Economic activities: Sustainability in production and consumption

2

- Structure of greenhouse gas emissions by sector and sub-sector in Latin America and the Caribbean
- Adaptation needs in the main sectors of Latin America and the Caribbean
- Adaptation and mitigation policies in the energy and agricultural sectors in Latin America and the Caribbean

Key messages

1

The agriculture, forestry and other land use (AFOLU) sector is the largest contributor to greenhouse gas (GHG) emissions in the region, accounting for 58% of total emissions. Land use change, largely due to deforestation caused by the expansion of the agricultural frontier, is the main contributor to these emissions.

2

The energy systems sector, the largest emitter in the world, with 34% of GHGs produced, accounts for only 13% of emissions in Latin America and the Caribbean. This is explained, in part, by the lower levels of development that characterize the region and because it has a relatively clean electricity matrix.

3

Adaptation to climate change in the agricultural sector should be the main focus of efforts in Latin America and the Caribbean, given the sector's importance in their economies and the global food market. This is particularly crucial due to the high proportion of small-scale farms primarily dedicated to subsistence farming and the already observed decline in the production of certain crops.

4

The region requires significant investments in infrastructure for adaptation in the energy sector and cities. This is of utmost importance for Caribbean countries, which account for a very small portion of global emissions but will experience the greatest impacts from climate-related events in the short and medium term.

5

Latin America has a great potential for mitigation through reductions in emissions associated with livestock, particularly cattle, both from direct methane emissions and by halting the progression of deforestation for pastureland.

6

Nature-based solutions (NbS) promote adaptation and mitigation, as well as offer additional co-benefits. In the agricultural sector, agroforestry stands out as it provides natural protection and has the potential to increase productivity.

7

Carbon pricing is the most efficient mechanism to reduce greenhouse gas (GHG) emissions. Its implementation should be accompanied by the phase-out of fossil fuel subsidies and the redistribution of tax revenues to offset its regressive impact.

8

The region has enormous potential for electricity generation from renewable energy sources. Investments in these technologies, as well as in transmission and distribution networks, along with distributed power generation from solar panels, would lead to energy autonomy and a decrease in energy price variability.

9

To mitigate emissions from transportation (which accounts for 11% of the total), the region should focus its short-term efforts on policies that promote the adoption of technical improvements in internal combustion engines, the use of public transportation (ideally electric), and the adoption of alternatives to private vehicles. The transition to a fully electric vehicle fleet should be a medium to long-term goal, given the high cost involved in the short term.

10

Industry generates 16% of the region's emissions and has limited mitigation options given current technologies. Within this sector, the main emitters are waste management, the chemical subsector, metal production and cement. In some industrial sectors, carbon-free hydrogen can replace fossil fuels, but this requires overcoming challenges associated with its distribution.

11

Mining can play a key role in the global energy transition by providing critical minerals such as lithium and copper, but it needs to focus its efforts on minimizing environmental impacts.

12

The tourism sector, which is of great importance for generating revenue and employment in Caribbean economies, is threatened by climate-related events, the deterioration of marine coastal ecosystems, and biodiversity loss. Some adaptation policies for the sector include coastal and water resources management, as well as regulations that promote sustainable tourism.

Economic activities: Sustainability in production and consumption[1]

Introduction

The impacts of climate change are far-reaching and affect all economic sectors. In Latin America and the Caribbean (LAC), economies rely heavily on natural resources, with agriculture and tourism being particularly vulnerable to climate variability. As temperatures rise and climate patterns become more extreme and unpredictable, these sectors face increasing challenges to avoid productivity losses, cost increases, and ultimately, competitiveness declines. Additionally, the effects of climate change on infrastructure, due to the increased frequency and intensity of extreme weather events and rising sea levels, also pose significant economic challenges across all sectors.

The magnitude of these challenges is reflected, at least in part, in the climate change vulnerability index for the region developed by CAF (2014). This index consists of the risk of exposure to climate change and extreme events, human sensitivity to this exposure, and a country's capacity to adapt or take advantage of potential climate changes. This indicator reveals the great heterogeneity of climate change impacts in the region and highlights the high risk faced by countries in Mesoamerica, the Caribbean, and the northern and central regions of South America.

Beyond the uneven effects of climate change on countries and sectors, a central challenge for the entire region, which affects all economic activities, is the energy transition. This refers to a shift in the global energy system that moves away from the current dependence on polluting energy sources such as fossil fuels and prioritizes renewable and cleaner sources such as hydroelectric, solar, wind, geothermal, and biomass.

1 This chapter was written by Juan Odriozola and Manuel Toledo, with research assistance from Agustín Staudt.

Agricultural activities and land use in Latin America and the Caribbean are major sources of greenhouse gas (GHG) emissions, providing opportunities for mitigation in this sector, especially regarding agricultural practices. These practices are responsible not only for high GHG emissions, particularly methane, but also for a significant portion of deforestation.

This chapter characterizes GHG emissions at the level of major economic sectors and discusses their importance for the region's economies. It also analyzes the specific impacts of climate change on each sector and strategies to adapt and mitigate GHG emissions in line with sustainable economic growth objectives. The chapter emphasizes the agricultural and energy sectors as they are the main contributors to GHG emissions and the sectors with the greatest opportunities and technological advancements in mitigation and adaptation policies. The goal of the chapter is to highlight the region's specific challenges and opportunities.

Sector-specific emissions and their environmental impact

This section describes the trends in greenhouse gas (GHG) emissions from economic sectors in the region. It also analyzes the various driving forces behind these trends and the challenges encountered by each sector in the face of the anticipated impacts of climate change.

For this analysis, it is useful to divide the economy into the following major sectors: energy systems industry, transportation, buildings, and agriculture, forestry, and other land use (AFOLU). The AFOLU sector can further be subdivided into the agricultural sector and land use, land-use change, and forestry (LULUCF) sector. The relative importance of these sectors as GHG emitters has remained stable since 1990, as shown in Graph 2.1. The AFOLU sector as a whole contributes to the majority of the region's GHG emissions, specifically 58%, compared to 22% globally, according to 2019 data. Separately, the agricultural and LULUCF sectors represent 20% and 38% of regional emissions, respectively, contrasting with 11% each globally.

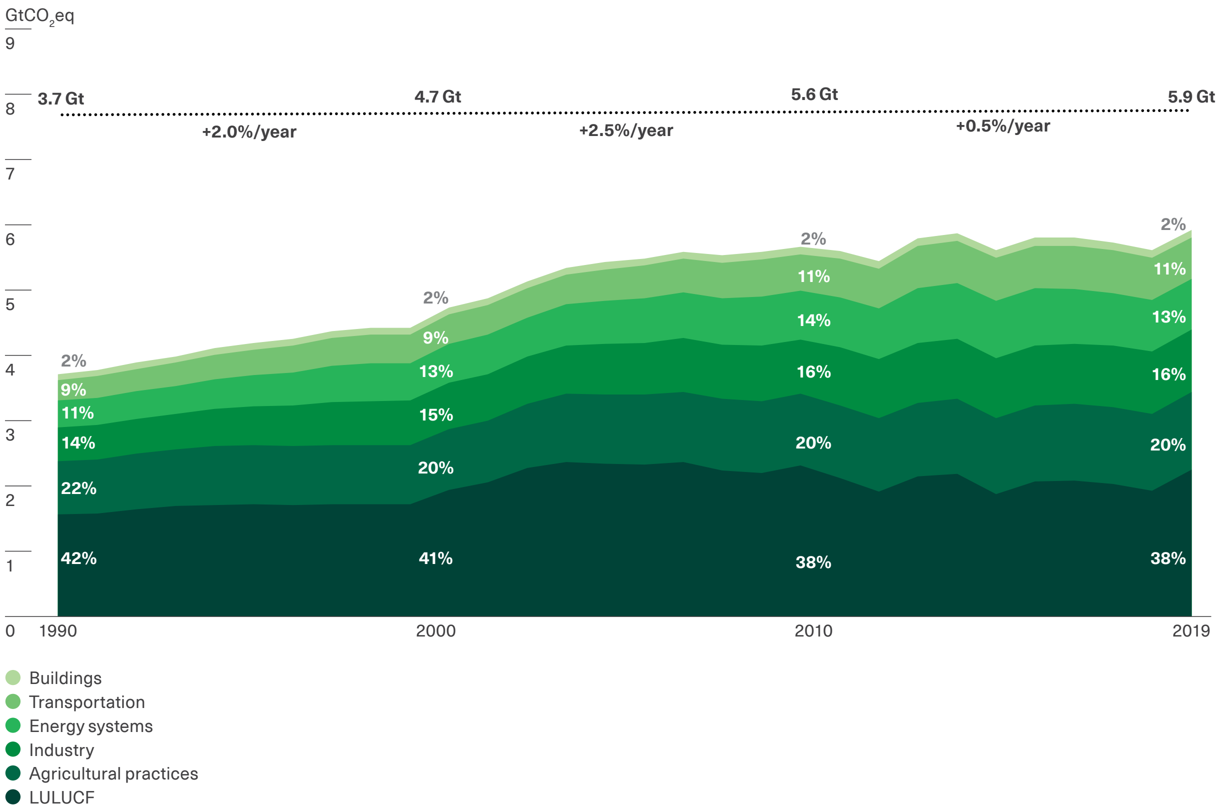
The rest of the sectors play a less significant role compared to the global level. In particular, the energy supply sector, the largest emitter in the world, with 34% of GHGs, accounts for only 13% of emissions in Latin America and the Caribbean. This implies that the region contributes 26% of global AFOLU emissions, but only 4% of emissions from the energy supply sector, 6% from industry, 7% from transportation, and 3% from buildings, which translates into 10% of total global emissions.

●●

AFOLU accounts for 58% of GHG emissions in LAC, while emissions from the energy sector account for 13%. Globally, these sectors account for 22% and 34% of emissions

This regional outlook reveals significant heterogeneity among countries. Graph 2.2 illustrates the percentage of GHG emissions by sector for a group of countries and subregions in 2019. It highlights the pivotal role played by LULUCF in South America, accounting for 35% of the subregion's emissions (see Chapter 1). In contrast, LULUCF contributes to 26% and 12% of the emissions in Central America and Mexico, respectively. Interestingly, in the Caribbean, LULUCF does not generate CO_2 emissions and actually serves as a carbon sink.

Graph 2.1
GHG emissions by sector in Latin America and the Caribbean in the period 1990-2019



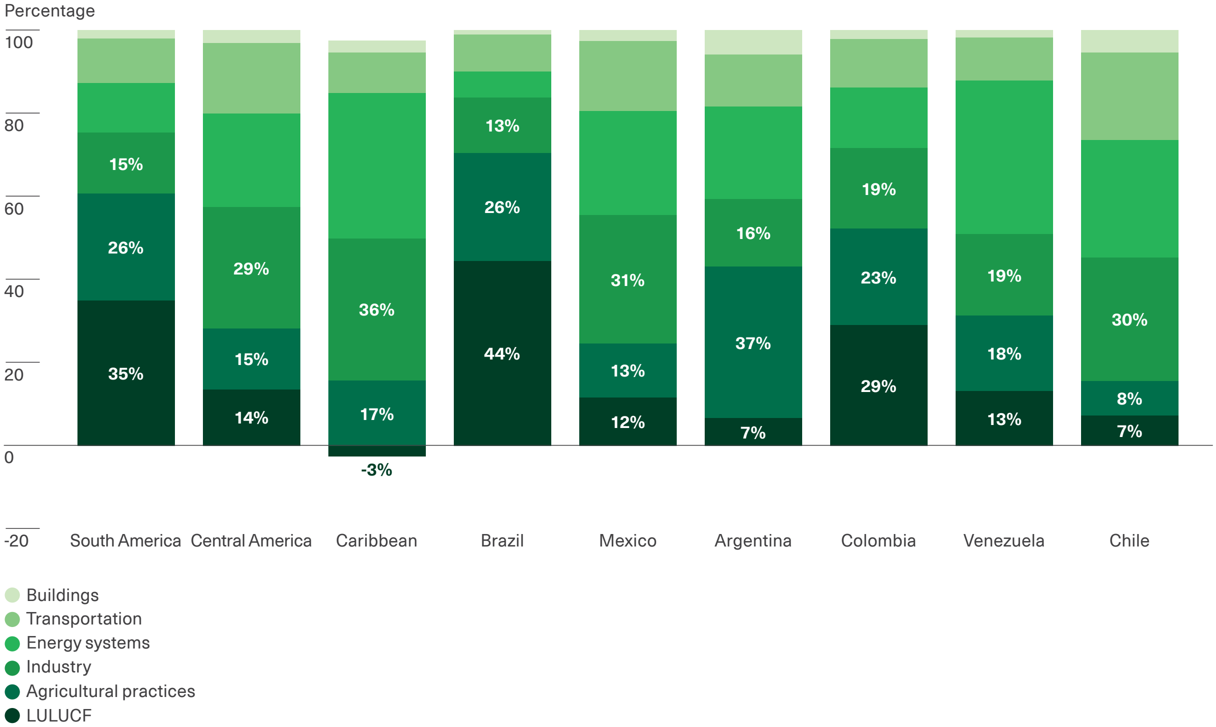
Note: The graph displays the evolution of GHG emissions in $GtCO_2eq$ disaggregated according to the following sectors: agriculture, LULUCF, buildings, energy systems, transportation, and industry. Additionally, the graph reports the total volume of emissions and sectoral contributions for the years 1990, 2000, 2010, and 2019, as well as the average interannual variation for each decade. The countries included in Latin America and the Caribbean (LAC) are those classified by the IPCC in the Sixth Assessment Report of Working Group III, Chapter Two (Dhakal et al., 2022).

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

The importance of agricultural activity in GHG emissions at the regional level is largely explained by the importance of this activity in South America, where 26% of emissions come from this sector. The three countries that emit the most GHGs in the subregion are Argentina, Brazil and Colombia, which together account for 70% of all agricultural sector emissions in Latin America and the Caribbean. Uruguay and Paraguay also stand out, where 60% and 31% of emissions come from the agricultural sector. In Central America, this activity contributes 23% of emissions, while in Mexico and the Caribbean, it accounts for 13% and 16%, respectively.

Another major difference between countries can be seen in the importance of the energy systems sector. In South and Central America, this sector is responsible for 12% and 10% of GHG emissions, due to a relatively clean electricity matrix, as explained below. In contrast, in Mexico and the Caribbean, where electricity generation from renewable sources is much smaller, this sector contributes 25% and 37% of emissions.

Graph 2.2
GHG emissions by sector in Latin America and the Caribbean in 2019



Note: The graph reports the sectoral share of total GHG emissions for the LAC subregions and the six main emitting countries in the region, ordered by total emissions. The list of countries included in each subregion can be found in the appendix of the chapter available online.

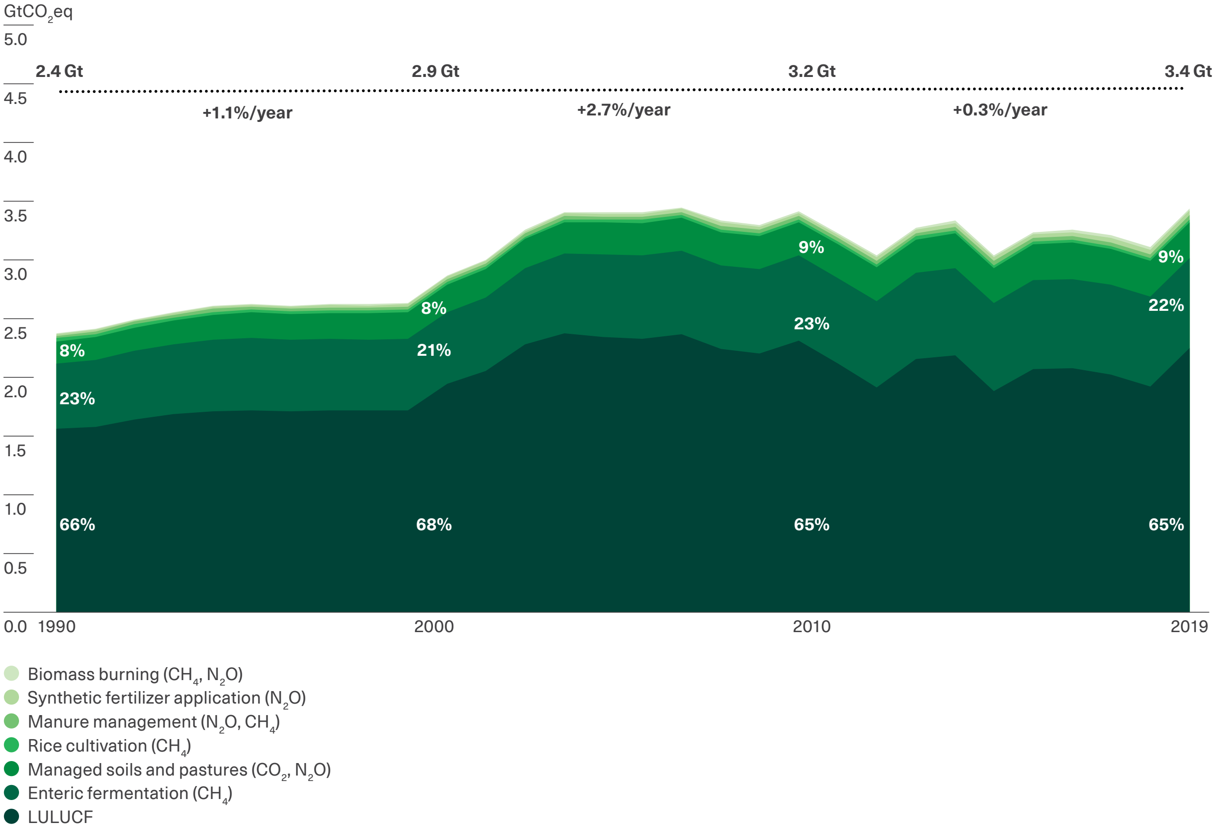
Source: Authors based on data from Minx et al. (2021) and Friedlingstein, O'Sullivan et al. (2022).

Agriculture, forestry and other land uses

Emissions

As mentioned earlier, the majority of GHG emissions in the region originate from the AFOLU sector. Within this sector, LULUCF is responsible for approximately two-thirds of the emissions, a proportion that has remained stable over the past three decades (see Graph 2.3). The remaining one-third consists of emissions from the agricultural sector, which contrasts with the global scenario where LULUCF and agriculture are each responsible for roughly half of the AFOLU sector's emissions.

Graph 2.3
GHG emissions from the AFOLU sector in Latin America and the Caribbean in the period 1990-2019



Note: The graph reports the total volume of emissions and the sectoral share for the years 1990, 2000, 2010 and 2019, as well as the average interannual variation for each decade. Countries included in LAC are those that are in the IPCC classification in the Sixth Assessment Report of Working Group III, Chapter Two (Dhakal et al., 2022).

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

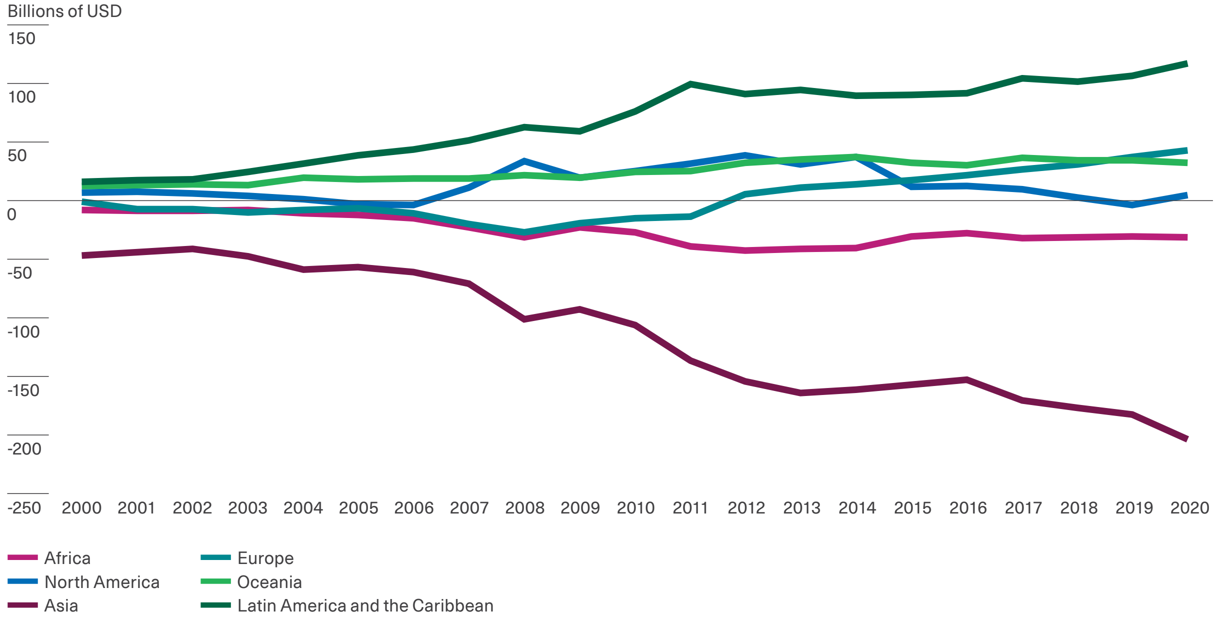
This high proportion of LULUCF emissions is due to deforestation and the expansion of agricultural frontiers in the region. According to World Bank data (2022a), Latin America and the Caribbean experienced a nearly 14% decrease in forest area from 1990 to 2020, while the agricultural land area increased by 36% from 1990 to 2017, as reported by land use data by Gauthier et al. (2021). Furthermore, data for the period 2000-2010 reveals that over 90% of regional deforestation is driven by agricultural activity (Hosonuma et al., 2012).

In South America, in particular, FAO (2022a) identified livestock grazing as the primary cause of deforestation between 2000 and 2018. Crop cultivation, meanwhile, also played an important role. During the first two decades of this century, forest cover declined by 5% while cultivated areas grew by 45%, representing the two highest rates of change among major regions worldwide (Potapov et al., 2022). Satellite data shows that forest losses were concentrated along the agricultural frontier surrounding the remaining intact Amazon rainforests. In fact, 17% of the expansion of cropland coincided with areas of forest loss, making it the region with the highest proportion of such spatial coincidence in the world.[2] The main hotspots of deforestation caused by cropland expansion were the humid forests of the Cerrado and the Amazon in Brazil, the forests of the Chaco in Argentina, and the Chiquitano forests in Bolivia (see Chapter 3).

This phenomenon of deforestation and the expansion of the agricultural frontier is closely linked to the region's growing importance as a global food provider. As shown in Graph 2.4, Latin America and the Caribbean stands out for its high food trade surplus in recent years, significantly surpassing any other region in the world. This is reflected in the extensive agricultural land area in the region, accounting for 14% of the world total, as well as in the high share of agricultural exports in the region's total exports. In 2020, 27% of exports were agricultural products, three times higher than the global average. Consequently, the region contributes 14.2% to world agricultural exports, contrasting with its smaller share in total exports (5.4%) and global GDP (around 6%). This contributes to the relatively high weight of the agricultural sector in the region's economy. As shown in Graph 2.5, agricultural value added represents 5.2% of regional GDP, compared to 4.4% in the rest of the world. However, there is considerable heterogeneity among countries in this regard.

The expansion of the agricultural frontier and deforestation are closely linked to the region's importance as a global food supplier

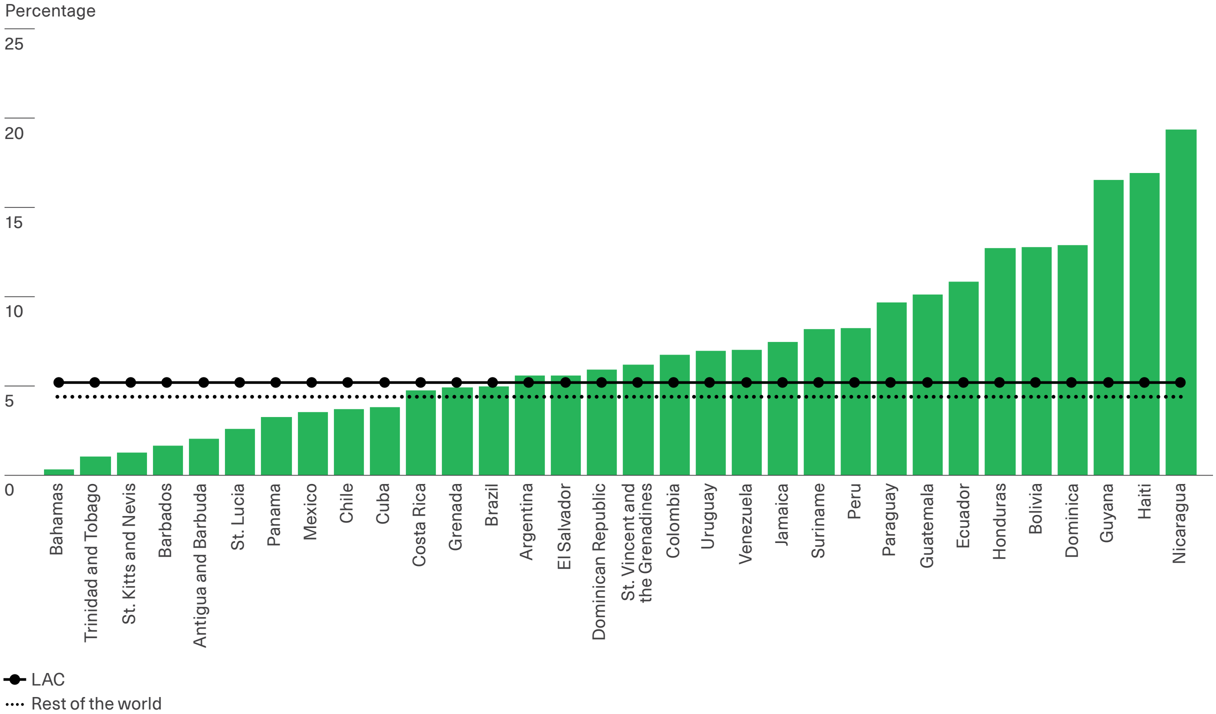
Graph 2.4
Net food exports by region for the period 2000-2020



Note: The graph reports net food exports (exports minus imports), excluding fish, in billions of US dollars for the period 2000-2020. Values are disaggregated by region.
Source: Authors based on FAO data (2022b).

2 As a reference, worldwide, the location of 8% of the area of cropland expansion coincides with that of forest loss.

Graph 2.5
Agricultural value added in Latin America and the Caribbean in 2020



Note: The graph shows the value added of crop cultivation, livestock, forestry and fisheries as a percentage of GDP in US dollars (at 2015 prices) for LAC countries with available information.

Source: Authors based on FAO data (2022c).

Another aspect worth highlighting in the region's agricultural sector is the greater importance of livestock compared to the rest of the world. Based on the gross production value in 2021, livestock activity in Latin America and the Caribbean accounted for 39% of the entire agricultural sector, while in the rest of the world, it accounted for 30%.[3] This is reflected in the GHG emissions profile of the sector, with the majority coming from livestock, particularly enteric fermentation of animals—a phenomenon that occurs during the digestive process of ruminants—which accounts for 64% of GHG emissions from the agricultural sector, in contrast to the global average of 46%. Managed soils and pastures, in contrast, contribute 26% of sector emissions. Finally, synthetic fertilizer application (3.4%), manure management (2.8%), rice cultivation (1.9%), and biomass burning (1.6%) contribute to the remainder.

In terms of emissions composition by gas type in agricultural activity, 69% is methane, mainly from enteric fermentation. Nitrous oxide represents 28% of sector emissions, primarily from soil and pasture management. Finally, CO_2 accounts for less than 3% of emissions.

3 These percentages were specifically calculated based on the gross value of production in current US dollars of both activities available in FAO (2022d).

As mentioned in Chapter 1, methane has a higher heat-trapping capacity than CO_2, making it significantly more damaging to the atmosphere and the environment. However, due to its short lifespan in the atmosphere of around 10 years, rapid reductions in methane emissions can have significant effects in a relatively short timeframe. Another relevant characteristic of methane is that it is one of the main precursors of tropospheric ozone. Besides being harmful to human health, it has adverse effects on vegetation and its growth capacity, reducing forest growth, biodiversity, and crop productivity. This, in turn, negatively impacts the carbon absorption capacity of forest biomass, contributing to global warming.

On the other hand, nitrous oxide, which has an atmospheric lifespan of over 100 years, is significantly more potent than CO_2 in terms of its heat-trapping capacity.[4] Due to the long duration of nitrous oxide in the atmosphere, controlling global emissions of this gas will not have an immediate impact on its atmospheric concentration. In fact, it will take over a century to achieve complete stabilization (IPCC, 2021a). Another important aspect is that nitrous oxide is one of the main contributors to the destruction of the stratospheric ozone layer, which filters harmful ultraviolet radiation from the sun. The reduction of this protective layer not only has adverse effects on human health but also on vegetation and its ability to absorb carbon from the atmosphere, further contributing to global warming and reducing agricultural productivity.

Unlike the other gases, nitrous oxide emissions are highly concentrated in agriculture. The sector is responsible for nearly three-quarters of the emissions of this gas in Latin America and the Caribbean. This high concentration in one activity allows mitigation measures to be more targeted and potentially effective. For example, measures that improve soil management and incentivize more efficient use of nitrogen fertilizers could have a significant impact on reducing nitrogen emissions.[5]

Adaptation needs to climate change

Many studies have analyzed the effects of climate change on agricultural activity. Some of the main factors highlighted in these studies include changes in rainfall patterns, significant increases in extreme temperatures, higher incidence of crop pests and diseases, and increased risk of droughts and other extreme weather events.[6]

Climate change affects agricultural activity through changes in rainfall patterns, an increase in extreme temperatures, and a higher incidence of pests, the risk of droughts, and other extreme weather events

In the case of Latin America and the Caribbean, these effects vary across subregions and countries. Geographical location is particularly relevant given the region's vast territory. In tropical and subtropical latitudes, rising temperatures have a negative impact on production as they can exceed heat tolerance thresholds for certain crops.[7] Conversely, in temperate latitudes, higher temperatures and an extended growing season tend to expand the area with production potential. Overall, negative impacts are expected in tropical and subtropical areas, while temperate zones are expected to experience mild or even positive effects.[8]

4 The IPCC (2021a) reports that the average atmospheric lifetime of nitrous oxide is 116 years. Taking into account the negative effect that the concentration of this gas has on its own atmospheric lifetime, its effective duration is estimated to be 109 years. The report also indicates that nitrous oxide has a global warming potential 273 times greater than CO_2 over a 100-year period.

5 However, the IPCC (2022a) notes that, under the different mitigation scenarios, methane and nitrous oxide emission reductions from the AFOLU sector are modest.

6 Some of these studies include Nelson et al. (2009), Campbell (2022), Outhwaite et al. (2022), Skendžić et al. (2021), Raza et al. (2019). Chapter 1 of this report also discusses these phenomena as a consequence of climate change.

7 In the case of Central America, for example, higher temperatures are expected to cause a reduction in coffee, corn, rice and bean crop yields, as well as in the area suitable for their cultivation.

8 See Cristini (2023) a study prepared for this report.

In Central America, the agricultural sector is particularly vulnerable to decreased precipitation because around 90% of production relies on rainfall for crop irrigation. In these countries, agricultural production follows a bimodal calendar marked by two rainy seasons and one dry season per year. The decline in rainfall occurs during the second rainy period, which coincides with the end of summer, jeopardizing the possibility of having a second harvest before the arrival of the dry season. This vulnerability is especially acute in the so-called Central American dry corridor, which spans Costa Rica, Nicaragua, Honduras, El Salvador, and Guatemala. It is an area highly susceptible to extreme weather events, experiencing prolonged periods of drought and intense rainfall that significantly impact agricultural production.[9]

Agrifood production in Caribbean countries faces similar challenges to those in Central America. In addition to water scarcity issues for agricultural production, this subregion is highly exposed to floods and other extreme weather events.

This vulnerability to climate change has already resulted in significant agricultural production losses in Mexico, Central America, and the Caribbean (Lachaud et al., 2017). In the future, the situation is expected to worsen due to declines in crop yields and agricultural labor productivity, caused by heat stress affecting workers during periods of high temperatures. For example, by 2050, crop production would decrease by 20% in Belize, 11% in Nicaragua, 7% in Panama and El Salvador, and 5% in Mexico (Banerjee et al., 2021).[10]

The effects of climate change on agriculture imply greater risks to food security regionally and globally

In a recent study, Prager et al. (2020) assessed the effects of climate change on crop cultivation in 15 Latin American and Caribbean countries. They consider not only the biophysical response of crops but also the economic responses of producers to adapt to yield losses, changes in agroecological suitability, and shifting conditions in international markets.[11] Their findings indicate that the Andean region, Mexico, and Central America will experience the greatest negative impacts, while countries in the Southern Cone could potentially increase their production. However, if temperature increases are more pronounced, the negative impacts could be more widespread.

These estimates imply higher risks for food security, not only in the region but also in other parts of the world, particularly Asia and Africa, which, as shown in Graph 2.4, have significant food trade deficits (see Box 2.1). Increased food insecurity, along with crop displacement due to climate change and increased demand for food, can generate additional pressures on forests and lead to more deforestation. This would have negative effects not only on GHG emissions and biodiversity but also on agricultural productivity itself since the returns from converting forests to agricultural land are generally low due to the rapid soil fertility loss.

9 See Molina-Millán (2023), a study prepared for this report.

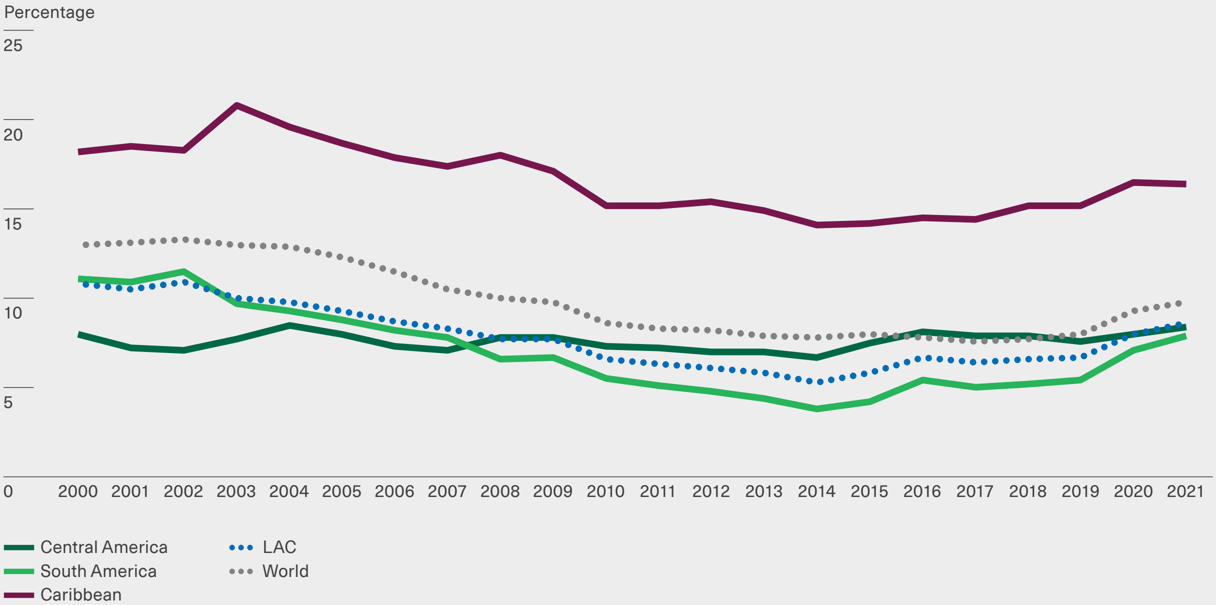
10 It is worth noting that these estimates do not consider potential adaptation and mitigation measures to climate change that governments and producers could implement, nor do they consider technological advancements to counteract its effects.

11 One consequence of the increasing vulnerability of crops to climate change is the rise in illegal migration. Danza and Lee (2022) find that in rural regions of Mexico, fluctuations in precipitation and temperatures during the wet season decrease the total harvested area and maize production, leading to an increase in migration to the United States. Additionally, they document that this migration is predominantly composed of illegal migrants.

Box 2.1
Food security

Recent estimates from the United Nations indicate that approximately 10% of the global population and 9% of the population in Latin America and the Caribbean suffer from hunger (FAO, 2021, 2020), reaching the highest levels in the past 15 years (United Nations, 2015). This situation has been further exacerbated by the impacts of the COVID-19 pandemic. Graph 1 illustrates the prevalence of malnutrition worldwide and in Latin America and the Caribbean. It is evident that the region is experiencing a slight upward trend in malnutrition, which began in 2014, with the countries of the Caribbean facing the highest levels. And, as mentioned in Chapter 1, the Caribbean countries are also among those most at risk of exposure to the effects of climate change.

Graph 1
Prevalence of malnutrition by subregion in Latin America and the Caribbean in the period 2000-2021



Note: The graph shows the percentage of the population suffering from undernutrition in the period 2000-2021 for the world, LAC, and its subregions. The list of countries included in each subregion can be found in the appendix of the chapter available online.

Source: Authors based on FAO (2022e).

Family farming (FF) is a major source of livelihood and employment generation in Mesoamerica and the Caribbean. Table 1 reflects the importance of this type of agriculture for most Central American countries[a] and highlights its weight in food production and employment. According to estimates by Leporati et al. (2014). family farms account for 81% of the total farms in the region.

Basic grains occupy a substantial portion of the region's agricultural land. While their contribution to the overall agricultural value-added is less than 10%, their production is vital for feeding a large part of the regional population, including the subsistence consumption of small-scale farmers. These farmers and their families face significant threats from the impacts of climate change on their crops and should be considered a priority sector in public policies, especially regarding the financing of adaptation measures.

Table 1
Contribution of family farming to agricultural production in 2013

	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama
Proportion of food production generated by FF						
Rice	22%	84%	73%	78%	21%	16%
Bean	75%	42%	13%	14%	2%	52%
Corn	97%	44%	30%	40%	23%	81%
Fruits	10%	32%	3%	12%	8%	6%
Vegetables	9%	64%	3%	8%	66%	9%
Meat	2%	9%	21%	10%	2%	6%
Share of sectoral employment belonging to FF						
Employment	36%	51%	63%	76%	65%	70%

Note: The table reports the participation of the main crops in family farming in Central America.
Source: Molina-Millán (2023).

a. No data or estimates are available for Belize or the Caribbean countries.

One aspect that deserves special attention is the productive structure of the agricultural sector in Latin America and the Caribbean, which is highly relevant when assessing the impact of climate change on activity and food security. A key characteristic is that agricultural operations tend to be small, occupying a significant portion of arable land. As seen in Table 2.1, for countries in the region with relatively recent available data, on average, 46% of the crop area consists of farms smaller than 2 hectares (ha), and 75% are farms smaller than 10 ha. These small farms are often family-based and subsistence-oriented, and they concentrate a large portion of sectoral employment, which in many countries accounts for a high percentage of total employment. Additionally, these types of farms typically use traditional production systems and face marked access barriers to water and productive land, financing, and markets that would enable them to integrate into agro-industrial production chains. As a result, their productivity levels tend to be low.

Table 2.1
Relevant characteristics of the agricultural sector in Latin America and the Caribbean

	Employment in agriculture/total (%)	Rainfed crop area (%)	Area under cultivation with farms of < 2 ha (%) *	Area under cultivation with farms < 10 ha (%) *
Argentina	0.1	86.7		
Bahamas	2.2			
Barbados	2.7	88.3		
Belize	16.8	96.5		
Bolivia	30.5	86.0	40.3	72.7
Brazil	9.1	90.8	25.2	53.1
Chile	9.0	99.1	20.6	60.3
Colombia	15.8	68.4	28.2	81.1
Costa Rica	12.0	88.8	30.3	67.6
Cuba	17.4	98.3		
Ecuador	29.7	50.4		
El Salvador	16.3	98.0	69.2	94.1
Guatemala	31.3	78.3		
Guyana	15.4	46.9		
Haiti	29.0	95.2	85.1	99.8
Honduras	29.5	95.7		
Jamaica	15.2	88.0	83.5	99.1
Mexico	12.5	73.3	44.2	75.6
Nicaragua	30.6	91.6	34.6	64.2
Panama	14.4	99.3	59.5	81.5
Paraguay	18.7	96.5	14.4	63.6
Peru	27.4	57.7	57.9	89.4
Dominican Republic	8.8	82.2		
St. Vincent and the Grenadines	10.1	100.0		
St. Lucia	10.0	100.0	83.1	99.2
Suriname	8.1	42.7	69.9	94.5
Trinidad and Tobago	3.0	100.0		
Uruguay	8.4	97.6	2.2	16.2
Venezuela	7.9	49.5	31.4	63.9
LAC	15.2	83.8	45.9	75.1

Note: The table shows four indicators that summarize relevant characteristics of the sector analyzed: percentage of employment over total in 2019 (first column); percentage of rainfed crop area in 2017 (second column); percentage of crop area on farms smaller than 2 ha (third column); and percentage of crop area on farms smaller than 10 ha (fourth column).* Figures based on agricultural censuses conducted in different years, ranging from 2006 in Brazil to 2014 in Colombia and Costa Rica.

Source: Authors based on World Bank data (2022b), FAO (2022f) and Gauthier et al. (2021).

Linked to this is the fact that a very high percentage of crops in the region are rainfed. Table 2.1 clearly shows the significant weight of rainfed agriculture in the majority of countries in the region. On average, 84% of crop areas rely exclusively on rainfall. Given the expected effects of climate change on precipitation, with longer periods of drought and more intense rainfall in many places, dependence on rainfall can become a serious problem for agricultural producers, especially small-scale farms, putting the food security of small-scale producers, particularly those focused on subsistence farming, at risk.

This situation presents several challenges for the sector. The first challenge is how to cope with the decline in agricultural productivity as a result of climate change. The second challenge is how to meet the expected increase in demand for agricultural products while simultaneously reducing or mitigating GHG emissions from the AFOLU sector. This underscores the need to design a set of measures to boost agricultural productivity while also halting or at least slowing down the expansion of the agricultural frontier, in order to reduce the high rate of deforestation in the region or even encourage reforestation on certain lands, such as those that previously belonged to forested areas. These challenges are addressed in the section on "Adaptation and mitigation in the agricultural sector."

To mitigate emissions, the agricultural sector must boost productivity and, at the same time, slow the expansion of the agricultural frontier

Energy systems

Emissions

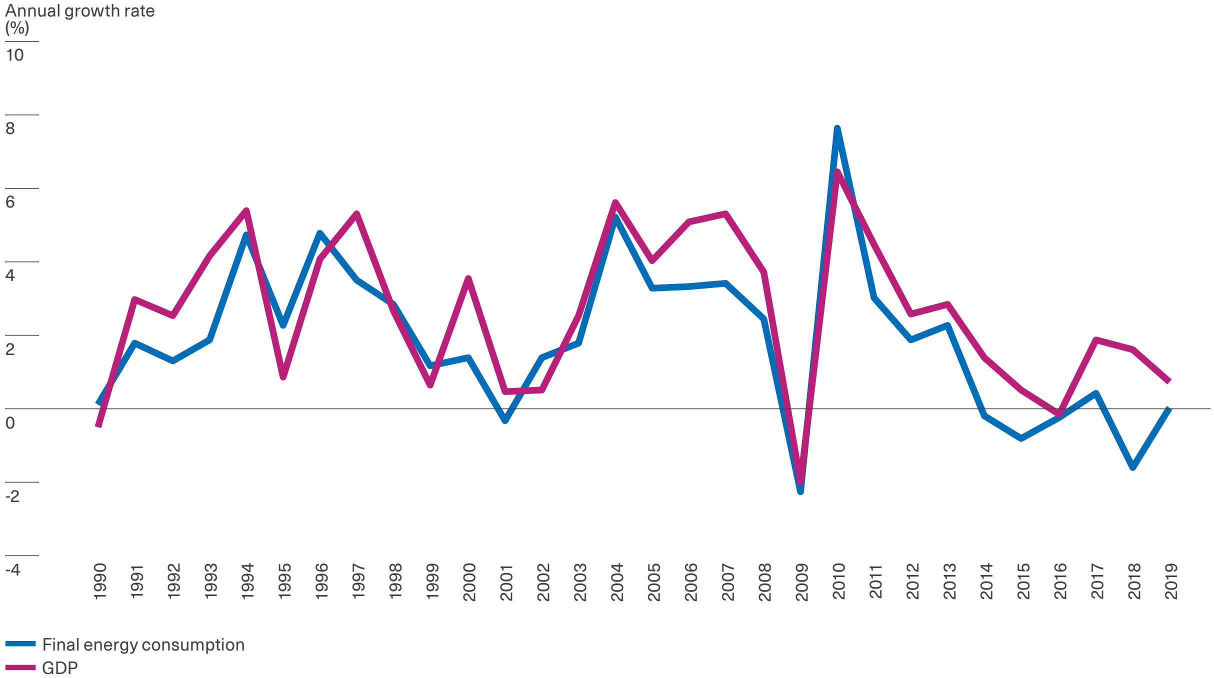
The energy systems sector encompasses all processes of extraction, conversion, storage, transmission, and distribution of energy used by end-use sectors such as industry, transportation, agriculture, and households. This includes the exploitation of hydrocarbons and coal, oil refining, and the generation of electricity and heat.[12] Thus, GHG emissions from this sector only correspond to those generated by these activities and do not reflect emissions from energy consumption.

This sector is responsible for 13% of emissions in Latin America and the Caribbean, a contribution well below the global average of 34%. This is partly due to the significant weight of the AFOLU sector in the region. However, even if the AFOLU sector is excluded, the energy systems sector still has a lower share of emissions in the region compared to the global level (31% versus 44%). This can be explained by the lower per capita energy consumption in Latin America and the Caribbean, which is associated with lower per capita income levels, and because the region's electricity matrix is relatively clean, as shown later.

This section begins by characterizing the energy consumption in the region since it largely determines the energy supply. In the period from 1990 to 2019, final energy consumption increased by 74%, driven by the growth of the region's economies. Graph 2.6 illustrates the close relationship between energy consumption and GDP, resulting in a high correlation of 0.87 between their annual growth rates.

12 Hereafter, electricity and heat will be referred to simply as electricity.

Graph 2.6
Final energy consumption and GDP in Latin America and the Caribbean for the period 1991-2019



Note: The graph reports the annual percentage growth rate of GDP at market prices in local currency (at constant prices) and final energy consumption. Aggregates are expressed in USD at constant 2010 prices. The list of countries included in LAC can be found in the appendix of the chapter available online

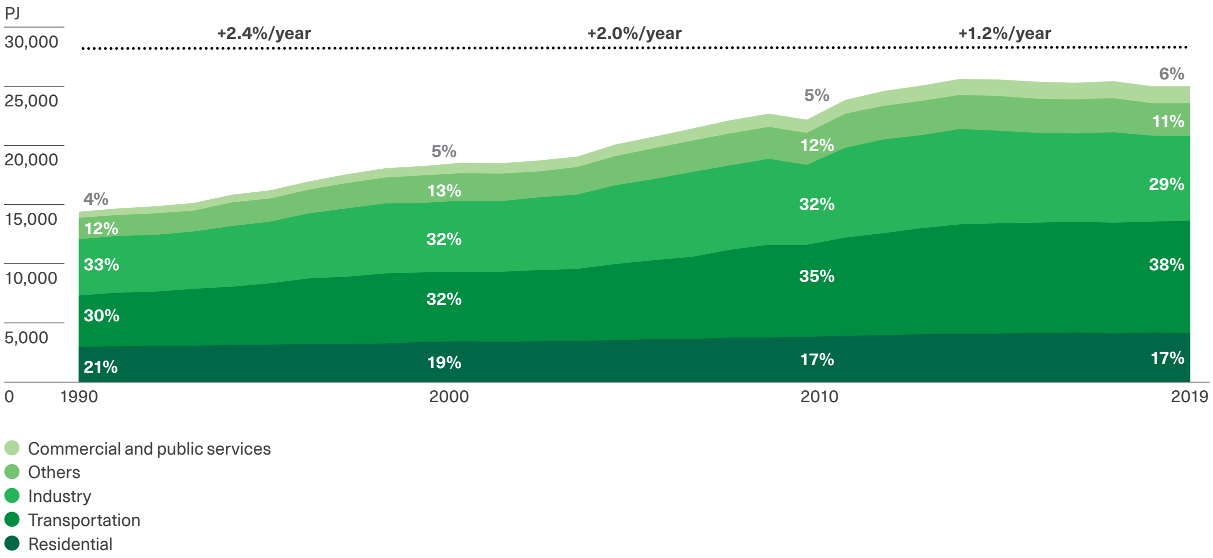
Source: Authors based on IEA data (2021a) and World Bank (2022c).

Energy consumption was driven by all sectors of the economy, especially transportation, which recorded a 120% increase in consumption. This can be primarily attributed to the significant expansion of the vehicle fleet in the region (Kreuzer and Wilmsmeier, 2014). As shown in Panel A of Graph 2.7, the growth rate of energy consumption has been slowing down in the past 30 years. In the 1990s, the average annual growth rate was 2.4%, while in the 2000s and 2010s, it was 2% and 1.2%, respectively. In fact, in the last decade, consumption reached a peak in 2013 and then experienced a slight decline of 2.3% until 2019.

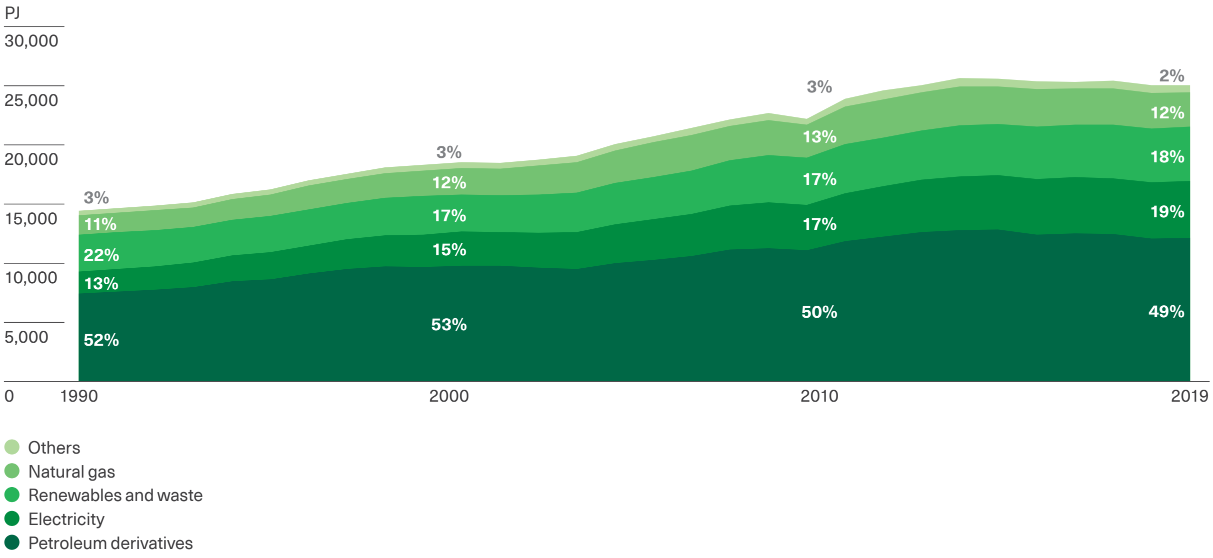
Graph 2.7

Final energy consumption by sector and source in Latin America and the Caribbean for the period 1990-2019

Panel A.
Final consumption by sector



Panel B.
Final consumption by energy source



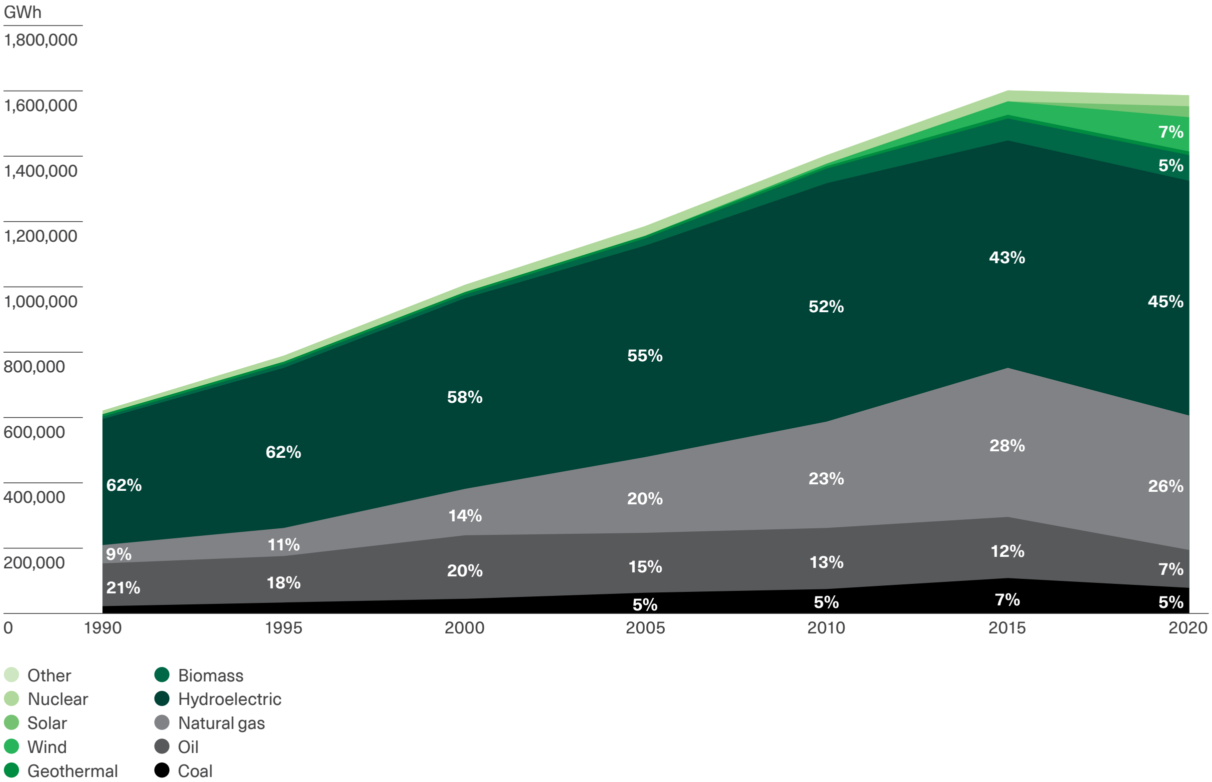
Note: The graph shows the evolution of the share by sector and source of final energy consumption in petajoules (PJ) for LAC during the indicated period. In addition, the average interannual rate per decade is shown. The list of countries considered in the graph can be consulted in the appendix of the chapter available online.

Source: Authors based on International Energy Agency (IEA) data (2021a).

Panel B of Graph 2.7 shows that this growth in final energy consumption has been accompanied by an increase in consumption from all sources, especially electricity, which grew by 157% during the period 1990-2019, from 13% to 19% of total final consumption. Natural gas, on the other hand, grew by 83%, slightly increasing its share. As for petroleum derivatives, they account for about half of total energy consumption. This consumption grew by 64%, driven mainly by the aforementioned increase in the transportation sector. However, since 2013, when energy consumption reached its peak, a decline of 5.1% in petroleum derivatives consumption and 10.5% in natural gas consumption can be observed.

The increase in electricity consumption was accompanied by a rise in the use of all primary energy sources used for electricity generation. Graph 2.8 shows the evolution of electricity production by source in Latin America and the Caribbean. It can be seen that electricity from fossil fuels has increased proportionally more than electricity from renewable energy sources. This has resulted in an increase in the share of fossil fuels from 34% in 1990 to 38% in 2020, while the share of renewable energy has decreased from 64% to 60%.

Graph 2.8
Electricity production by energy source in Latin America and the Caribbean during the period 1990-2020



Note: The graph shows the evolution of electricity production in gigawatt-hours (GWh) for the period indicated and the share of selected energy sources in LAC for the years 1990, 1995, 2000, 2010, 2015 and 2020. The list of countries considered in the graph can be found in the appendix of the chapter available online.

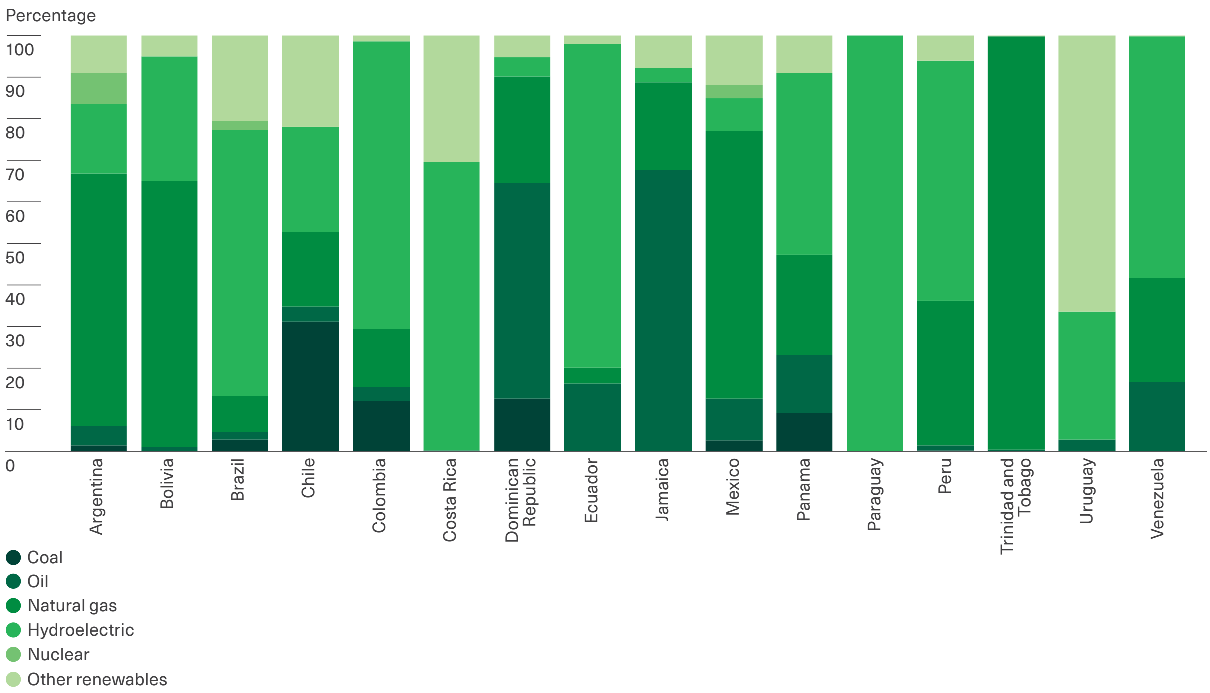
Source: Authors based on IEA data (2021a).

The increase in fossil fuels in electricity generation in the region is primarily explained by the growth in the use of natural gas, whose share increased from 9% in 1990 to 26% in 2020, while coal increased slightly from 4% to 5%, and oil decreased from 21% to 7% during the same period. Despite this increase, the intensity of fossil fuel use in electricity production in Latin America and the Caribbean is significantly lower than in other regions of the world (Lamb et al., 2021). This transition to natural gas at the expense of other fossil fuels, combined with the high proportion of electricity production from renewable sources, especially hydroelectric power, makes the region's electricity matrix much cleaner than the global average.

However, within the region, there is high heterogeneity in the electricity mix among countries, as shown in Graph 2.9. Three groups can be distinguished. First, there are countries whose electricity generation is mainly sourced from renewables, particularly hydroelectric power. Paraguay, Costa Rica, and Uruguay stand out in this group, where almost all electricity comes from these sources. Brazil, Colombia, Ecuador, Panama, Peru, and Venezuela also belong to this group, with hydroelectric power being the dominant source.

The second group consists of countries whose electricity generation is predominantly from natural gas. Argentina, Bolivia, Mexico, and particularly Trinidad and Tobago fall into this category. In the case of Trinidad and Tobago, almost all electricity generation comes from natural gas (99.6%), while in the other countries, this figure is above 60%. Finally, there are countries where the most polluting sources, oil and coal, dominate electricity production. These include Chile, the Dominican Republic and Jamaica.

Graph 2.9
Electricity generation by energy source for Latin American and Caribbean countries in 2020



Note: The graph shows the share of different energy sources in electricity generation in gigawatt-hours (GWh) in LAC countries with available information.
Source: Authors based on IEA data (2021a).

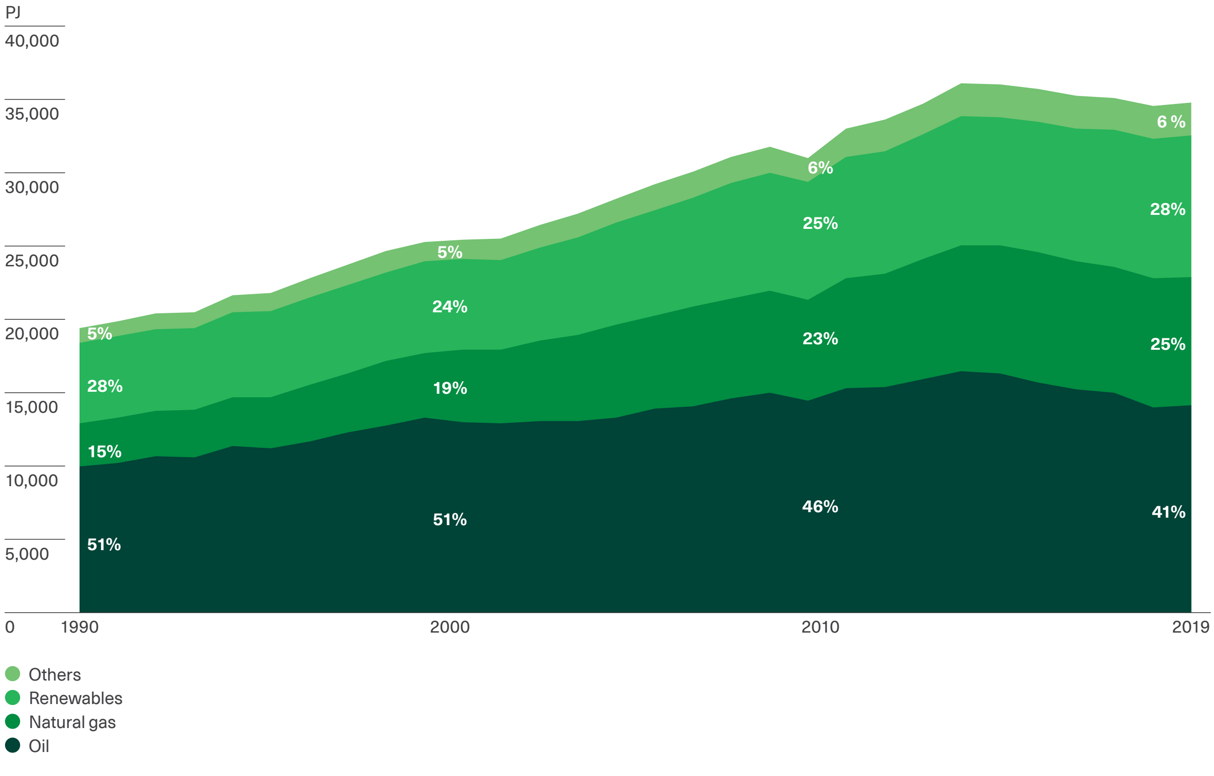
Using data from the Latin American and Caribbean Energy Information System (OLADE, 2022a) the countries in the region can be classified based on the level of renewable energy in their electricity generation. The data indicates that all Central American countries, not just Costa Rica and Panama, have a predominantly clean electricity matrix. In this subregion, 76% of the electricity generation comes from renewable sources. In contrast, in the Caribbean, only 10% of electricity is generated from such sources.

Regarding the energy supply in Latin America and the Caribbean, Graph 2.10 shows its evolution by energy source from 1990 to 2019. The total energy supply increased by 78% during this period, mainly driven by natural gas, which nearly tripled its share due to the growing importance of this commodity in electricity generation. As a result, natural gas as a primary energy source rose from 15% in 1990 to 25% in 2019. On the other hand, the proportion of oil as a primary energy source declined from 51% in 1990 to 41% in 2019, primarily due to its reduced use in electricity generation, as mentioned earlier.

The high participation of natural gas and renewable sources makes the region's electricity matrix the cleanest in the world

Graph 2.10

Total energy supply by source in Latin America and the Caribbean for the period 1990-2019



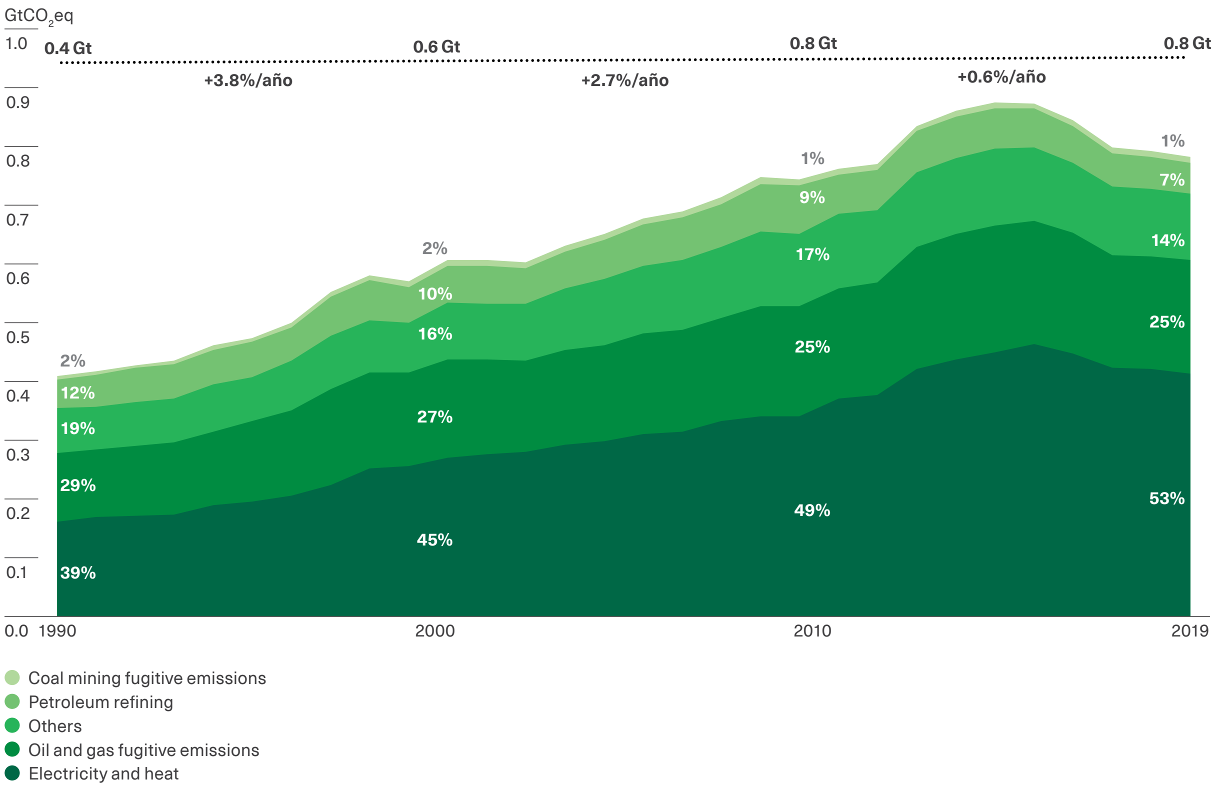
Note: The graph shows the evolution of total energy supply in petajoules (PJ) for LAC in the period indicated and the share by energy source for the years 1990, 2000, 2010 and 2019. The list of countries considered in the graph can be found in the appendix of the chapter available online.

Source: Authors based on IEA data (2021a).

This evolution of the primary energy supply in the region is reflected in the GHG emissions profile of the energy supply sector shown in Graph 2.11. It can be observed that GHG emissions have increased by 91% in the past 30 years. However, similar to the trend observed in final energy consumption, the growth of emissions has been slowing down over the same period, even registering a decline after peaking in 2014.

The growth of GHG emissions over the past three decades is largely attributed to the increase in emissions from electricity generation (and heat), which rose from 39% of the sector's total emissions in 1990 to 53% in 2019. This rise in electricity's share can be attributed to improved access to electricity in the region and the increased use of fossil fuels for its generation, as mentioned earlier. Currently, only 1.5% of the population in Latin America and the Caribbean lacks access to electricity, compared to around 12% in the early 1990s, primarily due to improved access for rural populations (World Bank, 2022d).

Graph 2.11
GHG emissions from the energy systems sector in Latin America and the Caribbean in the period 1990-2019



Note: The graph shows the evolution of GHG emissions in $GtCO_2$ eq for the energy systems sector and the participation of its subsectors in the indicated period. In addition, total emissions are reported for the years 1990, 2000, 2010 and 2019, together with the average interannual variation for each decade. Countries included in LAC are those that are in the IPCC classification in the Sixth Assessment Report of Working Group III, Chapter Two (Dhakal et al., 2022).

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

While the region's electricity generation matrix is relatively cleaner compared to other regions of the world, one of the main challenges is how to maintain or make it even cleaner in the context of climate change while meeting growing electricity demand.

●●

The energy sector's GHG emissions grew between 1990 and 2019 due to increased electricity generation as well as improved regional access to this service

Adaptation needs and mitigation to climate change

The Latin American Energy Organization's business-as-usual scenario, which is based on the latest sectoral expansion plans for energy in the region, projects that fossil fuel sources will maintain their predominance in Latin America and the Caribbean until 2050[13] (OLADE, 2022b). The share of renewable sources is also expected to slightly drop from 30% in 2020 to 28% in 2050, mainly due to a drop in the share of biomass in energy consumption—especially residential firewood, replaced by fossil sources—and the substantial growth of natural gas in electricity generation.

Projections for electricity generation under this scenario foresee natural gas becoming the main energy source, going from a 27% share in 2020 to 35% in 2050. In contrast, renewable energy sources maintain a relatively constant weight despite the sharp growth of non-conventional renewable energy sources such as wind, solar, and geothermal, with an increase in share from 10% to 24% in the same period. Conversely, hydropower loses importance in electricity generation, decreasing from 46% to 32%.[14]

This scenario also forecasts a growth of around 90% in final energy consumption from 2020 to 2050—equivalent to an annual growth rate of 2.1%—driven by a significant increase in electricity and oil consumption. This presents a worrisome outlook for the consequences of inaction regarding climate change mitigation policies.

The projected increase in natural gas use in electricity generation would help reduce emissions—to the extent that it replaces dirtier sources such as coal or oil—and at the same time, it could be the key to meeting the region's growing energy demand. This is especially relevant given the current challenges faced by the region in terms of energy security. While only 1.5% of the population in Latin America and the Caribbean lacks access to electricity, the quality of this service is deficient due to relatively frequent and long power outages,[15] which disrupt not only households but also the productive processes of businesses. On the other hand, 15% of the population relies on firewood and charcoal as their main heating source. These biomass sources, in addition to being environmentally harmful, are detrimental to health, releasing fine particulate matter (PM2.5).

Rural populations are the most affected by access issues in the region. In this regard, renewable energy sources such as wind and solar present an opportunity as they allow access to electricity in remote areas without the need for costly infrastructure installation and connection.

13 More specifically, this scenario "represents a projection of the region's energy sector [...], based on national energy balances for the base year (2020), the latest energy development plans, programs and policies published by OLADE member countries, GDP-energy consumption correlations [...] and forecasts of nominal GDP variation [...]".

14 Nuclear energy plays a minor role in LAC and will continue to do so even in a favorable energy transition scenario, with a significant reduction in CO_2 emissions. This marginal role of nuclear energy is mainly due to its higher costs, the scarce or non-existent availability of adequate human capital, and public resistance, among other factors.

15 According to World Bank data (2022e) on the duration and frequency of electricity supply interruptions (specifically the SAIDI and SAIFI indicators), the countries in the region with available data suffered 11 interruptions and a total of 15 hours of interruptions in 2020. For reference, high-income countries, according to the World Bank classification, excluding the LAC countries in that group and Palau because it has a very atypical data, suffered on average less than one interruption per year, for a total of less than one hour without electricity service.

The problem of the quality of the electricity system and access to electricity can be exacerbated by the effects of climate change. This is particularly relevant for hydropower generation in the region, especially in countries such as Brazil, Colombia, Costa Rica, Ecuador, Paraguay, and Venezuela, whose electricity matrix is highly dependent on this energy source. Increasing temperatures, greater precipitation fluctuations, and other atmospheric phenomena lead to greater instability in hydrological cycles and increased evaporation losses from reservoirs, which significantly impact water flow and availability, and consequently, hydropower generation. This poses the challenge of identifying and designing effective measures to minimize the adverse effects of climate change on the region's hydroelectric system and enhance its resilience.[16]

The problem of the quality of the electrical system and access to electricity can be exacerbated by the effects of climate change, especially in countries highly dependent on hydroelectric generation

At the same time, extreme weather events, which are becoming more frequent due to climate change, can damage energy infrastructure, particularly electricity transmission and distribution systems. These types of events pose a threat not only to existing traditional infrastructure, which may not be designed to withstand them in some cases but also to renewable energy infrastructure, such as solar and wind farms, which rely on favorable weather conditions. This presents a challenge for the energy transition in the region and further underscores the need for alternative sources as a safeguard.

Other sectors: Transportation, industry, and buildings

Emissions in transportation

The transportation sector includes the movement of people or goods by vehicles such as cars, trucks, and motorcycles, as well as through airplanes, ships, railways, and pipelines. This sector is responsible for 11% of GHG emissions in Latin America and the Caribbean (see Graph 2.1) and contributes 35% of CO_2 emissions related to fossil fuel consumption, which is much higher than the global average of 23%.

The high share of CO_2 emissions from the transportation sector is primarily due to the dominance of road freight transport (RFT) in the region. This is reflected, among other things, in the high rates of freight road transport. Approximately three-quarters of interurban freight movement at the national level is done by road. In countries in the region, except for Brazil and Mexico, which have a more developed railway network, more than 90% of metric ton-kilometers transported are by road. Additionally, road freight transport plays a significant role in intraregional trade. For example, in South America, 30% of intraregional trade volume is transported by truck, while in Central America, almost everything is transported by this means. Furthermore, road transport dominates the movement of goods within cities (Barbero et al., 2020).

As shown in Graph 2.12, road transport accounted for 88% of the sector's GHG emissions in 2019, slightly increasing from 85% in 1990. Emissions from road transport and the entire sector nearly doubled during this period, mainly due to the rapid growth of the vehicle fleet, private and commercial,[17]

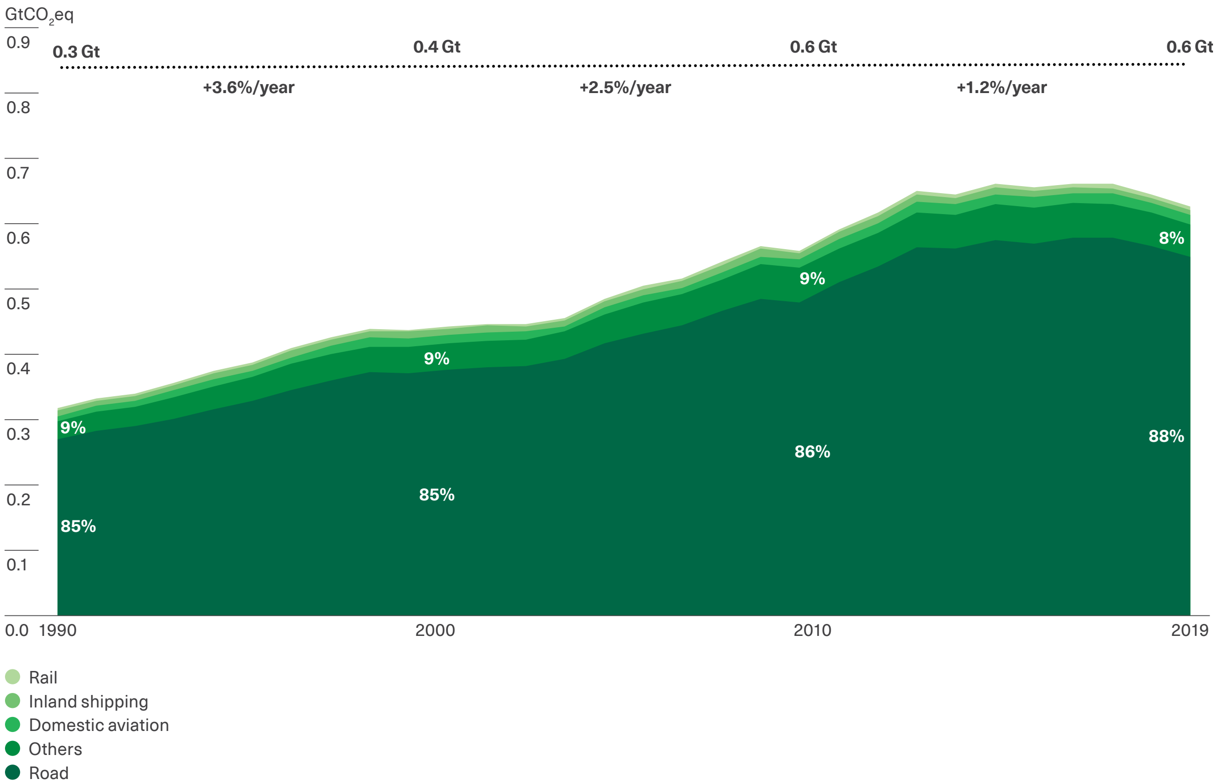
16 The IEA (2021b) discusses this topic in detail.

17 See Barbero et al. (2020), Rivas et al. (2019), ECLAC (2019), Viscidi and O'Connor (2017), among others.

and low fuel taxes in the region.[18] Population growth and even more importantly the significant increase in motorization rates driven by income growth, the expansion of the middle class, and the greater availability of low-cost vehicles, account for the sharp increase in vehicle fleets in the region.[19] In fact, when comparing emission growth with that of GDP, a high correlation of 0.75 is observed. Emissions from the sector grew particularly fast during the 1990s, further aligning with GDP growth rates. However, in the last 10 years, the pace of emission growth slowed, with emissions actually declining from 2016 onward, partly due to the economic slowdown in the region since 2015.

Graph 2.12

GHG emissions from the transportation sector by type of means of transport in Latin America and the Caribbean for the period 1990-2019



Note: The graph reports the evolution of GHG emissions in $GtCO_2$ eq of the transport sector for the period 1990-2019 in LAC and the participation of each subsector. Additionally, the GHG totals for the years 1990, 2000, 2010, and 2019 are presented, together with their average interannual variation in each decade. The countries in LAC are those included in the IPCC classification in the Sixth Assessment Report of Working Group III, Chapter 2 (Dhakal et al., 2022).

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

18 View gasoline and diesel tax data by country at U.S. Department of Energy (2022).

19 See de la Torre et al. (2009), Estupiñan et al. (2018) and Yañez-Pagans et al. (2018).

Finally, the increase in motorization rates, together with inadequate road infrastructure, has led to high levels of congestion in the region's big cities, significantly increasing travel times, fuel consumption, and pollutant emissions. This is reflected in the high road occupancy rates observed in the countries of the region, which, as shown by Dulac (2013), are well above those in other regions of the world.[20]

Industry-generated emissions

Industry accounted for 16% of GHG emissions in Latin America and the Caribbean in 2019, ranking as the second highest-emitting sector after AFOLU (Graph 2.1). The industrial sector has seen a slight increase in its share of emissions since 1990 when it contributed 14% of the total. As depicted in Graph 2.13, waste management is the most significant contributor to sector emissions, accounting for 38% in 2019. The chemical subsector also plays a significant role, contributing 18%, followed by metals and cement at 9% and 7% respectively. However, more than a quarter of industry emissions come from other industrial activities.

Industry contributed 16% of LAC's GHG emissions in 2019, second to AFOLU

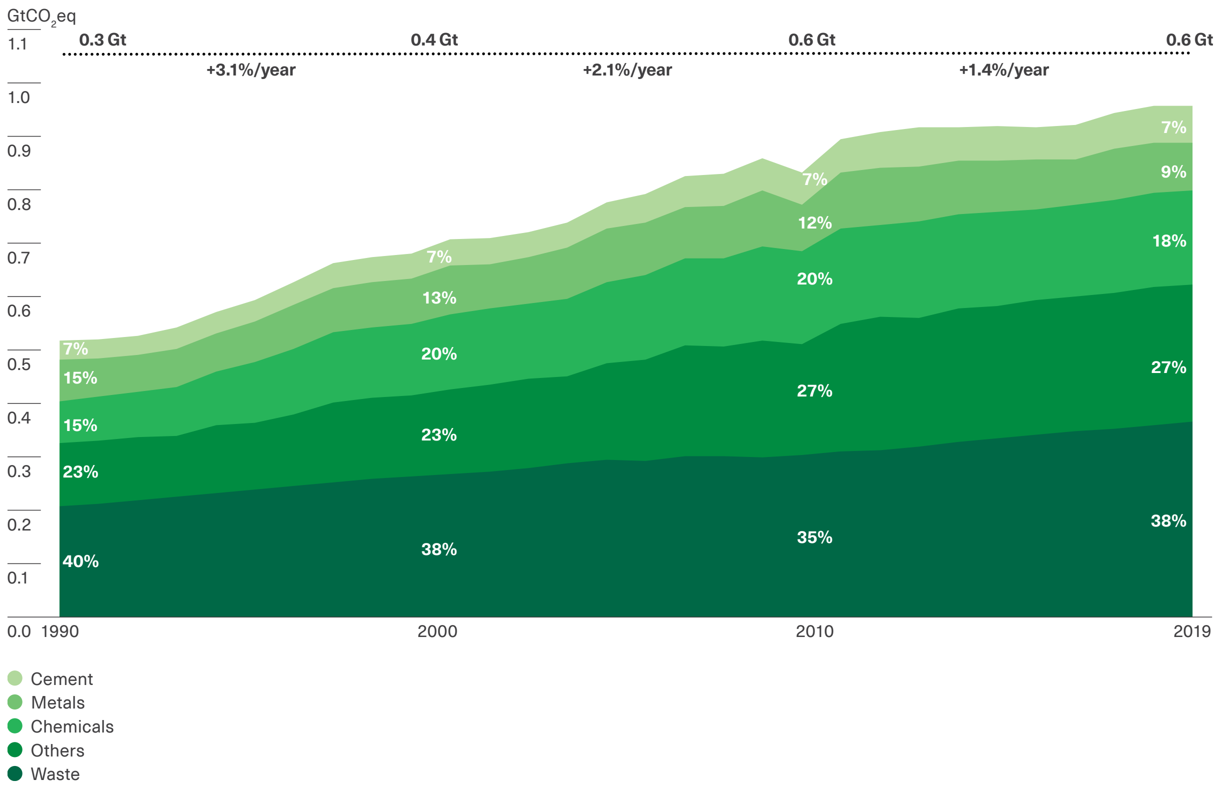
Between 1990 and 2019, industry emissions rose by 85%, driven primarily by the chemical subsector and other industries, which grew by 124% and 116%, respectively. This increase is closely associated with the regional industrial GDP performance, as reflected in a high correlation of 0.77 between the annual growth rates of both variables during the same period.[21]

Taking into account indirect emissions associated with industry's electricity consumption (generated off-site), the industry's contribution to the region's total GHG emissions increases to 19% in 2019. Indirect industry emissions represent 42% of all emissions from electricity generation and, for reference, are approximately equal to the direct emissions of the chemical industry.

20 The road occupancy rate in 2010 in LAC was about 1.1 million vehicle-km per paved lane-km, while the world average is 450,000.

21 Annual growth rate of industrial GDP is taken from the World Bank (2022c) and refers specifically to the percentage change in industrial value added in local currency, at constant prices. Aggregates are expressed in U.S. dollars at constant 2010 prices.

Graph 2.13
GHG emissions from the industrial sector in Latin America and the Caribbean for the period 1990-2019



Note: The graph illustrates the evolution of GHG emissions in $GtCO_2$ eq from the industrial sector for the indicated period and the participation of each subsector. Additionally, the GHG totals for the years 1990, 2000, 2010, and 2019 are presented, as are their average interannual variation in each decade. The countries in LAC are those included in the IPCC classification in the Sixth Assessment Report of Working Group III, Chapter Two (Dhakal et al., 2022).

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

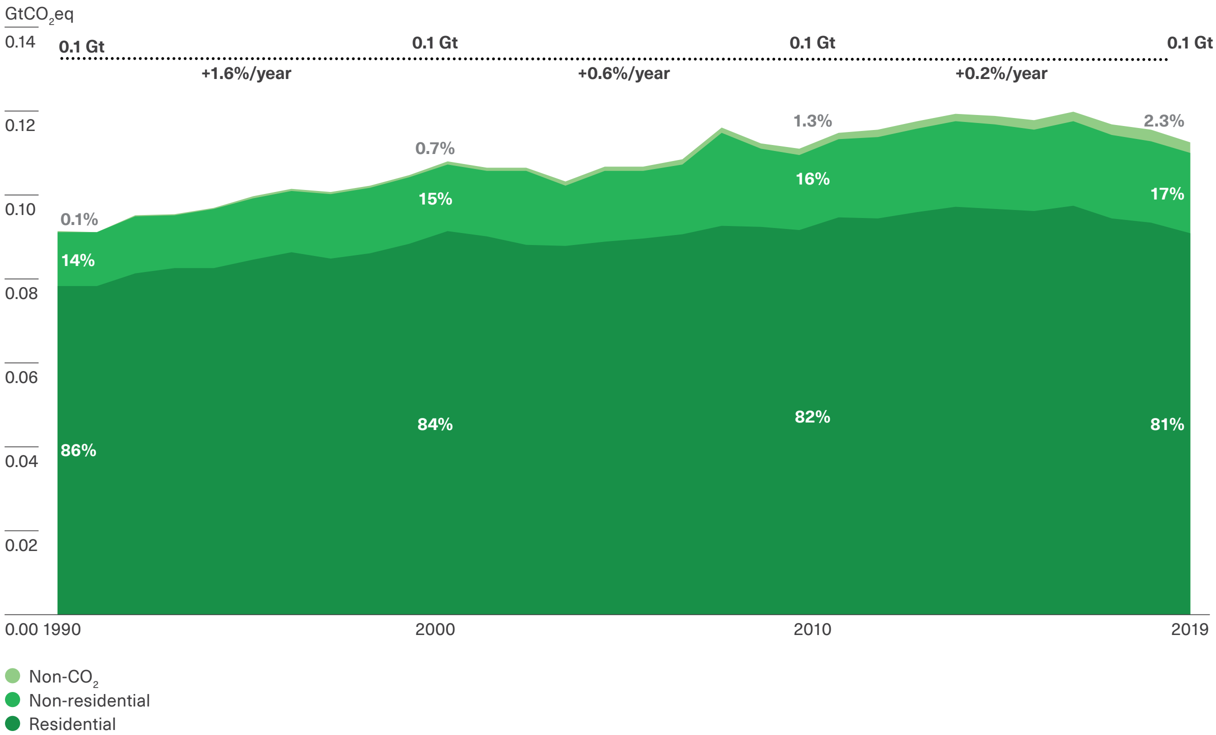
Emissions in buildings

The building sector encompasses the use and operation of both residential and commercial buildings. GHG emissions from this sector stem from energy consumption for heating, cooling, lighting, water heating, cooking, as well as the operation of appliances, electronic devices, and office equipment, among others. They also include the leakage of fluorinated gases used in refrigeration and air conditioning. The majority of these emissions are indirect and come from external electricity generation. The remaining emissions are direct and mainly result from the burning of fossil fuels and biomass for heating, hot water, cooking, and on-site electricity generation. In 2019, direct emissions from buildings accounted for only 2% of the total GHG emissions in Latin America and the Caribbean (see Graph 2.1).

The residential sector contributes to 81% of the direct emissions within the building sector, while the non-residential sector contributes 17%. The remaining 2% corresponds to the leakage of hydrofluorocarbons commonly used in refrigeration systems, which are potent greenhouse gases (see Graph 2.14).

Graph 2.14

GHG emissions from the building sector in Latin America and the Caribbean in the period 1990-2019



Note: The graph illustrates the evolution of GHG emissions in $GtCO_2$ eq from the buildings sector for the indicated period and the participation of each subsector. In addition, the GHG totals for the years 1990, 2000, 2010, and 2019 are presented, with their average interannual variation in each decade. The countries in LAC are those included in the IPCC classification in the Sixth Assessment Report of Working Group III, Chapter Two (Dhakal et al., 2022).

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

Indirect GHG emissions from buildings—which represent 46% of the total emissions from the electricity subsector within energy systems—account for over 3% of the region's total emissions. In total, the combined direct and indirect emissions from buildings contribute 5.1% to the overall emissions in the region.

It is important to note that these figures do not include emissions associated with the construction and renovation of buildings, especially those resulting from the production of cement and steel used in construction. If these emissions were considered, buildings would be responsible for around 7% of the region's GHG emissions.[22]

22 On a global scale, emissions associated with the production of cement and steel for construction account for 75% of the direct emissions from buildings (IPCC, 2022a). If this is extrapolated to Latin America and the Caribbean (LAC), these emissions would amount to 1.5% of the total regional emissions. Furthermore, the cement industry, without considering its indirect emissions from electricity use, is responsible for 1.2% of the region's emissions. When these emissions are combined with the direct and indirect emissions from the building sector, it amounts to 6.3% of the total emissions, without even considering the emissions related to steel production and indirect cement emissions. Taking all of this into account, it seems reasonable to estimate that the figure is around 7%.

Thus, the building sector is a significant emitter of GHGs, both through the use of fossil fuels in building operations and through emissions associated with the production of construction materials, transportation of materials, and the construction and demolition of buildings.

Climate change adaptation and mitigation needs in transportation, industry, and buildings

The big challenge confronting the transportation sector is reducing carbon emissions while keeping people and goods moving. Although this challenge is not exclusive to Latin America and the Caribbean, the region faces unique obstacles in this regard.

First, the region has a growing dependence on private vehicles. This has resulted in a decrease in the proportion of urban trips taken by public transportation, while private vehicle trips have increased. This modal shift in urban travel, contrary to what is observed in Europe, is due to inadequate public transportation infrastructure and insufficient planning for sustainable urban mobility, which has led to increased traffic congestion. While this could serve as an incentive for the adoption of sustainable transportation modes, many countries in the region lack the necessary infrastructure, such as bike lanes or pedestrian paths, and adequate public transport systems, making change difficult.

This situation highlights the need to develop sustainable transportation infrastructure while promoting behavioral changes among citizens in favor of using public transportation and active modes like bicycles and walking. Public policies in this regard and their implications are discussed in the section on "Transportation: Electrification and sustainable mobility."

Climate change can also affect transportation infrastructure, such as roads, bridges, and ports. This presents the challenge of building infrastructure that is more resilient to the impacts of climate change, such as rising sea levels and extreme weather events.

The industrial sector faces the challenge of increasing energy efficiency, adopting low-carbon technologies, and using renewable energy sources to reduce emissions. The industry also needs to adapt to the physical impacts of climate change, such as extreme weather events, by enhancing the resilience of its infrastructure, operations, and supply chains.

Finally, the building sector plays an important role in climate change adaptation, as buildings need to be designed and constructed to withstand the impacts of phenomena such as heatwaves, floods, and other extreme weather events. In terms of mitigation, the report from the Intergovernmental Panel on Climate Change (IPCC, 2022a) highlights the importance of improving the energy efficiency of buildings, reducing GHG emissions during construction and operation, and increasing the use of renewable energy to achieve significant emissions reductions and promote climate resilience.

Carbon Pricing

Carbon pricing policy is widely regarded as the most efficient approach to emission reduction as it creates a financial incentive for agents to reduce their emissions enabling cost-effective mitigation. This policy establishes a price for CO_2 and other GHG emissions, acknowledging their environmental and societal costs. This policy effectively reduces emissions through two primary mechanisms.

First, it raises the prices of high-carbon footprint products, such as petroleum derivatives and goods relying on fossil fuels in their production processes, electricity generation, and food production and transportation. By increasing prices, it stimulates a decline in demand, leading to reduced production and subsequently lowering CO_2 emissions. A notable example of this is the carbon floor price policy implemented by the United Kingdom in 2013. According to Leroutier (2022), this policy progressively phased out coal-based electricity generation, resulting in a remarkable reduction in coal's contribution to the electricity mix from 40% in 2013 to a mere 5% in 2018. The second way carbon pricing reduces emissions is by creating incentives for businesses and consumers to invest in cleaner technologies. In the absence of a price on emissions, firms may choose not to pursue green technologies, such as solar panels, because in economic terms the investment may not be profitable. However, by implementing carbon pricing, the cost-benefit analysis shifts, encouraging the development and adoption of environmentally friendly technologies. Consequently, a global carbon pricing policy can act as a catalyst to accelerate investments in research and development (R&D).

The implementation of carbon pricing can take two forms. The first is through carbon taxes, which set a specific emission cost per ton of CO_2eq[23] for each individual emitter or a selected group. This mechanism allows the market to adjust the quantity of emissions accordingly. The second form is cap-and-trade systems. This approach limits the overall emissions quantity, determined by the number of permits issued, while the carbon price is established through market-based trading of these permits.

In Latin America and the Caribbean, five countries have implemented carbon pricing measures: Argentina, Chile, Colombia, Mexico, and Uruguay. All these initiatives exclusively adopt national carbon taxes, except Mexico, which in addition to implementing subnational carbon tax schemes in Baja California, Tamaulipas, and Zacatecas, has launched a pilot project for permit markets applied to the energy and industry sectors. In contrast, Europe and the United States have seen more extensive adoption of emissions permit initiatives.

Chapter 4 delves into a more comprehensive analysis of existing carbon pricing initiatives, while Box 2.2 provides an in-depth comparison of the two implementation approaches.

Carbon pricing is the most efficient emission reduction policy because it creates a financial incentive for private agents

23 CO_2equivalent is a measure used to compare the climate impact of different greenhouse gases based on their ability to retain heat in the atmosphere and the time they remain in the atmosphere.

Box 2.2
Comparison between carbon taxes and cap-and-trade systems

In theory, the expected reduction in emissions and the impact on prices of both policies—i.e., carbon taxes and cap-and-trade systems—are equivalent, but they present different advantages and limitations. The main advantage of a carbon tax is the simplicity and flexibility of the instrument. The tax simply sets a price on emissions and allows the market to adapt. This system is also the most immediate, as its effects materialize upon the introduction of the tax, whereas the cap-and-trade system requires more implementation time. However, carbon pricing does not guarantee the desired emissions reductions. For it to be effective, the price must be set at a level that induces the desired emissions reductions. There have been cases where relatively low carbon taxes (around USD 20 per ton of CO_2eq) have been set, which do not achieve the necessary emission reductions to reach global targets and, in some cases, even fail to meet nationally determined contributions (NDCs). This is not a weakness of the instrument itself, but rather an implementation issue or a consequence of the political and social resistance that a higher tax may face. The permit system allows for setting a maximum quantity of emissions, for example, equivalent to the NDC commitments, creating a stronger obligation to meet environmental goals.

Another advantage of the permit system is that as economies adjust to the system and invest more in green technologies, reducing total emissions, the cost per ton of carbon should decrease. These price changes are also observed during periods of economic recession or growth. In the case of permits, the price is adjusted in the market, while the tax would need to be administratively updated to reflect the new social cost of carbon.

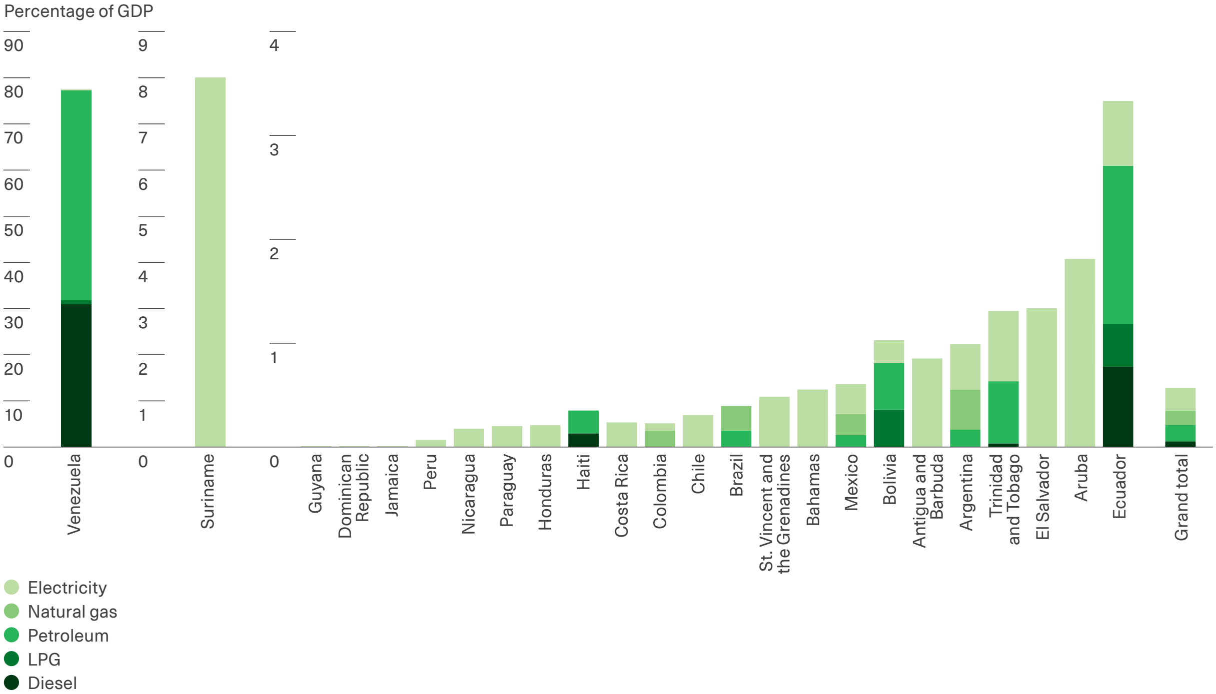
However, the permit policy requires more implementation efforts. While both policies require monitoring emissions, imposing penalties, and tracking the price (in the case of taxes) or the quantity of permits, the permit policy adds the extra complexity of the permit allocation system. This can be based on historical emissions, where the government distributes permits for free based on historical emissions data, or through auctions. The latter is the preferred mechanism lately as it allows for generating fiscal revenue similar to what would be obtained with a tax.

Another key difference lies in the available mechanisms for international cooperation depending on the implemented system. In the case of a carbon tax, the only possible coordination policies are global unification of the price per ton of carbon or the Carbon Border Adjustment Mechanism (CBAM). This mechanism enables countries to impose a carbon tax on imported products, ensuring that the carbon price of these products is equalized with domestic products. This prevents carbon leakage, meaning the shift of "dirty" production to economies without carbon pricing. Chapter 4 discusses this mechanism and current experiences in greater detail.

Another relevant difference is the volatility of both systems. While a tax sets a carbon price or, in some cases, a price schedule, the carbon price can fluctuate within the cap-and-trade system. This price variability has impacts on consumers as well as companies' investment projects. The fuel market is already subject to strong price fluctuations, which have marked impacts, for example, on consumer prices. Therefore, the permit system could further increase this volatility.

Beyond the choice of instrument, carbon pricing emerges as an efficient, necessary and urgent policy. It is perhaps this need and urgency that highlight the significant contradiction posed by current subsidies to polluting sources, which exist in most of the world's economies. Parry et al. (2021) demonstrate that worldwide subsidies amount to around USD 400-600 billion annually, while in Latin America and the Caribbean, they reach approximately USD 44 billion per year, equivalent to about 1% of the region's GDP, with a range varying from slightly above 0% to 46% of their GDP, depending on the country. Guatemala falls into the former category with small subsidies to diesel and petroleum, while Guyana, the Dominican Republic, and Jamaica also belong to this category but have subsidies for electricity. The highest value is observed in Venezuela, where almost all subsidies are for diesel and petroleum. Graph 2.15 displays hydrocarbon subsidies by country as a proportion of their respective GDP. It is evident that a significant number of countries in the region subsidize electricity, and a considerable group also subsidizes petroleum. These subsidies act in opposition to carbon taxes by promoting fossil fuel consumption. One of the initial steps that the region should take is the progressive reduction and eventual elimination of these subsidies.

Graph 2.15
Hydrocarbon subsidies in Latin American and Caribbean countries in 2020



Note: The graph shows explicit subsidies to hydrocarbons in LAC countries with available information for the year 2020. An explicit subsidy is understood as the difference between the retail price and the supply cost of a fuel. In the case of the global total, the total subsidy for each energy source was added up for all available regions, and each one was divided by the sum of the GDP of those regions. Both indicators (subsidies and GDP) are measured in billions of dollars. For more methodological information, please refer to the data source.

Source: Authors based on data from IMF(2022a).

Parry et al. (2021) also identify what they call the efficient price of these goods, which would be the price that reflects not only production and distribution costs but also environmental costs such as carbon emissions, air pollution, and traffic congestion. Adjusting prices in this way, the differential between current prices and efficient prices is around USD 6 billion. This differential is mainly explained by the environmental costs not internalized in prices (around 90% of the differential). The authors also show how, if efficient prices were charged, GHG emissions projections would be reduced to the extent that the target of a 1.5°C temperature increase by 2050 would be achieved. This is essentially the application of a carbon tax that internalizes all these environmental costs, along with the elimination of current subsidies to polluting sources.

While carbon pricing is the most efficient policy, resulting in the most immediate emission reductions, it is insufficient on its own and must be accompanied by other mitigation policies

One of the main weaknesses of carbon pricing, which has generated considerable political debate, is its uneven impact. For example, if the policy were to cover all GHG emission sources, agricultural production should be subject to the tax, resulting in increased food prices and further exacerbating issues of food security. It should be noted that Blanchard et al. (2022) suggest the implementation of a general tax that covers all GHG emission sources, which would allow for emission reductions in the agricultural sector and indirectly discourage agricultural expansion, thus reducing LULUCF emissions.

But the unequal impact is not only on food. Lower-income households allocate a higher proportion of their income to food, electricity, heating, and public transportation. The prices of all these goods would increase with the implementation of a carbon pricing system and the elimination of subsidies, making the tax system more regressive. For this reason, various policy alternatives have been discussed that utilize the revenue or part of the revenue from the system and ensure that, with this redistribution, the carbon tax is not regressive (Blanchard et al., 2022; Metcalf, 2007; Stavins, 2020). The same could be applied to redistribute current subsidies and offset the regressive impact of their elimination. For example, redistribution through lump-sum transfers, income tax reductions, or a combination of both could make the tax revenue neutral and mitigate its distributional impacts.

While carbon pricing policy is the most efficient instrument and would result in the most immediate emission reductions, it is insufficient if it is not accompanied by other mitigation policies. This is mainly explained by the positive externalities involved in R&D investments. When a company invests in a new technology, the private benefits it receives are only part of the overall social benefits. Encouraging R&D investments requires incentives other than carbon taxes, such as subsidies in some cases. Through lower costs and technological improvements, Latin America and the Caribbean can benefit from the costly R&D investments made in more developed c ountries. Moreover, as mentioned earlier, there is a significant political economy problem in implementing carbon pricing policies, which partly explains the extensive discussion of alternative policy instruments, which are discussed in the following sections. Lastly, carbon pricing also suggests the need to value environmental externalities, ecosystem services (see Chapter 3), and a carbon market (see Chapter 4).

Adaptation and mitigation in the agricultural sector

Mitigation efforts in the agricultural sector face two main challenges. The first is food security, which imposes the need for the sector to increase its production, considering that Latin America is a key player in global food trade and that global food production should be increased by 50% by 2050 compared to 2012 production (FAO, 2017). The second challenge is the economic importance of agriculture in the region, which is a fundamental sector for most countries and with a high participation of subsistence agriculture, mainly in Central America and the Caribbean. Therefore, mitigation efforts must take into account these two issues and prioritize those that lead to improvements in productivity, promote afforestation and reforestation, and discourage deforestation.

This section discusses the main techniques for reducing emissions in the agricultural sector and adapting to the impacts of climate change. Next, the case of biofuels and bioenergy with carbon capture and storage (BECCS) is analyzed, as these are cross-cutting issues between the agricultural and energy sectors. Finally, some demand-side practices related to the agricultural sector are mentioned. Policies related to reforestation in the LULUCF sector or based on ecosystem conservation and biodiversity, although offering the greatest mitigation potential (Nabuurs et al., 2022), are discussed in Chapter 3.

Agricultural techniques linked to climate change

In this sub-section, the techniques for reducing greenhouse gas (GHG) emissions are divided into those applicable to livestock, crop cultivation and, finally, nature-based solutions.

Livestock

The two main techniques in the livestock sector that enable reductions in GHG emissions are improved animal nutrition and health, primarily through feed supplements and manure coverage and management. The IPCC's Sixth Assessment Report (Chapter 7) states that the mitigation potential of manure management practices and dietary improvements exceeds 10%, with Latin America and the Caribbean being the second region with the highest potential for methane and nitrous oxide emission mitigation (Nabuurs et al., 2022).

The quality and composition of animal feed, particularly those that increase energy utilization in metabolism, have significant effects on methane emissions. Supplementing animal diets with lipids—with flaxseeds being generally the most efficient supplement—increases the energy content of the diet and improves digestion, thereby reducing methane emissions. Additionally, the use of feed supplements reduces the need for grazing lands, which would decrease LULUCF emissions.

Regarding manure management, effective practices for reducing methane emissions include lowering temperature and storage time, storing it in cool open spaces, capturing and subjecting methane to combustion, and aerating and using manure for composting. Furthermore, urease inhibitors can be added to mitigate nitrous oxide emissions. Manure coverings mitigate gas and odor emissions and can be natural, such as natural crusts and straw, among others, or artificial, like polyethylene, polystyrene, or foam, providing protection against wind dispersal of waste.

A complementary technique is anaerobic digestion, a microbiological process where organic matter decomposes in the absence of oxygen, which can be used for biofuel production. The process generates residual “digestate,” a material that can be used as fertilizer. Anaerobic digestion can be carried out using manure, as well as crop residues and various organic wastes. While manure utilization is not highly efficient for biofuel production, it is effective in terms of reducing methane emissions.

In addition to reducing GHG emissions, precision farming and direct seeding improve crop productivity

Specific crop cultivation practices

Two specific techniques stand out for crop cultivation. The first one is precision farming, a crop administration system that heavily relies on information and technology for analysis, measurement, identification, and management, with the aim of improving crop productivity and sustainability. This technique incorporates remote sensing tools, variable input application technology, and global positioning systems (GPS), geographic information systems, and machine learning, among others. In addition to reducing GHG emissions by minimizing the use of fertilizers and fuels and improving soil management, this technology primarily results in increased crop productivity. Implementing this approach requires well-trained human capital and investments in some of the mentioned technologies.

The second technique is no-till farming, which involves cultivating crops without plowing and maintaining permanent soil cover with crop residues. No-till farming increases the volume and retention of organic matter, conserves nutrients, improves soil properties, and enhances water infiltration. This process increases crop productivity and reduces CO_2 emissions, as soil is not removed by plowing and less fertilizer and fuel are used for machinery.[24]

Nature-based solutions

Nature-based solutions (NbS) are actions that involve the protection, management, and restoration of ecosystems with the aim of effectively and adaptively addressing social challenges while benefiting both people and nature (IUCN, 2023). NbS can be used to reduce the impacts of climate change and mitigate emissions from the agricultural sector, while also improving crop productivity. Therefore, they are among the techniques that offer the greatest synergies and positive externalities. The main alternatives within these practices are cover crops and, above all, agroforestry.

Cover crops involve planting certain crops on land that would otherwise remain fallow. The goal of cover crops is to protect and enhance soil fertility. Through this practice, soil erosion and the need for fertilizers can be reduced, while soil carbon levels are increased and the impact of floods and droughts on crops decreases. Cover crops are also useful for weed and pest control.

Agroforestry combines forestry with agriculture, integrating plants and trees with crops and livestock. Agroforestry enhances crop productivity and health, provides ecosystem services, and contributes to soil restoration. Minnemeyer et al. (2011) estimate that approximately 400 million hectares in South America could be restored using agroforestry-based systems. For this reason, this technique is a clear example of an adaptation policy that would yield multiple benefits: it would increase sector productivity, mitigate some expected effects of climate change, and contribute to carbon capture

24 Regarding adaptation measures, in response to excessive rainfall in Colombia in 2010-2011, the Federación Nacional de Cafeteros de Colombia (FNCGC), a national association representing coffee growers, encouraged farmers to protect themselves against future crises by conditioning credit programs for coffee crop renewal to the use of pest-resistant seed varieties. A study by Helo Sarmiento et al. (2023) analyzes the impact of this policy in detail.

and biodiversity conservation through biomass generation and soil regeneration.

Agroforestry increases biodiversity by providing more complex habitats with a greater presence of trees, which supports the development of living organisms. The coexistence of these organisms promotes ecosystem sustainability. Some of the consequences of this practice include soil protection and recovery due to natural coverage, improved nutrient absorption in the soil, diversification of agricultural products, increased crop stability and soil fertility, and reducing the need for synthetic fertilizers. Other advantages are enhanced plant pollination, reduced reliance on synthetic pesticides through the development of natural alternatives, growth of native fauna, reduced air pollution, resilience to strong wind gusts, and improved livestock welfare through increased shelter.[25]

Agroforestry increases crop productivity and health, provides ecosystem services, increases biodiversity and helps soil restoration

Policies for adaptation in the AFOLU sector

While the mentioned agricultural techniques, particularly NbS, are mitigation measures with the potential for adaptation to the impacts of climate change, the region requires specific adaptation measures for a sector as vulnerable as ASOUT. These measures should be supported by national governments, given the role that this sector plays not only in the economies of the region but also in regional and global food supply. This is particularly relevant in Central America and the Caribbean, where family farming represents a significant portion of food production, and agricultural production challenges threaten these countries' food security.

First, it is essential to strengthen the resilience of agricultural systems against the impacts of climate change. This involves promoting sustainable agricultural practices that optimize the use of resources such as water and soil and are more resistant to extreme weather events such as droughts and floods.

Second, governments must encourage and support investment in infrastructure and research, as well as the development and application of appropriate technologies for climate change adaptation in the agricultural sector. These include the adoption of efficient irrigation systems, improvements in food storage and distribution infrastructure, and the promotion of innovative agricultural techniques that increase productivity and reduce the vulnerability of farmers and ranchers, such as the use of climate-resistant seeds.

Finally, it is necessary to develop and strengthen financial mechanisms, such as agricultural insurance, production financing, and futures markets. These measures would help reduce uncertainty and investment risks. It is crucial for the region to ensure that small-scale establishments have access to these instruments, especially in regions exposed to extreme weather events where there are limited capacities for adaptation through agricultural practices.

25 The application of NbS is not limited to the agricultural sector. Some specific examples include the use of cypress trees in areas prone to forest fires, expanding tree cover in urban areas to reduce temperatures and the need for air conditioning, the planting of trees or shrubs to mitigate desertification hazards and the risks of landslides and collapses in mountainous areas, and the conservation of mangroves and coral reefs to reduce the risks of flooding (see Chapter 3).

Implementation challenges in AFOLU's sector

The aforementioned mitigation and adaptation actions prove to be cost-effective, mainly improved livestock feeding (Marques et al., 2020, 2022) and nature-based solutions (Reid et al., 2019; Vignola et al., 2019). However, they have not been universally adopted, suggesting that there are limiting factors.

All these mitigation and adaptation practices involve implementation costs. In the case of NBS, the costs can vary greatly, not only due to infrastructure investment but also because they require the availability of labor and investments in human capital. An example of this is agroforestry, where the major challenge is that the costs involved are short-term, while the expected benefits are long-term, so significant economic results would not be seen in at least the first three to eight years (Do et al., 2020). Even these measurements are not very precise due to the scarcity of data on implemented cases. Encouraging their adoption among producers, especially small-scale producers focused on subsistence farming, can be difficult because, in the short term, the cost of the policy outweighs the benefits.

The adoption of agricultural techniques that could reduce GHG emissions and improve productivity and soil conditions requires improved access to financing and awareness about their benefits

In that sense, one of the reasons why these practices are not universally used is the lack of financing. This can be due to the lack of developed markets, limited access to credit for small-scale operations, or producers' reluctance to incur debt to adopt technologies they do not believe will guarantee improvements in their production in the short term.

This last point is related to another main limiting cause: the lack of information on the profitability of these initiatives and the timeframe for recovering the investment, the lack of training or complete unawareness of the previously mentioned alternatives, and the influence of tradition, which can make farmers more resistant to change. All of this, combined with the inherent risk of agricultural activities where external climate shocks can have enormous impacts on profitability, generates resistance to the adoption of new practices.

An important characteristic of these limitations is that they are all correlated with the size of the producer. Small-scale operations face more difficulties in accessing financing, have less capital, liquidity, and human capital, a greater need for short-term returns, and a stronger attachment to traditions. It is perhaps for this reason that if governments or multilateral organizations seek to support these initiatives, additional efforts should be made to reach small-scale producers, given the importance of family farming in the region and the goals of zero hunger.

The importance of aligning government policies is a current problem. According to a report by United Nations agencies (FAO et al., 2021), global support to producers amounts to USD 540 billion annually, which is mostly distributed among distortionary policies that reduce sector efficiency, with little support for small-scale producers, and policies harmful to both the environment and human health. Lowder et al. (2021) estimate that although small-scale operations smaller than 2 hectares produce approximately 35% of the world's food, these operations receive less than 2% of the financial flows for climate change adaptation and mitigation. In summary, there are agricultural techniques that could reduce GHG emissions, with a mitigation potential in methane and overall positive externalities in terms of productivity and the environment. Despite their profitability, the adoption of these techniques has been limited due to issues involving credit access, uncertainty, and lack of information. Therefore, the implementation of financing and education policies could promote these actions.

Regarding financing, it is important to facilitate access to credit or establish specific credit lines for mitigation in the sector. Additionally, subsidies for sustainable practices with a focus on small-scale producers can be highlighted. In terms of education, it is not only necessary for producers to be aware of the existence of these techniques, but also technical and legal support is suggested, once again with a focus on small-scale producers who have limited resources to invest in this aspect. Box 2.3 presents a case of a policy implemented in Colombia with these characteristics.

Box 2.3
Climate-smart initiatives for the agricultural sector: A case study in Colombia

In Colombia, the project "Climate-Smart Initiatives for Climate Change Adaptation and Sustainability in Prioritized Agricultural Production Systems" (CSICAP) has been approved and is ready for implementation. CAF—Development Bank for Latin America and the Green Climate Fund (GCF) are providing financial support for the program.

The project aims to reduce the vulnerability of agricultural production to climate threats and decrease GHG emissions in the sector's production using precision agriculture. This includes improvements in climate services and the use and development of new low-emission and high-climate-resilience technologies, such as genetically modified crops.

The development of this initiative addresses two major limitations to the implementation of adaptation and mitigation policies in the agricultural sector: i) financing and ii) the development, distribution, and access to information. Moreover, the project focuses on the most vulnerable populations in rural areas, especially women, and emphasizes efficiency gains through the application of precision agriculture, along with the associated adaptation and mitigation benefits. It is considered that agricultural unions in Colombia do not have the capacity to develop the tools and instruments that will be created through the project, but they can apply them and continue the work after their development, accelerating efficiency gains and the realization of economic benefits. In the case of stronger unions, such as those related to coffee, bananas, and rice, it is estimated that it would take them 20 years to achieve the results expected within five years with CSICAP.

The project is expected to benefit over 600,000 people, enhance climate resilience in approximately 1 million hectares, and reduce GHG emissions by more than 9 million metric tons of CO_2 equivalent ($MtCO_2eq$). While the main focus is climate adaptation, it is also expected to generate economic co-benefits, such as productivity improvements and reduction of rural poverty; social co-benefits, such as enhanced food quality and access and narrowing of the gender income gap in the rural sector; and finally, environmental co-benefits through GHG emission reductions.

a. Private sector organizations dedicated to specific crops that bring together small, medium, and large-scale farmers.

Biofuels

The development of biofuels is a cross-cutting policy in the energy and agricultural sectors. While mitigation efforts take place in the energy sector by utilizing fuels that emit fewer GHG emissions than fossil-derived products, the production of biofuels occurs in the agricultural sector through biomass conversion.

One of the challenges associated with biofuels is the land requirement for production. Generally, the development of biofuels is linked to increased land use, resulting in higher LULUCF emissions. Surprisingly, this data is sometimes overlooked in the calculations of the impacts of biofuel mitigation. In a literature review on the subject, the Organisation for Economic Co-operation and Development (OECD, 2019) analyzes the carbon footprint of different biofuel categories, demonstrating that depending on the input used, total emissions could even surpass those of gasoline. In this regard, biofuels produced from waste and residues, sugarcane, and certain energy crops prove to be the most efficient in terms of mitigation, whereas palm oil exhibits extremely high LULUCF emissions, followed by soybean oil, which are the two most commonly used feedstocks for biofuel production. To ensure that biofuels become a desirable mitigation solution, LULUCF emissions per unit of output must be considered in project evaluations.

One technology highlighted by the IPCC as crucial for achieving the 1.5-2oC targets, which is still in the development stage with a few initial projects underway, is bioenergy with carbon capture and storage (BECCS). This process involves extracting bioenergy from biomass while capturing the carbon emitted during this process and storing it in natural reservoirs such as depleted oil fields, saline aquifers, or other geological formations. This technology can be used in the production of ethanol and biogas, cellulose and paper, as well as for heating or power generation through biomass utilization.

Bioenergy with carbon capture and storage has the particularity of being net emissions-free

BECCS has the unique characteristic of potentially achieving negative net emissions due to its gas capture capabilities. This is possible because the CO_2 absorbed by the trees used in the process is captured during combustion instead of being released into the atmosphere, as occurs in traditional biomass-based electricity generation. The captured CO_2 is then stored in reservoirs, resulting in a process (from tree planting to power generation) that effectively removes CO_2 from the atmosphere, with only a fraction of the captured CO_2 being released. However, the potential for negative emissions has yet to be rigorously documented.

One limitation of this technology is its considerable land and water requirements, which could increase LULUCF emissions per unit of energy output, reduce biodiversity, and encroach upon productive agricultural land. Additionally, the net emissions balance or cost-benefit ratio of this policy is still not clear.

Another possibility for utilizing this technology, with lower water and land consumption, is the use of waste as feedstock. Such waste can come from agriculture, forestry, or even urban sources.

Demand-side changes

A set of policies that does not directly correspond to the agricultural sector but could impact it, particularly in food production, are those that consider actions on the demand side. Responsible consumption practices and the reduction of food waste have the potential to reduce total anthropogenic emissions by between 8% and 10% (Mbow et al., 2019), while also contributing to food security objectives. Substituting meat consumption with vegetables would alleviate the expansion of land used for livestock, thereby reducing emissions associated with land-use change for this activity, which account for 5% to 14% of GHG emissions.

While education and awareness campaigns will be necessary to generate the necessary behavior modifications to achieve these reductions, changes in the desired direction are already being observed. Criscuolo and Cuomo (2018) document the growing demand for "sustainable meat," non-genetically modified soy, and organic dairy products. This increase in demand creates certification markets and offers incentives for producers to adopt sustainable practices, which, in some cases, are more efficient, improve product quality, and result in emissions and environmental pollution reductions. Chapter 3 provides further details on these environmental or eco-certifications.

Responsible consumption practices and food waste reduction have the potential to reduce total anthropogenic emissions by 8-10%

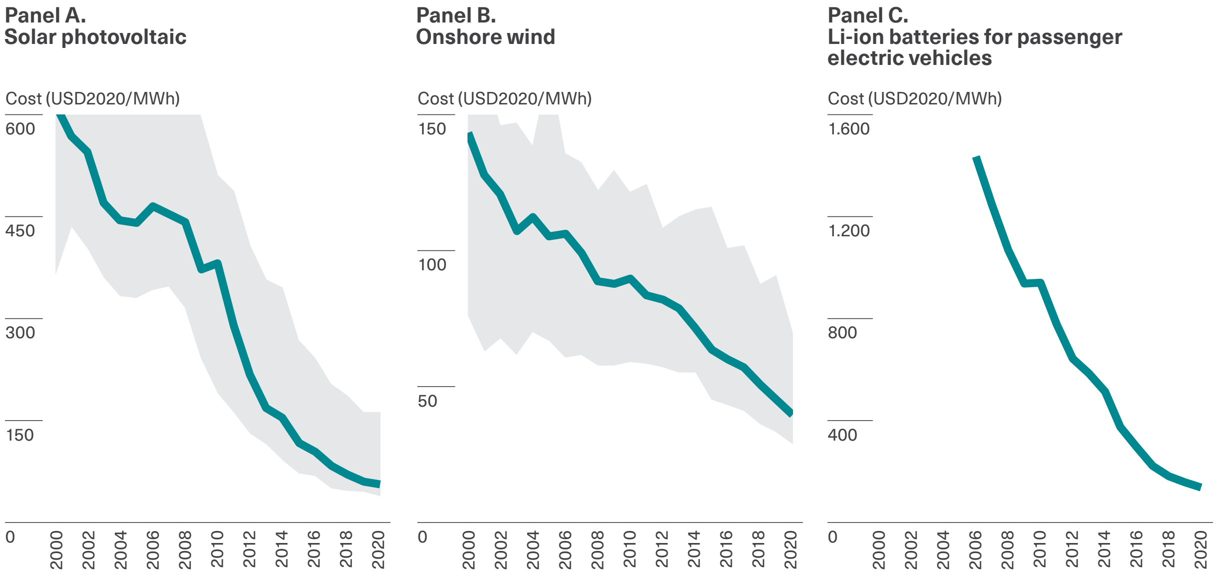
Energy transition and mitigation in the energy sector

Energy transition refers to the shift from fossil fuels to renewable and sustainable energy sources. It involves not only changes in energy production and transportation but also changes in energy consumption, including improvements in energy efficiency and the electrification of the economy, such as the electrification of transportation. This section examines the energy transition in Latin America and the Caribbean, starting with the supply side, focusing on the electricity generation sector, and then moving on to transportation. It then explores actions on the demand side and analyzes adaptation measures for the energy sector.

Electricity generation, renewable energy sources and the role of natural gas

Electricity generation creates approximately 25% of total GHG emissions globally, making it the primary emitter among sectors. As a result of the ongoing energy transition process, primarily in developed countries (see Chapter 5), significant improvements have been achieved in the efficiency and cost reduction of electricity generation from renewable sources, especially solar and wind energy. Graph 2.16 illustrates the evolution of the unit cost of renewable energy and the price of lithium batteries for electric vehicles from 2000 to 2020. It is evident that over the span of 20 years, the cost of solar energy has drastically decreased, with advancements also seen in onshore wind energy. Furthermore, the cost of rechargeable lithium-ion (Li-ion) batteries used for electric energy storage has dropped more than tenfold. These rapid improvements are making the installation and storage of electricity more accessible, thereby facilitating broader access to this technology.

Graph 2.16
Unit cost of renewable energies and batteries in the period 2000-2020



Note: The graph shows the evolution of unit costs in USD at constant 2015 prices per megawatt-hour (USD/MWh), for solar (panel A) and wind (panel B), as well as for lithium batteries (panel C) in the indicated period. The gray areas represent the range between the fifth and 95th percentile for each year. Further methodological information can be found in IPCC (2022b).

Source: Authors based on IPCC (2022b).

Solar and wind energy present a great opportunity for the region not only because of the reduction in emissions, but also because of their near-zero marginal cost and their positive externality on air quality

In addition to emissions reductions, solar and wind energy present a great opportunity for the region for several reasons. The first advantage of these technologies is their efficiency in electricity generation. The marginal cost of solar and wind power production is close to zero because they do not require fuel inputs and require minimal maintenance (Craig and Brancucci, 2021). A second advantage is that they do not create air pollution or emit GHG emissions, resulting in a positive externality for air quality when they are installed.

There are two alternatives for solar power generation. The first is distributed generation through the installation of solar panels and generators in homes, buildings, parking lots, small farms, and so on. The second alternative is solar parks, which require larger land areas but can serve a greater number of users. In Latin America and the Caribbean, there are deficiencies in access to energy and the stability of the electricity supply in rural areas, as well as in electricity distribution and transmission infrastructure. One advantage of distributed generation is that it allows a portion of the transition to clean energy to occur without requiring large investments in large-scale solar and wind parks or extensive transmission systems, thus avoiding the use of vast parcels of productive land and enabling access to electricity in rural areas. On the other hand, solar parks and wind farms sometimes face challenges related to stringent regulations and litigations initiated by environmental groups due to damage to local wildlife. Distributed solar systems are more efficient in terms of energy losses in generation, transmission, and distribution, provide autonomy to users, and have a rapid installation process. Another characteristic of distributed generation is that it increases property value (Adomatis et al., 2015; Adomatis and Hoen, 2015), partially transferring the installation cost to the property's value. The opposite occurs with solar panel farms, which, as shown by some studies, devalue the prices of nearby properties (Dröes and Koster, 2021; Gaur and Lang, 2020).

The transition to renewable energies would allow net oil-importing countries to reduce their dependence on fossil fuels. Regional cooperation and investment in technologies that minimize dependence would help the region shield itself from the volatility of fossil fuel markets, ensuring domestic supply. Moreover, the energy transition would improve countries' resilience and energy self-sufficiency, reducing their dependence on imports and protecting their economies from energy price volatility. The effect that the Russia-Ukraine conflict had on fossil fuel prices and, consequently, on global price levels is an example of the advantage the region would have if it had a renewable energy matrix. Box 2.4 discusses the potential for renewable energy generation and the challenges it faces.

While renewable technologies are more accessible and even more efficient than fossil fuels, achieving a complete energy transition in the electricity sector of Latin America and the Caribbean in the short term would require significant investment in infrastructure and regional cooperation for electricity trade.[26] Moksnes et al. (2019) explore 324 investment projects in electric infrastructure for South America, revealing that the total discounted cost ranges from 0.9% to 1.9% of the region's GDP, with most scenarios falling at the lower end of this range. It is worth noting that estimates by Rozenberg and Fay (2019) indicate that globally, infrastructure investment costs in electricity generation infrastructure in the low-emission scenario (1%-3% of GDP) are similar to those in a business-as-usual scenario (0.9%-2.4% of GDP).

The transition to renewable energy would allow net-importing countries of fossil fuels to reduce their dependency on these products

Another consequence of transitioning to a green electricity matrix is the issue of stranded assets, such as gas and oil fields, as well as the infrastructure installed for their extraction. Tables 2.2 and 2.3 show proven hydrocarbon reserves and technically recoverable resources. Among these, gas reserves are projected to have a longer period of exploitation, while coal reserves are expected to be the first to be phased out. Although some preliminary estimates suggest that the energy transition could generate net employment (CEPAL et al., 2023; Saget et al., 2020), in the short term, the relocation of workers from the fossil fuel industry will be costly and will require the support of policies focusing on labor retraining and social protection. Lastly, hydrocarbon-producing countries would face significant fiscal costs in adopting clean technologies. This reinforces the need for a gradual transition over time and for hydrocarbon-producing nations to first shift toward an energy matrix based on natural gas and renewables, utilizing the existing infrastructure for gas extraction and commercialization.

26 The work of Airaudo et al. (2022) proposes a model to investigate the inflationary dynamics that could be generated during the green transition.

Box 2.4
Green power generation

The IPCC's Sixth Assessment Report emphasized the technical feasibility of transitioning to a net-zero emissions energy matrix, even in the absence of certain technologies such as nuclear or carbon capture. These estimates are based on integrated assessment models (IAMs). Similarly, specialized literature on the capacity and potential of renewable energy for electricity generation highlights the possibility of meeting current and projected demand using solely renewable energy sources.

In a meta-analysis for the IPCC, Edenhofer et al. (2011) report the technical potential of renewable energies, demonstrating that this potential exceeds current demand. Deng et al. (2015) estimate the global energy generation potential from solar and wind power and conclude that even in their scenarios with lower generation, it would still surpass the projected demand for 2070. Calculations by Molnár et al. (2022) on the potential for rooftop solar panel installations in residential buildings indicate that the potential is enormous and would meet the majority of local electricity demand, with the capacity possibly doubling by 2060. The authors highlight that the construction of new buildings with designs that consider solar panel installations is one of the main possibilities for the coming decades in Latin America. However, all of these papers emphasize the importance of investment in distribution, transmission, and storage infrastructure to realize this potential, as the current infrastructure is inadequate, especially in scenarios with greater regional coordination.

A clean electricity matrix faces the challenge of potential intermittency in generation, primarily due to the current lack of large-scale and cost-competitive storage and insufficient investment in transmission, not only at the country level but also regionally. Another challenge is the insufficient infrastructure to connect renewable sources with distant consumption areas and for regional interconnection. While more efficient storage systems are being developed, it is necessary for energy systems to be flexible, allowing for meeting demand with multiple sources and addressing potential clean energy generation shortages at specific times. A good balance between renewable sources and natural gas, combined with regional coordination that would require significant investment in transmission lines between countries, would result in a clean regional matrix and ensure proper supply.

There are two significant challenges that are not considered in these studies. The first relates to managing the waste generated from the replacement of solar panels, wind turbines, and batteries. In the case of turbines, most of their components can be recycled, while for batteries, there are certain recycling initiatives. However, comprehensive solutions for recycling all of these waste materials are still lacking, with solar panel waste presenting the greatest challenge currently. The second challenge is related to the minerals required for the transition to a clean electricity matrix. The high global demand for these metals, both for batteries, electric vehicles, and electric power transmission, can lead to a shortage in supply and a consequent increase in the price of these vital components for the energy transition.

Table 2.2
Proven hydrocarbon reserves

Country	Oil (million barrels) Year 2021	Coal (million m³) Year 2019	Natural gas (million m³) Year 2021
Argentina	2,482	500	396,464
Barbados	2	0	113
Bolivia	240	1	30,299
Brazil	12,714	7	363,984
Chile	150	1	97,976
Colombia	2,036	5	87,782
Ecuador	8,273	24	10,902
Mexico	5,786	1	180,321
Peru	858	102	300,158
Trinidad and Tobago	243	0	298,063
Venezuela	303,806	731	5,673,894
Total	336,590	15	7,712,647

Note: The table shows reserves for countries with available information.

Source: Hancevic et al. (2023).

Table 2.3
Technically recoverable resources of shale gas and low permeability oil in 2015

Country	Gas (trillions of cubic feet)	Oil (billions of barrels)
Argentina	801.5	27
Bolivia	36.4	0.6
Brazil	244.9	5.3
Chile	48.5	2.3
Colombia	54.7	6.8
Mexico	545.2	131
Paraguay	75.3	3.7
Uruguay	4.6	0.6
Venezuela	167.3	13.4

Note: Three LAC countries rank among the top ten worldwide for shale gas reserves: Argentina (4), Venezuela (7), and Mexico (8). In terms of low permeability oil reserves, three countries also rank among the top ten: Argentina (2), Mexico (6), and Brazil (10).

Source: Hancevic et al. (2023).

Latin America and the Caribbean hold large natural gas reserves, accounting for approximately 4% of global reserves, with a major concentration in Venezuela, where 75% of the region's reserves are located (Di Sbroiavacca et al., 2019). Of all the fossil fuels, natural gas emits the least CO_2 when burned, with its tons of CO_2 emissions per MWh being roughly half of those produced by coal. Furthermore, it is a flexible and versatile energy source that can be utilized across various sectors, including power generation, industry, transportation, and heating. Its affordability and widespread availability in the region make it particularly suitable for countries with high energy demand and limited financial resources to invest in renewable energy during the energy transition.

Moreover, natural gas can also serve as a complementary source to intermittent renewable energies such as solar and wind power, as it can be used to generate electricity when these sources are unavailable or insufficient to meet demand . This enables greater integration of renewable energies into the energy mix, reducing dependence on more polluting fossil fuels. In this regard, some countries in the region have begun implementing policies and programs to promote the use of natural gas in the energy transition. For example, Argentina has launched a plan to develop natural gas infrastructure and increase its share in the energy matrix, while Colombia has established incentives for vehicle conversion to natural gas and the utilization of gas in power generation.

Natural gas can act as a complementary source to renewable energies, being used to generate energy when these sources are not available or are insufficient

It is important to ensure that investments in natural gas do not divert resources away from non-polluting technologies. First, electricity generation using clean technologies is currently more efficient and less polluting than natural gas. Secondly, any investment in infrastructure would not be quickly recovered, posing the risk of becoming a stranded asset in the medium term or creating a commitment to utilize that infrastructure in the medium run, indirectly leading to locked-in emissions from natural gas-based power generation. Similarly, new long-term exploitation rights would pose the same threat. Ultimately, transitioning toward an energy matrix based on renewable energy and natural gas could even provide an opportunity to trade this fuel with other regions, such as Europe.

Transportation: Electrification and sustainable mobility

There are three avenues to reduce emissions in the transportation sector: technical improvements in internal combustion engines, the electrification of the vehicle fleet, and the promotion of public transportation and non-polluting modes of mobility. McKinsey & Company (2013) estimate that available technical improvements for internal combustion engines are more cost-effective compared to electric and hybrid vehicles. While this alternative does not allow for the decarbonization of the transportation sector, it is a more efficient short-term option than transitioning to a fully electric transport fleet.

The transition to an electric vehicle fleet involves costly infrastructure investments. Currently, there are no operational fast-charging terminals that can replace existing fuel stations, which generally limits the ability of electric vehicles to travel long distances in Latin America and the Caribbean. However, it is worth noting that the sector is undergoing rapid evolution, and in the short or medium term, technological and cost differences may not be limiting factors. An example of economic progress is the 85% decrease in the cost of lithium batteries between 2000 and 2019 (IPCC, 2022a). Regarding technology, information from the U.S. Environmental Protection Agency, updated as of November 15, 2022, indicates that electric vehicles available in the United States have an average range of up to 160 km on a full charge and require eight hours for a complete recharge (EPA, 2023). When looking solely at the most recent models, such as 2021 electric cars, the average range is significantly higher, approaching 400 km. However, the average range for gasoline vehicles is around 650 km (U.S. Department of Energy, 2023).

In addition to infrastructure costs, there are cost issues for users. Although costs have decreased dramatically in recent years and more affordable models have emerged, on average, electric vehicles with higher demand, both for personal and commercial use, are comparatively more expensive than combustion vehicles with similar features, and the existing supply of electric vehicles is much smaller. Furthermore, the range and average speed of electric vehicles still fall short of those achieved by internal combustion vehicles, resulting in a limited selection of vehicles that meet consumers' needs. Another difference between electric and combustion vehicles is the greater weight of electric vehicles, mainly due to the batteries.

Finally, the demand for metals such as lithium, nickel, and cobalt, which are key for battery production, may not be met (BloombergNEF, 2022), hindering the rapid adoption of electric vehicles as projected. This obstacle could have effects on prices, further delaying adoption in Latin America and the Caribbean. Natural gas-powered heavy-duty vehicles can be an alternative that allows for the utilization of this resource and the adoption of technology with lower emissions in a high-emission sector. Another alternative for replacing fossil fuel-based freight transport is the use of rail freight. However, their electrification requires more infrastructure investment, a high traffic density to be commercially viable, and a constant and reliable supply of electricity from renewable sources to ensure continuous operation (Lawrence and Bullock, 2022).

The transition to a fully electric vehicle fleet should be a medium to long-term goal for the region, considering the high costs involved in the short term. In the immediate future, there are three policies that would reduce the use of fossil fuels in transportation and have significant positive externalities, particularly in densely populated cities. The first policy is investing in efficient, accessible, and ideally electric public transportation.[27] The second is promoting the use of non-polluting modes of transportation, such as bicycles, through the construction of bike lanes and offering public bicycles or creating pedestrian-friendly walkways. Lastly, the third involves the implementation of low-emission zones that restrict traffic in specific areas and during certain hours (Barahona et al., 2020; Galdón-Sánchez et al., 2022). While the emissions reductions achieved through these policies may be significantly lower than those resulting from a reduction in road emissions, they serve as examples of measures with positive externalities and significantly lower costs. The key positive externalities resulting from these policies include reducing traffic congestion in cities, which would decrease travel times for urban commuting—an issue extensively debated in densely populated areas such as major cities in Latin America and the Caribbean. Additionally, these policies would lead to a decrease in emissions of harmful particles emitted by vehicles when burning fossil fuels. These particles have well-documented health effects (Bishop et al., 2018; Di et al., 2017; Krewski et al., 2009; Lepeule et al., 2012; Wu et al., 2020), including the development or exacerbation of respiratory conditions (e.g., asthma or chronic obstructive pulmonary disease), the onset of dementia, and increased mortality rates.

27 See Box 2.5 for a description of a public transportation electrification initiative in the region.

The migration to a fully electric vehicle fleet should be a medium to long-term objective for the region, given the high cost it would entail in the short term

Although implementing these policies would require less investment compared to establishing nationwide electric vehicle charging infrastructure the region faces challenges regarding public transportation and non-polluting modes of transportation that need to be addressed. Regarding public transportation, issues such as poor connectivity, low frequency, high costs, vehicle quality, and overcrowding during peak hours discourage its use and push commuters toward private vehicles, resulting in increased emissions, traffic congestion, and longer travel times for the same distances (Daude et al., 2017; Rivas et al., 2019). As for non-polluting modes of transportation like bike lanes and pedestrian walkways, one of the deterrent factors for their use in the region is insecurity. Therefore, the necessary investment goes beyond the construction of pedestrian or bike paths; it also involves investing in adequate street lighting, signage, and the installation of security cameras (Alcántara de Vasconcellos, 2019). Furthermore, secure bicycle parking spaces are needed given how easy it is to steal bicycles and their parts.

Box 2.5
Electrification of public transportation in Latin America

In October 2022, CAF approved the “E-Motion” program, financed by the Green Climate Fund (GCF), to promote low-emission transportation in Panama, Paraguay, and Uruguay. The program will finance the large-scale adoption of electric buses, the development of fast-charging infrastructure, and the implementation of light electric commercial vehicles.

The program countries have included specific targets to reduce emissions in the transportation sector in their Nationally Determined Contributions (NDCs). For instance, Paraguay aims to reduce fossil fuel consumption by 20% by 2030. In 2019, Panama established a National Electric Mobility Strategy with the goal of electrifying 25% to 50% of the public transportation fleet by 2030. Similarly, Uruguay’s first NDC set quantitative targets to promote electromobility by 2025, focusing on the adoption of electric buses and the establishment of electric charging stations along major routes. These countries also have a significant capacity for clean energy generation, making the promotion of transport electrification potentially more effective in reducing greenhouse gas emissions than in other contexts.

Diagnostic assessments of the program have identified that transportation in the targeted countries is fragmented and faces issues with service quality and safety. Consequently, the initiative aims to accelerate the sector’s transformation by offering concessional loans for the renewal of the public bus fleet and providing technical assistance to the sector´s key stakeholders. The goal is to promote a new business model that separates asset ownership, service-providing concessionary institutions, and management and administration entities. The expected impact of the project is a total reduction of 3.3 MtCO_2eq of greenhouse gas emissions over its 25-year lifespan. Additionally, it is anticipated that costs related to energy consumption, pollution, and external effects of global warming will be saved, amounting to USD 40 million.

Demand-side solutions

At the beginning of this section, distributed generation or the installation of solar panels on homes and buildings was highlighted as one of the main actions that households or businesses can take. However, this is not the only measure that could achieve significant emissions reductions. Two actions with the greatest potential are linked to energy efficiency: responsible energy consumption and the use of energy-efficient appliances, including heating devices. The International Energy Agency (IEA) estimates that between 2000 and 2017, energy efficiency measures enabled global energy consumption to be 12% lower than estimated for that period (IEA, 2022a). Zehner (2012) demonstrates that California (United States) began implementing measures to promote energy efficiency in the mid-1970s, resulting in the state's per capita energy consumption remaining constant, whereas it doubled at the national level.

In Latin America and the Caribbean, 75% of household electricity consumption is divided among food refrigeration, lighting, and environmental conditioning, according to a report by the Inter-American Development Bank (Urteaga & Hallack, 2021). Emissions from this consumption can be reduced through the use of efficient household appliances such as high-energy-efficiency refrigerators, LED lamps, and modern and highly energy-efficient heat pumps. Additionally, responsible consumption practices can contribute to emissions reduction, such as adjusting the refrigerator temperature to the necessary level, avoiding unnecessary use, leveraging natural lighting during the day, turning off lights in unoccupied rooms, using natural ventilation, regulating heat pump temperature, and not using heat pumps in empty spaces. The same report estimates that savings from replacing these appliances can reach up to 40% of each device's consumption, and the estimated cost of replacing refrigerators in major Latin American markets could be USD 7 trillion. Finally, improved home insulation could increase the savings from the mentioned policies by 15%.

Regarding transportation, in addition to the use of electric vehicles, there are three actions that, when feasible, can effectively reduce emissions. The first is active mobility, which refers to traveling on foot, by bicycle, or similar means instead of using a car. This action is mainly viable for short distances and in cities that have the appropriate infrastructure, such as well-maintained sidewalks, bike lanes, pedestrian-only streets, etc. The second action complements the first and involves the use of public transportation, as mentioned in the previous section, which can be implemented for distances where walking or cycling is not feasible. Lastly, both companies and workers should consider remote work, if viable and not detrimental to their productivity. The IEA (2020a) estimates that globally, 60% of car trips cover distances of less than 10 km, and only 5% of those trips are at least 50 km. The authors estimate that if 50% of trips of 5 km or less were replaced by non-polluting alternatives, emissions of 130 $MtCO_2$ could be avoided, roughly equivalent to 2% of global road transport emissions.

One measure related to responsible consumption is the use of timers, external devices that allow for automatic switching on or off of appliances. Another option is the use of smart appliances, some of which come equipped with automatic on/off functions or can be controlled via a mobile phone. Smart electric meters enable electricity consumption to be programmed, ensuring that electricity is used when it is abundantly available, thereby reducing consumption during periods when volatile renewable energy sources are scarce.

Sluisveld et al. (2016), include demand-side measures in an integrated assessment model and find that such measures could potentially reduce emissions by 35% in the transportation sector and 13% in residential areas. The IEA (2020a) estimates that demand-side solutions could lead to reductions of 2 $GtCO_2$ by 2030. Approximately half of these reductions would come from road transport, and a quarter attributed to a decrease in long-distance flights. Additionally, significant emissions abatement would be achieved through changes in household behavior, particularly a decrease in the use of energy-intensive heating and cooling appliances in homes.

However, it is important to highlight that one of the main barriers to the adoption of energy-efficient measures by households is economic constraints, followed by a lack of education or knowledge (Andrews-Speed & Ma, 2016; Wolske & Stern, 2018). National and subnational governments have sought to promote the adoption of energy-efficient technologies through purchase subsidies. In Latin America and the Caribbean, there are cases of economic incentives for purchasing electric vehicles, installing solar panels, and buying high-energy efficiency appliances. Nevertheless, as previously mentioned in the discussion on inequality, these subsidies tend to be highly regressive, as households mainly from the middle and upper classes have sufficient resources to afford such goods. For instance, Borenstein and Davis (2016) demonstrate that in the United States, the bottom 60% of the population received only about 10% of the income tax credits for clean energy investments, while the top quintile received nearly 60% of these credits. They emphasize that these credits can be even more regressive than carbon taxes without redistributive policies. Not only are these subsidies highly regressive, but there is also evidence that they often fail to generate new demand. Xing et al. (2021), using U.S. data, estimate that 70% of federal subsidies were used for purchases that would have been made even without such assistance.

Adaptation in the energy sector

Climate change has multiple impacts on the energy sector. Some key examples include changes in seasons, which alter the energy demands for heating and air conditioning; reduced efficiency in electricity generation due to overheating or infrastructure damage caused by extreme events; challenges in hydroelectric generation due to water stress; damages to roads, leading to increased transportation times and the need for road infrastructure investment; and disruptions in transmission and distribution systems or infrastructure. These potential infrastructure damages further exacerbate existing deficiencies and the need for investment, posing a significant threat to access to electricity and worsening energy security concerns.

Much of the current energy sector infrastructure in the region was not constructed or designed to withstand the anticipated climate conditions projected for the mid-century. Therefore, it is crucial that climate considerations be taken into account in new infrastructure projects within the sector. Additionally, most electric transmission lines are located outdoors, making them more vulnerable to climate-related threats. High temperatures also affect the effectiveness of transmission lines and increase the risk of short circuits in areas with trees. One possible solution to this problem is the construction of underground transmission lines. However, in regions expecting higher temperatures and precipitation, there may be increased vegetation growth that could impact underground lines, which must be considered during the design process. Implementing this solution can be costly as it requires replacing all above-ground transmission lines. Nonetheless, it could be vital for regions experiencing a higher frequency of extreme events. Research by Sathaye et al. (2011) indicates that the energy potential of natural gas plants could decrease by 0.7% to 1% for every degree the temperature rises above 15°C. Dowling (2013) shows that efficiency changes would be around 0.17% for coal plants, 0.24% for gas plants, and 0.27% for combined cycle plants.

Not only are transmission lines at risk but the power generation system itself is also threatened. Higher temperatures reduce the efficiency of thermal and nuclear power plants, increase the water requirements for cooling, and raise the risk of operational shutdowns. The decrease in rainfall frequency also increases the demand for water in cooling processes while reducing its availability. Furthermore, extreme events pose a threat to the infrastructure of these plants and their connection to distribution networks. All of these factors should be considered when selecting sites for new thermal power plants, and additional maintenance efforts should be made to ensure that the existing infrastructure can withstand expected events. As an example, within a three-week period between August and September 2008, the Caribbean islands suffered extensive damage from the impacts of hurricanes Gustav, Hanna, and Ike. It is estimated that Ike alone damaged or destroyed around 95% of buildings in the Turks and Caicos Islands and caused severe damage to oil and gas platforms in the Gulf of Mexico. Hurricanes Rita and Katrina in 2005 destroyed 115 platforms and 180 pipelines, with industry damages estimated to exceed USD 15 billion (Contreras-Lisperguer and de Cuba, 2008).

The region's energy sector infrastructure was not designed to cope with current and future climate conditions. New infrastructure projects will have to consider the climate factor

Renewable energies are not exempt from these risks. With the exception of a few cases, hydroelectric power plants were mostly installed in the mid to late 20th century, which means they were not designed considering the threats posed by climate change.

One of the primary risks for hydroelectric facilities, aside from extreme events, lies in the changes in precipitation patterns. Excessive rainfall can lead to damage to dam walls and turbines, causing flooding, while a decrease in precipitation limits the capacity for electricity generation. Moreover, changes and variability in the rainy seasons can result in both excess and scarcity of generation, ultimately impacting the quality of service. According to Yalew et al. (2020), the energy potential of hydroelectric installations in Latin America and the Caribbean may decrease by almost 20% due to the impacts of climate change, primarily due to water stress. To mitigate these damages, necessary investments focus on improving climate event prediction, increasing water storage capacity, enhancing turbines, adjusting water release frequencies, and clearing debris after storms or strong winds.

In the case of solar and wind energy, the situation is different. Since the installation of these plants is more recent, the aforementioned risks were most likely taken into account during the design phase. The main meteorological risk for wind power generation is the presence of extremely strong winds and variability in blustery periods. Strong winds can cause damage to turbine infrastructure, while variability affects electricity generation. These risks need to be considered when deciding the optimal locations for wind turbines. Another potential adaptation measure involves improving meteorological services to better predict these events.

Lastly, the greatest risks for solar energy come from increases in cloud cover and air humidity. These risks, which reduce the capacity for electricity generation and conversion, can be partially mitigated by increasing the utilization of diffuse light by solar panels and investing in storage capacity.

It is worth noting that these three renewable technologies rely on different environmental resources and face distinct climate threats. Consequently, an electricity generation matrix that incorporates all three technologies reduces threats because of the unlikeliness of simultaneous adverse impacts. However, as previously mentioned, these policies require significant investments in a region with low savings rates.

Adaptation and mitigation in other economic sectors

Industry: Sustainability through recycling and demand reductions

The main emissions from industry come from industrial waste, followed by chemical manufacturing, metal extraction and production, cement, steel, and aluminum processes, and their energy consumption.

In the case of chemical manufacturing, the production of ammonia accounts for the majority of CO_2 emissions. Ammonia, primarily used in agriculture, has adverse effects on human health and contributes to soil and water acidification, as well as nitrous oxide emissions. Ammonia is utilized not only in fertilizers but also in the production of pharmaceuticals, plastics, textiles, and even explosives. Thus, the primary approach to mitigating emissions of this compound lies in reducing demand by minimizing the use of ammonia-rich fertilizers in agriculture and manufactured products that rely on ammonia production, such as plastics.

In addition, plastics are major contributors to pollution because they have a decomposition process that spans from 100 to 1000 years. Moreover, the global recycling rate for plastics is only around 10%, meaning that 90% of plastic is discarded and replaced. Geyer et al. (2017) show that plastic production has grown by 8.4% in the last 70 years, nearly 2.5 times the growth rate of the global GDP, and it is projected to maintain an annual increase of over 3% in the coming years.

The production process for plastics, in addition to ammonia, relies on petroleum and is energy-intensive, resulting in a high carbon footprint. Consequently, like ammonia, the key emissions reduction policies are those that encourage reduced demand for goods with high plastic content.

As for metals, the main emissions come from steel, aluminum, and iron production. Metal recycling rates are significantly higher than those of plastics, with steel at around 40%, iron close to 50%, and aluminum approaching 35%. Nevertheless, there is still room for improvement in these percentages, which would lead to emissions reduction in the production of these metals.

In the case of steel, the use of hydrogen derived from carbon-free sources can make steel production nearly CO_2-neutral (Vogl et al., 2018). The main challenge lies in the distribution of green hydrogen, which requires suitable pipelines and may render its use unfeasible in many cases. For iron, the electrolysis of molten oxide manufacturing method also holds the promise of near-neutral emissions if the electricity used is generated from clean sources.

Lastly, in the case of cement, there are limited mitigation options available. One policy that could achieve neutrality in the production process is carbon capture and storage (CCS). However, the current costs associated with this option may render it largely unviable. Alternatives to conventional cement, such as ecological or green cement, which incorporates at least one component made from waste materials, offer environmentally friendly production processes with high performance and lifecycle sustainability. Some limitations to the utilization of this input include building codes that indirectly restrict its use, resistance to changing construction practices due to tradition, and the need for specific technical knowledge and skills.

Tourism: Sustainability through ecosystem preservation

Emissions from the tourism sector primarily come from electricity consumption and fuel usage, particularly in transportation. In the case of Central America and the Caribbean, the biggest threats to the tourism industry are its impact on the environment and the expected consequences of climate change. These include biodiversity loss, rising average temperatures, and more frequent extreme weather events, among others.

The greatest threats facing tourism in the region are the expected impacts of climate change, such as loss of biodiversity, higher average temperatures, and more frequent extreme weather events

One of the main attractions of tourism in the Caribbean and certain Latin American countries is the climate. The region's stable warm climate and distinct rainy seasons, combined with its biodiversity and beaches, draw a constant flow of visitors. However, hurricanes and storms serve as deterrents when tourists choose their destination.

In addition to temperature and climate stability, the region's biodiversity is a major draw for tourism, and it is currently under threat (see Chapter 3). The growing water demand is deteriorating the quality of this resource and increasing the risks of desertification and forest fires. Infrastructure development is transforming habitats, and if not properly planned, it can have significant impacts on both terrestrial and marine landscapes. Rising sea levels pose risks of flooding and infrastructure loss, while ocean acidification and increased temperatures can lead to biodiversity loss and other environmental risks. All these threats to biodiversity directly impact tourism, which is of particular importance to Caribbean countries.

While coastal areas face the greatest threats, climate change also poses risks to other tourist destinations, such as Patagonia, where it will result in glacier retreat, reduced precipitation, and less snowfall. Similarly, culturally significant sites like Easter Island or the Galapagos Islands are also at risk. A report by the International Union for Conservation of Nature (IUCN) (Osipova et al., 2020) indicates that climate change is a significant threat to 93 out of 252 World Heritage sites considered in the report. Of these 93 sites, 23 are located in Latin America and the Caribbean, such as the islands and protected areas of the Gulf of California in Mexico and the Río Plátano Biosphere Reserve in Honduras. According to the study, these sites are in a critical state, requiring immediate large-scale conservation measures to maintain or restore their values in the short and medium term.

The greatest efforts to preserve tourism revenue and activity should focus on implementing biodiversity conservation and adaptation policies to minimize the anticipated damages from climate change. The following is a list of policies that should be adopted in the short term in both areas:

- Regulation for sector projects or in regions of high tourism interest, including construction standards and prohibitions on tourism development in areas with high environmental risks.
- Recognition and adoption of environmental practices, such as sustainable tourism.
- Coastal and water resource management, including water quality protection, biodiversity conservation, coastal erosion management, flood prevention, and fisheries resource management.
- Lastly, a policy that would greatly benefit the tourism sector is the establishment of markets for payments for environmental services. These markets would provide an additional monetary incentive that generates an extra benefit for biodiversity conservation. Chapter 3 provides a more detailed analysis of this instrument.

Construction: Sustainable cities and buildings

The majority of emissions in the construction sector stem from energy consumption. Additionally, the sector demands a large amount of industrial inputs such as cement, steel, and aluminum, among others, which have a high carbon footprint. However, there are relevant adaptation and mitigation measures for the sector, which have great potential in Latin America and the Caribbean due to the region's high urbanization rate and the pressing need for investment in physical infrastructure.

Energy code certification for buildings is a critical policy tool that addresses both climate change adaptation and mitigation in the construction sector. These codes regulate the construction and operation of buildings with the aim of minimizing energy consumption. The certification of green or sustainable buildings, in addition to a measurable environmental impact, generates value for builders and property owners by enhancing the value of the property while providing energy savings for occupants. Some of these codes include provisions for solar panel installation, natural ventilation, multifunctional green roofs, solar water heating, rainwater capture and recycling, and green spaces. These policies reduce the need for heating and cooling, harness solar energy, improve water management, incorporate carbon-capturing green areas, and are designed to withstand the anticipated adverse weather conditions posed by climate change.

In Latin America and the Caribbean, there are local and international certification cases. The International Finance Corporation created the EDGE (Excellence in Design for Greater Efficiencies) building certification system in 2012, which is present in all countries of Latin America and the Caribbean. Locally, notable initiatives include the EDIF and Procel EDIFICA labels in Brazil, the CES label in Chile, and the CASA Colombia certification in Colombia.

Energy code certification is a key policy tool for the building sector to address adaptation and mitigation of climate change

The construction sector has a lot to offer in terms of housing and office design and construction, as well as urban planning. García and Giambiagi (2022) provide a detailed vision of urban planning and management focused on health promotion, with a regional perspective. These initiatives allow for temperature control in urban areas, reduction of noise and air pollution, provision of buffer zones to reduce visual pollution and stabilize riverbanks, protection against storms and floods, and provision of recreational spaces and areas that promote physical activity. Chapter 3 will delve into more detail on policies for public spaces. Adaptation policies must address the challenge posed by the large number of informal settlements that characterize cities in the region (Daude et al., 2017), many of which are located in areas exposed to the impacts of climate change. Hagen et al. (2022) assess the literature on climate change-related risks for loss of life and infrastructure in Latin America and the Caribbean, highlighting threats such as floods, landslides, and droughts, among others, and outlining the main adaptation measures for each risk.

Mining: Inputs for a renewable energy future

Minerals such as lithium and copper play a vital role in the transition to renewable energy. Lithium is a key element for the batteries required in the storage of electricity generated from renewable sources and for electric vehicles. On the other hand, copper is an excellent energy conductor and infinitely recyclable. As economies electrify and the demand for electricity rises, driven in part by population growth, the demand for copper and lithium will further grow.

While the lithium market remains small compared to major minerals like steel, coal, aluminum, and even copper, projections from the IEA estimate that demand for this mineral could increase 40-fold by the middle of the century (see Chapter 5).

Due to its mineral endowment, the region has the potential to be a key player in the global energy transition. Chile is the world's leading copper producer, followed by Peru. In terms of lithium, Chile and Argentina rank second and third in global production respectively, collectively holding 51.8% of the world's lithium reserves. Bolivia possesses the largest untapped lithium reserves, and lithium deposits have also been recently discovered in Mexico and Peru.

Copper and lithium are not among the most environmentally damaging minerals, with aluminum being the mineral that generates the most GHG emissions during its extraction and production processes. Since nearly all emissions in the sector result from energy use, energy transition policies would mitigate almost all the sector's emissions in the region. Mines could contribute by utilizing renewable energies such as solar panels and wind turbines where geographic conditions are suitable. Additionally, the use of green hydrogen for industrial processes requiring high temperatures would help mitigate emissions from fuel burning and fugitive emissions. Regarding energy consumption in transportation, replacing trucks with electricity-powered conveyor belts, when feasible, would also reduce another major emission source in the sector.

The main challenge faced by the sector lies not so much in its GHG emissions but in the impact of mining on the environment and local communities. This has led to social conflicts that have hindered or even canceled mining projects. Governments and the industry must be proactive in minimizing these damages and the resulting social conflicts, ensuring that local communities are the primary beneficiaries of these projects.

Water resource damage stands out as one of the significant environmental consequences of mining. Mining contaminates rivers and groundwater, affecting not only ecosystems but also drinking water and productivity in nearby agricultural areas. At the same time, mining consumes large amounts of water in its production processes. The three key policies in this regard are 1) water management and wastewater treatment to minimize the generated damage, 2) increased use of seawater in the production process, and 3) reuse of wastewater in the production process.

IEA projections estimate that lithium demand could increase 40-fold by mid-century

Finally, one of the practices already being carried out and of great relevance to the sector is the reclamation of abandoned mines. Abandoned mining sites are sources of pollution, releasing greenhouse gases and air pollutants. Projects aimed at reclamation typically include topographic reconstruction, replacement and reconstruction of the topsoil layer, and re-vegetation.

For more information about CAF projects to support the agricultural sector and to regenerate biodiversity, watch the video by scanning this QR code.