The Climate and Development Challenge for Latin America and the Caribbean

Options for climate-resilient, low-carbon development

Preface by R. Pachauri

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Photos: Jennifer Doherty-Bigara.

Acronyms and Abbreviations

AF	Adaptation Fund
AFOLU	Agriculture, forestry, and other land use
AR4	Fourth Assessment Report
BAU	Business-as-usual
BRT	Bus rapid transit
CAIT	Climate Analysis Indicators Tool
CC	Climate change
CCCCC	Caribbean Community Climate Change Centre
CCS	Carbon capture and storage
CDIAC	Carbon Dioxide Information Analysis Center
CDM	Clean Development Mechanism
CIF	Climate Investment Fund
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CONAGUA	Comisión Nacional del Agua (National Water Commission; Mexico)
CSIRO	Commonwealth Scientific and Industrial Research Organization
DALYs	Disability adjusted life years
DIVA	Dynamic Interactive Vulnerability Assessment
EAF	Ecosystem Approach to Fisheries
EBA	Ecosystem-based Adaptation
ECLAC	Economic Commission for Latin America and the Caribbean
EPPA	Emissions Prediction and Policy Analysis
GDP	Gross domestic product
GEA	Global Energy Assessment
GEF	Global Environment Facility
GHG	Greenhouse gas

$GtCO_2e$	Gigatons of carbon dioxide equivalent
HLZ	Holdridge Life Zone
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales (Institute of Hydrology, Meteorology and Environmental Studies; Colombia)
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
INAP	Integrated National Adaptation Program
INRENA	Instituto Nacional de Recursos Naturales (National Institute of Natural Resources; Peru)
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and the Caribbean
LED	Light-emitting diode
LULUCF	Land use, land-use change, and forestry
NAMA	Nationally Appropriate Mitigation Action
NOAA	National Oceanic and Atmospheric Administration
PPCR	Pilot Program for Climate Resilience
ppm	Parts per million
PPP	Purchasing power parity
REDD	Reducing Emissions from Deforestation and Forest Degradation
REDD+	Reducing Emissions from Deforestation and Degradation in Developing Countries
SPA	Strategic Priority on Adaptation
SRES	Special Report on Emissions Scenarios
tCO_2e	Tons of carbon dioxide equivalent
tpc	Tons per capita
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wide Fund For Nature
ZNDD	Zero net deforestation and forest degradation
ZNDD 2020	Zero net deforestation and forest degradation by 2020
ZNLU	Zero net emissions from land use, land-use change, and forestry
ZNLU 2030	Zero net emissions from land use, land-use change, and forestry by 2030
ZNLU 2030+	Zero net emissions from land use, land-use change, and forestry by 2030, with continued augmentation of sinks producing net negative annual emissions of 350 tCO_2e each decade thereafter

The word *tons* signifies metric tons.
All dollar amounts are U.S. dollars, unless otherwise noted.

Preface

This report is being issued in the context of the United Nations Conference on Sustainable Development, held in Rio de Janeiro from June 20 to June 22, 2012. It deals with a matter that is bound to affect the likelihood of achieving sustainable progress in Latin America and the Caribbean. Indeed, climate change is already affecting the foundations on which Latin American societies rely for sustenance and welfare.

The report appropriately reminds us of the physical impact of climate change in the region, which are almost certain to escalate over time. The Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) observed in 2007 that even if the concentration of all greenhouse gases and aerosols had been kept constant at the levels of year 2000, further warming of about 0.1°C would be expected because of inertia in the global system. At the same time, for the entire range of emissions scenarios used by the IPCC, a warming of about 0.2°C per decade has been projected. Therefore, climate change will continue to affect agriculture, biodiversity, and water availability: Many areas of tropical Latin America will continue to face a risk of significant loss of biodiversity through species extinction; productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. Even if, as is expected, soybean yields rise in temperate zones, the number of people at risk of hunger is projected to rise. Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect the availability of water for human consumption, agriculture, and energy generation. The AR4 also highlighted the fact that anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending on the rate and magnitude of climate change.

All of these impacts have economic consequences. This report includes a necessarily partial estimate of those consequences, while also recognizing that no economic estimate can fully capture the effects of climate change.

The case for adaptation, if deployed early, is forcefully presented. The report also recognizes that adaptation can go only so far if impacts are allowed to accumulate. In the end, adaptation at best buys time while we put in place lasting mitigation efforts (which will have to be drastic) and embrace global stabilization goals. The AR4 noted that adaptation and mitigation, pursued together, can significantly reduce the risks of climate change, but that neither adaptation nor mitigation alone can avoid all climate-change impacts.

Although the carbon footprint of Latin America and the Caribbean is modest and appears to be decreasing, efforts to further reduce that footprint are required if global climate stabilization goals are to be achieved. A substantial contribution of this report is the outlining of specific paths (expressed as sets of actions) toward the achievement of a footprint of two tons per capita per annum in the region.

The carbon budget of Latin America is heavily weighted toward contributions from changes in land use, energy, and transport. For that reason, a focus on reductions in these sectors is, therefore, most appropriate. The actions identified and presented here are technologically viable. They would result in significant cobenefits for food and energy security, health, welfare, and technology development. The budget associated with the actions is substantial, but the analysis presented here shows that the cost of inaction would be much greater.

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in the Practice of Sustainable Development

Executive Summary

Changes in climate during this century will have broad and deep impacts on human activities and ecosystems. The consequences of those changes are likely to be so great that the simultaneous need to adapt to new climate conditions and to reduce carbon emissions to prevent even further damage is almost certain to become one of the global community's defining challenges over the coming decades.

Unless drastic and immediate action is taken, it is likely that a 2°C rise in temperatures will occur in this century

Unless drastic and immediate action is taken, a rise of 2°C—and perhaps even more—over the preindustrial level is now seen as all but inevitable. Because of the lagged effect of greenhouse gases already emitted and accumulating in the atmosphere, such a temperature rise is now considered to be structurally built into our future, to result in significant negative impacts on economic activities, social conditions, and natural assets by 2050.

The associated physical and natural damage to Latin America and the Caribbean are expected to be substantial

The region of Latin America and the Caribbean (LAC) is particularly vulnerable to the observed and projected effects of climate change because of its geographic location, distribution of population and infrastructure, and reliance on fragile natural resources for economic activities and livelihoods. Key impacts on the region, forecasted to occur by midcentury due to current emissions trends, include the collapse of a significant portion of the coral biome in the Caribbean, the disappearance of most glaciers under 5,000 meters in the tropical Andes, the likelihood of some degree of savannization in the Amazon basin, reductions in the agricultural yields of many staple crops, increased flooding and inundation of coastal zones, increased exposure to tropical diseases, the destabilization of the hydrological cycle in major basins, and the intensification of extreme weather events. More worrisome is the fact that many of these changes are considered to be not only inevitable but also irreversible. Climate change will therefore continue to adversely affect the region over the long term.

The economic impacts of such physical damage will be significant

Based on recent analysis and new estimates, the projected yearly economic damages in LAC caused by some of the major physical impacts associated with this likely rise of 2°C over preindustrial levels are estimated to gradually increase and reach approximately $100 billion annually by 2050—or approximately 2.2 percent of 2010 gross domestic product (GDP, $4.6 trillion).[1] This estimate is conservative and is limited to key impacts on certain geographic locations. It is not inclusive of the damage to biodiversity, the change in the stock of natural resources, or other nonmonetary values (such as certain ecosystem services that are intrinsically difficult to value, and cultural and social damages).

Losses of this magnitude will undermine the region's prospects for improvements in quality of life, by significantly limiting development options and severely restricting access to natural resources and ecosystem services. The damage is already taking place and will intensify as temperatures increase. Economic resources, already inadequate to meet competing demands, will be further strained. The resulting cumulative impact promise to far exceed the indicated 2.2 percent of 2010 GDP and to also negatively affect equity and poverty levels.

Rapid and decisive adaptation action could reduce many of the expected economic damages—although not all of the losses in natural capital—at only a fraction of the long-term cost of no action

The overall investment required to adapt to the unavoidable physical impacts—irrespective of even drastic reductions in emissions—has been estimated at $17 billion to $27 billion, or approximately one-fourth to one-sixth of the costs of those physical impacts. The implication is that adaptation action is clearly cost-effective. Much of the adverse economic impact otherwise expected can be avoided or compensated for by dedicating sufficient financial resources to adaptation activities.

The impact of adaptation measures is ultimately limited, however. Even if they are undertaken, some irreversible damages would remain as these measures can only ameliorate the socioeconomic impacts of climate change. Adaptation measures do not generally result in the restoration of lost natural and cultural capital, which will likely affect future generations.

Global mitigation actions are essential to prevent greater damage to the region

To contain economic damages and to avoid crossing yet more irreversible and change-accelerating tipping points that would be provoked by temperature increases above and beyond a likely 2°C rise, global greenhouse gas (GHG) or CO_2 equivalent (CO_2e) concentrations must ultimately stabilize at approximately 450 parts per million (ppm). For this level to be successfully achieved and credibly maintained, no more than 20 gigatons (Gt) of CO_2e annually can be released globally by 2050—or about 2 tons per capita (tpc) of CO_2e per year. Further, no more than 10 $GtCO_2e$ can be emitted annually in global terms by the end of the century (less than 1 tpc per year).

There is evidence of some decoupling of economic growth from carbon emissions in Latin America and the Caribbean

The total carbon footprint of the LAC region has decreased by about 11 percent since the start of the century, to nearly 4.7 Gt CO_2e, while its GDP has grown at an annual rate of about 3 percent. The decline in emissions is attributed to a decreased rate of deforestation and improvements in energy efficiency. While this is far too short a trend from which to draw long-term conclusions, the recent pattern in the region seems to imply that it is possible to decouple growth in the value of economic activity from GHG emissions, and that there are immediate opportunities to do so.

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[1] All gross domestic product (GDP) values, including future projections, are measured in 2005 dollars.

LAC's business-as-usual (BAU) trajectory would bring the region to a level of annual emissions nearly five times the level the 2 tpc required as part of global climate stabilization goals (9.3 tpc)

Although the LAC region's emissions footprint accounts for only 11 percent of the world's total, climate stabilization goals require all regions, including LAC, to emit about 2 tpc of CO_2e per year by 2050. While land-use emissions are projected to fall significantly, and the overall share of agriculture is projected to remain roughly constant, the emissions shares of transportation and power generation are anticipated to grow by 50 percent—to reach a combined contribution of approximately 2 $GtCO_2$e per year. Indeed, under the BAU trajectory, the LAC region would emit nearly 7 $GtCO_2$e, or 9.3 tpc, a year by 2050.

Significant mitigation efforts, affecting both land use and energy, are essential to achieve intermediate stabilization goals of 2 tpc by 2050

Bending the emissions curve sufficiently to achieve the 2 tpc goal is not easy. An effort of this magnitude implies significant changes in the structure of the region's economies and patterns of natural resource use. Only a pathway that promotes energy emissions mitigation efforts sufficient to minimize the carbon footprint in the power and transport sectors by 2050 combined with agriculture, forestry, and other land use (AFOLU) policies stringent enough to achieve (i) zero net emissions from deforestation and land use by 2030, and (ii) 50 percent fewer agricultural emissions than projected in the BAU by 2030 could achieve the 2 tpc target.

Meeting global climate stabilization goals of 2 tpc by 2050 would cost Latin America and the Caribbean approximately $100 billion per year, with an average abatement cost of less than $20 per tCO_2e

The net additional annual financial costs implied by such actions—above and beyond the expected investment and expenditures required under the current BAU scenario—are estimated to reach approximately $100 billion by 2050. This represents approximately 2.2 percent of LAC's 2010 GDP (0.5 percent of projected 2050 GDP). Such a financial requirement, while significant, needs to be seen in the context of a global effort to prevent further catastrophic damage, caused by exceeding the 2°C guardrail.

Adaptation and mitigation generate significant development cobenefits, but these benefits are not yet sufficiently perceived or understood to guarantee the removal of barriers to action against climate change

Adaptation and mitigation efforts are essential to sustainable development, the generation of cobenefits in terms of improved human health and well-being, enhanced food and energy security, more efficient use of natural resources, and accelerated technological development. At a societal level, the value of cobenefits may offset a significant share of the net additional costs. Such cobenefits are usually local and tend to complement national pollution abatement programs with considerable health-related benefits. Although these cobenefits provide financial inducements, additional resources are required for rapid and decisive actions to confront the climate change challenge in LAC.

Introduction

During this century, climate change will have broad impacts on human activities and ecosystems (IPCC 2007a). The projected consequences are of such a magnitude that the simultaneous need to adapt to the new climate conditions and reduce the carbon footprint to prevent further damage will likely become one of the main driving forces for the global community.

This document attempts to address several questions related to the threat of climate challenge in Latin America and the Caribbean (LAC). First, which key physical impacts and consequences will most affect the region, what will these effects cost regional economies, and what adaptation measures may minimize these adverse impacts? Second, how and at what cost will the region be able to reduce its contribution to the global carbon footprint at a level consistent with climate stabilization goals?

The global average concentration of carbon dioxide (CO_2) in the atmosphere has increased considerably, rising from a base of approximately 280 parts per million (ppm) in the late 18th century to 392 ppm of CO_2 in 2011 (NOAA 2012). This trend is just below the most pessimistic scenario (A1FI) visualized by the Intergovernmental Panel on Climate Change (IPCC) in 2000, and might trigger climate feedback effects that are not yet completely understood (Ackerman and Stanton 2011). Scientific analyses indicate that a CO_2 atmospheric concentration of 450 ppm is consistent with a 2°C increase in global temperature, relative to preindustrial levels (table I.1).

The 2°C threshold is important because an anomaly of this magnitude has been linked to the strong likelihood of "dangerous" (UNFCCC, Objective 2) changes in the climate (Schellnhuber 2009; IPCC 2007a). This threat is the basis behind efforts to stabilize climate conditions, including the Copenhagen Accord, which was later ratified at the Cancun and Durban summits. Despite a degree of uncertainty regarding the future "business-as-usual" emissions trajectory and climate sensitivity, there is a growing consensus that emissions need to be reduced to a level consistent with this guardrail to avoid further climate destabilization.

Table I.1 Likelihood that Selected CO_2e Levels will Result in at Least a Particular Temperature Increase (in %)

Stabilization levels (in ppm of CO_2e)	2°C	3°C	4°C	5°C	6°C	7°C
450	78	18	3	1	0	0
500	96	44	11	3	1	0
550	99	69	24	7	2	1
650	100	94	58	24	9	4
750	100	99	82	47	22	9

Source: Stern (2009).

Stabilizing the temperature rise to no more than 2˚C above preindustrial levels would require considerable global efforts to reduce emissions and likely require major changes in behavior and resource use. Global emissions of greenhouse gases (GHGs) were on the order of 47 gigatons of CO_2 equivalent ($GtCO_2e$) in 2010 (EDGAR database), or nearly 7 tons per capita (tpc). Keeping this rise from exceeding 2°C degrees above preindustrial levels would require that annual global emissions go no higher than 20 $GtCO_2e$ by 2050 (IPCC 2007a), which is equivalent, on a global basis, to 2 tpc.[2] A stable climate, meanwhile, would require further reductions in global emissions.

Adaptation measures play a critical role in any emissions abatement. Under present conditions, the global temperature will continue rising even under the most optimistic (low GHG emissions) scenario. Even if GHG emissions are effectively reduced, climate change is still likely to impact LAC, in large part because of the region's substantial but intrinsically fragile natural capital (which includes climate-sensitive ecosystems) and vulnerable infrastructure. Adaptation responses to the impacts of a 2˚C temperature rise are therefore necessary. The costs of such responses are small when compared to the risk of no action.

Cost-effective mitigation activities are also needed, to avoid the dire projections of temperature rise above 2˚C. To minimize the risk of crossing environmental thresholds, the global emissions goal of 2 tpc of CO_2e per year by 2050 has been adopted. This is (i) a very challenging goal and (ii) insufficient in itself. Further efforts are required to reach a 1tpc needed for climate stabilization by century's end.

Chapter 1 provides an overview of the key physical impacts and associated costs of climate change, and identifies adaptation responses. Credible pathways to reaching the 2050 goal in LAC and their associated costs are the central subjects of chapter 2. Chapter 3 reviews the cobenefits expected from adaptation and mitigation efforts.

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[2] Stabilization of GHG concentrations in the atmosphere sufficient to maintain a 2°C anomaly would require a target of 1 tpc of CO_2e per year to be reached by the end of the century.

Chapter 1

Climate Impacts and Adaptation Responses

Climate impacts

Some now consider a midcentury temperature increase of 2°C over preindustrial levels to be virtually unavoidable (Hansen, Sato, and Ruedy 2012) unless drastic and immediate actions are undertaken. Climate change of this magnitude will significantly disrupt livelihoods, social conditions, and ecosystems (IPCC 2007b). While the pace of change is somewhat uncertain, the impacts are likely to increase over time. In addition, some adverse climate feedback effects, or tipping points, are expected, that are not yet completely understood (IPCC 2007a; Ackerman and Stanton 2011).

Some of the key physical consequences projected for the region include:

- Loss of soil moisture, temperature and changes in rainfall patterns affecting yields and agro-ecological zones
- Higher sea levels and surface temperatures affecting coastal and marine zones
- Increased frequency and intensity of extreme weather events in coastal zones
- Additional exposure to tropical disease vectors owing to higher temperatures and changing climates
- Increased retreat of glaciers in the Andes owing to warming
- Impacts on hydrological basins from changes in rainfall patterns
- Potential rainforest dieback
- Loss of biodiversity and ecosystem integrity

Without adaptation measures, these physical impacts will have significant economic and social consequences that will likely hinder sustainable development and could delay and increase the costs of achieving higher standards of living for the region.

Climate change is also likely to occur alongside existing environmental stresses (for example, mangrove removal and chemical discharge in coastal areas may further weaken coral already affected by ocean warming and acidification). As a result, adaptation strategies must enhance the capacity of human settlements and ecosystems to respond to a combination of climate and non-climate related stresses. In a few instances other factors, whether caused by human activity or natural cycles, may even lessen the adverse effects of climate change. In any case, a comprehensive adaptation strategy should anticipate the likely effects—both adverse and occasionally beneficial—of climate change, non-climate driven human actions, and changes in natural cycles.

Even with adaptation measures, however, the consequences of these changes may limit access to and the availability of natural resources in the future, restricting development options.

Impacts on agriculture caused by warming, reduction of soil moisture, and changes in rainfall patterns

Agriculture plays a key role in the region's economy, accounting for approximately 6 percent of regional gross domestic product (GDP) and 15 percent of employment in 2010. In 2008 food exports represented 16 percent of merchandise exports, whereas food imports accounted for 8 percent of imports (CEPALSTAT 2012).[3] Agriculture also represents a key factor in food security in Latin American and the Caribbean (LAC).

Overall, the impacts of climate change on agriculture must be seen in the contexts of increasing demand for food and agricultural products (Dawson and Spannagle 2009) and exports to the global market. Specifically, impacts on agriculture are expected to reduce food supply and increase food prices, with potentially negative impacts on income, food security, poverty, and nutrition (Ahmed et al. 2009; Nelson et al. 2009).

As temperature, moisture, and rainfall patterns change, so will crop yields and the distribution of agricultural production (Dawson and Spannagle 2009). Shifts in climate variability (the intensity/frequency of floods, rainfall, drought, and storms) are expected to reduce yields. More difficult to assess is the long-term increase in the temperature of the top layer of soil, which may eventually surpass the genetic ability of many crops to adjust to different environmental conditions. In the short run, yields of certain crops may increase or decrease in different areas, according to projected rainfall, temperature, and weather variations.[4] Over the longer term, LAC's agricultural output is expected to fall because of combined changes in rainfall patterns and soil conditions (ECLAC 2010; Tubiello et al. 2008; Mendelsohn and Dinar 2009).

A recent study concludes that the negative impacts of climate change on key crops could be significant for LAC and are expected to play a major role in the global food supply chain (Fernandes et al. 2012). The analysis also suggests significant impacts over much shorter time frames than those previously reported (figure 1.1). Simulated responses to the use of simple adaptation alternatives (improved varieties, change of sowing dates, and modest irrigation) suggest that these strategies are not sufficient to overcome the projected impacts of climate change but could dampen the yield shocks to a degree. The report also estimates that these impacts will reduce the value of annual agricultural exports in the region by $32 billion–$54 billion by 2050. Impacts of this magnitude, particularly in the context of a tight global food supply-demand balance, may also trigger other consequences, including food market speculation and threats to food security.

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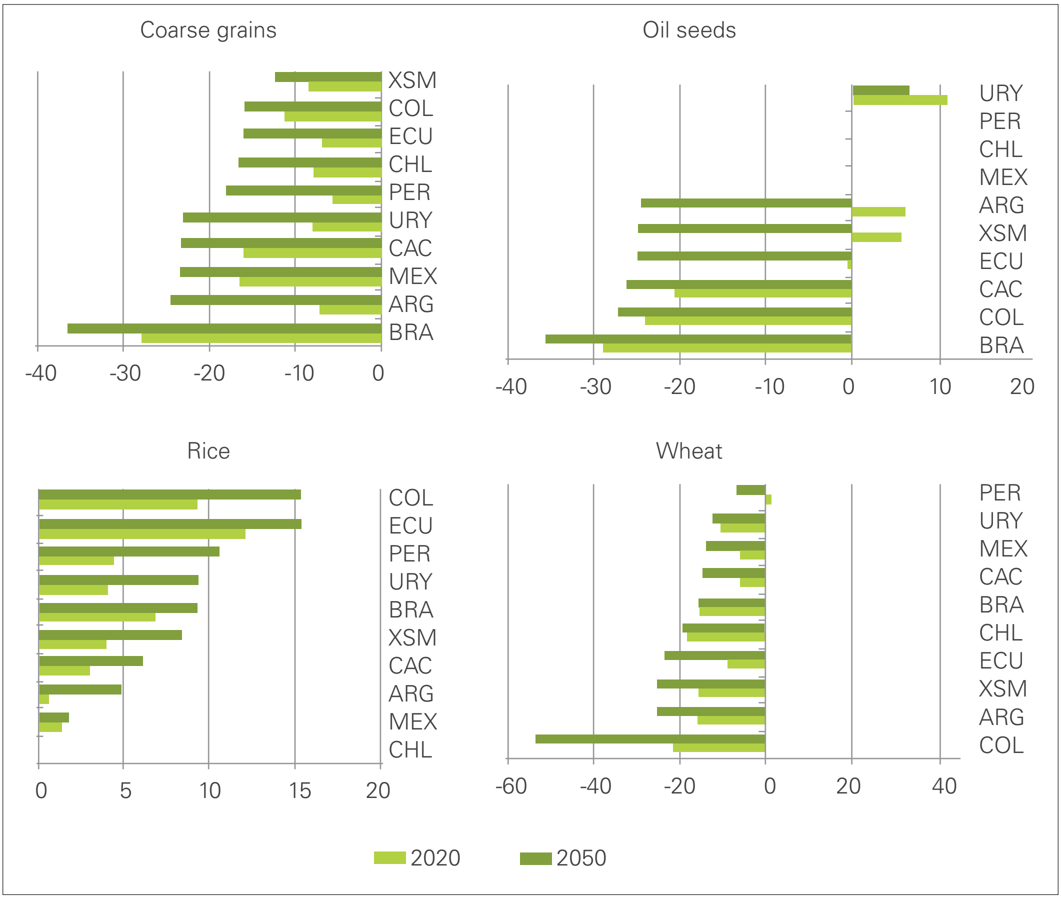
[3] http://websie.eclac.cl/sisgen/ConsultaIntegrada.asp.

[4] For instance, yields might increase because of a CO_2 fertilization effect or more benign weather conditions (Nelson et al. 2010; Magrin et al. 2007; Seo and Mendelsohn 2008a, 2008b, 2008c; Mendelsohn and Dinar 2009).

Figure 1.1 Projected Impact of Climate Change on Key Crop Yield Losses (in %) by 2020 and 2050 under the A1B scenario

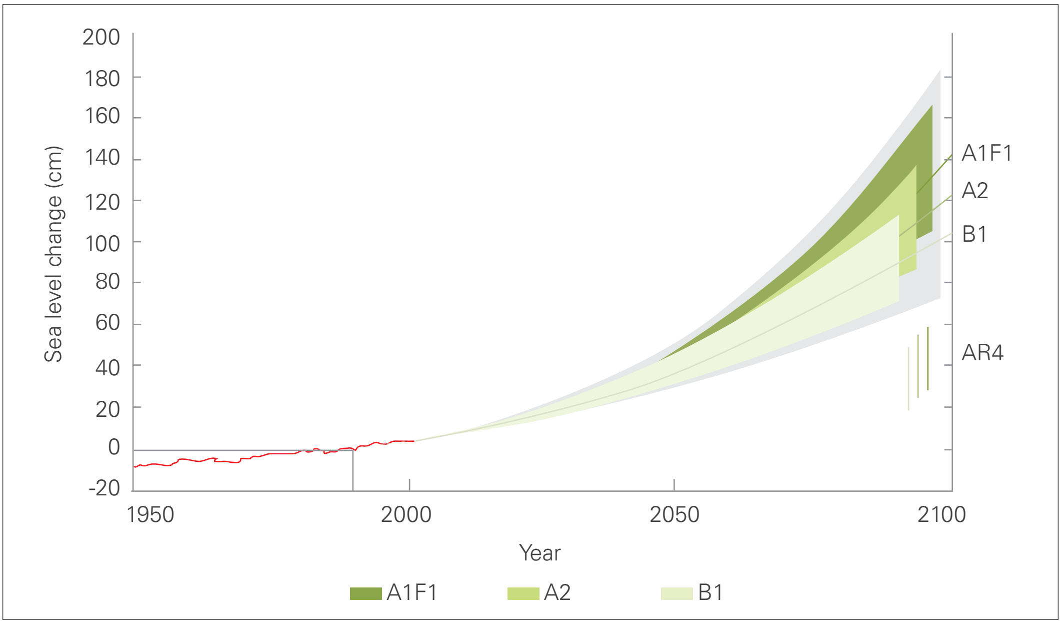


Source: Fernandes et al. (2012).
Note: For information on the A1B scenario of the IPCC, see annex 1 of this report. ARG: Argentina, BRA: Brasil, CAC: Central America & Carribean, CHL: Chile, COL: Colombia, ECU: Ecuador, MEX: Mexico, PER: Peru, URY: Uruguay, XSM: Rest of South America.

Impacts on coastal and marine zones caused by increased sea levels and increased sea surface temperature

Sea warming and the melting or displacement of land-based ice shields will cause sea levels to rise. Globally, the sea level rose by an average annual rate of 1.8 millimeters (mm) between 1961 and 2003, and by an average annual rate of 3.1 mm between 1993 and 2003 (IPCC 2007a; Anderson et al. 2009). This rate is expected to increase as warming continues to affect the oceans and ice fields. Recent studies suggest that a sea-level rise of 1–2 meters (m) is possible during the 21st century (figure 1.2). This suggests the urgent need for more significant contingency planning and adaptation efforts along coastlines.

Figure 1.2 Projection of Sea-Level Rise between 1990 and 2100, based on IPCC Temperature Projections for Three Emissions Scenarios



Source: Vermeer and Rahmstorf (2009).
Note: Estimated sea-level rise between 1990 and 2100 is based on IPCC temperature projections for three different emissions scenarios (labeled on right; see Projections of Future Sea Level for explanation of uncertainty ranges). For comparison, the sea-level range projected in the IPCC AR4 (IPCC 2007a, 2007b) for these scenarios is shown in the bars on the bottom right. Also shown are the observations-based annual global sea level data (Church and White 2006) (red), including artificial reservoir corrections (Chao et al. 2008).

Recent studies have concluded that Latin America is vulnerable to sea-level rise because of its extended coast, its geomorphology, the prevalence of coastal settlements, and the value of its coastal economic activities (Nicholls and Tol 2006; Sugiyama 2007). A study conducted by ECLAC (2011) indicates that Mexico and Brazil have the greatest areas of coastal land within 10 m of sea level (figure 1.3); at least 40 percent of the populations living in the coastal areas of Chile and Uruguay would be affected by a 1 m rise in sea level.

Sea-level rise and an increased frequency and severity of storm events will likely lead to greater coastal flooding and erosion, which may cause substantial property and infrastructure damage, ecosystem losses, and partial land loss (Suarez et al. 2005; Jacob et al. 2007; Williams et al. 2009). The impacts of sea-level rise will very likely harm the transport sector, human settlements (Jacob et al. 2007), ports, and other coastal assets. Considering capital and net wetland losses, the accumulated costs associated with a 1 m rise in sea level are estimated at approximately $255 billion in Latin America, a magnitude of loss second only to that projected for North America (Sugiyama 2007).[5] An analysis by Dasgupta et al. (2007) places the annual cost of a 1 m rise in sea level in the region at approximately $19 billion. Moreover, recent data show that a 1 m rise in sea level would affect approximately 6,700 kilometers (km) of roads in the region (ECLAC 2011).

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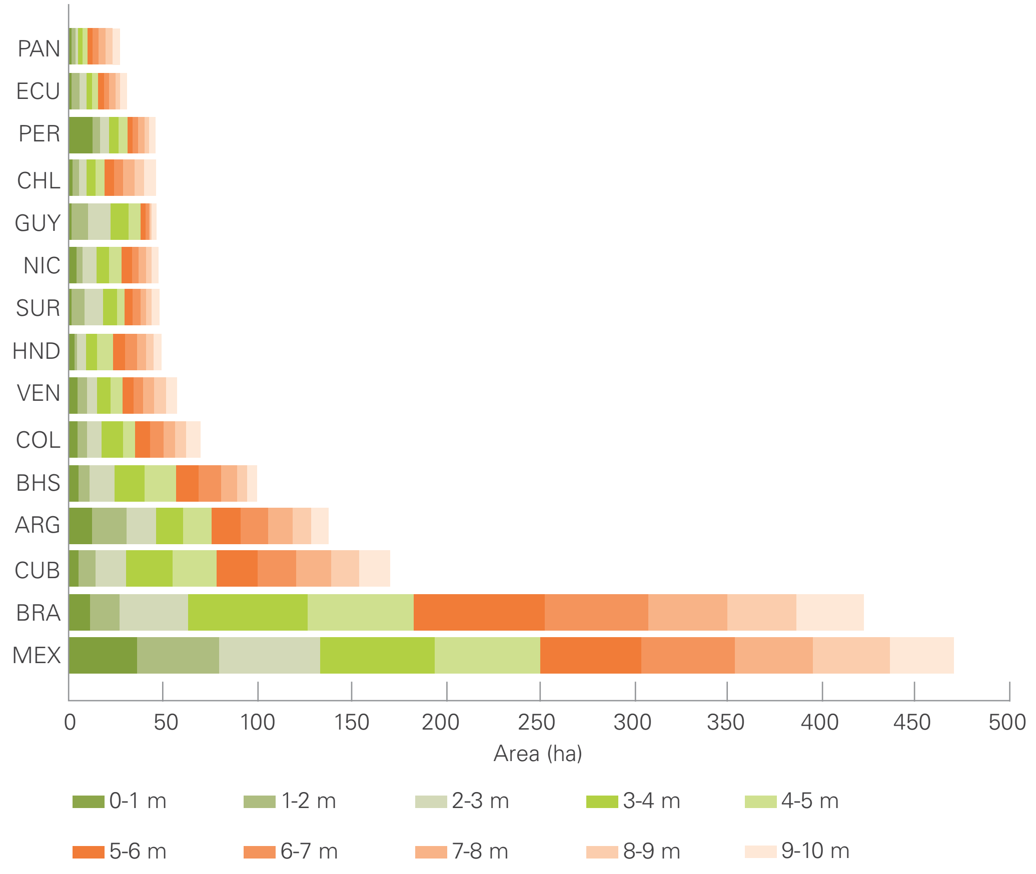
[5] Analysis performed using the Emissions Prediction and Policy Analysis (EPPA) model, a computable general equilibrium combined with a sea-level vulnerability database, the Dynamic Interactive Vulnerability Assessment (DIVA).

Figure 1.3 Distribution of Land Surface between Sea Level and 10 Meters above Sea Level in LAC Countries (in thousands of hectares)



Source: ECLAC (2011).
Note: ARG: Argentina, BHS: Bahamas, BRA: Brazil, CUB: Cuba, CHL: Chile, COL: Colombia, ECU: Ecuador, GUY: Guyana, HND: Honduras, NIC: Nicaragua, PAN: Panama, PER: Peru, SUR: Suriname, VEN: Venezuela.

Salinization of coastal freshwater supplies

Evidence indicates that sea-level rise is increasing hydrostatic pressure on coastal freshwater aquifers, some of which play a critical role in water supply in the Caribbean islands and other low-lying areas. For example, measurements of conductivity in the San Andres Islands (INAP 2012) indicate a long-term trend that, if continued, will eventually render the water supply unsuitable for human consumption. Such trends add to the pressures caused by unsustainable management of aquifers. To our knowledge, an overall estimate of compromised water supplies in coastal areas is not available at this time.

Coral bleaching

Directly linked to increases in sea surface temperature. Because coral reefs support more than 25 percent of all marine species, they are the most biologically diverse marine ecosystem and equivalent in terms of biomass productivity to rainforests within land ecosystems. Most corals are highly sensitive to changes in environmental parameters. When stressed by rising temperatures, corals can lose the symbiotic arrangements needed for photosynthesis. Loss of photosynthetic ability leads to bleaching and may eventually cause death.

In the Caribbean Sea, gradual and consistent increases in sea surface temperatures have increased the frequency of bleaching events, the latest of which affected reefs throughout the region.[6] The viability of reefs can be partially recovered over time if no subsequent bleaching occurs, but more than one severe bleaching event over a short period can be devastating. The Intergovernmental Panel on Climate Change (IPCC) anticipates that during this century temperatures in the Caribbean may reach threshold values that would lead to repeated bleaching and a collapse of the coral biome. This phenomenon could lead to significant economic impacts in addition to losses in biodiversity. The estimated annual cost derived from losing either 50 percent or 90 percent of the coral cover in the Caribbean has been estimated at approximately $7 billion and $12 billion, respectively (Vergara et al. 2009).[7]

Like corals, mangroves appear to be among the ecosystems most vulnerable to the physical consequences of climate change. Mangroves will be affected by sea-level rise that changes the salinity of the coastal areas in which they stand. Mangroves are also likely to be affected by sea-level temperatures, and precipitation changes will affect their productivity. Most of these impacts will be accumulative. But there is a lack of information on their magnitude, making it difficult to estimate the net impacts.

Impacts derived from changes in the frequency and intensity of extreme weather events in coastal zones

Climate change has been linked to the intensification of extreme weather events. Although the global warming signal in the tropical cyclone count is difficult to discern because of the convolution of the decadal climate variations with global warming and the issue of undercounting in the earlier part of the data record, Emanuel (2005) and Webster et al. (2005) have shown that hurricanes are intensifying globally. An assessment of hurricanes in the Caribbean region concluded that the observed surge in land-falling hurricanes indicates a broader increase in average tropical cyclone wind speeds as sea-surface temperature rises, and a shift toward a greater number of Category 4 and 5 hurricanes (Curry et al. 2009).

Curry et al. (2009) find it likely that the recent increase of major hurricane landfalls in the region is largely due to increasing sea surface temperatures, which, in turn, result from the warming caused by higher greenhouse gas (GHG) concentrations. Variability makes precise projections difficult, but it appears that the combination of natural and anthropogenic forcing mechanisms will lead to multiple landfalls by major hurricanes in the region during typical years later in the century. The economic impact of damages from tropical cyclones is considerable and is projected to be $110 billion–$149 billion for the period between 2021 and 2025, including $80 billion–$103 billion for Mexico's Gulf Coast and $30 billion–44 billion for Central America and the Antilles (Curry et al. 2009).[8] An assessment made by Toba (2009) places the annual costs of intensified hurricane activity by 2050 at approximately $5 billion.

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[6] The latest bleaching events were registered in 1993, 1998, 2005 (Vergara et al. 2009, and 2010).

[7] Economic losses by 2050 are in 2008 dollars. They include the lost value of coastal protection, fisheries, tourism, and biochemicals. The assessment was performed using results from a COMBO7 simulation linked to the anticipated sea surface temperature increases under SRES A1B (Buddemeier et al. 2008). The effects of ocean acidification, an important side effect of increased CO_2 concentrations in the atmosphere, may add substantial detrimental consequences to the global marine ecosystem. The magnitude of this effect is still difficult to discern.

[8] This figure was estimated based on tropical cyclone intensification of between 2–5 percent and an overall increase in frequency of between 0–35 percent, normalized for increases in population and GDP. The upper-range values are for the B2 scenario, while the lower range corresponds to scenario A1.

Additional exposure to tropical vector diseases and other health impacts caused by increases in ambient temperatures and other changing climate conditions

Climate change has an overall adverse effect on health. Key consequences include an increase in exposure to tropical vector diseases, greater incidence of respiratory and water-borne illnesses and mortality, and higher exposure to heat waves and other extreme weather events. These health impacts will likely be stronger in countries with low adaptation capacity or among groups with low income per capita (IPCC 2007b). Positive health impacts are only anticipated in temperate or very cold regions.

The main health threats associated with climate change in Latin America are malaria, dengue, cholera, and heat stress (Githeko and Woodward 2003). Sensitivity of malaria in response to increased temperature and precipitation will expose the region to a higher transmission risk (Magrin et al. 2007). The association between spatial and temporal patterns of dengue and climate change is described in numerous studies (for example, Hales et al. 2002; Confalonieri et al. 2007). Projections for the region indicate an increase in the number of people at risk of contracting dengue because of changes in both the geographical transmission limits (Hales et al. 2002) and the distribution of vector-borne diseases (Peterson et al. 2005).

These impacts will require additional resources for the health sector. For instance, the estimated cost for LAC to treat the health burden associated with climate change and higher incidence of diarrheal diseases and malnutrition is around $1.3 billion annually by 2030.[9]

Changes in hydrology

A growing number of studies indicate that climate is affecting the terrestrial components of the water cycle. In this context, the IPCC concludes, "There is high confidence that hydrological systems are being affected: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. Increasing seasonal variability will also affect hydrological systems" (IPCC 2007a).

Intensification of rainfall patterns

Global warming will result not only in changes in average conditions but also increases in the amplitude and frequency of extreme precipitation events that would affect the hydrological regime of basins in the region. High-resolution models covering Latin America indicate both an intensification of rainfall and a lengthening of dry periods. For example, simulations of the Magdalena River in Colombia indicate changes in the amplitude of seasonal variations as a consequence of climate change (Nakaegawa and Vergara 2010). Simulations of the Amazon basin indicate that the hydrology of major rivers will become less stable, with probabilities of higher peaks and lower nodes (Vergara and Scholz 2011). Mexico has reported an intensification of flooding in the Grijalva basin, with costs reaching 30 percent of the region's GDP for 2007, which is equivalent to approximately $250 million (CONAGUA 2009). Unusual flooding events have also been reported in the State of Rio de Janeiro in Brazil and over the entire territory of Colombia.

Less stable hydrological regimes in major basins would result in lower firm capacities in hydropower production and the need for additional storage to maintain reliability in water supplies. De Lucena, Schaeffer and Szklo (2010) have concluded that such unstable conditions would

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[9] This estimate is based on the additional incident cases and average treatment costs reported by Ebi (2008) for a stabilization of 550 ppm of CO_2e by 2170.

reduce the firm guaranteed minimum capacity of hydropower reservoirs by 29–32 percent under the A2 and B2 scenarios (see annex 1 for more information on the IPCC scenarios). Without adaptation, this loss would represent an estimated cost of approximately $18 billion annually.

Glacier retreat, disruption of water services, and other consequences of warming in the Andes

Recent research shows that climate change will be even more pronounced in high-elevation mountain areas and that mountain ranges that extend into the troposphere have been warming faster than adjacent lowlands (Bradley et al. 2006; Ruiz et al. 2012). The visible impacts of the changes caused by these new climate patterns are already evident in the Andes. Warming temperatures have caused rapid retreat of glaciated areas, and variability and extremes in weather conditions have started to affect Andean ecosystems and human activities. For instance, higher temperatures are affecting evaporation rates, water storage in lakes and reservoirs, soil moisture, and the evapotranspiration rates of mountain vegetation. These changes are expected to have significant repercussions for water regulation and the water and power supply.[10]

Black carbon emissions within the region from land clearance, biomass burning, and other sources like transportation may also be contributing to glacier retreat (Simões and Evangelista 2012) through the atmospheric transport of soot and black carbon to the glaciated basins in the Andes. Some have posited that regional black carbon emissions are changing the albedo in the Antarctic Peninsula by means of atmospheric exchanges with South America (Bueno Pereira et al. 2006)

A reduction in the size of glaciers is evident in Venezuela, Peru, Bolivia, Colombia, Ecuador, and Chile. The area of tropical glaciers in the Andes decreased by more than 15 percent in the 1970–2002 period (Kaser 2005; INRENA 2006).[11] Recent analysis indicates a 45 percent loss of glacier surface in the Cordillera Real in Bolivia (Ramírez 2012) over the past 25 years. A substantial reduction in the surface area of smaller glaciers and a significant loss in water reserves during the past 50 years have also been registered in Peru (National Communication -Perú 2001). It is now generally accepted that most glaciers under 5,000 m will disappear by midcentury.

Studies foresee considerable consequences of the ongoing reductions in glacier volume (IPCC 2007b). Reduced melt water is projected to start limiting stream flow between 2015 and 2025, which would affect water availability and hydroelectricity generation in Colombia (IDEAM 2004). In the case of Peru, glacier retreat is likely to affect the availability of water for population centers and the power sector, where there will be an estimated annual incremental cost ranging from $212 million to $1.5 billion for the generation of energy (Vergara et al. 2007). The city of Quito would require an additional investment of $100 million over the next 20 years to guarantee its future water supply (Vergara et al. 2007).

Potential rainforest dieback

The Amazon basin is a key component of the global carbon cycle. The old-growth rainforests in the basin represent a stock of approximately 120 billion tons of CO_2 in their biomass. Annually, these tropical forests process approximately 18 billion tons of CO_2 through respiration and photo-

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[10] Tropical glaciers and Andean lakes also contribute to runoff seasonality by serving as storage or buffers during periods of rain and by releasing the water stored over longer periods of time.

[11] The Chacaltaya glacier in Bolivia has recently disappeared, joining a list of glaciers—including Purace and Cisne in Colombia—that have already melted completely. The San Quintín glacier in Chile has also been rapidly decreasing in size. Additionally, the snowcapped volcano of Santa Isabel in Colombia showed a 44 percent decrease in its ice-covered peak. This decrease has diminished its appeal as a tourist site, with significant economic consequences (UNEP/ECLAC 2010).

synthesis. This amount is more than twice the rate of global anthropogenic fossil fuel emissions. The basin is also the largest global repository of biodiversity and produces approximately 20 percent of the world's flow of fresh water into the oceans. Despite the CO_2 efflux from deforestation, the Amazon basin ecosystem is considered to be a net-carbon sink because growth per year, on average, exceeds mortality (Phillips et al. 2008).

However, current climate trends and human-induced deforestation may be transforming the structure and behavior of the Amazon forest (Phillips et al. 2009). The probability of a substantial reduction in Amazon forest biomass due to climate change toward the end of this century, or Amazon forest dieback, is currently the subject of an emerging body of literature. Different assessments based on various methodologies and field measurements, drought experiments, remote sensing, and modeling studies have been conducted to evaluate the Amazon forest ecosystem's resilience (Malhi et al. 2004, 2006; Phillips et al. 2009; Nepstad et al. 2006; Brando et al. 2008; Saleska et al. 2007; Cox et al. 2004; Sitch et al. 2008).

While individual results vary, climate change will likely have an adverse effect on the rainforest biome in the Amazon basin during this century. Any drastic changes in the ground cover of the basin will change its carbon storage, modify regional water cycles, and affect regional and local climate. As a result, further devastation of the Amazon has been identified as a potential "tipping element" of earth's entire system (Lenton et al. 2008).

Nevertheless, the direction and intensity of the future change are still uncertain. They will depend on future rainfall and physiological processes, such as how rising atmospheric CO_2 concentrations affect vegetation growth and plant efficiency in water use, commonly called CO_2 fertilization (Hickler et al. 2008). There are no records of tropical rainforests growing under a 2–3°C anomaly. Subjecting forests to this temperature increase represents an unprecedented experiment with potential long-term consequences.

A recent study (Vergara and Scholz 2011) modeled the risk of Amazon dieback. In a scenario without CO_2 fertilization, the results indicate high probabilities of biomass loss. In addition, the probabilities of dieback events in eastern and southern Amazonia were estimated at 15 and 61 percent, respectively. Significant Amazon dieback would have regional and global impacts on carbon and water cycles and may even affect the amount of rainfall available for agriculture in southern Brazil and Argentina. If strong positive effects of CO_2 fertilization are assumed, however, biomass is more likely to increase across all five regions. Without those CO_2 effects, biomass reductions in all modeled regions and dieback in some regions become likely.

Although further research is certainly needed, in the absence of better information, the precautionary principle strongly suggests that the assumption that CO_2 fertilization will significantly enhance the Amazon's resilience cannot be used as a basis for sound policy advice. Using the information from this study, a partial analysis of the likely economic impacts of Amazon rainforest dieback on ecological resources, tourism, and other services projects a loss of \$4 billion–\$9 billion annually.[12]

Adverse effects on biodiversity and ecosystem stability

In addition to impacts affecting human activities, climate change will also alter natural ecosystems and individual species. Climate change is accelerating the natural process of biodiversity modifications and thereby affecting vegetation, the composition of ecosystems, and the distribution and migration of various animal species (IPCC 2001 and 2007b).

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[12] This figure is estimated by the authors based on TEED's (2010) valuation of environmental services and Vergara and Scholz (2011). Note that many of the services provided by the biome are transnational and global services, their valuations are not considered.

Additionally, climate change is affecting food availability, predator-prey relationships, and competitive interactions, which can alter community structures and generate irreversible damages, such as species extinction (Blaustein et al. 2010). This point is particularly important for Latin America because of its large share of the world's biodiversity and because biodiversity in the region is already being affected by other processes, such as deforestation, forest degradation, and hunting (i.e., overexploitation) (Asner et al. 2005).

Different methods can be used to evaluate climate change impacts on biodiversity. One option is the Holdridge Life Zone (HLZ) (Leemans 1990).[13] A HLZ is a global bioclimatic scheme for the classification of land areas that links weather conditions to the characteristics of ecosystems (Holdridge 1947) in a way that provides a quantitative basis for estimating the changes in ecosystems.[14] Assuming that CO_2 concentrations double, the distribution of the HLZ in LAC at present and under a climate change scenario is presented in figure 1.4. The region possesses 37 of the 38 HLZs in the world, with 67 percent of the overall land area in the region covered by tropical moist forest, subtropical dry forest, tropical dry forest, and subtropical moist forest.[15]

Climate change scenarios indicate that moist HLZ will diminish and drier HLZ will expand. For example, an increase of approximately 156 percent in "tropical very dry forest" and a decrease in rain and moist forest (-67 percent of boreal rain forest and -60 percent of warm temperate moist forest) are expected. In the event of a CO_2 doubling, the results for the region's four principal HLZs indicate that subtropical moist forest and subtropical dry forest will decrease by 22 and 31 percent, respectively, while tropical moist forest and tropical dry forest will increase by 63 percent and 50 percent, respectively.

Although assigning monetary values to ecosystems functions entails significant methodological difficulties (Arrow et al. 1993; Heal 2000; Splash and Vatn 2006),[16] it is possible to use a meta-analysis that includes all possible environmental valuations for all ecosystem functions to identify use and non-use value before transferring these values to the areas within the same HLZ classifications. Using this approach, the total value of all HLZs in South America is approximately $344 billion annually, with the highest share represented by subtropical moist forests, where the consequences of climate change represent a net annual economic loss of $36.5 billion (table 1.1).[17]

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[13] A life zone is a group of vegetal associations inside a natural climate division that are determined by taking into account soil conditions and stages of succession. Particular life zones are assumed to have a similar appearance everywhere in the world.

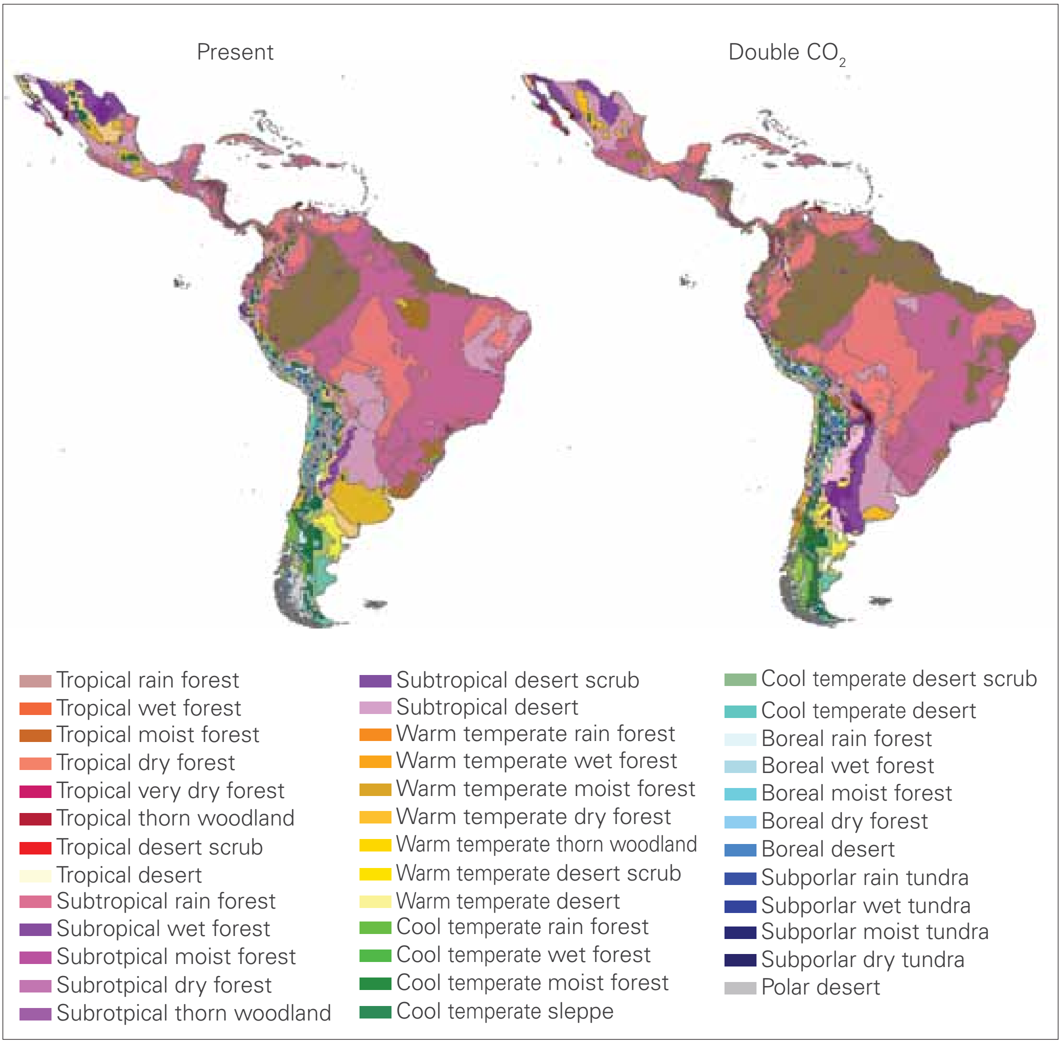
[14] This approach has the following strengths: it is based on climatic driving factors of ecosystem processes and recognizes the ecophysiological responses of plants; it is hierarchical and allows for the use of other mapping criteria at the association and successive levels of analysis; it can be expanded or contracted without losing functional continuity among different levels of ecological complexity; and it is a relatively simple system based on limited empirical data (Lugo et al. 1999).

[15] This report considers the whole LAC region in terms of vegetation types without subtracting urban, productive, and degraded areas. Therefore, it represents only the possible distributions of potential vegetation types under a specified climate scenario.

[16] The economic valuation of the ecosystem services in Latin America presents mixed results, which are attributable to the methodology used, the characteristics of the study area (conservation type), and the perception and social importance of each site. The values are in the range of $0.03–$2.89 per hectare per year, with an average of $199.00. According to the categorization of ecosystem services, the valuation is rather variable.

[17] Results of the meta-analysis are available upon request.

Figure 1.4 Holdridge Life Zone Map of Latin America: The Present Climate and a Future in which CO_2 has Doubled



Source: Authors' compilation based on data from Leemans (1989).

Climate change has other irreversible effects on biodiversity, and it may produce significant feedback effects that cannot yet be properly valued. For example, there is increasing concern that the Amazon region, a key component of the global carbon cycle, will become destabilized and that its modification or destruction will cause major changes in global climate conditions (Vergara and Scholz 2011). The impacts of such irreversible harm to biodiversity are more than merely an economic matter; they have significant ethical implications and important feedback effects that are not yet fully understood. Many of these impacts represent committed changes that will not be easily reversed and will continue over time, even if reductions in the rate of emissions are secured. Conversely, continuing the trend of increasing GHG concentration in the atmosphere will exacerbate the net impacts and will likely trigger additional changes in the biosphere.

Table 1.1 Climate Change and Economic Impacts on Biodiversity in Latin America

Holdridge Life Zones (HLZ)		Average value ($/ha^{-1})	HLZ value at present (millions of $)	HLZ value at present with doubled CO$_2$ (millions of $)	Economic loss (millions of $)	Economic loss (%)
Number	Name					
1	Polar desert	94.22	3,268.36	1,506.35	1,762.01	53.91
10	Boreal rain forest	106.25	2,562.24	846.94	1,715.30	66.95
11	Cool temperate desert	56.09	1,573.13	872.39	700.74	44.54
12	Cool temperate desert scrub	117.00	3,074.66	2,071.68	1,002.98	32.62
13	Cool temperate steppe	90.73	3,330.86	3,123.75	207.11	6.22
14	Cool temperate moist forest	86.32	2,641.81	3,000.73	-358.92	-13.59
15	Cool temperate wet forest	62.77	948.63	1,543.94	-595.31	-62.75
19	Warm temperate thorn steppe	108.86	5,869.35	1,969.78	3,899.57	66.44
20	Warm temperate dry forest	171.46	17,692.77	6,302.91	11,389.85	64.38
21	Warm temperate moist forest	130.58	7,716.84	3,061.08	4,655.76	60.33
26	Subtropical thorn woodland	128.56	6,844.17	10,144.97	-3,300.81	-48.23
27	Subtropical dry forest	196.84	51,972.92	35,614.67	16,358.24	31.47
28	Subtropical moist forest	263.70	169,873.44	132,482.67	37,390.76	22.01
29	Subtropical wet forest	77.06	2,563.23	2,000.64	562.59	21.95
34	Tropical very dry forest	77.16	2,125.15	5,454.21	-3,329.06	-156.65
35	Tropical dry forest	101.32	27,803.89	41,680.92	-13,877.02	-49.91
36	Tropical moist forest	140.72	34,353.18	56,069.00	-21,715.82	-63.21
Total HLZ in Latin America			344,214.63	307,746.65	36,467.98	10.59

Source: Authors' elaboration based on data from Leemans (1989).

In addition, other discernible impacts are emerging, such as the impacts of climate on ecosystem functioning and migratory species. The changes induced by seasonal variations in climate and the responses of different species may be affecting the integrity of ecosystems in ways yet to be fully understood. Mounting evidence also indicates that migratory species may be casualties of climate change (Robinson et al. 2005). For instance, the migration pattern of raptors in the Central American corridor may be altered by climate changes in the Gulf Coast of Mexico and in the Kikolde area of Costa Rica. The concern in this regard is that changes in air temperature and the onset of seasonal variations will affect both the capacity of species to migrate and the composition of the habitats on which they depend in their well-timed routes.

Estimate of the damage from physical impacts

The information reviewed above is presented in table 1.2, along with the caveats and limitations of the estimate. The aggregated value of the projected annual economic damages in LAC resulting from some of the major physical impacts associated with this unavoidable 2°C increase over pre-industrial levels is expected to grow gradually, reaching approximately \$85 billion–\$110 billion annually by 2050 (in current values), compared to a GDP of approximately \$4.6 trillion in 2010.[18]

The unmitigated annual losses from climate change will increasingly become an impediment to sustained growth, acting as a drag on the deployment of human, natural, and physical capital. In the long term, the cumulative losses would be manifest in effective annual income losses.

Several aspects need to be considered when assessing the severity of the economic impact. First, the available estimates are not comprehensive and include only partial estimates in many cases, such as the effects of hydropower loss, which are only considered for Brazil, and the consequences of glacier retreat, which are only considered for Peru. Thus, the estimates in table 1.2 are a conservative calculation of annual damages. The actual loss will probably far exceed the annual figure of \$85 billion–\$110 billion by 2050.

Second, the estimates do not include the damage to biodiversity, the change in the stock of natural resources or other nonmonetary values (for example, the intrinsic worth of species extinction), biome collapse, or irretrievable damages in natural capital). Certain ecosystem services are intrinsically difficult to value, and other cultural and social damages have not been considered.

Third, it is difficult to quantify the long-term effects in economic terms (that is, GDP losses). In the short term, increasing investment in infrastructure and production facilities to replace losses may even boost GDP, with dynamic multiplier and accelerator effects, as the additional investment may have growth impacts, particularly if there is underutilization of production capacity. In the longer term, however, the diminished growth of capacities for production of goods and services (and even reduced capacities for ecosystem services) would limit the ability to produce and generate income.

For example, with respect to fixed capital, one would expect:

- Lower returns from production and service facilities due to extreme events and changed weather patterns (including hydropower plants, coastal industrial and production assets and agriculture production), to result in less financing for rehabilitation and expansion investment
- Damage from extreme events that would require investment for repair instead of investing accumulated funds to expand productive capacities
- Loss in functionality of infrastructure, including water supply systems depending on glacier runoff, urban or tourism infrastructure threatened by sea-level rise, and other impacts that would require investment in new systems

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[18] All GDP values, including future projections, are measured in 2005 dollars.

With respect to natural capital, the expectation is that:

- In order to maintain production and services, producers profiting from the lost ecosystem functions would need to invest in alternative provision of such services
- Other ecosystem functions, particularly those from biodiversity losses, may not immediately require replacement investment, but obviously will result in the biological impoverishment of affected areas
- More severely, if large-scale changes occur (for example, the potential Amazon dieback), this would likely influence the region's development potential and may even set into motion global long-term economic adjustments

With respect to human capital:

- Increased health problems would immediately reduce productive capacity and would imply additional costs for the health-care system

Fourth, the effects of climate change accumulate over time. Damage is already occurring and will intensify as extreme events become more frequent or intense, and more gradual changes like temperature increases take effect. The responses to these impacts will continuously strain scarce investment resources.

This is a simplified analysis in macroeconomic terms. It is related to a scenario in which adaptation does not take place, which obviously will not be the case. People, households, economic entities, and other businesses will adjust in view of climatic changes and continuous losses. But unplanned adaptation and learning from losses is still costly and could be preempted by adaptation programs and measures that increase resilience.

Nevertheless, under any plausible scenario, the region's natural assets will be affected. Even if forceful action on mitigation is immediately taken and adaptation efforts implemented, glaciers under 5,000 m in the tropical Andes will disappear, the coral biome will be seriously affected, cold-weather mountain ecosystems will shrink, coastal wetlands and coastal freshwater lagoons will be flooded, and the Amazon rainforest is likely to experience some degree of savannization. While these effects are already discernible, the greatest implications will be experienced by future generations, whose worth should not be discounted.

Without prompt and drastic mitigation actions, losses will increase, tipping points will likely be reached, and the rate of extinctions and pace of change in compromised ecosystems will accelerate. As a consequence, economic damages will increase far beyond what can now be estimated. Moreover, further irreversible impoverishment of the biosphere will be triggered. The value of these losses cannot be measured in economic terms.

The need for a better understanding of climate consequences in the region is leading to the identification of priority bio-climate hotspots. These ecosystems are experiencing rapid change and showing irreversible damage, which, in turn, could translate into substantial losses of natural and economic capital. The proposed hotspots for the region are shown in table 1.3.

Table 1.2 Estimates of Annual Damages from Some Key Physical Impacts by 2050

Impact	Area	Projected annual costs[*] (2005 $ billion)	Projected cumulative costs	Source
Loss in net export agricultural revenues: wheat, soybean, maize, and rice	LAC	26–44		Fernandes et al. 2012[a]
Sea-level rise (1m)	LAC	22		Dasgupta et al. 2007[b]
Coral bleaching	Caribbean	8–11		Vergara et al. 2009[c]
Intensification and frequency increase of extreme weather events	CARICOM	5		Toba 2009[d]
	Mexico's Gulf coast, Central America, and the Caribbean		110–149 for 2021–2025	Curry et al. 2009[e]
Health (increase in incident cases of diarrhea and malnutrition)	LAC	1		Ebi 2008[f]
Amazon dieback	Latin America	4–8		Authors' estimation[g]
Glacier retreat	Peru	1		Vergara et al. 2007[h]
Loss of ecosystem services	Latin America		36	Authors' estimation[i]
Hydropower generation	Brazil	18		Authors' estimation[j]
Estimated total (% LAC GDP)[**]		*85–110* *(1.8–2.4)*		

[*] The total reported must be considered a range and a conservative estimate with the following caveats: (a) estimations are gathered from different studies with varying methodologies, assumptions, and uncertainties; (b) many costs are only partially presented, and others are difficult to estimate; and (c) nonmonetary costs are not considered. The CPI is used to convert costs to 2005 U.S. dollars (Bureau of Labor Statistics). When information was not available, costs were assumed to be reported in U.S. dollars of the year of publication.

[**] 2010 GDP measured in 2005 dollars.

[a] Projected loss in net export revenues in 2050.

[b] Impact on GDP observed when a 1 m rise in sea level is reached.

[c] Estimation derived from losing 90 percent of coral cover, SRES A1B scenario. Includes the lost value of coastal protection, fisheries, tourism, and bio-chemicals.

[d] Includes impacts of "climate disasters" (floods, droughts, and windstorms) on agricultural production, human health, tourism, government, and GDP loss.

[e] 2007 U.S. dollars. Projected costs correspond to tropical cyclones during the 2020–2025 period, scenario A1 (lower range) and scenario B2 (upper range).

[f] Projected costs in 2030 under a scenario assuming stabilization of emissions at 550 ppm of CO_2e by 2170. Assumes that annual cases and treatment costs remain constant.

[g] Projected cost in 2100 includes ecosystem services in terms of carbon storage and sequestration, agricultural productivity, hydropower generation, sustainable timber harvest, reduced siltation in hydropower reservoirs, commercially viable fish populations, subsistence life styles, and improvements in quality of life. Information on costs obtained from TEED (2010). Vergara and Scholz (2011) project that climate change will reduce one-third of the rainforest biome by 2100. This value is used in the estimations.

[h] Incremental cost for the power sector based on rationing cost.

[i] Economic impact assuming a doubling of CO_2. Costs estimated in 2000 dollars.

[j] Value estimated based on the reduction in firm power hydroelectric generation in 2035 under scenario B2 reported by de Lucena, Schaeffer, and Szklo (2010), hydropower generation from Brazilian National System Operator (ONS), and the cost of rationing from Maurer et al. (2005).

Table 1.3 Some Bioclimate Hotspots in Latin America and the Caribbean

Climate hotspot	Direct effect	Immediacy	Irreversibility	Impacts on natural capital	Economic consequences
Coral biome in the Caribbean	Bleaching and mass mortality of corals	Now	Once temperatures pass the threshold for thermal tolerance, corals in the Caribbean may collapse	Total collapse of ecosystem and wide-ranging extinction of associated species	Impacts on fisheries and tourism, as well as increased vulnerability of coastal areas
Mountain ecosystems in the Andes	Warming	Now	The thermal momentum in mountain habitats will result in significant increases in temperature, leading to major uni-directional changes in mountain ecology	Disappearance of glaciers, drying up of mountain wetlands, and extinction of cold climate endemic species	Impacts on water and power supply, displacement of current agriculture, and changes in planting patterns (with varying impacts depending on location, seasonality, and ability to adapt)
Coastal wetlands	Subsidence and salinization of aquifers; increased exposure to extreme weather; decline of coastal mangroves	This century	Irreversible sea-level rises will submerge coastal wetlands and thereby affect their ecology	Disappearance of coastal wetlands, as well as displacement and extinction of local and migratory species	Impacts on coastal infrastructure, fisheries, and agriculture
Amazon basin	Forest dieback	This century	If rainfall decreases in the basin, biomass densities would also decrease	Drastic change in the ecosystem that may lead to savannization and disruption of many species endemic to the Amazon rainforest	Impacts on global biodiversity, global water circulation patterns, and regional agriculture, water, and power supply

Source: Authors' elaboration, adapted from Vergara (2009).

Adaptation response

Adaptation is broadly defined as an adjustment in human activities or ecosystems to new climate conditions.[19] Adaptation includes changes in behaviors, processes, practices, and structures as either anticipatory or reactive measures to offset potential damages or exploit climate changes (IPCC 2001 and 2007b; World Bank 2010). Given the unavoidable physical impacts of climate change and the potential magnitude of the associated costs, the region must mount a major effort to adapt.

Adaptation response to physical impacts

The praxis of adaptation is evolving. A comprehensive list of possible response measures to impacts in the region cannot yet be compiled. However, the existing data generally indicate that a broad portfolio of measures already exists (table 1.4). Adaptation measures are being tested widely, funded in part by several financing mechanisms linked to the UNFCCC, the Clean Development Mechanism (CDM), and, more recently, the Adaptation Fund (AF). In addition, many adaptation responses are likely being internalized locally without being properly counted as such.

As of today, most investments in adaptation focus on agricultural activities, water resources, coastal areas, biodiversity, and health. Some of these measures, such as better agricultural management practices or seasonal adjustments in crop mix, have very low costs (Agrawala and Fankhauser 2008). In other sectors, significant investments in, for example, the protection of coastal areas and assets are needed.

Recent investments in adaptation in the region

Most investments in adaptation in the region have taken place in the context of externally funded programs sponsored by the Global Environment Facility (GEF) and other bilateral programs. The Caribbean region has been the focal point of several adaptation projects funded as part of the GEF's Enabling Facility Program and Strategic Priority on Adaptation (SPA). Three adaptation projects, with a total estimated budget of $40 million, have been implemented since 1998. Additionally, in the tropical Andes, the GEF has funded adaptation responses to glacier retreat. With an estimated budget of $35 million, the project has funded specific responses and monitoring systems in glaciated basins in Bolivia, Ecuador, Peru, and Colombia. In Mexico a project approved in 2009 focuses on developing adaptation measures in coastal wetlands in the Gulf of Mexico.

The project emphasizes the concept of ecosystem-based adaptation (EBA) and utilizes the restoration and strengthening of coastal wetlands, mangroves, and dunes as a key adaptation strategy to protect coastal settlements and infrastructure.

Ecosystem-based adaptation

Ecosystem-based approaches to adaptation constitute a promising option for sustainable and efficient adaptation to climate change. EBA is "the use of biodiversity and ecosystem services to help people adapt to the adverse effects of climate change" (Andrade et al. 2011). The use of EBA in the region has already been pioneered under the Integrated National Adaptation Program (INAP) in Colombia, which relies on ecosystem-based measures to maintain water regulation flows in

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[19] Unless specified in the main text, adaptation costs and actions are generally referred to under conditions anticipated under scenario A1B and a 2°C anomaly.

paramo ecosystems in the Chingaza area. Other efforts have been attempted in Belize through the Caribbean Community Climate Change Centre (CCCCC) to restore the functions of coral ecosystems affected by bleaching events. EBA can be an effective first tool to address climate impacts affecting ecosystems and the services these provide.

Table 1.4 Examples of Potential Responses to the Regional Consequences of Climate Change

Agriculture	Sea-level rise and extreme events in coastal zones
• Mixed crop-livestock systems • More efficient use of irrigation water (amount and timing) • Climate monitoring and forecasting to reduce production risks • Development and use of heat-, drought-, and excess water-resistant crops • Development and use of varieties and species resistant to pests and diseases • Animal breeding programs • Integrated pest and pathogen management • Adjustment of planting dates and farming practices • Improved land management • Liberalization of agricultural trade to buffer regionalized losses • Insurance • Irrigation	• Integrated coastal planning and management • Coastal watershed management • Building standards/codes • Living shorelines • Coastal development setbacks • Coastal wetland protection • Coastal defenses/seawalls/storm surge barriers • Beach and dune nourishment • Desalinization of coastal aquifers • Flood warning systems • Improved urban drainage • Land use zoning • Community-based disaster risk reduction
Changes in hydrology	Glacier retreat
• Restoration of land cover • Water conservation and demand management • Land use zoning • Watershed management • Rainwater harvesting • Water storage and conservation techniques • Loss reduction (leakage control, conservation plumbing) • Recycling of water • Irrigation efficiency • Water management infrastructure	• Design of high-altitude reservoirs • Adoption of drought-tolerant varieties in high-altitude agricultural areas • Demand management measures • Extension and design of water collection networks
Exposure to tropical vector diseases	Biodiversity and ecosystems
• Prophylactic and sanitation measures • Early response, disease surveillance, and awareness systems • Prevention of water-borne diseases • Provision of safe water • Vector control programs • Improvements in public health • Disease eradication programs • Heat-health action plans • Improved sanitation	• Modification of park boundaries • Adoption of setbacks and buffer zones • Reduction in the use of ecosystem services • Good practices in the fisheries sector • Protection of large areas, increased reserve size • Improvements in connectivity • Increase and maintenance of the number of reserves • Increase and maintenance of monitoring systems • Land planning • Management practices

Source: Authors' elaboration.

The AF has also recently approved projects on water and coastal management issues and farming in Jamaica, Honduras, and Uruguay, respectively, for $10 million; on food security (in terms of climate change resilience) in Ecuador for $7.4 million; on the reduction of vulnerability to floods and droughts in Nicaragua for $5.5 million; on climate resilience and land management in Argentina for $4.3 million; on climate-resilient infrastructure in El Salvador for $5.4 million; and on climate-resilient productive landscapes in Guatemala for $5.5 million. Other activities include a project in Peru to address the impacts of climate change on fisheries.

In addition, Canadian, Australian, and Italian aid agencies have also helped to implement adaptation projects in LAC. These activities have mostly focused on building capacity on adaptation, mainstreaming adaptation concerns in sector policies, and deploying specific adaptation measures in coastal zones and water supply. The experience with these early projects is being used to design new approaches to adaptation, which are being funded by the Pilot Program on Climate Resilience (PPCR) window of the Climate Investment Funds (CIF). Under the PPCR, a regional adaptation project and national projects in Jamaica and Haiti are being formulated. Table 1.5 presents examples of recent adaptation investments in LAC.

Based on the recommendations contained in its Second National Communication, the Government of Colombia launched the ambitious National Program on Adaptation (INAP) in 2005. This project supported responses to the impacts of warming on mountain habitats, insular and coastal zones, and the health sector. The project, which has resulted in the development of pioneering adaptation approaches in these regions and sectors, was also used to draft policy approaches and strengthen key institutional capacity. The project had an estimated budget of approximately $30 million.

Table 1.5 Examples of Recent Adaptation Investments

Climate change impact	Type of adaptation measure in practice	Affected sectors/ natural assets	Countries
Accelerated tropical glacier retreat	Civil works to replace glaciers' capacity to store and regulate water; conservation of high mountain ecosystems as an element to retain water	Agriculture	Colombia, Ecuador, Peru, Bolivia
Temporal and spatial changes in precipitation occurrence affecting the availability of water	Rainwater-retaining ponds, use of ancient knowledge to maximize soil water infiltration and minimize runoff (atajados), use of efficient irrigation systems	Agriculture, livestock, ecosystems	Central and South America
Sea-level rise and salinization of aquifers	Integrated coastal zone management plans, inundation areas, restoration of coastal ecosystems	Agriculture, ecosystems	Caribbean countries and countries with coastal areas
Increased variability and uncertainty of fishery yields	Economic diversification, implementation of the ecosystem approach to fisheries (EAF)	Fisheries, coastal marine ecosystems	Peru, Chile, Caribbean
Changes in distribution of fisheries	Bio-oceanographic monitoring and ecological modeling to predict changes in resource availability Ecological risk assessments of key species for integrated adaptive management	Fisheries	Peru, Chile
Increase in climatic extremes (precipitation, floods, storm surges)	Improved climatic and oceanographic surveillance and deployment of early warning systems Use of scenarios of climate change impacts for ecosystem-based adaptation, coastal-marine zonification, and infrastructure planning	Agriculture, low-level coastal settlements	Mexico, the Caribbean
Changes in the spatial distribution of vector diseases, such as malaria and dengue	Early warning and dynamic monitoring systems	Human health	Colombia

Source: Authors' elaboration

Overall adaptation costs

There are different estimations of the overall cost of adapting to a 2°C anomaly for LAC (table 1.6). For example, the World Bank (2010) estimates annual adaptation costs for the region to be $16.8 billion–$21.5 billion by 2050, while Agrawala et al. (2010) estimate adaptation costs to be approximately $28 million by 2105. These estimates have significant limitations and uncertainties and are difficult to compare because they use different methodologies, sectors, time spans, geographical regions, scales, and adaptation definitions and assumptions (Agrawala and Fankhauser 2008; Stern 2007). Furthermore, these estimates only consider a fraction of the total expenses.

Nonetheless, a common finding in these studies is that adaptation costs are an order of magnitude lower than the estimated damages. Adaptation investments would thus mitigate the costs associated with the physical impacts of climate change and highlight the importance of deploying efforts to adapt. The cost of adaptation is a small fraction of the cost of physical impacts. Some impacts are difficult to estimate and were not included. Thus, the estimates of the costs provided in this report should be seen as conservative.

Table 1.6 Adaptation Cost Estimates for Latin America and the Caribbean ($ billions)

UNFCCC 2007		World Bank 2010			Agrawala et al. 2010 AD-WITCH	
Scenario	B1-A1B	Scenario	NCAR	CSIRO	Scenario	Doubling CO_2
Year	2030	Year	2050	2050	Year	2105
		Agriculture	1.20	1.30	Water in agriculture (irrigation)	4.30
		Fisheries	0.18–0.35	0.18–0.35	—	—
Water supply	23.00	Water supply	5.50	3.20	Water infrastructure costs in other vulnerable countries	1.80
Coastal zones	0.57–0.68	Coastal zones	11.70[1]	11.70[1]	Coastal protection costs	7.75
		Extreme weather events	1.30	0.70	Early warning systems	5.00
					Investment in climate-proof settlements	5.90
Infrastructure	0.40–1.72	Infrastructure	3.50	1.70	Cooling expenditure	2.00
		Human health	0.00	0.00	Disease treatment costs	5.72
					Adaptation R&D	0.07
		Total	21.50	16.80	Total	27.70

Source: Authors' estimate based on UNFCCC (2007), World Bank (2010), and Agrawala et al. (2010).
Note: NCAR: National Centre for Atmospheric Research, wettest scenario. CSIRO: Commonwealth Scientific and Industrial Research Organization, driest scenario. [1] Medium rise in sea-level scenario (28.5 cm above 1990 levels in 2050). UNFCCC (2007) estimates are for Latin America only.

A four-degree anomaly

The costs of the physical consequences and the estimates of adaptation costs refer generally to a trajectory consistent with a 2°C temperature anomaly. But it is likely that actions will not be taken in time to maintain this trajectory. In that case, the physical consequences will likely escalate and the adaptation costs will become more expensive.

A 4°C rise would place a very significant stress on the natural world. The pace of change, anticipated over a century or so, would be unprecedented. Yet, in the face of failure to embark on a drastic path of emission reductions, it is a prospect that cannot be discounted. As it stands today, the actual path of emissions is closer to scenario A1FI—a fossil-fuel-intensive, resource-intensive growth that would, if continued, surpass a temperature anomaly during this century, consistent with an atmospheric concentration of CO_2 above 800 ppm.

Under such a future, the impacts discussed in this chapter would, in most cases, intensify. For example, the onset and extent of coral mortality would likely be more drastic. The pace of sea-level rise and Andean glacier retreat would accelerate. There would be an increased likelihood of greater rainforest dieback. The changes induced in a 4°C degree future would likely be long lasting, even if emissions patterns could be quickly reversed. That said, identification of physical impacts and quantification of economic losses and damage under a 4°C scenario is beyond the scope of this report.

Chapter 2

The Region's Carbon Footprint and Pathways to Change by 2050

Preventing additional irreversible damage to the biosphere would require global emissions to not exceed a yearly 20 gigatons of carbon dioxide equivalent ($GtCO_2e$) (or 2 tons per capita, tpc) by 2050—and to reduce this to 10 $GtCO_2e$ (or 1tpc) by the end of the century. The achievement of such a goal would demand a significant deviation from the current path of global emissions. This chapter examines the current carbon footprint of Latin America and the Caribbean (LAC) and presents some of the available pathways by which the region can contribute to this global climate stabilization goal by 2050.

Current emissions profile

LAC's total greenhouse gas (GHG) emissions for 2010 are estimated at 4.7 $GtCO_2e$ (10.8 percent of total global emissions). That figure represents a decline of about 11 percent since the start of the century, mainly caused by reductions in land-use change-related emissions and in energy intensity.[20] This drop occurred during a period of robust (3 percent annual) net increases in regional

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[20] For the purposes of this report, the Climate Analysis Indicators Tool (CAIT) Version 9.0 (CAIT 2012) was used as a primary source of emissions for the region. This source is one of the best available databases and includes information both on carbon sinks and emissions of GHGs. Although all historical emissions data come from the CAIT database, all future projections into 2020 and 2050 (both for the "business-as-usual" trajectory and the various "intervention" pathways) come from Version 2.0.rc1 of the GEA Scenario Database of the International Institute for Applied Systems Analysis (IIASA). Furthermore, all references to "current" emissions (that is, figures corresponding to the year 2010, for which CAIT still does not have comprehensive GHG data) are also taken from the GEA Scenario Database to ensure consistency with this report's projection trajectories. The CAIT historical data include all GHGs, including CO_2, CH_4, N_2O, PFCs, HFCs, and SF6. In contrast, all current and projected emissions data, which are taken from IIASA's GEA Scenario database, include only the three most significant GHGs: CO_2, CH_4, and N_2O. Finally, all CAIT data used in this report were downloaded before the latest updating of the CAIT (May 12, 2012). Given the demands of the editorial and publication process, this report was unable to incorporate any changes reflecting this latest updating of the CAIT database.

gross domestic product (GDP), which indicates that economic growth has decoupled to some degree from carbon emissions. From a historical perspective, the region has contributed less than 3.7 percent of the cumulative global CO_2 emissions due to energy use since 1850.[21]

Agriculture and land-use emissions

In contrast to the global picture, the bulk of the emissions in LAC are generated not from energy use but from land use, land-use change, and forestry (LULUCF), as well as agriculture. Indeed, LAC's emissions profile was the mirror opposite of the world's profile in 2005: nearly two-thirds of LAC emissions stemmed from agriculture and land use, whereas only a little over one-quarter came from energy (figure 2.1). This global outlier status with respect to agriculture, forestry, and land-use (AFOLU) emissions is referred to as the LAC emissions anomaly.

Power generation and transport

Traditionally, energy emissions have been of secondary importance for the region as a whole. While LAC's energy emissions rose sharply (50 percent) between 1990 and 2005, per capita energy emissions were 2.8 tons of CO_2e in 2005, well below the world average of 4.4 tpc.

Within the subcategory of energy, power generation accounted for about 30 percent of the region's total energy emissions in 2005, whereas the power sector contributed a much higher total (44 percent) to global energy emissions.[22] In addition, transportation accounts for a much greater share of LAC's energy emissions profile (29 percent) than it does within the global profile (only 19 percent). This anomaly is explained by the dominance of hydropower in the regional power mix and transportation within the final LAC energy demand.

Emissions intensity

As LAC's developing economies have continued to mature, the sensitivity (or "elasticity") of economic growth to annual emissions levels has declined in recent years. The region's emissions intensity fell from 1,500 tCO_2e (tCO_2e) per million dollars of GDP in 1990 to approximately 1,200 tCO_2e per million dollars of GDP in 2005. Global emissions intensity has also declined, though somewhat less steeply and from a lower base.[23]

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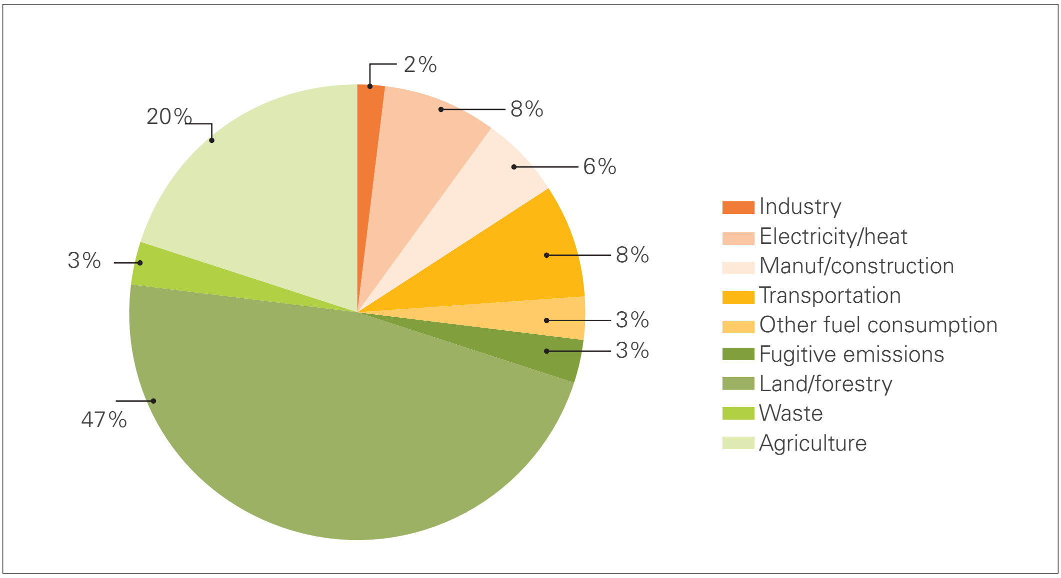
[21] In its annual historical emissions data series, the CAIT database generally includes figures for both energy and land-use emissions. However, the data available for cumulative historical emissions do not include land-use emissions and therefore can only be expressed in terms of total cumulative energy emissions over time.

[22] Note that the sector contributions presented in figure 2.1 refer to the percentage shares of total LAC GHG emissions, while the sector contribution figures presented on power generation and transport refer to the region's emissions within the energy emissions subcategory. Therefore, while transportation, for example, accounts for 8 percent of the region's total emissions, as seen in figure 2.1, this sector accounts for 29 percent of LAC's energy emissions (which account for only 28 percent of LAC's total GHG emissions).

[23] LAC's relatively high emissions intensity has been linked to the region's significant land use-related emissions. Discounting land-use emissions, however, changes the picture substantially. LAC's non-LULUCF emissions intensity has long been lower than that of the world (generally constant at 625–650 tCO2e/million $ of GDP from 1990 to 2005 compared with some 825 tCO_2e/million $ for the world in 1990 and approximately 650 by 2005).

Figure 2.1 Sector Composition of Total Greenhouse Gas Emissions in LAC, 2005[24]



Source: Authors' compilation based on WRI (2012) data.
Note: The above sector contributions refer to percentage shares of total LAC GHG emissions. Therefore, while transportation, for example, accounts for 8 percent of the region's total emissions, as seen above, this sector accounts for 29 percent of LAC's energy emissions (which account for only 28 percent of LAC's total GHG emissions).

Energy profile and final demand

In 2010 LAC's primary energy mix included more oil (42 percent), hydropower (21 percent), and biomass (13.5 percent) than the global average mix (32 percent, 6.7 percent, and 8.7 percent, respectively). At the same time, the regional LAC mix incorporated far less coal (4.7 percent vs. 27 percent) and nuclear power (0.8 percent vs. 5.6 percent) than the global mix. Furthermore, LAC has only small shares of geothermal, solar, and wind power.[25]

LAC's final energy demand differs considerably from that of the global average as well. While LAC per capita emissions have historically been higher than the global per capita emissions level, LAC's final per capita energy demand (39 gigajoules) is lower than the global average (49 Gj). Thus, not only is per capita energy demand low by global standards, but it is also considerably lower in associated GHG emissions.

Recent trends

The dominance of AFOLU within the LAC emissions profile is changing. Evidence points to significant declines in the regional rate of deforestation in recent years, which dropped 67 percent in Brazil's Amazon since 2004 and one-third in Central America since the mid-1990s (INPE 2010; Kaimowitz 2008; and Hecht 2012). These achievements, if maintained, augur well for a significant lasting reduction in land-use-related emissions.

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[24] See footnote 27 for further discussion of the possibility that Brazil's recent decline in land-use emissions may have pushed down the land-use sector's contribution to LAC's total emissions from 47 percent (as reflected in the CAIT data presented above in Figure 2.1) to less than 35 percent in 2010 (as reflected by the IIASA GEA data presented in figure 2.3).

[25] Figures for LAC and world primary energy mixes come from estimates for 2010 from IIASA's GEA Scenario database (see annex 2) using the substitution method. These estimates are projected from historical data series coming from the IEA.

Per capita emissions

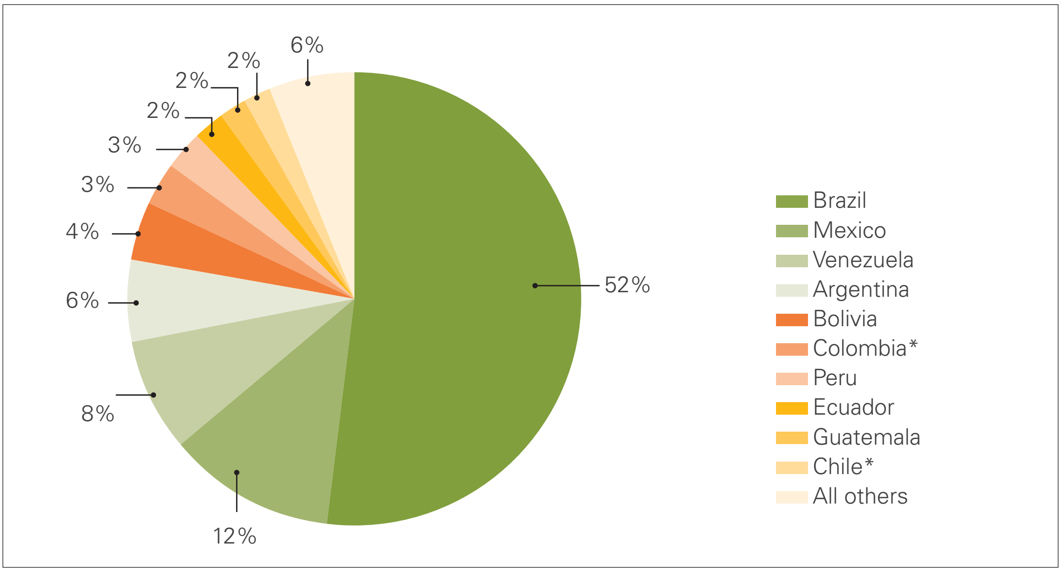
Total LAC per capita emissions fell from 10.4 tons (WRI 2012) in 1990 to 8.1 tons (IIASA GEA) in 2010, driven by a decrease in land-use emissions and improvements in energy efficiency. According to the GEA figures, which do appear to incorporate the recent decline in emissions from deforestation, the region's total per capita emissions were 8.5 tons in 2005 and 8.1 tons in 2010.

This recent trend could be reversed, however, by rising rates of deforestation or an increase in energy-related emissions. Indeed, the region's per capita energy emissions rose from 2.3 tons in 1990 to 2.8 tons in 2005 and are projected to continue increasing under the "business-as-usual" trajectory. Thus, LAC's projected energy emissions may yet cancel out the emission reductions in land use.

Country emissions

On its own, the regional carbon footprint can be deceiving. While most countries in Latin America are small contributors of GHGs (with emissions well below 1 percent of the global total), the region includes some very large carbon emitters: countries with high rates of deforestation, countries with carbon-intensive economies, and countries that are in a transition process induced by various structural changes. Figure 2.2 illustrates the relative contributions of principal countries to the regional emissions profile.[26] Country-based GHG intensity and per capita emissions are included in annex 3.

Figure 2.2 Country Contributions to Total LAC Emissions, 2005 (%)



Source: Authors' elaboration based on WRI (2012) data.
* These cases do not include land-use emissions.

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[26] See the next footnote for further discussion of the possibility that Brazil's recent decline in land-use emissions may have brought its relative contribution to the LAC total down to below 50 percent.

Brazil was the dominant source of LAC emissions (52 percent) in 2005, followed by Mexico (12 percent), Venezuela (8 percent), and Argentina (7 percent) (WRI 2012).[27] In fact, the LAC region is only globally relevant in terms of GHG emissions because of Brazil, which alone contributed one-third of global land-use emissions, and Mexico. Nevertheless, the probability of reaching any per capita emissions target for the entire region by 2050 increases substantially if medium-sized and small LAC countries follow Brazil and Mexico in contributing their own mitigation efforts.

Projected emissions: the business-as-usual scenario

The peculiar features of the LAC emissions anomaly—small historical and current contributions to global emissions and the concentration of LAC emissions in AFOLU sectors—often leads observers to conclude that the mitigation efforts needed to significantly bend the region's emissions curve are simply unnecessary and too expensive.

But while land-use emissions have recently fallen, sustained economic growth is driving an increase in the region's energy emissions, particularly from power generation and transport. Energy emissions will soon rival AFOLU emissions within the region's emissions profile (see the analysis of LAC's business-as-usual trajectory, below). Also, the region is now positioned as a major supplier of food stocks and other natural resources, which, if unchecked, may expand its carbon footprint.

The BAU trajectory

While an international accord to reduce GHG emissions has proved elusive, the current path of emission trends leads toward a future that must be avoided. Most analyses are based on the assumption that actions will be taken in time to avert dangerous impacts. But there is increasing concern that the guardrail for a 2°C rise in global temperatures may be exceeded, with grave implications for the global biosphere.[28]

For the purposes of this study, IIASA's GEA model "counterfactual" (International Institute for Applied System Analysis, GEA Message Pathways Database, v.2.0 rc1)[29] is used as the "business-as-usual" (BAU) scenario in 2050. Although there are countless other BAU emissions scenarios, IIASA's integrated approach is based on a number of comprehensive databases and provides the only available set of total emissions projections that also includes both energy and land-use emissions for the LAC region as a whole. This BAU trajectory also fits well into a global view of how emissions are expected to evolve over time.

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[27] In recent years, Brazil experienced a significant decline in the rate of deforestation and, presumably, in land-use emissions. This apparent shift in Brazil has not yet been fully captured in the international databases, such as CAIT, which serve as global references. Nevertheless, the figures for the LAC region used in IIASA's GEA Scenarios Database, which is the reference for this study's future projections, reflect this apparent decline in land-use emissions. The emissions level that the GEA model uses for its departure year (2005) is lower than that cited by CAIT, which apparently captures this decline. The discrepancies that are often found among different international sources for LAC emissions data over the past 10 years are most likely accounted for by this significant recent decline in Brazil's land-use emissions. Using IIASA GEA figures for land-use emissions would bring down this category's share of total LAC emissions from 47 percent—as reflected in the CAIT data presented in figure 2.1—to below 35 percent. Such a reduction would imply that Brazil's total GHG emissions in 2010 would have been only approximately 45 percent of the LAC total (instead of 52 percent, as reflected in the CAIT data for 2005 presented in figure 2.2).

[28] An analysis of the consequences of a much warmer world this century is beyond the scope of this document, but such consequences are being considered in the IPCC's Fifth Assessment Report.

[29] A full description of this scenario is included in annex 2.

Table 2.1 summarizes the driving forces within the structure of the BAU scenario for the region. Even with no significant change in the trajectory of status quo policy and behavior patterns, under this scenario, LAC's large land-use emissions will gradually diminish, while the region's energy-induced fossil fuel emissions will continue to increase, with the fastest growth expected from transport and power generation. These drivers are well tied to the current momentum of change in the region.

Table 2.1 Sector Breakdown of Expected (BAU) Future Emissions Changes and Key Driving Forces, 2010–50 (Gt, percent)

Category	2010	2050	Percent change	Driving forces
LAC BAU trajectory	4.73	6.73	+42	
Electricity	0.24	0.54	+120	Carbonization
Industry	0.33	0.66	+102	Economic growth
Feedstocks	0.11	0.23	+106	Economic growth
Residential/commercial	0.18	0.21	+15	Economic growth
Transportation	0.56	1.20	+116	Motorization, urbanization
Land use	1.60	0.67	-59	Reduced deforestation
CO_2 total	3.30	4.56	+38	Energy demand
CH_4	1.00	1.50	+48	Livestock, agriculture
N_2O	0.34	0.63	+67	Fertilizer use

Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and authors' elaboration.

For example, while LAC's energy sector is cleaner than that of any other region, economic growth has increased electricity demand, strained installed capacity, and driven demand for a greater share of fossil fuels in the region's power matrix.

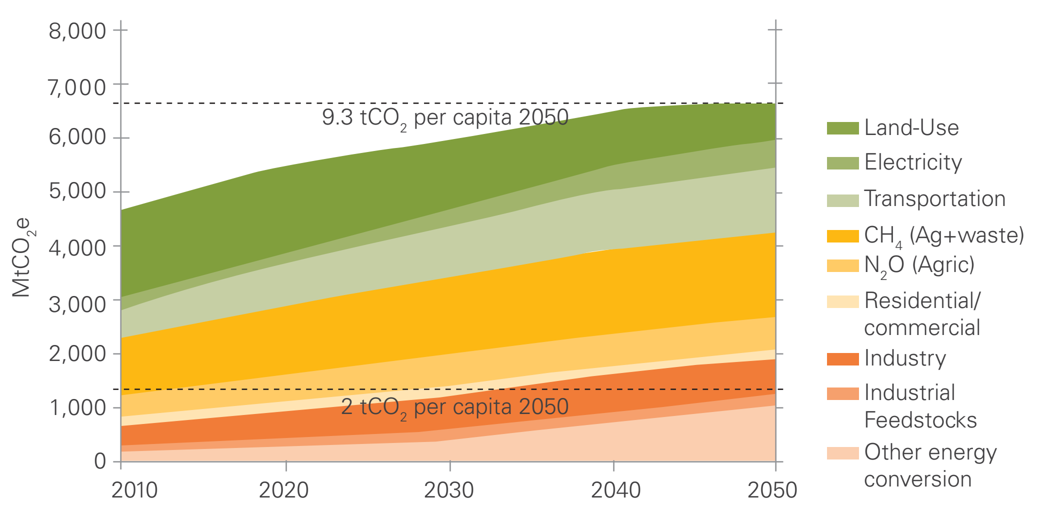
Additionally, climate change threatens the future reliability of hydropower, which accounts for about 60 percent of the region's installed capacity and 70 percent of power generation, as well as other energy assets. Indeed, changes in climate and increased exposure to extreme weather events may force the relocation of coastal refineries, pipelines, and transmission infrastructure.

Changes in demand caused by shifting temperatures would require different patterns in energy supply. Indeed, warming in tropical areas could eventually force major increases in space cooling requirements. A recent report on the subject (Ebinger and Vergara 2011) has concluded that many aspects of the energy sector may be quite vulnerable to impacts from climate change.

In order to satisfy rapidly rising demand for energy, the generation mix is incorporating a growing share of fossil fuel, which is projected to grow nearly 5 percent annually over the coming decade (Riahi et al. 2011). Rapid urbanization and motorization rates are increasing transport sector demand for gasoline and diesel. The substantial growth of food exports has driven higher emissions from the agricultural sector. The BAU scenario for LAC is presented in figure 2.3.

The anticipated reductions in land-use emissions will be overshadowed by increased emissions from agriculture, energy generation, and transport. While the overall share of agriculture is projected to remain roughly constant, the percentage shares of transport and power generation are anticipated to grow by 50 percent under the BAU trajectory, reaching an overall contribution of approximately 2 $GtCO_2e$ per year. Thus, under the BAU scenario, the region will emit nearly 7 $GtCO_2e$ by 2050, when LAC per capita emissions will reach 9.3 tCO_2e. But despite the significant increase in projected energy emissions under the BAU trajectory, LAC is still expected to have the lowest carbon content of any regional energy mix through 2050.[30]

Figure 2.3 Regional BAU Emissions Trajectory, by Sector, 2010–50



Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and authors' elaboration.
Note: All per capita emissions projections are based on the following population estimates from IIASA's GEA model (based on UN projections): 585 million in 2010, 641 million in 2020, 686 million in 2030, 714 million in 2040, and 725 million in 2050.

Pathways to reach stabilization goals by 2050

Bending the emissions curve enough to bring the region's current (8 tons) and projected (9.3 tons) per capita emissions levels down to 2 tCO_2e in 2050 would require substantial investment and changes in behavior. To visualize how this change can be achieved, this study mapped potential alternative emissions pathways. This mapping is facilitated by a breakdown analysis of separate emissions categories, or "emissions wedges."

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[30] Currently, LAC's primary energy mix is approximately 35 percent "low carbon" and 53 percent "lower carbon" (compared with 22 percent and 41 percent, respectively, for the world as a whole). In 2050, LAC's "low-carbon" and "lower-carbon" shares will be 40 percent and 65 percent, respectively (compared with 21 percent and 40 percent, respectively, for the world). The "low-carbon" standard includes hydropower, nuclear power, and modern renewables (including geothermal, solar, and wind power and other forms of renewable energy). The "lower-carbon" standard would also include natural gas, which typically emits from 50 percent to 75 percent of the CO_2 released by the use of coal and oil, along with fossil fuels using CCS. Although there are different ways of calculating the primary energy mix, this report has relied on the "substitution method" by using estimates and projections from IIASA's GEA database.

Wedge analysis

This study reconstructed the BAU emissions trajectory to 2050 to present nine "abatement wedges," which represent the quantity of emissions available for abatement between 2010 and 2050 in each sector. None of these abatement wedges are meant to indicate any particular level of effort required or the relative political or financial viability of achieving the full abatement of any particular wedge. Nevertheless, in each of the wedges shown, certain available technologies can be deployed to significantly reduce emissions.

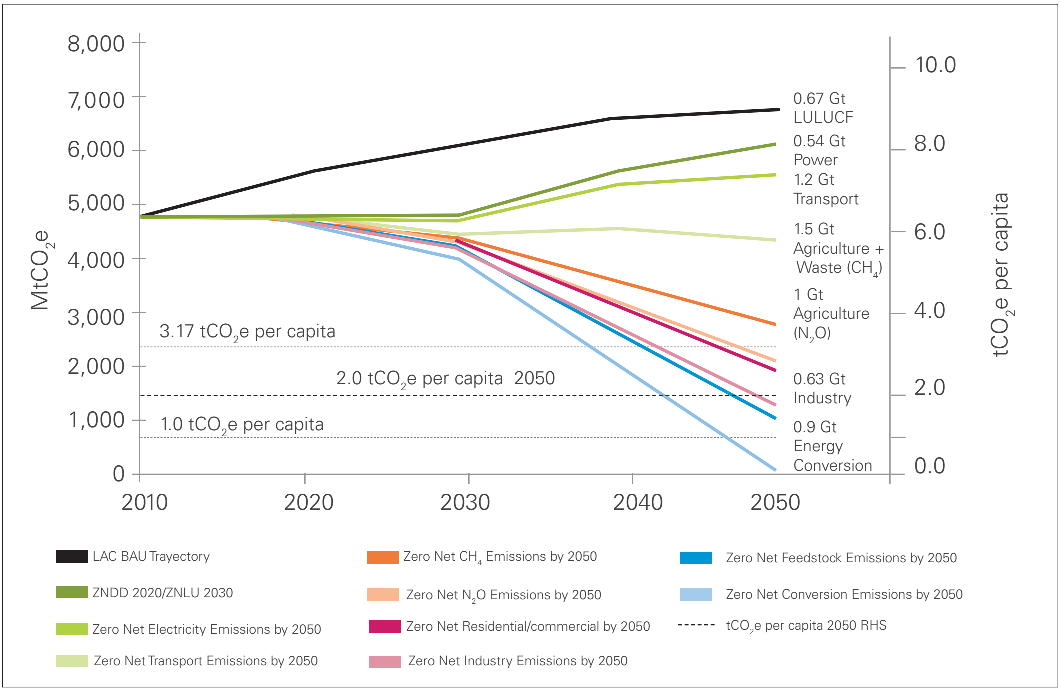
This analysis shows that even the complete elimination of land-use-based emissions would not be sufficient to meet the 2 tpc target by 2050. An emissions reduction strategy capable of reaching zero net deforestation and degradation by 2020 (ZNDD 2020) and zero net land-use emissions by 2030 (ZNLU 2030) would only reduce the expected BAU emissions by 0.67 $GtCO_2e$. Even the implementation of stronger land-use policies, capable of increasing net carbon sinks (by 350 tons annually per decade) beyond 2030, (ZNLU 2030+) would bring down emissions in 2050 by only 1.37 Gt, compared to the BAU trajectory, leaving LAC emissions at 5.4 $GtCO_2e$.

Expanding the scope of land-use changes to include a significant reduction of agricultural emissions—the so-called AFOLU approach—would substantially increase the abatement potential. Nevertheless, even if LAC were to successfully eliminate all land-use and agriculture emissions (2.84 $GtCO_2e$) by 2050, this decrease to 3.9 $GtCO_2e$ would correspond to just 53 percent of the necessary effort to reach the 2 tpc goal.

Similarly, an exclusively energy-focused approach will not work. In sectors such as transport and power, which are characterized by long-term path dependencies and therefore vulnerable to infrastructure and technological lock-ins, transitions to a low-carbon future would need to be planned and implemented with sufficient lead time. In order for emissions to peak between 2020 and 2030, significant reductions of energy-induced GHGs would need to begin almost immediately. But even if all energy emissions expected in 2050 were completely eliminated, the region would only be 56 percent of the way to the 2 tpc goal.

On the other hand, an especially aggressive land-use policy—one that successfully and significantly augmented carbon sinks—could relax the required emissions targets in other sectors and thereby expand the range of feasible options available for the future energy mix. If such an aggressive land-use approach were combined with an energy-based approach designed to "decarbonize" LAC's national economies, the region would reach the 2 tpc goal.

Figure 2.4 The Business-as-Usual Trajectory vs. Emissions Wedges (Without Net Carbon Sinks), 2020 and 2050



Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and own elaboration.
Note: (a) ZNDD 2020 = zero net deforestation and degradation by 2020; ZNLU 2030 = zero net emissions from land use, land-use change, and forestry (LULUCF) by 2030. (b) LULUCF emissions are cut in half between 2010 and 2020 and reach net zero emissions (ZNLU) in 2030 but do not become negative in net terms thereafter. Nevertheless, this study's base intervention scenario assumes that net deforestation and degradation is halted (in net terms) by 2020. (c) Emissions from all other categories are assumed to peak in 2020, remain flat until 2030, and then fall to zero by 2050. These peaks could actually occur any time between 2020 and 2030 provided that emissions return to their 2020 level by 2030 before continuing their path to zero. (d) Under these land-use assumptions (ZNDD 2020, ZNLU 2030 no+), full abatement of the other emissions sectors by 2050 would bring LAC emissions to zero.

Emissions reduction pathways

A number of pathways can be articulated from the emissions wedges (figure 2.4).

Land-use-change pathways

Under land-based pathways the following is pursued: (i) zero net deforestation and degradation by 2020 (ZNDD 2020) and (ii) zero net emissions from land use, land-use change, and forestry by 2030 (ZNLU 2030). Achieving this dual target would reduce land-use emissions from 1.9 $GtCO_2e$ in 2010 to zero by 2030.[31]

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[31] Zero net deforestation and degradation (or ZNDD)—or the complete halt to deforestation, at least in net terms by 2020—is probably necessary to achieve zero net GHG emissions in the somewhat broader category of zero net emissions from LULUCF (or this study's ZNLU) by 2030. This is because (1) some LULUCF emissions do not come from the forest sector, requiring additional actions beyond ZNDD 2020, and (2) due to the nature of the biological and chemical processes involved, there is some degree of time lag involved between the execution of the mitigation actions in the land-use sector and the registering of the effect in terms of net emissions reduction.

The ZNDD 2020/ZNLU 2030 pathway would indefinitely maintain this level of zero net land use-based emissions from 2030 into the future.

The ZNDD 2020/ZNLU 2030+ (plus) pathway would continue to reduce net land-use emissions beyond 2030 through further actions to augment net carbon sinks until annual net negative land-use emissions of 0.7 $GtCO_2e$ are achieved in 2050.

The AFOLU+ (plus) pathway would intensify the ZNDD 2020/ZNLU 2030+ (plus) pathway with an additional 50 percent cut in agricultural emissions by 2050. In addition to innovative livestock and cultivation practices targeting CO_2, CH_4, and N_2O emissions, other conservation and forestry practices targeting deforestation and degradation would be required to achieve this pathway.

Energy pathways[32]

Energy pathways would bring the region's emissions to between 3.4 tpc (under the "supply" version of the pathways, as explained below) and 4.3 tpc (under the "efficiency" version) by 2050.[33] These would require:

- Further improvements upon the historical rate of reduction in energy intensity
- 60–80 percent share of the primary energy mix from renewables
- 75–100 percent share of electricity mix from low-carbon sources

All of these energy pathways also require real reductions in aggregate emissions levels only after 2020 and avoid 3.5–4.1 $GtCO_2e$ annually by 2050 (see figure 2.5 and table 2.2). Furthermore, all of these pathways assume nuclear-free development.[34]

This study's central reference pathway, the mix-I pathway, is characterized by: (i) a reduction of final energy demand in 2050 to roughly 40 percent below the expected BAU level; (ii) the progressive electrification of the current conventional liquids-based transportation sector; and (iii) a full portfolio of available renewable energy sources and technologies.[35]

The mix-II pathway is the same as mix-I except that it implies that the current conventional liquids-based transportation system will be maintained.

The efficiency-I pathway requires: (i) significant improvements in energy efficiency, achieving a 50 percent reduction in final energy demand by 2050 (compared to BAU); (ii) the displacement of the conventional transport sector with an advanced transport system based on electrification; and (iii) an energy/technology mix that includes carbon capture and storage (CCS).

Finally, the supply-I pathway implies: (i) final energy demand only 23 percent below the BAU level in 2050; (ii) an advanced "electrified" transportation system; and (iii) the exclusion of existing nuclear power from the primary energy mix (necessitating an even more substantial deployment of CCS).

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[32] Our energy (or "moderate intervention") pathways were based directly on a number of IIASA's GEA model pathways, except that the land-use emissions reductions and associated intervention costs have been stripped from IIASA's versions to produce "pure energy intervention" pathways. The authors' combined (or "aggressive intervention") pathways were derived by combining, in different permutations, the pure energy intervention pathways with our land-use (or ZNLU/AFOLU) pathways, the latter of which have been based on the authors' own elaboration (although they rely on IIASA GEA's projections of the financial expenditures necessary to achieve reductions in land use emissions along their model pathways). See annex 2 for further explanation of the IIASA GEA model pathways.

[33] In general, IIASA GEA's efficiency pathways would bring down the region's per capita emissions more slowly than the mix or supply pathways, but with the enormously beneficial trade-off of requiring far lower financial expenditures, as falling final demand nullifies the need for enormous amounts of energy expenditures otherwise required under the business-as-usual trajectory. Among this study's aggressive pathways, the least expensive are those in which AFOLU actions have been combined with the energy interventions of the efficiency pathways.

[34] All energy pathways designated type "I" also incorporate the gradual transformation of the conventional liquids-based, transportation systems into advanced transportation systems based on electrification (and some use of hydrogen). Conversely, the pathways designated as type "II" imply the maintenance of the status quo's liquids-based transportation infrastructure.

[35] This does not necessarily imply that LAC would eliminate nuclear power from the regional energy matrix completely by 2050, but rather that nuclear power would not be expanded from the current low production levels.

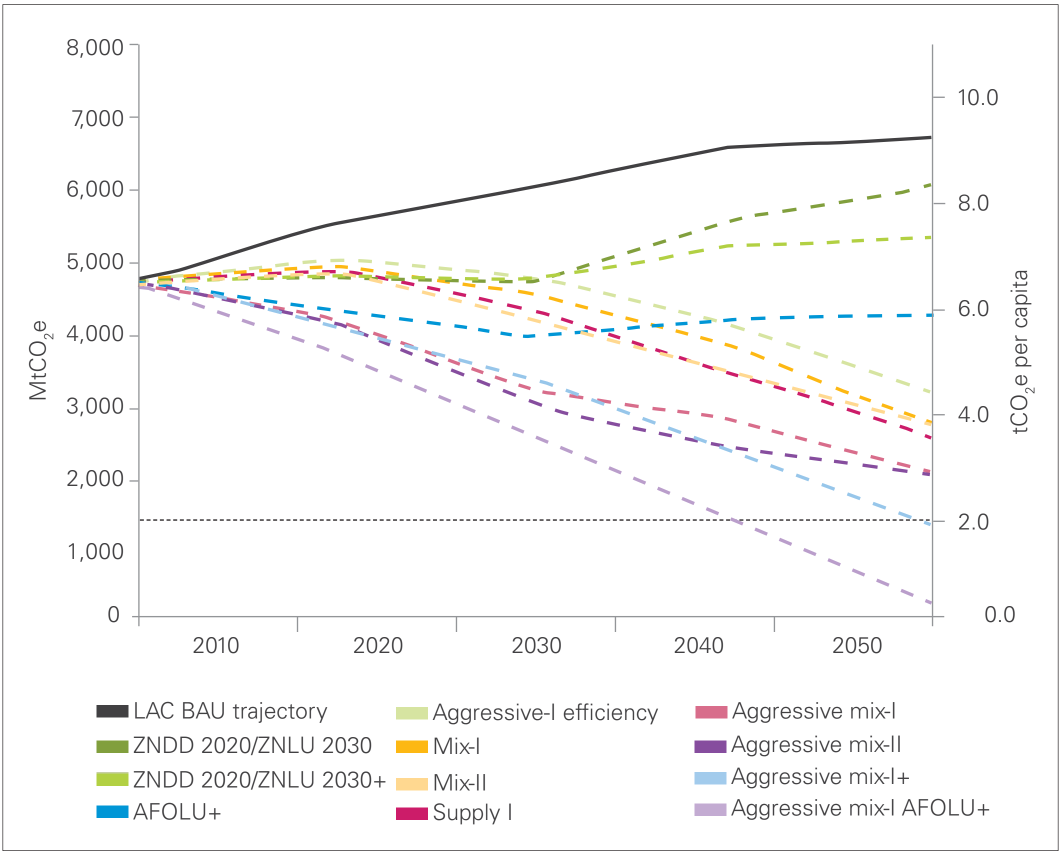
"Combined" pathways

"Combined" pathways combine energy actions with land-use policies stringent enough to achieve both the goals of the AFOLU (that is, ZNDD 2020/ZNLU 2030+) and the energy pathways, thus attaining the 2 tpc goal (or even, in some cases, 1tpc or below) by 2050. The principal difference between the energy (or "moderate") and combined (or "aggressive") pathways is an aggressive cut in land-use emissions.

A summary of the extent to which some of these pathways comply with the 2 tpc target is presented in figure 2.5 and table 2.2. To reach the 2 tpc goal, LAC clearly requires a "combined" approach.

In addition, reductions in the emissions of short-lived pollutants that contribute to changes in albedo, such as soot or black carbon, could offer an immediate benefit by delaying the onset of local changes such as rate of glacier retreat in the Andes.[36]

Figure 2.5 Alternative Emissions Pathways, 2010–50



Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and authors' elaboration.

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[36] This includes energy and transportation emission reductions and changes in agriculture, forestry, and land-use changes needed, for example, to ensure that the region reduces its radiative forcing by a proportion that, if matched everywhere else on the globe, would hold overall global warming averages within a certain possible range, such as 2°C above preindustrial levels. That said, if other major regions fall short, even heroic measures in the LAC would likely be insufficient to realize this global goal.

Table 2.2 Summary of Alternative Emissions Pathways to Reach 2050 Goals

Actions					
Pathway	Land use	Energy	Other	Reduced $GtCO_2e$ vs. BAU	Percentage of 2 tpc target (–5.3Gt)
Approaches that center on land-use change					
ZNDD 2020/ ZNLU 2030	Zero net deforestation or degradation by 2020 and zero net CO_2e from all LULUCF post-2030	No change from BAU	No change from BAU	0.67	13
ZNDD 2020/ ZNLU 2030+	ZNDD 2020 and zero net CO_2e LULUCF post-2030 (as above), with annual net negative 0.35 Gt in 2040, and 0.7 Gt in 2050	No change from BAU	No change from BAU	1.37 (includes the 0.67 above)	26 (includes the 13 percent above)
AFOLU+	Same as ZNDD 2020/ ZNLU 2030+ (above)	No change from BAU	50 percent cut in agriculture CO_2e compared with BAU in 2050	2.45	47
Energy-centered approaches					
Mix-I	No land-use emissions reductions compared with BAU	Increased efficiency, [a] 70 percent low-carbon primary energy,[b] 97 percent low carbon generation and no nuclear	Progressive electrification of the transportation system; significant use of CCS post-2030	3.90	74
Mix-II	No land-use emissions reductions compared with BAU	Same as mix-I	Maintenance of conventional transp. system; bioenergy + CCS in the long run	4.00	75
Combined approaches					
Aggressive mix-I	Same as ZNDD 2020/ ZNLU 2030	Same as mix-I	Same as mix-I	4.67	88
Aggressive mix-I+ (plus)	Same as ZNDD 2020/ ZNLU 2030+	Same as mix-I	Same as mix-I	5.38	102
Aggressive mix-I AFOLU+	Same as AFOLU+	Same as mix-I	Same as mix-I	6.40	121

Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and authors' elaboration.

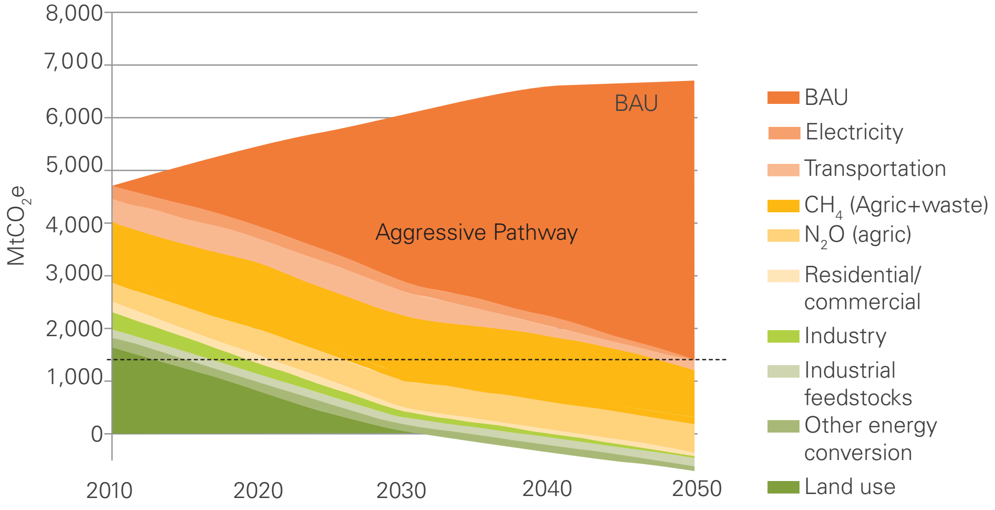
Note: BAU = business as usual; CCS = carbon capture and storage.

[a] Final energy demand is nearly 40 percent less than the demand under the BAU trajectory.

[b] This figure is compared with only 36 percent low-carbon content in 2010 and 41 percent low-carbon content under the BAU trajectory in 2050.

Table 2.2 indicates that, of the pathways analyzed, the combined (or "aggressive") I+ (plus) pathway does the job by 2050.[37] Figure 2.6 illustrates the route assumed under the aggressive-I+ pathway. This pathway reflects the relative difficulties associated with agricultural activities, which constitute a major part of the remaining carbon footprint by 2050. Still, even those emissions will need to be tackled to reach further climate stabilization goals after 2050.

Figure 2.6 Aggressive-I+ Pathway, 2010–50



Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA), and own elaboration.

Some of the principal actions considered under the mix-I+ (plus) pathway include:

- Aggressive actions to stop net deforestation by 2020. This implies acceleration of recent trends that are only likely to be achieved through strong policy, regulatory, and enforcement action combined with forceful economic incentives. Quick action would also be required to combat new and emerging threats, including the potential damage from uncontrolled mining in the Amazon and Andes Piedmont regions that could quickly undermine recent gains.
- No net emissions from land-use change by 2030, net accumulation of carbon sinks to 2050, and a 50 percent cut in agricultural emissions compared to the BAU trajectory. This would also require major improvements in forestry, land-use planning, agriculture, and animal husbandry practices (some of which have not yet been widely deployed). Such an effort would include opportunities to increase carbon sinks and a major campaign to recover at least some of the 3 million hectares of degraded lands in the region. Innovative forestry conservation and sustainable land-use management practices would need to be implemented

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[37] Some of the other aggressive+ (plus) pathways would also achieve the target, but the supply versions could do so only at much greater cost, in terms of net financial additionality, than the mix versions of the pathway. The efficiency versions of the aggressive + (plus) pathway fall somewhat short of the 2 tpc target in 2050, but they do so at a fraction of the financial cost involved in the supply, or even the mix, versions of this pathway (see table 2.5).

on a progressively wider scale. To meet the target, the aggressive-I+ pathway would need to increase carbon sinks enough to achieve annual net negative land-use emissions of 0.35 $GtCO_2e$ by 2040 and 0.7 $GtCO_2e$ by 2050.

- An effort to abate final energy demand by 40 percent compared to the BAU. This can only be achieved through bulk improvements in energy efficiency (that is, mass evolution of residential lighting toward LED devices, efficiency improvements in the delivery of high-pressure steam and low-enthalpy heat, improvements in the energy efficiency of domestic appliances, and space heating/air conditioning to counteract anticipated increase in use), as well as other net reductions in demand.
- Arresting and reversing the current carbonization path of the regional power matrix to achieve at least 90 percent zero-carbon installed nominal capacity in the sector. This implies a major shift toward quick deployment of the region's substantial renewable energy endowment, including solar, geothermal, wind, and other resources. Some other resources (marine energy, for example) are not yet commercially available but could quickly become so with a strong technology push targeting barriers to market entry. The wide use of marine energy in coastal nations could yield significant technology benefits as techniques are developed to attend to local conditions.[38] Actions would also be needed to remove barriers to private investment in the power sector.
- Widespread electrification of the transport sector. A continuing low or near-zero carbon power matrix would be required to support a transformation of the transport sector by 2050. To decarbonize the transport sector, public modes would need to be quickly electrified, using novel technologies that allow for high-density energy storage and fast charging stations. Fortunately, the large investments already made in bus rapid transit systems (BTRs) can accommodate with relative ease the adoption of battery-powered vehicles. Deployment of these technologies would also benefit local technology development. Total decarbonization would also require that automobiles and freight vehicles move away from the use of internal combustion engines. While this was merely an aspirational goal a few years ago, technology developments now allow for quick electrification of all modes of transport in the region.

As with all pathways considered in this report, expansion of nuclear energy is not considered. The future exclusion of nuclear energy does not increase the costs of actions required under this pathway.[39]

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[38] Such coastal "low-carbon" and mitigation efforts should be closely coordinated with adaptation efforts in order to avoid duplication and to capture potential synergies in terms of ultimate additional costs and cobenefits.

[39] Some of the 41 potential pathways elaborated by IIASA-GEA for LAC do register a slight increase in the overall net additional financial costs when nuclear expansion is excluded. But at least as many other pathways produce some small reduction in expected overall net additional financial costs annually. Excluding nuclear power expansion from the definition of the pathways only changes the cost equation in one direction or the other by 10 percent at most. Most of the variation is accounted for by combining nuclear expansion, or not, with the requirement to both electrify the transport sector (or not) and to achieve very significant "low-carbon" levels in the electricity generation mix (75–100 percent). Given the uncertainties surrounding the future of nuclear power, and its attendant cost structures, a 10 percent difference is not likely to persuade LAC policymakers and investors to expand nuclear power, at least not very rapidly or by very much. Indeed, all of the IIASA GEA Pathways (for more, see annex 2) that allow for the expansion of nuclear power, in competition with other energy sources within the matrix, project only a very minor increase above the already low levels (less than 1 percent of the LAC primary energy mix). In this sense, nuclear power remains nearly irrelevant to this study.

Table 2.3 presents a summary of the different emission scenarios, including the estimated emissions, the volume of emissions avoided, and the estimated per capita emissions by 2050.

Table 2.3 Summary of Emissions Scenarios, 1990–2050

Scenario	Emissions 2050 $MtCO_2e$	Percent change in 1990 levels	tCO_2e per capita in 2050	$MtCO_2e$/yr avoided vs. BAU in 2050: 6,727 $MtCO_2e$	Percent difference from BAU in 2050
LAC BAU	6,727	+47	9.30	—	—
ZNDD 2020/ZNLU 2030+	5,360	–35	7.15	1,370	–25
Energy mix-I	2,780	–39	3.71	3,947	–59
LAC 2 tpc target	1,450	–68	2.00	5,277	–78
Combined aggressive-I+	1,390	–70	1.86	5,337	–79

Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and authors' elaboration.
Note: These potential LAC "shares" of the global mitigation burden are substantially lower (by 30 percent–60 percent) than LAC's share of global annual emissions (11 percent in 2005).

Financial costs of the intervention pathways

Using the financial projections of IIASA's GEA message model, this study has estimated the additional financial needs (both investment and expenditures) required of the LAC economy to achieve the emissions reductions implied in each of the potential pathways.

The financial costs of the land-use (or AFOLU) pathways

Based on the analysis of the financial cost projections incorporated into IIASA's GEA mix pathway scenario, we estimate that upwards of \$24 billion annually (by 2030) would be required to achieve the ZNDD 2020/ZNLU 2030 pathway (see tables 2.4 and 2.5, and annex 3). Additionally, the estimate suggests that some \$53 billion annually would be required by 2050 to continue augmenting LAC's carbon sinks enough to achieve the ZNDD 2020/ZNLU 2030+ (plus) pathway. The average net cost of abatement required along these pathways is estimated to be \$22–\$24/tCO_2e.[40]

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[40] This study's estimates for the ZNDD 2020/ZNLU 2030 pathways are based on the "nonenergy expenditures" projected by IIASA for its GEA mix-II pathway and assigned to actions to preserve and augment carbon sinks (including REDD/REDD+). These projected costs (calculated by subtracting the "nonenergy expenditures" under the GEA mix-II pathway with conventional transport and no sinks from those "nonenergy expenditures" under the GEA mix pathway with conventional transport and a full portfolio) are approximately \$2.2 billion/year by 2020, \$6.4 billion/year by 2030, \$15.7 billion/year by 2040, and \$32.5 billion/year by 2050. (See annex 3 for a fuller explanation of how net additional financial cost projections were formulated for the pathways, and the major components of the Aggressive I+ (plus) pathway.) But our refinements to produce the land-use pathway estimates assume that the projected GEA mix-I and -II pathway REDD/REDD+ expenditures are responsible for reducing land-use emissions from their current (2010) levels (as opposed to only from the BAU levels between 2020 and 2050). This assumption is made because the IIASA GEA BAU/counterfactual includes no nonenergy expenditures in any year, despite the projected 60 percent decline in land-use emissions between 2010 and 2050 under the BAU/counterfactual trajectory. It appears that this decline is assumed by IIASA to come only from the global macro effects of rising income, wealth, and modernization—a highly uncertain, if not unlikely assumption. Finally, these expenditures are also assumed to include readiness, implementation, and transactions costs in addition to compensation for opportunity costs.

While such an estimate implies a range of uncertainty, it falls clearly within the wide range of global estimates in the existing literature (table 2.4). For example, some estimates for a complete global halt to deforestation by 2030 (the ZNDD 2030 scenario) are as low as $12 billion annually to compensate for the opportunity costs of deforestation and forest degradation, with an average abatement cost of approximately \$2/tCO_2e (Blaser and Robledo 2007). At the other end of the spectrum, one of the most widely quoted estimates (Eliasch 2008) suggests that $17 billion–$33 billion would be required annually to compensate for opportunity costs associated with only a 50 percent reduction in global deforestation emissions by 2030. Meanwhile, the European Commission has estimated that a 50 percent global abatement of deforestation emissions by 2020 would cost $20 billion–$33 billion a year, while a complete global halt to deforestation emissions by 2030 would cost $38 billion–$96 billion annually—at an overall average abatement cost as high as $90 per t$CO_2$e (see Grondard, Martinet, and Routier 2008).[41]

Of the few existing LAC regional estimates, the McKinsey Report (of Enkvist, Nauclér, and Rosander 2007) estimated that the average abatement costs for a 75 percent reduction in deforestation emissions would be \$50/tCO_2e.

While such top-down estimates tend to be relatively high, local bottom-up estimates for LAC are much lower. Olsen and Bishop (2009), for example, estimate the opportunity costs for avoiding deforestation in the Amazon to be around \$5/tCO_2e of abated carbon.

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[41] Global estimates from the IPCC are even higher, and range from $40 billion to as much $350 billion a year (Grondard et al. 2008, using authors' currency conversion of $1.28/euro).

Table 2.4 Selected Estimates of the Opportunity Cost of Halting Deforestation

Level of abatement	Cost $ billion/year, $/tCO$_2$e	Source
Deforestation (50 percent abatement by 2020)	$20–33 billion/year	European Commission 2008
Deforestation (complete eradication by 2030)	$38–96 billion/year, up to $90/tCO$_2$e	European Commission 2008
Deforestation (50 percent abatement by 2030)	$17–33 billion/year	Eliasch 2008
LAC ZNLU 2030	$20–40 billion/year	Eliasch 2008, adjusted through authors' assumptions to LAC region (see below)
Deforestation (full halt)	$40–350 billion/year	IPCC WGIII AR4
Deforestation (49 percent abatement)	$2.2/tCO$_2$e	Kindermann et al. 2008
Deforestation (65 percent abatement)	$4.0/tCO$_2$e	Blaser and Robledo 2007
Deforestation	$5/tCO$_2$e	Olsen and Bishop 2009
Deforestation (65 percent abatement by 2030)	$11.2 billion/year, $2.8/tCO$_2$e	Blaser and Robledo 2007
Deforestation (full halt by 2030)	$12 billion, $2/tCO$_2$e	Blaser and Robledo 2007
LAC deforestation (75 percent abatement)	$50.00/tCO$_2$e	McKinsey Report by Enkvist, Nauclér and Rosander 2007
Avoided degradation	$7.3 billion/year, $1.1/tCO$_2$e	Blaser and Robledo 2007
LAC ZNDD 2020/ZNLU 2030	$17 billion/year in 2020 ($21/tCO$_2$e); $24 billion/year in 2030 ($15/CO$_2$e); $30 billion in 2040 ($18/tCO$_2$e); $37 billion in 2050 ($23/tCO$_2$e)	Authors' estimates based on IIASA GEA projections and assumptions

Source: Meridian Institute (2009) and authors' estimates.

These cost estimates for land-use change mitigation measures typically compensate for opportunity costs but not all of the additional costs of REDD/REDD+ readiness and implementation. Together with transactions costs (related principally to land-use governance), these additional costs are estimated by some to be approximately one-third of the value of opportunity costs (Olsen and Bishop 2009).[42]

Nevertheless, our analysis adjusts one of the most widely cited estimates from the existing literature—the $17 billion–$33 billion/year estimate for a 50 percent reduction in global land-use

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[42] Other sources (Meridian Institute 2009) place readiness, implementation, and transactions costs at 50 percent of opportunity costs, while some (WWF 2011) have estimated that these additional costs can be as much as 100 percent of opportunity costs—potentially doubling the current range of financing estimates.

emissions by 2030 (Eliasch 2008)— to generate an equivalent projection of the total financial cost of \$20 billion–\$40 billion annually by 2030 for LAC for complete ZNDD 2020/ZNLU 2030. Our adjustment to this regional estimate is based on the following assumptions:

Total abatement of emissions from deforestation by a particular date will cost roughly twice the amount needed to achieve 50 percent abatement by the same date. Readiness, implementation, and transaction costs are approximately 50 percent of opportunity costs.[43] Roughly 40 percent of the abatement costs for global land-use emissions can be assigned to LAC.[44]

This estimate (\$20 billion–\$40 billion by 2030)[45] is in line with our IIASA-based financial projections for LAC (presented in table 2.5): total annual financial costs reach \$17 billion by 2020 with ZNDD, \$24 billion by 2030 with ZNLU, \$30 billion by 2040 (assuming no net additions to sinks, as in the aggressive-I pathway), and \$37 billion by 2050.[46]

Although this estimate is based on regional (not global) cost projections, it remains vulnerable to the potential overestimation typical of such top-down approaches (Olsen and Bishop 2009). One factor that could lower these estimates would be additional synergies (not included in these cost projections) that may emerge if the "combined" or "aggressive intervention" pathways are pursued. Nevertheless, when incorporated into estimates of the combined net financial costs of the aggressive pathways, even these relatively high cost estimates do not appear to be prohibitive. [47]

The financial costs of the energy ("moderate") and combined ("aggressive") pathways

The overall costs of the energy pathways, presented in table 2.4, are based on the projected energy expenditure and energy investment requirements generated by IIASA's GEA model pathways (see Riahi et al. 2011). These estimates are presented in both total and net terms (that is, in both gross terms and net of the expected BAU expenditures). The annual net costs associated with the various alternative mitigation pathways correspond to the additional funds required each year to move from the scenario of the BAU trajectory to any particular energy intervention pathway.[48]

While the gross financial requirements are higher in annual terms over the 40 years to 2050, once the required BAU investment and expenditures are netted out (as they will need to be incurred in any event), the additional costs are less onerous.

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[43] This result is in line with the Meridian Institute's estimate and between Olsen and Bishop's 33 percent and the WWF's 100 percent.

[44] This figure is derived by using IIASA GEA's LAC land-use figures to adjust CAIT's 46 percent share of global land-use emissions assigned to LAC down to 38 percent.

[45] This projection adjusts existing global estimates to become LAC specific and takes into account readiness, implementation and transaction costs.

[46] The total financial costs beyond 2030 rise more sharply in the case of the ZNDD 2020/ZNLU 2030 + (plus) pathway, which adds net sinks and reduces net emissions by a further 0.35 $GtCO_2e$ each year in the decade to 2040 and a further 0.7 $GtCO_2e$ each year in the decade to 2050. In this pathway, these annual costs reach \$36 billion by 2040 and \$53 billion by 2050.

[47] Caution must nevertheless be exercised when considering the potential financial requirements of land-use emissions abatement interventions. Given the wide range of available estimates, and the enduring nature of the underlying uncertainties, it is difficult to know with any certainty how much these scenarios will ultimately cost in terms of financial additionality.

[48] The net additional financial costs include the estimated total annual financial costs required to achieve the necessary energy transformations and associated emission reductions implied by each pathway, which encompass the total investment and other noninvestment expenditures for energy actions, including supply and demand sides, minus the total annual financial costs that would be required under the BAU scenario used in this report (that is, the IIASA GEA message model's counterfactual scenario). For example, achieving the mix-I version of the moderate intervention (energy) pathway would imply rising total financial costs that would reach \$132 billion annually by 2020 and \$508 billion annually by 2050. In any case, approximately \$460 billion (in annual investment and other "noninvestment" expenditures) would have to be channeled into the region's energy sector by 2050 just to meet the supply and demand requirements under the current fossil-fuel dominated BAU trajectory (even with no specific interventions to transform the energy or land-use systems). In this sense, the mix-I moderate intervention pathway requires only \$43 billion in "net financial additionality" above and beyond the BAU scenario by 2050.

For example, the moderate intervention "mix-I" pathway, which would electrify LAC's transportation systems while excluding nuclear power from the energy mix, would cost $132 billion annually in gross financial terms by 2020 (including lower current, though still substantial, financial requirements that would increase each year). But this pathway would also imply systemwide net savings of more than $8 billion annually (once annual BAU expenditures to 2020 are factored out). Thus, the pathway yields an average financial abatement cost of $213/t$CO_2$e (gross) and negative -$13/tCO_2e (net), respectively, in that year (see table 2.4).[49]

The mix-I pathway would require a gross total of $508 billion annually by 2050— nearly 2.67 percent of the region's projected GDP in that year or 11 percent of its 2010 GDP. In net terms, this pathway would require only $43 billion annually, with an average net abatement cost of only $11/t$CO_2$e by 2050. This total would represent less than 0.25 percent of the region's projected GDP (PPP) in 2050 (or 0.93 percent of LAC's 2010 GDP).[50] However, the mix-I pathway would only reduce LAC per capita emissions to 3.71t.

In order to reach the 2 tpc goal, the LAC would need to pursue the combined mix-I+(plus) pathway. The total gross and net cost estimates for the combined pathways reflect the combination of cost projections from both the energy and the land-use pathways.[51] The combined aggresive mix-I+ (plus) pathway would imply total gross and net additional annual costs of nearly $150 billion and $10 billion, respectively, by 2020 (lower, but substantial and rising annual sums will be required in each year leading up to that date). By 2050 these annual requirements would reach $561 billion in gross terms, but only $97 billion in net terms.

A number of other combined pathways would also reduce LAC emissions to near or below the 2 tpc goal. For example the aggressive mix-II+(plus) pathway (with conventional transportation) would result in a level of 1.88 tpc in 2050.

In addition, the aggressive-I+ efficiency (plus) pathway, while only bringing the region to 2.5 tpc, implies net financial additionality of only $39 billion. If additional land-use emissions interventions could force an adjustment down to 2.0 tpc, such a fortified version of the aggressive-I+ efficiency (plus) pathway would cost $48 billion in net financial additionality in 2050, far more economical than the aggressive mix-I+ (plus) and the aggressive mix-II+ (plus) pathways. On the other hand, a similarly fortified version of the aggressive-II+ efficiency (plus) pathway (with conventional transportation) would ultimately cost only $30 billion annually by 2050 in net financial additionality, one of the cheapest ways to reach the 2 tpc goal identified in this study.

Table 2.5 makes clear that the efficiency versions of the pathways are cheaper than their mix and supply counterparts. The aggressive-I AFOLU+ efficiency pathway would bring LAC emissions to nearly 1 tpc by 2050, although the net financial additionality would come to only $49 billion annually while the aggressive-II AFOLU+ efficiency pathway would reach just below 1 tpc, with an annual net financial additionality of $40 billion in 2050.

Even the most vigorous and expensive of the presented pathways—the aggressive II AFOLU+ supply pathway, which would bring net emissions to nearly zero and per capita emissions to 0.15 tpc—is projected to cost no more than $187 billion annually, in net terms, by 2050, less than 1 percent of the region's projected 2050 GDP.

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[49] "Net financial additionality" and "net average financial cost" ($/$CO_2$e) can be negative at certain points in time along some of the pathways, as some interventions displace certain rising BAU-related financial requirements. In the case of the mix-I pathway, the displacement is produced by both the reduction in final demand of 40 percent by 2050 and the shift from conventional to advanced transportation, which displaces more expensive petroleum-based transportation.

[50] The projected LAC GDP for 2050—$19 trillion, measured in 2005 dollars—comes from the IIASA GEA Scenario Database's message model and reflects an assumption of approximately 3.6 percent average annual growth between 2010 and 2050 for the region. For comparative purposes, LAC's GDP for 2010 (in 2005 dollars) was $4.6 trillion.

[51] Note that the average net financial abatement cost of mitigation is not the same as the well-known "marginal abatement cost" (or MAC) of mitigation activities. Rather, it is the per tCO_2e average of the net additional financial costs (that is, the necessary financial resources in addition to those that would be required in any case under the BAU trajectory) of any particular mitigation pathway.

Table 2.5 Emissions Pathways: Cost from 2010 to 2050

Alternative pathways* (based on ZNDD 2020/ ZNLU 2030)		Financial cost** $ billion/ year 2020	Financial cost** $ billion/ year 2050	Percent of GDP (LAC, PPP) $19 trillion (2005) in 2050	Average financial cost (2005 $)/ tCO$_2$e in 2050	Total and per capita emissions 2050 GtCO$_2$e and tCO$_2$e
ZNDD 2020/ ZNLU 2030***		18	37	0.19	23	6.06
						8.06
ZNDD 2020/ ZNLU 2030+***		18	53	0.28	23	5.36
						7.15
AFOLU+**		19	64	0.33	19	4.27
						5.89
Moderate intervention "mix-I" (adv. transport)	Total	132	508	2.67	129	2.78
	Net of BAU	-8.2	43	0.23	11.0	3.71
Moderate intervention "mix-II" (conv. transport)	Total	144	485	2.60	122	2.76
	Net of BAU	3.1	20.3	0.1	5.1	3.68
Moderate intervention "efficiency-I" (adv. trans.)	Total	115	450	2.36	128	3.21
	Net of BAU	-25	-15.0	-0.07	-4.0	4.29
Moderate intervention "supply-I" (adv. trans.)	Total	162	544	2.86	131	2.59
	Net of BAU	22	80.0	0.42	19.0	3.45
Moderate intervention "supply-II" (conv. trans.)	Total	203	588	3.10	141	2.57
	Net of BAU	62	124.0	0.65	30.0	3.42
Aggressive mix-I (adv. trans.)	Total	150	545	2.87	118	2.09
	Net of BAU	10.0	81.0	0.43	17.4	2.79
Aggressive-I efficiency (adv. trans.)	Total	133	487	2.56	117	2.55
	Net of BAU	-7	23.0	0.12	5.4	3.40
Aggressive-I supply (adv. trans.)	Total	180	581	3.10	121	1.92
	Net of BAU	40	117.0	0.62	24.0	2.56
Aggressive mix-II (conv. trans.)	Total	162	522	2.75	113	2.10
	Net of BAU	21	58.0	0.31	12.5	2.80
Aggressive-II efficiency (conv. trans.)	Total	136	478	2.52	113	2.50
	Net of BAU	-4.7	14.0	0.07	3,2	3.35

Aggressive-II supply (conv. trans.)	Total	221	626	3.30	130	1.90
	Net of BAU	80.5	161.0	0.85	33.0	2.53
Aggressive mix-I+ (adv. trans.)	Total	150	561	2.95	105	1.39
	Net of BAU	10	97.0	0.51	18.0	1.86
Aggressive-I+ efficiency (adv. trans.)	Total	133	503	2.65	103	1.85
	Net of BAU	-7	39.0	0.21	8.0	2.46
Aggressive-I+ supply (adv. trans.)	Total	180	597	3.14	109	1.22
	Net of BAU	40	133.0	0.70	24.0	1.63
Aggressive mix-II + (conv. trans.)	Total	162	538	2.83	101	1.41
	Net of BAU	21	74.0	0.39	14.0	1.88
Aggressive-II+ efficiency (conv. trans.)	Total	136	494	2.60	100	1.81
	Net of BAU	-4.7	30.0	0.16	6.0	2.42
Aggressive-II+ supply (conv. trans.)	Total	221	642	3.40	116	1.20
	Net of BAU	80	177.0	0.93	32.0	1.60
Aggressive mix-I AFOLU+ (adv. trans.)	Total	151	571	3.00	89	0.31
	Net of BAU	11	107.0	0.56	17.0	0.41
Aggressive-I AFOLU+ efficiency (adv. trans.)	Total	134	513	2.70	86	0.76
	Net of BAU	-6	49.0	0.26	8.0	1.02
Aggressive-I AFOLU+ supply (adv. trans.)	Total	181	607	3.20	92	0.14
	Net of BAU	41	143.0	0.75	22.0	0.18
Aggressive mix-II AFOLU+ (conv. trans.)	Total	163	548	2.90	86	0.33
	Net of BAU	22	84.0	0.44	13.0	0.44
Aggressive-II AFOLU+ efficiency (conv. trans.)	Total	137	504	2.65	84	0.73
	Net of BAU	-3.5	40.0	0.21	6.60	0.97
Aggressive-II AFOLU+ supply (conv. trans.)	Total	222	652	3.40	99	0.11
	Net of BAU	82	187.0	0.98	28.0	0.15

Source: Version 2.0.rc1 of the GEA Scenarios Database of IIASA and authors' elaboration.
Note: *All pathways presented here assume nuclear-free development, that is to say, no nuclear expansion beyond the current reactor infrastructure, which in any event only contributes 0.8 percent of the region's current primary energy mix.
**Financial cost (net of BAU) = projected annual energy capital investment plus annual operation and maintenance costs to the energy system and other nonenergy expenditures related to REDD+ (halting of deforestation, net creation of carbon sinks) and the abatement of non-CO_2e emissions. Financial cost (net of BAU) = net financial additionality: these costs are incremental costs to the system corresponding to the different potential interventions. The average financial cost of abatement is also presented in both total (gross) and net terms.
***The ZNDD 2020/ZNLU 2030, ZNDD 2020/ZNLU 2030+ and AFOLU+ costs are derived internally from the GEA mix model's land-use expenditures and emissions reductions. While these land-use cost estimates are well within the range of other existing estimates, the wide variability of existing estimates suggests caution when assessing the potential costs of land-use emissions abatement.

Net additional financial costs of the major interventions required under the aggressive mix-I+ (plus) pathway

To facilitate investment planning, this section summarizes the annual projected gross and net additional financial costs by 2050 at the sector—or policy intervention—level (that is, deforestation and land use, agriculture, efficiency, power, and transportation). Further elaboration on how projections were formulated can be found in annex 3.

A halt to deforestation (ZNDD 2020) and land-use (ZNLU 2030) emissions, and the augmentation of carbon sinks ("plus" pathways)

In order to reach the goals of zero net deforestation by 2020, zero net land-use emissions by 2030, and net additional sinks by 2050, "net additional financial costs" would be required, beginning immediately and reaching $53 billion by 2050 (see table 2.5). Gross and net financial additionality for the ZNDD 2020/ZNLU 2030 pathway are the same ($37 billion annually for 2050), given that there are no expenditures projected under the BAU trajectory for the LULUCF sectors.[52] These net additional land-use expenditures would be spent on:

- Efforts to increase the productivity of forestry and agricultural activities to avoid any additional forest cover loss (urgent action will be required to combat emerging threats to forests, including damage from uncontrolled mining in the Amazon and Andes Piedmont regions)
- The costs of enforcing deforestation restrictions
- The costs of REDD/REDD+ readiness and implementation, which, combined with transactions costs (related principally to land-use governance), typically make up as much as one-third of total net financial additionality for LULUCF mitigation activities
- Investments in the support and enhancement of carbon sinks, among other activities

This last cost component ($16 billion spent annually by 2050 on the net addition of sinks) is likely to be even more challenging than simply arresting deforestation by 2020, and all other LULUCF emissions by 2030 (that is, ZNLU 2030).[53] This more rigorous pathway would also require major improvements in forestry, land-use planning, agriculture, and animal husbandry practices (some of which are yet to be deployed widely).[54] Innovative forestry conservation and sustainable land-use management practices will need to be implemented on a progressively wider scale.

This implies acceleration of recent trends that are not yet fully consolidated and are only likely to be achieved through strong policy, vigorous regulatory and enforcement action, and forceful economic incentives.

A significant reduction of agricultural emissions

To cut agricultural emissions in half by 2050, the study estimates that gross and net additional costs of $10 billion would be required (no expenditures on nonenergy mitigation activities are projected for the BAU). The required expenditures would include: the marginal costs for market entry of new low-carbon agricultural practices; the costs of dissemination, extension services, and awareness; investments in new cultivars that reduce the need for agricultural inputs, such as synthetic fertilizers and pesticides; the conversion process to maximize local and organic agriculture; and others.

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[52] These gross and net figures for financial additionality required to achieve the ZNDD 2020/ZNLU 2030 pathway come directly from table 2.5 (see the relevant section in annex 3 for a detailed explanation of how these projections were formulated).

[53] To meet the 2 tpc target, the aggressive mix-I+ pathway would need to increase carbon sinks enough to achieve annual net negative land use emissions of 0.35 $GtCO_2e$ by 2040 and annual net negative land use emissions of 0.7 $GtCO_2e$ by 2050.

[54] There are significant areas of overlap between LULUCF mitigation activities and agricultural mitigation activities. Major synergies might be exploited through pursuit of the more inclusive and holistic approach implied in the AFOLU+ pathway. Although we have projected LULUCF net financial additionality separately from that of agriculture, there is clear potential to reduce financial requirements by integrating the approaches and taking advantage of such synergies.

Table 2.6 AFOLU+ Pathway Components: Required Financial Additionality, 2050 ($ billions)

Sector components	Gross additional annual total by 2050	Annual total expenditures under BAU by 2050	Net additional annual total by 2050
ZNDD 2020/ZNLU 2030 (net zero deforestation by 2020 and net zero land-use emissions by 2030)	$37	No expenditures projected under the BAU	$37
ZNDD 2020/ZNLU 2030+ (Additional net carbon sinks)	An additional $16	No expenditures projected under the BAU	An additional $16
Agriculture (50 percent reduction against BAU by 2050)	An additional $10	No expenditures projected under the BAU	An additional $10
AFOLU+ pathway	$63	—	$63

Source: IIASA GEA model database and authors' elaboration.
Note: AFOLU cost projections here assume the development of the mix-II (conventional liquid transportation) pathway. But each GEA illustrative pathway implies slightly different AFOLU costs. This accounts for the slight deviation between the total gross additional financial requirements of the aggressive I+ (plus) pathway ($560 billion annually in 2050) and a simple summation of AFOLU costs (assuming mix-II) and energy costs (assuming mix-I), or $571 billion in 2050. Such a $10 billion–$20 billion variation is typical among gross financial additionality projections (particularly in the realm of AFOLU) for the various pathways. See table 2.4.

Increased energy efficiency

In order to improve energy efficiency enough to reduce final demand by 40 percent compared to BAU, the necessary net additional expenditures would reach $88 billion annually by 2050 (once all related projected expenditures under the BAU have been discounted; see table 2.7). Required gross additional annual expenditures—compared to the "current" level of expenditures in 2010—would rise to $104 billion in 2050 (see annex 3 for a detailed explanation of projected efficiency-related expenditures under the BAU).

Table 2.7 Moderate Energy Mix-I Pathway Components: Required Financial Additionality, 2050 ($ billions)

Sector components	Gross additional annual total by 2050	Annual total expenditures under BAU by 2050	Net additional annual total by 2050
Energy efficiency (final demand 40 percent below BAU by 2050)	*104*	*16*	*88*
—demand-side investment	83	0	83
—electricity transmission & distribution	21	16	5
Decarbonization of electricity (more than 90 percent of installed capacity)	*133*	*67*	*66*
—investment in nonfossil electricity	62	31	31
—electricity transmission and distribution	21	16	5
—unallocated IIASA noninvestment expenditure	50	20	30
Electrification of transportation	*50*	*20*	*30*
—unallocated IIASA noninvestment expenditure	50	20	30
Carbon capture and storage	*17*	—	*17*
—investment in CCS	7	0	7
—unallocated IIASA noninvestment expenditure	10	0	10
Other energy actions	*204*	*362*	*-158*
—investment in fossil fuel extraction	54	170	-116
—investment in fossil electricity generation	2	4	-2
—"other" supply-side investment (district heat, oil refineries, bioenergy extraction, production of hydrogen, synfuels)	42	38	+4
—unallocated IIASA noninvestment expenditures (fuel and other energy inputs, both private spending and public subsidies)	106	150	-44
Moderate energy mix-I pathway	*508*	*465*	*44*

Source: IIASA GEA model database and authors' elaboration.
Note: This energy pathway (a) requires over $2.1 trillion in cumulative gross additional investment in transmission and distribution (including storage) and in non-fossil-fuel-generated electricity; (b) achieves 97.8 percent low-carbon generation by 2050, counting biomass without CCS and all forms of generation with CCS as low-carbon sources.

These financial requirements stem from the estimated marginal additional costs of adopting new energy conservation and efficiency practices and technologies, the dissemination costs of adopting new energy efficiency practices, and additional operational and maintenance costs. Any effort to abate final energy demand by 40 percent compared to the BAU can only be successful through bulk improvements in energy efficiency, as well as other net reductions in demand.

Decarbonization of the power sector

By 2050 the costs of achieving 97 percent decarbonization of the LAC power sector would require $133 billion annually in gross financial additionality and $66 billion annually in net terms (once fossil-fuel electricity and grid-related investment expenditures projected under the BAU have been discounted). Such net additional expenditures would cover: (i) the additional annualized costs of generation caused by entry of renewable energy resources, (ii) the costs of upgrading and expanding transmission grids, including the expenditures required to incorporate intermittent sources (that is, the costs of additional reserves to manage firm capacity of intermittent sources), and (iii) costs related to additional capacity-building and training of grid operators.

Arresting and reversing the current carbonization path of the regional power matrix by 2050 would imply a major shift toward rapid deployment of the substantial renewable energy endowment in the region. Fortunately, there is a sizable endowment of solar, geothermal, wind and other resources in the LAC region that can be put to use. Some other resources (marine energy, for example) are not yet commercially available, but could be, if a strong technology push is adopted that would target barriers to market entry. Large-scale entry of marine energy in the coastal nations may revert in substantial technological benefits, as techniques and practices are developed to attend to local conditions. Actions would also be needed to remove barriers to private investment in the power sector.

Electrification of transport

To achieve widespread electrification of the transport sector, our estimated projection foresees net additional expenditures of about $30 billion annually by 2050 ($50 billion annually in gross terms, compared with $20 billion annually projected under the BAU by 2050; see table 2.8, and annex 3). This would include the additional capital and net additional operation and maintenance costs of electric systems, power storage and charging stations, training for operators of public transport systems and maintenance stations, and roll-out of an electric vehicle fleet.

A continuing low-, or near-zero, carbon power matrix would be required to support a low carbon transport sector by 2050. To decarbonize the transport sector, public modes would need to be quickly electrified, using novel technologies that allow for high density energy storage and fast charging stations. Fortunately, the large investments already made in bus rapid transit systems (BTRs) can accommodate with relative ease the adoption of battery-powered vehicles. Deployment of these technologies would also benefit local technology development. Total decarbonization would also require that automobiles and freight vehicles move away from internal combustion engines. Whereas this was just an aspirational goal a few years ago, recent technology developments allow for the possibility of quick electrification of all modes of transport in the region.

Together, the six principal interventions analyzed above (halting deforestation, augmenting carbon sinks, reducing agricultural emissions, improving energy efficiency, decarbonizing the power sector, and electrifying transport) would entail total gross additional financial expenditures of $350 billion annually by 2050 (see table 2.9). But this is still some $210 billion annually below the total gross financial additionality (the total amount of finance that must be mobilized). Furthermore, because a projected $103 billion required annually under the BAU will be displaced (or "saved" in terms relative to the BAU), under the reference intervention pathway (aggressive mix-I+), the net financial additionality required to implement these six interventions would only be $247 billion annually by 2050.

Table 2.8. Priority Mitigation Interventions: Required Financial Additionality, 2050 ($ billions)

Sector components	Gross additional annual total by 2050	Annual total expenditures under BAU by 2050	Net additional annual total by 2050
ZNDD 2020/ZNLU 2030	37	0	37
ZNDD 2020/ZNLU 2030+	16	0	16
Agriculture: (50 percent reduction against BAU by 2050)	10	0	10
Energy efficiency	104	16	88
Decarb power	133	67	66
Electrification of transportation	50	20	30
Subtotal	350	103	247

Source: IIASA GEA model database and authors' elaboration.

Other interventions and financial requirements of the aggressive mix-I+ (plus) pathway

There are other costs associated with actions to be taken under the reference pathways. First, CCS efforts under the intervention pathways would require an additional $17 billion annually by 2050, in both gross and net terms, as no CCS expenditures are projected under the BAU (see table 2.8).

Second, a range of other energy actions are incorporated into the reference pathways, including: (i) investment in fossil extraction ($54 billion annually in 2050, versus $170 billion annually under the BAU; or negative -$116 billion annually, in net terms, once displaced BAU expenditures have been discounted); (ii) investment in fossil electricity generation ($2 billion annually in 2050, versus $4 billion annually under the BAU); (iii) "other" supply-side investment ($42 billion annually in 2050, including investments in oil refineries, district heat, and bioenergy extraction, as well as production of hydrogen and synfuels, versus $38 billion annually under the BAU); and (iv) other "noninvestment expenditures" that are estimated within the overall intervention pathways, but which are not allocated to any specific line items by IIASA as discrete projections ($106 billion annually by 2050, versus $150 billion annually under the BAU).[55]

These "other" financial expenditures required under the aggressive mix-I+ (plus) pathway are projected to reach $204 billion annually in 2050, in gross terms. But in terms of net financial additionality, this "other" category turns out to be negative (-$158 billion annually by 2050).

This implies that, compared to the BAU trajectory, the aggressive mix-I+ (plus) pathway involves significantly fewer new additional annual expenditures in certain subsectors, in which large savings are reaped because of lower future investment in expensive fossil-fuel extraction and generation (by far the largest cross-sectoral savings from the aggressive mix-I+ (plus) pathway: around $118 billion annually in savings in 2050, when compared with the BAU), and from lower "noninvestment" spending on increasingly costly fossil fuels for transportation and electricity consumption ($44 billion annually in savings in 2050; see tables 2.6 and 2.8).

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[55] Much of this large projected additional financial requirement under the BAU trajectory stems from the rising price of fossil fuels in particular, and of carbon in general, projected to occur in the future. Increasingly expensive fossil fuel, extraction, transport, refining and processing, and distribution represents much of the potential "savings" available through a displacement of the BAU trajectory by our reference intervention pathways.

The projected additional financial requirements described above are presented in both gross and net terms.[56] Nevertheless, this is not the most relevant category of required financial additionality, given that current financial expenditures on energy and AFOLU sectors will be insufficient to meet the rising demands of both over the decades until 2050.

Indeed, total additional financial expenditures required under the BAU are also much greater than the current financial expenditures required to maintain the status quo: an additional $464 billion in financial expenditures will be required annually by 2050 (compared to those required at present) just to meet rising LAC energy demand projected under the BAU trajectory and without any additional emissions mitigation efforts. This means that even if LAC actors do nothing to change the current policy trajectory, required annual financial additionality will rise to $464 billion annually by 2050. Meanwhile, LAC emissions would increase from around 4.7 $GtCO_2e$ in 2010 to around 6.7G tCO_2e (or from over 6 t/CO_2e to over 9t/CO_2e, in per capita terms; see the previous section on projected emissions in the BAU scenario). In that context, a more relevant category of financial additionality for the evaluation of policy and budget options would be what we have termed total net additional financial requirements: the result of discounting the additional financial expenditure required under the BAU from the total gross financial additionality required to achieve a particular intervention pathway.

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[56] For the six principal intervention components identified and analyzed above, these gross and net additional financial requirements are projected to collectively total $350 billion and $247 billion annually, respectively, by 2050. For the entire aggressive mix-I+ (plus) pathway, gross and net additional financial requirements are projected to reach $561 billion and $96 billion annually, respectively, in 2050. This distinction between gross and net financial additionality required is important, and easily misunderstood. It should be remembered that our projections for the total amount of additional financial resources required—for any intervention component (that is, decarbonization of the electricity sector) or any pathway (like aggressive mix-I+ (plus))—come directly (in the case of energy interventions) and indirectly (in the case of the LULUCF/AFOLU interventions and pathways) from the financial projections contained in IIASA's GEA model database (see annex 3 for a full explanation of our use of IIASA's emissions and financial projections to generate our own AFOLU and energy pathways). But IIASA's financial projections are presented explicitly only in what we have termed gross terms: that is, the amount of additional investment and noninvestment expenditures required to achieve the aggressive mix-I+ (plus) pathway by 2050 starting from the current situation (or, more accurately, 2010). In the case of the aggressive mix-I+ (plus) pathway—as can be seen in tables 2.4 and 2.8, and in annex 3)—this required financial additionality comes to $561 billion annually by 2050, above and beyond what is currently being spent on energy and land-use change across LAC. These gross financial requirements are "additional" relative to past and current financial requirements. In other words, it represents the increase in annual financial requirements compared to the present.

Table 2.9. Aggressive Mix-I+ (plus) and Aggressive Mix-I AFOLU+ (plus) Pathway Components ($ billions)

Sector components	Gross additional annual total by 2050	Annual total expenditures under BAU by 2050	Net additional annual total by 2050
ZNDD 2020/ZNLU 2030	37	0	37
ZNDD 2020/ZNLU 2030+	16	0	16
Energy efficiency	104	16	88
Decarb power	133	67	66
Electrification of transportation	50	20	30
CCS	17	0	17
Other energy actions	204	362	–158
Aggressive mix-I+ (plus) pathway total	561	465	96
Additional Aggressive mix-I AFOLU+ (plus) pathway component			
—Agriculture: (50 percent reduction against BAU by 2050)	10	0	10
Aggressive mix-I AFOLU+ (plus) pathway total	571	465	106

Source: IIASA GEA model database and authors' elaboration.
Note: Electricity output under the aggressive mix-I+ (plus) pathway is 12 percent higher than in the BAU pathway, due to greater electricity use from the electrification of transportation. The aggressive mix-I+ (plus) pathway implies savings over the BAU pathway in the areas of fossil-fuel-generated electricity and fossil-fuel extraction of $128 billion annually by 2050.

Significant additional finance will indeed need to be mobilized between now and 2050, in any case: $561 billion annually by 2050, and approximately $11.2 trillion in cumulative terms, under the aggressive mix-I+ pathways; and $464 billion annually by then, and $9.3 trillion cumulatively under the BAU. In other words, the gross financial additionality will not be much higher than that required simply to move from the status quo present into the future along a business-as-usual trajectory. Even without any additional mitigation policy actions, LAC will still have to spend $464 billion annually by 2050 under the BAU trajectory (or approximately $9.3 trillion in cumulative terms to 2050). These financial expenditures projected under the BAU are equivalent to more than 80 percent of what would be required to achieve the aggressive mix-I+ (plus) pathway.

The implication is that for less than $100 billion annually in 2050 (or less than $2 trillion cumulatively) in incremental, or "net," additional financial requirements, the region could reduce its emissions from its projected level in 2050 under the BAU (9.3 t/CO_2e per capita) to a level consistent with defending the 2°C guardrail analyzed in the introduction (2 t/CO_2e), far below the current level of 6.4 t/CO_2e. Indeed, the marginal additional finance required to meet the 2 t/CO_2e per capita target would be less than 20 percent over what the amount that will need to be mobilized anyway. In this sense, the most relevant category for determining pathways and policies remains the net additional financial requirement.

While gross financial additionality indicates the funds needed to achieve any emissions mitigation objective, net financial additionality represents the additional effort required in comparison to the BAU trajectory. The net additional financial requirements category can also be thought of as the "savings" implied by displacing (or taking advantage of) the additional financial resources that are necessarily built into the status quo trajectory.

In sum, if LAC can afford to spend an additional $464 billion annually by 2050 under the

BAU trajectory, while continuing to rely on fossil fuels and allowing regional emissions increase by more than 40 percent, then the region can certainly afford to spend an incremental $97 billion annually (over what must be spent in the BAU) by 2050. This is particularly clear given the additional economic, social, political, environmental, and technological cobenefits (see chapter 3) that should stem from a significant mitigation effort.

The systemwide nature of projections for financial additionality, and policy implications

Finally, it is important to keep in mind that the IIASA projections for required financial additionality, and the extensions of their projections, are systemwide, incorporating all expenditures required across the region's entire energy system, regardless of the nature of the actors involved (that is, public and private sectors, producers and consumers). Investment includes all public and private investment, and noninvestment expenditures include not only operations and maintenance of public and private aspects of the system, but also all of the expenditures required to purchase the final energy product. Such expenditures are undertaken both by private household, commercial, and industrial consumers, on the one hand, and by states in the form of subsidies to maintain price controls or other types of public support for private purchase of final energy, on the other.

The nature of such financial projections facilitates evaluation of policy and investment priorities across the entire system. Often, this makes it easier to compare the substantial built-in financial costs of the status quo (BAU) trajectory with the financial additionality required under available intervention options.

Chapter 3

Development Cobenefits from Adaptation and Mitigation

Climate impacts will impose substantial costs on development. This report estimates these costs at approximately $100 billion per year by 2050, equivalent to approximately 2.2 percent of 2010 gross domestic product (GDP). Reducing the carbon footprint of the region to levels consistent with global climate stabilization goals will require a similar annual figure. These costs would add to the region's already pressing investments needs, which include poverty eradication and better health, education, food, water and energy security, and housing. But these costs must be addressed because pursuing a path that ignores adaptation and mitigation needs would likely make development efforts less effective.

As posited by Wilbanks et al. (2007), the physical impacts of climate change depend on atmospheric concentrations of greenhouse gas (GHG) emissions and the capacity to adapt to these changes. Thus, mitigation and adaptation targets are interrelated—mitigation attenuates the risks of global climate change, while adaptation ameliorates specific impacts in a particular location. Additionally, some mitigation and adaptation actions might interact with one another to create synergies or might offer different alternatives to tackle a climate change impact.

Development cobenefits from adaptation

The magnitude of the adaptation problem and the associated financial needs for the region are far in excess of the resources available today for this purpose. That said, the information at hand implies that the cost of adaptation efforts is probably lower than the costs of physical damages (as seen in chapter 1). This finding highlights the need to invest early in adaptation. Unless addressed, physical impacts will represent a heavy burden to development agendas in the region.

Adaptation has the potential to not only reduce the net impact of climate consequences but also support the overall sustainability of development in Latin American and the Caribbean (LAC). Rather than being viewed as separate from development (Leary et al. 2008), adaptation should be seen as an integral component of development.

Whereas development needs are immediate, the problems created by climate change, though substantial, are perceived as gradual, far off, and (in some cases) uncertain. But a lack of action on adaptation will only generate more development needs in the future, as the effects of climate change limit access to and the quality of natural resources. Thus, adaptation measures should be tightly intertwined with development to increase the long-term sustainability of development policies.

Adaptation actions can contribute to sustainable development practices and produce cobenefits. Table 3.1 summarizes some of the cobenefits expected from adaptation actions by sector or area of concern. These cobenefits include improved water and food security, technology development, and progress toward long-term development goals.

Adopting adaptation policies would also improve the use of natural resources, which would trigger associated gains in productivity. For example, investments today to adapt the water supply to the impacts of climate change would result in better management practices and a reduction in waste. Likewise, improvements in the management of fisheries to address climate impacts would generate more sustainable practices, further reductions in waste, and additional improvements in productivity.

Even with forceful adaptation actions in place, only a major reduction in GHG emissions will affect the long-term future. Mitigation is the ultimate firewall against lasting damages to the biosphere and the human activities it sustains.

Table 3.1 Adaptation Cobenefits by Sector

Adaptation investment	Development cobenefit
Adapting agriculture to new climatic conditions	• Technological development and innovation • Maintenance of natural land cover and services of ecosystems • Arrest of land degradation • Recovery of degraded lands
Minimizing the impact of sea-level rise on coastal zones through protection and retreat	• Long-term land zoning • Development of resilient infrastructure and coastal settlements • Improved waste and sanitation management • Reduced health impacts
Recovering coral biome	• Maintenance of environmental services, including coastal protection, tourism, and fisheries
Adapting to new hydrology regimes	• Improvements in productivity • Maintenance of ecosystem services
Minimizing exposure to tropical vector diseases	• Improved public health and longer life expectancy • Improved productivity and reduced loss of life
Adapting based on biodiversity and ecosystems	• Maintenance of ecosystem services • Maintenance of environmental services

Source: Authors’ compilation.

Development cobenefits from mitigation

The mitigation effort required for LAC to reach the 2 tons of carbon dioxide equivalent (tCO_2e) per capita goal by 2050 would also generate significant cobenefits for the region, including improvements in human health and welfare, enhanced energy security, and more technological development. These cobenefits, valued at \$2-\$196/tCO_2 for air quality alone (Nemet, Holloway, and Meirer 2010), could make the mitigation investments and expenditure outlays analyzed in chapter 2 appear more feasible. Beyond the direct mitigation benefits of avoiding costly future climate change and adaptation policies, such cobenefits also provide further economic incentives for LAC countries to engage more fully in the effort to forge an effective and workable post-2012 global climate agreement.

Potential mitigation cobenefits are large enough to encourage a number of mitigation actions (see table 3.2). Mitigation cobenefits have been estimated to amount to anywhere from 30 percent to 100 percent (or more) of total abatement costs (Bollen et al. 2009; Pearce et al. 1996; IPCC 2001). Most (70 percent–90 percent) of these estimated cobenefits are health related, stemming from lower levels of local air pollution, improvements in water quality, and superior sanitation (Aunan, Aaheim, and Seip 2000). This concentration of health-related cobenefits suggests that within the region's overall mitigation efforts, low-carbon energy strategies—particularly transportation policy interventions in urban zones and the promotion of distributed renewable power, including modern cook stoves, in rural areas—should be prioritized, along with mitigation interventions in the waste and sanitation sectors.

Furthermore, the cobenefits of emissions mitigation are usually local, whereas the direct benefits of mitigation tend to be global in nature. These locally accrued cobenefits (table 3.2) can potentially stimulate key stakeholders from the public and private sectors as well as at the grassroots level to actively engage the problem of climate change. Because climate change is a global phenomenon, it is often perceived to be irrelevant to local interests. In the end, however, emissions mitigation is not a purely international public good; it is often a local public good as well (OECD 2002).

For example, low-carbon energy actions can cut emissions, but they also tend to reduce energy demand (through efficiency measures) or provoke shifts in the energy mix toward cleaner sources (through the rollout of renewables). As a result, mitigation policies reduce local air pollution, leading to lower morbidity and mortality. Additionally, by reducing acid rain, these policies can generate higher crop yields and lower maintenance costs for buildings (and other structures). Similarly, transportation activities could produce further cobenefits beyond those stemming just from lower air pollution.

These cobenefits include reduced urban congestion, lower noise levels, and possibly even fewer road fatalities as a consequence of fewer vehicle miles traveled. Finally, cutting emissions by halting deforestation and creating carbon sinks, forestry, agriculture, and other land-use mitigation practices could also protect biodiversity and related ecosystem services as well as reduce soil erosion and agricultural productivity losses through intensified reforestation and tree farming, changes in agricultural practices and technologies, and the creative rethinking of the role of forest and agricultural land-use policies in sustainable development (Hecht 2012).

Table 3.2 Mitigation Cobenefits

Area	Cobenefit
Economic	• Employment, net job creation, and income • Human capital accretion • Technological development and innovation • National competitiveness (value-added chain)
Development / environmental	• Energy access and reduction of energy poverty • Local community benefits • Biodiversity and other ecosystem services • Reduced soil erosion • Improved agricultural productivity • Reduced acid rain
Human health	• Reduced air pollution • Improved water quality • Improved waste and sanitation management • Improved public health, longer life expectancy, reduced emergency room visits, and fewer work days lost
Strategic	• Energy security • National competitiveness

Source: Riahi et al. (2011) and authors' elaboration.

In addition, climate change, pollution, and energy security goals could be simultaneously achieved, with significantly reduced energy costs, if multiple economic benefits are properly accounted for. Note that the investment and savings figures presented in table 3.3 are global in scope. While the savings in LAC would correspond to a smaller fraction of these global figures for cobenefit gains, their significance should still be noteworthy for the region.[57]

Table 3.3 Additional Benefits of Pursuing Various Objectives Simultaneously at the Global Level

Cobenefit	Investment required if pursued in isolation ($billion/yr)	Benefits	Additional synergistic benefits from an integrated approach ($billion/yr)
Universal modern energy access (provision of electricity and modern heating and cooking fuels)	22–38	24 million DALYs (disability-adjusted life years) saved in 2030	
Tightened pollution controls	200–350 by 2030 (10 percent–20 percent of total energy costs)	21 million DALYs saved in 2030	Up to $500 billion saved annually by pursuing stringent climate objectives at the same time
Enhanced energy security (reduced import dependence, increased exports, and diversification)	Strengthened macroeconomic positions; heightened geopolitical influence	Decarbonization could reduce the need for fossil fuel subsidies (oil and coal) to affluent populations: $70 billion–$140 billion/yr by 2050	The extensive decarbonization required by the pathway's climate objective could translate into global costs savings of $150 billion/yr

Source: Riahi et al. (2011) and authors' elaboration.

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[57] IIASA's GEA message pathways model does not break down such cobenefits and savings on a regional basis. Therefore, the global figures are presented instead.

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Annex 1

IPCC Emissions Scenarios

In 1996 the Intergovernmental Panel on Climate Change (IPCC) decided to develop a new set of emissions scenarios (the so-called Special Report on Emissions Scenarios, or SRES) that provided input to the IPCC's Third Assessment Report (TAR) in 2001. The scenarios of SRES were also used for the Fourth Assessment Report (AR4) in 2007. Since then, the SRES scenarios have been subject to discussion because the emissions growth since 2000 might have rendered these scenarios obsolete. It is clear that the fifth assessment report of the IPCC will develop a new set of emissions scenarios.

The SRES scenarios cover many of the main driving forces of future emissions, which range from demographic to technological and economic developments. None of the scenarios include any future policies that explicitly address climate change, although all scenarios necessarily encompass various policies of other types and for other sectors. The set of SRES emissions scenarios is based on an extensive literature assessment, six alternative modeling approaches, and an open process that solicited wide participation and feedback from many scientific groups and individuals. The SRES scenarios include emissions of all relevant greenhouse gases (GHGs) and sulfur, and their underlying driving forces.

For the scenarios, the IPCC developed different narrative storylines to describe the relationships between emission driving forces and their evolution over time (figure A1.1). Each storyline represents different demographic, social, economic, technological, and environmental developments. Each emissions scenario represents a specific quantitative interpretation of one of the four storylines. All scenarios based on the same storyline constitute a so-called scenario family.[58]

The A1 storyline describes a future world characterized by rapid economic growth, a global population that peaks by the mid-21st century (and declines thereafter), and the rapid introduction of new and more efficient technologies. The major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system: fossil-intensive energy sources (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

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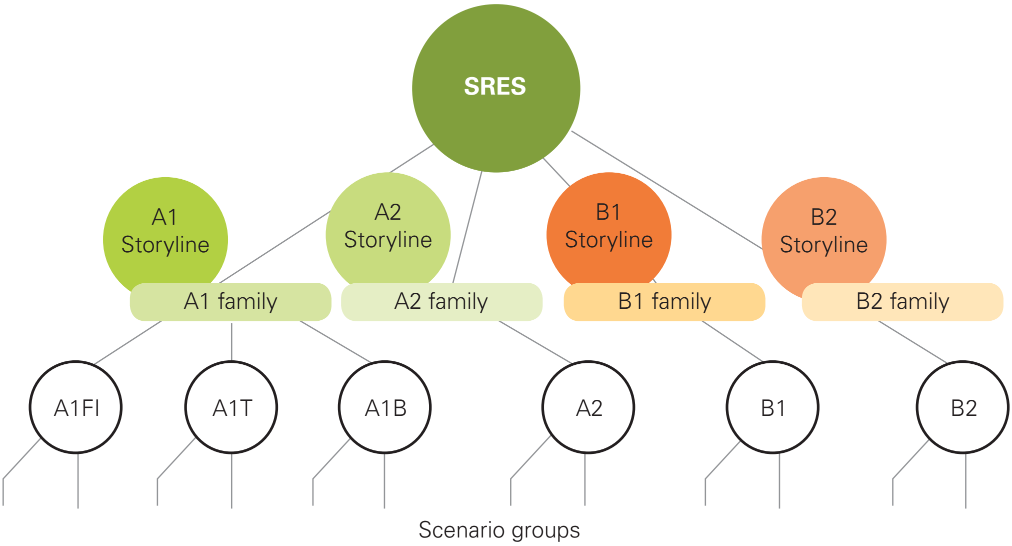
[58] For each storyline, several different scenarios were developed using different modeling approaches.

Figure A1.1 Schematic Illustration of SRES Scenarios



Source: Adapted from IPCC (2000).

The A2 storyline describes a more heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The global population increases continuously. Economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slower than in the other storylines.

Similar to the A1 storyline, the B1 storyline describes a convergent world where the global population peaks in mid-century and declines thereafter. But in the B1 storyline, there are rapid changes in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions that include improved equity without requiring additional climate initiatives.

The B2 storyline describes a world that emphasizes local solutions to achieving economic, social, and environmental sustainability. It includes a global population increasing continuously at a rate lower than A2, intermediate levels of economic development, and technological change that is less rapid and more diverse than that in the B1 and A1 storylines. The scenario is also oriented toward environmental protection and social equity because it focuses on local and regional levels.

Table A1.1 summarizes the likely temperature changes under each of the above-described scenarios.

Table A1.1 Projected Global Average Surface Warming and Sea-level Rise at the End of the 21st Century: Different SRES Scenarios

Case	Temperature change (°C at 2090-2099 relative to 1980-1999)[a,b]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[c]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Source: IPCC (2007).

Notes: All scenarios above are six SRES marker scenarios. Approximate CO_2 –eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the Working Group I TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550 ppm, respectively.

[a] Temperatures are assessed best estimates and likely uncertainty ranges from hierarchy of models of varying complexity as well as observational constraints.

[b] Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 and 0.5°C.

[c] Year 2000 constant composition as derived from Atmosphere-Ocean General Circulation Models (AOGCMs only).

Annex 2

IIASA GEA Scenarios

The moderate intervention (or energy) pathways presented in this report were derived from the three principal Global Energy Assessment (GEA) transformation pathways (GEA efficiency, GEA supply, and GEA mix) of IIASA's GEA message model and its GEA scenario database.[59] The GEA scenario database aims to document the results and assumptions of the GEA transformation pathways and serves as a central data repository for the dissemination of GEA scenario information.[60] For the purposes of this report, in order to contrast the potentials for Latin America and the Caribbean (LAC) to pursue land-use-based mitigation approaches versus energy-based strategies, the GEA transformation pathways have been stripped of their land-use emissions interventions, leaving purely "energy-based" intervention pathways and reductions of greenhouse gas (GHG) emissions produced solely from energy activities and use. On the other hand, our land-use pathways (ZNDD 2020/ZNLU 2030, ZNDD 2020/ZNLU 2030+ and AFOLU+) have then constructed upon the projected relationships between (i) projected financial costs (investment/expenditures) required, and (ii) the emissions reductions observed in the land-use and agricultural intervention realms of the original "full" GEA transformation pathways of the GEA scenario database (see annex 3 for a fuller explanation of our pathways and the projections).

Each of the three principal modified GEA illustrative pathways represents high (efficiency), low (supply), or intermediate (mix) levels of energy-efficiency improvements into the future. This is the first critical, defining difference between these three respective groups of pathways. In turn, each of the 41 GEA pathways shares this defining efficiency feature with its particular group's "illustrative case" (in a similar fashion to the family of storylines used by the IPCC for the creation of its scenarios; see annex 1). While all three pathway groups assume at least some improvement in the historical rate of decline in energy intensity, the GEA efficiency pathway assumes the most significant reduction, whereas the GEA supply pathway registers only minor improvements over the historical rate into the future. Meanwhile, the GEA mix pathway exhibits an intermediate level of energy efficiency and decline in energy intensities.

Additionally, depending on the following factors, each GEA pathway can differentiate itself at least slightly from each of the other pathways, even within the same group, by:

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[59] See http://www.iiasa.ac.at/web-apps/ene/geadb/dsd?Action=htmlpage&page=about#intro.

[60] For a complete and in-depth description of the GEA Message Model and its respective 41 pathways (including, in particular, the three "illustrative" pathways mentioned in this report), see Riahi et al. (2011).

- The type of transportation system (that is, a conventional, traditional "liquids-" transport infrastructure versus an advanced transport infrastructure based upon electrification and, in some cases, some use of hydrogen), assumed to dominate the economy in the future
- The energy sources—or technologies—assumed to be included (or excluded) from the energy and technology mix along any particular pathway

Therefore, the first "branching point" of a single possible future energy reality into distinctly separate scenarios (or pathways) concerns the level of preferred or potential, future energy-efficiency. The second major split of these three scenarios into still more pathways would be the type of assumed transportation system (conventional versus advanced). Finally, the third "branching point" of distinct scenarios into 41 potential pathways includes the range of energy sources and technologies assumed to be included in (or excluded from) the future mix.

What this study refers to as the moderate intervention pathways are basically identical to the three GEA illustrative pathways—mix, efficiency, and supply (in our study, mix-I, efficiency-I, and supply-I). In addition, this study's versions of the three moderate intervention (or "energy") pathways assumes the following:

- Only the energy interventions (expenditures and emissions reductions) of the pathway are to be included (nonenergy expenditures and emissions reductions have been stripped from the pathway, and used as the foundation for the construction of the distinct "land-use" pathways)
- The transportation system is assumed to be transformed, over time, from the current conventional, liquids-based, system to an advanced transportation system based on electrification
- Each pathway experiences nuclear-free development

The inclusion of a second moderate intervention (mix-II) pathway into this report's analysis is done for comparative purposes, and allows for the consideration of two different infrastructure development paths for the transportation sector in the future. The mix-II (conventional transport) pathway follows practices that maintain the conventional, status quo, liquids-based transportation system, with petroleum-based transport fuels giving way over time to biofuels (and, to some degree, "gas-to-liquids" synfuels). In contrast, the mix-I (advanced transport) pathway pursues a systemic transformation of the transportation sector through electrification of the transportation mix.

Furthermore, all of the GEA pathways share certain other common defining features as well, the most significant of which is significant mitigation of GHG emissions into the future. In each of the 41 GEA pathways that IIASA has assessed, IIASA finds that this reduction of emissions is significant enough to make a regionally appropriate contribution to a credible global defense of the 450 parts per million (ppm) atmospheric concentration limit and the 2°C guardrail by 2050 (Riahi et al. 2011). In fact, it is set as a minimum assumption of the model. Nevertheless, even before we stripped the pathways of AFOLU interventions and emissions reductions, the GEA model pathways were only capable of bringing LAC to around 3.2 tons per capital (tpc) a year, thus necessitating deeper, more effective, and more expensive AFOLU interventions.

If the GEA pathways are presented as only energy intervention scenarios, they would bring LAC to anywhere between 3.4 tpc and 4.3 tpc by 2050, and would therefore need to be supplemented with significantly more intensive AFOLU policy measures in order to follow the aggressive mix-I+ (plus) (combined) intervention pathway to the LAC goal of 2 tpc annually by 2050. In other words, the energy interventions bring LAC's per capita emissions from 9.3 under the BAU trajectory down to below 4 tpc; another 2 tpc must be reduced through AFOLU interventions in order to achieve the 2 tpc goal by 2050.

Significant decarbonization of the energy sector also unfolds in all of IIASA's GEA pathways, with low-carbon energy reaching 60 percent to 80 percent of the primary mix in all of the pathways, and 75 percent to 100 percent of the electricity mix in all cases, by 2050. For example, the central reference pathways in this study—the aggressive mix-I+ (combined) pathway—achieves 97 percent decarbonization of the electricity generation mix by 2050.

For the purposes of this report, the so-called moderate intervention pathway will generally be considered to be the mix-I energy pathway, and the aggressive intervention pathway will be taken to refer to the aggressive mix-I+ (combined) pathway unless one of the other group pathways is explicitly identified.

Distinguishing characteristics, features, assumptions, common benefits, and cobenefits of the GEA pathways

All of the 41 global pathways (when including all energy and AFOLU emissions for the entire world) would contribute to successfully limiting global temperatures to no more than 2°C over preindustrial levels by rapidly reducing the emissions from the energy sector (and achieving certain AFOLU emissions gains against BAU). At the global level, emissions will peak in approximately 2020 and then reach 30–70 percent of their 2000 levels by 2050. They will ultimately reach nearly zero or even negative values in the second half of the century.

All GEA energy pathways involve a rapid shift over the next 20 years, away from traditional biomass to modern fuels while providing (near) universal access to modern energy (both electricity and modern fuels for heating and cooking). The global investment required for such a reduction in energy poverty, and assumed for all pathways, ranges from $22 billion to $38 billion a year (half in Africa), according to IIASA. Such an investment would save 24 million DALYs (disability-adjusted life years) in 2030 as a result of the health improvements associated with access to modern energy while displacing reliance on traditional biomass.

All GEA energy pathways secure significantly tightened pollution controls through global investments of $200 billion to $350 billion annually by 2030 (10 percent–20 percent of energy costs). Such investments would save 21 million DALYs in 2030.

All GEA pathways imply enhanced energy security through reduced import dependence, source diversification, and increased resilience of energy systems (and in particular the electricity sectors). A focus on efficiency and renewable energy can increase the share of domestic supply in primary energy by a factor of 2, resulting in significantly reduced import dependence. They also promise to achieve the following (as adapted from Riahi et al. 2011):

- Improvement in the historical rate of energy intensity decline (1.2 percent per year since the 1970s); a 1.5 percent decline per year achieved by the supply pathway versus 2.2 percent achieved by the efficiency pathway. Nevertheless, different levels of final energy use are implied across the different pathways: for LAC, the efficiency pathways would produce energy end-use demand levels some 50 percent below the BAU levels in 2050; the mix pathways would imply energy end use 40 percent below the BAU levels in 2050; and the supply pathways would reduce energy end use to only 23 percent below the BAU levels in 2050
- A broad portfolio of supply options focusing on low-carbon noncombustible renewables, bioenergy, nuclear, and carbon capture and storage (CCS). This portfolio reaches low-carbon shares in the primary energy mix of 60 percent to 80 percent by 2050. For the specific pathways articulated in this study, nuclear power is assumed to be excluded
- Significant expansion of renewable energy beginning immediately and ultimately reaching 165–650 EJ (exajoules) in primary energy by 2050
- Increased storage technology that supports variable/intermittent solar and wind power
- Growth in bioenergy, particularly in the middle term, to 80–140 MJ by 2050. This would involve extensive use of agricultural residues and second-generation bioenergy technology to mitigate the adverse impact on land use and food production
- Increased use of fossil CCS as a bridge technology in the middle run, and increased reliance on CCS used with bioenergy in the long run (if demand is high, 250 $GtCO_2e$ of storage capacity will be needed by 2050)

- Aggressive decarbonization of the electricity sector, with the low-carbon share of the electricity mix reaching 75 percent to 100 percent by 2050. Conventional coal (without CCS) is phased out, and natural gas-fired power could be used as a "lower-carbon" bridge or transition technology in the short to middle run
- Enhancements in the transportation sector, including the possibility of electrification, the introduction of hydrogen vehicles, or the further development of the current liquid transportation infrastructure, with biofuels/synfuels substituting progressively for petroleum
- A reduction in fossil-fuel use. A peak in oil use in the transportation sector by 2030 would be followed by a phase out over the medium term and strong growth of liquid biofuels in the short and medium term. In the long term, the liquid-gaseous fuel mix would be determined by future decisions concerning the transportation system and by technological breakthroughs

All of the pathways would require investments—at the global scale—of $1.7 trillion to $2.2 trillion annually (compared with $1.3 trillion currently). Of this total, $300 billion–$550 billion would need to go to energy-efficiency measures/technologies on the demand side every year. Globally, total required investments would be equivalent to 2 percent of global GDP. There is a limited role for nuclear in some versions of the pathways. But it can be avoided in all of them, without significantly affecting net financial additionality. In our versions of the pathways, nuclear energy has been excluded.

Annex 3

Basis for Projections for "Net Financial Additionality" and Activity Costs of Mitigation Efforts

Chapter 2 presented financial cost projections for a number of possible mitigation pathways that would help Latin America and Caribbean achieve stabilization goals by 2050 (see table 2.5). But these projections were global—presented with no sector or activity breakouts—and regionwide with respect to the relevant geographical unit of analysis (LAC). Meanwhile, the International Institute for Applied Systems Analysis (IIASA) Global Energy Assessment (GEA) model database offers projections that are detailed enough to contemplate attempting sectoral (or intervention activity component) projections for "net financial additionality." Table 2.9 presented this other, more detailed, type of net financial additionality projections for a number of the principal activity (or investment sector) components of the aggressive mix-I+ (plus) pathway, one of the potential pathways that could deliver LAC's 2050 emissions mitigation goal. This annex presents details on the process used for formulating the activity-cost projections presented in this report.

The IIASA's GEA database includes projections from 2005 through to 2100, for the world and its principal component regions (including LAC), in the categories of greenhouse gas (GHG) emissions; required expenditure and investment figures; levels of primary, secondary, and final energy use (broken down by energy type); and levels of final energy demand, along with a number of other energy, emissions, or economic indicators (for more on the IIASA GEA model and database, see annex 2).

IIASA has elaborated most such projections for a "counterfactual" trajectory for the region until 2100. These IIASA projections, released in ten-year annual splits (and all presented in $2005 equivalent), form the basis of this study's BAU trajectory for LAC. In addition to the BAU trajectory, IIASA has further elaborated projections for 41 different intervention pathway scenarios, grouped in categories around three illustrative pathway cases: efficiency, mix, and supply (see annex 2). These illustrative pathways are differentiated primarily by the level of relative gains assumed to be achieved in energy efficiency by 2050. They are also further differentiated by an assumption with respect to the future transportation system: conventional liquids-based infrastructure or electrification (see annex 2).

This report has directly adopted IIASA's three illustrative pathways as the efficiency-I, mix-I, and supply-I pathways, the only caveats being that:

- IIASA's illustrative mix pathway was based on the assumption of a transportation sector rely-

ing upon the traditional, conventional, liquids-based fuel mix and infrastructure, while this report's version of mix-I is based upon an advanced, electrified, transportation system
- IIASA's version of the illustrative pathways assumes a (very limited) role for nuclear power in the future LAC energy mix, whereas nuclear power has been excluded from this study's illustrative pathways
- Land-use and AFOLU interventions and emissions gains have been eliminated from the GEA model pathways used in the current report. But AFOLU interventions, articulated separately as land-use pathways, have been reintegrated into the aggressive or "combined" pathways

Together these three IIASA pathways form this study's moderate (or energy) pathways group (all of which achieve a LAC per capita emissions level of 3.4–4.3 tons, exclusively through reductions in energy-based emissions). The total LAC projections of net financial additionality for the three moderate intervention pathways (presented in table 2.7) therefore have been taken directly from the GEA database. The GEA's gross data were further elaborated by subtracting from them GEA's own BAU projection levels to produce a net level of financial additionality: that is, how much "extra" finance must LAC mobilize—above and beyond that which would be already required under the BAU trajectory?

As mentioned more summarily in the text, the AFOLU pathway projections have been elaborated independently, but they are based on certain core elements of the GEA projections. The aggressive (or combined) pathway projections combine this report's own AFOLU pathway projections (based, themselves, on certain IIASA projections) with those of the IIASA GEA database for the moderate (or energy) pathways.

Each aggressive pathway has been formulated independently, producing certain changes in the net financial additional costs of the AFOLU sectors, and therefore deviates to a minor degree from a strict summation of the AFOLU pathway projections with the energy pathway projections.

This annex provides a a step-by-step summary of how the AFOLU cost projections were produced. This exercise will be followed by a similar explanation of how the aggressive pathway projections were formulated.

Activity costs for land-use (or AFOLU) pathways

The ZNDD 2020/ZNLU 2030 pathway would, through deforestation and other land-use efforts, achieve: (i) net zero deforestation in LAC by 2020; and (ii) net zero emissions from deforestation and land use in the broadest sense (that is, LULUCF, but not agriculture) by 2030, maintaining this level of net zero ZNLU emissions indefinitely. This pathway carries a projection of $37 billion annually by 2050 in terms of "net financial additionality" required across the entire LAC region. This projection was reached following the next steps.

Each of the IIASA GEA "illustrative" pathways includes some emissions abatement in the AFOLU sector. However, the mix pathways only involve modest gains in land-use emissions—less than 50 percent of the decline (against 2010 levels) when compared to the land-use emissions reductions that IIASA assumes would be achieved under the BAU. The mix-I pathway would reduce such annual emissions to 0.23 GtCO$_2$e in 2050, while the mix-II pathway would bring these land-use emissions to 0.18 GtCO$_2$e.

In addition, for each of these pathways IIASA has projected required "nonenergy expenditures" in ten-year, annual, splits to 2100:
- $31.4 billion annually in 2050 for the mix-I (advance trans., no nuclear) pathway
- $39 billion for mix-II (conventional trans., no nuclear)
- $38.4 billion annually in 2050 for the mix-II pathway with conventional transport and a full portfolio—that is, IIASA's "illustrative" mix pathway

According to IIASA, this "nonenergy" category includes expenditures on sink recovery and expansion (including REDD/REDD+ and related activities), along with expenditures dedicated to mitigation efforts to reduce emissions of non-CO_2 gases, including N_2O and CH_4, in both agriculture and industry (and also some in waste).[61]

But IIASA does not present a split of the required expenditures between these various nonenergy-emissions reduction efforts. This report therefore uses a different method to determine how much sink expenditures are required, according to the IIASA projections, in order to achieve the extra amount of land-use emissions reduction secured under these moderate/energy pathways.

To do this, the report develops a proxy for projected land-use and sinks expenditures by taking the IIASA GEA projection for annual nonenergy expenditures to 2050 for a particular version of the mix pathway (one which includes conventional transport, allows for nuclear power to compete within the technology portfolio, but which excludes activities on land-use and sinks from the pathway).[62] This yields a projected annual financial expenditure figures for each decade to 2050 ($0.47 billion annually in 2020, $2.5 billion annually in 2030, $4.6 billion annually in 2040, $5.9 billion annually in 2050) for nonenergy expenditures (which have been stripped of expenditures on the defense and net expansion of sinks, at least in the forestry and land-use change fields).

The projected nonenergy expenditures for the mix-II (no sinks) pathway are then subtracted from the total figure for the "nonenergy expenditures" ($2.7 billion annually in 2020, $9 billion annually in 2030, $20.3 billion annually in 2040 and $38.4 billion annually in 2050) of the (IIASA illustrative) mix-II pathway (with conventional transport and no restrictions on its technology portfolio) to yield the total annual nonenergy expenditures required for the maintenance and net expansion of sinks under the mix-II pathway ($2.2 billion annually in 2020, $6.4 billion annually in 2030, $15.7 billion annually in 2040, and $32.5 billion annually in 2050).

This derived projection for the "net additional financing" required to reduce deforestation and land-use emissions to the degree indicated by the projections for the illustrative mix-II pathway are then divided by IIASA's projection for the reduction of annual land-use emissions against the BAU by 2050 (0.48 $GtCO_2e$) along the mix-II pathway. In 2020, this projection comes to $58/$tCO_2e$ for the average cost (or "financial additionality") of each ton of land-use emissions abated by 2020 along the mix-II pathway and in 2050, $67/$tCO_2e$.

These projection figures for the average cost (or "financial additionality) of each ton of land-use emissions abated by 2050 are multiplied by the amount of land-use emissions abatement required annually in each decade up until 2050 under the ZNDD 2020/ZNLU 2030 pathway against the BAU to yield total gross financial additionality required under the ZNDD 2020/ZNLU 2030 pathway ($43 billion annually in 2020, $45 billion annually in 2050).

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[61] Although the GEA database defines this "nonenergy expenditure" category to include "expenditures for nonenergy mitigation, such as mitigation of emissions of F-gases,CH_4 and N_2O in industry, agriculture and waste," IIASA researchers have verified that this category includes sinks (that is, deforestation and land-use, or AFOLU/REDD+) expenditures. But IIASA has not produced more detailed splits of this category to break down investment from noninvestment expenditures, or to break out the sublevels between sinks (CO_2), industry (mainly N_2O), agriculture (N_2O and CH_4), and waste (CH_4). We therefore have had to make certain assumptions, or rely on certain GEA projection data to transform into our own projections, as explained in this annex.

[62] We could not create this proxy using a pathway that excludes nuclear power. Of IIASA's 41 potential pathways, there are none that exclude both nuclear power and sinks. Nevertheless, there is only minor variation among IIASA pathways in terms of total nonenergy expenditures and relative land-use emissions gains against the BAU. (This is true across the IIASA pathways used as foundations in this study.) Therefore, our use of this proxy seems reasonable. But when this proxy for land-use and sinks expenditures is used to produce each of our pathways independently, it is divided by each independent pathways land-use emissions reductions (not simply that achieved under the illustrative mix pathway). Therefore, while the AFOLU pathways all use the proxy for sinks expenditures and the land-use emissions reductions achieved under under IIASA's illustrative mix pathway, the aggressive pathways use the proxy but compare it to their own reductions in land-use emissions, which are always slightly different than those achieved under the illustrative mix pathway. In this way, the aggressive pathways vary slightly from a simple summation of the AFOLU pathways and the energy pathways.

This yields a projection figure for the gross "financial additionality" required by the ZNDD2020/ZNLU 2030 pathway of $78 billion annually by 2050 ($43 billion annually by 2020).[63] But when attempting to subtract IIASA-based BAU projected expenditures for the same nonenergy sink expenditures to distinguish gross from net financial additionality (and to determine gross and net "average financial additionality" per tCO_2e), an issue is encountered in the sense that IIASA projects no (zero) nonenergy expenditures along the BAU trajectory, despite the fact that the BAU trajectory projects a net decline in land-use emissions of nearly 1.0 $GtCO_2e$ compared to current levels. This entire land-use emissions decline along the BAU trajectory is assumed by IIASA to occur as an organic result of projected increases in income, wealth, urbanization, and modernization across LAC.

Given the projections available in IIASA's GEA model public database, at this point, a methodological challenge appears. Because equivalent BAU expenditure projections are zero, there is no difference between gross and net financial additionality for the ZNDD 2020/ZNLU 2030 pathway ($45 billion annually by 2050 in both cases). But given that the sink expenditures projected under the full mix-II pathway come to $32.5 billion annually by 2050, and achieve only a further 0.3 $GtCO_2e$ reduction against the BAU (which itself reduces such emissions by more than three times that amount against the present level), it seems unreasonable to assume that such BAU land-use emissions reductions could be achieved with no additional expenditures dedicated directly to land-use emissions abatement.

Furthermore, both total financial additionality and average additional financial cost of a ton of CO_2e reduction, if calculated assuming that the net figure is no different than the gross, tend to be two to three times higher (at least for 2020) than the range of current projections for deforestation and land-use emissions abatement (see chapter 2).

But if one calculates differently, assuming that the BAU does not achieve any LULUCF emissions reductions without at least some financial support (and accepting that the IIASA illustrative mix, our mix-II, projections for required financial additionality would achieve the full 100 percent of land-use emissions reductions over the present level, instead of just against BAU) the total and average net financial additionality under the illustrative mix (our mix-II) pathway would fall—from $43 billion annually, and $58/$tCO_2e$, in 2020—directly into the range of similar financial cost projections from the existing literature (see chapter 2), down to $17 billion annually, and $21/ tCO_2e, in 2020. The projections for 2050 would likewise fall from $78 billion annually, and $67/$tCO_2e$, to $37 billion annually, and $23/$tCO_2e$.

Such an assumption is supported by the consensus of opinion, which holds that the financial costs of ending deforestation and land-use emissions are relatively low when compared to the financial requirements of abatement in the energy realm. It is also consistent with a related assumption that the cost of reducing land-use emissions rises with time—as the economic opportunities costs of reducing such emissions rises over time (as land and timber values rise over time, for example).

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[63] Even though there are no projected declines in land-use emissions from 2030 (when they reach zero) until 2050, we assume the same level of total additional expenditures will be required annually to 2050 as in 2030, given that opportunity costs for maintenance of sinks with net zero emissions will still have to be paid.

ZNDD 2020/ZNLU 2030+ (plus) pathway

The same assumption is made when calculating projections for the ZNDD 2020/ZNLU 2030+ (plus) pathway, which continues beyond 2030 (through deeper and continued financial commitment in innovative forestry and land-use practices) to reduce net emissions from sinks to well below zero, achieving 0.35 $GtCO_2e$ of further abatement annually until 2040, and 0.7 $GtCO_2e$ annually to 2050. Again, multiplying the average financial cost per ton ($23) by the amount of land-use emissions reductions achieved by this pathway by 2050 (2.3 $GtCO_2e$ annually), this report's projection for the net financial additionality of this pathway comes to $53 billion annually in 2050. This pathway's much greater level of emissions abatement beyond 2030 (an additional 0.7 $GtCO_2e$) accounts for its higher net financial additionality figure ($53 billion annually in 2050 compared to only $37 billion for the ZNDD 2020/ZNLU 2030 pathway option).

Relying on such an assumption implies either that (i) IIASA's BAU trajectory for LAC should be adjusted upwards by as much as 0.7 $GtCO_2e$ annually in 2050, or (ii) much, if not all, of the land-use emissions reductions projected by IIASA to occur under the BAU should be reassigned to the IIASA illustrative (our moderate) pathways.

While there might be an argument in favor of shifting IIASA's BAU (up to over 7.5 $GtCO_2e$ in 2050, compared to around 6.7 $GtCO_2e$), or even maintaining an assigned portioned of land-use emissions reduction for the BAU, we decided that we would rather alter IIASA's projections for nonenergy expenditures (in particular, the dedicated sinks portion) by changing their assumptions concerning land-use emissions under the BAU (reassigning 100 percent to the pathways and keeping the BAU land-use emissions level constant at the present level into the future), rather than changing IIASA's projections for the total BAU levels themselves.

The above-described assumption (reassigning BAU land-use emissions reductions to each of the pathways, while maintaining the BAU trajectory total emissions stable), however problematic, seems even further justified by the very sensitive political nature of any BAU emissions trajectory projection, both in private industry and international climate negotiations, implying as it does potentially differing levels of national emissions abatement from commitments previously made to targets measured in percentage terms against the (old versus new) projected BAU levels.

Agricultural emissions and the AFOLU+ pathway

The AFOLU+ pathway assumes the expenditures and land-use reductions of the ZNDD 2020/ZNLU 2030 + (plus) pathway, plus a further 50 percent in agricultural emissions by 2050 when measured against those projected in the BAU trajectory.

The first step then is to calculate the projected "average" financial additionality per tCO_2e to achieve a certain reduction in agricultural emissions. Using the IIASA projections for nonenergy expenditures with no sinks along the illustrative mix pathway ($0.47 billion annually in 2020, $2.5 billion annually in 2030, $4.6 billion annually in 2040, $5.9 billion annually in 2050), we can calculate projected "average" financial additionality per tCO_2e by dividing the above nonenergy expenditures with no sinks by the net reduction in agricultural emissions (0.18 $GtCO_2e$ annually in 2020, 0.37 $GtCO_2e$ in 2030, 0.48 $GtCO_2e$ in 2040, and 0.63 $GtCO_2e$ in 2050) of the AFOLU+ pathway compared with the BAU trajectory. This would yield average financial additionality per tCO_2e abated in the LAC agricultural sector of $2.6/$tCO_2e$ in 2020, $6.9 in 2030, $9.6 in 2040, and $9.3 in 2050.

The second step is to calculate the projections of total net financial additionality. BAU agricultural emissions are projected to increase from 1.4 $GtCO_2e$ in 2010, to 1.8 $GtCO_2e$ annually in 2020, to 2.0 $GtCO_2e$ annually in 2030 and to 2.17 $GtCO_2e$ annually in both 2040 and 2050. Under the AFOLU+ pathway, however, agriculture emissions would fall to 1.3 $GtCO_2e$ annually in 2020, to 1.25 $GtCO_2e$ annually in 2030, to 1.67 $GtCO_2e$ annually in 2040, and to 1.08 $GtCO_2e$ annually in 2050. This yields a net reduction in agricultural emissions under the AFOLU+ pathway, against the BAU levels, of 0.46 $GtCO_2e$ annually in 2020, 0.75 $GtCO_2e$ annually in 2030, 1.0 $GtCO_2e$ annually in 2040, and 1.08 $GtCO_2e$ annually in 2050. If one multiplies these net reductions in agricultural emissions against the BAU by the average financial additionality per t/CO_2e in each year ($2.6/$tCO_2e$ in 2020, $6.9/$tCO_2e$ in 2030, $9.6/$tCO_2e$ in 2040, and $9.34/$tCO_2e$ in 2050), the result is the total net financial additionality required to achieve the reductions in agricultural emissions projected under the AFOLU+ pathway: $1.2 billion annually in 2020, $5.16 billion in 2030, $9.6 billion in 2040, and $10.1 billion in 2050 .

Finally, a third step would involve summing the total net financial additionality of the ZNDD 2020/ZNLU 2030+ (plus) pathway ($53 billion annually in 2050) with that of the net financial additionality of the AFOLU+ pathway's agricultural emissions reductions ($10.1 billion annually in 2050) to produce a total net financial additionality required annually by 2050 for the entire AFOLU+ Pathway (which includes the ZNDD 2020/ZNLU 2030+ (plus) pathway) of $63 billion (see table A3.1). If one then divides this figure by the total amount of all emissions reductions achieved under the AFOLU+ pathway compared to BAU (2.45 $GtCO_2e$), the result is an average financial additionality per tCO_2e of $18.4/$tCO_2e$.

The illustrative GEA pathways and our moderate intervention/energy pathways

The moderate (or energy) intervention pathways in this study are based directly on six IIASA GEA pathways: (i) efficiency with advanced transportation and no nuclear (our efficiency-I), (ii) mix with advanced transportation and no nuclear (our mix-I), (iii) supply with advanced transportation and no nuclear (our supply-I), (iv) efficiency with conventional (or traditional) transportation and no nuclear (our efficiency II), (v) mix with conventional (or traditional) transportation and no nuclear (our mix-II), and (vi) supply with conventional (or traditional) transportation and no nuclear (our supply-II).

All of these pathways bring LAC to somewhere between 2.0 tpc and 3.0 tpc annually in 2050—before we strip them of their limited AFOLU interventions and emissions gains (and to between 3.4 tpc and 4.3 tpc once they have been reduced to pure "energy intervention" pathways). The gross and net financial additionality for each of these pathways has been taken from the total energy expenditures projections found in the GEA model database. Total energy expenditures projected under IIASA's message "counterfactual" pathway (our BAU trajectory) have been subtracted from the gross total energy expenditures to yield net total additional energy expenditures—or net financial additionality. These gross and net financial additionality projections for each of these six "moderate intervention" pathways can be seen in table 2.7.

The aggressive (or combined) pathways

We have constructed three different groups of six aggressive pathways that combine the pure energy intervention trunk of the three IIASA GEA illustrative pathways (and their versions assuming conventional transportation) together with our three different AFOLU pathways (ZNDD 2020/ZNLU 2030; ZNDD 2020/ZNLU 2030+; and AFOLU+). These 18 different combined pathways include:

Aggressive mix-I, aggressive efficiency-I, aggressive supply-I, aggressive mix-II, aggressive efficiency-II, aggressive supply-II, aggressive mix-I+, aggressive efficiency-I+, aggressive supply-I+, aggressive mix-II+, aggressive efficiency-II+, aggressive supply-II+, AFOLU+ mix-I, AFOLU+ efficiency-I, AFOLU+ supply-I, AFOLU+ mix-II, AFOLU+ efficiency-II, and AFOLU+ supply-II.

All of these pathways are included in table 2.9 But for explanatory purposes, this section describes how the pathway financial projections were arrived at for the aggressive mix-I+ (plus) pathway, along with the various sector intervention components.

We start by taking the net financial additionality required under the mix-I moderate (or energy) intervention pathway found in table 2.7: negative -$8 billion annually by 2020, and some $43 billion annually by 2050 ($0.5 billion annually by 2030 and $12 billion annually by 2040).

To these sums we add the net financial additionality required under the ZNDD 2020/ZNLU 2030+ (plus) pathway ($18 billion annually by 2020, $24 billion annually by 2030, $37 billion annually by 2040, $53 billion annually by 2050) to yield the total net financial additionality for the aggressive mix-I+ (plus) pathway: $11 billion annually by 2020, $25 billion annually by 2030, $49 billion annually by 2040, and $97 billion annually by 2050.

If we add back into these figures the total amounts expected under the BAU trajectory ($140 billion annually in 2020, $241 billion annually in 2030, $371 billion annually in 2040, and $464 billion annually in 2050), we get total gross financial additionality under the aggressive mix-I+ (plus) pathway: $151 billion annually by 2020, $266 billion annually by 2030, $420 billion annually by 2040, and $561 billion annually by 2050.

To arrive at the average financial additionality (gross) for this pathway, we must divide the above gross projections by the total number of tons of GHG emissions to be abated (1.3 $GtCO_2e$ annually by 2020, 2.8 $GtCO_2e$ annually by 2030, 4.1 $GtCO_2e$ annually by 2040, and 5.3 $GtCO_2e$ annually by 2050) along this pathway: this yields $113/$tCO_2e$ in 2020, $95/$tCO_2e$ in 2030, $102/$tCO_2e$ in 2040, and $105/$tCO_2e$ in 2050.

To arrive at net average financial additionality for this pathway, we must divide the above projections for net financial additionality by the total number of tons of GHG emissions to be abated (1.3$GtCO_2e$ annually by 2020, 2.8$GtCO_2e$ annually by 2030, 4.1$GtCO_2e$ annually by 2040, and 5.3$GtCO_2e$ annually by 2050) along this pathway. This yields net average financial additionality of $7/$tCO_2e$ in 2020, $9/$tCO_2e$ in 2030, $12/$tCO_2e$ in 2040, and $18/$tCO_2e$ in 2050.

Investment/sector intervention components of the aggressive mix-I+ (plus) pathway

In tables 2.8 and 2.9, we have presented projected expenditures required to achieve each major sectoral component of the aggressive mix-I+ (plus) pathway.[64] Below we review the steps whereby we arrived at such projections.

The first intervention component included within the aggressive mix-I+ (plus) pathway is ZNDD 2020/ZNLU 2030 pathway itself. Gross and net financial additionality are the same ($37 billion annually for 2050) and come directly from table 2.6 (see the relevant subsection in this annex for a detailed explanation of how this projection was arrived at).

Likewise, to achieve the additional gains implied in the ZNDD 2020/ZNLU 2030+ (plus) pathway, an additional $16 billion annually would be required by 2050.

Finally, for the last additional gains to come from moving beyond the ZNDD 2020/ZNLU 2030+ (plus) pathway to achieve the AFOLU+ pathway (50 percent cut in agricultural emissions against the expected BAU levels), we likewise include an additional $10 billion annually by 2050 (see table 2.6).

The next step involves projecting the financial requirements for four different major intervention components included in the moderate mix-I (energy intervention) pathway: energy effi-

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[64] Table 2.9 presents financial projections for the sectoral components of the aggressive mix-I AFOLU+ (plus) pathway, whereas in the preceding explanatory text here presents only the aggressive mix-I+ (plus) pathway, the difference between the two being the exclusion (in the latter case) or inclusion of the emissions mitigation assumed in the agriculture sector (50 percent against the BAU in 2050) or only $10 billion annually in 2050 in both gross and net terms.

ciency gains, decarbonization of the electricity generation sector, electrification of transportation, and the roll-out of sufficient carbon capture and sequestration technology.

- Energy efficiency measures, capable of reducing LAC final energy demand by 40 percent compared to the expected BAU levels of energy consumption, would cost approximately $104 billion annually by 2050 in terms of gross financial additionality (and $88 billion in terms of net financial additionality). The gross projection is arrived at by adding (i) $83 billion annually by 2050, projected by IIASA to be required demand-side investment, and (ii) $21 billion annually by 2050, half of what is projected by IIASA to be required investment in electricity transmission and distribution (the other $21 billion annually is distributed to electricity decarbonization; see the following subsection)
- In terms of the net financial additionality required for energy efficiency measures under the aggressive mix-I+ (plus) pathway, the projection of $88 billion annually by 2050 is arrived at by subtracting $16 billion annually (half of the $32 billion expected annually in 2050 for electricity transmission and distribution investment under the BAU) from the gross financial additionality ($104 billion annually)
- Electricity sector decarbonization would entail $133 billion annually by 2050 in gross financial additionality and $66 billion annually by 2050 in net financial additionality. The former is arrived at by summing (i) $62 billion annually by 2050 projected by IIASA to be required investment in nonfossil electricity generation, (ii) $21 billion annually by 2050, half of what is projected by IIASA to be required investment in electricity transmission and distribution (the other $21 billion annually has been distributed to energy efficiency, see above paragraph), and (iii) an additional $50 billion in "expenditures"—out of the total $216 billion in annual "noninvestment" expenditures by 2050 under the mix-I pathway, which remain unallocated under the IIASA projections (we have allocated another $50 billion annually to transportation electrification, $10 billion annually to CCS, and $100 billion annually to "other" energy expenditures)

On the other hand, net financial additionality for electricity sector decarbonization—$66 billion annually by 2050—is arrived at by subtracting from each element of the gross financial additionality, the following: (i) $31 billion annual investment required under the BAU for nonfossil electricity generation; (ii) the $16 billion annually expected for electricity transmission and distribution investment under the BAU, and finally (iii) the $20 billion in noninvestment expenditures that we have allocated to electricity sector decarbonization under BAU from IIASA's unalloted noninvestment expenditures under the BAU.

The total gross financial additionality of CSS comes to $17 billion annually by 2050 ($7 billion annually is projected by IIASA to be required investment, while $10 billion annually is assigned out of IIASA's projected "noninvestment" expenditures to CCS expenditures). Net financial additionality is the same as gross, given that no CCS expenditures are projected to occur under the BAU trajectory.

"Other" gross financial expenditures under the aggressive mix-I+ (plus) pathway are projected to reach $204 billion annually in 2050, and include: (i) investment in fossil extraction ($54 billion annually in 2050, versus $170 billion annually under the BAU); (ii) investment in fossil electricity generation ($2 billion annually in 2050, versus $4 billion annually under the BAU); (iii) other supply-side investment ($42 billion annually in 2050, including investments in oil refineries, district heat and bioenergy extraction as well as production of hydrogen and synfuels, versus $38 billion annually under the BAU); and (iv) other noninvestment expenditures that are not allocated to specific line items by IIASA ($106 billion annually by 2050, versus $150 billion annually under the BAU).

In terms of net financial additionality, this "other" category turns out to be negative -$158 billion annually by 2050. This implies that, compared to the BAU trajectory, the aggressive mix-I+ (plus) pathway involves significantly fewer new additional expenditures annually in certain subsectors, in which large savings are registered from less investment taking place in the future on expensive fossil fuel extraction and generation ($118 billion annually in savings in 2050), and from fewer “noninvestment” expenditures spent on increasingly expensive fossil fuels in the future for transportation and electricity consumption ($44 billion annually in savings by 2050).

Of the four principal intervention components for which we make isolated projections of financial requirements (that is, energy efficiency, electricity decarbonization, CCS, and electrification of the transportation sector) along the aggressive mix-I+ (plus)/aggressive mix-I AFOLU+ (plus) pathways, all of them except transportation can be derived directly, or at least partially directly, from the IIASA GEA model database figures. But projections for the electrification of the transportation sector can be derived indirectly from data in the model, even if additional assumptions are required to extend and more fully complete the model.

Our estimated projection for this sector comes to $50 billion annually in 2050, compared with $20 billion annually projected under the BAU, yielding a projection for “net additional financial expenditures” of $30 billion annually in 2050. This projection is based only indirectly on the IIASA GEA model database figures, because the database offers no specific breakdown for any required expenditures (investment or noninvestment) projected for the electrification of transportation. Nevertheless, half of the IIASA model’s illustrative pathways (which serve as the foundation for our intervention pathways) assume the electrification of transportation (and even small amounts of hydrogen in the generation or fuel mix). Because the IIASA projections for investment and noninvestment expenditures are “energy systemwide”—including everything, public and private, from the exploratory upstream to the final consumption of energy—the required expenditure for electrification of transportation would be included somewhere within the global projection for total required expenditures, even if it cannot be found on any explicit breakdown line in the database.

Furthermore, it can be assumed that at least some of the financial requirements for an electrification of the transportation sector will need to take the form of investment (particularly for infrastructure adaptation and construction), whereas our projection of $50 billion annually in 2050 is assumed to be entirely in the form of noninvestment expenditures (for example, for the private purchase of hybrid and/or electric vehicles, and any government incentives provided to support such purchases), given that it is based on our reallocation of the projected amount that the IIASA GEA model database infers will be necessary “noninvestment energy expenditures.”

But at least some, if not all, of the investment expenditures required for the electrification of transportation would come in the form of modified or upgraded electricity transmission and distribution systems—an essential supporting investment of electrification. This would require a modal shift from gasoline filling stations to a distinct infrastructural mode designed for charging car batteries in a way that takes advantage of the synergies available in “smart grids” by integrating the objectives and dynamics of transportation electrification with those of decarbonizing the power sector and improving the efficiency, resilience, and flexibility of the grid.

In this sense, much of the investment expenditures required to modify the transportation infrastructure would already be included in the IIASA projections for the investment required in electricity transmission and distribution. We have split this discrete financial projection from IIASA evenly between the energy efficiency and electricity decarbonization components. Again, one could argue that at least some of this should be allocated to the transportation component, but it would not alter our estimated projection for the electrification of LAC transportation by more than 10 percent. This is because a three-way split of the projected required additional investment expenditure for transmission and distribution would add only $8 billion annually in 2050 in gross terms and only $2 billion annually in 2050 in net terms (if the projected equivalent investment expenditures under the BAU were also evenly split three ways among efficiency, decarbonization, and electrification). Nor would it alter our projections for any of the intervention pathways, although it would likewise marginally reduce our projections for the other intervention components. In any event, at least some of this investment, however split, is essential for underpinning systemwide electrification.

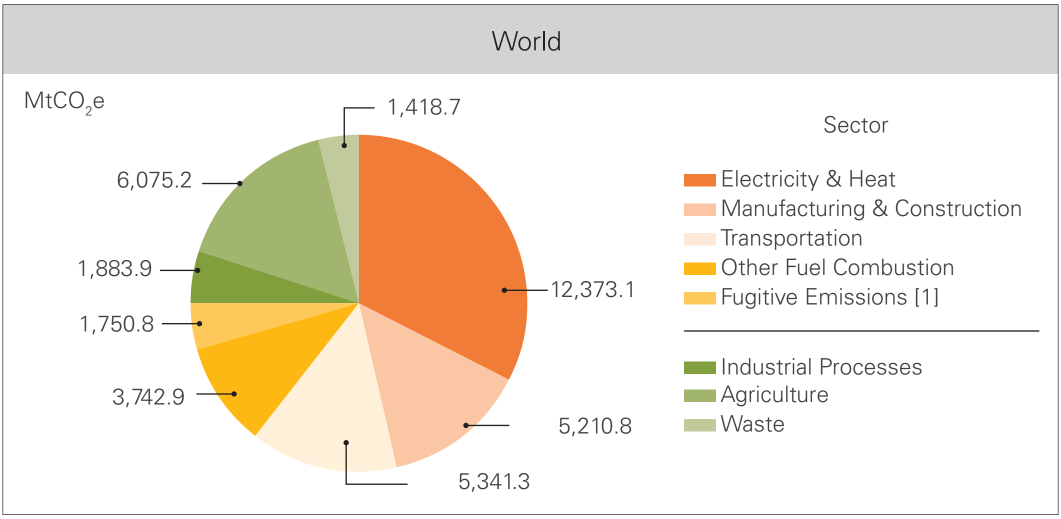
On the other hand, while directly offering total energy, systemwide expenditure projections for its pathways, the IIASA GEA model database leaves a large quantity of projected noninvestment expenditures unspecified—$216 billion annually in 2050, in the case of IIASA's mix (advanced transport) pathway (and our aggressive mix-I+ pathway), and $189 billion annually in 2050, in the case of the IIASA "counterfactual" BAU trajectory. According to IIASA, the category of "noninvestment expenditures" refers to those expenditures necessary to support continued investment, and in particular, those required for operations and maintenance. Assuming that these include all spending in the energy system that is not dedicated to investment, but necessary for the system's sustained functioning, then noninvestment expenditures (both public and private) to purchase (or support the purchase of) fuel, electric vehicles, or batteries, would be included in IIASA's non-specified "noninvestment expenditure" projections (as would noninvestment expenditures on petroleum and coal, and their related investment in their unique infrastructure under the fossil-fuel economy, in the case of the BAU trajectory).

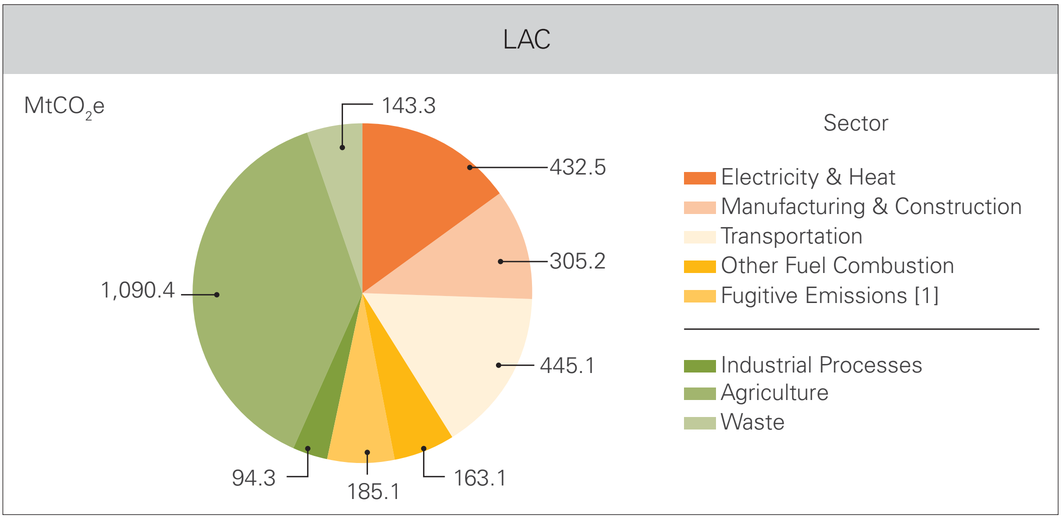
Given this assumption, we have allocated these projected expenditures to various of our intervention components within the aggressive mix-I+ pathway: (i) $50 billion has been allocated to the electrification of the transportation sector to support the conversion to an electric vehicle fleet, including the deployment of battery technology (we assume the intervention component will need to at least double the equivalent efforts of the BAU trajectory in electrification, and therefore allocate only $20 billion in electrification expenditures under the BAU, which will likely take the form of supporting a higher percentage of hybrid vehicles—as opposed to pure electric—than equivalent expenditures in the intervention pathway); (ii) another $50 billion annually in 2050 has been allocated to the decarbonization of electricity to support the purchase of initially higher priced renewable energies (likewise, only $20 billion annually has been allocated under the BAU); (iii) $10 billion has been allocated as expenditure to support investment in CCS (none has been allocated under BAU); and (iv) $106 billion has been allocated to support final end-use purchase of energy, mainly low-carbon electricity (compared to the $150 billion allocated to this purpose in the BAU, representing increasingly expensive fossil fuels which would be displaced under the intervention pathways).

Based on the global and integrated nature of the IIASA GEA model, such a reallocation of IIASA's unspecified "noninvestment expenditures" seems reasonable. One could argue that the allocation to electrification of transportation should be higher—more in line with its 38 percent of final energy consumption, both currently and in 2050. But this is not necessarily the case once we have considered the tight linkages and overlap of many investments targeted on efficiency, the transmission grid, and decarbonization of electricity.

Annex 4

Greenhouse Gas Emissions by Sector in 2005 CO_2, CH_4, N_2O, PFCs, HFCs, SF6 (excludes land-use change)





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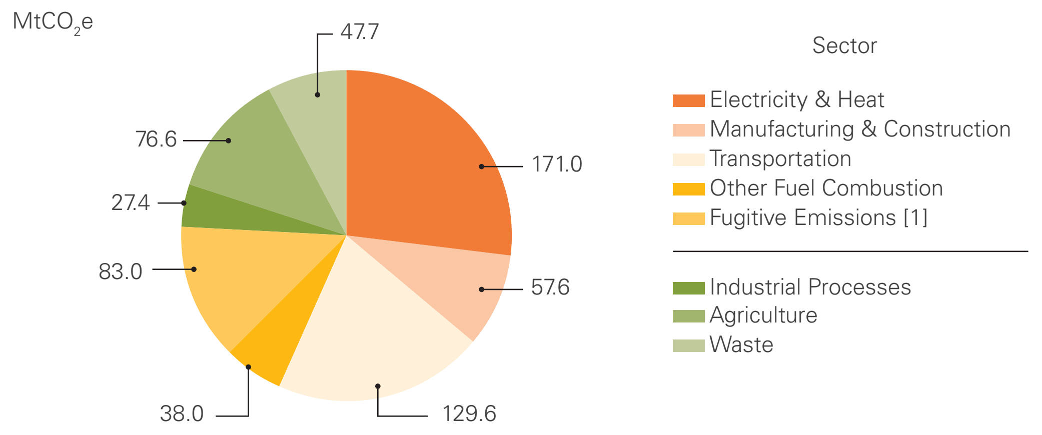
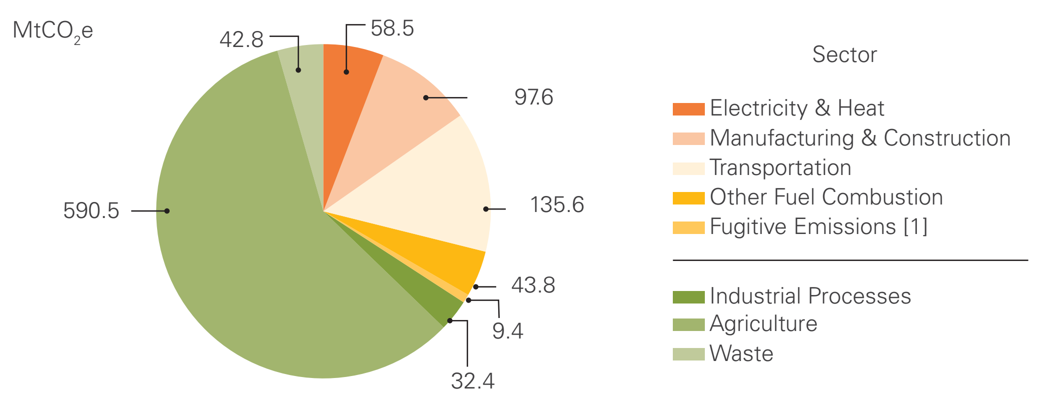
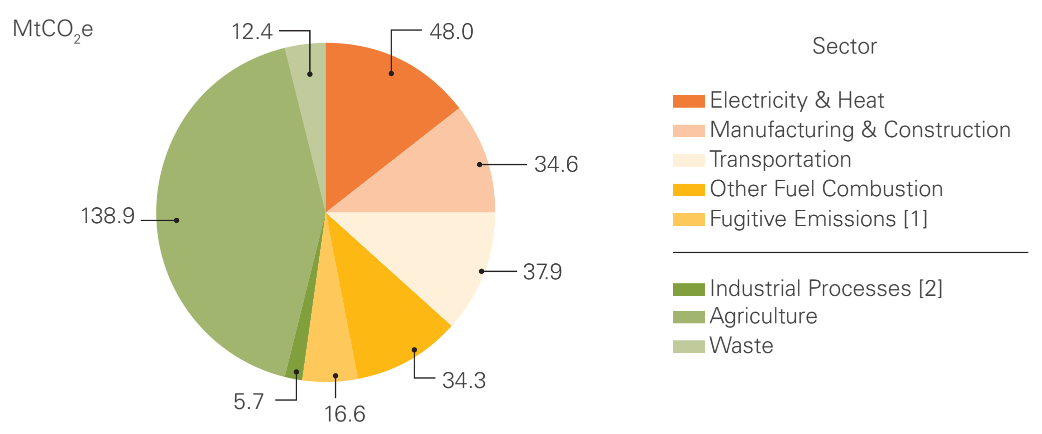
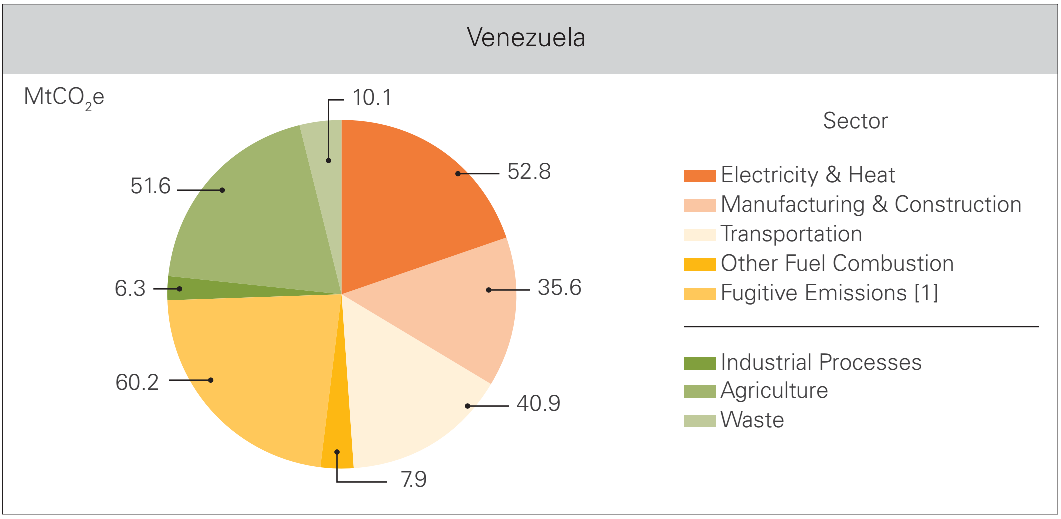


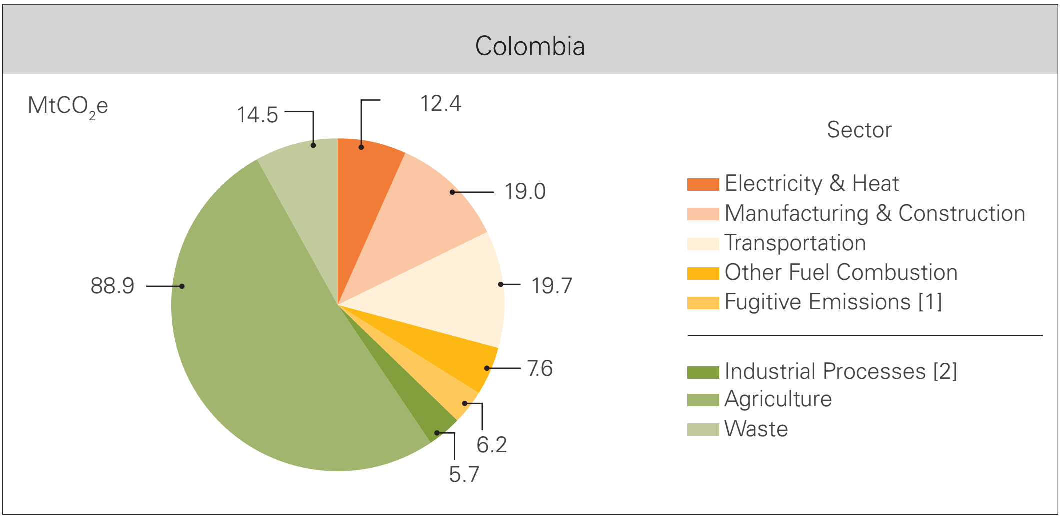
Brazil

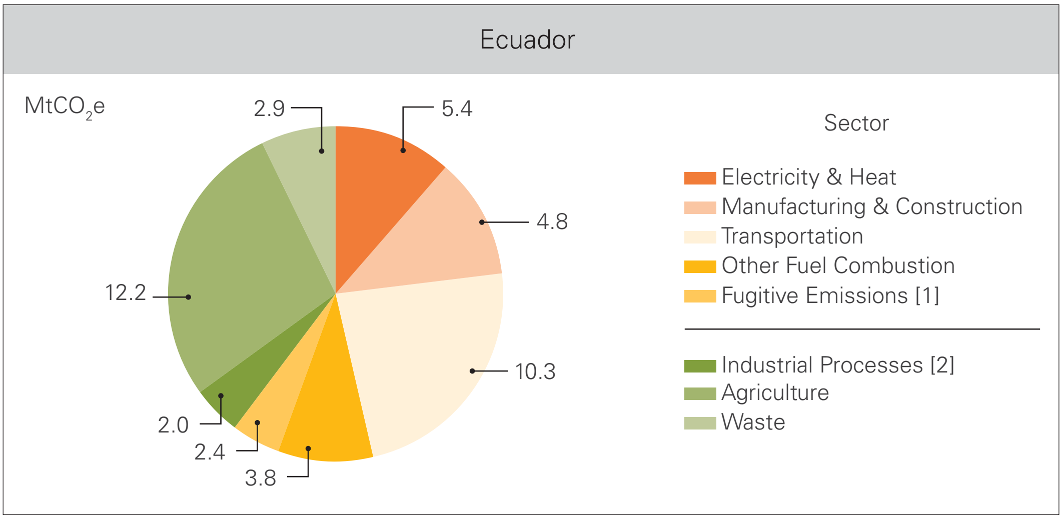


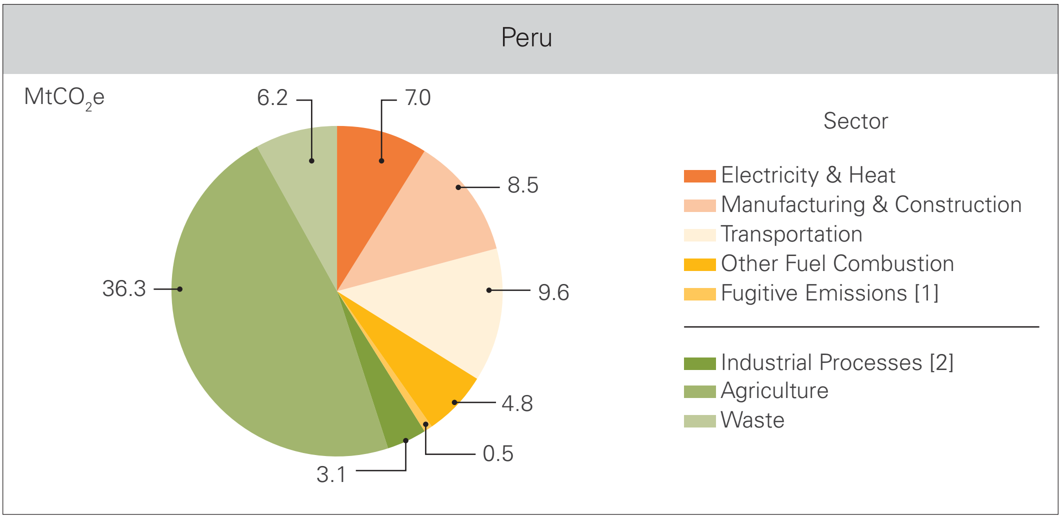
Argentina

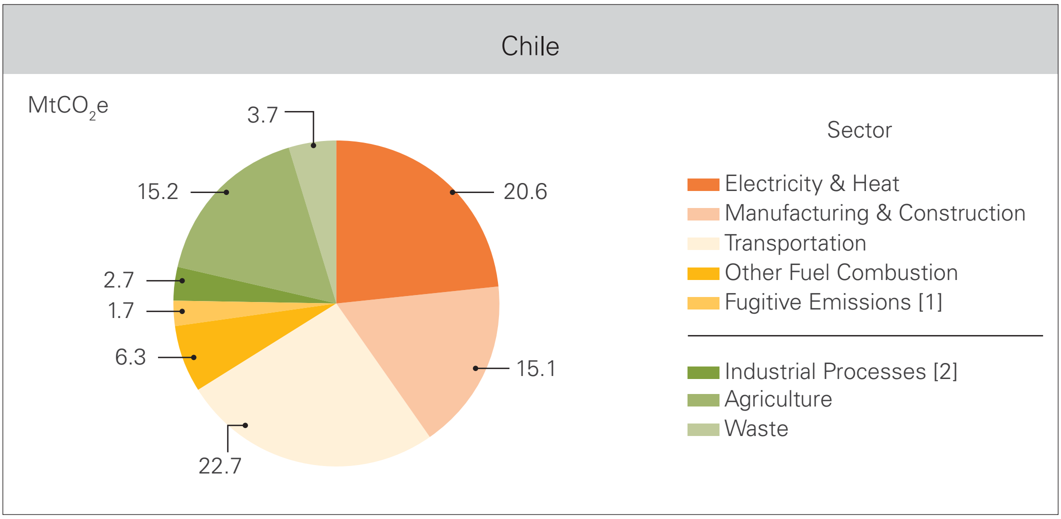


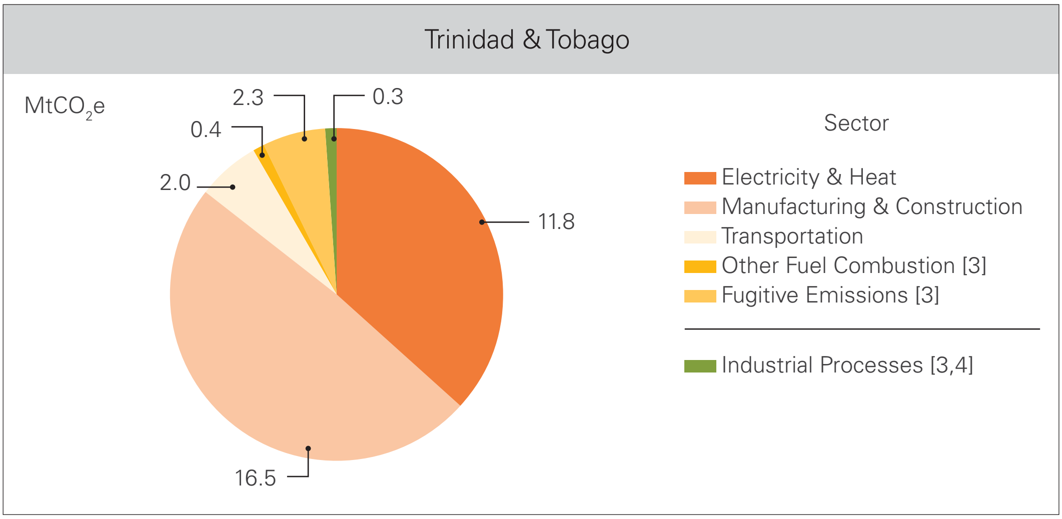

Venezuela
MtCO₂e
10.1
52.8
51.6
35.6
6.3
60.2
40.9
7.9
Sector
Electricity & Heat
Manufacturing & Construction
Transportation
Other Fuel Combustion
Fugitive Emissions [1]
Industrial Processes
Agriculture
Waste

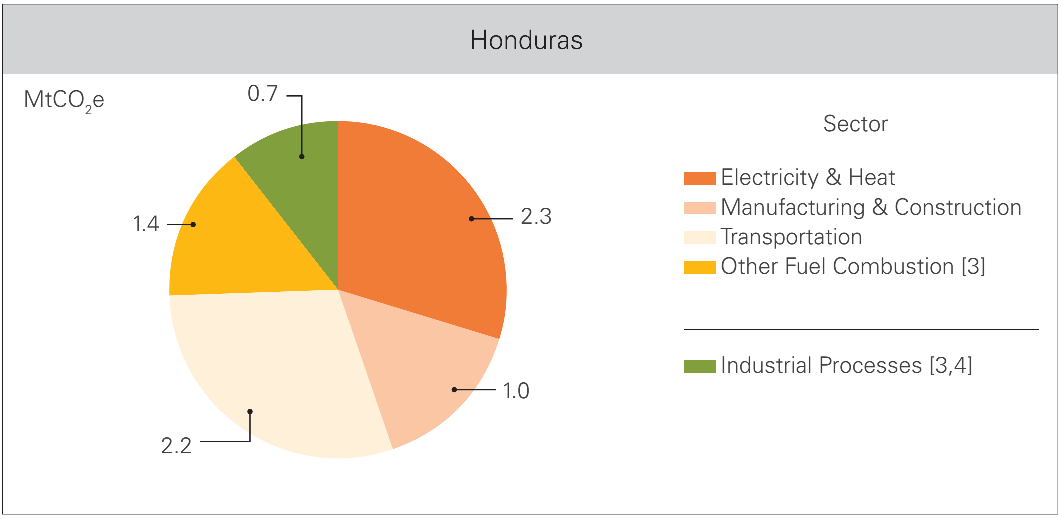

Colombia
MtCO₂e
14.5
12.4
19.0
88.9
19.7
7.6
6.2
5.7
Sector
Electricity & Heat
Manufacturing & Construction
Transportation
Other Fuel Combustion
Fugitive Emissions [1]
Industrial Processes [2]
Agriculture
Waste

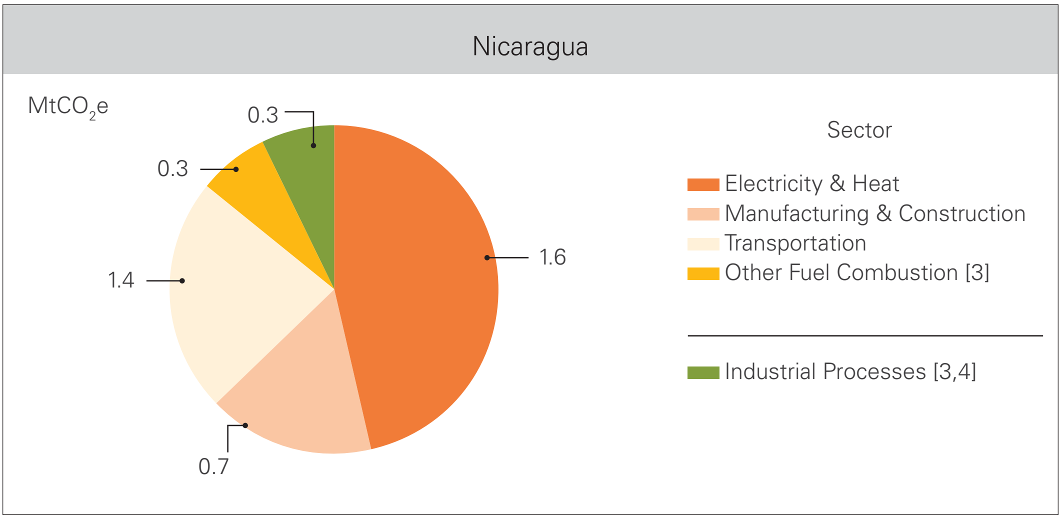

Ecuador
MtCO₂e
2.9
5.4
4.8
12.2
10.3
2.0
2.4
3.8
Sector
Electricity & Heat
Manufacturing & Construction
Transportation
Other Fuel Combustion
Fugitive Emissions [1]
Industrial Processes [2]
Agriculture
Waste

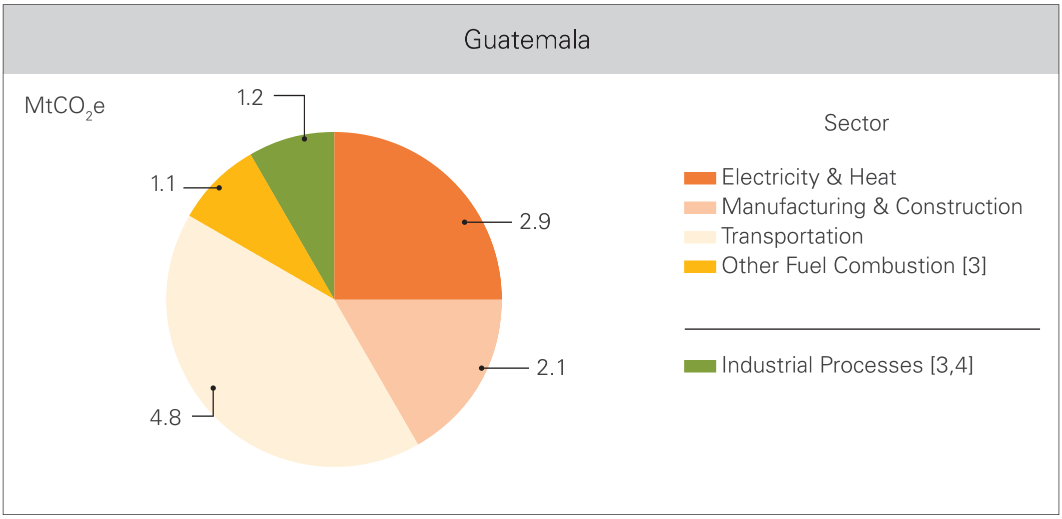

Peru
MtCO$_2$e
6.2
7.0
8.5
9.6
4.8
0.5
3.1
36.3
Sector
Electricity & Heat
Manufacturing & Construction
Transportation
Other Fuel Combustion
Fugitive Emissions [1]
Industrial Processes [2]
Agriculture
Waste


Chile
MtCO$_2$e
3.7
20.6
15.2
2.7
1.7
6.3
15.1
22.7
Sector
Electricity & Heat
Manufacturing & Construction
Transportation
Other Fuel Combustion
Fugitive Emissions [1]
Industrial Processes [2]
Agriculture
Waste


Trinidad & Tobago
MtCO$_2$e
2.3
0.3
0.4
2.0
11.8
16.5
Sector
Electricity & Heat
Manufacturing & Construction
Transportation
Other Fuel Combustion [3]
Fugitive Emissions [3]
Industrial Processes [3,4]







Source: WRI 2010.
Note: [1] N_2O data not available. [2] CH_4 data not available. [3] CH_4 & N_2O data not available. [4] PFC, HFC & SF_6 data not available.

"A compelling argument for prompt action on climate change in Latin America, based on the analysis of the high costs of non-action, the lower costs of action via both adaptation and mitigation, and the local co-benefits to be garnered."

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