controls by industry are included. The asterisks denote statistically significant coefficients with p < 10; ** p < 5%; *** p < 1%.

Source: Authors based on the Annual Manufacturing Survey of Colombia 2018–2020 (DANE, 2020).

Along the same lines, Schutze et al. (2019) document that, given how energy allocation issues correlate with other factors in Brazil, removing distortions that lead to poor allocation has the potential not only to increase productivity and consequently promote economic growth but also to improve energy efficiency and thereby reduce emissions.

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Removing distortions that induce misallocation of inputs has the potential to increase productivity and, at the same time, improve energy efficiency, reducing emissions

In general, policies and distortions that depend on size have the potential to generate misallocation issues. In the region, this problem is closely associated with informality, which enables some companies, typically smaller ones, to evade regulations. This results in policies and regulations de facto favoring certain sizes, with the efficiency implications of such allocation bias. Therefore, productive informality also poses a challenge for energy transition (see Box 10.7).

The body of evidence documented in this section seems to support the idea that promoting energy efficiency can lead to higher productivity[10] and growth. Reciprocally, policies that promote productivity can make an important contribution to achieving decoupling and favoring the reduction of energy emissions. Thus, productive development becomes an ally of the environment.

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[10] Energy policy design at the firm level can promote increased production as a strategy to comply with environmental regulations, with low impact on the absolute level of emissions. For example, in the case of India, Bansal et al. (2023) show that factories tried to meet the energy intensity mandate (energy consumed per unit of output) imposed by regulation by increasing their production, rather than reducing their energy consumption through technological improvements.

Box 10.7
Another challenge for the energy transition: Productive informality

It is well-known that the Latin America and Caribbean region is characterized by a large proportion of small businesses operating outside of state regulation. By their very nature, informal businesses would evade regulatory frameworks penalizing CO_2 emissions. Moreover, the presence of environmental regulations may further stimulate the growth of the informal sector, with all its associated productivity implications.

In this regard, Abid et al. (2023) study the impact of carbon taxes in 25 Sub-Saharan African economies. These are developing economies with informal levels even higher than those observed in Latin America and the Caribbean. The article demonstrates that environmental regulation would increase the carbon footprint of the economy by further promoting informality and argues that traditional carbon taxes would not be suitable for economies with high informality, as they incentivize formal companies to shift some of their activities into informality.

This phenomenon not only affects carbon emissions, but can also have a considerable impact on the emission of water and air pollutants. Bali Swain et al. (2020) show that, in developing countries, the informal sector has a significant impact on local air and water pollution, mainly explained by the lack of control over its practices. Bali Swain et al. (2020), Brännlund et al. (2017) and Gani (2012) show that reductions in corruption, which imply improvements in the efficiency of environmental control, can have relevant positive effects on environmental quality and this is especially important for countries with a large informal economy.

Productive and environmental policies must therefore internalize the propensity for informality among businesses in the region. Improving state oversight capacities is an indispensable ingredient in the array of policies for energy transition.

Harnessing natural advantages: New opportunities in the context of the energy transition

Another group of arguments that connects the climate sphere with the productive sphere has to do with how countries in the region can exploit their natural advantages to gain competitiveness and improve their international insertion in the face of the energy transition. In this context, the so-called powershoring and potential insertion in value chains are analyzed, as well as the new carbon regulations in international trade, including border adjustment mechanisms and climate clubs.

Powershoring: clean energy as an industrialization policy[11]

The last decade has witnessed a great deal of movement in global commodity production and distribution operations as a result of different factors that are redrawing the map of direct investments and global value chains (GVCs). Financial crises, technological changes that eliminated the comparative advantage of cheap

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[11] This section is based on an internal note developed by Juan Carlos Elorza for the report. In addition to powershoring, another opportunity for the region arises from its abundance of critical minerals for the energy transition, a topic explored in Chapter 9.

labor, the trade war with China, war conflicts, the COVID-19 pandemic, and global quarantine have led to a recomposition in supply chain actors and the relocation of production plants to remedy, reduce or avoid further GVC disruptions. This phenomenon has been alternatively called reshoring, nearshoring or friendshoring, among other names (as opposed to off-shoring), depending on its cause or end result.

Today, other determining factors for investment relocation in production are gaining strong momentum. These include environmental sustainability standards and the mandatory reduction of carbon footprint in manufacturing and marketing processes worldwide, in which the use of clean and renewable energies plays a very important role.

This strategy of selecting geographical locations that offer ample availability of clean and sustainable energy sources, such as wind, solar, hydroelectric, or geothermal energy, to produce and avoid trade barriers associated with carbon footprint is known as powershoring. It is a business strategy for productive relocation based on the growing awareness and demand for renewable and sustainable energy sources, as well as the search for cost-effective but environmentally friendly ways to produce and consume energy.

Powershoring not only benefits the environment but also has the potential to improve the competitiveness of companies in the region as trade penalizes the carbon content of products, as explained in the following section, and companies in the region can access clean energy at competitive prices. In addition, current models of sustainable energy production contribute to the creation of productive chains with formal and quality local employment. Of course, as in any case of production relocation strategy, this potential will drive the creation of companies and value chains in various sectors provided they are combined with conducive public policies for foreign investment and productive transition towards clean energies, as well as with a favorable institutional environment.

Latin America and the Caribbean has a great opportunity in powershoring, as it is well positioned from the point of view of clean energy generation capacity, but this advantage does not exempt countries from working on providing attractive business environments for productive investment. In particular, powershoring requires consideration of multiple factors. These include transportation infrastructure, logistics capacity, supply chain efficiency, local regulations, economic and political conditions in the countries, and the existence of government incentives.
In addition, there are policies favorable to the production and consumption of renewable energies, which consider the intensive use of new technologies, a sufficient supply of human capital, and well-developed clean energy infrastructure that allows linking production sources with consumption centers.

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The region is well positioned in terms of clean energy generation capacity, but this advantage does not exempt countries from working to provide attractive business environments for productive investment

On the other hand, powershoring has socioeconomic implications that must be taken into account. Some, such as the very likely relocation and substitution of jobs, technology transfer, and possible dependence on the policies and technical regulations of other countries or regions, have already been discussed in the general context of the energy transition. It is essential to carefully consider the economic, environmental, and social aspects when promoting the powershoring strategy in business decision-making and country policy adoption.

New regulations for trade in carbon-footprint goods

Environmental regulations impose costs on the countries that apply them, affecting their competitiveness. For example, a carbon tax applied in one country increases the costs of fossil fuel energy and the production of fossil fuel-intensive goods compared to another country with no carbon tax or a lower tax. This creates perverse incentives for countries and can trigger unintended effects on the location of firms and the level of emissions. Box 10.8 describes an example of these costs in the case of aluminum.

Box 10.8

Border adjustment mechanisms for aluminum in Europe

The European Union plans to implement its border adjustment mechanism (CBAM) in 2026, to match the cost of the carbon price imposed on local producers with the implicit cost of certain products in the country of origin. This CBAM would act as a tariff on imports. It will be implemented progressively, starting in 2026, to be stepped up progressively until 2034.

Aluminum serves as an example to illustrate the potential effects of the implementation of such a mechanism. According to a report prepared by ING Bank (2023), an initial effect would be a price increase paid by European consumers. In addition, a negative effect on import and export trade flows is anticipated. Thirdly, and this is perhaps a logical but central point of the analysis, and perhaps a logical but central point of the analysis, the report acknowledges that not all countries or sectors will be affected in the same way.

In the aluminum industry, a major difference lies in current adherence to regulations. Countries like Norway, Iceland (the first and third suppliers of aluminum to the EU, respectively), Liechtenstein, and Switzerland will not be affected by the CBAM implementation as they are already part of the European Union Emissions Trading System (ETS). China, on the other hand, is expected to experience reduced flows of aluminum and other exportable products after CBAM implementation (Chen, 2023). The cost of Chinese aluminum products could increase by up to 17%, making them less competitive. However, the report also acknowledges the possibility that China may implement policies to strengthen its ETS in the short or medium term, bringing it closer to EU requirements.

The case of India appears to be even more complex. This country does not have carbon taxes or an institutionalized ETS. The gap with EU requirements seems even wider, coupled with the fact that Indian aluminum production has the highest emissions intensity in the world for this sector. The cost of importing Indian aluminum products could increase by up to 40% following CBAM implementation.

Source: Authors based on ING (2023).

In view of this problem, some countries began to implement mechanisms to avoid the loss of competitiveness of their companies by complying with more stringent environmental regulations or the strategic location of companies in countries with laxer environmental regulations, without reducing their emissions levels. The downside of these instruments is that they make companies located in countries with clean energy more competitive than those in countries with fossil energy, promoting powershoring.

A first instrument along these lines is the carbon border adjustment mechanism (CBAM) under discussion in the European Union (EU). This instrument requires imported goods to pay for imported goods an amount similar to what they would have paid for GHG emissions if they had been produced in a member country. These border adjustments can be for all sectors or specific sectors, for example, the more energy-intensive ones, such as aluminum, steel, or fertilizers (World Bank, 2022).

A second instrument under discussion is the climate club. In theory, this consists of an association of states with a similar level of ambition in terms of climate policy, which band together to define internal actions and policies and use trade policy to penalize non-member countries for having less ambitious environmental regulations (Nordhaus, 2015). Simply put, they use trade policy as a tool for penalization. Unlike the Paris Agreement, they seek to standardize members' climate policies and impose sanctions on non-participants. For such an instrument to work, a critical mass of members with weight in international trade is needed to generate the necessary incentives to belong to the club.

Another instrument under discussion is carbon content standards for products. However, the high implementation costs, related, among other things, to the need to develop methodologies for carbon accounting and certification, led to low or no implementation of this initiative.

Cross-cutting instruments for energy transition

This report has discussed specific policies and initiatives, either on the energy supply side (Chapters 3, 4 and 5) or on the energy demand side (Chapters 6, 7 and 8). There are also some more cross-cutting instruments that are key to promoting a just energy transition, which are presented in this section.

Green finance and the importance of green taxonomies

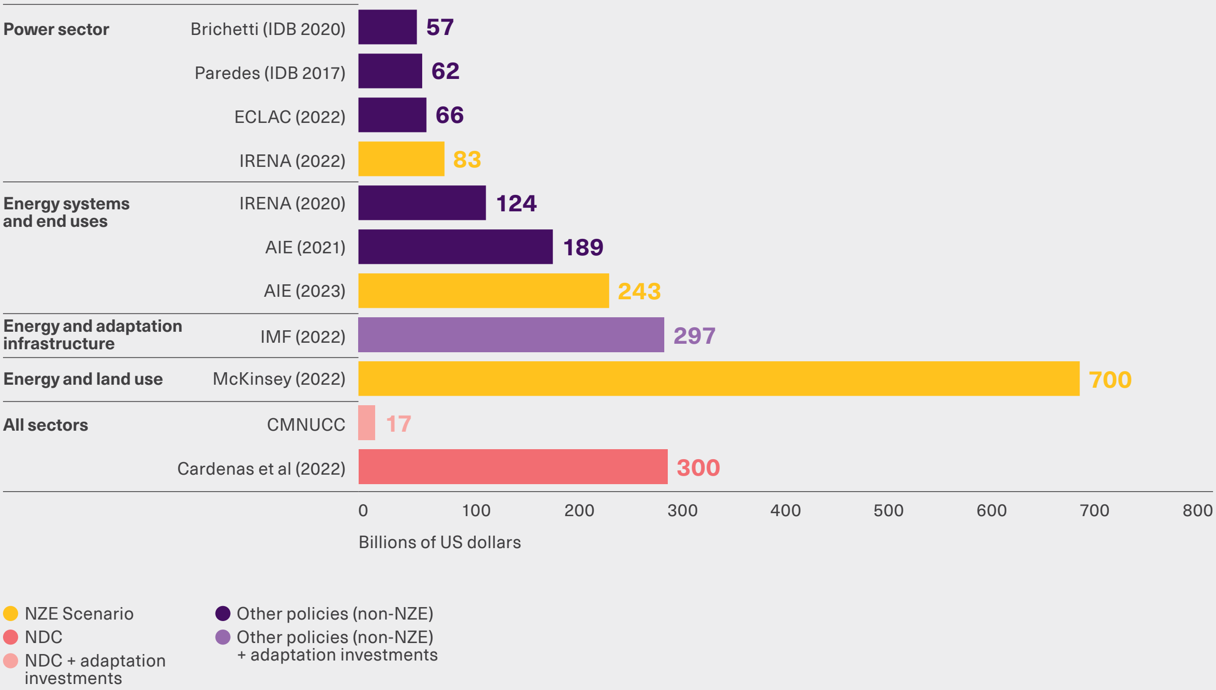
Although it is difficult to know the amounts of investment needed to advance in the energy transition in a manner consistent with the pledges made, it is expected that these will be significant. Chapter 1 of this report states that the financing needs for investment in climate change adaptation and mitigation at the global level are around 1.3% of GDP per year until 2050, of which 75% is concentrated in the energy generation and distribution sector (ETC, 2023a). The few estimates for the region indicate significant investment needs (see Box 10.9).

Box 10.9
Financing needs in Latin America and the Caribbean

Palacios and Guzmán (2023) present consolidated measurements of financing needs for climate strategy in the region. The authors highlight the wide range that exists by virtue of the scope (sectors), objectives (mitigation vs. mitigation plus adaptation) and scenarios considered.

Some studies that focus on the needs for energy systems find values that vary between USD 57 billion and USD 83 billion per year. Others, which also incorporate the financing needs of end users, find figures that can vary between USD 124 billion and USD 243 billion per year (see Graph 1).

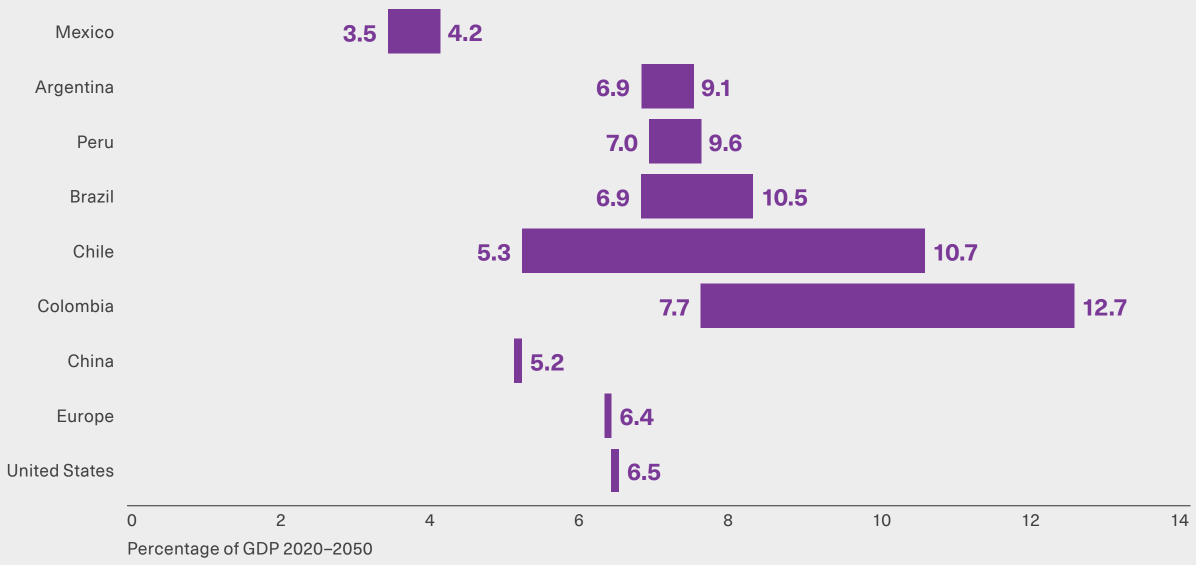
Graph 1
Estimated annual investment needs for the energy transition in Latin America and the Caribbean (billions of US dollars)



Source: Palacios and Guzmán (2023).

The study by Cárdenas and Orozco (2022), on the other hand, presents estimates for achieving the goals set out in the NDCs in six countries in the region. The calculations are based on two different models and, therefore, generate a range for each country in the region. The authors' estimates range on average from 7% to 11% of GDP per year, higher than the amounts required in the developed world, which are around 6.5%.

Graph 2
Expenditure needed to achieve NDC targets



Note: The bars in the graph represent estimated investment ranges for each country or region.
Source: Cardenas and Orozco (2022).

The authors note that the region's higher financing needs stem from lower levels of output and productivity, the need for faster growth requiring greater mitigation efforts, and significant asset reallocation costs from fossil fuel industries.

As discussed at the beginning of the chapter, this energy transition must be just and green finance can be a tool to help achieve this. Developed countries that achieved this status with a more emissions-intensive growth strategy can allocate resources to help developing countries adopt strategies to close the per capita income gap between the two and, at the same time, reduce the amounts of GHGs released.

When analyzing the evolution of climate finance[12] in Latin America and the Caribbean between 2013 and 2020, it is observed that it fluctuated between USD 14.77 billion in 2016 and USD 22.91 billion in 2020 (Schneider, 2023). During this period, there has been an increase in the share of financing from multilateral development banks, green bonds and climate funds and a fall in that from national development banks.[13] Box 10.10 discusses some of the energy transition financing initiatives of CAF – Development Bank of Latin America and the Caribbean.

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[12] This includes all climate finance and not only that related to the energy sector.

[13] For more details, see Schneider et al. (2023).

Box 10.10
Financing Just Transition

CAF has a long-standing tradition of involvement in financing projects aimed at ensuring a just transition in the region. Beyond its participation in iconic projects, such as the São Paulo Metro, the Quito Metro, or the Néstor Kirchner Gas Pipeline in Argentina, the development bank has played a leading role in financing specific renewable energy generation projects. A paper by Paniagua (2023) analyzes the composition of the project portfolio in this area and its results.

Between 2014 and 2023, CAF financed 11 such energy transition projects for a total amount of USD 347 million in Argentina, Brazil, Chile, Ecuador, Peru, and Uruguay. They consisted of the construction, commissioning and maintenance of six wind farms, 26 solar plants, and two hydroelectric plants, which would provide 2,850 GWh of electricity generation per year,[a] equivalent to supplying energy to a total of 1,101,980 families.

It is estimated that, from the start of operations through 2022, this power generation from renewable sources reduced GHG emissions by a total of nearly 4 million tons of CO_2 equivalent (tCO_2eq). In the latter year, GHG emission reductions from these projects amounted to almost 1 million tCO_2eq, 1.1% of the total CO_2eq emissions attributable to grid-connected power generation in these six countries.

Some noteworthy projects include the Cafayate solar farm and the Villalonga and Chubut del Norte wind farms in Argentina; the financing of the Chico Mendes solar farm in Brazil; the photovoltaic solar farm in Atacama in Chile; the hydroelectric power plant in DUE Hidroalto in Ecuador; the Marcona, Tres Hermanas, Huambos and Dunas wind farms and the La Virgen hydroelectric power plant in Peru; and the Artilleros Rouar wind farm in Uruguay.

a. The calculation does not include contributions from the Chico Mendes solar plant in Brazil and 23 solar panels in Chile.

Source: Paniagua (2023).

The 2023 Report on Economic Development (Brassiolo et al., 2023) discusses five central points related to international climate financing. A first point is that the resource flows available for green financing—taking into account the various public and private sources—are typically significantly lower than the investment needs, which calls for actions to channel greater resources.

Another key point relates to the optimal strategy for the initiatives to be financed. Creditors have incentives to fund mitigation activities, as these generate income flows and are easier to verify, unlike adaptation activities, where income flows are not generated and actions and policy results are harder to observe. This may lead to effectively funded projects not being optimal when considering emissions reduction and biodiversity preservation.

The third point raised is that multilateral climate funds can help channel financing toward green activities by increasing the visibility of each country's contributions to climate goals, as well as by contributing to a higher proportion of funds taking the form of non-repayable transfers rather than loans. This allows developing countries to address climate objectives without sacrificing funds available for other development goals.

A fourth point is that increasing and improving methods for calculating financing needs to achieve climate goals can help to size up the challenge facing the world and promote the allocation of funds for mitigation, adaptation, and damage and loss.

Finally, the report points out the need to increase transparency regarding the amounts allocated to climate projects. In this regard, the development of clear green taxonomies and improved reporting and classification methods for green projects could help increase transparency and achieve more homogeneous criteria among countries.

A green taxonomy is a tool for classifying economic activities or financial assets that contribute to the achievement of environmental objectives. It serves to help investors and financial stakeholders determine which investments are environmentally sustainable and qualify as "green." It is based on certain criteria, which typically include greenhouse gas emissions reduction, efficient resource use, biodiversity protection, and promotion of the circular economy, among others.

Taxonomies are especially useful in that they enable the creation of a common language for finance in this area and provide a clear signal to investors and actors in the public and private sectors about what constitutes a green investment. They contribute to improving the reliability and comparability of information, avoiding so-called greenwashing, essential for mobilizing resources toward environmentally sound investments consistent with sustainable development. They also facilitate the creation of regulatory frameworks that promote investment and development of sustainable activities and contribute to the development of policies aligned with sustainability and emission reduction goals.

A green taxonomy creates a common language for finance and gives a clear signal to investors and public and private sector actors about what is a green investment

Numerous global initiatives for green taxonomies or classifications are underway. One of them is CAF's taxonomy, which identifies green businesses in ten strategic sectors and establishes the criteria and indicators that must be met to move toward greener businesses (Gómez García et al., 2022). The Climate Bonds Initiative (CBI), launched in 2014, serves as a guide for developing certification criteria for sectors and activities in the global economy.

There are also national taxonomies established by regulations or legislation of countries, primarily created to have green classification systems aligned with the local circumstances of each one. The pioneering case is China, whose taxonomy was launched in 2015 and updated in 2020, consisting primarily of a catalog of projects for green bonds. The European Union, meanwhile, developed a taxonomy that it began to apply in 2020. It is the foundation for several initiatives carried out or under development in different countries. This taxonomy consists of a classification system of economic activities (not financial products) that are considered environmentally sustainable.[14] In Latin America and the Caribbean, Brazil was the first country to have its own green classification in 2015, followed by Colombia and Mexico (since 2022 and 2023, respectively), and several countries that are in the process of developing it (for example, Argentina, Chile, Peru, and the Dominican Republic).[15]

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[14] Other countries with green taxonomies include Canada, France, Japan, and the Netherlands.

[15] Argentina, within the framework of the Technical Working Group on Sustainable Finance, presented a project to develop a roadmap for sustainable finance taxonomy, with support from the United Nations Development Programme (UNDP). Chile released in 2021 the Roadmap for a Taxonomy, guiding the government in developing a green taxonomy, supported by the Inter-American Development Bank (IDB) and CBI. In the Dominican Republic, the Securities Market Superintendence launched the project "Green Taxonomy in the Dominican Republic." In Peru, the Ministry of Environment is developing a system for classifying green economic activities.

Overall, all these taxonomies define environmental objectives and establish sectors, subsectors, and economic activities that comply with them. They also set the criteria and thresholds that each activity must meet to be considered environmentally sustainable. The main differences between taxonomies stem from the sectors each one covers and, within certain sectors, the eligibility criteria for "green" activities.[16] The same taxonomy can be reviewed or updated over time, for example, to include activities not previously considered, as they are not static instruments (see the chapter's annex available online).[17]

Significant differences between taxonomies can affect their comparability and interoperability, leading to difficulty in channeling international green capital flows. In this regard, there is a need to create and coordinate a common framework that establishes principles and harmonizes criteria for the development of national or regional taxonomies. In recent years, there have been advances in this direction. For example, the International Platform on Sustainable Finance (IPSF) developed a "Common Ground Taxonomy" (CGT) in 2021, highlighting common points and differences in approaches between the taxonomies of the European Union and China. In Latin America and the Caribbean, the Common Framework for Sustainable Financial Taxonomies has been published, which establishes guiding principles to guide countries that are in the process of developing green taxonomies.

Carbon markets and carbon taxes

The first question worth asking is: why are these carbon markets or carbon taxes needed? The answer lies in the fact that GHG emissions create a negative externality for the rest of the planet, as these gases spread in the atmosphere, contributing to global warming and, in some cases, generating particles with negative effects on other dimensions of well-being. In economic literature, the traditional solution to this type of problem has been to establish a tax that reflects the social cost of the externality. Carbon taxes, carbon prices, or offset markets fulfill the objective of putting a price on the externality generated. However, calculating this tax or price and enforcing the regulation is a very complicated task, hence the different degrees of progress and the dispersion of carbon prices in different countries.[18]

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Carbon taxes, carbon pricing, and offset markets serve the purpose of putting a price on the externality generated by GHG emissions

Additionally, the expenses involved in complying with environmental regulation become part of the company's cost structure, affecting production location. They also affect volumes and selling prices of products, making it necessary to reach a certain degree of international agreement to prevent companies or countries from engaging in opportunistic behaviors with regard to environmental objectives. Instruments such as climate clubs or border adjustment mechanisms, discussed earlier, are initiatives seeking this international consensus to penalize such behaviors.

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[16] For example, Colombia and the EU's taxonomies encompass cement, aluminum, and steel industries, whereas others like France and the Netherlands do not. The CBI taxonomy includes them under review.

[17] Initially, the EU taxonomy omitted activities related to nuclear energy and gas from the list of environmentally sustainable economic activities. Currently, the European Commission has amended the taxonomy regulation to include both sources, deeming them essential for the economy's decarbonization transition.

[18] The difficulty stems from several elements, among which the following can be highlighted: the uncertainty in production levels and the set of events that will occur in the economy; the dynamic component of the emissions problem, which requires considering not only present but also future generations and choosing a discount value for this type of problem; and the impact that the current carbon stock has on production and productivity in the economy, as well as how much is added to the carbon stock in the atmosphere.

Carbon markets, as defined by the United Nations (UNDP, 2022), are trading systems where carbon credits are exchanged. Various economic agents, like companies or families, can offset their emissions by acquiring carbon credits offered by other agents that eliminate or reduce GHG emissions. Once these credits have been used, they cannot be traded again. These carbon markets can be of two types: regulated, where companies and entities purchase credits to comply with national or international regulations, or voluntary, where companies and entities purchase credits voluntarily (UNDP, 2022). In regulated markets, emission permits are allocated by the state based on its mitigation goals. In voluntary markets, however, private actors or governments spearheading carbon reduction projects supply the credits, while demand comes from those seeking to reduce their carbon footprint. Domestic offset markets are often closely linked to carbon pricing schemes, in which carbon taxes can be paid with the carbon credits purchased.[19]

One form of compliance market is emissions trading systems (ETS).[20] In these markets, emissions permits are allocated, for example, under a *cap and trade* system. Companies or countries that exceed their carbon emissions levels must purchase credits from other companies that have not used theirs, i.e., emissions permits are traded. Supply and demand determine the price of the permits.

Carbon taxes, on the other hand, set a price on CO_2 and other GHG emissions. The government sets a price per ton of CO_2 equivalent, and emissions quantities are adjusted according to this price. In addition to assigning a social cost to GHG emissions, these taxes provide tax revenues that can be used to finance projects needed for the energy transition. Under certain conditions, prices per ton of carbon and emitted quantities of CO_2 equivalent under compliance regimes, such as those discussed above, are identical to those generated under a carbon tax regime.

Among the advantages of carbon markets is that the price is determined by the market, whereas carbon taxes require administrative processes to change their amount. This may give carbon markets more flexibility to adjust to specific economic situations. Moreover, at the international cooperation level, carbon taxes would require global unification of the price per ton of CO_2 equivalent or border adjustment mechanisms to prevent what is called carbon leakage,[21] whereas if leaks occur in carbon markets, they would lead to a price increase due to increased demand for emission permits.

Finally, carbon markets experience greater volatility in carbon prices, as these are determined by supply and demand, unlike carbon taxes, which are set by the government and, as mentioned, require administrative procedures to do so.

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[19] For more details, see chapter 4 of RED 2023 (Brassiolo et al., 2023).

[20] There are different ways of distributing these emission permits, some of which (e.g., auctions) give the government the possibility of generating tax revenues from them.

[21] These refer to emissions from companies that migrate their production from countries with strict regulations to others where they are more permissive (manufacturing and polluting in similar quantities), so that they no longer count for the initial country but for the host country.

Carbon capture, use, and storage (CCUS)

Even in net zero emissions scenarios, the complete decarbonization of economies is not envisaged until the middle of the 21st century (Chapter 1). The presence of hard-to-abate sectors (see Chapters 6 and 8) or the need to use thermal power plants as backup for electricity systems are just two of the reasons (see Chapter 4). This highlights the need to advance in the development of carbon capture, use, and storage (CCUS) technologies to eliminate emissions associated with fossil fuels that continue to be used. However, the incentives for the penetration of these technologies will be conditioned by the cost assigned to GHG emissions.

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The complete decarbonization of economies is not on the agenda until at least the middle of the 21st century. This highlights the need to advance in the development of carbon capture, use, and storage technologies

The natural process of carbon capture, use, and storage (CCUS) occurs through the expansion of forest cover (e.g., reforestation or afforestation). If, on the other hand, new crops are planned for biodiversity conservation, a double benefit occurs (Pörtner et al., 2021).[22]

To the extent that carbon recovery is not achieved by natural means, the technological solutions that have been developed may have a place in the set of mitigation measures. The CCUS value chain has three key links, not necessarily integrated, which are (i) carbon capture, (ii) transport of captured CO_2 to storage sites, and (iii) alternative use of CO_2 or its storage. The options for reducing the amounts of carbon released into the atmosphere are extensive.

Within the CCUS technology options, the most developed applications are in the electricity and industrial sectors. In the capture phase, there are two types of technology: one that captures emissions directly at the emission site (a physical location, such as a factory or a thermal power plant) and another that captures emissions from the air (direct air capture [DAC]), originating from different fixed or mobile sources. The latter technology is more expensive because it consumes more energy and has higher costs for a given capture.

The retrofitting of natural gas-fired generators with CCUS contributes to the system by providing a reliable source of generation with fewer emissions than a conventional plant. Technologies for carbon capture in oil refining, liquefied natural gas processing, and fertilizer production have also been developed. Moreover, progress is being made on carbon capture projects in cement, steel, and other industrial activities.

Industrial CCUS technologies are still under development but estimates indicate that they will make it possible to capture 90%–99% of CO_2 emissions at a plant (according to estimates presented in Paltsev et al., 2021). Furthermore, this activity could help recover some of the value of energy assets at risk of abandonment during the transition process, given that their negative impact on the climate would be lower (Clark & Herzog, 2014; IPCC, 2005). Finally, advances have been made in bioenergy with carbon capture and storage (BECCS) technologies in the electricity sector, which contribute to negative emissions.

For these technologies to be economically viable, investors need to perceive that this activity has a monetary value and that it reflects future environmental costs. For example, CCUS is estimated to be viable in sectors such as cement, iron, steel, and energy generation at USD 100/tCO_2

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22 Several intermediate options exist for CO_2 capture, including enhanced weathering (stimulating rock degradation processes and cation release to enhance CO2 capture), improved soil CO2 capture practices (land use changes enhancing gas absorption), and ocean fertilization (to stimulate CO2 uptake). See details in Terlouw et al. (2021).

(IEA, 2021d), but implementation at the country level varies.[23]

As of 2022, the capture capacity of operational and ongoing CCUS projects in the electricity, industrial, and transformation sectors reached 45 million tons of CO_2 ($MtCO_2$) per year, with expectations for 2030 of 383 $MtCO_2$ between operational, developing, and feasibility projects, well below the 1,176 $MtCO_2$ that would correspond in a net-zero emissions scenario (IEA, 2023d).

Circular economy

The transition to a low-carbon economy necessarily requires transforming the dominant development paradigm into one that is compatible with the joint objective of sustainable, inclusive, and economic development.

In this regard, the circular economy (CE) seeks to replace the current linear economic model, which consists of extraction, production, consumption, and waste, with a circular model in which a waste stream re-enters the productive system to be used as a resource. CE makes it possible to increase efficiency in the use of natural resources, contributing to the balance between economy, environment, and society (Ghisellini et al., 2016) and, therefore, playing a fundamental role in the energy transition.

The circular economy is a systemic approach to industrial processes and economic activity, allowing resources to maintain their maximum value for as long as possible (UN Environment, 2019).

The CE is based on a series of pillars representing strategies to be developed in production, distribution, and consumption processes to achieve an efficient resource management system (see Figure 10.1). While its current implementation primarily focuses on activities of reducing, reusing, and recycling (the 3R approach), significant progress is being made globally in adopting other strategies such as refuse and rethink, where environmental and sustainability education is crucial.

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The circular economy enables an increase in the efficiency of natural resource utilization, thus contributing to the balance between the economy, the environment, and society

The CE can be considered as an intermediate goal for achieving the ultimate objective of decoupling (a concept addressed in Chapter 2), as it involves redesigning products and processes to maximize the value of resources in the economy in order to unlink economic growth from environmental pressures resulting from input consumption and emissions (Ghisellini et al., 2016).[24]

The use of resources is closely related to energy technologies and policies. For example, the reuse of materials in the manufacturing of renewable technologies, such as solar panels and wind turbines, demonstrates how the circular economy can drive sustainability in energy production. On the other hand, the CE can be a strategic tool for addressing the provision of critical minerals needed for the energy transition (see Box 10.11).

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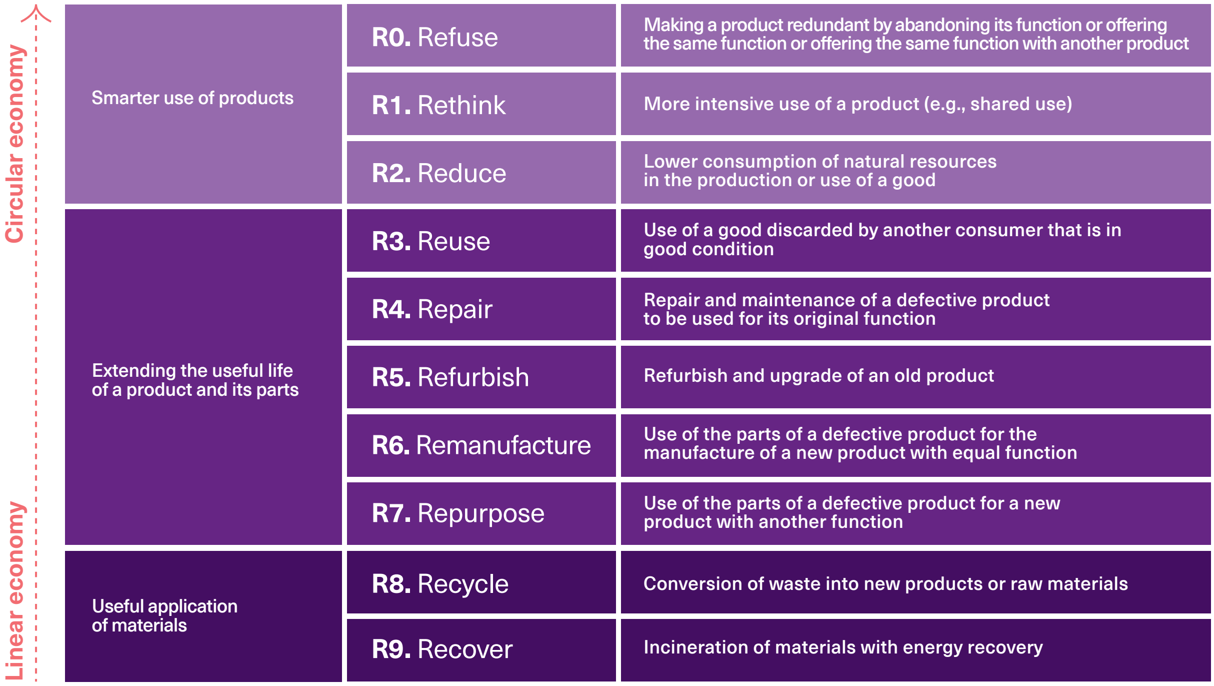
[23] Recent studies (Wilberforce et al., 2021) indicate that the practice of carbon capture in combined cycle power generation can increase costs in the range of USD 10 to USD 20 per MWh when capture is accompanied by carbon reuse processes and in the range of USD 10 to USD 30 per MWh when capture is accompanied by storage.

[24] However, there is a discussion in the literature about the extent to which it is possible to achieve absolute decoupling through circular economy strategies. This is due to the presence of the so-called “rebound effect”, i.e. the fact that eco-efficient strategies implemented at the micro level, which increase resource productivity, may not translate into a reduction in resource use, but rather an increase. If these strategies fail to decrease resource use, achieving sustainability would necessarily imply an overall decrease in economic activity at the macro level (Figge et al., 2014).

The development of a CE requires robust policies to account for and manage resources efficiently. Many governments have implemented policies addressing different aspects of the circular economy.[25] Some have aimed to tackle the waste problem through recycling and resource recovery, while others have focused on the eco-design and manufacturing of products or have aimed to generate behavioral change to limit the amount of waste produced, to name a few (UN Environment, 2019). Box 10.11 provides examples of policies developed to promote the CE.

Adopting these or other specific measures to advance toward a circular economy is a necessity in the context of energy transition. This is because the transition requires not only technological innovation but also changes in business models, cleaner production patterns, and social responsibility and awareness of the importance of closing product life cycles. In the context of the energy transition, circularity can also contribute to addressing the issue of critical minerals, a challenge for the energy transition.

Figure 10.1
Conceptual framework of the circular economy



Smarter use of products	**R0.** Refuse	Making a product redundant by abandoning its function or offering the same function or offering the same function with another product
	R1. Rethink	More intensive use of a product (e.g., shared use)
	R2. Reduce	Lower consumption of natural resources in the production or use of a good
Extending the useful life of a product and its parts	**R3.** Reuse	Use of a good discarded by another consumer that is in good condition
	R4. Repair	Repair and maintenance of a defective product to be used for its original function
	R5. Refurbish	Refurbish and upgrade of an old product
	R6. Remanufacture	Use of the parts of a defective product for the manufacture of a new product with equal function
	R7. Repurpose	Use of the parts of a defective product for a new product with another function
Useful application of materials	**R8.** Recycle	Conversion of waste into new products or raw materials
	R9. Recover	Incineration of materials with energy recovery

Source: Authors based on Kirchherr et al. (2017).

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[25] For example, Denmark has legislation that prohibits sending waste that could be recycled to landfills, and the European Union's Waste Electrical and Electronic Equipment Directive addresses the management of waste from such equipment.

Box 10.11

The circular economy and critical minerals

Building a world with net zero emissions depends on renewable energy and the progressive replacement of traditional energy sources. This will require batteries and other equipment, the production of which depends on minerals primarily extracted in only a few countries. To address this challenge, the circular economy will be the best solution.

Hund et al. (2023) estimate that more than 3 billion tons of minerals are required to meet energy production and storage demands in a scenario that limits temperature rise to 2°C by 2050. This represents an increase of up to almost 500% over current levels in demand for some minerals, such as lithium, graphite and cobalt, used in energy storage technologies. Other estimates put demand for resources such as indium by 2050 at more than 12 times current production levels.

Redesigning products along with the reuse, recycling, and repurposing of these resources can alleviate pressure on raw material supplies to meet demand. Estimates suggest that recycling has the potential to cover 20% of the demand for these critical minerals in the next three decades (Simas et al., 2022). Furthermore, the implementation of good practices can reduce the environmental and social impact of mining. Implementing these best practices requires an appropriate regulatory system.

The central issue is not the quantity of minerals, as known global reserves are sufficient to meet current projections of demand for many of these resources. Future supply faces two key risks: 1) extraction and production will face increasing scrutiny on environmental, social, and governance (ESG) issues from industries that consume these inputs, investors, and the public, and 2) access to these resources.

Any potential gap or limitation between supply and demand could affect the speed and scale at which certain technologies are implemented and the energy transition progresses. Circular economy solutions throughout the resource lifecycle may be the answer in this context to alleviate pressure on raw material supplies and meet demand, reducing the need for extraction and emissions by leveraging materials available in the market.

The circular economy will be instrumental in addressing geopolitical, geographic and economic barriers, mitigating potential price volatility and supply shortages. Supply security has been enhanced by existing circular economy strategies; for example, Japan and South Korea made significant investments in indium recycling.

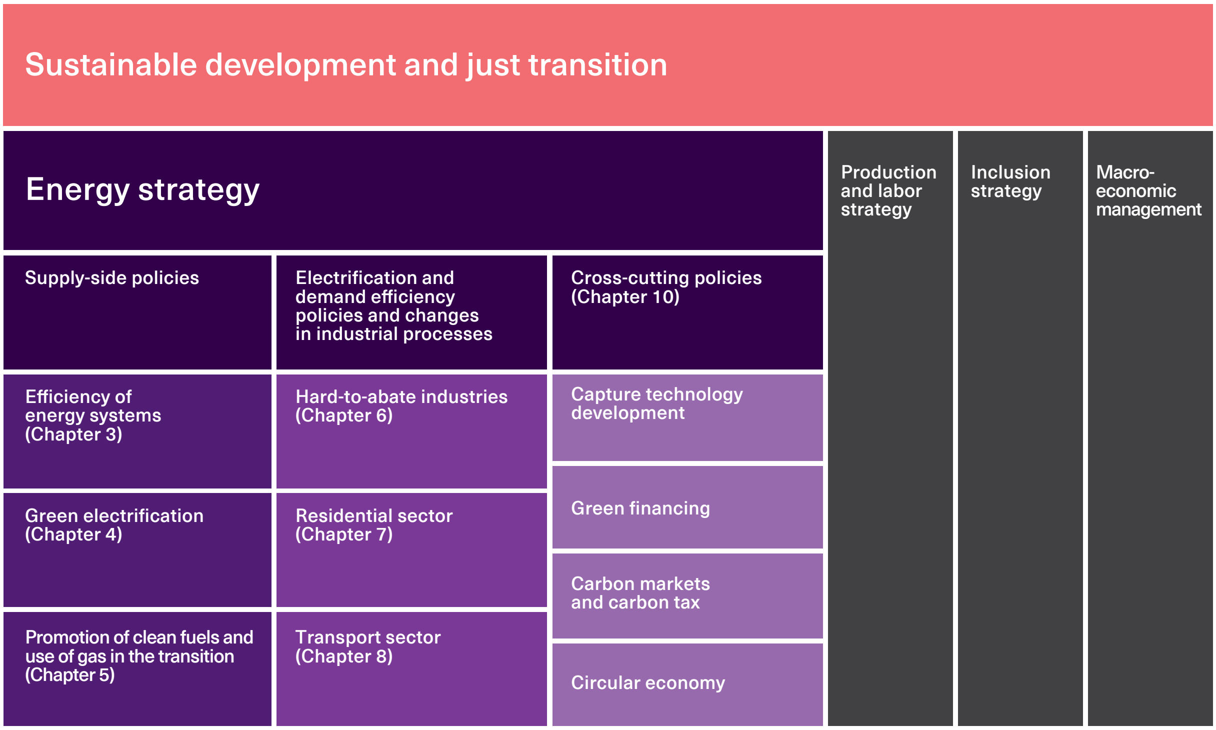
However, the expansion of these circular economy strategies presents cost, design and technical challenges. Governments, investors, producers, businesses and end-users all play a central role in providing a comprehensive response to changes in energy mix and resource availability. End-users have proven to be one of the strongest agents of change for sustainable and responsible sourcing of critical minerals. Governments can incentivize urban mining from used products (such as e-waste). Producers of critical minerals will face shortages, raising prices and increasing price volatility, while consumers will seek more circular and sustainable practices. Companies can assist in a circular transition with efforts to reduce the use of critical metals and increase recovery potential by introducing circular production processes (KPMG, 2022).

An agenda for just transition

The energy transition is a complex and transformative phenomenon affecting the economy as a whole. It must be addressed simultaneously with other non-energy source mitigation strategies and concurrently with other development challenges in the countries of Latin America and the Caribbean. Consequently, to seize the opportunities and overcome the challenges associated with this transition, the region must manage a range of policies that go beyond purely energy-related issues.

Throughout the report, priority actions related to the energy strategy have been discussed in detail, while recognizing the importance of incorporating an agenda for productivity, inclusion, and macroeconomic management to achieve sustainable development (see Figure 10.2).

Figure 10.2
Facets of the just energy transition agenda



The first component of the energy agenda concerns energy supply. Three pillars stand out here. In the short term, it is important to reduce existing inefficiencies in electricity generation, transmission, and distribution systems, as well as in fuel production (e.g., reducing fugitive gas emissions). Additionally, in transitioning to a decarbonized economy, there are potential gains from substituting high-carbon fossil sources (coal and oil) with lower-emission alternatives like gas, while ensuring long-term environmental objectives are not compromised. To further advance the decarbonization of the economy, achieving green electrification and promoting the development of clean fuels, such as low-emission hydrogen, are important.

As for energy demand, a just energy transition requires the electrification of certain processes or uses currently reliant on fossil fuels. It also involves promoting energy efficiency, behavioral changes, and the transformation of certain industrial processes. Concrete policies in the energy demand sphere will vary by sector. In hard-to-abate industries, policies range from specific measures, such as reducing clinker content in cement production, to cross-cutting policies like promoting the circular economy. In urban mobility, sustainable public transport (mass and active) is important. In urban logistics, there is room for electrification, while in freight transport, promoting efficiency and the use of alternative fuels are effective short-term measures. On the demand side, particularly in residential areas, a just transition also requires closing persisting gaps in access and quality. Highlighted policies for this sector include electrifying some consumption areas, such as heating and cooking, along with energy efficiency measures, including appliances with lower consumption and better building envelopes.

As mentioned in the previous section, there are key energy technologies, instruments, and institutions for the transition that are not exclusive to the realms of energy supply or demand. The report also emphasizes the need for more comprehensive economic development policies, in particular, labor policies favoring green job creation and the reallocation of workers from non-green jobs, as well as productive policies complementing the advantages of clean energy endowment.

The energy transition entails costs and benefits that are not evenly distributed among various stakeholders, leading to a reshaping of interests and powers both nationally and globally. Understanding the political economy challenges of the energy transition is crucial for advancing the agenda.

The energy transition entails costs and benefits that are not evenly distributed among the various stakeholders, leading to a reshaping of interests and powers nationally and globally. Understanding the political economy challenges of the energy transition is key to promoting the agenda.

One primary source of resistance to this progress is social. Global climate objectives imply that the transition must occur relatively rapidly. This could entail, at least in its initial stage, a higher energy cost compared to current energy alternatives. In other words, in the short term, the energy transition may result in energy impoverishment as renewable sources may not be available to the necessary extent, compounded by the potential rise in fossil fuel prices due to policies like carbon taxes.

●●

The energy transition involves costs and benefits that are not evenly distributed among the various stakeholders. Understanding the political economy challenges of the energy transition is key to moving forward

Another source of resistance is the presence of stranded assets and the significant losses it would entail for economies dependent on fossil fuel sources. These losses may also be unevenly distributed within regions and countries. This is exacerbated in those with low potential for developing non-conventional renewable energies and lacking critical minerals.

A third source of resistance is related to the rapid growth in global energy demand. Meeting this demand remains a strategic priority for national economies, which may hinder the fulfillment of national and international commitments to cut GHG emissions. This explains why some countries

(Germany, China, the United States) are increasing their use of renewable energy while continuing to invest in fossil fuels (Bukowski, 2021). Meeting the growing energy demand without compromising the global climate agenda necessarily requires significant investment flows for the development of technology to expand renewable energy sources (De Haas, 2023).

The policy agenda described above also alleviates these challenges by seeking to improve the trade-offs between emissions and growth, maximizing the opportunities that the energy transition brings to the region, and making citizen protection a high priority.

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Appendixes

Chapter 1 Appendix

Example of inefficiencies associated with the scale of definition of NDCs

To illustrate the extent to which the definition of country-level emissions expressed in the NDCs could lead to inefficiencies in the absence of global carbon markets, an example has been developed with hypothetical countries.

In this example, a region consisting of three countries with different endowments for power generation from renewable and fossil resources is assumed. For simplicity, it is also assumed that emissions generated from green sources are emission-free and that gas emits less GHG than coal.

Currently, each country generates 100 units of energy from the sources specified in Table 1. The green potential of each country is shown in the last column of the table.

Table 1
Share of each source in the generation of 100 units of energy by country

	Current production			Green potential
	Coal	Gas	Green	
Country A	80	0	20	50
Country B	0	80	20	100
Country C	50	50	0	50

Assume that each country commits in its NDC to generate electricity using all its green potential. Then, the three countries fill in the remainder according to their availability of fossil resources. In this example, to generate the 100 units of energy the distribution would be as in Table 2.

Table 2
Share of each energy source with use of all green potential by country

	NDC Production		
	Coal	Gas	Green
Country A	50	0	50
Country B	0	0	100
Country C	0	50	50

That is, generation from green sources increases from 40 to 200 and production from gas and coal is reduced from 130 to 50 for each source. It can be seen that the region has the potential to generate the remaining energy that cannot be covered by green generation from gas. However, this is not achieved in the NDC scenario because each country commits to generate as much energy as it needs. If the decision were regional, the energy matrix would look like in Table 3. Thus, country B would export the

50 units of energy needed for country A to meet its demand without the need for coal-fired generation.

This simple example shows that a regional target could meet demand by producing fewer emissions, but for this to happen, energy must be traded and the targets must be considered at the regional level. For instance, if country B commits to 100% green generation, it would be reluctant to generate the 50 units of energy for country A as it would undermine its commitment.

Table 3
Share of each source in energy generation with a regional vision

	Optimal regional production		
	Coal	**Gas**	**Green**
Country A	0	0	50
Country B	0	50	100
Country C	0	50	50

Complementary tables

Table A.1.1
Socioeconomic level and prioritization of environmental topics

	OLS	**Probit (dy/dx)**
sex	-0.000504	-0.000536
	(0.00721)	(0.00718)
Between 30 and 49 years old	0.000092	0.000306
	(0.00854)	(0.00856)
Over 50 years old	-0.0176*	-0.0187*
	(0.0101)	(0.0101)
Complete primary education	0.0178	0.00818
	(0.0139)	(0.0135)
Incomplete secondary education	0.0552***	0.0481***
	(0.0146)	(0.0139)
Completed secondary education	0.0449***	0.0351***
	(0.0126)	(0.0121)
Incomplete higher education	0.156***	0.147***
	(0.0179)	(0.0175)
Complete higher education	0.106***	0.0982***
	(0.0154)	(0.0151)

Note: OLS: Ordinary Least Squares. Base category: male, between 15 and 29 years old, with incomplete primary education. Dependent variable: environment; 0 priority: economic growth; 1 priority: environmental protection. The higher the level of education, the greater the concern for the environment. The same is not true for age: those over 50 attach greater importance to economic growth than people between 15 and 29 years of age.

Source: Authors based on the World Values Survey (Haerpfer et al., 2022).

Table A.1.2

Quality of electricity service according to companies in selected countries of Latin America and the Caribbean

Country and last available year	Companies that experienced power outages (percentage)	Power outages in a typical month (quantity)	Average duration of a typical power outage (hours)	Average loss due to power failure (percentage of annual sales)	Companies that consider electricity as the main constraint (percentage)
Antigua and Barbuda (2010)	95.5	2.8	2.2	0.2	45.1
Argentina (2017)	65.1	0.8	5.2	0.8	47.2
Bahamas (2010)	75.0	2.2	1.5	1.5	24.6
Barbados (2023)	55.6	1.1	1.8	0.2	47.3
Belize (2010)	78.4	2.5	1.8	0.1	36.3
Bolivia (2017)	35.1	0.6	1.3	0.9	23.6
Brazil (2009)	45.8	1.6	4.2	3.4	46
Chile (2010)	42.6	0.7	2.3	1.3	30.1
Colombia (2017)	53.9	0.8	2.8	1.9	50.1
Costa Rica (2023)	49.4	1.3	1.8	1.7	63.2
Dominica (2010)	100.0	2.8	2.0	0.1	66.1
Ecuador (2017)	62.4	1.2	1.0	1.1	27.4
El Salvador (2023)	36.2	1.2	2.9	2.1	36.8
Grenada (2010)	59.5	0.7	4	1	16.9
Guatemala (2017)	54.4	1.3	2.3	1.4	11.7
Guyana (2010)	81.8	8.5	2.9	2.8	43
Honduras (2016)	69.8	2.4	4.3	3.7	34.5
Mexico (2023)	45.1	1.6	6.8	3.4	46.7
Paraguay (2017)	83.0	1.7	1.2	2.5	30.9
Peru (2023)	52.2	0.5	4.6	2.1	27.5
Dominican Republic (2016)	54.1	7.4	4.0	3.1	37.6
St. Kitts and Nevis (2010)	94.0	4.2	2.9	2.1	63.7
Saint Vincent and the Grenadines (2010)	83.3	1.7	1.5	0.8	25.4
St. Lucia (2010)	99.8	3	2.1	0	55.7
Suriname (2018)	86.0	2.8	2.8	1.1	28.2
Trinidad and Tobago (2010)	65.7	0.5	1.9	0.4	14.6
Uruguay (2017)	56.6	0.8	4.4	0.3	55
Venezuela (2010)	64.6	2.6	2.1	8.3	54.2

Source: Authors based on World Bank (2023a).

Table A.1.3

Countries incorporated in graph 1.8 with the corresponding ISO code

Country	ISO	Country	ISO
Anguilla	AIA	Guyana	GUY
Antigua and Barbuda	ATG	Haiti	HTI
Argentina	ARG	Honduras	HND
Aruba	ABW	Jamaica	JAM
Barbados	BRB	Mexico	MEX
Belize	BLZ	Nicaragua	NIC
Bolivia	BOL	Panama	PAN
Brazil	BRA	Paraguay	PRY
Chile	CHL	Peru	PER
Colombia	COL	Puerto Rico	PRI
Costa Rica	CRI	Saint Lucia	LCA
Dominica	DMA	Saint Vincent and the Grenadines	VCT
Dominican Republic	DOM	Suriname	SUR
Ecuador	ECU	The Bahamas	BHS
El Salvador	SLV	Uruguay	URY
Guatemala	GTM	Venezuela	VEN

Table A.1.4

Emissions composition of selected countries in Latin America and the Caribbean

	Categories		FFIP						
	AFOLU	FFIP	Energy systems - Fugitive	Fugitive	Transport	Buildings	Cement + chemicals + metal	Other industries	Waste
Argentina	**43%**	**57%**	16%	7%	12%	6%	5%	8%	4%
Antigua and Barbuda	**4%**	**96%**	34%	0%	40%	8%	0%	6%	8%
Bahamas	**0%**	**100%**	34%	0%	39%	8%	0%	6%	13%
Belize	**89%**	**11%**	3%	0%	3%	1%	0%	0%	4%
Bolivia	**68%**	**32%**	7%	8%	10%	2%	1%	2%	2%
Brazil	**70%**	**30%**	5%	2%	9%	1%	4%	2%	7%
Barbados	**-3%**	**103%**	35%	2%	37%	8%	5%	5%	10%
Chile	**15%**	**85%**	27%	2%	21%	5%	4%	16%	10%
Colombia	**52%**	**48%**	9%	6%	12%	2%	4%	7%	8%
Costa Rica	**28%**	**72%**	2%	0%	40%	3%	5%	7%	15%
Cuba	**20%**	**80%**	31%	2%	5%	2%	3%	26%	13%
Dominica	**-1%**	**101%**	33%	0%	37%	8%	2%	5%	16%
Ecuador	**34%**	**66%**	11%	13%	23%	5%	3%	4%	7%
El Salvador	**12%**	**88%**	10%	0%	35%	5%	5%	14%	19%
Guatemala	**37%**	**63%**	14%	0%	19%	7%	3%	6%	15%
Guyana	**80%**	**20%**	6%	0%	6%	1%	1%	1%	4%
Honduras	**51%**	**49%**	11%	0%	14%	3%	2%	7%	11%
Haiti	**41%**	**59%**	27%	0%	8%	5%	2%	4%	13%
Jamaica	**1%**	**99%**	33%	0%	24%	4%	5%	26%	6%
Mexico	**25%**	**75%**	21%	4%	17%	3%	16%	7%	8%
Nicaragua	**78%**	**22%**	4%	0%	6%	3%	1%	2%	5%
Panama	**40%**	**60%**	12%	0%	21%	4%	4%	12%	8%
Peru	**42%**	**58%**	13%	6%	19%	3%	5%	5%	8%
Paraguay	**87%**	**13%**	1%	0%	8%	1%	1%	1%	1%
Dominican Republic	**19%**	**81%**	30%	0%	17%	4%	5%	13%	11%
St. Kitts and Nevis	**-16%**	**116%**	37%	0%	43%	9%	0%	6%	20%
St. Lucia	**-5%**	**105%**	30%	0%	34%	7%	0%	21%	12%
Saint Vincent and the Grenadines	**-5%**	**105%**	31%	0%	35%	7%	1%	5%	26%
Suriname	**63%**	**37%**	14%	2%	14%	1%	0%	1%	4%
Trinidad and Tobago	**0%**	**100%**	24%	26%	5%	1%	32%	5%	7%
Uruguay	**72%**	**28%**	1%	0%	10%	1%	1%	2%	12%
Venezuela	**31%**	**69%**	17%	20%	10%	2%	8%	6%	6%

Note: The transport sector includes emissions stemming from domestic aviation, river transportation, roads, railways, and other modes. The sector of energy systems encompasses emissions from electricity generation, heating, petroleum refining, and other systems (excluding fugitive emissions). The buildings sector includes emissions from both residential and non-residential sectors, as well as non-CO$_2$ emissions generated by all structures. Fugitive emissions arise from both coal mining and petroleum and gas extraction. Finally, emissions from waste, other industries, and cement, chemical, and metal industries sectors lack further disaggregation beyond what is indicated by their respective names.

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

Table A.1.5
Mapping of sectors and sub-sector\

Sector	Subsector	Composition
Agriculture, Forestry and Other Land Use (AFOLU)	Biomass burning	Biomass burning
	Enteric fermentation	Enteric fermentation
	Managed soils and pastures	Managed soils and pastures
	Manure management	Manure management
	Rice cultivation	Rice cultivation
	Synthetic fertilizer application	Synthetic fertilizer application
	LULUCF	Land use, land use change and forestry
Buildings	No CO_2	
	Non-residential	Commercial or institutional
	Residential	Residential
Fugitive emissions	Fugitive emissions from coal mining	Fugitive emissions from coal mining
	Fugitive oil and gas emissions	Exploration, transportation, production, upgrading, refining, distribution and other abandoned oil and gas wells
Energy systems – fugitive	Electricity and heating	Electricity generation; combined heat and power generation (cogeneration); heat plants
	Other (power systems)	Manufacture of solid fuels and other energy industries; agriculture, forestry and fisheries
	Oil refinery	Oil refinery
Cement + chemistry + metals	Cement	Cement
	Chemistry	Manufacturing industries; lime production; other carbonate process uses; ammonia production; nitric acid production; adipic acid production; caprolactam; carbide; titanium; soda ash; methanol; ethylene; carbon black; solvent use; propellant; propellant
	Metals	Solid fuels and other energy industries; iron and steel; nonferrous metals; fuel processing; production of iron, steel, ferroalloys, aluminum, lead, zinc, and magnesium
Other industries	Other industries	Pulp, paper and printing; food, beverages, tobacco; non-metallic minerals; refrigeration and air-conditioning; food, beverages, tobacco; non-metallic minerals; refrigeration and air conditioning.
Waste	Waste	Disposal of solid waste; incineration and open burning of waste; wastewater treatment and discharge
Transportation	Domestic aviation	Domestic aviation
	Internal navigation	Internal navigation
	International navigation	International navigation
	Other (transportation)	Other (transportation)
	Railroad	Railroad
	Roads	Roads

Source: Authors based on IPCC (2019).

Table A.1.6

Historical and future trends (according to stated mitigation targets) of GHG emissions in selected countries of Latin America and the Caribbean

Country	Variation in GHG emissions 2010–2020 (percentage)	2020 GHG Emissions ($MtCO_2eq$) [a/]	GHG Emissions 2030 - NDC Target ($MtCO_2eq$) [b/]	Change GHG emissions 2020–2030 (percentage)
Argentina	-10.29	394.76	349.00	-11.59
Bahamas	23.35	2.80	4.44	58.68
Barbados	-5.68	3.65	1.27	-65.13
Brazil	-30.77	1,469.64	1,176.27	-19.96
Chile	16.51	106.72	95.00	-10.98
Colombia	11.46	270.31	169.44	-37.32
Costa Rica	-44.43	7.08	9.11	28.67
Dominica	-4.35	0.22	0.12	-45.07
El Salvador	-8.44	12.15	5.33	-56.14
Grenada	7.14	2.40	0.13	-94.58
Guatemala	-3.74	36.78	65.00	76.73
Haiti	20.98	10.90	17.77	-35.77
Honduras	-54.01	10.90	24.31	123.06
Jamaica	18.44	7.58	5.37	-29.14
Mexico	4.23	609.07	644.15	5.76
Paraguay	0.74	97.29	92.29	-5.14
Peru	19.92	179.78	208.80	16.14
Dominican Republic	15.07	35.50	47.43	33.61
St. Kitts and Nevis	0.01	0.33	0.10	-70.10
St. Lucia	2.94	0.70	0.47	-32.91
Uruguay	31.44	34.28	36.58	6.71
Total	**-15.52**	**3,292.84**	**2,952.38**	**-10.79**

Note: The table presents a measure of the ambition of the NDCs of Latin American and Caribbean countries that present a global GHG emissions reduction target. a/ The level of net emissions in 2020 includes the same sectors that are contemplated in the target declared by each country in its NDC for 2030. b/ The net GHG emissions for 2030 were estimated by applying the mitigation target to the declared base emissions level (in the baseline year or the BAU scenario). Emissions from the sectors included in the target are considered and, for countries that do not specify the sectors, it is assumed that the target includes all of them (including LULUCF).

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

Table A.1.7

Energy sector targets included in NDCs

Country	Goal
Antigua and Barbuda	• Achieve 86% of electricity generation from renewable sources by 2030.
Bahamas	• Generate at least 30% of the energy matrix from renewable sources by 2030.
Bolivia	• Achieve universal access to electricity coverage. • Reach 9% of the energy consumed comes from plants based on renewable energies. • Ensure that 19% of the energy consumed comes from plants based on alternative energies (biomass, solar, wind and geothermal). • Annual growth of 10% in the share of electric vehicles in the public transport fleet.
Chile	• Achieve 80% of electricity generation from renewable sources by 2030.
Colombia	• Manage fugitive emissions associated with the hydrocarbon production chain. • Demand management: reduce the difference in electricity consumption between peak and off-peak hours to flatten the demand curve. • Manage off-peak electricity generation from non-polluting sources. • Diversify the energy matrix. • Promote self-generation of energy through alternative sources. • Increased coverage for the provision of electric energy services.
Costa Rica	• Achieve and maintain 100% renewable electricity generation by 2030. • Develop energy demand electrification planning. • By 2030, develop or update energy efficiency standards and regulations for end-use technologies (air conditioners, boilers, heat pumps, vehicles). • Develop and promote green hydrogen.
Cuba	• Base 24% of electricity generation on renewable sources by 2030. • Increase energy efficiency. • Reduce carbon intensity in the transportation sector.
Dominica	• Achieve 100% of the energy matrix from renewable sources by 2030.
Ecuador	• Promote the use of renewable energy. • Strengthen energy efficiency and consumption behavior change. • Promote and implement sustainable mobility.
El Salvador	• Increase installed renewable energy capacity by 50% (compared to 2019) by 2030. • Achieve more than 80% of electricity generated from renewable sources by 2030. • Energy efficiency in public lighting. • Introduce electromobility in the vehicle fleet, with primary focus on passenger transportation.
Guatemala	• Renewal of the vehicle fleet: replace 24.3% of gasoline vehicles with electric vehicles by 2032. • Partial substitution of gasoline for ethanol nationwide. • Achieve that 80% of the energy matrix comes from clean or renewable energies.
Guyana	• Achieve 100% share of renewable energies by 2025.
Honduras	• Promote renewable energies. • Strengthen energy efficiency. • Promote electromobility. • Strengthen bioenergy.

Continued on the next page →

Country	Goal
Mexico	• Integrate clean energy in power generation. • Substitute high-carbon fuels for natural gas. • Promote and consolidate an electric mobility strategy. • Develop Mexico's Emissions Trading System. • Reduce fugitive emissions from the oil and gas subsector. • Strengthen energy efficiency.
Nicaragua	• Increase the percentage of electricity generation through renewable sources to 60% by 2030.
Panama	• Achieve universal access to electricity • Ensure the rational and efficient use of energy. • Implement an electric mobility strategy. • Develop a strategy for innovation and modernization of the National Interconnected System (NIS) that allows the integration of renewable energies into the generation system. • Define a national policy that positions Panama as an energy hub (natural gas and green energy). • Modernize the regulatory framework of the hydrocarbons sector.
Paraguay	• Generate and promote the use of alternative energy sources to hydroelectric power in vulnerable communities. • Protect and restore watercourses in priority sub-basins for hydroelectric power generation. • Improve the provision of electric power.
St. Kitts and Nevis	• Achieve 100% of energy generation from renewable sources by 2030. • Improve the efficiency of electricity transmission and distribution. • Achieve 2% of total electric vehicles by 2030.
Suriname	• Achieve at least 35% of electricity generated from renewable sources by 2030.

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

Clarifications regarding the graphs and tables in this chapter

Graph 1.9

Latin America includes 20 countries: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela.

The Caribbean comprises 13 countries: Antigua and Barbuda, Bahamas, Barbados, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago.

OECD includes 34 countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

Table 1.2

Latin America includes 19 countries: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, and Uruguay.

The Caribbean includes seven countries: Barbados, Cuba, Dominican Republic, Grenada, Haiti, Jamaica, and Trinidad and Tobago.

OECD comprises 23 countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

Table 1.3

Africa includes 37 countries: Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Côte d'Ivoire, Democratic Republic of Congo, Djibouti, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Guinea, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Mauritania, Mauritius, Mauritania, Morocco, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Seychelles, Somalia, South Africa, Tanzania, Togo, Tunisia, Uganda, and Zambia.

North America includes two countries: Canada and the United States.

Latin America and the Caribbean comprises 21 countries: Argentina, Bahamas, Barbados, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Paraguay, Peru, St. Kitts and Nevis, St. Lucia, and Uruguay.

Asia also includes 21 countries: Azerbaijan, Bangladesh, Cambodia, China, India, Indonesia, Israel, Japan, Jordan, Kazakhstan, Lebanon, Marshall Islands, Mongolia, North Korea, Oman, Philippines, South Korea, Tajikistan, Thailand, Tajikistan, United Arab Emirates, and Vietnam.

Oceania includes six countries: Australia, Cook Islands, Kiribati, New Zealand, Solomon Islands, and Samoa.

European Union includes its 27 members: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, and Slovak Republic.

The rest of Europe includes 19 countries: Albania, Andorra, Armenia, Belarus, Bosnia and Herzegovina, Georgia, Iceland, Liechtenstein, Macedonia, Moldova, Monaco, Montenegro, Norway, Russia, Serbia, Switzerland, Turkey, Ukraine, United Kingdom.

Methodological considerations for estimating the level of GHG emissions in 2030 based on the mitigation targets announced in the NDCs (Table 1.3)

One hundred and thirty-three countries are analyzed (out of a total of 198 that signed the Paris Agreement), as they are the ones that report a global GHG emissions reduction target in their NDCs.

For the countries of Latin America and the Caribbean, the NDCs were reviewed up to August 2023. For the rest of the countries, the data published in the Economy and Development Report 2023 was used, with a cut-off date of December 2022 for the NDC survey.

How the GHG emissions reduction target is set varies among countries, with the following cases being identified:

i) Absolute emissions target, without reference to a comparison value. Examples of countries that apply this type of target are Argentina, Brazil, Chile, and Colombia.

ii) Relative target expressed as a percentage of emissions reduction with respect to a reference year (base year) or a hypothetical emissions scenario in the absence of mitigation policies (also known as a BAU scenario). Examples of this modality are Mexico, Panama, and Paraguay.

iii) Relative target expressed as a percentage of emissions reduction per unit of output compared to a reference year. This is the case for China and India.

In order to estimate the level of GHG emissions in 2030, the mitigation target announced by each country in its NDC is considered.

In case (i), where the target is absolute, the reported target emissions level is used directly.

In case (ii) the target (percentage reduction) is applied to the BAU scenario or base year emissions level. Generally, the NDC states what the baseline emissions value is, but in cases where the NDC does not state it and the baseline year is a historical year, the emissions of that year according to the latest emissions inventory of the country are used.

In case (iii), emissions per unit of product are calculated in the reference year ($GHG_{i,ref}/GDP_{i,ref}$), and the NDC reduction (Var_{NDC}) is applied:

$$GHG_{i,2030} / GDP_{i,2030} = GHG_{i,ref} / GDP_{i,ref} \times (1 + Var_{CDN})$$

Finally, the emission level for 2030 is obtained as:

$$GHG_{i,2030} = GDP_{i,2030} \times (GHG_{i,2030} / GDP_{i,2030})$$

The GDP value for 2030 is obtained from IMF (2022) and Asian Development Bank (ADB, 2023; Peschel and Liu, 2022) projections.

Chapter 2 Appendix

Clarifications on the groups of countries and sectors represented in the tables and graphs

Tables 2.1, 2.3, and 2.4

Latin America includes 19 countries: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, and Uruguay.

The Caribbean comprises seven countries: Barbados, Cuba, Dominican Republic, Grenada, Haiti, Jamaica, and Trinidad and Tobago.

The OECD is made up of 23 countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Luxembourg, Norway, New Zealand, Netherlands, Portugal, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

Table 2.2

Africa includes 37 countries: Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Côte d'Ivoire, Democratic Republic of Congo, Djibouti, Equatorial Guinea, Eritrea, Equatorial Guinea, Ethiopia, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Mauritania, Mauritius, Morocco, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Seychelles, Somalia, South Africa, Tanzania, Togo, Tunisia, Uganda, and Zambia.

North America includes two countries: Canada and the United States.

Latin America and the Caribbean comprises 21 countries: Argentina, Bahamas, Barbados, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, and Uruguay.

Asia includes 21 countries: Azerbaijan, Bangladesh, Cambodia, China, India, Indonesia, Israel, Japan, Jordan, Kazakhstan, Lebanon, Marshall Islands, Mongolia, North Korea, Oman, Philippines, South Korea, Tajikistan, Thailand, United Arab Emirates, and Vietnam.

Oceania comprises six countries: Australia, the Cook Islands, Kiribati, New Zealand, Samoa, and the Solomon Islands.

The European Union includes its 27 members: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.

The rest of Europe comprises 19 countries: Albania, Andorra, Armenia, Belarus, Bosnia and Herzegovina, Georgia, Iceland, Liechtenstein, Macedonia, Moldova, Monaco, Montenegro, Norway, Russia, Serbia, Switzerland, Turkey, Ukraine, and the United Kingdom.

Graph 2.4

In both panels, Latin America includes 20 countries: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay, and Venezuela.

The Caribbean comprises seven countries in Panel A: Barbados, Cuba, Dominican Republic, Grenada, Haiti, Jamaica, and Trinidad and Tobago. Panel B includes 12 countries: all of the above, plus the Bahamas, Dominica, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines.

Graphs 2.5, 2.6, and 2.7

The 59 economic sectors that are final energy consumers are included based on the information provided by the GTAP. Graph A.2.1 (in this Annex) details each of these sectors and shows their percentage share in the total value added of the group of countries in the region and the OECD.

Latin America and the Caribbean includes 19 countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, and Uruguay.

The OECD includes all member countries except for those in Latin America (Chile, Colombia, Costa Rica, and Mexico) and Iceland, as it is not included in the GTAP databases.

Graph 2.8

Latin America and the Caribbean includes 12 countries: Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, El Salvador, Honduras, Jamaica, Mexico, Paraguay, and Peru.

The OECD includes member countries, except for those in Latin America (Chile, Colombia, Costa Rica, and Mexico) and Iceland, as it is not included in the GTAP databases.

Supplementary tables and graphs

Table A.2.1

Mitigation effort by 2030 in selected Latin American and Caribbean countries

Country	Average annual change in GHG emissions per GDP in 2010–2020 (percentage)	Average annual change in GHG emissions per GDP in 2020-2030 (percentage)			GHG emissions 2030 - NDC (MtCO$_2$eq)
		Scenario 1	Scenario 2	Scenario 3	
Argentina	-0.37	-1.71	-3.64	-5.49	349
Bahamas	4.20	4.14	2.10	0.14	4
Barbados	0.69	-10.08	-11.84	-13.53	1
Brazil	-3.93	-2.68	-4.59	-6.42	1,176
Chile	-0.53	-1.48	-3.41	-5.26	95
Colombia	-1.35	-5.14	-7.00	-8.79	169
Costa Rica	-8.25	1.95	-0.05	-1.97	9
Dominica	0.95	-6.20	-8.04	-9.81	0
El Salvador	-2.27	-8.29	-10.08	-11.81	5
Grenada	-0.65	-25.68	-27.13	-28.53	0
Guatemala	-3.34	4.06	2.02	0.06	65
Haiti	0.43	3.80	1.76	-0.20	18
Honduras	-9.57	6.77	4.68	2.67	24
Jamaica	1.92	-3.33	-5.23	-7.05	5
Mexico	-0.87	-0.10	-2.05	-3.94	644
Paraguay	-2.92	-1.66	-3.59	-5.45	92
Peru	-0.61	0.53	-1.44	-3.34	209
Dominican Republic	-2.54	2.06	0.06	-1.86	47
Saint Kitts and Nevis	-0.88	-11.48	-13.22	-14.89	0
Saint Lucia	1.86	-4.13	-6.01	-7.81	0
Uruguay	1.30	0.67	-1.31	-3.20	37
Total	**-3.19**	**-1.72**	**-3.65**	**-5.50**	**2,952**

Note: The table shows the average annual rate of change in GHG emissions per unit of output for a selection of countries in the region between 2010 and 2020 and compares it with the average annual rate of change required between 2020 and 2030 to meet the mitigation target declared by each country in its NDC under three different scenarios: scenario 1 considers the population growth rate of United Nations population projections and a per capita GDP growth of 0% per year; scenarios 2 and 3 consider the same population growth rates of scenario 1, but the per capita annual GDP growth is 2% in the second scenario and 4% in the third. Net GHG emissions for 2030 were estimated by applying the countries' unconditional mitigation target to the baseline emissions level declared in their NDC (in the reference year or a business-as-usual scenario). For countries that do not specify the sectors considered in the target, it is assumed that the target covers all sectors (including LULUCF); whereas, if countries clarify that the target does not take that sector into account, then emissions excluding LULUCF are used.

Source: Authors based on World Bank (2023c, 2023f), Climate Watch (2023b), United Nations (2022) and UNFCCC Secretariat (2023).

Table A.2.2

Final energy consumption by source in selected Latin American and Caribbean countries

	2000							2019						
	Coal	Oil and its derivatives	Natural gas	Electricity	Biofuels and waste	Total	Other	Coal	Oil and its derivatives	Natural gas	Electricity	Biofuels and waste	Total	Other
	Percentage							Percentage						
Argentina	0.6	38.7	35.9	15.7	2.7	6.4	100	0.6	39.2	34.0	18.9	2.0	5.3	100
Barbados	-	76.0	1.3	13.0	8.8	0.9	100	-	76.9	2.7	18.2	2.1	-	100
Belize	-	100.0	-	-	-	-	100	0.6	69.8	-	15.2	14.4	-	100
Bolivia	-	52.4	12.6	10.8	23.6	0.6	100	-	54.1	25.9	10.5	9.3	0.3	100
Brazil	6.0	49.0	3.8	17.6	15.2	8.4	100	3.2	49.8	5.4	19.1	13.4	9.1	100
Chile	2.6	54.9	6.3	15.8	19.7	0.7	100	0.5	56.2	6.0	22.4	13.4	1.6	100
Colombia	10.2	43.3	8.6	13.6	24.0	0.3	100	6.9	46.3	14.8	18.4	13.6	0.0	100
Costa Rica	0.2	68.7	-	21.1	6.7	3.3	100	0.0	67.3	-	21.2	7.5	4.0	100
Cuba	0.8	54.3	1.3	15.7	25.7	2.2	100	0.9	56.7	1.3	21.4	16.0	3.7	100
Ecuador	-	80.2	-	11.4	6.2	2.3	100	-	78.2	0.3	16.6	3.4	1.5	100
El Salvador	0.8	70.3	-	10.7	16.9	1.3	100	0.5	74.7	-	18.1	5.8	0.9	100
Grenada	1.3	72.9	-	16.8	8.3	0.7	100	1.8	70.8	-	19.8	7.2	0.5	100
Guatemala	0.3	35.8	-	5.1	58.0	0.7	100	-	35.9	-	7.3	56.1	0.7	100
Guyana	0.1	64.5	-	5.6	29.9	0.0	100	0.1	76.2	-	10.0	10.4	3.2	100
Haiti	26.1	18.7	-	1.1	53.5	0.5	100	26.9	23.6	-	1.1	48.3	0.1	100
Honduras	3.4	38.2	-	10.0	47.9	0.5	100	0.0	46.1	-	15.1	38.5	0.4	100
Jamaica	3.1	84.0	-	11.2	0.7	1.0	100	2.9	82.4	-	9.5	4.4	0.8	100
Mexico	-	60.0	13.8	13.4	8.9	4.0	100	2.5	57.0	12.2	20.9	5.8	1.6	100
Nicaragua	1.1	35.9	-	7.2	54.4	1.4	100	0.3	43.4	-	12.4	41.4	2.5	100
Panama	2.6	62.5	-	19.2	15.8	-	100	0.0	67.0	-	25.0	6.7	1.3	100
Paraguay	3.2	30.7	-	10.3	39.0	16.8	100	3.2	42.6	-	17.0	27.6	9.6	100
Peru	4.4	55.9	0.0	12.3	23.6	3.8	100	3.0	52.9	11.3	19.9	10.8	2.0	100
Dominican Republic	2.0	60.1	-	19.9	15.2	2.7	100	2.5	61.5	1.6	20.8	9.9	3.6	100
Suriname	0.2	73.2	-	15.6	7.5	3.4	100	0.2	64.9	-	25.7	4.4	4.9	100
Trinidad and Tobago	-	11.3	81.2	5.7	1.7	0.1	100	-	7.7	86.7	5.4	-	0.2	100
Uruguay	0.1	55.9	1.6	22.2	16.1	4.1	100	0.1	37.2	1.0	20.3	37.5	4.0	100
Venezuela	0.4	46.6	34.7	15.0	0.0	3.3	100	1.3	53.6	17.5	26.1	0.7	0.8	100

Source: Authors based on OLADE (2023e).

Table A.2.3

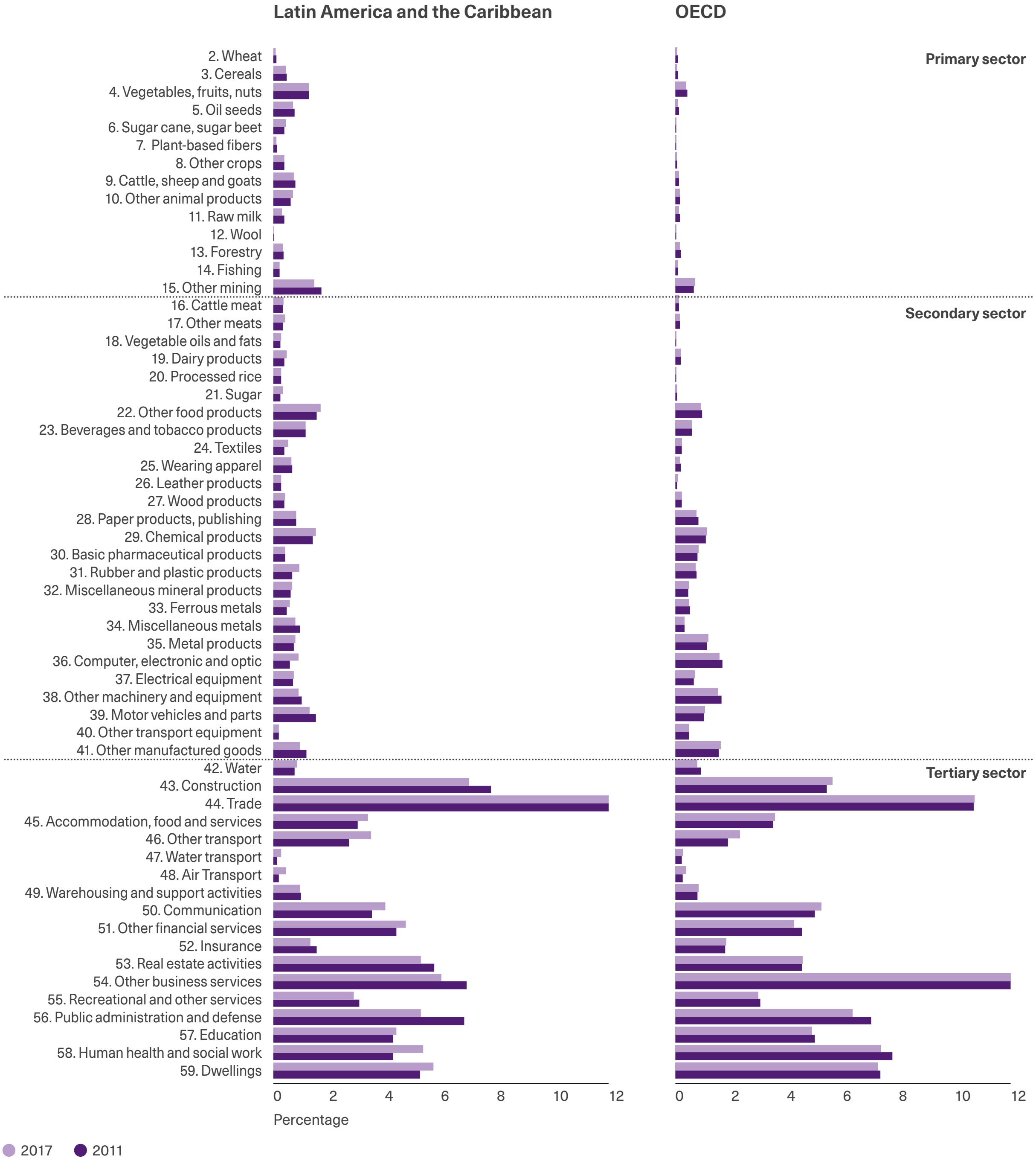
Electrical energy generation by source in selected Latin American and Caribbean countries

	2000										2019									
	Coal	Gas	Hydro	Solar	Wind	Oil	Nuclear	Bioenergy	Other renewables	Total	Coal	Gas	Hydro	Solar	Wind	Oil	Nuclear	Bioenergy	Other renewables	Total
	Percentage										Percentage									
Antigua and Barbuda	-	-	-	-	-	100.0	-	-	-	100	-	-	-	2.9	-	97.1	-	-	-	100
Argentina	2.0	53.9	33.4	-	0.0	3.2	7.0	0.4	-	100	0.8	64.7	20.5	0.6	3.7	2.4	6.0	-	1.2	100
Bahamas	-	-	-	-	-	100.0	-	-	-	100	-	-	-	-	-	100.0	-	-	-	100
Barbados	-	-	-	-	-	100.0	-	-	-	100	-	-	-	3.9	-	96.1	-	-	-	100
Belize	-	-	50.0	-	-	50.0	-	-	-	100	-	-	34.1	1.1	-	46.6	-	-	18.2	100
Bolivia	-	34.2	51.7	-	-	11.1	-	2.9	-	100	-	54.0	32.2	1.9	0.7	4.0	-	-	7.2	100
Brazil	3.1	1.1	88.0	-	-	4.2	1.4	2.2	-	100	3.8	9.4	64.3	1.1	9.0	1.5	2.5	-	8.5	100
Chile	22.9	25.6	47.5	-	-	3.9			-	100	36.7	18.5	26.9	8.2	6.2	3.1		0.3		100
Colombia	6.8	16.3	75.3	0.0	-	1.2	-	0.5	-	100	7.5	16.2	67.8	0.2	0.1	6.9	-	-	1.5	100
Costa Rica	-	-	82.0	-	2.6	1.0	-	-	14.3	100	-	-	67.8	0.7	15.7	2.2	-	13.2	0.3	100
Cuba	-	-	0.6	-	-	99.4	-	-	-	100	-	7.7	0.7	1.2	0.1	77.0	-	-	13.3	100
Dominica	-	-	42.9	-	-	57.1	-	-	-	100	-	-	22.2	-	-	77.8	-	-	-	100
Ecuador	-	-	72.8	-	-	27.2	-	-	-	100	-	1.1	76.4	0.1	0.3	20.9	-	-	1.3	100
El Salvador	-	-	31.1	-	-	45.6	-	2.1	21.2	100	-	-	24.0	8.3	-	30.7	-	24.5	12.4	100
Grenada	-	-	-	-	-	100.0	-	-	-	100	-	-	-	-	-	100.0	-	-	-	100
Guatemala	7.0	-	41.5	-	-	40.1	-	8.1	3.3	100	24.3	-	32.4	1.7	2.4	15.6	-	2.2	21.4	100
Guyana	-	-	-	-	-	93.2	-	6.8	-	100	-	-	-	0.8	-	86.9	-	-	12.3	100
Haiti	-	-	52.8	-	-	47.2	-	-	-	100	-	-	16.7	-	-	83.3	-	-	-	100
Honduras	-	-	63.3	-	-	36.7	-	-	-	100	4.5	-	21.9	10.1	7.4	44.0	-	2.7	9.5	100
Jamaica	-	-	1.8	-	-	92.6	-	5.6	-	100	-	29.2	3.8	2.1	6.4	55.5	-	-	3.1	100
Mexico	8.9	18.9	16.9	0.0	0.0	45.2	4.0	3.0	3.0	100	9.2	59.1	7.4	2.2	5.3	9.8	3.4	1.6	2.1	100
Nicaragua	-	-	9.9	-	-	79.3	-	4.7	6.1	100	-	-	5.1	0.7	16.3	48.4	-	17.4	12.1	100
Panama	-	-	71.0	-	-	28.6	-	0.4	-	100	9.3	8.4	49.1	3.3	7.0	22.2	-	-	0.7	100
Paraguay	-	-	100.0	-	-	0.0	-	-	-	100	-	-	99.7	-	-	0.1	-	-	0.1	100
Peru	1.2	2.6	81.9	-	-	14.0	-	0.3	-	100	0.9	30.8	55.3	1.4	2.9	7.5	-	-	1.3	100
Dominican Republic	5.6	-	9.3	-	-	85.2	-	-	-	100	18.2	20.7	5.0	1.9	4.1	48.8	-	-	1.2	100
Saint Kitts and Nevis	-	-	-	-	-	100.0	-	-	-	100	-	-	-	-	4.5	95.5	-	-	-	100
Saint Vincent and the Grenadines	-	-	33.3	-	-	66.7	-	-	-	100	-	-	14.3	-	-	85.7	-	-	-	100
Saint Lucia	-	-	-	-	-	100.0	-	-	-	100	-	-	-	-	-	100.0	-	-	-	100
Suriname	-	-	50.7	-	-	49.3	-	-	-	100	-	-	48.7	0.5	-	50.8	-	-	-	100
Trinidad and Tobago	-	90.1	-	-	-	9.3	-	0.6	-	100	-	98.8	-	0.1	-	1.0	-	-	-	100
Uruguay	-	-	93.2	-	-	6.5	-	0.3	-	100	-	10.8	50.5	2.6	29.6	0.9	-	-	5.5	100
Venezuela	-	15.3	74.7	-	-	10.0	-	-	-	100	-	27.7	59.8	0.0	0.1	12.4	-	-	-	100

Source: Authors based on data processed by Our World in Data (2023b), obtained from Ember (2023) and Energy Institute (2023).

Graph A.2.1

Economic structure of Latin America and the Caribbean and OECD in 2011 and 2017

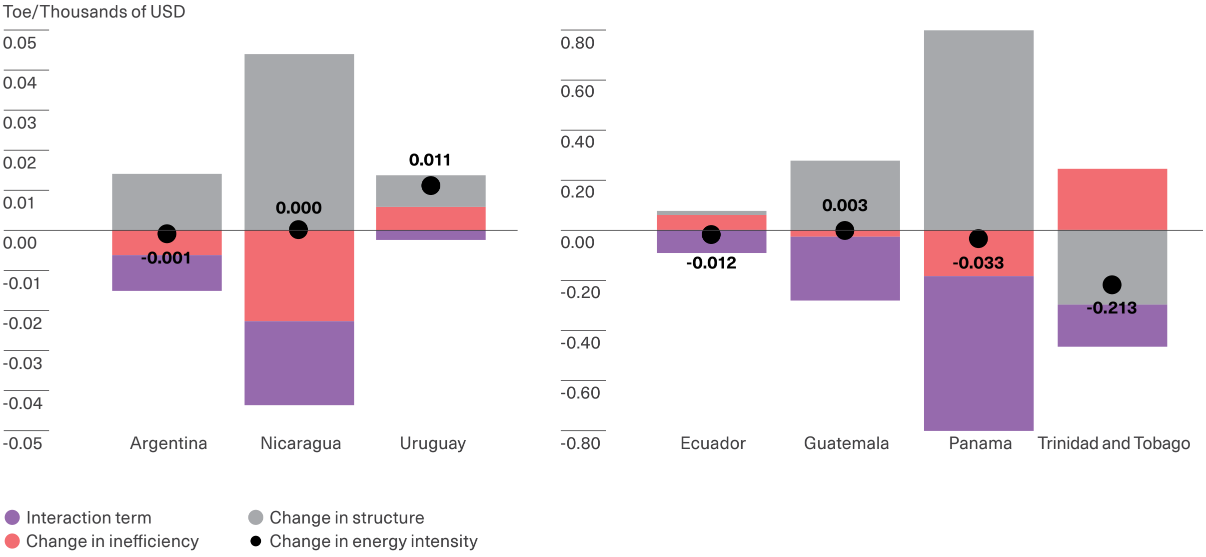


Note: Latin America and the Caribbean includes 19 countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago and Uruguay). The OECD includes member countries, with the exception of those in Latin America (Chile, Colombia, Costa Rica, and Mexico) and Iceland, as it is not included in the GTAP databases.

Source: Authors based on World Bank (2023h, 2023i) and Aguiar et al. (2016, 2022).

Graph A.2.2

Decomposition of changes in energy intensity (countries not included in the main text)



Source: Allub, Álvares and Brugiafreddo (2024).

Chapter 3 Appendix

Energy matrix of Latin America and the Caribbean

Table 3.1 provides a snapshot of the energy matrix of Latin America and the Caribbean for the period 2017–2021, based on data from OLADE's energy matrix (EM) (2023b) and electricity generation reports (OLADE, 2023a). All data represent the regional aggregate and the average for the period 2017–2021.

The table is divided into two sections: the upper section corresponds to the electricity sub-matrix, and the lower section pertains to the fuel sub-matrix.

Electricity sub-matrix

This section includes the final consumption of electricity across all non-energy sectors and all the primary inputs necessary to meet that consumption. On the right side, in column (e), the table displays the final consumption of electricity across all non-energy sectors (residential; agriculture, fishing, and mining; commerce; transportation; industry; and construction), as reported in the EM. On the left side, in column (a), it shows all the primary energy inputs required to produce that electricity, distinguishing between non-fuel and fuel inputs, as well as the composition of these inputs within each category. Non-fuel primary inputs include hydro, geothermal, solar, wind, and nuclear energy. Fuel-based primary inputs encompass natural gas, coal, oil, and biomass (which includes all organic materials such as firewood and sugarcane).

Between the primary inputs and the final consumption of electricity in non-energy sectors, there are losses associated with the processes of transformation and transportation of the inputs until they reach the end users. Column (d) highlights the electricity losses that occur between total generation and consumption, calculated as the difference between the total generation of electricity (from both power plants and self-producers, as reported in the EM) and the final consumption of electricity.

Column (c) shows total electricity generation, distinguishing between generation from fuel and non-fuel sources. These values are calculated by taking the share of generation from thermal sources relative to the rest of the generation matrix (GM) and attributing it to the electricity generated shown in the EM. In addition, net electricity imports, which are negligible for the region as a whole, are detailed.

Column (b) shows the energy losses incurred during electricity generation, derived from the difference between the inputs used and the electricity generated. These losses occur partly during the transformation of primary fuels (biomass, oil, and coal) into their derivatives (e.g., firewood, diesel, coke), and partly during the generation phase due to the operational efficiency of the generators. For instance, thermoelectric generation involves substantial energy losses in the form of unused heat.

Column (a) lists the primary energy inputs by source. The figures in this column represent the total primary energy estimated to be required to generate the electricity produced by power plants and self-producers as reported in the EM. For hydro, geothermal, and nuclear energy, the reported value corresponds to the total supply quantities indicated in the EM. For solar energy, the total inputs are derived from the "other primary" category in the EM, based on the reported share of solar energy in the GM with respect to solar, wind, other renewables, and renewable thermal energy:

$$\textit{Input for solar energy} = \begin{array}{r}\textit{other primary}\\ \textit{sources}^{EM}\end{array} \times \frac{\textit{solar energy}^{MG}}{\textit{solar}^{EM}+\textit{wind}^{EM}+\textit{other}^{EM}+\textit{renewable thermal}^{EM}}$$

This procedure is applied analogously for wind energy.

For the case of fuels used in electricity generation, the total inputs required are estimated from the values reported in the EM as input in power plants and self-producers, adjusted for: 1) primary energy self-consumption, 2) transformation process losses, and 3) secondary energy self-consumption, as applicable. The factors are calculated as follows:

$$\text{self-consumption factor}_{s,p\,i} = \frac{\text{production}_i + \text{self-consumption}_i + \text{losses}_i + \text{adjustments}_i}{\text{production}_i}$$

Where *i* represents the energy source, which can be either primary (subscript *p*) or secondary (subscript *s*).

$$\text{transformation factor}_i = \frac{\sum I_{ct\,i}}{\sum O_{ct\,i}}$$

Where *I* and *O* correspond to the energy entering and leaving the transformation center, respectively. The subscript *ct* indicates the type of transformation center: refineries, gas plants, coking plants and blast furnaces, coal plants, and other transformation centers. The subscript *i* indicates the type of fuel: oil, natural gas, coal, gasoline, diesel, charcoal, etc.

In the case of primary fuels (coal, natural gas, oil, firewood, and sugarcane) used directly in electricity generation, only the primary energy self-consumption factor is adjusted, which accounts for the energy required for primary production and transportation of these fuels. For secondary energy inputs, that is, those that have undergone transformation processes, the primary energy self-consumption factor, the transformation loss factor, and the secondary energy self-consumption factor are applied. This applies to fuels derived from oil (e.g., diesel, fuel oil), coal (e.g., coke), and biomass (e.g., charcoal). In biomass-based fuel generation, the sum of biomass from firewood, sugarcane, and other non-conventional renewable energy (NCRE) sources (which corresponds to the net value of solar and wind energy) is considered.

Fuel sub-matrix

In the lower module of the table, this sub-matrix presents the consumption of all types of fuels in non-energy sectors, including energy use and inputs for production processes. Up the supply chain, it includes all the energy inputs required to obtain the fuels consumed in non-energy sectors. Fuel consumption in non-energy sectors is presented in column (e) by sector, as reported in the EM.

Column (b) shows the transformation losses of fuels, obtained by the difference between the reported final consumption values and the estimated primary inputs. Column (a) lists the primary fuels by source (natural gas, oil, coal, biomass), estimated by the difference between the total supply of each source reported in the EM and the primary energy allocated to the electricity sub-matrix, whose estimation is described above.

Calculation of emission factors

The methodology for calculating direct, indirect, and domestic fugitive emission factors associated with the fuels and electricity consumed in non-energy sectors is outlined below.

Natural gas emissions

1. Direct emissions:

$$\text{Direct factor} = \alpha_{GN}$$

This value corresponds to the emission factor for natural gas in stationary sources as per IPCC (2006)

2. Indirect emissions, accounting for losses in the production, transportation, and transformation processes:

$$\beta_{NG} = \alpha_{NG} \times \frac{\underset{\text{production}}{\text{NG}} + \underset{\text{losses}}{\text{NG}} + \underset{\text{adjustments}}{\text{NG}} + \underset{\text{NG attributed to NG}}{\text{self-comsump. of P and}}}{\text{NG production}}$$

The term “attributed self-consumption” refers to the consumption of oil and gas during the production phase of both products, attributable to natural gas. Oil and gas are typically extracted together, requiring energy for processes such as pressurization of reservoirs and pipeline pumping. Since the source data does not allow distinguishing self-consumption associated with oil production from that associated with gas production, it is attributed according to their share in joint production.

3. Indirect emissions also include fugitive methane emissions:

$$\gamma_{NG} = \beta_{NG} + \frac{\underset{\text{in the production and transport}}{\text{NG-attributed methane emissions}}}{\underset{\text{consumption}}{\text{NG final}} + \underset{\text{electricity generation}}{\text{consump.in NG}} + \underset{\text{ofNG}}{\text{net exports}}}$$

This factor accounts for methane leaks and releases in exploration, production, and transportation processes, including leaks in pipelines and natural gas liquefaction and regasification facilities. Methane emissions data are obtained from IEA (2023j).

Emissions of petroleum products (example for gasoline)

1. Direct emissions:

Direct factor = α_G

This value corresponds to the emission factor for gasoline in stationary sources as per IPCC (2006).

2. Indirect emissions, accounting for losses in gasoline transformation processes.

$$\beta_G = \alpha_G \times \frac{\underset{\text{of P}}{\text{production}} + \underset{\text{of P}}{\text{loses}} + \underset{\text{of P}}{\text{adjustments}} + \underset{\text{and NG attributed to P}}{\text{self-conump. of P}}}{\text{producction of P}} \ldots$$

(Component of oil self-consumption, P).

$$\times \frac{\text{input of P in transformation centers}}{\text{derivative production of P}} \ldots$$

Component of oil transformation losses (P). Multiplier is 1 if oil is not refined

$$\times \frac{\underset{\text{production}}{\text{derivative}} + \underset{\text{losses}}{\text{derivative}} + \underset{\text{adjustments}}{\text{derivative}} + \underset{\text{NG attributed to derivates}}{\text{self-conump. of P and}}}{\text{derivative production}}$$

(Component of self-consumption of oil derivatives).

For this computation, refineries and gas centers reported in the EM are considered as transformation centers.

The term “attributed self-consumption” refers to the consumption of oil and gas during the production phase of both products, attributable to oil. Oil and gas are typically extracted together, requiring energy for processes such as pressurization of reservoirs and pipeline pumping. Since the source data does not allow distinguishing self-consumption associated with oil production from that associated with gas production, it is attributed according to their share in joint production.

3. Indirect emissions, additionally accounting for fugitive emissions and methane releases attributable to gasoline:

$$\gamma_G = \beta_G \times \frac{\underset{\text{and transportation attributed to P}}{\text{fugitive methane emissions in production}}}{\underset{\text{of P and der.}}{\text{final consump.}} + \underset{\text{generation of P and der.}}{\text{consump.in electricity}} + \underset{\text{of P and der.}}{\text{net exports}}}$$

This factor accounts for methane leaks and releases during oil exploration, production, and transportation processes. Methane emission data is obtained from IEA (2023j). This term applies to all oil derivatives.

Emissions associated with electricity

1. Direct combustion emissions for generation:

$$\alpha_E = \frac{\sum Q_i \alpha_i}{Electricity\ generation}$$

In this formula, *i* refers to the different fuels used, Q_i is the quantity of fuel and α_i is the factor applied to it. This factor is an average of the emission factors for fuels in stationary sources as per IPCC (2006), weighted by the amounts used in each country.

2. Indirect emissions, accounting for energy losses in the transformation processes of fuels used in generation:

$$\beta_E = \frac{\sum Q_i \beta_i}{Electricity\ generation}$$

In this formula, β are the indirect fuel emissions factor estimated in this work for the countries of Latin America and the Caribbean as a whole.

3. Indirect emissions, accounting for fugitive emissions and methane releases associated with the fuels used in generation:

$$\gamma_E = \frac{\sum Q_i \gamma_i}{Electricity\ generation}$$

In this formula, γ are the indirect and fugitive fuel emissions factor estimated in this work for the countries of Latin America and the Caribbean as a whole.

4. Indirect emissions, accounting for self-consumption of electricity by generators and electricity transmission and distribution losses in each country:

$$\eta_E = \frac{\sum Q_i \gamma_i}{electricity\ generation} \times \frac{electricity\ generation}{electricity\ consumption}$$

Chapter 4 Appendix

Electrical generation technologies

Combustion

Combustion power plants, which rely on either internal combustion engines or turbine generators for thermoelectric generation, are quite common in the region. Frequently used in transportation, internal combustion engines have a wide range of capacity, from domestic and industrial micro-generators to large-scale applications on the wholesale market that can cover peak demand. Two types of turbine generators are used in electrical generation: gas turbines, powered by the burning of fuel inside the turbine, and steam turbines, powered by steam produced in a boiler located outside the turbine. Coal plants, which generally have a greater capacity than thermoelectric ones, run on steam turbines.

Combined-cycle thermoelectric generation plants that run on natural gas operate in two stages. The first stage consists of a gas turbine, like the one described earlier. The second takes the high-temperature gases produced in the first stage and circulates them via a heat exchanger to produce steam, which then flows through a turbine.

The type of technology used for this type of generation requires fuels with certain characteristics. In steam-power thermoelectric plants like those described above, steam is produced via combustion inside boilers. This enables compatibility or the reconversion of the types of fuels that can be used. For example, the co-combustion of coal (or gas) and biomass from sustainable sources has been cited as a promising strategy for the decarbonization of the electricity sector during the energy transition, given that it enables a reduction of emissions within a relatively short period and with moderately low capital costs (IRENA and ETSAP, 2013).

On the other hand, thermoelectric generation that relies on gas turbines is mainly fueled by natural gas and can incorporate gases produced in the fermentation of waste (biogas) or hydrogen, either in their pure state or mixed with the principal component, e.g., natural gas. These power plants cannot utilize solid fuels, nor is it viable to reconvert them for this use. The exception to this is the biomass gasification process, which is highly energy-intensive and has scarcely been used to date.

In thermoelectric generation, as with any process involving mechanical heat conversion, a significant portion of the energy is lost to residual heat, which generally dissipates in the atmosphere or can be used for applications with lower energy quality. The efficiency (relationship between the electricity produced and the inputs used) of thermoelectric plants varies according to the type of input and the technology used. As for plants that rely on internal combustion—which mainly use heavy petroleum distillates like diesel and kerosene—their efficiency is approximately 45%. Besides the higher cost of these inputs, petroleum distillates release more emissions and contaminate local air. Steam-powered plants run on coal, the most economical input but also the one with the highest emissions and air contaminants, with an average efficiency of around 43%. The efficiency of open-cycle plants that run on natural gas—an input cleaner than oil or coil, with middle-range costs and lower GHG emissions—ranges between 35 and 39%, while combined-cycle plants reach efficiency rates of 51% (IRENA, 2019a).

Thermoelectric plants also differ in terms of their operating flexibility. Each power plant has specific limitations in terms of the startup time, the minimal operating load, ramp-up speed, and the minimum time they must remain off or on. Operational flexibility is an increasingly valuable feature as intermittent generation sources (like solar and wind power) are integrated. This adds another layer of complexity to the balance between costs, efficiency, and emissions. In general, coal plants are the least flexible and are typically designed for baseload generation, followed by combined-cycle gas plants and finally, open-cycle gas plants. Power plants that run on internal combustion are more flexible and generally serve peaks, particularly unpredictable ones, though their running costs are also the highest (IRENA, 2019a).

Geothermal energy

Geothermal energy relies on heat deep beneath the ground, mainly generated by nuclear reactions between the mantle and crust, as well as primordial heat left over from the earth's original formation. This heat flows to the upper, cooler layers, and accessing it for its use as energy depends on factors like the depth of the well and the presence of faults. When the temperature in the well exceeds 150°C, electricity can be generated with steam.

Geothermal energy can be applied for heat generation and direct uses. Shallow, cool geothermal energy has direct uses like heating and cooling. In order to generate electricity, it is necessary to access deeper geothermal wells (generally more than 2 km underground) where the temperature and pressure are high enough to produce steam. The surface is drilled to access the steam, which is drawn to the surface to power a turbogenerator and later reinjected into the reservoir to maintain its level and pressure.

Geothermal energy is a renewable, sustainable resource but there are major obstacles to increasing its installed capacity due to restrictions associated with its availability, high levels of uncertainty, and the hefty investments associated with exploration and drilling. These factors make geothermal energy development a risky wager and it generally relies on the public sector for funding.

Nuclear energy

Unlike many sources of electricity, nuclear energy has low GHG emissions and unlike solar, wind, geothermal, and hydropower, it does not depend on natural conditions. In addition, nuclear generation is less affected by the price volatility of inputs, given that fuel represents a very low portion of running costs in comparison to fossil fuel generation. In addition, nuclear plants go for lengthy periods before refueling. Therefore, nuclear energy can be a valuable asset as intermittent energy sources are incorporated. In the region, only three countries have nuclear power plants: Argentina, which has three power plants with a total capacity of 1.8 MW; Brazil, which has two power plants (2 GW); and Mexico, with a single 1.5 GW power plant.

A major obstacle to the expansion of nuclear energy is the more demanding security standards that new projects must meet. While the levelized costs of electrical generation using solar and wind energy have fallen continuously in recent decades, the costs of nuclear energy have risen, especially since the 2011 accident in Fukushima, Japan, when security standards increased. Currently, levelized costs for nuclear generation start at USD 141/MWh, almost doubling the upper range of estimates for wind energy (Lazard, 2023).

However, the comparison requires careful analysis given that nuclear energy offers a firm supply during dips in renewable sources when the value of the generated energy is higher. At the same time, nuclear energy can offer ancillary services such as frequency regulation that are paid separately from generation. In addition, most nuclear power plants currently in operation and all those under construction have a certain capacity for flexible operations. This allows generation to be adjusted to demand requirements at each moment while ensuring variation from one season to the next to optimize the availability of freshwater resources (IEA, 2019b; Jenkins et al., 2018).

Small modular reactors (SMR) represent a promising development for nuclear generation. Research and development is being done on these low-capacity reactors (power capacity of between 10 and 300 MW)[1] and micro-generators (up to 10 MW) that can almost be completely built in a controlled factory setting while leveraging economies of scale. These two features, along with the smaller capital investment that SMR requires in comparison to traditional power plants, can help overcome the main barriers to new nuclear power projects.

SMRs are being developed in several formats, mainly in the United States, France, China, and Russia. These countries are working on the large-scale production of micro-generators of electric energy with capacities ranging from 1 MW to 350 MW (Derdevet and Mazzucchi, 2021). In 2020, the IEA identified over 70 projects in 16 different countries (Perczyk and Rabinovich, 2023). Although the small modular reactor technology is not yet mature and is still in the research, development, and demonstration phase, it can play a prominent role in supply security at times and in places where renewables are scarce.

Hydropower

Societies have leveraged the power of moving water as a source of energy for centuries, principally to power mills for the production of flour. Nowadays, more electric plants run on hydropower than any other generation source. The Itaipú dam, a hydroelectric power plant shared in equal parts by Paraguay and Brazil, is the second largest in the world in terms of its average annual output.

There are two principal types of hydroelectric plants: those with the capacity to store water, and those without. Hydroelectric plants with dams have a reservoir that allows them to control electric generation, closing the floodgates and increasing the stored volume when the electricity demand is low, and opening the floodgates to enable water to flow out from the dam, even at a flow rate greater than the water the dam receives. Hydroelectric power plants located on a watercourse, in contrast, have little or no capacity for storage.

Water storage capacity offers advantages to the electric system, given that it enables a flexible response to demand, addressing daily, seasonal, and on occasion, multi-annual requirements. In addition, storage can contribute ancillary services to electric systems that other renewable technologies are not able to provide (such as power capacity reserves and frequency regulation) and therefore, are an ideal way to increase the share of all renewable technologies.

However, the construction of a dam can cause major environmental and social impacts, including global warming. The flooding of large stretches of vegetation-covered land and the retention of organic sediment to build a hydroelectric dam can result in CO_2 and methane emissions due to the decomposition of the organic material. The emissions at nearly 10% of the world's hydroelectric plants are similar to or higher than those of thermoelectric power plants running on fossil fuels (Scherer and Pfister, 2016). The emissions profile of man-made water reservoirs

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[1] 300 MW of nuclear power capacity is the equivalent of nearly 2 MWh annually. For comparison purposes, the average capacity of nuclear power plants worldwide is over 2,000 MW.

depends on the amount of carbon stored in the vegetation and flooded soils. Their intensity increases with higher water temperatures and is more or less proportional to the surface size of the reservoir. Therefore, the choice of the site of a dam is key to achieving the lowest possible emissions as electricity is generated (Almeida et al., 2019).

Pumped-storage hydro plants are one type of hydroelectric plant that have sparked growing interest. These consist of two dams with storage capacity located at two points along a single watercourse. When demand is greater, they can generate electricity, enabling water to flow from the upper reservoir to the lower reservoir. When there is surplus electricity, the water can be pumped and the energy can be stored in the upper reservoir. This type of installation will be increasingly more valuable as intermittent generation sources are incorporated. At the same time, the region has great unexplored potential for this technology, given the conditions of the terrain and the availability of water in the Andes (Perczyk and Rabinovich, 2023).

Solar energy

Photovoltaic energy is a source of energy from sun radiation that allows electricity to be produced through semiconductors or a thin film for the deposition of metals.

To date, there are two types of photovoltaic solar energy facilities: 1) parks connected to the transmission network with a high electric power capacity, and 2) individual household, business, or industrial installations that may or may not be connected to the distribution network (distributed generation). In both cases, battery storage systems can be included. These prove highly useful in isolated systems or towns far from transmission networks.

Solar energy can also be transformed into electricity using a technology known as concentrating solar-thermal power (CSP). This technology produces electricity by using mirrors to concentrate sun rays that heat a medium (generally a liquid or gas), producing steam that is then used to power a turbine or gas to drive an electric generator. One alternative that this technology permits is thermal chemical storage, heating molten salts to general electricity even at moments in which solar power is not available.

Wind energy

The power of wind can be transformed into mechanical energy, for example, to pump underground water or power mills, technologies that date back to the nineteenth century. Nowadays, it is mainly used to power generators and produce electricity.

Though the first wind parks were built on shore, they are increasingly located offshore, where wind conditions are generally more favorable. Offshore wind parks also reduce negative impacts on the landscape and environment. However, offshore wind parks are more costly and in order to reduce the unit generation costs, they need to produce appreciable profits in order to be competitive. There are two types of technology for offshore wind parks. The first is installed in shallow coastal waters that rest on the sea floor (for example, the parks in Northern Europe, installed in 30-meter deep waters and, on average, 33 km from shore). The second requires floating semi-submersible platforms or tension leg platforms in deeper coastal waters (like those located in the Pacific Ocean in the Americas).

As technology evolves, essentially through an increase in the power unit modules of aerogenerators and the subsequent reduction in unit production costs, the share of this technology in the world's electric matrix has risen. The improved efficiency of aerogenerators has also increased the capacity of existing wind parks. Smaller equipment has been replaced by units with more power, increasing the installed capacity without requiring additional space.

Batteries and other storage methods

Unlike other secondary energy sources, electricity has presented the most challenges in terms of storage. Batteries and other storage devices play an important role by providing time-bound services: a few seconds or minutes in the case of frequency control, and hours or days when the stored energy is released upon demand (hourly or daily matching). The most common types of storage today include hydroelectric pump storage systems, which cost less than other alternatives and are most commonly used for matching; flywheels for frequency control and backup energy; and, though to a lesser extent, air compression storage systems.

Though batteries have existed for some time, they have found a new use as a storage device for energy matching. They are also being used to satisfy peak demand and in frequency regulation services, for both utility-scale batteries and for those located on solar or wind farms or behind the meter (independent batteries or those coupled to residential or industrial solar panels).[2] The cost of Li-ion batteries has been falling for both large-scale and distributed generation but must continue dropping in order to be competitive. As the market develops, competitive solutions will gradually appear for the recycling or disposal of these batteries (Pellow et al., 2020).

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[2] See Noussan (2022) and Lazard (2023). Li-ion are also used to power electric vehicles.

Changes in renewable energy generation (solar and wind), 2010–2021

Table A.4.1

Changes in solar and wind generation, 2010–2021 in GWh per year and as a percentage of annual generation

Country	Wind energy		Solar energy		% NCRE in generation 2010	% NCRE in generation 2021
	2010	2021	2010	2021		
Argentina	25	12,938	0	2,196	0%	11.1%
Barbados	0	0	2	85	0%	8.0%
Belize	0	0	1	3	0%	1.0%
Bolivia	0	120	0	351	0%	4.3%
Brazil	2,177	72,286	0	16,752	0%	13.6%
Chile	318	7,210	0	10,787	1%	22.1%
Colombia	39	60	0	323	0%	0.5%
Costa Rica	359	1,573	0	9	4%	12.6%
Cuba	11	28	1	237	0%	1.4%
Ecuador	3	62	0	37	0%	0.3%
El Salvador	0	132	0	1,074	0%	18.6%
Grenada	0	0	0	4	0%	1.8%
Guatemala	0	324	0	230	0%	4.6%
Guyana	0	1	0	13	0%	1.2%
Haiti	0	0	0	4	0%	0.4%
Honduras	0	775	0	1,129	0%	17.4%
Jamaica	53	264	0	132	1%	9.2%
Mexico	166	21,075	0	20,194	0%	12.6%
Nicaragua	163	656	0	27	4%	16.2%
Panama	0	530	0	586	0%	8.0%
Paraguay	0	0	0	0	0%	0.0%
Peru	1	1,823	0	802	0%	4.6%
Dominican Republic	0	1,231	0	486	0%	8.0%
Suriname	0	0	0	13	0%	0.5%
Trinidad and Tobago	0	0	0	0	0%	0.0%
Uruguay	70	4,991	0	483	1%	34.3%
Venezuela	0	18	2	0	0%	0.0%

Note: The table shows the total values and share of wind and solar energy in total generation in 2010 and 2021 for the countries of LAC with available data.

Source: Author based on data from OLADE (2023a).

Table A.4.2

Prices assigned in solar and wind energy auctions

Source	Country	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Wind energy	Argentina								56.2	40.9		58.0				
	Brazil	76.5	75.2	59.3	45.0	54.2	58.0	57.5		31.0	24.3	24.7		33.0	35.0	
	Chile							57.1	45.3	34.1						
	Colombia											30.3		41.6		
	Costa Rica					71.6	62.8	74.8	80.0	77.7	77.0	77.4		81.7	86.0	
	El Salvador									98.8						
	Jamaica															
	Mexico							52.9	40.9	19.0	18.6					
	Panama			90.6		96.7		95.0								
	Peru		80.4	69.0					37.8							
	Uruguay		85.0	63.0	63.0											
Solar energy	Argentina								57.0	42.8		57.6				
	Brazil						91.4	89.8		45.6	32.3	20.3		29.6	35.2	
	Chile							62.3	29.1	35.7						
	Colombia										29.5			41.6		
	Costa Rica					136.1	90.4	211.3								
	El Salvador					184.7	118.0			55.3						
	Jamaica							85.4								
	Mexico						50.7	30.1	37.8	21.8	19.0					
	Panama						95.4		74.9					55.1		104.8
	Peru		221.0	119.9					48.1							
	Uruguay					87.5										

Note: The table presents the prices assigned in the electricity generation auctions for wind and solar carried out in LAC countries where information is available. The table does not include calls for tenders that were declared null and void or those that do not specify the technology assigned. In certain countries, pricing may vary between geothermal and biomass sources. No information is provided for Guatemala because the auction values there are for power. In Mexico and Panama, the values of the energy auctions are included (see OLADE, 2020, for the power auction). In the case of Panama, the prices assigned in 2021 and 2023 correspond to the solar energy companies Photovoltaics Development Corp. and Photovoltaics Investment Corp. (2021), and Gensol and Spower (2023). At the same time, prices were also assigned for other renewable energy sources like hydropower.

Source: Author based on Rodríguez Pardina (2022), the CCEE (2023), Grupo ICE (2020, 2021, 2022), ETESA (2021, 2023), and OLADE(2020).

Table A.4.3

Latin American and Caribbean countries and territories included in Graph 4.9 with the corresponding ISO code

Country	ISO	Country	ISO
Argentina	ARG	Haiti	HTI
Antigua and Barbuda	ATG	Jamaica	JAM
Bahamas	BHS	Saint Kitts and Nevis	KNA
Belize	BLZ	Saint Lucia	LCA
Bolivia	BOL	Mexico	MEX
Brazil	BRA	Nicaragua	NIC
Barbados	BRB	Panama	PAN
Chile	CHL	Peru	PER
Colombia	COL	Puerto Rico	PRI
Costa Rica	CRI	Paraguay	PRY
Cuba	CUB	El Salvador	SLV
Dominica	DMA	Suriname	SUR
Dominican Republic	DOM	Sint Maarten (Dutch part)	SXM
Ecuador	ECU	Turks and Caicos Islands	TCA
Grenada	GRD	Trinidad and Tobago	TTO
Guatemala	GTM	Uruguay	URY
Guyana	GUY	Saint Vincent and the Grenadines	VCT
Honduras	HND	Venezuela	VEN
Guatemala	GTM	British Virgin Islands	VGB
Guiana	GUY	US Virgin Islands	VIR
Honduras	HND		

Incorporation of renewable generation: Experiences of LAC countries

This annex describes the regulatory mechanisms introduced in the region's countries to incorporate NCRE sources into electric generation.

Argentina

Under Argentine legislation (Law 26,190 from 2006 and Law 27,191 from 2015), 8% of energy demand was supposed to have been met with renewable sources by 2017 and 20% by 2025. From 2009–2011, a series of auctions were held as part of the Electric Energy Generation from Renewal Sources (GENREN) Program. Though the assigned prices were USD 125.97 per MWh for wind and USD 567.71 per MWh for photovoltaic solar energy, less than 25% of the energy awarded was actually put into service. From 2016–2019, the Ministry of Energy organized a series of renewable energy auctions (different ones for each type of technology) under a program called RenovAr. The winning offers were structured under a power purchase agreement (PPA) with CAMMESA, Argentina's dispatch authority, which pays for capacity or energy delivered to the system. The government pays the difference between the price guaranteed under the PPA and the price paid for demand (which is subsidized). Auctions were held for wind, photovoltaic solar, biomass, biogas, small hydroelectric, and biogas from sewage and industrial waste. At the end of 2021, the Department of Energy passed Resolution 1260/21 to terminate contracts or get execution back on track for projects that had not yet obtained operating permits in order to free up capacity and network engagements for new projects. Bellato (2022) provides a summary of 91 projects yet to begin that are at different stages of contract termination, renegotiation, negotiated exits, or court proceedings.

Brazil

Due to limits to the incorporation of capacity—most notably due to the drought in 2001 (Dutra and Menezes, 2005)—the generation market was reformed in 2004. The new centralized structure was based on a combination of auctions and long-term contracts (Hochberg and Poudineh, 2021). Distributors must procure 100% of estimated demand. These auctions are centralized under the Electric Energy Trading Chamber (CCEE, the dispatch authority), which establishes the origin of the energy (new or existing), the eligible technologies, the quotas by technology type, the service rendered (reserve energy services are auctioned separately and the buyer is the CCEE, which is financed by a charge applied to all users). The entity also sets the quantities and term of the contracts (for existing energy, 1–15 years regardless of technology type; for new hydropower, 30 years; for new thermal energy, 20–25 years). Major users (those with a demand exceeding 1.5 MW) and some consumers with a special status whose demand exceeds 0.5 MW negotiate storage conditions individually with generators or resellers (under bilateral contracts or private auctions). All contracts must be backed by firm energy certificates (the capacity that a generator can procure) issued by the Mining and Energy Ministry.

This mechanism facilitated the incorporation of NCRE sources, first through feed-in tariffs and later, since 2007, through auctions. Initially, these were applied to new energy (wind, solar, hydroelectric, biomass, and solid urban waste) under 20-year contracts and, later, to existing energy auctions.

Chile

Chile has held tenders for electric energy provision since 2013. Unlike other countries, where parties bid on power capacity in MW, what is auctioned here are blocks of energy (in GWh). Contracts are technology-neutral (not specific to any single technology) and thus do not directly target electric generation with renewables (OLADE, 2020). Renewable energies in Chile thus compete price-wise with energies from conventional sources, unlike what occurs in countries like Argentina and Peru (Rodríguez Pardina et al., 2022). Each tender is organized into "provision blocks" that individually represent the maximum amount of energy any single supplier can provide and also the total amount of energy that should be covered by the tender (OLADE, 2020).

This market design is based on an auction system to supply most of the regulated demand in contracts lasting 5–30 years. The tender process can be decentralized (at the level of distribution companies or groups of distributors) or partially centralized (delegating the responsibility for the tender design and management to the Chilean National Energy Commission, or CNE). In order to promote the integration of NCREs, a fraction of the energy that generators supply must come from these sources (10% in 2008 and 20% since 2013) either directly or indirectly (through other companies). Based on this requirement, the energy auction system was expanded to incorporate time blocks (11 pm to 8 am, 8 am to 6 pm or 11 pm) or quarterly blocks. The Chilean Ministry of Energy is in charge of tracking these auctions and, if necessary, holding other auctions to meet the required quotas. Instead of subsidies, the cost was incorporated directly into tariffs, but benefits for small generators (9 MW, later increased to 20 MW) include a total or partial exemption from the payment of transmission costs. The combination of existing energy prices and the increasingly lower costs of wind or solar generation allowed these sources to be incorporated without any problems (Moreno and Larrahondo, 2021).

Another way in which Chile is incorporating NCRE sources into its electric systems is through small-scale generators (PMG) and small-scale distributor generators (PMGD) (Decree No. 244 from 2006, updated in Decree No. 88 from 2020). This framework is designed to improve interconnection, energization, and commissioning of the PMG and PMGD and establishes a methodology that generators can use in energy sales to charge a levelized price (Garrigues, 2020; Ministerio de Energía, 2022). The difference between them is that the PMG connects to the transmission system and the PMGD connects to the distribution system. These can inject excess energy and power of up to 9 MW and be used for self-consumption or the injection of energy into the electric system (ACESOL, 2022; CNE, 2021). Projects under this framework are self-managed, receive discounts on transmission quotas, and have access to a stabilized price regime, with less price volatility than the spot market. The PMGD can be developed as either direct injection or shared installation (prosumer).

According to Sphera Energy (2023), the PMG and PMGD contribute 2.6 GW of capacity (88% of which correspond to the PMGD), or 8% of the total installed capacity of Chile's National Energy System as of June 2023. These generators produced 4% of the energy injected into the system, distributed between photovoltaic solar (57%), hydropower (33%), and wind (4%). The installed capacity of 2023 represented a 400% increase over the installed capacity of the PMGD in 2016.

Colombia

Colombia relied on auctions to incorporate renewables, mainly for energy supply projects generated with solar or wind energy for batches of 0.5 MW and in hourly time blocks. A secondary auction covered the difference between the demand that the auction is expected to cover and the quantity of energy ultimately assigned in the tender.

The framework was laid out in Law 1715 (2014) and Decree 570 (2018). The energy purchased using the primary and secondary auctions is considered part of the obligation resellers have to use NCRE sources for a portion of the energy they supply (between 8 and 10% in 2019, according to Law 1955 from 2019).

Three auctions were held between 2019 and 2021, though no projects were commissioned in the first. The second auction resulted in two generation projects from non-conventional energy sources under 15-year contracts (starting in January 2022). The third auction involved a primary auction followed by a secondary one with more favorable conditions for bidders if the quotas of the primary auction were not met. This resulted in commissions that covered 83% of the target demand of 5,520 MWh/day (55% in the main auction, 45% in the secondary auction). In the future, the auction procedures will be adjusted to avoid manipulation, a risk that experts have warned of for some time (see Klemperer (2002).

Costa Rica

The government body entrusted with the sale of electric energy is the Costa Rican Institute of Electricity (ICE), which organizes the purchase of electricity from cooperatives and private companies in two ways: direct contracts with interested generators in compliance with the Electricity Act (Law 7,200 from 1990) and another competitive structure. Under the competitive structure, energy is purchased at competitive pricing in batches of 50 MW, with contracts between the ICE and private actors for up to 20 years. NCRE technologies cannot exceed 30% of the power produced at all plants that are part of the National Electric System (OLADE,2020).

El Salvador

The Salvadorean electric market is comprised of two markets: long-term contracts and the regulatory market. The General Electricity Act establishes the framework for tenders, and the invitations are sent by electricity distributor DELSUR, which sets the procurement guidelines. DELSUR establishes the power capacity required for each type of technology and awards quantities to each distribution company (companies it also represents). The procurement guidelines are reviewed and approved by the Electricity and Telecommunications Authority (SIGET), which is also responsible for the assignments in a tender process.

On behalf of seven distribution companies, DELSUR issued three calls for NCRE tenders between 2013 and 2017. The first, held in 2013, focused on small hydroelectric, photovoltaic solar, and biogas plants. The following year, the tender was for photovoltaic solar and wind energy, though only solar energy projects were commissioned (under a PPA with 20-year contracts). In 2017, a call for tenders for photovoltaic solar and wind energy projects was issued. Later, the distribution companies of El Salvador, the National Energy Council (CNE), and SIGET held a distributed renewable energy auction to assign a total capacity of up to 15 MW (under a PPA with 15-year contracts), followed by another auction held by the CNE to obtain an addition 28 MW (IRENA, 2020; OLADE, 2020).

Guatemala

Under the General Electricity Act, the distribution companies of Guatemala must purchase electricity through open tenders. However, the law does not make any distinction by technology type, thus preventing purchases that exclusively or specifically target renewables while enabling the continuation of conventional technologies. In tenders to increase installed power capacity, the law establishes a maximum of 15 years for contracts.

The National Electric Energy Commission (CNEE) is the agency that establishes the terms and criteria that distributors must meet before drafting the procurement guidelines (the distributors are also entrusted with procurement, which is then approved by the CNEE) (OLADE, 2020).

The economic evaluation process involves successive rounds with decreasing prices.
Per OLADE (2020), in each round, the system administrator carries out the optimization process to determine whether guaranteed power has been allocated to a bidder or not. At the end of each of these rounds, price adjustments or bids can be made to reassign to bidders. The respective rounds

continue until the administrator deems it necessary. Once this process is completed, each bidder proceeds to the final bid. Then, the administrator evaluates each of these final bids to determine the power plants that are awarded. The awarded bidders enter into a supply contract with the distributor (OLADE, 2020). The last auction between 2022 and 2023 incorporated 235 MW, of which 81% corresponds to new energy (pv magazine, 2023).

Jamaica

In Jamaica, the Office of Utilities Regulation (OUR) is the agency entrusted with organizing and implementing the energy auctions and drafting the statement of conditions. Interested parties must present a proposal, indicating the technology type and generation capacity. Once the candidates that meet the technical requirements have been identified, a final negotiation round is held to later proceed to the assignment and the power purchase agreement (PPA).

According to OLADE (2020), little information is available on the 2008 auction (only the capacity of wind and small hydroelectric sources, for a total of 9.4 MW), while that of 2015 shows that solar energy projects were awarded (33.1 MW). In September 2023, a call for tenders was made to assign 100 MW for new or existing plants relying on solar, hydro, or wind energy, including both standalone or hybrid projects accompanied by storage (GPE, 2023).

Mexico

Between 2015 and 2017, renewable generation tenders were held in keeping with the Electric Industry Act, associated regulations, the Electric Market Guidelines, the Long-Term Auction Manual, and the Operational Guide by the Electricity Compensation Chamber (OLADE, 2020). The attempt at a tender was canceled in 2018 (CENACE, 2019).

The auctions held distinguished between generation source (wind, solar, geothermal) and contract type (energy, output, and clean energy certified) (for more details, see OLADE, 2020). Since the intervention in 2019, the future is uncertain following legislative and regulatory overhaul. The agreement approved in 2023 by the Electric Regulation Commission (CRE Agreement A/018/2023) allows part of the natural gas combined-cycle production to obtain clean energy certificates, discouraging investments in renewables due to the drop in the value of the certificates (for more details, see Perczyk and Rabinovich (2023)).

Panama

Under Law No. 6 (2009), the company Transmisión Eléctrica S.A. (ETESA) is entrusted with the tender process, which means developing the statement of objectives and carrying out the tender and award process, which can be for energy supply or output. This law also establishes a preferential 5% of the evaluated price for renewable energy technologies, while Law No. 44 introduces incentives to promote the construction and exploitation of wind plants for utility (electricity) provision. The law aims to promote the use of renewables, specifically wind.

Since 2011, technology-specific tenders have been held for both renewable and conventional power plants to procure firm power capacity, energy, or both, and can be either short or long term (OLADE, 2020).

ETESA has mainly awarded projects to hydroelectric plants, though a good number of other projects rely on wind and solar power and these also include thermal generation technologies (OLADE, 2020). In the 2021 tender, there were limited bids for the energy component (in comparison to the power capacity component) (ETESA, 2021; Singh, 2021), while in 2023, a high percentage of proposals for short-term provision relied on renewable sources (mainly hydropower and, to a less extent, solar and wind) (ETESA, 2023; Singh, 2023).

Peru

Legislative decree No. 1002 (2008) promotes the use of renewable energy resources and prioritizes dispatchable electricity relying on renewable energy generation. Generators sell their energy on the short-term market, subject to a guarantee according to the obtained price. Under this framework, four technology-specific auctions were held for renewable energy: two in 2009, one in 2011, another in 2013, and a final one in 2016. In total, 1,312 MW of renewable power capacity was assigned, with average prices falling over time. In each of these auctions, the Energy and Mining Ministry (MINEM) was entrusted with drafting and approving the guidelines, while the Investment in Energy and Mining Authority (OSINERGMIN) issued the invitations.

Based on the auction design, bids that satisfy the technical criteria are ranked by order of merit and assigned until the energy required for each technology has been satisfied (OLADE, 2020).

Uruguay

Based on the regulatory framework of Uruguay's electricity sector (Decree 360/2002), tenders are held to award special contracts for NCRE generation. In the case of distribution companies, the contract costs are passed on to the tariff (UTE is the state company entrusted with electricity transmission and distribution in Uruguay). Between 2007 and 2011, three auctions were held (a fourth was planned for 2012 but supporters of the third auction agreed to produce at the price set the previous year). In parallel, the state expanded wind capacity via APP. Thus, between 2007 and 2012, projects for 1,500 MW commenced, most of which relied on wind energy and a smaller percentage, on biomass (Factor, 2017).

In addition to the auctions and the approval of a feed-in tariff by other generators, the government established private-public partnerships (PPPs) in 2014, incorporating another 420 MW in six parks of 70 MW. In these cases, the UTE oversees the PPP and is the buyer of the generated energy. The PPA signed between the UTE and the private firm stipulates the same price as that of the auction: USD 63/MWh (Factor, 2017).

On the other hand, it is interesting to note that in 2013, Uruguay experimented with wind leasing of a 70 MW park. In this case, the UTE contributed the land and the wind and held an auction for the construction of an on-site park by an investor to be leased by the UTE for 20 years (the park, its operation and maintenance) with a purchase option upon expiry. In this procedure, the MWh price was slightly lower than the auction price, since the risk for the bidder was also lower (Factor, 2017).

Challenges for the incorporation of distributed generation in the region

Distributed generation technologies have been gradually integrated into electrical systems with the introduction of favorable regulatory frameworks and different incentives. This annex highlights three regulatory challenges: payment for the flows consumed and delivered to the system, load balancing, and the type of restrictions that users and their technologies face.

In the first place, the buyback of energy flows impacts the incentives for the incorporation of distributed generation. Net metering offers advantages to the user, as it values the injection at the same price as the purchase of one unit of energy (a variable charge, depending on the tariff), especially if the tariff scheme is based on increasing blocks. However, this can impact the financing of the system and lead to a phenomenon known as the death spiral for the distributor (which stops receiving these revenues and must increase the average tariff for the increasingly fewer existing users). On the other hand, net billing is less attractive for the consumer, particularly when energy injections are valued at the price of it, but it provides better signals for the introduction of this generation source and is the suggested mechanism when advancing to more mature stages (MRC Consultants and PSR, forthcoming).[3]

The second aspect relates to load balancing schemes, including the buyback, renewal, and settlement of these balances.

The third has to do with restrictions users face to incorporate solar panels. This can be quantitative (that is, panels with a maximum capacity) or qualitative (technical procedures for the installation and use of panels), the aim of which is to avoid risks to the distribution networks. Table A 4.4 summarizes these variables in the countries of the region today.

Table A.4.4

Invoicing mechanisms and load balancing in Latin America and the Caribbean

Country	Mechanism	Accumulation period		Accumulation unit	Expiry
		Number	Unit		
Argentina	Net invoicing	6	Month	$	Payment
Bahamas		1	Year	kWh	Payment
Barbados	Net invoicing	3	Month	$	Payment
Brazil	Net metering	60	Month	Mixed	Loss
Chile	Net invoicing	12	Month	$	Loss
Colombia	Mixed	Indefinite		$	
Costa Rica	Net invoicing	12	Month	Mixed	Payment
Ecuador	Net metering				
El Salvador	Net invoicing	Indefinite		$	
Guatemala		Indefinite		kWh	
Honduras		Indefinite		$	
Jamaica	Net invoicing	1	Month	$	Payment
Mexico	Mixed	12	Month	$	Payment
Nicaragua	Net invoicing	12	Month	$	Payment
Panama	Net metering	12	Month	$	Payment
Paraguay	Not identified				
Peru	Not identified				
Dominican Republic	Net metering	1	Billing period	$	Loss
Suriname		12	Month	kWh	Payment
Uruguay	Net metering	0	Month	kWh	Payment

Note: The graph shows pricing mechanisms and load balancing for LAC countries with available information. Column 2 shows the pricing alternatives in each country: net metering, net invoicing, and the possibility of an alternative that combines both mechanisms. The following columns show the mechanisms for accumulated imbalances (money [$] or energy, in kWh), the accumulation period in time unit and number, and the payment at the end of said period.

Source: Author based on Muñoz et al. (2017), Hochberg and Poudineh (2021), MRC Consultants and PSR (forthcoming), and López Soto et al. (2019).

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[3] One important component is wheeling charges when self-production and demand are located at different points of the network, as it pays for the costs of the network utilized in bilateral (peer-to-peer) energy transactions.

Chapter 5 Appendix

Oil and natural gas value chain

The extraction of crude oil and natural gas can be schematized into four stages: exploration, development, production, and restoration and disposal. The exploration stage generally consists of a seismic campaign, followed by drilling. On average, approximately 1 in 5 explored reservoirs have commercial exploitation potential. Given this risk profile, this process is usually financed almost exclusively with own resources (or state participation), resulting in high entry barriers.

Once the exploration stage is completed and the decision has been made to proceed with oil extraction, the development stage begins. The investments required in the development phase are considerable, representing between 40% and 60% of the total cost of the project. However, this phase has a lower risk profile, with most of the unknowns about the viability of commercial exploitation having been cleared in the previous phase.

The production stage consists of keeping the crude oil and gas extraction and pumping elements operational to the storage and transportation sites to the refinery. Reservoir production consists of a primary recovery phase, where the reservoir pressure itself allows the extraction of crude oil and gas; secondary, which depends on the injection of gas or water into the reservoir to maintain the pressure that allows extraction; and tertiary, where thermal or chemical processes are required to release and separate the crude oil from the earth and rock capillaries that contain it, allowing its extraction. Operating costs vary widely, depending on the difficulty of extraction (gas, oil, heavy oil, etc.), the size of the field, the geographic location and physical-environmental conditions (onshore or offshore, region, desert, jungle, extreme north, temperate zones, etc.).

Finally, after the possibilities of commercial exploitation of a field have been exhausted, regulations and contracts usually provide for decommissioning and rehabilitation activities. This stage entails a considerable cost; for example, the decommissioning of an offshore oil platform has costs equivalent to those of its installation.

The next link in the value chain of petroleum and petroleum products is refining for the production of liquid fuels, lubricants, and other end-use goods. The establishment and operation of a modern petroleum refinery involves a great deal of complexity and investment. The initial investment required is substantial, especially for complex refineries, i.e. those with crude conversion capacity (cracking and reforming). The installation of the transportation infrastructure to bring the crude to the refinery is another significant component of the capital costs. This can include pipelines, barges, trucks, and other modes of transportation, each with its own costs and logistical complexities. Depending on the distance between the oil fields and the refinery, initial investment costs for transportation infrastructure can vary considerably and add an additional layer of complexity and cost to operations.

The petroleum value chain is integrated with the petrochemical industry, whose development in close geographic proximity can -offer significant economic advantages to the refining industry. The direct provision of common inputs and support services between refining and petrochemical operations can result in economies of scale and scope, thus optimizing unit costs and improving margins.

Clarifications regarding Figure 5.1

The countries represented under the “other countries” category are as follows: Belize, Bolivia, Barbados, Chile, Dominican Republic, El Salvador, Grenada, Guatemala, Guyana, Honduras, Haiti, Jamaica, Mexico, Nicaragua, Panama, Peru, Suriname, Trinidad and Tobago and Venezuela.

Chapter 6 Appendix

The countries and territories included in the Minx et al. (2021) analysis are listed below.

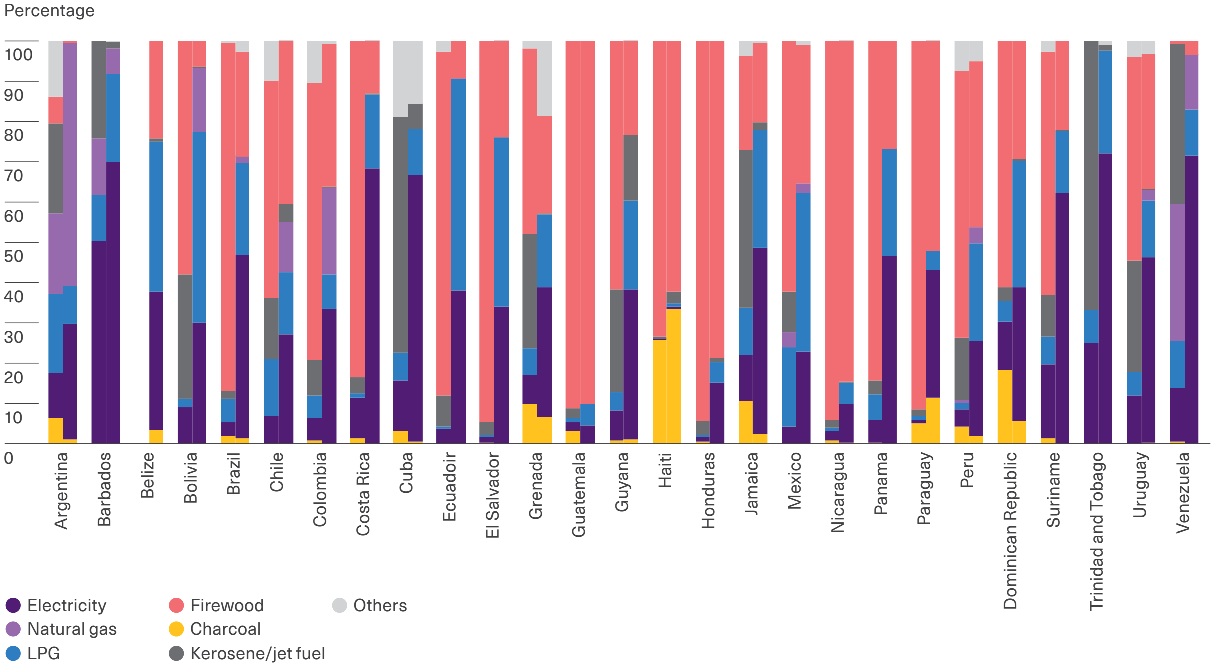
In Latin America: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, French Guiana, Guyana, Honduras, the Falkland Islands, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela.

In the Caribbean: Aruba, Anguilla, Netherlands Antilles, Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominica, Granada, Guadeloupe, Haiti, Cayman Islands, Jamaica, Martinique, Montserrat, Puerto Rico, Dominican Republic, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia, Trinidad and Tobago, and the British Virgin Islands.

Chapter 7 Appendix

Complementary graphs and tables

Graph A.7.1
Residential energy consumptions by source in 1990 and 2021

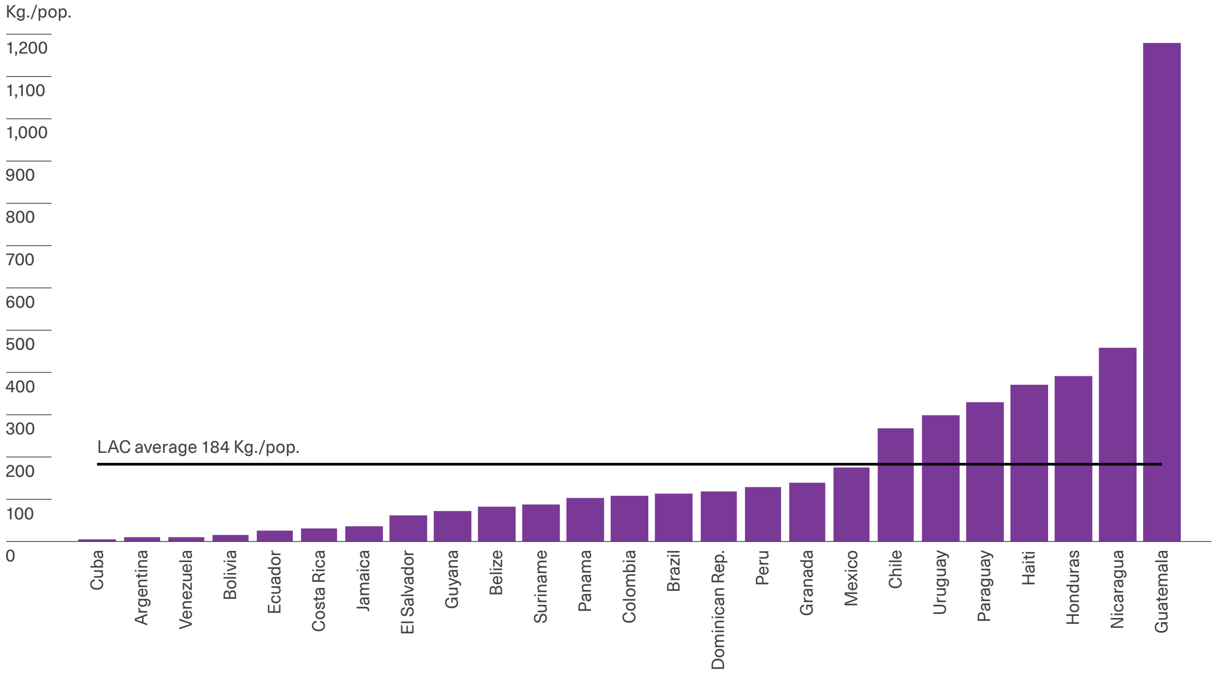


Note: The graph displays the percentage distribution of residential energy consumption by source in 27 LAC countries in the years 1990 (left column) and 2021 (right column).

Source: Authors based on data from OLADE (2021b).

Graph A.7.2

Residential firewood consumption per capita in 2021

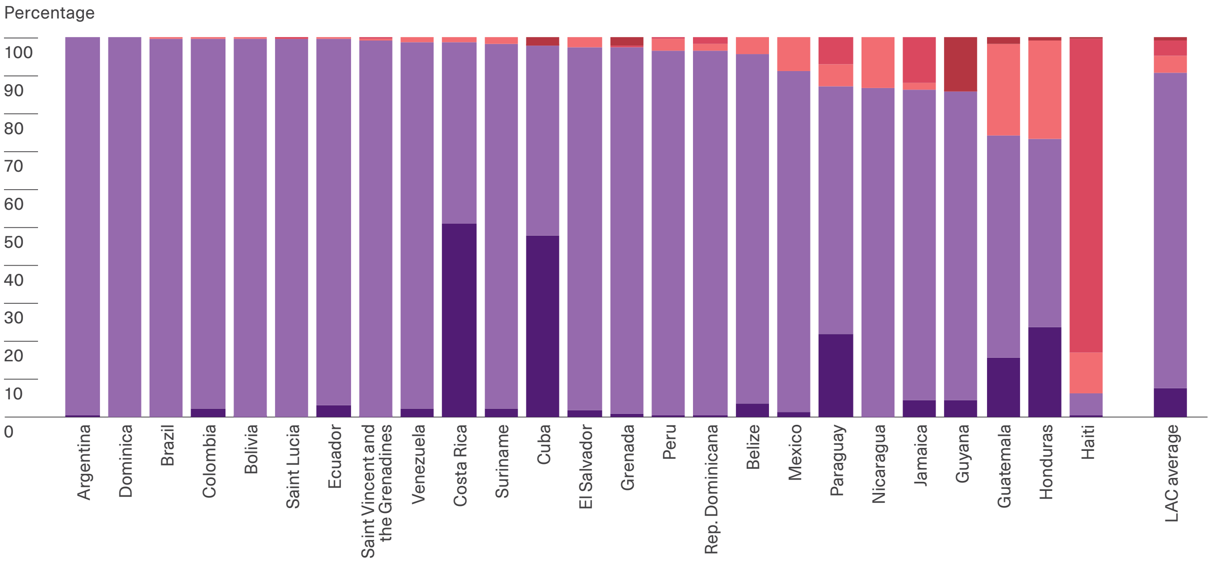


Note: The graph illustrates residential consumption measured in tons per capita across 25 countries, along with the average for LAC, in 2021

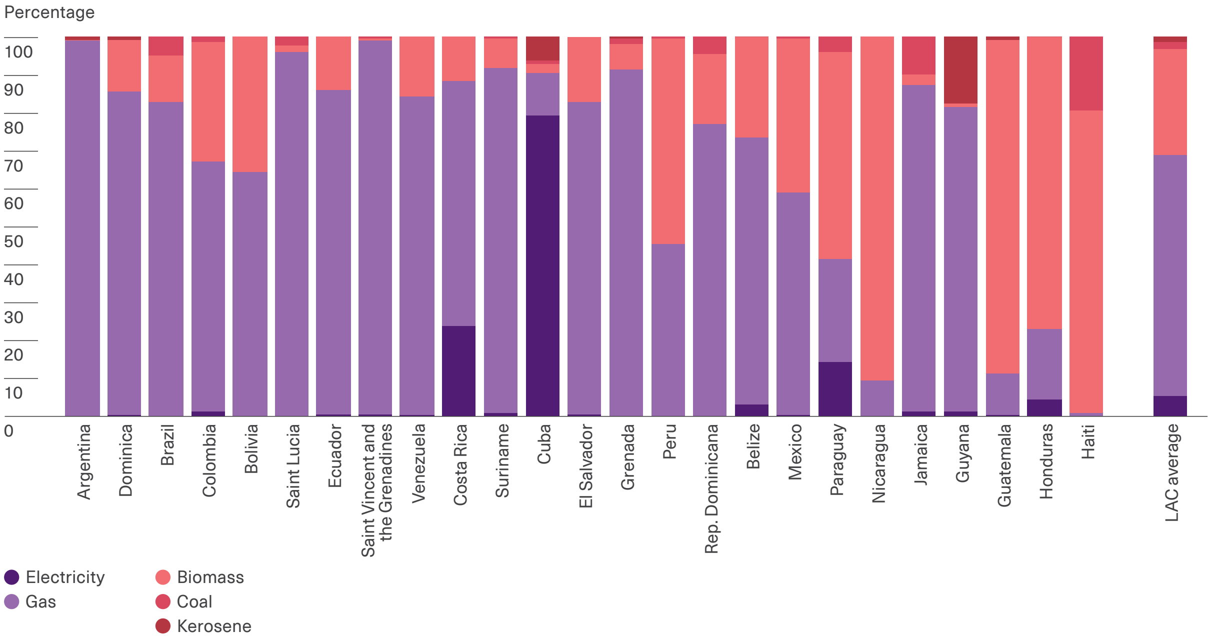
Source: Authors based on data from OLADE (2021b).

Graph A.7.3
Main energy source used for cooking in urban and rural households in 2021

Panel A.
Urban households



Panel B.
Rural households



Note: The graph depicts the distribution of urban households (Panel A) and rural households (Panel B) according to the primary fuel used for cooking in 25 countries and the LAC average in 2021. Cleaner energy sources (electricity and gas) are highlighted in green, while various shades of red represent dirtier sources in terms of emissions (biomass, coal, and kerosene).

Source: Authors based on data from the WHO (2021).

Table A.7.1

Year of household surveys processed for Graphs 7.5 and 7.7

Country	Present day	Beginning of the century
Argentina	2017/2018	2004/2005
Barbados	2016	-
Bolivia	2021	2001
Brazil	2019	2001
Chile	2017	2003
Colombia	2021	2001
Costa Rica	2021	2001
Ecuador	2021	2003
El Salvador	2021	2001
Guatemala	2014	2000
Honduras	2019	2001
Jamaica	2018	-
Mexico	2020	2000
Nicaragua	2014	2001
Panama	2021	-
Paraguay	2021	2001
Peru	2021	2003
Dominican Republic	2021	-
Uruguay	2021	-

Note: The table specifies the year in which household surveys used in graphs 7.5 and 7.6 were conducted, as well as those employed to obtain the variable "percentage of households with electrical connection" for 19 LAC countries, in the "present day" and "beginning of the century" periods, presented in graph 7.7.

Source: Puig y Tornarolli (2023).

Table A.7.2
Electricity subsidies as a percentage of GDP (average 2011–2013)

Country	Percentage of GDP	Country	Percentage of GDP
Antigua and Barbuda	0.8	Haiti	2.7
Argentina	1.8	Honduras	0.9
Bahamas	0.5	Jamaica	0.1
Barbados	0.2	Mexico	0.7
Belize	2.7	Nicaragua	2.1
Bolivia	0.0	Panama	0.5
Brazil	0.1	Paraguay	0.1
Chile	0.0	Peru	0.0
Colombia	0.2	Dominican Republic	1.9
Costa Rica	0.0	Saint Kitts and Nevis	0.5
Dominica	0.1	Saint Vincent and the Grenadines	0.0
Ecuador	0.4	Saint Lucia	0.0
El Salvador	1.5	Suriname	1.7
Grenada	0.5	Trinidad and Tobago	0.6
Guatemala	0.4	Uruguay	0.0
Guyana	1.3	Venezuela	1.8

Note: The table shows electricity subsidies as a percentage of the average GDP for the period 2011–2013 for 32 countries in the region.
Source: Authors based on data from Di Bella et al. (2015).

Clarifications in the graphs and tables in the chapter

Graphs 7.1, 7.4, and 7.5

The countries of Latin America and the Caribbean and Europe represented in graphs 7.1, 7.4, and 7.5 are the ones that appear in the following table.

The ISO codes used in the other graphs are the same ones in the list.

Latin America and Caribbean	ISO code	Other countries	ISO code
Argentina	ARG	Albania	ALB
Barbados	BRB	Germany	GER
Belize	BLZ	Austria	AUT
Bolivia	BOL	Belgium	BEL
Brazil	BRA	Bosnia and Herzegovina	BIH
Chile	CHL	Bulgaria	BGR
Colombia	COL	China	CHN
Costa Rica	CRI	Cyprus	CYP
Cuba	CUB	Croatia	HRV
Ecuador	ECU	Denmark	DNK
El Salvador	SLV	Slovenia	SVN
Granada	GRD	Spain	ESP
Guatemala	GTM	Estonia	LVA
Guyana	GUY	Finland	FIN
Haiti	HTI	France	FRA
Honduras	HND	Georgia	GEO
Jamaica	JAM	Greece	GRC
Mexico	MEX	Hungary	HUN
Nicaragua	NIC	Ireland	IRL
Panama	PAN	Italy	ITA
Paraguay	PRY	Kosovo	XXK
Peru	PER	Latvia	LVA
Dominican Republic	DOM	Lithuania	LTU
Suriname	SUR	Luxembourg	LUX
Trinidad and Tobago	TTO	North Macedonia	MKD
Uruguay	URY	Malta	MLT
Venezuela	VEN	Moldova	MDA
		Norway	NOR
		Netherlands	NLD
		Poland	POL
		Portugal	PRT
		Czech Republic	MDA
		Slovakia	SVK
		Romania	ROU
		Serbia	SRB
		Sweden	SWE

The regions represented in Graph 7.3 are composed as follows:

Africa includes 47 countries: Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cape Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, South Africa, South Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

Europe consists of 50 countries: Albania, Andorra, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, North Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tajikistan, Turkey, Turkmenistan, Ukraine, United Kingdom, and Uzbekistan.

Southeast Asia consists of 11 countries: Bangladesh, Burma, Bhutan, East Timor, India, Indonesia, Maldives, Myanmar, Nepal, North Korea, Sri Lanka, and Thailand.

Table 1 in Box 7.2

The calculations take into 33 countries from LAC. The Caribbean region includes Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia, and Trinidad and Tobago. The countries in Central America include Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. South America includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela.

Chapter 8 Appendix

Table A.8.1

Year of household surveys processed for the preparation of Graph 8.2 and Graph 1 in box 8.2

Country	Year
Argentina	2017/2018
Barbados	2016
Bolivia	2021
Brazil	2019
Chile	2017
Colombia	2021
Costa Rica	2021
Ecuador	2013/2014
El Salvador	2021
Guatemala	2014
Honduras	2019
Jamaica	2018
Mexico	2020
Nicaragua	2014
Panama	2021
Paraguay	2021
Peru	2021
Dominican Republic	2021
Uruguay	2021

Table A.8.2

Average age of urban private vehicles in Latin American countries

Country	Average age	Year	Source
Argentina	13	2022	AFAC (2023)
Brazil	10.7	2020	Rodrigues (2023)
Chile	9.4	2021	ANAC (2021)
Colombia	17.5	2021	Andemos (2023)
Costa Rica	16	2019	RITEVE (2020)
Ecuador	16.1	2019	AEADE (2021)
Mexico	17	2022	Morales Romero (2023)
Panama	9	2011	BBVA Research (2011)
Peru	13.6	2019	AAP (2019)
Uruguay	12	2017	CPA Ferrere (2020)
Venezuela	22	2022	Primicia (2023)

Table A.8.3

Countries surveyed and reference exchange rate used to express prices in US dollars in Table 8.1

Country	Currency	Exchange rate (NMU/USD)
Argentina	Argentine peso	356.50
Brazil	Real	4.90
Chile	Chilean peso	883.60
Colombia	Colombian peso	3,921.60
Costa Rica	Costa Rican Colon	534.70
Ecuador	US dollar	1.00
Mexico	Mexican peso	17.10
Panama	Balboa	1.02
Peru	Peruvian sun	4.01
Dominican Republic	Dominican peso	56.70

Note: NMU= National Monetary Unit. The reference exchange rate for each country was taken from the respective central bank.

Table A.8.4

Availability in each country of the car models presented in Table 8.1

Model / Country	Argentina	Brazil	Chile	Colombia	Costa Rica	Ecuador	Mexico	Panama	Peru	Dominican Republic
Toyota Corolla Cross Hybrid	x	x	x	x	x	x	x		x	x
Toyota Corolla Cross Fossil	x	x	x	x	x	x	x	x	x	x
Nissan Leaf Hybrid	x	x	x	x	x	x	x			
Nissan Sentra Fossil	x	x	x	x	x	x	x	x	x	x
BYD Dolphin Electric		x	x	x			x			x
BYD Han Electric		x	x	x			x			x
BYD Yuan Plus Electric		x	x	x			x			x
Renault KWID Fossil		x	x	x			x	x	x	
Volkswagen Taos Fossil	x	x	x	x	x	x	x	x	x	x
Tesla Model S Electric							x			

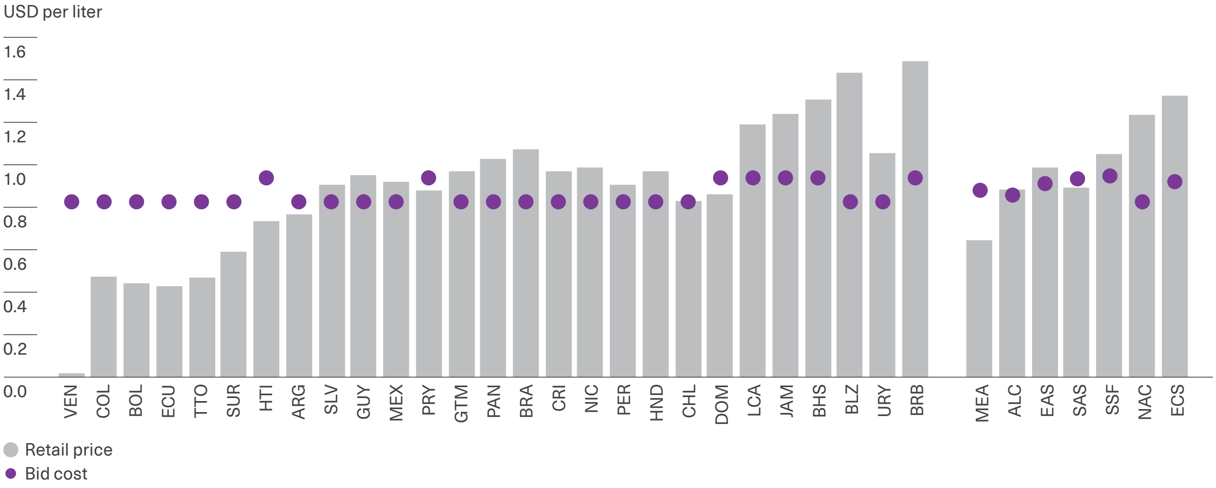
Table A.8.5

Sources of information for the data in Figure 8.1

Country	Source	Country	Source
Argentina	Liborio (2023)	Honduras	Electromaps (2023)
Bolivia	Electromaps (2023)	Mexico	Mexican Institute of Transportation (2022)
Brazil	Venditti (2023)	Nicaragua	Electromaps (2023)
Chile	Sustainable Journal (2023)	Panama	Electromaps (2023)
Colombia	Electromaps (2023)	Paraguay	Electromaps (2023)
Costa Rica	Electromaps (2023)	Peru	Electromaps (2023)
Cuba	Electromaps (2023)	Puerto Rico	Electromaps (2023)
Ecuador	Electromaps (2023)	Dominican Republic	Electromaps (2023)
El Salvador	Electromaps (2023)	Uruguay	Electromaps (2023)
Guatemala	Electromaps (2023)	Venezuela	Electromaps (2023)

Graph A.8.1

Costs and retail prices (including taxes for diesel) per liter in 2022



Note: The graph shows the cost and retail price (including taxes and subsidies) of diesel per liter, in constant 2021 US dollars for 27 LAC countries and regional averages for the rest of the world in 2022.

Source: Authors based on data from Black et al. (2023).

Table A.8.6

Pathway of electro-corridors in operation in Latin America and the Caribbean in 2023

	Approximate length (km)	Coverage	Source
(1) Argentina	212	Province of San Luis	UNEP (2020)
	512	Retiro (CABA) - Cariló (Atlantic Coast)	La Nación (2022)
	-	Shell private initiative plan: Cordoba - Rosario - PBA - Atlantic Coast	Ámbito (2023)
(2) Uruguay	300	Colonia - Punta del Este	Electromovilidad (2018)
(3) Chile	730	Marbella - Termuco	UNEP (2020)
	570	Termuco - Chiloé - Coyhaique - Aysén	UNEP (2020)
(4) Brazil	434	Rio de Janeiro - São Paulo	UNEP (2020)
	1200	Salvador (Bahia) - Natal (Rio Grande do Norte)	Neoenergía (2020)
(5) Colombia	256	Coffee region: Caldas - Risaralda - Quindío	Mobility Portal (2022)
(6) Panama	450	Eco Route	Move (2021)
(7) Costa Rica	-	La Fortuna and Monteverde	Move (2021)
(6) Panama and (7) Costa Rica	900	San José - Panama City	Move (2021)
(8) Mexico	620	Potosi - CDMX - Puebla	UNEP (2020)
(9) Pan American Corridor Enel X	-	Connects 11 countries from Ushuaia (ARG) to Ensenada (MEX)	Enel X (2020)

Clarifications regarding Graph 8.4

The regions represented in the graph are as follows:

The Middle East and North Africa includes 19 countries: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, United Arab Emirates, Yemen and Djibouti.

East Asia and Pacific comprises 21 countries: Australia, Burma, Brunei, Cambodia, China, Fiji, Indonesia, Japan, Kiribati, Laos, Malaysia, Mongolia, New Zealand, Papua New Guinea, Philippines, Singapore, Solomon Islands, South Korea, Thailand, Tonga, Vietnam.

South Asia includes 8 countries: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka.

Sub-Saharan Africa includes 44 countries: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Central African Republic, Democratic Republic of Congo, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

North America includes 2 countries: Canada and the United States.

Europe and Central Asia comprise 46 countries: Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Slovakia, Slovenia, Spain, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, North Macedonia, Moldova, Netherlands, Norway, Poland, Portugal, United Kingdom, Czech Republic, Romania, Russia, Serbia, Sweden, Switzerland, Tajikistan, Turkey, Turkmenistan, Ukraine and Uzbekistan.

Chapter 9 Appendix

Table A.9.1

Type I and II backward linkage multipliers by country normalized by the value of the economy average

BL1	**Electricity generation sectors**							**Extractive sectors**				
	Coal	**Gas**	**Oil**	**Wind**	**Solar**	**Hydroelectricity**	**Nuclear**	**Coal**	**Gas**	**Oil**	**Mining**	**Electricity**
Argentina	1.2	1.6	3.0	1.4	1.3	1.4	1.5	1.4	1.2	1.3	1.4	2.0
Bolivia	0.7	1.6	1.7	0.8	0.8	0.8	0.7	1.1	0.9	0.9	0.9	1.4
Brazil	0.8	1.2	1.6	0.7	0.7	0.7	0.8	1.2	1.1	1.1	1.1	0.9
Chile	0.9	1.0	0.9	0.8	0.8	0.8	0.6	1.0	0.9	1.0	1.1	0.9
Colombia	1.2	1.6	1.5	0.8	0.8	0.8	0.7	0.9	0.8	1.0	1.2	1.0
Costa Rica	0.7	0.7	1.1	0.9	0.9	0.9	0.7	1.3	1.3	1.3	1.0	1.0
Ecuador	0.7	1.4	1.7	1.1	1.0	1.0	0.7	1.2	0.9	0.8	1.0	1.2
El Salvador	0.7	0.7	0.9	0.7	0.9	0.9	0.7	1.3	1.3	1.1	3.2	1.0
Guatemala	0.9	0.7	0.9	0.9	0.9	0.9	0.7	1.0	0.9	1.0	0.9	1.0
Haiti	0.2	0.2	0.3	0.2	0.3	0.3	0.2	1.1	0.9	0.3	0.7	0.3
Honduras	1.6	0.7	0.9	1.0	1.0	1.0	0.7	1.3	1.3	1.2	1.1	1.0
Jamaica	0.7	0.8	0.9	0.8	0.8	0.8	0.7	1.1	1.1	0.9	1.0	0.9
Mexico	1.3	0.9	1.7	1.0	0.9	0.9	1.0	1.0	0.9	0.9	1.1	1.1
Nicaragua	0.7	0.7	1.0	0.9	0.9	0.9	0.7	1.1	0.9	1.0	1.3	1.0
Panama	1.0	0.7	0.9	1.0	0.9	0.9	0.7	0.7	0.8	0.9	0.9	1.0
Paraguay	0.7	0.7	1.3	0.7	0.7	0.9	0.7	1.0	0.8	1.0	1.1	0.7
Peru	1.0	1.2	1.4	0.7	0.7	0.7	0.6	0.7	0.8	0.7	1.1	0.8
Puerto Rico	0.6	0.6	0.6	0.7	0.7	0.7	0.6	1.2	1.1	0.9	1.1	0.7
Dominican Rep.	1.1	1.1	1.0	1.0	0.9	0.9	0.7	1.1	1.2	1.0	1.1	1.1
Trinidad and Tobago	0.7	1.3	2.1	0.8	0.8	0.7	0.7	0.9	1.0	0.9	1.0	1.2
Uruguay	0.7	0.7	1.1	0.9	0.8	0.8	0.7	0.8	1.0	0.8	1.0	0.9
Venezuela	0.5	1.5	2.4	0.8	0.8	0.8	0.5	0.9	0.6	0.8	0.9	1.1
Rest of Central America	0.8	0.8	1.3	0.8	0.9	0.9	0.8	0.9	0.9	1.2	1.0	1.0
Rest of the Caribbean	0.7	2.1	1.1	10.1	1.6	2.4	0.7	1.0	0.9	1.0	1.0	1.1
Rest of South America	0.7	0.7	1.1	0.8	0.8	0.8	0.7	1.1	0.9	3.3	1.0	1.2
Latin America and the Caribbean	1.3	1.4	2.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.5	1.4

Continued on the next page →

BL2	Electricity generation sectors							Extractive sectors				
	Coal	Gas	Oil	Wind	Solar	Hydroelectricity	Nuclear	Coal	Gas	Oil	Mining	Electricity
Argentina	0.5	0.9	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.2
Bolivia	0.2	1.1	1.0	0.9	0.9	0.9	0.2	0.9	0.9	0.9	0.9	1.2
Brazil	0.7	1.0	1.2	0.9	0.9	0.9	0.9	1.1	1.0	1.0	1.0	1.3
Chile	0.8	0.6	0.6	1.0	1.0	1.0	0.3	1.0	1.0	1.0	1.0	0.9
Colombia	1.1	1.2	1.0	1.0	1.0	1.0	0.2	1.0	1.0	1.0	1.0	1.0
Costa Rica	0.3	0.3	0.9	1.0	1.0	1.0	0.3	1.1	1.1	1.1	1.0	1.0
Ecuador	0.3	1.1	1.1	1.0	1.0	1.0	0.3	1.1	1.0	1.0	1.0	1.0
El Salvador	0.3	0.3	0.6	0.3	1.0	1.0	0.3	1.0	1.0	1.0	4.7	0.9
Guatemala	0.7	0.2	0.5	1.0	1.0	1.0	0.2	0.7	0.8	0.8	1.0	0.9
Haiti	0.1	0.1	0.2	0.1	0.6	0.6	0.1	1.0	1.0	0.8	0.8	0.2
Honduras	1.0	0.3	0.5	0.9	0.9	0.9	0.3	1.0	1.0	1.0	0.8	0.8
Jamaica	0.2	0.5	0.5	1.1	1.1	1.1	0.2	0.9	0.9	0.9	0.5	0.7
Mexico	0.9	0.4	1.1	1.0	1.0	1.0	1.0	1.0	1.0	0.7	1.0	0.8
Nicaragua	0.3	0.3	0.7	1.0	1.0	1.0	0.3	1.1	0.9	1.0	1.0	0.9
Panama	0.7	0.3	0.5	1.0	1.0	1.0	0.3	0.3	0.3	1.0	1.0	0.9
Paraguay	0.2	0.2	0.9	0.2	0.2	1.0	0.2	1.0	0.7	1.0	1.0	1.2
Peru	0.9	1.1	0.9	0.9	0.9	0.9	0.2	0.9	0.9	0.9	1.0	0.9
Puerto Rico	0.1	0.1	0.2	0.5	0.5	0.5	0.1	1.0	1.0	0.9	0.8	0.3
Dominican Rep.	1.1	1.0	0.6	1.1	1.1	1.1	0.2	0.9	1.0	0.8	1.0	0.8
Trinidad and Tobago	0.3	1.1	1.1	1.0	1.0	0.3	0.3	1.0	1.0	1.0	1.0	1.1
Uruguay	0.2	0.3	0.8	1.0	1.0	1.0	0.2	0.4	0.9	1.0	1.0	1.0
Venezuela	0.0	1.3	0.8	1.0	1.0	1.0	0.0	0.9	0.8	0.8	0.9	0.3
Rest of Central America	0.3	0.3	0.8	0.3	0.9	0.9	0.3	0.6	0.7	0.9	1.0	0.8
Rest of the Caribbean	0.3	1.8	0.6	27.1	3.5	6.2	0.3	0.9	1.0	1.0	0.9	0.7
Rest of South America	0.3	0.3	0.7	1.0	1.0	1.0	0.3	1.0	1.0	2.1	1.0	1.0
Latin America and the Caribbean	1.1	1.0	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.3

Note: BL stands for backwards linkage.

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

Table A.9.2
Fiscal mechanisms in extractive industries: analysis by key objectives

Objectives	Bonuses	Royalties	Sliding-scale royalties	NRRT	CIT and VIT	State participation
Maximize NPV for the government.	All risk is borne by the investor, thus the expected level of public revenue is lower, though revenues occur earlier. Useful bidding mechanism to absorb expected revenue.	Slows down some projects and does not capture the benefit of projects that move forward.	Different effects on different projects; probable deterrent for low-quality or high-cost projects.	Captures a higher expected NPV for the government in exchange for assuming more risk.	Relatively neutral and progressive. Vulnerable to undercapitalization.	If entirely non-concessionary (Brown tax), it would maximize expected government revenue in exchange for assuming an equal share of risk. However, usually there is a concessionary element, thus producing distortions.
Progressiveness (higher returns at higher prices).	No effect: regressive (the bonus reflects expected, not actual, prices).	Regressive: government share of profits declines as commodity prices rise.	Different effect (profit share) on different projects.	Effectively captures profit but may defer greater share. Reduces burden in case of low prices.	Immediate response of VIT to variations in profitability.	Free participation is regressive (as is withholding tax on dividends); passive participation is progressive.
Progressiveness (higher returns with lower costs).	No effect: regressive.	Does not respond: regressive.	Does not respond: regressive.	Captures profit regardless of its cause. Automatically reduces the burden on high-cost projects.	Immediate response of VIT to variations in costs.	Free participation is regressive; passive participation is progressive.
Neutrality (to avoid distorting investment and operational decisions, thereby dissipating revenue potential).	Impact on exploration decisions; no impact on development or operational decisions.	Risk of halting marginal projects and shortening the lifecycle or reducing production of viable projects.	Different effect on different projects, thus generating distortions. High risk of incorrectly specified parameters.	Neutral: participation is only paid by projects that truly exceed the minimum return.	Depends on design of parameters. Potential distortion in VIT due to depreciation (drastic change in rate).	Free or passive participation has a negative impact on exploration decisions.
Ensure adequate incentives for investment.	Increases exploration risk, but relatively neutral if part of a competitive bid.	Deterrent if too high; increases the risk of unviable projects.	Depends on parameters. Reduces investor profit: likely deterrent.	Moderately deterrent effect as long as there is sufficient benefit for the investor.	Effective as long as the maximum rate is not set too high.	Raises negative perception among investors unless entirely non-concessionary but offers some risk mitigation benefits.
Risk for the government.	Minimizes risk for the government.	Risk borne by the investor.	Risk borne by the investor.	Risk (of not receiving revenues or doing so only at later stages) borne by the government.	The government assumes the risk if the minimum rate of the VIT is lower than the rate of the CIT.	Depends on the terms and conditions: if free participation acts as a tax on retained dividends at source, low risk; if passive participation acts as a tax on natural resources revenue, higher risk.
Minimize burden and administrative risks.	Easy to administer.	Relatively straightforward calculations, but risks of measurement and valuation.	Complex: requires multiple parameters for each mineral. Net margin royalty requires margin definition.	Relatively straightforward. The same data required for income tax. Additional simple calculation (for natural resources revenue tax on cash flow).	The same data for VIT as required for CIT. Simple additional calculation of the rate.	Complex. Generates pressure to negotiate at the expense of other fiscal elements.

Note: CIT: Corporate Income Tax. VIT: Variable Income Tax. NPV: Net Present Value. NRRT: Natural resources revenue tax. Bonuses: Lump sum payment made for mining rights (oil, gas, or minerals) or at the time of signing the contract or when certain production thresholds are reached. Royalties: Charge for mineral extraction, typically ad valorem on gross revenue, but may be specific (fixed amount) by volume or weight or vary with price. “Net profit royalty” is also used when certain costs are deducted, in which case it is similar to an income tax.

Source: FMI (2012).

Input-output models

The primary objective of input-output models is to analyze the interdependent relationships between industrial sectors of an economy, and assess the effects of a project or policy on specific socioeconomic variables. An input-output matrix (IOM) records the transactions between productive sectors, including both final demand goods and intermediate consumption goods, thereby reflecting the diversity and productive structure of the country or region. The matrix provides a means of examining the relationships between different productive sectors and quantifying the direct and indirect impacts on employment and production from increased final demand and intermediate demand (see Table A.9.3). The impact of exogenous changes can be analyzed at the level of sectoral production when changes occur in the short term and involve a small number of agents.

Table A.9.3
Open and closed input-output models

		PRODUCERS AS CONSUMERS								FINAL DEMAND			
		Agriculture	Mining	Construction	Manufacturers	Commerce	Transportation	Services	Other industries	Personal consumption expenditures	Gross private domestic investment	Government expenditures	Net exports of goods and services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturers												
	Commerce												
	Transportation												
	Services												
	Other industries												
VALUE ADDED	Employees	Employee compensation								GROSS DOMESTIC PRODUCT			
	Capital and business owners	Profits and capital consumption allowances											
	Government	Indirect business taxes											

A: Technical coefficients matrix
y: Final demand vector
x: Production vector for each sector
$(\mathbf{1}-\boldsymbol{A})^{-1}$: Leontief inverse matrix **L**

$$a_{ij} = \frac{z_{ij}}{x_j} = \frac{\textit{Input value } i}{\textit{Output value } j}$$

$$x = Ax + y$$

$$x = (I - A)^{-1}.\, y$$

Source: Authors based on Miller and Blair (2009).

An I-O model in matrix notation has the following structure: $x = Ax + y$ (2), where A is the technical coefficients matrix, y is the final demand vector and x is the production vector for each sector.

The equation can be reformulated into the following expression: $x = (I - A)^{-1} . y$ (3), where $(I - A)^{-1}$ is the Leontief inverse matrix and each element indicates the direct and indirect production requirements necessary to fulfill final demand. It is also known as the multiplier matrix, since it measures the response in total production to changes in final demand.

Linkages and multipliers

The concept of the multiplier captures the difference between the initial effect of an exogenous change and the total effects of that change. Total effects comprise both the direct and indirect effects, referred to as simple or Type I multipliers, or the direct, indirect and induced effects, known as total or Type II multipliers (Henriques et al., 2016).

Direct effects represent the response of a specific industry to changes in the final demand of that same industry. Indirect effects represent the response of all the input supplier industries to changes in the final demand of a specific industry. Finally, induced effects represent the responses of all industries caused by increases in household spending and inter-industry transactions.

In I-O models, a change in production in one sector has two types of effects on other sectors of the economy. First, increased output in a sector means there will be an increase in the demand it places, as a purchaser, on the sectors whose goods it uses as inputs. The term backward linkage (BL) refers to the interconnections of a particular sector with the sectors from which it purchases inputs. On the other hand, increased output in a sector also means that additional units of its products will be available for use by other sectors as inputs in their respective productions; that is, it increases that sector's supply to others that use its product as an input. In this case, the term forward linkage (FL) indicates the interconnections of a particular sector with those sectors to which it sells its output (Miller and Blair, 2009).

The backward linkages of each sector are calculated as the sum of the columns of the Leontief matrix, corresponding to the product multipliers mentioned earlier. Meanwhile, the forward linkages of each sector are calculated as the sum of the rows of the Leontief matrix.

Chapter 10 Appendix

Table A.10.1
Development indicators by country

	GDP per capita relative to U.S. (percentage)		Gini Index		Poverty incidence rate (percentage)	
	1970-1979	2009-2019	1970-1997	2009-2019	2002	2020
Latin America and the Caribbean						
Latin America	**19.6**	**22.6**	**52.5**	**47.4**	**45.9**	**27.1**
Argentina	15.0	37.0	40.8 (1980)	42.10	62.4	34.2
Belize	15.0	11.8				
Bolivia	8.4	12.5	58.2 (1997)	45.80	66.8	32.3
Brazil	17.9	26.4	57.9 (1981)	53.06	37.8	18.4
Chile	23.3	39.3	56.2 (1987)	45.52	40 (2003)	14.2
Colombia	22.6	23.4	51.5 (1992)	52.11	53.8	39.8
Costa Rica	26.8	28.0	47.5 (1981)	48.65	28	19.4
Ecuador	23.1	19.5	53.4 (1994)	46.18	53.5 (2001)	30.6
El Salvador	3.7	12.9	54.0 (1991)	41.31	50.6 (2001)	30.7
Guatemala	12.2	13.0				
Guyana	14.5	19.0				
Honduras	9.4	8.4	59.5 (1989)	50.53	57.4 (2001)	52.3 (2019)
Mexico	38.0	32.0	50.6 (1989)	47.80	46.4	37.4
Nicaragua	25.1	8.7				
Panama	20.9	42.1	58.9 (1989)	50.77	34	14.6 (2019)
Paraguay	12.0	20.3	40.8 (1990)	48.57	47.9	22.3
Peru	14.5	20.0	53.3 (1997)	43.90	43.3	28.4
Suriname	20.6	25.2				
Uruguay	29.7	34.5			20.7	5
Venezuela	40.0	17.6				
Caribbean	**29.6**	**26.9**	**47.8**	**45.5**	**33.6**	**21.8**
Antigua and Barbuda	25.5	29.6				
Bahamas	82.8	56.4				
Barbados	50.4	23.1				
Dominica	19.9	17.6				
Granada	10.4	22.4				
Haiti	5.6	3.0				
Jamaica	24.2	13.9				
Dominican Republic	13.9	26.0	47.8 (1986)	45.52	33.6 (2002)	21.8
St. Kitts and Nevis	20.0	37.1				
St. Lucia	22.2	22.2				

Continued on the next page →

	GDP per capita relative to U.S. (percentage)		Gini Index		Poverty incidence rate (percentage)	
	1970-1979	2009-2019	1970-1997	2009-2019	2002	2020
St. Vincent and the Grenadines	15.4	18.5				
Trinidad and Tobago	65.1	53.2				
OECD countries						
OECD	**62.4**	**79.5**	**31.7**	**32.7**		**11.1**
Germany	64.5	84.2	29.5 (1991)	31.2		11.6
Australia	78.9	89.7	31.3 (1981)	34.3		12.6
Austria	61.3	85.6	30.8 (1994)	30.6		9.6
Belgium	67.4	76.2	25.2 (1985)	27.8		7.3
Canada	86.8	83.2	37.3 (1971)	33.2		8.6
Denmark	75.4	85.9	26.2 (1987)	27.9		
Slovenia						7.0
Spain	49.4	62.5	34.5 (1980)	35.4		15.4
United States	100.0	100.0	36.6 (1970)	41.0		16.4
Estonia						15.8
Finland	62.3	74.3	22.2 (1987)	27.3		5.7
France	73.5	71.6	37.1 (1970)	32.5		7.7
Greece	48.7	46.2	37.0 (1995)	34.7		13.0
Hungary	27.3	44.2				8.7
Ireland	39.0	123.5	35.5 (1987)	32.2		7.7
Iceland	81.5	81.7				
Israel	61.9	63.3	36.3 (1979)	40.4		16.9
Italy	56.3	67.0	32.5 (1986)	35.0		13.5
Japan	56.3	68.2				
Latvia						16.9
Lithuania						14.1
Luxembourg	89.0	136.3	26.3 (1985)	32.7		9.8
Norway	68.3	138.0	26.9 (1979)	26.8		8.4
New Zealand	64.2	65.4				12.4
Netherlands	79.0	91.4	28.4 (1983)	28.2		8.2
Poland	24.5	47.0				9.1
Portugal	35.4	50.4				12.8
United Kingdom	64.7	72.4	28.0 (1970)	33.3		11.2
Czech Republic						5.3
Republic of Korea	14.5	65.7				15.3
Slovak Republic						9.4
Sweden	74.2	86.2	24.3 (1975)	28.6		8.8
Switzerland	114.1	123.8	36.0 (1982)	32.5		9.9
Turkey	29.9	42.3	43.5 (1987)	40.9		14.7

Note: For the period 1970–1997, the year to which the Gini index data corresponds is shown in parentheses. No poverty data are available prior to 2004 for OECD countries, with the exception of Canada, Finland, and the United Kingdom, whose poverty rates in 2002 were 12.3%, 6.2%, and 12.6%, respectively.

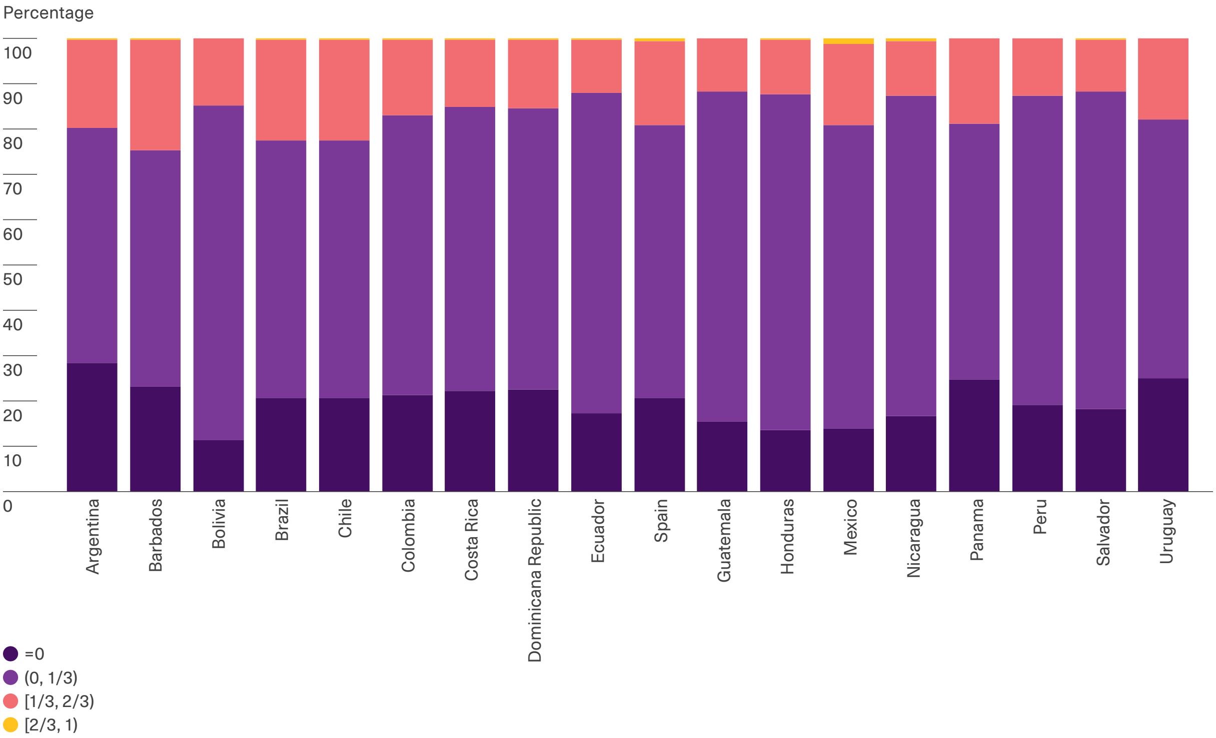
Source: Authors based on World Bank (2024), ECLAC (2022), Feenstra et al. (2015) and OECD (2024).

Clarifications regarding tables 10.1 and 10.2

The Latin American countries considered in Table 10.1 are Chile, Ecuador, Mexico, and Peru (without wage information), and in Table 10.2, the same with the exception of Peru.

The OECD countries considered in both tables are Austria, Belgium, Denmark, France, Germany, Ireland, Israel, Italy, Japan, Lithuania, New Zealand, the Netherlands, Poland, Slovakia, Spain, Sweden, Turkey, South Korea, the United Kingdom and the United States.

Graph A.10.1
Distribution of green and non-green employment by type of tasks



Note: Prepared with data from O*NET and household surveys with 2-digit coding. Set of occupations composed entirely of non-green occupations takes value 0. Between 0 and 1/3 the set that has less than one-third of green occupations. Between 1/3 and 2/3 the set that has between one-third and two-thirds of green occupations and between 2/3 and 1 the set that has between two-thirds and all of its occupations green.

Source: Authors with data from De la Vega et al. (2024).

Taxonomy development process and governance structure[4]

The development of a taxonomy is not a singular process but varies with national contexts and circumstances. In general terms, based on international experiences, the following stages can be identified in the development of a green taxonomy:

1. The need to develop a green taxonomy is identified

This need may arise from various sources: through mechanisms such as surveys or interviews with key stakeholders, suggestions from an independent committee, an analysis of market needs, among others.

2. Taxonomy development process

It involves defining a methodology, identifying which sectors and activities to include, and establishing eligibility criteria.

Coordination and consultation among stakeholders (public agencies, private companies, financial institutions, technical experts) are required throughout this process. Although there is no standardized process for developing a taxonomy, common steps or tasks can be identified in existing experiences, such as:

- Definition of strategic objectives.
- Establishment of institutional working groups.
- Setting up a governance structure (defining roles).
- Identification of national policies that address environmental objectives.
- Analysis of gaps between strategic objectives, national targets (NDCs), and national policies.
- Review of international experiences and assessment of the applicability of international taxonomies in the local context.
- Initial definition of sectors, activities, and eligibility criteria.
- Sector-specific technical working groups and expert consultations.

As a result of this iterative process of consultations, technical discussions, reviews, etc., a draft emerges.

The tasks for developing a taxonomy depend on the existing governance structures in each country. For example, technical working groups (public or public-private) for the exchange of information, the formation of inter-ministerial technical teams, or the establishment of supervisory committees for taxonomies, among others.

3. Public consultation

A common strategy observed in the existing taxonomies is to submit the draft to public consultation.

4. Review and update

Based on the comments and contributions collected during the public consultation, the taxonomy undergoes revision (inclusion of sectors, activities, and eligibility criteria adopted). It should be noted that taxonomies are not static but rather dynamic and flexible instruments to respond to technological and scientific changes and the emergence of new activities and data.

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[4] Based on CBI (2021).

Governance of a taxonomy

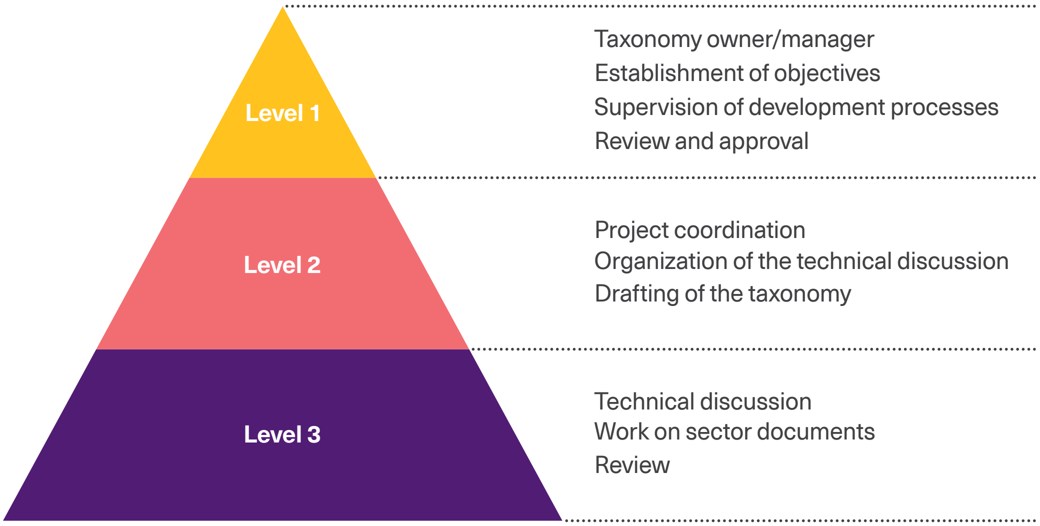
The process of developing a taxonomy involves coordination among many actors, requiring their interaction under a hierarchical structure of established functions.

Level 1 is tasked with establishing objectives, ensuring alignment with national goals and policies (with NDCs, for example), reviewing, approving, and publishing the taxonomy, and overseeing the entire development process.

Level 2 is composed of the coordinators and consultants of the entire taxonomy development process, since their role is to execute and harmonize all the tasks involved. They are responsible for the administrative work, coordinating with technical experts, and gathering their feedback, and drafting the taxonomy to be presented to the main committee for approval.

Level 3 consists of technical experts by sector and industry, appointed for their technical and regulatory knowledge in the respective economic sector. They are primarily responsible for technical discussions, reviewing the taxonomy draft, providing inputs for adding or modifying activities, and defining eligibility criteria.

Figure A.10.1
Governance structure of a taxonomy



Source: CBI (2021).

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:
Las ventajas competitivas de América Latina y el Caribe para la transición energética, CAF en la COP (youtube.com)

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