The Climate and Development Challenge for Latin America and the Caribbean

Options for climate-resilient, low-carbon development

UNITED NATIONS

ECLAC

IDB

WWF

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Abbreviations

AF	Adaptation Fund
AFOLU	Agriculture, Forestry and Other Land Use
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 Sequestration/Storage?
CDIAC	Carbon Dioxide Information Analysis Center
CDM	Clean Development Mechanism
CIF	Climate Investment Funds
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 Gases
$GtCO_2e$	Gigatonnes 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
$MtCO_2e$	Metric Tonne (ton) Carbon Dioxide Equivalent
NAMA	Nationally Appropriate Mitigation Action
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Co-operation and Development
PPCR	Pilot Program for Climate Resilience
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
SPACC	Special Program on Adaptation to Climate Change
SRES	Special Report on Emissions Scenarios
tCO2e	Tonnes of Carbon Dioxide equivalent
tpc	Tonnes 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 350MtCO_2e each decade thereafter

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PREFACE

This report is being issued in the context of the UN Conference on Sustainable Development of 2012, held in Rio de Janeiro. It touches on a key aspect that is bound to affect the likely achievements of sustainable progress. Climate change impacts are already affecting the very basic foundations on which Latin American societies rely for sustenance and welfare.

The report appropriately reminds us of the major physical impacts of Climate Change in the region, which are based on observations and projections for the future, which are likely to show progressively escalating magnitudes. The Fourth Assessment Report (AR4) of the IPCC, clearly pointed out that on account of inertia in the system even if the concentration of all greenhouse gases and aerosols had been kept constant at year 2000 levels a further warming of about 0.1°C would be expected. 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. The impacts of Climate Change would, therefore, continue in the form of impacts on agriculture, biodiversity and water availability. Low altitude glaciers will continue to melt. There is risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. Further, productivity of some important crops is projected to decrease and livestock productivity to decline with adverse consequences to food productivity. In temperate zones soyabean yields are projected to increase. However, overall the number of people at risk of hunger is projected to increase. Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability 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 upon the rate and magnitude of Climate Change.

All of these impacts have economic consequences and the report includes an estimate, partial by necessity and the report does recognize that the consequences go beyond any economic estimate.

The case for adaptation, if deployed early, is forcefully presented. However, the report also recognizes that adaptation can only go so far if mounting impacts are allowed to accumulate. In the end, adaptation is a time saver while lasting and drastic mitigation efforts are being put in place and global stabilization goals are embraced. The AR4 clearly stated that many impacts can be avoided, reduced or delayed by mitigation and that neither adaptation nor mitigation alone can avoid all Climate Change impacts. Adaptation and mitigation can complement each other and together significantly reduce the risks of Climate Change.

While the region's carbon footprint is modest and appears to be decreasing, efforts to further reduce its contribution is required if global climate stabilization goals are to be achieved. A substantial achievement of this report is represented by the drawing of specific pathways or package of actions identified as necessary to reach a 2 tons per capita in the region.

The carbon budget of Latin America is heavily weighted toward land use change contributions, energy and transport and a focus on reductions in these sectors is, therefore, most appropriate. The actions identified and presented are technologically viable and would result in significant co-benefits in food and energy security, health, welfare, and technology development. The budget associated with the actions is substantial but the analysis shows that much larger would be the cost of inaction.

Rajendra Pachauri, August 2012

EXECUTIVE SUMMARY

Changes in climate during this century will have broad impacts on human activities and ecosystems. The likely consequences are of such a magnitude that the simultaneous need to adapt to the new climate conditions and to reduce the carbon footprint to prevent even further damage will likely become one of the main driving forces for the global community over the coming decades.

1. **Unless drastic and immediate action is taken, it is likely that a 2°C rise in temperatures will take place this century.**

Unless drastic and immediate action is taken, a rise of 2°C degrees, and perhaps even higher, 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 and will result in significant negative impacts on economic activities, social conditions, and natural assets by 2050.

2. **The associated physical and natural damages for Latin America are expected to be substantial.**

The Latin America and Caribbean region (LAC) is particularly vulnerable to the observed and projected impacts of Climate Change because of its geographic location, distribution of population and infrastructure, and reliance on fragile natural resources for economic activities and livelihoods. The key observed and anticipated impacts in the region by mid-century due to current emissions trends include the forecast collapse of a significant portion of the coral biome in the Caribbean, the disappearance of most glaciers under 5000 m 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 nearly inevitable but also irreversible. Therefore, they will continue to adversely impact the region over the long-term.

3. The economic impacts caused by 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 degrees over preindustrial levels are estimated to gradually increase and reach approximately US$100 billion annually by 2050—or approximately 2.2% of 2010 GDP (US$4.6 trillion).[1] This estimate is conservative, partial in geographic coverage, limited to key impacts, and not inclusive of the damage to biodiversity, the change in the stock of natural resources or other non-monetary values (such as certain ecosystem services that are intrinsically difficult to value and other cultural and social damages).

Losses of this magnitude will undermine the region's future growth by significantly limiting development options and severely restricting access to natural resources and ecosystem services. These damages are already occurring and will intensify as temperature increases. Consequently, they will continuously strain scarce investment resources already facing competing demands. The resulting cumulative impact will far exceed the indicated 2.2% of 2010 GDP and also induce negative impacts on equity and poverty levels.

4. Rapid and decisive adaptation action could reduce many of the economic damages—although not much of the losses caused in natural capital—at only a fraction of these costs.

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

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

However, the impact of adaptation measures is ultimately limited. Even if they are undertaken, some irreversible damages would remain. Further, these measures seek only to 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.

5. Global mitigation actions are essential to prevent further damages in the region.

To prevent even further economic damages and to avoid crossing many irreversible and change-accelerating biospheric tipping points that would be provoked by temperature increases above and beyond a likely 2^{o}C rise, global GHG (CO_2e) concentrations must ultimately stabilize at approximately 450 ppm. For such an atmospheric stabilization level to be successfully achieved and credibly maintained, no more than 20 gigatons of CO_2e annually can be released globally by 2050—equivalent to approximately 2 tons of CO_2e per capita per year (2tpc)—and no more than 10GtCO_2e can be emitted annually in global terms by the end of the century (less than 1tpc).

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

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

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

Although the region's emissions footprint accounts for only 11% of the world's total emissions, climate stabilization goals would require all regions, including LAC, to reach 2tpc 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% to reach a combined contribution of approximately 2 $GtCO_2e$ per year. Indeed, under the BAU trajectory, the LAC region would emit nearly 7$GtCO_2e$, or 9.3tpc, by 2050.

8. Significant mitigation efforts, including both land-use and energy actions, are essential to achieve the intermediate stabilization goal of 2tpc by 2050.

Bending the emissions curve sufficiently to bring the projected regional level of emissions per capita down to 2tpc would constitute a significant change of trajectory and require an intense mitigation effort in the region. 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 both land-use and AFOLU policies (stringent enough to achieve (a) zero net emissions from deforestation and land use by 2030, (b) 50% fewer agriculture emissions than projected in the BAU by 2030) and (c) energy emissions mitigation efforts sufficient to minimize the carbon footprint in the power and transport sectors by 2050) could achieve the 2tpc target.

9. The net additional financial cost to LAC of a pathway that reaches 2tpc by 2050 is estimated to be approximately US$100 billion per year by 2050, with an average abatement cost of less than US$20 per tCO_2e.

The net additional financial costs implied by such actions—above and beyond the expected investment and expenditures already required under the current BAU scenario—are estimated to be approximately US$100 billion annually in 2050 (with an average net financial abatement cost of less than US$20/$tCO_2e$ by 2050). This total would represent approximately 2.1% of LAC's 2010 GDP (0.5% of LAC's projected 2050 GDP). This net additional financial requirement needs to be seen as part of a global effort to prevent further damages due to increases in temperatures beyond the 2^oC guardrail and as part of an effort to avoid reaching tipping points.

10. Adaptation and mitigation generate significant development co-benefits, 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 co-benefits in terms of improved human health and welfare, enhanced food and energy security, more efficient use of natural resources, and accelerated technological development. In some instances, the value of co-benefits may offset a significant share of the net additional costs at a societal level. Such co-benefits are usually local and tend to complement national pollution abatement programs with considerable health-related benefits. Although these co-benefits provide financial inducements, additional resources are required for rapid and decisive actions to confront the Climate Change challenge in LAC.

I. 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 the following questions related to the climate challenge for Latin America and the Caribbean (LAC). First, what are the key physical impacts and consequences of Climate Change (CC) that will most affect the region, what are the likely costs to the regional economies derived from these impacts, and what are some of the key adaptation measures that need to be deployed to minimize these adverse impacts? Second, how and at what cost would 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 CO_2 in the atmosphere has increased considerably, rising from a base of approximately 280 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, which might also 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 of global temperature relative to preindustrial levels (Table 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) and has thus been the basis behind efforts to stabilize climate conditions in 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 1. Likelihood (in %) of exceeding a temperature increase at a given CO_2e level

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. Current (2010) global emissions of GHG are on the order of 47 gigatons of CO_2 equivalent per year (EDGAR database), or nearly 7 tpc. Limiting warming to no more than 2°C degrees above preindustrial levels would require that annual global emissions be no more than 20 gigatons of CO_2e by 2050 (IPCC 2007a), which is equivalent, on a global basis, to 2 tpc[2]. However, a stable climate would require further reductions in global emissions that lead to even lower levels by the end of the century.

Adaptation measures will 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. Efforts to reduce GHG emissions in the future will likely still impact LAC in large part because of the region's substantial but intrinsically fragile natural capital (which includes climate-sensitive ecosystems) and vulnerable infrastructure. Thus, to reduce the impact of some of the most damaging effects, the existing economic development path demands efficient adaptation responses to the impacts of a 2°C temperature rise. Such responses must minimize the adaptation costs, which are estimates of the investment outlays required to cope with the impacts of climate changes already built into our future until 2050.

[2] Stabilization of GHG concentration in the atmosphere sufficient to maintain a 2 degree anomaly will require 1 tCO_2e per capita to be reached by the end of the century.

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 intermediate goal of 2tpc by 2050 has been adopted while understanding that (i) it is a very challenging goal and (ii) further efforts are required to reach the 1tpc needed for climate stabilization by century's end.

Section II provides an overview of the key physical impacts and associated costs of Climate Change and identifies adaptation responses. Identifying credible pathways to reach the 2050 goal in LAC and the associated costs are the central subjects of Section III. Section IV reviews the co-benefits expected from adaptation and mitigation efforts.

II. CLIMATE IMPACTS AND ADAPTATION RESPONSES

A. Climate Impacts

Unless drastic and immediate mitigation efforts are undertaken, a rise of 2^{o}C in temperature over preindustrial levels by the mid-21st century is now seen by some as virtually unavoidable (Hansen, Sato and Ruedy 2012). Climate change of this magnitude will have significant negative effects on socioeconomic activities, social conditions, and ecosystems (IPCC 2007b). These impacts will not be uniform but are likely to increase with time. However, the pace of change is somewhat uncertain. In addition, researchers expect some adverse climate feedback effects, or tipping points, that are still not completely foreseen (IPCC 2007a; Ackerman and Stanton 2011).

Some of the key physical consequences in the region are projected to include the following:

i. Impacts on agriculture caused by warming, which is projected to be induced by a reduction of soil moisture and changes in the intensity of rainfall.
ii. Impacts on coastal and marine zones caused by increased sea level rise and increased sea surface temperature.
iii. Impacts on coastal zones caused by a net increase in the frequency and intensity of extreme weather events.
iv. Additional exposure to tropical disease vectors caused by increases in temperature and changing climate conditions.
v. Retreat of mountain glaciers and other consequences of a strong warming anomaly in the Andes.
vi. Impacts due to changes in rainfall patterns on hydrological basins.
vii. Potential rainforest dieback.
viii. Impacts on biodiversity and ecosystem integrity.

Unless addressed through adaptation measures, these physical impacts will have significant economic and social consequences that will likely hinder the achievement of sustainable development and could delay and increase the costs of achieving higher standards of living for the region

Also, climate change is occurring simultaneously with other environmental stresses, for example, development pressures in coastal areas that involve removal of mangroves and chemical discharges that weaken coral over and above the stresses from ocean warming and ocean acidification. Impacts of climate change stresses together with these other stresses are likely to be greater than climate change stresses alone and adaptation strategies need to enhance the capacity of human settlements and ecosystems to respond to a combination of climate and non-climate related stresses. In a few instances these other factors, whether caused by human activity or natural cycles, may even lessen the adverse effects of climate change. In any case a comprehensive climate change adaptation planning strategy needs to anticipate likely effects of climate change, both adverse and occasionally beneficial, together with likely effects, both adverse and beneficial, of non-climate driven human actions and changes in natural cycles.

However, even if adaptation options are implemented, the consequences of these changes may limit development options in the future because access to and the availability of natural resources would be impaired. Key physical impacts include[3]:

a) Impacts on agriculture caused by warming, reduction of soil moisture, and changes in the intensity of rainfall. Agriculture plays a key role in the region's economy and accounted for approximately 6% of total regional GDP and 15% of total employment in 2010. In 2008, food exports represented 16% of total merchandise exports, whereas food imports accounted for 8% of total imports (CEPALSTAT).[4] Agriculture also represents a key factor in food security in LAC.

[3] The basis of the analysis of impacts is region-wide. However, there are significant sub regional differences that influence the type of physical impacts and adaptation responses in a given area. For example, it is clear to most analysts that the Caribbean region of Latin America will be severely exposed to the combined consequences of Climate Change in the marine ecosystem. Likewise, the Andes and other mountainous areas are being subjected to a much higher rate of increase of temperatures. The differential impacts and approaches required are not part of this analysis.

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

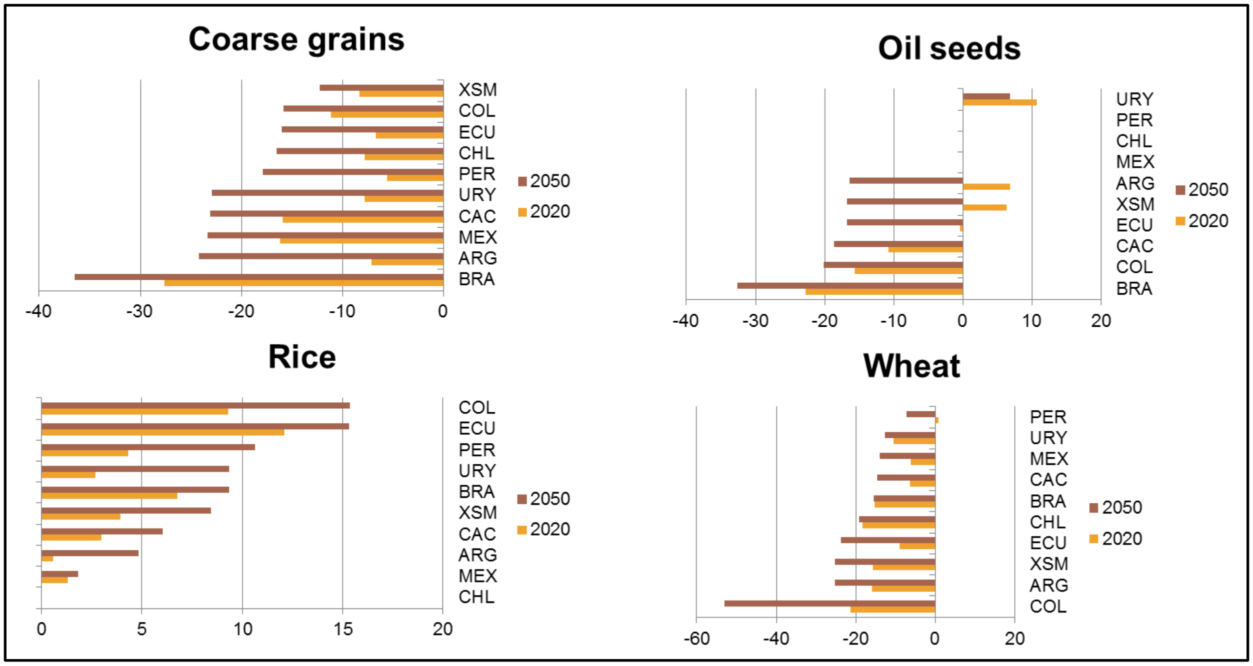
Overall, the impacts of Climate Change on agriculture must be placed in the context of increasing demand for food and agricultural products (Dawson and Spannagle 2009) and exports to the global market. Specifically, impacts on agriculture are expected to lead to reductions in food supply and higher food prices, with potentially negative impacts on income, food security, poverty, and nutrition (Ahmed et al. 2009; Nelson et al. 2009).

Through associated changes in temperature, moisture, and rainfall patterns, Climate Change is expected to alter crop yields and the distribution of agricultural production (Dawson and Spannagle 2009). Changes in climate variability, such as the intensity and/or frequency of floods, rainfall, drought, and storms, are anticipated 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. Additionally, according to projected rainfall and temperature and weather variations, some areas might show increased/decreased yields in the short run, depending on the crop and geographical conditions[5]. Over the longer term, however, LAC's agricultural output is expected to fall because of the 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 that significant impacts are to be expected over much shorter time frames than those previously reported (Figure 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 the value of lost agricultural exports in the region due to these impacts will range from US$32 to US$54 billion per year by 2050. Impacts of this magnitude— particularly in the context of a tight global food supply-demand balance—may also trigger other consequences, including speculation in food markets and negative impacts on food security.

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

Figure 1. Forecast of Climate Change impacts on key crop yields under the A1B scenario[6] projected losses (in %) by 2020 and 2050

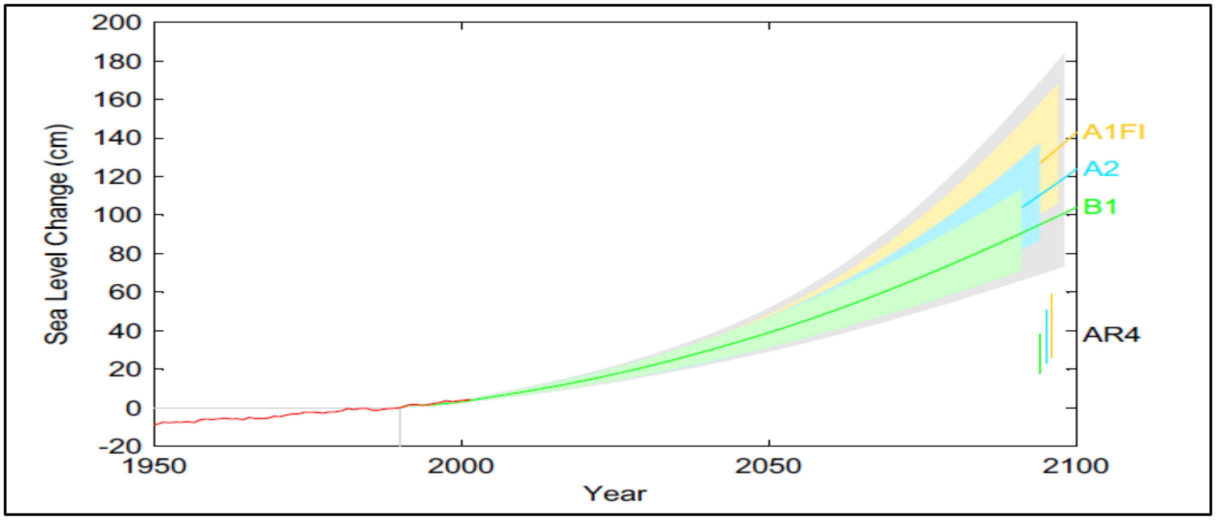


Source: Fernandes et al. (2012).

b) Impacts on coastal and marine zones caused by increased sea levels and increased sea surface temperature. The warming of the sea and melting of land-based ice shields (or their displacement to the sea) will result in increased sea levels. At a global scale, the sea level rose at a yearly average rate of 1.8 millimeter (mm) from 1961 to 2003 and rose at a rate of 3.1 mm per year during the 1993 to 2003 timeframe (IPCC 2007a; and Anderson et al. 2009). This rate is expected to further increase as warming continues to affect the oceans and ice fields. Recent studies suggest that a sea level rise of between 1 to 2 m is possible during the 21st century (Figure 2). This prediction suggests that a much more urgent and significant level of contingent planning and adaptation efforts along coastlines is needed.

[6] A description of IPCC scenarios is included in Annex I.

Figure 2. Projection of sea level rise from 1990 to 2100 based on IPCC temperature projections for three emission scenarios



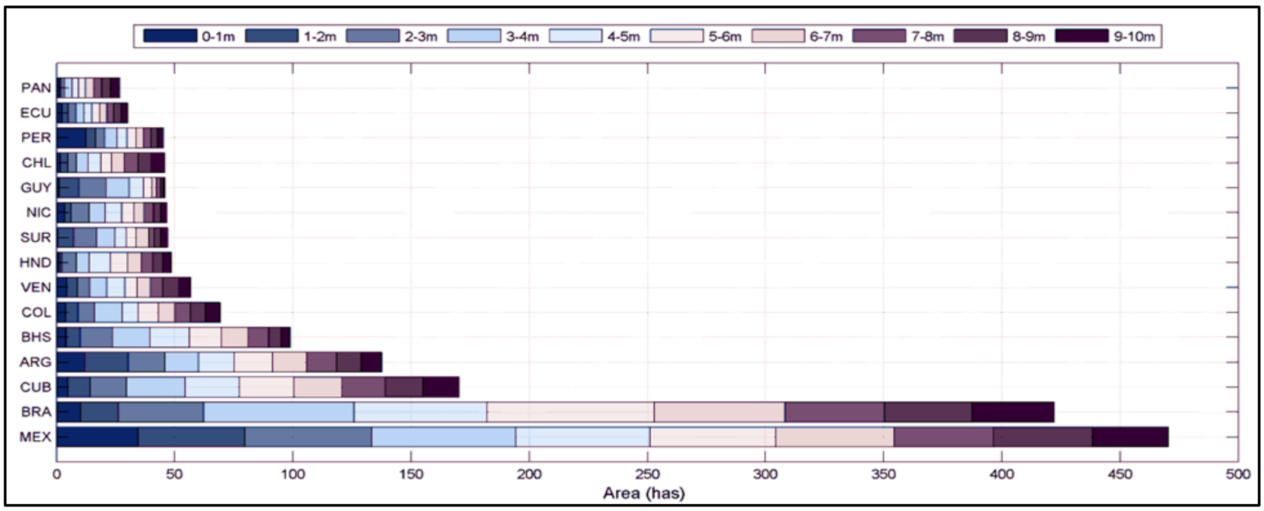
Source: Vermeer and Rahmstorf (2009).
Notes: Projection for sea level rise from 1990 to 2100 based on IPCC temperature projections for three different emission scenarios (labeled on right; see Projections of Future Sea Level for explanation of uncertainty ranges). The sea level range projected in the IPCC AR4 (IPCC 2007a, 2007b) for these scenarios is shown for comparison purposes 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 on the impacts of sea level rise 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 the countries with the highest amount of area in the coastal strip within 10 m above sea level are Mexico and Brazil (Figure 3) and that at least 40% of the populations living in the coastal areas of Chile and Uruguay would be affected by a one-meter rise in sea level.

Sea level rise and an increased frequency and severity of storm events are likely to 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 are highly likely to negatively affect the transport sector, human settlements (Jacob et al. 2007), ports, and other coastal assets. Considering capital and net wetland losses, the estimated accumulated costs associated with a one-meter rise in sea level are approximately US$ 255 billion in Latin America, which is second only to North

America in terms of magnitude of losses (Sugiyama 2007).[7] An analysis by Dasgupta et al. (2007) places the annual cost of the consequences of a 1 m rise in sea level in the region at approximately $19 billion. Moreover, recent data show that a one-meter rise in sea level would affect approximately 6,700 km of roads in the region (ECLAC 2011).

Figure 3. Distribution of land surface between sea level and 10 meters above sea level in LAC countries (in thousand 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.

Salination of coastal fresh water 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 (SPACC 2011). 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. However, to our knowledge, an overall estimate of compromised water supplies in coastal areas is not available at this time.

Coral bleaching has been directly linked to increases in sea surface temperature. Because coral reefs support more than 25% of all marine species, they are the most biologically diverse marine ecosystem and equivalent in terms of biomass productivity to rainforests within land ecosystems.

[7] 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).

Most corals are highly sensitive to changes in environmental parameters. When stressed by rising temperatures, corals can lose their symbiotic arrangements to conduct 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 led to increasingly frequent bleaching events, the latest of which caused wide-scale bleaching throughout the region.[8] The extended coral mortality caused during these events is only partially recovered over time provided that no subsequent bleaching takes place. More than one severe bleaching event over a short timeframe can be devastating. The IPCC anticipates that during the current 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 50% and 90% of the coral cover in the Caribbean has been estimated at approximately US$7 and 12 billion, respectively (Vergara et al. 2009).[9]

Like corals, mangroves appear to be in the list of most vulnerable ecosystems to the physical consequences of Climate Change. Mangroves will be affected by increases in sea level rise that would change the salinity of the coastal areas in which they stand. Mangroves are also lileky to be affected by sea level temperature and their productivity will be impacted by precipitation changes. Most of these impacts will be accumulative. However, there is a lack of information on the magnitude of the effects that could be used to estimate net impacts.

c) 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 is indicative of a broader increase in average tropical cyclone wind speeds as sea surface temperature rises and a

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

[9] Economic losses by 2050 are in 2008 dollars. They include the lost value of coastal protection, fisheries, tourism, and bio-chemicals. The assessment was performed using results from a COMBO9 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.

shift in the intensity distribution 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 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 derived from damages from tropical cyclones is considerable and is projected for the period 2021–2025 to range from US$110 to 149 billion, including US$80 to 103 billion for Mexico's Gulf Coast and US$30 to 44 billion for Central America and the Antilles (Curry *et al.* 2009).[10] An assessment made by Toba (2009) places the annual costs of intensified hurricane activity by 2050 at approximately US$5 billion.

d) 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. The impact on human health is anticipated to be stronger in countries with low adaptation capacity or groups with low income *per capita* (IPCC 2007b). Positive health impacts are only anticipated in temperate or very cold regions.

The main negative health effects associated with Climate Change in Latin America are due to 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). The projections for the region indicate an increase in the number of

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

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).

This negative impact of Climate Change on human health will require additional resources for the health sector. For instance, the estimated annual costs for LAC to treat the health burden associated with Climate Change and higher incidence of diarrhoeal diseases and malnutrition are estimated to be on the order of US$1.3 billion per year by 2030.[11]

e) Changes in hydrology. A growing set of studies indicate that climate is affecting the terrestrial components of the water cycle. In this context, the IPCC concludes (IPCC 2007a), “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”.

Intensification of rainfall patterns. Global warming will result not only in changes in mean conditions but also in increases in the amplitude and frequency of the 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 mayor rivers will become less stable, with probabilities of higher peaks and lower nodes (Vergara and Scholz 2011). Mexico has reported an intensification of flooding events in the Grijalva basin, with costs reaching 30% of the region’s GDP just for 2007, which is equivalent to approximately US$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 hydrology 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 the increase in unstable hydrological conditions will reduce the firm (i.e., guaranteed minimum) capacity of hydropower

[11] 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.

reservoirs by between 29 and 32% under the A2 and B2 scenarios. In the absence of adaptation responses, this loss would represent an estimated cost of approximately US$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 for the water and power supply.[12]

Black carbon emissions within the region from land clearance and biomass burning and from other sources such as transportation may also be contributing to glacier retreat (Simoes J., and H. Evangelista, 2012) through the atmospheric transport of soot and black carbon both to the Glaciated basins in the Andes. Regional black carbon emissions have also been posited as 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 over 15% in the 1970–2002 period (Kaser 2005; INRENA 2006).[13] Recent analysis indicates a 45% loss of glacier surface in the Cordillera Real in Bolivia (Ramirez 2012) in the last 25 years. A substantial reduction in the surface area of smaller glaciers and a significant loss in water reserves during the last 50 years have also been registered in Peru (NC-Peru 2001). It is now generally accepted that most glaciers under 5000 m will disappear by mid-century.

[12] 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.

[13] The Chacaltaya glacier in Bolivia has recently dissappeared and joins other glaciers like Purace and Cisne in Colombia which 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% decrease in its ice-covered peak. This decrease has caused it to lose part of its attraction as a tourist site, with significant economic consequences (UNEP/ECLAC 2010).

Vulnerability studies foresee considerable consequences of the ongoing reductions in glacier volume (IPCC 2007b). Reduced meltwater is projected to start limiting streamflow 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 both population centers (Vásquez 2004) and the power sector, where it is estimated that there will be an annual incremental cost ranging from US$212 million to US$1.5 billion dollars for the generation of energy. The city of Quito would require an additional investment of US$100 million over the next 20 years to guarantee its future water supply (Vergara et al. 2007).

f) 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 C through respiration and photosynthesis. 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% 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; Malhi et al. 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 Amazon basin will change its carbon storage, modify regional water cycles, and affect regional and local climate. As a result, the Amazon has been identified as a potential 'tipping element' of the Earth's system (Lenton et al. 2008).

Nevertheless, the direction and intensity of the future change is still uncertain. These uncertainties are partly explained by differences in future rainfall projections and uncertainty in the physiological processes related to the effects of rising atmospheric CO_2 concentration on vegetation growth and plant efficiency in water use, commonly called CO_2 fertilization (Hickler et al. 2008). Beyond this, there are no records of tropical rainforests growing under a 2-3 degree 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. The results indicate that in a scenario without CO_2 fertilization, high probabilities of biomass loss were generally identified. In addition, dieback events in eastern and southern Amazonia showed probabilities of 15 and 61%, 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. However, if strong positive effects of CO_2 fertilization are assumed, 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 at present as a basis for sound policy advice. Using the information from this study, a partial analysis of the likely economic impacts of the Amazon rainforest values the ecological resources, tourists, and other services that would be lost under a scenario of rainforest dieback at US$ 4 to 9 billion per year.[14]

g) Impact 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 2007).

[14] 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 impacted by other processes, such as deforestation, forest degradation, and hunting (i.e., overexploitation) (Asner et al. 2005).

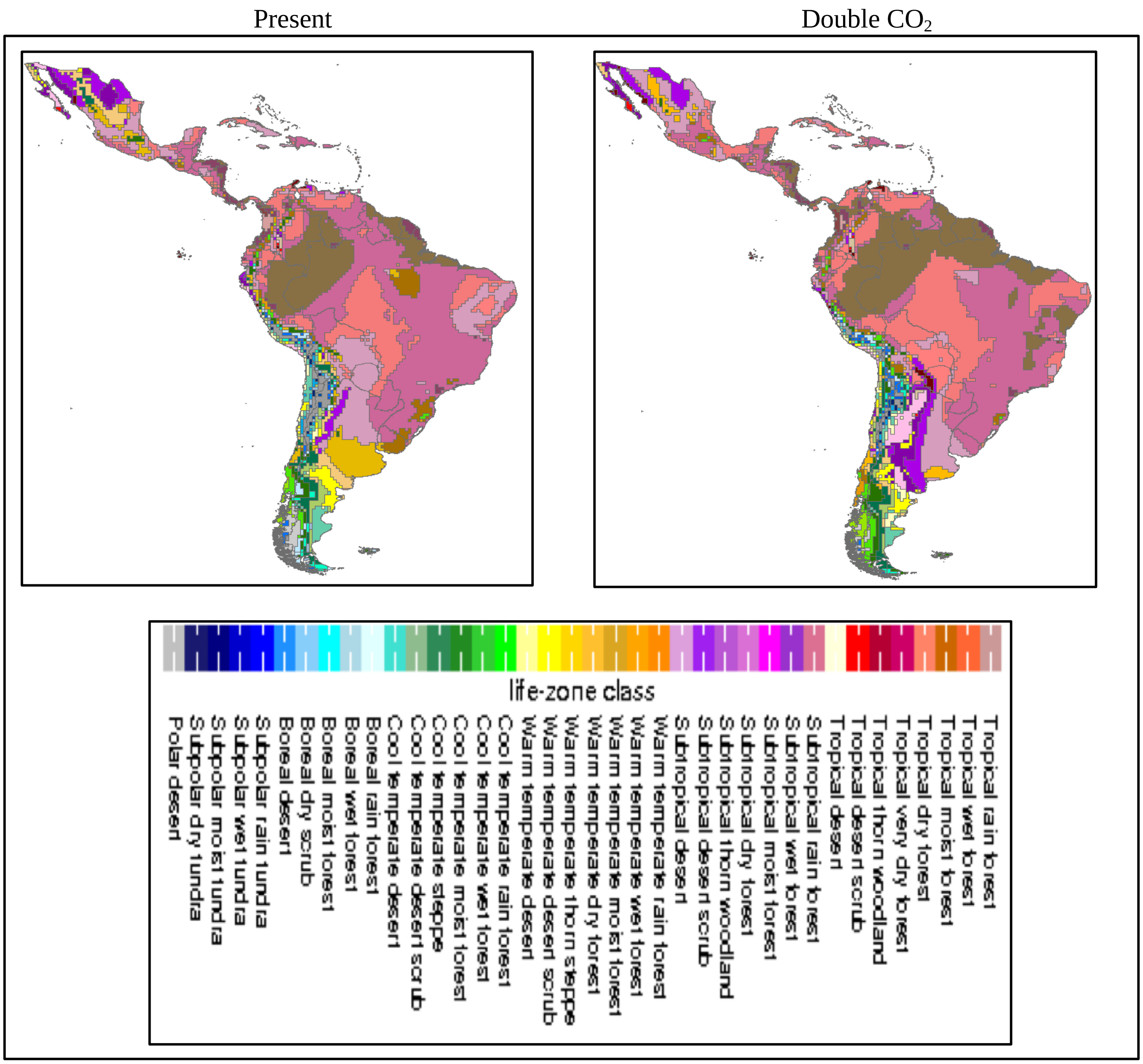
Different methods can be used to evaluate Climate Change impacts on biodiversity. One option is the Holdridge Life Zone (HLZ) (Leemans 1990).[15] A HLZ is a global bioclimatic scheme for the classification of land areas that links weather conditions to the characteristics of ecosystems (Holdridge 1947) in a way that provides a quantitative basis for estimating the possible changes in ecosystems in an objective framework.[16] Assuming that CO_2 concentration doubles, the current distribution of the HLZ in LAC and under a Climate Change scenario, is presented in Figure 4. The region possesses 37 of the 38 HLZs in the world, with 67% of the overall land area in the region covered by Tropical Moist Forest, Subtropical Dry Forest, Tropical Dry Forest, and Subtropical Moist Forest.[17]

[15] 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.

[16] 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).

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

Figure 4. Holdridge life zone map in Latin America with the present climate and a future in which CO_2 has doubled



Source: Own elaboration based on LEEMANS (1989) data.

Climate change scenarios indicate that moist HLZ will diminish and drier HLZ will expand its territory. For example, an increase of approximately 156% in Tropical Very Dry Forest and a decrease in rain and moist forest (Boreal Rain Forest -67% and Warm Temperate Moist Forest -60%) are expected. For the four principal HLZs of the region, it is projected that in the event of a CO_2 doubling, the subtropical moist forest and subtropical dry forest will decrease by 22 and 31%, respectively, while the tropical moist forest and tropical dry forest will increase by 63% and 50%, respectively.

Although assigning monetary values to ecosystems functions has significant methodological difficulties (Arrow et al. 1993; Heal 2000; Spash and Vath 2006),[18] it is possible to use a meta-analysis that includes all possible environmental valuations for all ecosystem services to identify use and non-use value before transferring these values to the areas within the same HLZ classifications. This approach estimated that the total value of all HLZs in South America is approximately US$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 US$36.5 billion (Table 2).[19]

Climate change has some other irreversible effects on biodiversity or may bring about significant feedback effects that cannot be properly valued at the current time. 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 (Jones et al. 2006; Vergara and Scholz 2011). These irreversible biodiversity damages have more than an economic dimension; 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 worsen the net impacts and will likely trigger additional changes in the biosphere.

[18] 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 between US$0.03-2.89 per hectare per year, with an average of US$199. According to the categorization of ecosystem services, the valuation is rather variable.

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

Table 2. Climate change and economic impacts on biodiversity in Latin America

Holdridge Life Zones (HLZ)		Average value (US$/ Ha^{-1})	HLZ value at present (millions of US$)	HLZ value at present with doubled CO_2 (millions of US$)	Economic loss (millions of US$)	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: Own elaboration based on data from Leemans (1989).

In addition, other impacts are beginning to be observed. For example, climate impacts are affecting ecosystem functioning and migratory species. The changes induced by the seasonal variations in climate and the responses by 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 some of the casualties of Climate Change (Robinson et al. 2005). For instance, the migration pattern of raptors in the Central American corridor is thought to be in danger of being altered by climate changes in the Gulf coast of Mexico and in the Kikolde area of Costa Rica. The feared impact is that changes in air temperature and in the onset of seasonal variations will affect both the capacity to migrate as well as the composition of the habitats on which migratory species depend in their well-timed routes.

B. Estimate of the Damages caused by Physical Impacts

The information reviewed above is presented in Table 3, along with the caveats and limitations of the estimate. The aggregated value of the projected yearly economic damages in LAC caused by some of the major physical impacts associated with this unavoidable rise of 2°C degrees over preindustrial levels are estimated to gradually increase from a now and reach approximately US$85 to US$100 billion annually by 2050 (in current values), compared to a GDP of approximately US$4.6 trillion in 2010[20] .

The unmitigated annual losses from Climate Change will become an ever growing 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 in perspective, when assessing the severity of the economic impact.

First, the available estimates are not comprehensive and only include 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 3 are a conservative calculation of annual damages. The actual loss will probably far exceed the annual figure of US$85 to US$110 billion by 2050.

Secondly, the estimates do not include the damage to biodiversity, the change in the stock of natural resources or other non-monetary values, i.e. the intrinsic worth of species extinction, biome collapse, or irretrievable damages in natural capital is not captured.since certain ecosystem services are intrinsically difficult to value and other cultural and social damages have not been considered.

Thirdly, it is difficult to quantify the long-term effects in economic terms, i.e. GDP losses. In the short term, increasing investment in infrastructure and production facilities to replace losses may even boost GDP, with dynamic multiplicator and accelerator effects, as the additional investment may have growth impacts – in particular if there is underutilization of production capacity. In the longer-term however, the diminished

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

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 in expanding the productive capacities

- loss in functionality of infrastructure including water supply systems depending on glacier run off, urban or tourism infrastructure threatened by sea level rise and other impacts that would require investment in new systems and again, this replacement capital may crowd out expansion investment.

With respect to natural capital, the expectation is that

- in order to maintain production and services, producers which currently profit from the lost ecosystem services, would need to invest in alternative provision of such services.

- other ecosystem servives in particular those from biodiversity losses may not immediately require replacement investment, but obviously will result in biological impoverishment of these regions.

- more severely, if large scope changes occur, like the potential Amazon dieback, this will likely influence the development potential of the region, and even may set into motion global long-term economic adjustments because of excessive climate changes.

With respect to human capital,

- Increased health problems would immediately lead to a reduction in productive capacity and would also imply additional costs to the health care system. More human beings will not be able to participate in economic activities. Investment in health care will have to be increased.

Forthly, climate change impacts accumulate over time. Damages are already occurring and will intensify, as extreme events become more frequent or intense and more gradual changes like temperature increases become effective. The reactions will continuously strain scarce investment resources which are already facing competing demands and lower productivity.

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. However, unplanned adaptation and learning from losses is still costly and could be preempted with adaptation programs and measures which increase resilience.

Nevertheless, under any plausible scenario, the region will see its natural assets affected. Even if forceful action on mitigation is immediately taken and adaptation efforts are implemented, glaciers under 5000 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 already being observed, the implications of these losses will be mostly experienced by future generations, whose worth should not be discounted.

If prompt and drastic mitigation actions are not taken, losses will increase, likely tipping points will be reached, and the rate of extinctions and the pace of change in compromised ecosystems will accelerate. As a consequence, economic damages will increase far beyond what can be estimated at the moment. Moreover, a further and irreversible impoverishment of the biosphere will be triggered. The value of these losses cannot be measured in economic terms.

Table 3. Estimate of annual damages from some key physical impacts by 2050

Impact	Area	Projected annual costs* (2005 US$ billion)	Projected cumulative cost	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 increase of frequency of extreme weather events	CARICOM Mexico's gulf coast, Central America, and the Caribbean	5	 110–149 for 2021–2025	Toba (2009)[d] 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: (i) estimations are gathered from different studies with varying methodologies, assumptions, and uncertainties; (ii) many costs are only partially presented, and others are difficult to estimate; and (iii) non-monetary costs are not considered. The CPI is used to convert costs to 2005 US dollars (Bureau of Labor Statistics). When information was not available, costs were assumed to be reported in US dollars of the year of publication.

** 2010 GDP measured in 2005 US$.

[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% 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 US 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 US$.

[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 ONS, and the cost of rationing from Maurer et al. (2005).

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/or show irreversible damage, which, in turn, can translate into substantial losses of natural and economic capital. The proposed hotspots for the region are shown in Table 4.

Table 4. Some bio-climate hotspots in Latin America

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 potential disruption to many endemic species to the Amazon rainforest	Impacts on global biodiversity, global water circulation patterns, and regional agriculture, water, and power supply

Source: Own elaboration, adapted from Vergara (2009).

C. Adaptation Response[21]

Adaptation is broadly defined as an adjustment in human activities or ecosystems to new climate conditions. 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 2010b). 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, In general, the existing data indicate that a broad portfolio of measures already exists (Table 5). 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 agriculture 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 US$40 million have been implemented since 1998. Additionally, in the tropical Andes, the GEF has funded adaptation responses to the Impacts of Glacier Retreat. With an estimated

[21] 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.

budget of US$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. Ecosystem-based Adaptation (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 INAP project in Colombia, which relies on ecosystem-based measures to maintain water regulation flows in Paramo ecosystems in the Chingaza area of Colombia. Other efforts have been attempted in Belize through the 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 5. Examples of potential responses to the regional consequences of Climate Change

Agriculture - 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	Sea level rise and extreme events in coastal zones - 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 - 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	Glacier retreat - 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 - Profilactic 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	Biodiversity and ecosystems - 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

The Adaptation Fund has also recently approved projects on water and coastal management issues and farming in Jamaica, Honduras, and Uruguay, respectively, for US$10 million; on food security (in terms of Climate Change resilience) in Ecuador for US$7.4 million; on the reduction of vulnerability to floods and droughts in Nicaragua for US$5.5 million; on climate resilience and land management in Argentina for US$4.3 million; on climate-resilient infrastructure in El Salvador for US$5.4 million; and on climate-resilient productive landscapes in Guatemala for

US$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, the OECD nations, and Haiti are being formulated. Table 6 presents examples of recent adaptation investments in LAC.

Based on the recommendations contained in its Second National Communication, the Government of Colombia launched an 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 approaches to adaptation to the impacts 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 US$30 million.

Table 6. 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 that are affecting the availability of water	Rainwater-retaining ponds, use of ancient knowledge to maximize soil water infiltration and minimize run-off (*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

Overall adaptation costs. There are different estimations of the overall cost of adapting to a 2°C anomaly for LAC (Table 7). For example, the World Bank (2010) estimates annual adaptation costs for the region ranging from US$16.8 to US$21.5 billion by 2050, while Agrawala et al. (2010) estimate adaptation costs to be approximately US$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 adaptation cost estimations 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.

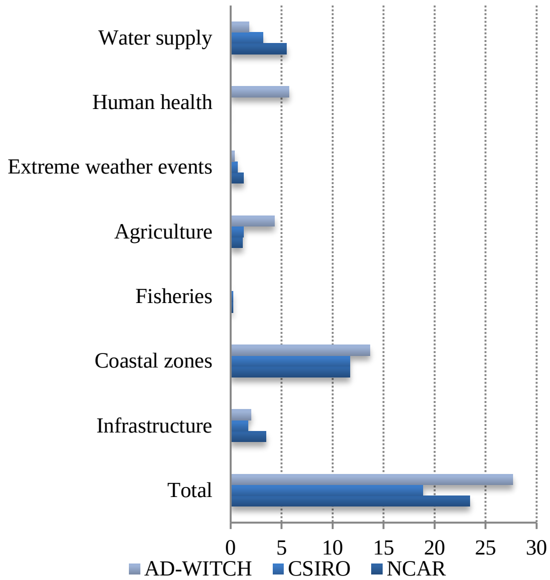
Table 7. Adaptation cost estimates for LAC (billion US$)

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	11.7[1]	11.7[1]	Coastal protection costs	7.75
		Extreme weather events	1.3	0.70	Early warning systems	5.00
					Investment in climate-proof settlements	5.90
Infrastructure	0.40–1.72	Infrastructure	3.5	1.70	Cooling expenditure	2.0
		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: Author's estimate based on UNFCCC (2007), World Bank (2010), and Agrawala et al. (2010).
Notes: 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.

Figure 5 compares various cost estimates of the physical impacts of Climate Change in the region. The cost of adaptation is a small fraction of the cost of physical impacts. However, 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.

Figure 5. Annual average adaptation cost estimates for LAC (billion US$)



Source: Data obtained from World Bank (2010) and Agrawala et al. (2010).

A Four Degree Anomaly. The costs of the physical consequences and the estimates of adaptation costs, refer generally to a path trajectory consistent with a 2 degree Celsius temperature anomaly. However, there is a probability that actions are not taken on time to maintain this trajectory. In that case, the physical consequences are likely to escalate and the adaptation costs would be more expensive.

A four degree world would result in changes that would place a very significant stress on the natural world. The pace of change, anticipated over a century or so would be unprecendented. Yet, in the face of failure to embarq 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 4 degrees of temperature anomaly during this century, consistent with an atmospheric concentration of CO_2 above 800 ppm.

Under such future, the impacts discussed in this chapter would in most cases intensify. For example, one would expect the onset of coral mortality and the extent of it to be more sudden and whole. The pace of sea level rise would also accelerate and the retreat of Andean glaciers would be more sudden. The likelihood of rainforest dieback would be more certain and extensive. It is the lasting effects that should raise even more concern. The continuation of changes induced under a 4 degree future is likely to continue far into the future even if such emission patterns can be quickly reversed and the damage to be caused to future generations even more complete.

However, identification of physical impacts and quantification of economic losses and damage under a 4 degree scenario is beyond the scope of this report.

III. LAC's CARBON FOOTPRINT AND PATHWAYS TO 2 TPC BY 2050

Preventing additional irreversible damage to the biosphere would require global emissions to not exceed 20 GtCO_2e (or 2tpc) by 2050 and that approach 10 GtCO_2e (or 1tpc) by the end of the century. Securing such a goal would require a significant deviation from the current path of global emissions. This section examines LAC's current carbon footprint and presents some of the available pathways in the region that can contribute to this global climate stabilization goal by 2050.

A. Current Emissions Profile

The total LAC GHG emissions for 2010 are estimated at 4.7 GtCO_2e (10.8% of total global emissions), this is a decline of about 11% since the start of the century, mainly caused by reductions in land-use change-related emissions and in energy intensity.[22] This drop took place during a period of robust net increases in regional GDP (3% annual), which indicates that economic growth has decoupled to some degree from carbon emissions. Additionally, from a historical perspective, the LAC region has contributed less than 3.7% of the cumulative global CO_2 emissions due to energy use since 1850.[23]

Agriculture and Land-Use Emissions. In contrast to the world as a whole, the bulk of the emissions in LAC are generated not from energy use but from land use, land-use change and

[22] 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 to 2020 and 2050 (both for the "business-as-usual" (BAU) trajectory and for 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 (i.e., 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 SF_6, while 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.

[23] 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.

forestry (LULUCF), along with 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 6). 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, LAC's energy emissions have been of secondary importance for the region as a whole. While the region's energy emissions rose sharply—by 50%—from 1990 to 2005, LAC's per capita energy emissions were 2.8 metric tons of CO_2e in 2005, well below the world average of 4.4tpc.

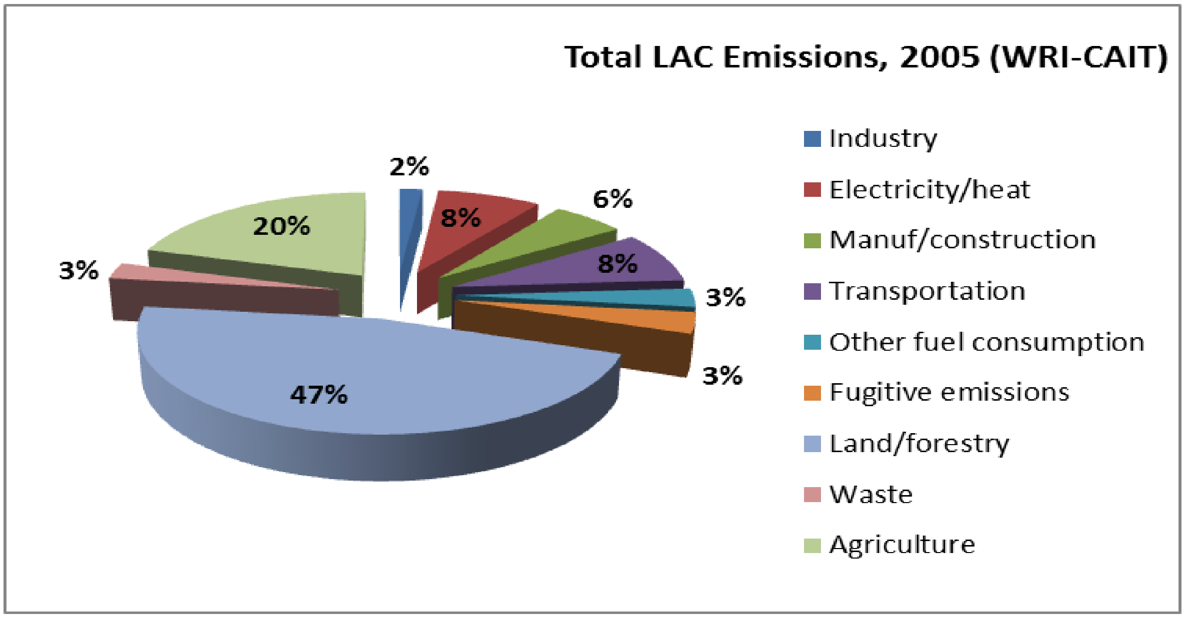
Within the subcategory of energy, power generation accounted for about 30% of the region's total *energy emissions* in 2005, whereas globally, the power sector contributed a much higher total (44%) to global energy emissions.[24] In addition, transportation is far more significant within the LAC's *energy emissions* profile (29%) than within the global profile (only 19%). Such divergence from the world averages are explained by the dominance of hydropower in the regional power mix and of transportation within the final LAC energy demand.

Emissions Intensity. As the region's developing economies have continued to mature, the sensitivity (or "elasticity") between economic growth and annual emissions levels in LAC has declined in recent years. LAC's "emissions intensity" fell from 1,500 tCO_2e/million US$ of GDP in 1990 to approximately 1,200 tCO_2e/million US$ in 2005. The world's emissions intensity also declined, though somewhat less steeply and from a lower base[25].

[24] Note that the sector contributions presented in Figure 6 refer to the percentage shares of total LAC GHG emissions, while the sector contribution figures presented in this subsection on Power Generation and Transport refer to the region's emissions within the energy emissions subcategory. Therefore, while transportation, for example, accounts for 8% of the region's total emissions, as seen in Figure 6, this sector accounts for 29% of LAC's energy emissions (which account for only 28% of LAC's total GHG emissions).

[25] 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 tCO_2e/million US$ of GDP from 1990 to 2005 compared with some 825 tCO_2e/million US$ for the world in 1990 and approximately 650 by 2005).

Figure 6. Sector composition of total LAC GHG emissions[26]



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

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

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

Recent Trends. The AFOLU (agriculture, forestry, and land use) dominance within the LAC emissions profile is changing. Evidence points to significant declines in the regional rate of

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[26] See Footnote 28 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% (as reflected in the CAIT data presented above in Figure 6) to less than 35% in 2010 (as reflected by the IIASA GEA data presented in Figure 8).

[27] 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.

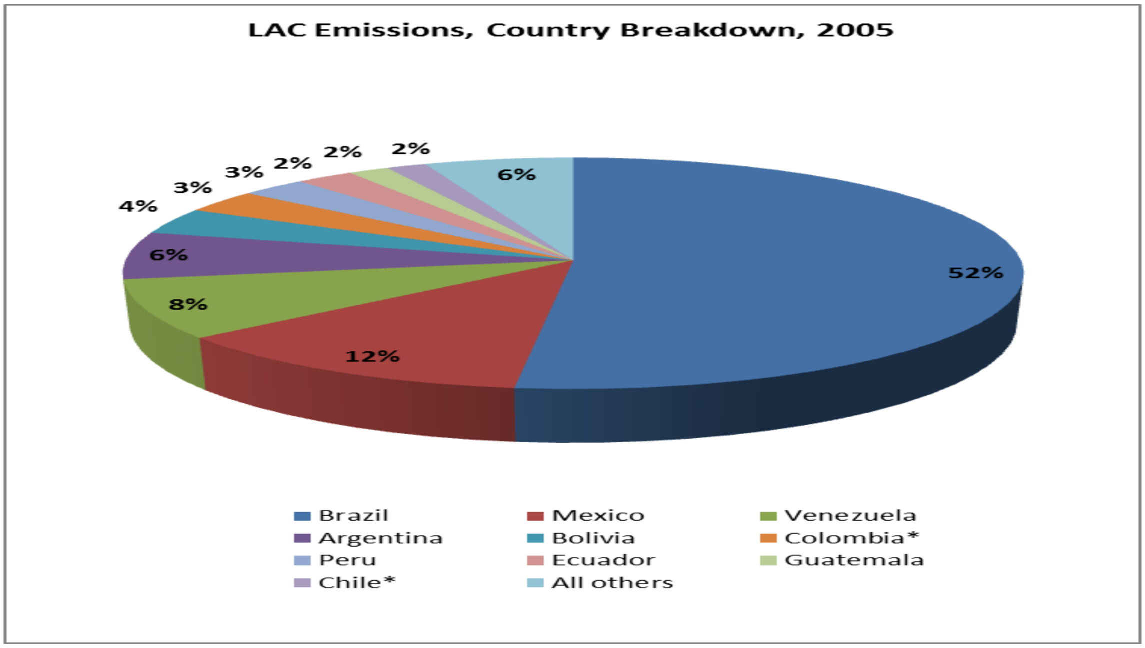
deforestation in recent years—down 67% since 2004 in Brazil's Amazon and down one-third in Central America since the mid-1990s (INPE 2010, Kaimowitz 2008 and Hecht 2012). These achievements, if maintained, augur well for a significant lasting reduction in land use related emissions.

Per capita emissions. Total LAC per capita emissions fell from 10.4t (CAIT) in 1990 to 8.1t (IIASA GEA) in 2010, a decline, as discussed before, driven by a drop in land-use emissions and improvements in energy efficiency. If one refers to the GEA figures—which do appear to incorporate the recent decline in emissions from deforestation—the LAC total emissions per capita were 8.5tCO_2e in 2005 and 8.1t in 2010.

However, this recent trend remains vulnerable to a reversal of the recent decline in deforestation and to a renewed increase in total emissions driven by a rise in energy-related emissions. Indeed, LAC's per capita energy emissions rose from 2.3t in 1990 to 2.8t in 2005 and are projected to continue rising under the BAU trajectory. Thus, LAC's projected energy emissions may yet nullify the improvements associated to land use.

LAC country breakdown. Looking at only the regional carbon footprint can be deceiving. While most countries in Latin America are small contributors of GHGs (with emissions well below 1% 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 7 presents the principal relative country contributions to the regional emissions profile. Country-based GHG intensity and per-capita emissions are included in Annex 3.

Figure 7. Country contributions to GHG as a percentage of total LAC emissions[28]



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

Brazil is the dominant source of LAC emissions (52%) in 2005, followed by Mexico (12%), Venezuela (8%), and Argentina (7%) (CAIT 2012).[29] 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 that any per capita emissions target for the region as a whole can be achieved by 2050 increases substantially if other medium-sized and small LAC countries follow Brazil and Mexico in contributing their own mitigation efforts.

[28] See Footnote 28 below 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%.

[29] 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—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 recent and significant downward shift 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%—as reflected in the CAIT data presented in Figure 6—to below 35%. Such a reduction would imply that Brazil's total GHG emissions in 2010 would have been only approximately 45% of the LAC total (instead of 52%, as reflected in the CAIT data for 2005 presented in Figure 7).

B. Projected Emissions: The "Business-as-Usual" Scenario

The peculiar features of the "LAC emissions anomaly"— relatively small historical and current contributions to the global emissions and the traditional concentration of LAC emissions in land-use and related (i.e., AFOLU) sectors, often leads observers to conclude that the challenging mitigation efforts required to significantly bend the region's emissions curve are simply not necessary and too expensive.

But, while, the region's land-use emissions have recently been falling (albeit tentatively), energy emissions, in particular from power generation and transport, continue to rise, driven by sustained economic growth, and will soon rival AFOLU emissions in prominence 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 foodstocks and other natural resources which if unchecked may also push upwards its carbon footprint.

The BAU Trajectory. While an international accord to reduce GHG emissions still eludes the worldwide community, the current path of emissions would lead to a future that must be avoided. Most analyses are based on the assumption that actions will be taken in time to avert dangerous impacts. However, there is increasing concern that the guardrail for a 2 degree increase in global temperature may be exceeded, with grave implications for the global biosphere.[30]

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)[31] is used as the business-as-usual scenario in 2050. Although there are countless other business-as-usual 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 Latin American and Caribbean (LAC) region as a whole. This business-as-usual (or "BAU") trajectory for the region also fits well into a global view of how future emissions are expected to evolve over time.

Table 8 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,

[30] An analysis of the consequences of a much warmer world during this century is beyond the scope of this document, but such consequences are being considered under the IPCC's Fifth Assessment Report.
[31] A full description of this scenario is included in Annex 2.

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 BAU growth expected from transport and power generation. These drivers are well tied to the current momentum of change in the region.

Table 8. Sector breakdown of expected (BAU) future emissions from 2010-2050 (Gt, %) and key driving forces

Category	2010	2050	% 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	1.6	0.67	-59%	Reduced deforestation
CO_2 total	*3.3*	*4.56*	*+38%*	Energy demand
CH_4	1.0	1.5	+48%	Livestock, agriculture
N2O	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 own elaboration.

For example, while LAC's energy sector is cleaner than the energy sectors of all other regions, economic growth has increased electricity demand and strained installed capacity and is carbonizing the region's power matrix.

Additionally, Climate Change has threatened the future reliability of hydropower (currently accounting for about 60% of the region's installed capacity and 70% of power generation) and 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.

Also changes in demand caused by shifting temperatures would require different patterns in energy supply. Indeed, continuous increases in temperature in tropical areas in the region could eventually force major increases in space heating requirements. A recent report on the subject

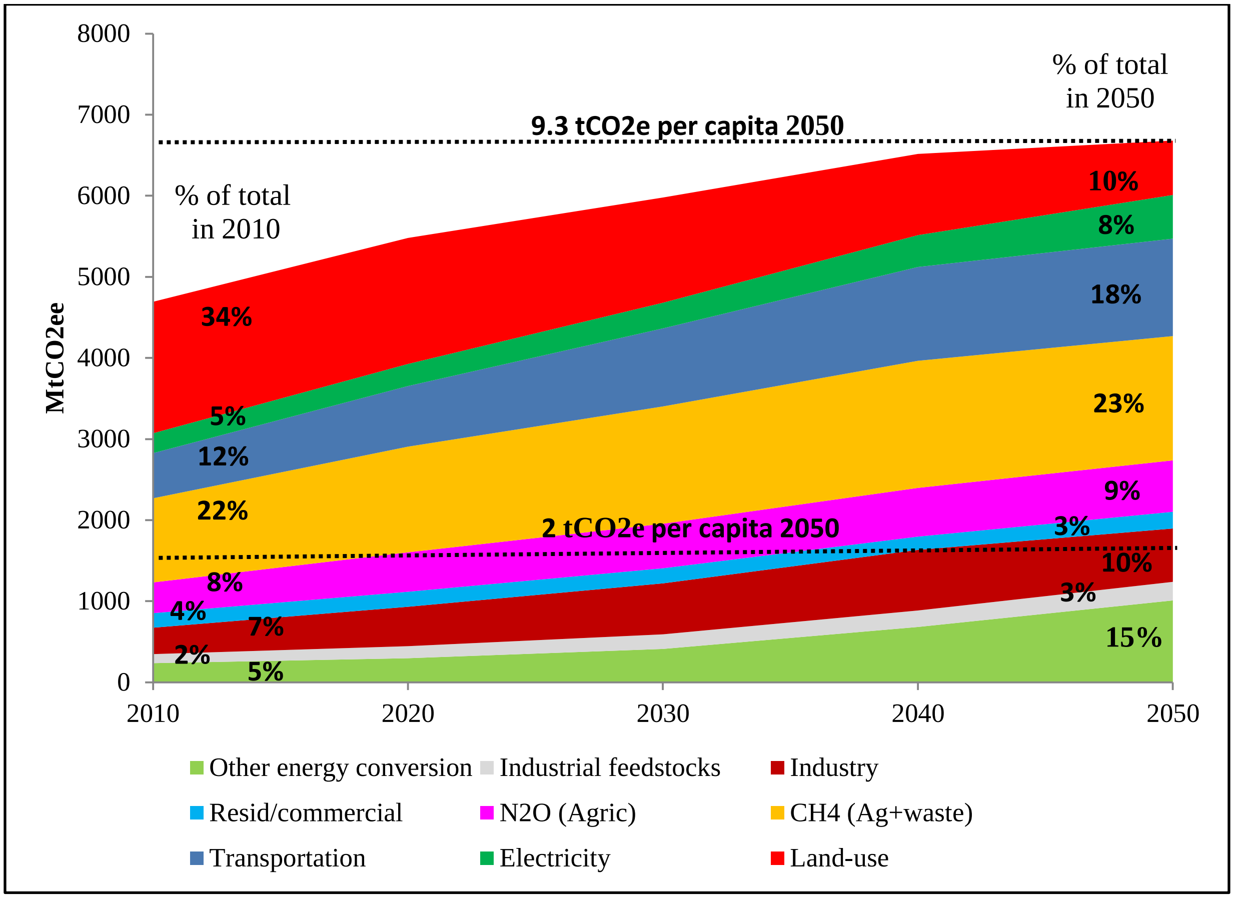
(Ebinger and Vergara, 2011) has concluded that many aspects of the energy sector can be quite vulnerable to impacts from Climate Change.

An increasing share of fossil fuels is also being incorporated into the generation mix to bridge the growing supply gap and to satisfy rapidly rising demand, which is projected to grow nearly 5% annually over the coming decade (Riahi et al. 2011). Rapid urbanization and motorization rates are increasing transport sector demand for fossil fuels as demand for gasoline and diesel in the transport sector increases and the pace of rural-urban migration continues. Large increases in food exports have also triggered higher emissions from agriculture. The BAU scenario for LAC is presented in Figure 8.

The anticipated reductions in land-use emissions will be more than compensated for 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% under the BAU trajectory to 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 become 9.3tCO_2e. Still, 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 until 2050.[32]

[32] Currently, LAC's primary energy mix is approximately 35% "low carbon" and 53% "lower carbon" (compared with 22% and 41%, respectively, for the world as a whole). In 2050, LAC's "low-carbon" and "lower-carbon" shares will be 40% and 65%, respectively (compared with 21% and 40%, 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% to 75% 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.

Figure 8. LAC BAU emissions trajectory by sectors from 2010 to 2050[33]



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

C. Pathways for Reaching 2tCO_2e Per Capita by 2050

Bending the emissions curve sufficiently to bring the region's current (8t) and projected (9.3t) per capita emissions levels down to 2tCO_2e in 2050 represents a significant change in trajectory, requiring substantial investment as well as changes in behaviour. 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".

Wedge Analysis: This study reconstructed the BAU emissions trajectory to 2050 to present nine "abatement wedges" that represent the quantity of emissions available to be abated between 2010

[33] 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.

and 2050 in each sector. None of these abatement wedges are meant to indicate any particular level of effort required or the relative political and/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.

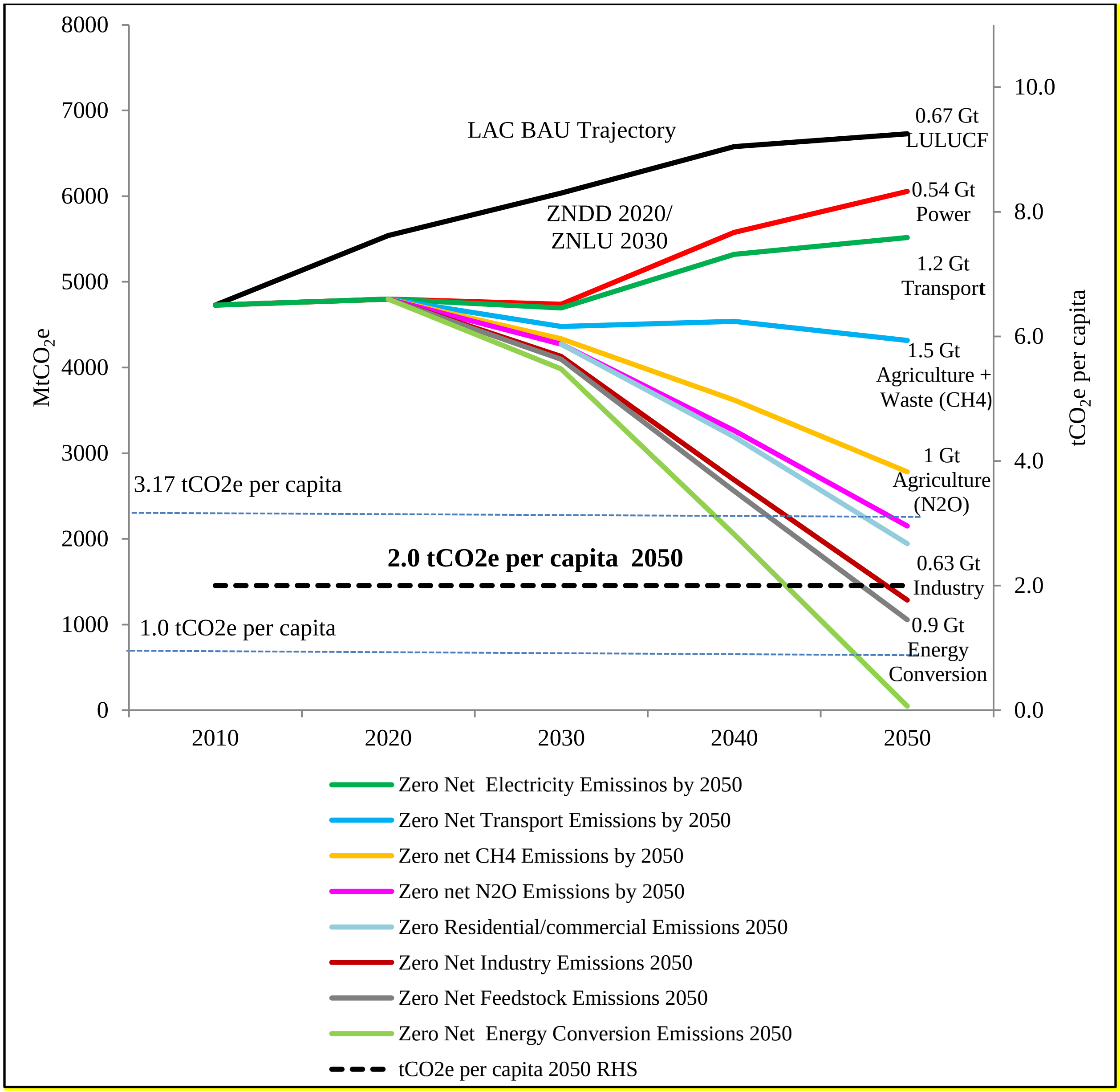
This analysis shows that *even the complete elimination of land use-based emissions would not be sufficient* to meet the 2t per capita target by 2050. An emissions reduction strategy capable of reaching zero net deforestation and degradation by 2020 (ZNDD 2020) and zero net land-use emissions by 2030 (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 Mt 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 decline to 3.9 $GtCO_2e$ would correspond to just over half (53%) of the necessary LAC effort to reach the 2t 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. Thus, for emissions to peak between 2020 and 2030, significant reductions of *energy-induced* GHGs would need to begin almost immediately. However, even if all energy emissions expected in 2050 were completely eliminated, the region would only be a little over halfway (56%) to the 2t 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 9. LAC BAU trajectory and emissions wedges* (without net carbon sinks) 2010-2050



Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and own elaboration. *Notes: (1) ZNDD 2020 = Zero Net Deforestation and Degradation by 2020; ZNLU 2030 = Zero Net Emissions from Land use, Land-use Change, and Forestry by 2030; LULUCF = Land use, Land-use change, and Forestry. (2) LULUCF emissions are cut in half from 2010 to 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. (3) 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. (4) 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 these wedges (see Figure 10).

Land-use Change Pathways: Under land-based pathways the following is pursued: (1) zero net deforestation and degradation by 2020 (ZNDD 2020) and (2) 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 and to zero by 2030.[34]

> 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 land-use emissions in net terms, beyond 2030, through further actions designed 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% cut in agricultural emissions compared with the BAU projection by 2050. In addition to innovative livestock and cultivation practices targeting CO_2, CH_4, and N_20 emissions, other conservation and forestry practices targeting deforestation and degradation would be required to achieve this pathway.

Energy Pathways:[35] The "energy" pathways would bring the region to between 3.4t (under the "supply" version of the the pathways; see below) and 4.3t (under the "efficiency" version) per capita by 2050.[36] *These would require the following*:

[34] Zero net deforestation and degradation (or ZNDD) – or the complete halt to deforestation, at least in net terms by the 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) there is also, due to the nature of the biological and chemical processes involved, 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.

[35] Our energy (or "moderate intervention") pathways were based directly on a number of IIASA's GEA model pathways – only the land-use emissions reductions, and associated intervention costs, have been stripped from IIASA's versions of the pathways to produce "pure energy intervention" pathways. Our 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 our 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.

(1) further improvements upon the historical rate of reduction in energy intensity;

(2) realization of a 60% to 80% share of the regional primary energy mix from renewables; and

(3) generation of a 75% to 100% share of the LAC electricity mix from low-carbon sources. All of these energy pathways also require real reductions in aggregate emissions levels *only after 2020* and avoid some 3.5 to 4.1 $GtCO_2e$ annually by 2050 (see Figure 10 and Table 9). Furthermore, all of these pathways assume nuclear-free development.[37]

The Mix I Pathway -- the foundation of this study's central reference pathway is characterized by the following: (1) final energy demand in 2050 some 40% below the expected BAU level; (2) the progressive electrification of the current conventional liquids-based transportation sector; and (3) a full portfolio of available renewable energy sources and technologies.[38]

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 the following: (1) significant improvements in energy efficiency, with *final energy demand in 2050 50% below the expected BAU* levels; (2) the displacement of the conventional transport sector with an advanced transport system based on electrification; and (3) an energy/technology mix that includes CCS.

Finally, **the Supply I Pathway** implies : (1) final energy demand only 23% below the BAU level in 2050; (2) an advanced "electrified" transportation system; and (3) the exclusion of existing nuclear power from the primary energy mix (but with the need for an even more significant deployment of CCS).

---

[36] In general, IIASA GEA's efficiency pathways would bring down the region's per capita emissions more slowly than in the Mix or Supply pathways, but with the enormous 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.

[37] All energy pathways designated type "I" also incorporate the gradual transformation of the current, 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.

[38] However, while the pathways are considered nuclear-free, this does not necessarily imply that LAC would eliminate nuclear power from the regional energy matrix completely by 2050; but it does imply no nuclear expansion from the current low production levels.

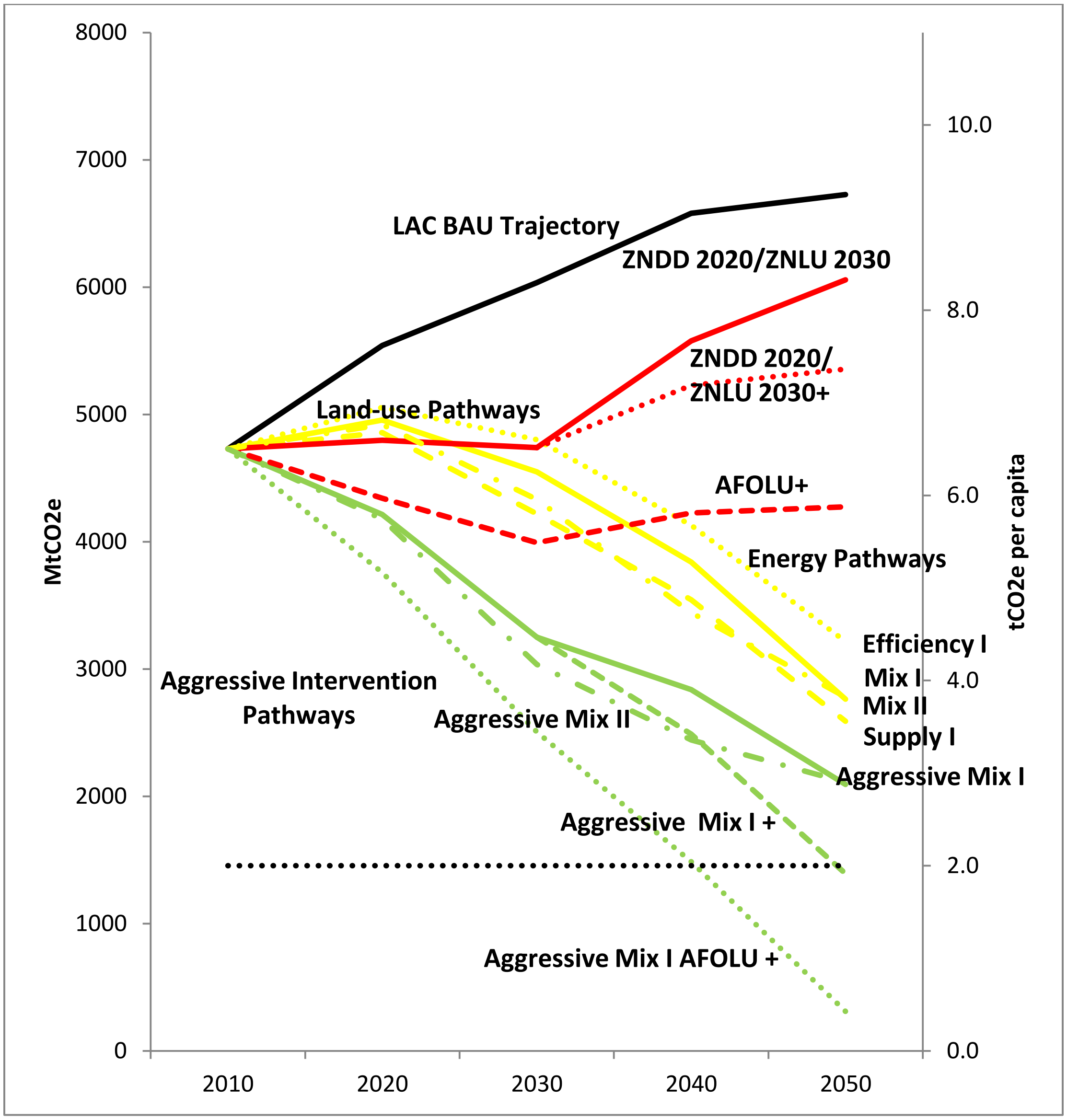
"Combined" Pathways**:** These combine energy actions with land-use policies stringent enough to achieve both the goals of the AFOLU (eg, ZNDD 2020/ZNLU 2030+) and the energy pathways, thus attaining the 2t per capita level (or even, as in some cases, 1tpc or below) by 2050. The principal difference 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 2t pc target is presented in Figure 10 and Table 9. To reach the 2tpc goal, LAC clearly requires a "combined" approach.

In addition, reductions in the emissions of short lived pollutants contributing to changes in albedo, such as soot or black carbon, could also have an immediate beneficial effect by delaying the onset of local changes in regional glaciated basins [39].

[39] Currently the book draft looks at energy and transportation emission reductions and changes in agriculture, forestry and land use changes needed, e.g. to ensure that the LAC 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 degrees C above pre-industrial levels. Yet if the LAC Region succeeds in achieving these goals, but other major regions such as Asia, Europe or North America (US and Canada) were to fall short, even heroic measures in the LAC Region would likely be ineffective in realizing this global goal.

Figure 10. Alternative emissions pathways for LAC from 2010 to 2050



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

Table 9. Summary presentation of alternative LAC emissions pathways to 2050

Actions needed					
Pathway	Land Use	Energy	Other	Reduced $GtCO_2e$ vs BAU	% of 2t target (-5.3Gt)
Land-use change-centered approaches					
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/ ZNLU2030+	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% above)
AFOLU+	Same as ZNDD 2020/ ZNLU 2030+ (above)	No change from BAU	50% 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,[40] 70% low-carbon primary energy[41], 97% low carbon generation and no nuclear	Progressive electrification of the transportation system; significant use of CCS post-2030	3.9	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	4.0	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	6.4	121%

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

[40] Final energy demand is nearly 40% less than the demand under the BAU trajectory.
[41] This figure is compared with only 36% low-carbon content in 2010 and 41% low-carbon content under the BAU trajectory in 2050.

Table 9 indicates that of the pathways analyzed, the Combined (or "aggressive") I+ (Plus) pathway does the job by 2050.[42] The route assumed under the Aggressive I+ pathway is depicted in Figure 11. The pathway recognizes the relative difficulties associated with agricultural activities and these 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.

Some of the principal actions considered under this Aggressive Mix I+ (plus) Pathway include:

a) *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 gains already achieved.

b) *No net emissions from land use change by 2030, net accumulation of carbon sinks to 2050, and a 50% cut in agricultural emissions against those projected in the LAC BAU trajectory*. This would also require of major improvements in forestry, land-use planning, agriculture and animal husbandry practices, some of which are yet to be field-deployed to a significant degree, including opportunities to increase carbon sinks and a major effort 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 will need to be implemented 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 0.35GtCO_2e by 2040 and *annual net negative* land use emissions of 0.7GtCO_2e by 2050.

c) *An effort to abate final energy demand by 40% compared to the BAU*. This can only be achieved through bulk improvements in energy efficiency (i., e. mass evolution of

[42] 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 2tpc 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 12 in Section D.

residential lighting toward LED devices; efficiency improvements in the demand for high pressure steam and low enthalphy heat; improvements in energy efficiency of domestic appliances and space heating/air conditioning that counter-acts the anticipated increase in use resulting from expected improvements in standard of living in the region) and other net reductions in demand.

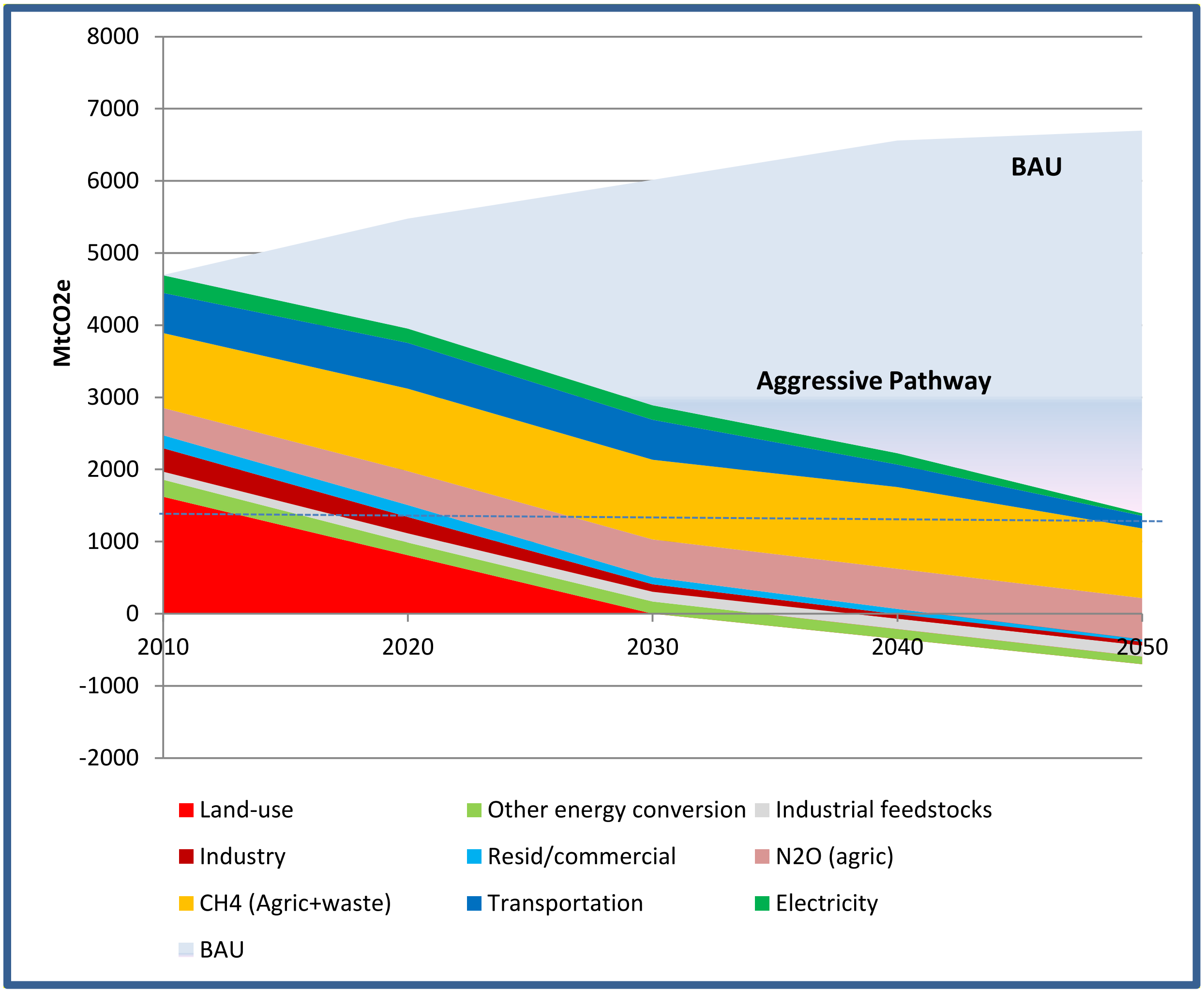
d) *A requirement for arresting and reversing the current carbonization path of the regional power matrix to an extent that would make viable at least 90% zero-carbon installed nominal capacity in the sector*. This, in essence, implies a major shift toward quick deployment of the substantial renewable energy endowment in the region. Fortunately, there is a sizable endowment of solar, geothermal, wind and other resources in the 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 for market entry. Large scale entry of marine energy in the coastal nations may revert in substantial technology benefits as techniques and practices are developed to attend to local conditions.[43] Actions to remove barriers for private sector investment in the power sector would also be required.

e) *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 internal combustion engines. While 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.

[43] Such coastal "low carbon" and mitigation efforts should be closely coordinated with adaptation efforts, so as to avoid duplication and to potentially capture synergies in terms of ultimate additional costs and cobenefits.

As with all pathways considered in this report, expansion of nuclear energy is not considered and the future exclusion of nuclear energy does not, in general, increase the costs of actions required under this pathway.[44]

Figure 11. "Aggressive Pathway I +", 2010-50



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

[44] 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 experience 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% 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% to 100%). Given the uncertainties surrounding the future of nuclear power, and its attendant cost structures, a 10% difference is not likely to persuade LAC policymakers and investors to expand nuclear power, at least very much or very rapidly. Indeed, all of the IIASA GEA Pathways (for more, see Annex B) that allow for nuclear power to expand, in competition with other energy sources within the matrix, only project a very minor increase over already very low levels (less than 1% of the LAC primary energy mix). In this sense, nuclear power remains nearly irrelevant to this study.

Table 10 presents a summary of the different emission scenarios, including the estimated emissions, the volume of emissions avoided vis-a-vis the BAU, and the estimated per capita emissions by 2050.

Table 10. LAC emissions scenario summary (1990–2050)

Scenario	Emissions 2050* $MtCO_2e$	% change in 1990 levels: 4,578 $MtCO_2e$	tCO_2e per capita in 2050	$MtCO_2e$/yr avoided vs. BAU in 2050: 6,727 $MtCO_2e$	% difference from BAU in 2050
LAC BAU	6,727	47% above	9.30	--	--
ZNDD 2020/ZNLU 2030+	5,360	35% below	7.15	1,370	25% below
Energy "Mix I"	2,780	39% below	3.71	3,947	59% below
LAC 2 ton per capita target	1,450	68% below 4,578 $MtCO_2e$	2.00	5,277	78% below
Combined "Aggressive I+"	1,390	70% below	1.86	5,337	79% below

Source: Version 2.0.rc1 of the GEA Scenarios Database of the International Institute for Applied Systems Analysis (IIASA) and own elaboration. Notes: *These potential LAC "shares" of the global mitigation burden are substantially (30%–60%) below LAC's share of global annual emissions (11% in 2005).

D. Financial Costs of the Intervention Pathways

Using the financial projections of IIASA's GEA Message Model, this study has made estimates of 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 US$24 billion/year (by 2030) would be required to achieve the ZNDD 2020/ZNLU 2030 pathway (see Tables 11 and 12, and Annex 3). Additionally, the estimate suggests that some US$53 billion a year (or an additional US$36 billion a year) would be required by 2050 to continue augmenting LAC's carbon sinks enough to achieve the ZNDD

2020/ZNLU 2030+ (Plus) Pathway. This report's estimate of the average net financial cost of abatement required along these pathways is US$22–US$24/tCO_2e.[45]

While such an estimate inherently implies a range of uncertainty, given necessary and reasonable assumptions, it falls clearly within the wide range of global estimates in the existing literature (see Table 11). For example, among the many global projections that exist , some estimates of a *complete global halt* to deforestation by 2030 (the ZNDD 2030 scenario) are as low as US$12 billion per year to compensate for the opportunity costs of deforestation and forest degradation, with an average abatement cost of approximately US$2/t$CO_2$e (Blaser and Robledo 2007). At the other end of the spectrum, one of the most widely quoted estimates (Eliasch 2008) suggests that some US$17 billion–US$33 billion would be required annually to sufficiently compensate for opportunity costs to achieve *only a 50% reduction in deforestation emissions* globally by 2030. Meanwhile, the European Commission has estimated that *a 50% global abatement of deforestation emissions by 2020* would cost US$20 billion to US$33 billion a year and that a complete global halt to deforestation emissions by 2030 would cost some US$38 billion to US$96 billion a year—at an overall average abatement cost of as much as US$90 per t$CO_2$e (see Grondard, Martinet, and Routier 2008).[46]

Of the few LAC regional estimates that exist, the McKinsey Report (of Enkvist, Nauclér and Rosander 2007) estimated that for the LAC region to achieve 75% deforestation emissions abatement, average abatement costs would be US$50/t$CO_2$e.

[45] This study's estimates for the ZNDD 2020/ZNLU 2030 pathways are based on the "non-energy 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 "non-energy expenditures" under the GEA Mix II pathway with conventional transport and no sinks from those "non-energy 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). However, 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 non-energy expenditures in any year, despite the projected 60% decline in land-use emissions from 2010 to 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. See Annex 3.

[46] Global estimates from the IPCC are even higher, and range from US$40 billion to as much US$350 billion a year (Grondard, Martinet, and Routier 2008). For the estimates from Grondard, Martinet, and Routier (2008), the authors' currency conversion of $1.28/euro was used.

While such top-down estimates tend to be relatively high, local bottom-up estimates for LAC are far lower. Olsen and Bishop (2009), for example, place the opportunity costs for avoiding deforestation in the Amazon at approximately US$5/t$CO_2$e of abated carbon.

Table 11. Selected estimates of the opportunity cost for halting deforestation

Level of abatement	Cost US$ billion/year, US$/t$CO_2$e	Source
Deforestation (50% abatement by 2020)	US$20 billion to US$33 billion/year	(European Commission 2008)
Deforestation (complete annihilation by 2030)	US$38 billion to US$96 billion/year, up to US$90/t$CO_2$e	(European Commission 2008)
Deforestation (50% abatement by 2030)	US$17 billion to US$33 billion/year	(Eliasch 2008)
LAC ZNLU 2030	US$20 billion to US$40 billion/year	(Eliasch 2008, adjusted through own assumptions to LAC region (see below))
Deforestation (full halt)	US$40 billion to US$350 billion/year	IPCC WGIII AR4
Deforestation (49% abatement)	US$2.2/t$CO_2$e	(Kindermann, Obersteiner et al. 2008)
Deforestation (65% abatement)	US$4.0/t$CO_2$e	(Blaser and Robledo 2007)
Deforestation	US$5/t$CO_2$e	(Olsen and Bishop 2009)
Deforestation (65% abatement by 2030)	US$11.2 billion/year, US$2.8/tCO_2e	(Blaser and Robledo 2007)
Deforestation (full halt by 2030)	US$12 billion, US$2/tCO_2e	(Blaser and Robledo 2007)
LAC deforestation (75% abatement)	US$50.00/t$CO_2$e	(McKinsey Report by Enkvist, Naucler et al. 2007)
Avoided degradation	US$7.3 billion/year, US$1.1/tCO_2e	(Blaser and Robledo 2007)
LAC ZNDD 2020/ZNLU 2030	US$17 billion/year in 2020 (US$21/t$CO_2$e); US$24 billion/year in 2030 (US$15/$CO_2$e); US$30 billion in 2040 (US$18/t$CO_2$e); US$37 billion in 2050 (US$23/t$CO_2$e)	(Own estimates based on IIASA GEA projections and assumptions; see below)

Source: Meridian Institute (2009) and own 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)[47].

Nevertheless, our analysis adjusts of one of the most widely cited estimates from the existing literature—the US$17 billion–US$33 billion/year global estimate for a 50% reduction in land-use emissions by 2030 (Eliasch 2008)— to generate an equivalent projection of the total financial cost of US$20 billion–US$40 billion a year by 2030 for LAC for complete ZNDD 2020/ZNLU 2030. Our adjustment to this regional estimate is based on the following assumptions:

(1) 100% abatement of emissions from deforestation by a particular date will cost roughly twice the amount needed to achieve 50% abatement by the same date;

(2) readiness, implementation, and transaction costs are approximately 50% of opportunity costs[48]; and

(3) roughly 40% of the abatement costs for global land-use emissions can be assigned to LAC.[49]

This estimated projection (US$20 billion to US$40 billion as of 2030), which adjusts one of the central global estimates within the existing literature to become LAC-specific and to take into account readiness, implementation, and transactions costs, is remarkably in line with our IIASA-based financial projections for LAC (presented in Table 12): total annual financial costs reach US$17 billion by 2020 with ZNDD, US$24 billion by 2030 with ZNLU, US$30 billion by 2040 (assuming no net additions to sinks, as in the Aggressive I pathway), and US$37 billion by 2050.[50]

Although this study's estimate is based on regional—as opposed to global—financial cost projections, they remain top-down and thus vulnerable to the potential overestimation typical of these 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"

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

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

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

[50] 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 0.35GtCO_2e per year in the decade to 2040 and a further 0.7GtCO_2e per year in the decade to 2050. In this pathway, these annual costs reach $36 billion by 2040 and $53 billion by 2050.

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 financial cost estimates do not appear to be prohibitive. [51]

The Financial Costs of the Energy ("Moderate") and Combined ("Aggressive") Pathways: The overall costs of the Energy Pathways, presented in Table 11, are based on the projected *energy* expenditure and *energy* investment requirements generated by IIASA's GEA Model pathways (see Riahi et al. IIASA-2011). These estimates are presented in both total and net terms (i.e., in both "gross" terms, and "net" of the expected BAU investment and non-investment expenditure requirements). The *annual "net" financial costs* associated with the various alternative mitigation pathways correspond to *the additional financial resources required each year to move from the scenario of the BAU trajectory to any of the particular energy intervention pathways* under study.[52]

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 financial requirements are less onerous.

For example, the Moderate Intervention "Mix I" Pathway—which would electrify LAC's transportation systems while excluding nuclear power from the region's energy mix—would cost US$132 billion/year in gross financial terms by 2020 (including lower current, but substantial and rising financial requirements each year until that date). However, this pathway would also imply system-wide savings of more than US$8 billion a year in net terms (once annual BAU expenditures to 2020 are factored out). Thus, the pathway yields an average financial abatement

[51] 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 fair to say that it is still difficult to know with certitude how much these scenarios will ultimately cost in terms of financial additionality.

[52] 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 non-investment 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 (i.e., 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 from the present that reach $132 billion annually by 2020 and some $508 billion annually by 2050. In any case, approximately $460 billion (in annual investment and other "non-investment" expenditures) would have to be mobilized and channeled into the energy sector of the region by 2050, in any event. just to meet the supply and demand requirements under the current fossil-fuel dominated BAU trajectory, even with no specific interventions designed 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.

cost of US$213/t$CO_2$e (gross) and negative -US$13/t$CO_2$e (net), respectively, in that year (see Table 11).[53]

Also, the Mix I Pathway would require a gross total of US$508 billion/year by 2050—or nearly 2.67% of projected LAC GDP in that year (11% of the region's 2010 GDP level)—in net terms, this pathway would require only US$43 billion/year, with an average net abatement cost of only US$11/t$CO_2$e by 2050. This total would represent less than 0.25% of the projected LAC GDP (PPP) in 2050 (or 0.93% of LAC's 2010 GDP). [54] However, *the Mix I Pathway would only get LAC to 3.71t emissions per capita*.

To reach the 2t per capita goal, *the LAC region would need to successfully pursue the Combined I+ Mix (Plus) Pathway*. The total gross and net cost estimates for this and the other Combined Pathways are constructed by combining the Energy Pathway financial cost projections with those of the Land-use Pathways.[55] The Combined I+ Mix (Plus) Pathway would imply a total gross and net additional financial cost of nearly US$150 billion/yr and US$10 billion/yr, respectively, by 2020 (although lower but substantial and rising annual sums will be required again in each of the years approaching that date from the present). These annual financial requirements would rise to US$561 billion/yr in gross terms but only US$97 billion/year, in net terms, by 2050.

A number of other Combined Pathways would also bring LAC down to, or below, the 2tpc goal. For example *the Aggressive II+ Mix (Plus) Pathway* (with conventional transportation) would bring the region to 1.88tpc in 2050.

In addition, the *Aggressive I+ Efficiency (Plus) Pathway*, while only bringing the region to 2.5 tpc, implies only US$39 billion in net financial additionality. If we were to force an adjustment of the pathway down to 2.0tpc through additional land-use emissions interventions, such *a fortified version* of the Aggressive I+ Efficiency (Plus) Pathway would cost US$48 billion in net financial additionality in 2050, far more economical than the Aggressive I+ Mix (Plus) and the

[53] "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 requirementes. In the case of the Mix I pathway, the displacement is produced by both the reduction in final demand of 40% achieved under the pathway when compared to BAU in 2050 and the shift from conventional to advanced transportation (which displaces more expensive petroleum-based transportation).

[54] 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% average annual growth from 2010 to 2050 for the region as a whole. For comparative purposes, LAC's GDP for 2010 (in 2005 dollars) was $4.6 trillion.

[55] 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 (i.e., the necessary financial resources in addition to those that would be required in any case under the business-as-usual trajectory) of any particular mitigation pathway.

Aggressive II+ Mix (Plus) pathways. On the other hand, a similarly fortified version of the *Aggressive II+ Efficiency (Plus) Pathway* (with conventional transportation), would ultimately cost only US$38 billion annually by 2050 in net financial additionality, one of the cheapest ways identified in this study to reach the 2tpc goal.

Table 12 makes clear that the Efficiency versions of the pathways are cheaper than their Mix and Supply counterparts. The *Aggressive AFOLU+ I Efficiency Pathway* would bring LAC emissions to nearly 1tpc by 2050, although the net financial additionality would come to only US$49 billion annually, while the *Aggressive AFOLU+ II Efficiency Pathway* would reach just below 1tpc, with an annual net financial additionality of US$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 – 0.11GtCO_2e – and per capita LAC emissions to 0.15tpc)—is projected to cost no more than US$187 billion/year in net financial terms by 2050, less than 1% of projected 2050 LAC GDP.

Table 12. Emissions pathways: cost from 2010 to 2050

Alternative Pathways* (Based on ZNDD 2020/ ZNLU 2030)		Financial Cost** US$billion/ year 2020	Financial Cost** US$billion/ year 2050	% of GDP (LAC, PPP) US$19tn 2005US$ in 2050	Average Financial Cost US$(2005)/ tCO_2e in 2050	Total and Per Capita Emissions 2050 $GtCO_2e$ and t/CO_2e
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	3.71
Moderate Intervention “Mix II”(conv. transport)	Total	144	485	2.60	122	2.76
	Net of BAU	3.1	20.3	0.10	5.1	3.68
Moderate Intervention “Efficiency I” (adv. trans.)	Total	115	450	2.36	128	3.21
	Net of BAU	-25	-15	-0.07	-4	4.29
Moderate Intervention “Supply I” (adv. trans.)	Total	162	544	2.86	131	2.59
	Net of BAU	22	80	0.42	19	3.45
Moderate Intervention “Supply II” (conv. trans.)	Total	203	588	3.1	141	2.57
	Net of BAU	62	124	0.65	30	3.42
Aggressive I Mix (adv. trans.)	Total	150	545	2.87	118	2.09
	Net of BAU	10	81	0.43	17.4	2.79
Aggressive I Efficiency (adv. trans.)	Total	133	487	2.56	117	2.55
	Net of BAU	-7	23	0.12	5.4	3.4
Aggressive I Supply (adv. trans.)	Total	180	581	3.1	121	1.92
	Net of BAU	40	117	0.62	24	2.56
Aggressive II Mix (conv. trans.)	Total	162	522	2.75	113	2.1
	Net of BAU	21	58	0.31	12.5	2.8
Aggressive II Efficiency (conv. trans.)	Total	136	478	2.52	113	2.5
	Net of BAU	-4.7	14	0.07	3,2	3.35
Aggressive II Supply	Total	221	626	3.3	130	1.9
	Net of	80.5	161	0.85	33	2.53

(conv. trans.)	BAU					
Aggressive I+ Mix (adv. Trans.)	Total	150	561	2.95	105	1.39
	Net of BAU	10	97	0.51	18	1.86
Aggressive I+ Efficiency (adv. Trans.)	Total	133	503	2.65	103	1.85
	Net of BAU	-7	39	0.21	8	2.46
Aggressive I+ Supply (adv. Trans.)	Total	180	597	3.14	109	1.22
	Net of BAU	40	133	0.70	24	1.63
Aggressive II+ Mix (conv. trans.)	Total	162	538	2.83	101	1.41
	Net of BAU	21	74	0.39	14	1.88
Aggressive II+ Efficiency (conv. trans.)	Total	136	494	2.6	100	1.81
	Net of BAU	-4.7	30	0.16	6	2.42
Aggressive II+ Supply (conv. trans.)	Total	221	642	3.4	116	1.2
	Net of BAU	80	177	0.93	32	1.6
Aggressive I AFOLU+Mix (adv. trans.)	Total	151	571	3.0	89	0.31
	Net of BAU	11	107	0.56	17	0.41
Aggressive I AFOLU+ Efficiency (adv. trans.)	Total	134	513	2.7	86	0.76
	Net of BAU	-6	49	0.26	8	1.02
Aggressive I AFOLU+ Supply (adv. trans.)	Total	181	607	3.2	92	0.14
	Net of BAU	41	143	0.75	22	0.18
Aggressive II AFOLU+ Mix (conv. trans.)	Total	163	548	2.9	86	0.33
	Net of BAU	22	84	0.44	13	0.44
Aggressive II AFOLU+ Efficiency (conv. trans.)	Total	137	504	2.65	84	0.73
	Net of BAU	-3.5	40	0.21	6.6	0.97
Aggressive II AFOLU+ Supply (conv. trans.)	Total	222	652	3.4	99	0.11
	Net of BAU	82	187	0.98	28	0.15

Source: Version 2.0.rc1 of the GEA Scenarios Database of IIASA and own 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% of the region's current primary energy mix. **Note: Financial Cost (net of BAU) = projected annual energy capital investment plus annual operation and maintenance costs to the energy system and other non-energy 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 further facilitate investment planning, this section summarizes, the projected gross and net additional financial costs, annually by 2050 at the sectorial – or policy intervention – level (ie, deforestation and land use, agriculture, efficiency, power and transportation). Further elaboration of how these projections have been 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 (ie, the "plus" pathways)**

To achieve 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 US$53 billion by 2050 (see Table 12). "Gross" and "net" financial additionality for the ZNDD 2020/ZNLU 2030 pathway are the same (US$37 billion annually for 2050), given that there are no expenditures projected under the BAU trajectory for the forestry, land-use and land-use change (or LULUCF) sectors.[56] These "net" additional land-use expenditures would be spent on:

(1) efforts to increase the productivity of forestry and agriculture activities to avoid any additional forest cover loss (particularly rapid action will be required to combat new and emerging threats to the forest frontiers, including potential damage from uncontrolled mining in the Amazon and Andes Piedmont regions that might undermine gains already secured),

(2) the costs of enforcement of deforestation restrictions,

(3) the costs of REDD/REDD+ readiness and implementation, together with transactions costs (related principally to land-use governance), that typically make up together as much as one-third of total net financial additionality for LULUCF mitigation activities, and

[56] These "gross" and "net" figures for financial additionality required to achieve the ZNDD 2020/ZNLU 2030 Pathway come directly from Table 12 (see the relevant section above in this Annex 3 for a detailed explanation of how these Table 11 projections were arrived at).

(4) the costs of investments in the support and enhancement of carbon sinks, among other activities.

This last cost component (US$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 (ie, ZNLU 2030).[57] 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 field-deployed to a significant degree), including the early and aggressive pursuit of opportunities to increase carbon sinks through forestry, agriculture and livestock activities, incorporating a major effort to recover at least some of the 3 million hectares of degraded lands in the region as an alternative to further expansion of the agricultural frontier.[58] 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, and vigorous regulatory and enforcement action, combined with forceful economic incentives.

- **A Significant Reduction of Agricultural Emissions**

To cut agricultural emissions by 50% in 2050, the projection implies that "gross and "net" additional financial costs of US$10 billion would be required (see Table 13, no expenditures on non-energy mitigation activities are projected to occur along the BAU). Such required expenditures would include: the marginal costs for market entry of new low carbon practices in agriculture; 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.

[57] To meet the 2tpc target, the Aggressive Mix I+ Pathway would need to increase carbon sinks enough to achieve annual net negative land use emissions of 0.35GtCO_2e by 2040 and annual net negative land use emissions of 0.7GtCO_2e by 2050.

[58] 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 additional financiality separately from that of agriculture, there is clear potential to reduce financial requirements by integrating the approaches and taking advantage of such synergies.

Table 13. AFOLU+ Pathway Components, Required Financial Additionality, 2050

Sector Components	"Gross" Additional Annual Total by 2050	Annual Total Expenditures under BAU by 2050	"Net" Additional Annual Total by 2050
ZNDD/ZNLU 2030 (net zero deforestation by 2020 and net zero land-use emissions by 2030)	US$37bn	No expenditures projected under the BAU	US$37bn
ZNDD/ZNLU 2030+ (Additional net carbon sinks)	An additional US$16bn	No expenditures projected under the BAU	An additional US$16bn
Agriculture (50% reduction against BAU by 2050)	An additional US$10bn	No expenditures projected under the BAU	An additional US$10bn
AFOLU+ Pathway	US$63bn	--	US$63bn

Source: IIASA GEA Model Database and own elaboration. *Notes: AFOLU cost projections here assume the development of the Mix II (conventional liquid transportation) pathway. However, the 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 (US$560 billion annually in 2050) and a simple summation of AFOLU costs (assuming Mix II) and energy costs (assuming Mix I)), or US$571 billion in 2050. Such a US$10-20 billion variation is typical among gross financial additionality projections (particularly in the realm of AFOLU) for the various pathways. See Table 11.

- **Increased Energy Efficiency**

To improve energy efficiency enough to reduce final demand by 40% compared to BAU, would require net additional annual expenditures to rise to US$88 billion annually in 2050, once all related projected expenditures under the BAU have been discounted (see Table 13). Required "gross" additional annual expenditures -- compared to the "current" level of expenditures in 2010 -- would rise to US$104 billion in 2050 (see Annex 3 for a detailed explanation of projected efficiency-related expenditures under the BAU).

Table 14. Moderate Energy Mix I Pathway Components, Required Financial Additionality 2050

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% below BAU by 2050)	**US$104bn**	**US$16bn**	**US$88bn**
--demand-side investment:	83bn	zero	83bn
--electricity transmission & distribution:	21bn	16bn	5bn
De-carbonization of Electricity (more than 90% of installed capacity)	**US$133bn**	**US$67bn**	**US$66bn**
--investment in non-fossil electricity:	62bn	31bn	31bn
--electricity transmission & distribution:	21bn	16bn	5bn
--unallocated IIASA non-investment expenditure:	50bn	20bn	30bn
Electrification of Transportation	**US$50bn**	**US$20bn**	**US$30bn**
--unallocated IIASA non-investment expenditure:	50bn	20bn	30bn
CCS	**US$17bn**	**--**	**US$17bn**
--investment in CCS:	7bn	zero	7bn
--unallocated IIASA non-investment expenditure:	10bn	zero	10bn
Other Energy Actions	**US$204bn**	**US$362bn**	***negative -US$158bn***
--investment in fossil fuel extraction:	54bn	170bn	-116bn
--investment in fossil electricity generation:	2bn	4bn	-2bn
--"other" supply-side investment: (district heat, oil refineries, bioenergy extraction, production of hydrogen, synfuels)	42bn	38bn	+4bn
--unallocated IIASA non-investment expenditures: (fuel and other energy inputs, both private spending and public subsidies)	106bn	150bn	-44bn
Moderate Energy Mix I Pathway	**US$508bn**	**US$465bn**	**US$44bn**

Source: IIASA GEA Model Database and own elaboration. *Notes: This Energy Pathway (1) requires over US$2.1 trillion in cumulative gross additional investment in transmission and distribution (including storage) and in non-fossil fuel generated electricity; (2) achieves 97.8% low-carbon generation by 2050, counting biomass without CCS and all forms of generation with CCS as low-carbon sources.

Such financial requirements would stem from the estimated marginal additional costs of adopting new energy conservation and efficiency practices and technologies, the extension and dissemination costs to adopt new energy efficiency practices, and additional operational and maintenance costs. Any effort to abate final energy demand by 40% compared to the BAU can only be successful through bulk improvements in energy efficiency (ie, mass evolution of residential lighting toward LED devices; efficiency improvements in the demand for high pressure steam and low enthalphy heat; improvements in energy efficiency of domestic appliances and space heating/air conditioning that counteract the anticipated increase in use resulting from expected improvements in standard of living in the region, and other rebound effects), along with other net reductions in demand.

- **Decarbonization of the Power Sector**

To achieve 97% decarbonization of the LAC power sector by 2050 would entail US$133 billion annually by 2050 in "gross" financial additionality and **US$66 billion annually by 2050** 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

> the additional annualized costs of generation caused by entry of renewable energy resources, the costs of upgrading and expanding transmission grids, including the expenditures required to incorporate intermittent sources (ie, the costs of additional reserves to manage firm capacity of intermittent sources), and
>
> costs related to additional capacity building and training of grid operators.

Arresting and reversing the current carbonization path of the regional power matrix to an extent that would make viable at least 90% zero-carbon installed nominal capacity in the sector 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 to remove barriers for private sector investment in the power sector would also be required.

- **Electrification of Transport**

To achieve widespread electrification of the transport sector, our estimated projection foresees net additional expenditures of about **US$30 billion annually by 2050** (US$50 billion annually in gross terms, compared with US$20 billion annually projected under the BAU by 2050; see Table 13, 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 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 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 analysed 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 US$350 billion annually by 2050 (see Table 14). However, this is still some US$210 billion annually below the total gross financial additionality (the total amount of finance that must be mobilized). Furthermore, because a significant amount (some US$103 billion annually), which is projected to be required 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 US$247 billion annually by 2050.

Table 15. Selected Prioritized Mitigation Interventions, Required Financial Additionality 2050

Sector Components	"Gross" Additional Annual Total by 2050	Annual Total Expenditures under BAU by 2050	"Net" Additional Annual Total by 2050
--ZNDD/ZNLU 2030	37bn	zero	37bn
--ZNDD/ZNLU 2030+	16bn	zero	16bn
--Agriculture: (50% reduction against BAU by 2050)	10bn	zero	10bn
--Energy Efficiency	104bn	16bn	88bn
--Decarb Power	133bn	67bn	66bn
--Electrification of Transportation	50bn	20bn	30bn
Subtotal	350bn	103bn	247bn

Source: IIASA GEA Model Database and own elaboration.

- **Other Interventions and Financial Requirements of the Aggressive Mix I+ (plus) Pathway**

There are still other costs associated with actions to be taken under the reference pathways. First, carbon capture and sequestration efforts under the intervention pathways would require an additional US$17 billion annually by 2050, in both "gross" and "net" terms, as no CCS expenditures are projected under the BAU (see Table 13).

Second, a range of other energy actions are incorporated into the reference pathways, including (a) investment in fossil extraction (US$54 billion annually in 2050, versus US$170 billion annually under the BAU; or negative -US$116 billion annually, in "net" terms, once displaced BAU expenditures have been discounted); (b) investment in fossil electricity generation (US$2 billion annually in 2050, versus US$4 billion annually under the BAU); (c) "other" supply-side investment (US$42 billion annually in 2050, including investments in oil refineries, district heat, and bioenergy extraction, as well as production of hydrogen and synfuels, versus US$38 billion annually under the BAU); and (d) other "non-investment expenditures" that are projected as required within the overall intervention pathways, but which are not allocated to any specific line items by IIASA as discrete projections (US$106 billion annually by 2050, versus US$150 billion annually under the BAU).[59]

These “other” financial expenditures required under the Aggressive Mix I+ (plus) Pathway are projected to reach US$204 billion annually in 2050 in gross terms. However, in terms of “net” financial additionality, this “other” category turns out to be negative -US$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 sub-sectors, in which large savings are registered from less investment taking place in the future on expensive fossil fuel extraction and generation (by far the largest cross-sectoral savings from from the Aggressive Mix I+ (plus) Pathway: around US$118 billion annually in savings in 2050, when compared with the BAU), and from fewer “non-investment” expenditures spent on increasingly expensive fossil fuels in the future for transportation and electricity consumption (US$44 billion annually in savings in 2050; see Tables 13 and 15).

The projected additional financial requirements described above are presented in both “gross” and “net” terms. [60]. 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 to 2050.

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[59] 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.

[60] For the six principal intervention components identified and analyzed above, these “gross” and “net” additional financial requirements are projected to collectively total US$350 billion and US$247 billion annually, respectively, by 2050. For the entire Aggressive Mix I+ (plus) Pathway “gross” and “net” additional financial requirements are projected to reach US$561 billion and US$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 (ie, 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). However, IIASA’s financial projections are presented explicitly only in what we have termed “gross” terms: that is, the amount of additional investment and non-investment 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 11 and 15, and in Annex 3) – this required financial additionality comes to US$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.

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 US$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 beyond those already assumed under the BAU. This means that even if LAC actors do nothing to change the current policy trajectory, required annual financial additionality will rise to US$464bn annually by 2050. Meanwhile, LAC emissions would increase from around 4.7GtCO_2e in 2010 to around 6.7GtCO2e (or from over 6 t/CO_2e to over 9t/CO2e in per capita terms; see section B on Projected Emissions: the Business-as-Usual Scenario). In such a context, a more relevant category of financial additionality for the evaluation of policy and budget options and priorities 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 particularl intervention pathway.

Table 16. Aggressive Mix I+ (plus) and Aggressive Mix I AFOLU+ (plus) Pathway Components

Sector Components	"Gross" Additional Annual Total by 2050	Annual Total Expenditures under BAU by 2050	"Net" Additional Annual Total by 2050
--ZNDD/ZNLU 2030:	37bn	zero	37bn
--ZNDD/ZNLU 2030+:	16bn	zero	16bn
--Energy Efficiency:	104bn	16bn	88bn
--Decarb Power:	133bn	67bn	66bn
--Electrification of Transportation:	50bn	20bn	30bn
--CCS	17bn	zero	17bn
--Other Energy Actions	204bn	362bn	negative -158bn
Aggressive Mix I+ (plus) Pathway Total	US$561bn	US$465bn	US$96bn
Additional Aggressive Mix I AFOLU+ (plus) Pathway Component			
--Agriculture: (50% reduction against BAU by 2050)	10bn	zero	10bn
Aggressive Mix I AFOLU+ (plus) Pathway Total	US$571bn	US$465bn	US$106bn

Source: IIASA GEA Model Database and own elaboration. *Notes: (1) Electricity output under Aggressive Mix I+ (plus) Pathway is 12% higher than in the BAU Pathway, due to greater electricity use from the electrification of transportation. (2) Aggressive Mix I+ (plus) pathways implies savings over the BAU Pathway in the areas of fossil-fuel generated electricity and fossil fuel extraction of US$128 billion annually by 2050.

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

The implication is that for less than US$100 billion annually in 2050 (or less than US$2 trillion cumulatively) in *incremental – or "net"* -- additional financial requirements, LAC could reduce regional 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 degree guardrail analysed in the Introduction (2 t/CO_2e), and far below the current level 6.4 t/CO2e. Indeed, the marginal additional finance required to meet the 2 t/CO_2e per capita target in LAC would be only less than 20% compared to what will need to be mobilized in any case. In this sense, then, the most relevant category – for determining pathways and policies -- remains the "net" additional financial requirement.

While "gross" financial additionality indicates the level of effort required to mobilize the necessary financial resources to achieve any emissions mitigation objective, "net" financial additionality represents the extra, additional effort required, compared to those assumed under the BAU trajectory. *Another way to view the "net" additional financial requirements category is as a reflection of the "savings" implied by displacing – or taking advantage of – the additional financial resources which are necessarily built into the status trajectory (if not the current moment).*

The System-wide nature of the 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 "system-wide", incorporating all of the investment and non-investment expenditures required across the entire energy system of LAC, irrespective of the nature or character of the actors (ie, public and private sectors, producers and consumers) along the productive chain of the energy system. Investment includes all public and private investment, and non-investment 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 “energy system-wide” nature of these financial projections facilitates evaluation of policy and investment priorities across the entire system, often making the substantial built-in financial costs of the status quo BAU trajectory easier to visualize and to compare with the financial additionality required by the available intervention options.

IV. DEVELOPMENT CO-BENEFITS FROM ADAPTATION AND MITIGATION

Climate impacts will impose substantial costs on development. This report estimates that those costs that can be calculated would equal approximately US$100 billion per year by 2050, equivalent to approximately 2.2% of 2010 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, better health, education, food, water and energy security, and housing. However, 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 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, whereas adaptation ameliorates specific impacts in a particular location. Additionally, some mitigation and adaptation actions might interact with each other to create synergies or might offer different alternatives to tackle a Climate Change impact.

A. Development Co-benefits 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 adaptation. However, the information at hand implies that the cost of adaptation efforts is probably lower than the costs of physical damages (as seen in section II). This finding highlights the need to invest early in adaptation. Unless addressed, the 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 LAC development. 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, can often be perceived as gradual and distant in time or even, in some cases, uncertain. However, a lack of action on adaptation will only generate more development needs in the future because the costs and impacts 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 co-benefits. Table 16 summarizes some of the co-benefits expected from adaptation actions by sector or area of concern. These co-benefits include improved water and food security, technology development, and an improved position with respect to securing 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 against the impacts of Climate Change would result in better management practices and a reduction of waste. Likewise, improvements in the management of fisheries to address climate impacts would generate more sustainable practices, greater reductions of waste, and additional improvements in productivity.

Still, even with forceful adaptation actions in place, only with a major reduction in GHG emissions would adaptation make sense over the long run. Mitigation is the ultimate firewall against lasting damages to the biosphere and the human activities it sustains.

Table 17. Adaptation co-benefits by sector

Adaptation investment	Development co-benefit
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

B. Development Co-benefits from Mitigation

The mitigation effort required for LAC to reach the 2tCO_2e per capita goal would also generate significant "co-benefits" for the region, including improvements in human health and welfare, enhanced energy security, and more technological development. These "co-benefits", valued at US$2-196/t$CO_2$ for air quality (Nemet, Holloway and Meirer 2010), could make the mitigation investments and expenditure outlays analyzed in section III. D appear far more feasible and sensible. Beyond the "direct" mitigation benefits of avoiding costly future Climate Change and adaptation policies, such co-benefits 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.

The full potential of mitigation co-benefits is large enough to make a number of mitigation actions highly attractive to pursue (see Table 17). Mitigation co-benefits have been estimated to amount to anywhere from 30% to 100% (or more) of total abatement costs (Bollen et al. 2009; Pearce et al. 1996; IPCC 2001). Most (70%–90%) of these estimated co-benefits are health-related, stemming from lower local air pollution, improvements in water quality, and superior sanitation (Aunan et al. 2000). This concentration of health-related co-benefits 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 co-benefits of emissions mitigation are usually local, whereas the direct benefits of mitigation tend to be global in nature. These locally accrued co-benefits (Table 17) 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 towards cleaner sources (through 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 co-benefits beyond those stemming just from lower air pollution.

These co-benefits include reduced urban congestion, lower noise levels, and possibly even fewer road fatalities as a consequence of fewer vehicle miles traveled. Finally, while 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 18. Mitigation co-benefits

Area	Co-benefit
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 own 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 18 below are global in scope. While the savings in LAC would correspond to a smaller fraction of these global figures for co-benefit gains, their significance should still be noteworthy for the region.[61]

Table 19. Additional benefits of pursuing various objectives simultaneously at the global level

Co-benefit	Investment Required if pursued in isolation (US$billion/yr)	Benefits	Additional synergistic benefits from an "integrated approach" (US$billion/yr)
Universal Modern Energy Access (provision of electricity and modern heating and cooking fuels)	22-38	24mn "Dalys"* (disability-adjusted life years) saved in 2030	
Tightened Pollution Controls	200-350 by 2030 (10%–20% of total energy costs)	21mn "Dalys"* saved in 2030	Up to US$500 billion saved annually by pursuing stringent climate objectives at the same time
Enhanced Energy Security (e.g., reduced import dependence, increased exports, and diversification)	Strengthened macroeconomic positions; heightened geopolitical influence	Decarbonization could reduce the need for FF subsidies (oil and coal) to affluent populations: US$70 billion–US$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 own elaboration. *Note: "Dalys" stands for "disability-adjusted life years".

[61] IIASA's GEA Message Pathways Model does not break down such co-benefits 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 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.

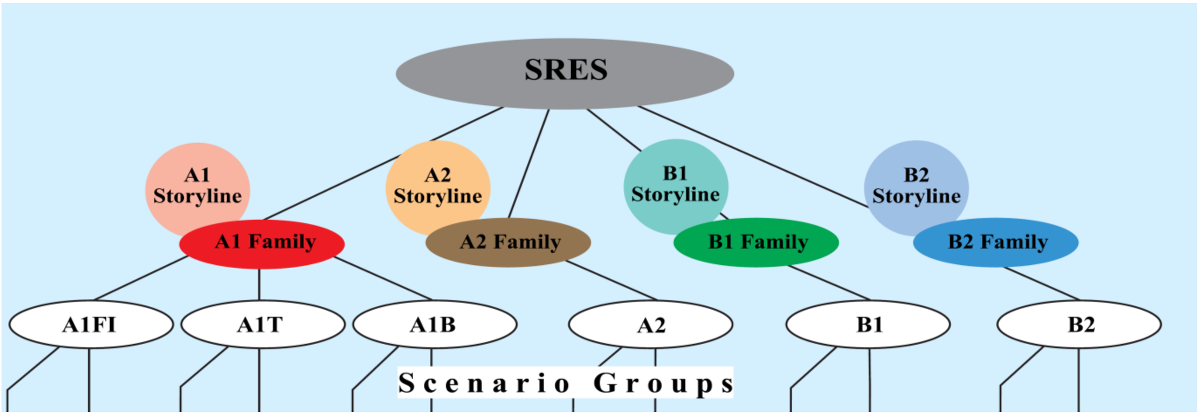
For the scenarios, the IPCC developed different narrative storylines to describe the relationships between emission driving forces and their evolution over time (Figure A.1). Each storyline represents different demographic, social, economic, technological, and environmental developments. Each emission 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".[62]

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:

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

fossil-intensive energy sources (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

Figure A.1. Schematic illustration of SRES scenarios (IPCC 2000, modified)



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. However, 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 A.1 summarizes the likely temperature changes under each of the above-described scenarios.

Table A.1. Projected global average surface warming and sea level rise at the end of the 21st century according to the different SRES scenarios (IPCC 2007)

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		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[b]	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

Notes:

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

b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

c) 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 1550ppm, respectively.

d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

Annex 2. IIASA GEA Scenarios

The Moderate Intervention (or Energy) Pathways presented in this report were derived from the three principal GEA Transformation Pathways ("GEA Efficiency", "GEA Supply", and "GEA Mix") of IIASA's GEA Message Model and its GEA Scenarios database.[63] 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.[64]

However, for the purposes of this report, in order to contrast the potentials for 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 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 (1) projected financial costs (investment/expenditures) required, and (2) 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 their 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. IPCC - Emissions Scenarios). 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

[63] See http://www.iiasa.ac.at/web-apps/ene/geadb/dsd?Action=htmlpage&page=about#intro.
[64] 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: Energy Pathways for Sustainable Development", Chapter 17 in *Global Energy Assessment: Toward a Sustainable Future, 2011*, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria and Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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 (see the table below for more details concerning this central defining difference between Illustrative Pathways and their respective pathway groups).

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:

> (1) the type of transportation system (ie, 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, and;
>
> (2) 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" differentiating a single possible future energy reality into distinctly separate "scenarios" or pathways concerns the level of preferred, or potential, energy efficiency gains into the future. The second major "branching point" splitting these three scenario pathways into still more scenarios would be the type of assumed transportation system ("conventional" versus "advanced"). Finally, the third "branching point" splitting off the 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). However, this study's versions of the three Moderate Intervention (or "Energy") Pathways assumes the following:

> (1) only the energy interventions (expenditures and emissions reductions) of the pathway are to be included (non-energy expenditures and emissions reductions have been stripped from the pathway, and used as the foundation for the construction of the distinct "land-use" pathways);
>
> (2) 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, and;

(3) 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 ppm atmospheric concentration limit and the 2 degree "guardrail" by 2050 (Riahi et al-IIASA 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 tpc, thus necessitating deeper, more effective and more expensive AFOLU interventions.

When presenting the GEA Pathways only as "energy intervention" scenarios, they would bring LAC to anywhere between 3.4tpc and 4.3tpc 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 2t per capita. In other words, the energy interventions bring LAC's per capita emissions from 9.3 under the BAU trajectory down to below 4tpc; another 2tpc must be reduced through AFOLU interventions in order to achieve the 2tpc goal by 2050.

Significant decarbonization of the energy sector also unfolds in all of IIASA's GEA Pathways, with low-carbon energy reaching 60% to 80% of the primary mix in all of the pathways, and 75% to 100% 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% decarbonization of the electricity generation mix by 2050*.

For the purposes of this report, the generically-referred-to "Moderate Intervention" Pathway will generally be considered to be the "Mix I" Energy Pathway, whereas the generically-labeled "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, and Assumptions of the GEA Pathways-Common Benefits and Co-benefits 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 degrees 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 peak in approximately 2020 and then reach 30–70% of their 2000 levels by 2050. They 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 povery, and assumed for all pathways, ranges from US$22 billion to US$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 US$200 billion to US$350 billion annually by 2030 (10%–20% of energy costs). Such investments will 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.

Common Characteristics, Features, and Assumptions of the GEA Pathways

--Improvement in the historical rate of energy intensity decline (1.2% per year since the 1970s); a 1.5% decline per year achieved by the Supply Pathway versus 2.2% 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% below the BAU levels in 2050; the Mix pathways would imply energy end use 40% below the BAU levels in 2050; and the Supply pathways would reduce energy end use to only 23% below the BAU levels in 2050.

--A broad portfolio of supply options focusing on low-carbon non-combustible renewables, bioenergy, nuclear, and CCS. This portfolio reaches low-carbon shares in the primary energy mix of 60% to 80% 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 run, to 80–140 MJ by 2050. Extensive use of agricultural residues and second-generation bioenergy technology to mitigate the adverse impact on land use and food production.

--Limited role for nuclear in some versions of the pathways. However, 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.

--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, 250GtCO2e 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% to 100% 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 of 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 peak in oil use in the transportation sector by 2030, 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 will 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 US$1.7 trillion to US$2.2 trillion annually (compared with US$1.3 trillion currently). Of this total, US$300 billion–US$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% of global GDP.

Source: Riahi et al. (2011).

Annex 3. Basis for Projections for "Net Financial Additionality" and Activity-Costs of LAC Mitigation Efforts

Section III. D. presented financial cost projections for a number of possible mitigation pathways that would bring LAC to – or at least help it achieve -- the 2tpc goal by 2050 (see Table 11). However, these projections were global in sectoral terms – presented with no sector or activity breakouts -- and regionwide with respect to the relevant geographical unit of analysis (LAC). However, the IIASA GEA model database does offer projections which are detailed enough to contemplate attempting sectoral (or intervention activity component) projections for "net financial additionality." Table 13 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. The following section presents details on the process used for formulating the activity-cost projections presented in this report.

The IIASA's Global Energy Assessment (GEA) Database includes projections from 2005 through to 2100, for the world and its principal component regions (including LAC), in the categories of GHG emissions, required expenditure and investment figures, levels of primary, secondary and final energy use (broken down by energy type), 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 US$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:

1) IIASA's "illustrative" Mix pathway was based on the assumption of a transportation sector relying 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;

2) 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, and;

3) land-use and AFOLU interventions and emissions gains have been eliminated from the GEA model pathways used in the current report. However, AFOLU interventions, articulated separately as "land-use" pathways, have been re-integrated 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 11) therefore have been taken directly from the GEA database. The GEA's "gross" data was further elaborated by subtracting from it 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.

However, 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 (ie, not arriving at the final pathway projection independently).

Below, there is a step-by-step summary of how the AFOLU cost projections were produced. That 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: (1) net zero deforestation in LAC by 2020; and (2) net zero emissions from deforestation and land-use in the broadest sense (ie, LULUCF, but not agriculture) by 2030, maintaining this level of net zero ZNLU emissions indefinitely. This pathway carries a projection of US$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% of the decline (against present, 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 GtCO2e in 2050, while the Mix II Pathway would bring these land-use emissions to 0.18GtCO2e.
>
> In addition, for each of these pathways IIASA has projected required "non-energy expenditures" in ten-year, annual, splits to 2100:
>
> > (a) US$31.4 billion annually in 2050 for the Mix I (adv. Trans., no nuclear) pathway;
> >
> > (b) US$ 39 billion for Mix II (conv. Trans., no nuclear); and
> >
> > (c) US$38.4 billion annually in 2050 for the Mix II Pathway with conventional transport and a full portofolio – ie, IIASA's "illustrative" Mix Pathway).
>
> According to IIASA, this "non-energy" 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).[65]

But IIASA does not present a split of the required expenditures between these various non-energy 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 "non-energy 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).[66] This yields a projected annual financial expenditure figures for each decade to 2050 (US$0.47 billion annually in 2020, US$2.5 billion annually in 2030, US$4.6 billion annually in 2040, US$5.9 billion annually in 2050) for "non-energy expenditures" which have been stripped of expenditures on the defense and net expansion of sinks, at least in the foresty and land-use change fields.

The projected "non-energy expenditures" for the Mix II (no sinks) Pathway are then substracted from the total figure for the "non-energy expenditures" (US$2.7 billion annually in 2020, US$9 billion annually in 2030, US$20.3 billion annually in 2040 and US$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

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[65] Although the GEA Database defines this "non-energy expenditure" category to include "Expenditures for non-energy 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 (ie, deforestation and land-use, or AFOLU/REDD+) expenditures. However, IIASA has not produced more detailed splits of this category to break down investment from non investment 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.

[66] We could not create this proxy using a pathway which 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 non-energy expenditures and relative land-use emissions gains against the BAU across the IIASA pathways used as foundations in this study. Therefore, our use of this proxy seems reasonable. However, 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.

annual “non-energy expenditures” required for the maintenance and net expansion of sinks under the Mix II pathway (US$2.2 billion annually in 2020, US$6.4 billion annually in 2030, US$15.7 billion annually in 2040 and US$32.5 billion annually in 2050).

This derived projection for the “net additional financiality” 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 (0.48GtCO_2e) along the Mix II Pathway. In 2020, this projection comes to US$58/t$CO_2$e 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, US$67/t$CO_2$e.

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 to 2050 under the ZNDD2020/ZNLU 2030 Pathway against the BAU to yield total “gross” financial additionality required under the ZNDD2020/ZNLU 2030 Pathway (US$43 billion annually in 2020, US$45 billion annually in 2050).

This yields a projection figure for the “gross financial additionality” required by the ZNDD2020/ZNLU 2030 Pathway of US$78 billion annually by 2050 (US$43 billion annually by 2020).[67] However, when attempting to subtract IIASA-based BAU projected expenditures for the same non-energy 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) “non-energy expenditures” along the BAU trajectory, despite the fact that the BAU trajectory projects a net decline in land-use emissions of nearly 1.0GtCO_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 LAC income, wealth, urbanization and modernization.

[67] 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.

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 ZNDD2020/ZNLU 2030 Pathway (US$45 billion annually by 2050 in both cases). However, given that the sink expenditures projected under the full Mix II pathway come to US$32.5 billion annually by 2050, and achieve only a further 0.3GtCO_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, arrive at projected levels that 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 reviewed from among the literature in section III., D.

However, if one calculates differently, assuming that the BAU does not achieve any LULUCF emissions reductions without the support of 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% 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 US$43 billion annually, and US$58/tCO2e, in 2020 -- directly into the range of similar financial cost projections from the existing literature analysed previously in section III., D. -- down to **US$17 billion annually, and US$21/ t$CO_2$e, in 2020**. The projections for **2050** would likewise fall from US$78 billion annually, and US$67/tCO2e, to **US$37 billion annually, and US$23/t$CO_2$e**.

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 economic opportunities costs of reducing such emissions rises over time (as land and timber values rise over time, for example).

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 0.35GtCO_2e of further abatement annually until 2040, and 0.7GtCO_2e annually to 2050. Again, multiplying the average financial cost per ton (US$23) by the amount of land-use emissions reductions achieved by this pathway by 2050 (2.3GtCO_2e annually), this report's projection for the "**net financial additionality" of this pathway comes to US$53 billion annually in 2050**. This pathway's much greater level of emissions abatement beyond 2030 (an additional 0.7GtCO_2e) accounts for its higher net financial additionality figure (US$53 billion annually in 2050 compared to only US$37 billion for the ZNDD 2020/ZNLU 2030 Pathway option).

Relying on such an assumption implies either that (1) IIASA's BAU trajectory for LAC should be adjusted upwards by as much as 0.7GtCO_2e annually in 2050, or 2) 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 up 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 non-energy expenditures (in particular, the dedicated sinks portion) by changing their assumptions concerning land-use emissions under the BAU (reassigning 100% 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% 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 tCO2e to achieve a certain reduction in agricultural emissions. Using the IIASA projections for "non-energy expenditures" with no sinks along the illustrative Mix pathway (US$0.47 billion annually in 2020, US$2.5 billion annually in 2030, US$4.6 billion annually in 2040, US$5.9 billion annually in 2050), we can calculate projected "average" financial additionality per tCO_2e by dividing the above "non-energy expenditures" with no sinks by the net reduction in agricultural emissions (0.18$GtCO_2e$ annually in 2020, 0.37$GtCO_2e$ annually in 2030, 0.48$GtCO_2e$ annually in 2040, and 0.63$GtCO_2e$ annually 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 US$2.6/$tCO_2e$ in 2020, US$6.9/$tCO_2e$ in 2030, US$9.6/$tCO_2e$ in 2040, and US$9.3/$tCO_2e$ 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 to 1.3 $GtCO_2e$ annually in 2020, to 1.25 $GtCO_2e$ annually in 2030 and 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 0.46GtCO_2e annually in 2020, 0.75 GtCO2e 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 (US$2.6/t$CO_2$e in 2020, US$6.9/tCO_2e in 2030, US$9.6/t$CO_2$e in 2040, and US$9.34/tCO_2e in 2050), the result is total "net financial additionality" required to achieve the reductions in agricultural emissions projected under the AFOLU+ pathway: US$1.2 billion annually in 2020, US$5.16 billion annually in 2030, US$9.6 billion annually in 2040, and US$10.1 billion annually in 2050. These are the relevant agricultural financial additionality figures cited in Table 11.

Finally, a third step would involve summing the total "net financial additionality" of the ZNDD 2020/ZNLU 2030+ (plus) Pathway (US$53 billion annually in 2050) with that of the net financial additionality of the AFOLU+ Pathway's agricultural emissions reductions (US$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 US$63 billion**. If one then divides this figure by the total amount of all emissions reductions achieved under the AFOLU+ Pathway compared to BAU (2.45GtCO2e), the result is an "average" financial additionality per tCO_2e of US$18.4/t$CO_2$e.

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: (1) Efficiency with advanced transportation and no nuclear (our Efficiency I), (2) Mix with advanced transportation and no nuclear (our Mix I), (3) Supply with advanced transportation and no nuclear (our Supply I), (4) Efficiency with conventional (or traditional) transportation and no nuclear (our Efficiency II), (5) Mix with conventional (or traditional) transportation and no nuclear (our Mix II), and (6) 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 3.4tpc and 4.3tpc 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 12.

The Aggressive (or Combined) Pathways

We have constructed three different groups of six aggressive Pathways which 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 12. However, 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 11: negative US$8 billion annually by 2020, and some US$43 billion annually by 2050 (US$0.5 billion annually by 2030 and US$12 billion annually by 2040).

To these sums we add the net financial additionality required under the ZNDD 2020/ZNLU 2030+ (plus) Pathway (US$18 billion annually by 2020, US$24 billion annually by 2030, US$37 billion annually by 2040, US$53 billion annually by 2050) to yield the total "net financial additionality" for the **Aggressive Mix I+ (plus) Pathway**: *US$11 billion annually by 2020;*

US$25 billion annually by 2030; US$49 billion annually by 2040; and US$97 billion annually by 2050.

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

To arrive at "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 (1.3GtCO_2e annually by 2020; 2.8GtCO_2e annually by 2030; 4.1GtCO_2e annually by 2040; and 5.3GtCO_2e annually by 2050) along this pathway: this yields gross "average financial additionality" of US$113/t$CO_2$e in 2020; US$95/tCO_2e in 2030; US$102/t$CO_2$e in 2040; and US$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" (found in paragraph 1 above: *US$10 billion annually by 2020; US$25 billion annually by 2030; US$49 billion annually by 2040; and US$97 billion annually by 2050*) by the total number of tons of GHG emissions to be abated (1.3GtCO_2e annually by 2020; 2.8GtCO_2e annually by 2030; 4.1GtCO_2e annually by 2040; and 5.3GtCO2e annually by 2050) along this pathway: this yields net "average financial additionality" of US$7/t$CO_2$e in 2020; US$9/tCO_2e in 2030; US$12/t$CO_2$e in 2040; and US$18/tCO_2e in 2050.

Investment/Sector Intervention Components of the Aggressive Mix I+ (plus) Pathway

In Tables A.2 and A.3, we have presented projected expenditures required to achieve *each major sectoral component* of the Aggressive Mix I+ (plus) Pathway.[68] 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

[68] Table 13 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% against the BAU in 2050) or only US$10 billion annually in 2050 in both gross and net terms.

(US$37 billion annually for 2050) and come directly from Table 11 (see the relevant section in this Annex 3 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 US$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% cut in agricultural emissions against the expected BAU levels), we likewise include an additional US$10 billion annually by 2050 (see Table A.2).

Table A.2. AFOLU+ Pathway Components, Required Financial Additionality, 2050

Sector Components	"Gross" Additional Annual Total by 2050	Annual Total Expenditures under BAU by 2050	"Net" Additional Annual Total by 2050
ZNDD/ZNLU 2030 (net zero deforestation by 2020 and net zero land-use emissions by 2030)	US$37bn	No expenditures projected under the BAU	US$37bn
ZNDD/ZNLU 2030+ (Additional net carbon sinks)	An additional US$16bn	No expenditures projected under the BAU	An additional US$16bn
Agriculture (50% reduction against BAU by 2050)	An additional US$10bn	No expenditures projected under the BAU	An additional US$10bn
AFOLU+ Pathway	US$63bn	--	US$63bn

Source: IIASA GEA Model Database and own elaboration. *Notes: AFOLU cost projections here assume the development of the Mix II (conventional liquid transportation) Pathway. However, the 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 (US$560 billion annually in 2050) and a simple summation of AFOLU costs (assuming Mix II) and energy costs (assuming Mix I)), or US$571 billion in 2050. Such a US$10-20 billion variation is typical among gross financial additionality projections (particularly in the realm of AFOLU) for the various Pathways. See Table 11.

The next step involves projecting the financial requirements for four different major intervention components included in the Moderate Mix I (energy intervention) Pathway: Energy efficiency 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% compared to the expected BAU levels of energy consumption, would cost approximately US$104 billion annually by 2050 in terms of "gross" financial additionality (and US$88 billion in terms of "net" financial additionality). The "gross" projection is arrived at by adding (a) US$83 billion annually by 2050, projected by IIASA to be required "demand side investment", and (b) US$21 billion annually by 2050, half of what is projected by IIASA to be required investment in electricity transmission and distribution (the other US$21 billion annually is distributed to electricity decarbonization; see the following section).

In terms of the "net" financial additionality required for energy efficiency measures under the Aggressive Mix I+ (plus) Pathway, the projectrion of US$88 billion annually by 2050 is arrived at by subtracting from the "gross financial additionality" (US$104 billion annually): US$16 billion annually (half of the US$32 billion expected expected annually in 2050 for electricity transmission and distribution investment under the BAU).

Electricity sector decarbonization would entail US$133 billion annually by 2050 in "gross" financial additionality and US$66 billion annually by 2050 in "net" financial additionality. The former is arrived at by summing (a) US$62 billion annually by 2050 projected by IIASA to be required investment in non-fossil electricity generation, (b) US$21 billion annually by 2050, half of what is projected by IIASA to be required investment in electricity transmission and distribution (the other US$21 billion annually has been distributed to energy efficiency, see above paragraph), and (c) an additional US$50 billion in "expenditures" -- out of the total US$216 billion in annual "non-investment" expenditures by 2050 under the Mix I pathway which remain unallocated under the IIASA projections (we have allocated another US$50 billion annually to transportation electrification, US$10 billion annually to CCS, and US$100 billion annually to "other" energy expenditures).

On the other hand, "net" financial additionality for electricity sector decarbonization – US$66 billion annually by 2050 – is arrived at by substracting from each element of the "gross" financial additionality, the following: (a) US$31 billion annual investment required under the BAU for non-fossil electricity generation; (b) the US$16 billion annually expected for electricity transmission and distribution investment under the BAU, and finally (c) the US$20 billion in non-investment expenditures which we have allocated to electricity sector decarbonization under BAU from IIASA's unalloted non-investment expenditures under the BAU.

Carbon capture and sequestration (CCS): total gross financial additionality comes to US$17 billion annually by 2050 (US$7 billion annually is projected by IIASA to be required investment, while US$10 billion annually is assigned out of IIASA's projected "non-investment" 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.

Table A.3. Moderate Energy Mix I Pathway Components, Required Financial Additionality 2050

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% below BAU by 2050)	US$104bn	US$16bn	US$88bn
--demand-side investment:	83bn	zero	83bn
--electricity transmission & distribution:	21bn	16bn	5bn
De-carbonization of Electricity (more than 90% of installed capacity)	US$133bn	US$67bn	US$66bn
--investment in non-fossil electricity:	62bn	31bn	31bn
--electricity transmission & distribution:	21bn	16bn	5bn
--unallocated IIASA non-investment expenditure:	50bn	20bn	30bn
Electrification of Transportation	US$50bn	US$20bn	US$30bn
--unallocated IIASA non-investment expenditure:	50bn	20bn	30bn
CCS	US$17bn	--	US$17bn
--investment in CCS:	7bn	zero	7bn
--unallocated IIASA non-investment expenditure:	10bn	zero	10bn
Other Energy Actions	US$204bn	US$362bn	negative -US$158bn
--investment in fossil fuel extraction:	54bn	170bn	-116bn
--investment in fossil electricity generation:	2bn	4bn	-2bn
--"other" supply-side investment: (district heat, oil refineries, bioenergy extraction, production of hydrogen, synfuels)	42bn	38bn	+4bn
--unallocated IIASA non-investment expenditures: (fuel and other energy inputs, both private spending and public subsidies)	106bn	150bn	-44bn
Moderate Energy Mix I Pathway	US$508bn	US$465bn	US$44bn

Source: IIASA GEA Model Database and own elaboration. *Notes: This Energy Pathway (1) requires over US$2.1 trillion in cumulative gross additional investment in transmission and distribution (including storage) and in non-fossil fuel generated electricity; (2) achieves 97.8% low-carbon generation by 2050, counting biomass without CCS and all forms of generation with CCS as low-carbon sources.

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

In terms of "net" financial additionality, this "other" category turns out to be *negative* -US$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 sub-sectors, in which large savings are registered from less investment taking place in the future on expensive fossil fuel extraction and generation (US$118 billion annually in savings in 2050), and from fewer "non-investment" expenditures spent on increasingly expensive fossil fuels in the future for transportation and electricity consumption (US$44 billion annually in savings by 2050).

Electrification of the Transportation System: Of the four principal intervention components for which we make isolated projections of financial requirements (ie, Energy Efficiency, Electricity De-carbonization, CCS and Electrification of the Transportation Sector) along the Aggressive Mix I+ (plus)/Aggressive Mix I AFOLU+ (plus) Pathways, all of them except that latter (ie, transportation) can be derived directly, or at least partially directly, from the IIASA GEA model database figures. However, 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 US$50 billion annually in 2050, compared with US$20 billion annually projected under the BAU, yielding a projection for "net additional financial expenditures" of US$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 non-investment) 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 non-investment expenditures are "energy system-wide" – 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 US$50 billion annually in 2050 is assumed to be entirely in the form of non-investment 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 "non-investment energy expenditures."

However, 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 which 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%. This is because a three-way split of the projected required additional investment expenditure for transmission and distribution would add only US$8 billion annually in 2050 in gross terms and only US$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 not alter our projections for any of the entire 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 system-wide electrification.

On the other hand, while directly offering total "energy system-wide" expenditure projections for its pathways, the IIASA GEA Model database leaves a large quantity of projected "non-investment expenditures" unspecified – US$216 billion annually in 2050, in the case of IIASA's Mix (advanced transport) Pathway (and our Aggressive Mix I+ Pathway), and US$189 billion annually in 2050, in the case of the IIASA "counterfactual" BAU trajectory. According to IIASA, the category of "non-investment 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 non-investment 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 "non-investment expenditure" projections (as would non-investment 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: (1) US$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 US$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); (2) another US$50 billion annually in 2050 has been allocated to the de-carbonization of electricity to support the purchase of initially higher priced renewable energies (likewise, only US$20 billion annually has been allocated under the BAU); (3) US$10 billion has been allocated as expenditure to support investment in CCS (none has been allocated under BAU); and (4) US$106 billion to support final end-use purchase of energy, mainly low-carbon electricity (compared to the US$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 "non-investment expenditures" seems reasonable. One could argue that the allocation to electrification of transportation should be higher -- more in line with its 38% of final energy consumption, both currently and in 2050. However, 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.

Table A.4. Selected Prioritized Mitigation Interventions, Required Financial Additionality, 2050

Sector Components	"Gross" Additional Annual Total by 2050	Annual Total Expenditures under BAU by 2050	"Net" Additional Annual Total by 2050
--ZNDD/ZNLU 2030	37bn	zero	37bn
--ZNDD/ZNLU 2030+	16bn	zero	16bn
--Agriculture: (50% reduction against BAU by 2050)	10bn	zero	10bn
--Energy Efficiency	104bn	16bn	88bn
--Decarb Power	133bn	67bn	66bn
--Electrification of Transportation	50bn	20bn	30bn
Subtotal	350bn	103bn	247bn

Source: IIASA GEA Model Database and own elaboration.

Table A.5. Aggressive Mix I+ (plus) and Aggressive Mix I AFOLU+ (plus) Pathway Components

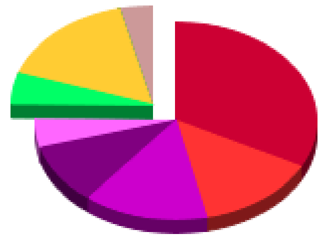
Sector Components	"Gross" Additional Annual Total by 2050	Annual Total Expenditures under BAU by 2050	"Net" Additional Annual Total by 2050
--ZNDD/ZNLU 2030:	37bn	zero	37bn
--ZNDD/ZNLU 2030+:	16bn	zero	16bn
--Energy Efficiency:	104bn	16bn	88bn
--Decarb Power:	133bn	67bn	66bn
--Electrification of Transportation:	50bn	20bn	30bn
--CCS:	17bn	zero	17bn
--Other Energy Actions:	204bn	362bn	negative -158bn
Aggressive Mix I+ (plus) Pathway Total	US$561bn	US$465bn	US$96bn
Additional Aggressive Mix I AFOLU+ (plus) Pathway Component			
--Agriculture: (50% reduction against BAU by 2050)	10bn	zero	10bn
Aggressive Mix I AFOLU+ (plus) Pathway Total	US$571bn	US$465bn	US$106bn

Source: IIASA GEA Model Database and own elaboration. *Notes: (1) Electricity output under Aggressive Mix I+ (plus) Pathway is 12% higher than in the BAU pathway, due to greater electricity use from the electrification of transportation. (2) Aggressive Mix I+ (plus) Pathways implies savings over the BAU Pathway in the areas of fossil-fuel generated electricity and fossil fuel extraction of US$128 billion annually by 2050.

Annex 4. GHG Emissions by Sector in 2005 CO_2, CH_4, N_2O, PFCs, HFCs, SF6 (excludes land-use change)

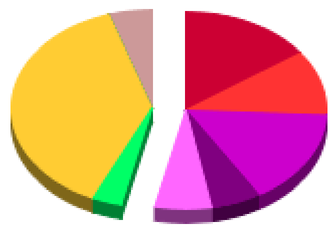
World

Sector	$MtCO_2e$	%
Energy	28,418.8	75.2
Electricity & Heat	12,373.1	32.7
Manufacturing & Construction	5,210.8	13.8
Transportation	5,341.3	14.1
Other Fuel Combustion	3,742.9	9.9
Fugitive Emissions [1]	1,750.8	4.6
Industrial Processes	1,883.9	5.0
Agriculture	6,075.2	16.1
Waste	1,418.7	3.8
Total	**37,796.6**	



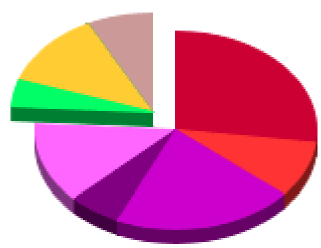
LAC

Sector	$MtCO_2e$	%
Energy	1,531.0	53.6
Electricity & Heat	432.5	15.1
Manufacturing & Construction	305.2	10.7
Transportation	445.1	15.6
Other Fuel Combustion	163.1	5.7
Fugitive Emissions [1]	185.1	6.5
Industrial Processes	94.3	3.3
Agriculture	1,090.4	38.1
Waste	143.3	5.0
Total	**2,859.0**	



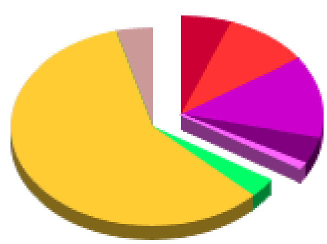
Mexico

Sector	$MtCO_2e$	%
Energy	479.2	75.9
Electricity & Heat	171.0	27.1
Manufacturing & Construction	57.6	9.1
Transportation	129.6	20.5
Other Fuel Combustion	38.0	6.0
Fugitive Emissions [1]	83.0	13.2
Industrial Processes	27.4	4.3
Agriculture	76.6	12.1
Waste	47.7	7.6
Total	**631.0**	



Brazil

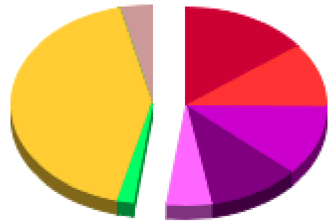
Sector	$MtCO_2e$	%
Energy	344.9	34.1
Electricity & Heat	58.5	5.8
Manufacturing & Construction	97.6	9.7
Transportation	135.6	13.4
Other Fuel Combustion	43.8	4.3
Fugitive Emissions [1]	9.4	0.9
Industrial Processes	32.4	3.2
Agriculture	590.5	58.4
Waste	42.8	4.2



Total	**1,010.5**	

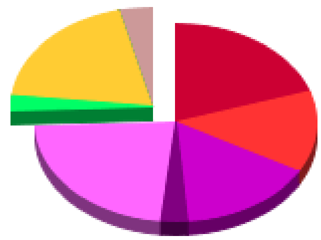
Argentina

Sector	$MtCO_2e$	%
Energy	171.3	52.2
Electricity & Heat	48.0	14.6
Manufacturing & Construction	34.6	10.5
Transportation	37.9	11.5
Other Fuel Combustion	34.3	10.4
Fugitive Emissions [1]	16.6	5.1
Industrial Processes [2]	5.7	1.7
Agriculture	138.9	42.3
Waste	12.4	3.8
Total	**328.4**	



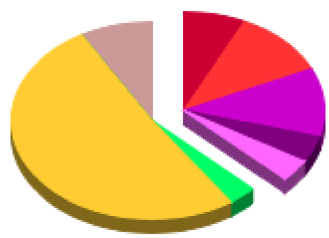
Venezuela

Sector	$MtCO_2e$	%
Energy	197.5	74.4
Electricity & Heat	52.8	19.9
Manufacturing & Construction	35.6	13.4
Transportation	40.9	15.4
Other Fuel Combustion	7.9	3.0
Fugitive Emissions [1]	60.2	22.7
Industrial Processes	6.3	2.4
Agriculture	51.6	19.4
Waste	10.1	3.8
Total	**265.6**	



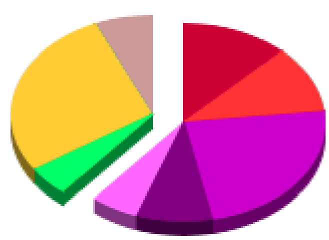
Colombia

Sector	$MtCO_2e$	%
Energy	64.8	37.2
Electricity & Heat	12.4	7.1
Manufacturing & Construction	19.0	10.9
Transportation	19.7	11.3
Other Fuel Combustion	7.6	4.4
Fugitive Emissions [1]	6.2	3.5
Industrial Processes [2]	5.7	3.3
Agriculture	88.9	51.1
Waste	14.5	8.4
Total	**174.0**	



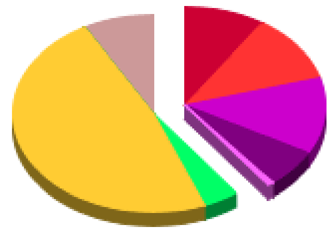
Ecuador

Sector	$MtCO_2e$	%
Energy	26.7	60.9
Electricity & Heat	5.4	12.3
Manufacturing & Construction	4.8	10.9
Transportation	10.3	23.6
Other Fuel Combustion	3.8	8.6
Fugitive Emissions [1]	2.4	5.5
Industrial Processes [2]	2.0	4.6
Agriculture	12.2	27.8
Waste	2.9	6.6
Total	**43.8**	



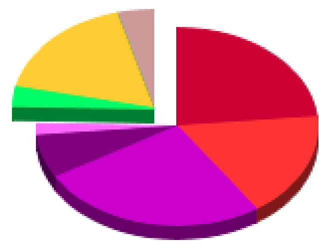
Peru

Sector	$MtCO_2e$	%
Energy	30.3	39.9
Electricity & Heat	7.0	9.3
Manufacturing & Construction	8.5	11.2
Transportation	9.6	12.6
Other Fuel Combustion	4.8	6.3
Fugitive Emissions [1]	0.5	0.6
Industrial Processes [2]	3.1	4.1
Agriculture	36.3	47.8
Waste	6.2	8.1
Total	**75.9**	



Chile

Sector	$MtCO_2e$	%
Energy	66.4	75.4
Electricity & Heat	20.6	23.5
Manufacturing & Construction	15.1	17.1
Transportation	22.7	25.8
Other Fuel Combustion	6.3	7.1
Fugitive Emissions [1]	1.7	1.9
Industrial Processes [2]	2.7	3.1
Agriculture	15.2	17.3
Waste	3.7	4.2
Total	**88.0**	

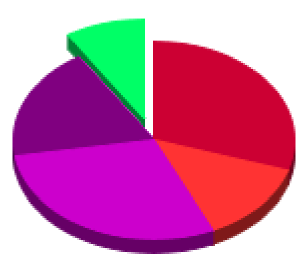


Trinidad & Tobago

Sector	$MtCO_2e$	%
Energy	33.0	99.0
Electricity & Heat	11.8	35.5
Manufacturing & Construction	16.5	49.5
Transportation	2.0	5.9
Other Fuel Combustion [3]	0.4	1.2
Fugitive Emissions [3]	2.3	7.0
Industrial Processes [3,4]	0.3	1.0
Agriculture	--	--
Waste	--	--
Total	**33.4**	

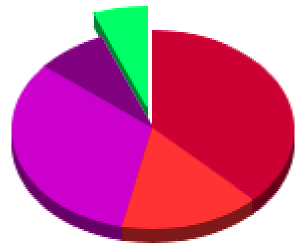
Honduras

Sector	$MtCO_2e$	%
Energy	6.9	91.0
Electricity & Heat	2.3	30.0
Manufacturing & Construction	1.0	13.1
Transportation	2.2	29.2
Other Fuel Combustion [3]	1.4	18.6
Fugitive Emissions [3]	--	--
Industrial Processes [3,4]	0.7	9.0
Agriculture	--	--
Waste	--	--
Total	**7.6**	



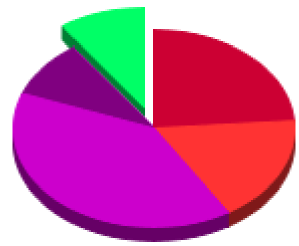
Nicaragua

Sector		MtCO$_2$e		%
Energy		4.1		94.0
Electricity & Heat	1.6		37.6	
Manufacturing & Construction	0.7		15.8	
Transportation	1.4		32.5	
Other Fuel Combustion [3]	0.3		8.0	
Fugitive Emissions [3]	--		--	
Industrial Processes [3,4]		0.3		6.0
Agriculture		--		--
Waste		--		--
Total		**4.4**		



Guatemala

Sector		MtCO$_2$e		%
Energy		11.0		90.2
Electricity & Heat	2.9		23.8	
Manufacturing & Construction	2.1		17.4	
Transportation	4.8		39.6	
Other Fuel Combustion [3]	1.1		9.4	
Fugitive Emissions [3]	--		--	
Industrial Processes [3,4]		1.2		9.8
Agriculture		--		--
Waste		--		--
Total		**12.2**		



Table/Chart Info

[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.

Source: CAIT (2012).