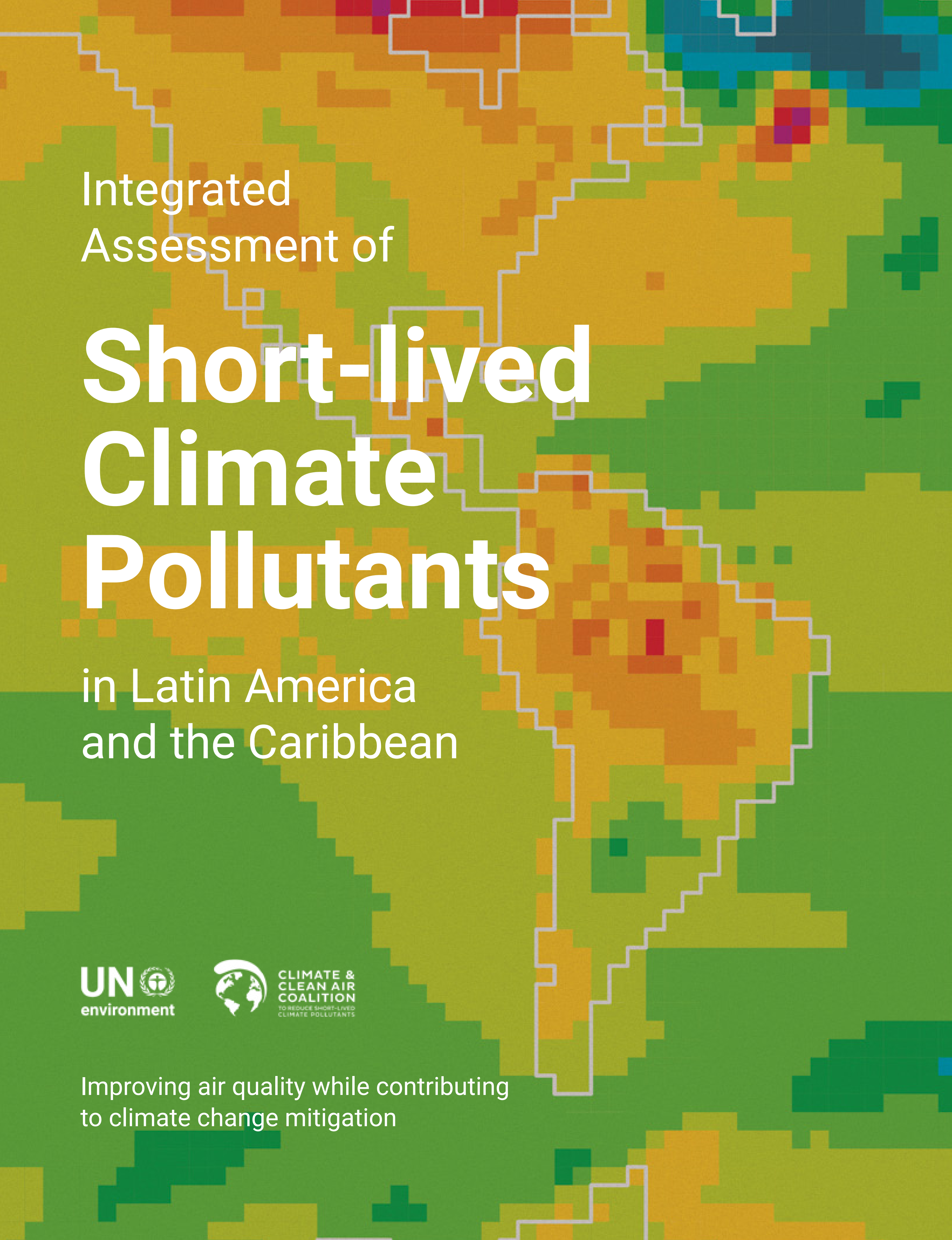

Integrated
Assessment of

Short-lived Climate Pollutants

in Latin America
and the Caribbean

UN environment

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Improving air quality while contributing
to climate change mitigation

Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean
Improving air quality while contributing to climate change mitigation

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Integrated Assessment of

Short-lived Climate Pollutants

in Latin America and the Caribbean

Improving air quality while contributing to climate change mitigation

UN environment / CCAC

Foreword

UN environment / CCAC

This report is the final result of an extensive process initiated by the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) and United Nations Environment (UNEP) in order to develop a Regional Integrated Assessment on Short-Lived Climate Pollutants (SLCPs) in the region of Latin America and the Caribbean (LAC). Furthermore, it is the culmination of a wide-ranging effort carried out by a large number of scientists, many from LAC, who have contributed to the first detailed diagnostic of SLCPs in the region with their expertise and available data.

This assessment provides, for 13 countries and regions within LAC, a comparable baseline of current emissions of fine particulate matter ($PM_{2.5}$), black carbon, methane, precursors of tropospheric ozone and hydrofluorocarbons for 2010. The emissions are presented in seven aggregated sectors, which facilitate comparison between countries and highlights the different emission profiles through the LAC region. The results indicate that *agriculture, mobile and commercial refrigeration, and transport* are the sectors that produce the largest emissions of methane, hydrofluorocarbon and black carbon in the LAC region as a whole.

Also included is the evidence of the impacts that global warming and the presence of SLCPs have already had on the regions' climate, ecosystems, human health, and agriculture. Temperatures have been increasing in LAC, and at high altitude have contributed to the retreat of glaciers, particularly in the tropical Andes. Some regions have already seen significant increasing trends in precipitation while others are facing long and strong droughts. Premature mortality from exposure to ambient $PM_{2.5}$ has been estimated around 47000 in 2010, with another 5000 due to exposure to tropospheric ozone. The estimates of crop losses in 2010 due to exposure to tropospheric ozone for four major crops – soybean, wheat, maize and rice –are approximately 7.4 million tonnes.

This report provides a consistent future reference scenario of the key emissions up to 2050 for the LAC region as a whole but also per country and per sector, which take into account the technological advances and the mitigation plans already considered by different countries. Additionally, greenhouse gas mitigation and SLCP-mitigation scenarios have been developed up to 2050. Modelling has identified the impacts of SLCPs on the regional climate, as well as health and agriculture by 2050. The results indicate a maximum potential reduction in warming of up to 0.9º C by 2050, if implementing SLCP measures across the LAC region. This is an important reduction on potential climate impacts in the region.

A range of options to mitigate SLCPs are presented, which have already been implemented in some parts of LAC and the assessment evaluates the challenges as well as their potential for larger penetration and fuller implementation across the region.

The different emission profiles and their future projections allow the different countries to select the mitigation measures that are most applicable to their particular mix of emission sectors. This knowledge allows individual country choices to most efficiently mitigate SLCPs.

In view of the LAC countries commitments in the Paris Agreement and their Nationally Determined Contributions the reductions in emissions of SLCP have a large social and economic benefit. Our hope is that the results of this integrated assessment will be considered by stakeholders and public officials in the region and will motivate them into action for the benefit of their population and to protect ecosystems from the changes in regional climate that have already been experienced.

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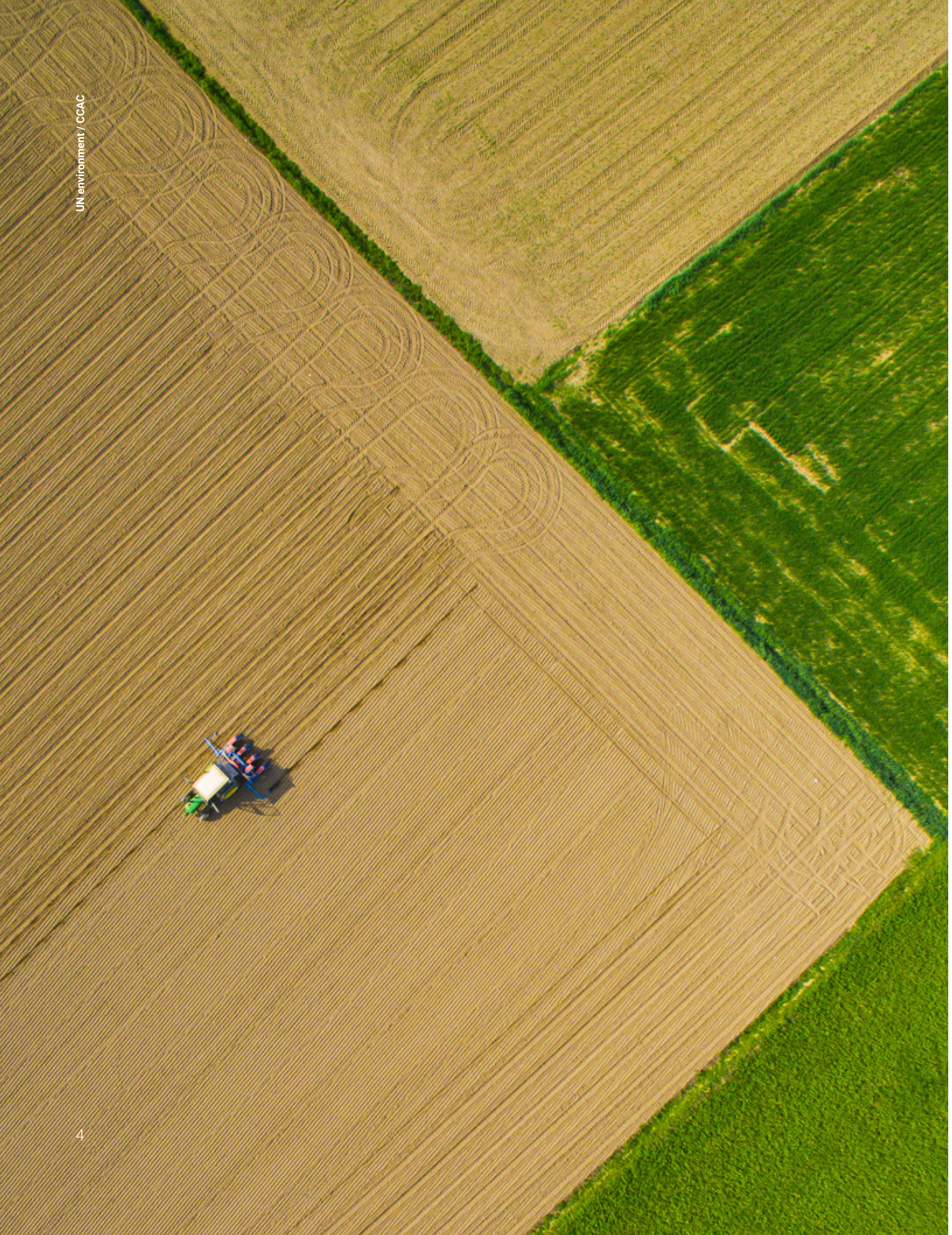

Foreword

The impacts of climate change are being felt every day all around the world. Poor air quality is a chronic and urgent issue which is now recognized as the single largest environmental health problem effecting the world today. Climate change and air pollution are not independent problems, they are inexorably linked, and so too are their solutions. More than a decade of painstaking science has built the case that fast action to address the multiple sources of pollutants, such as black carbon, methane, and hydrofluorocarbons, that are short-lived in the atmosphere, can deliver extraordinary and tangible benefits in terms of public health, food security, sustainable development and near-term climate protection.

The Climate and Clean Air Coalition is an action-oriented Coalition of countries, international organizations, non-state partners and sub-national entities, working together to address these short-lived climate pollutants. This work is prioritized based on the availability of robust and policy-relevant science, which shows the local and regional impact of these short-lived climate pollutants. The Coalition's Regional Assessment Initiative supports science-based action by collecting, developing, and disseminating regionally-relevant information and knowledge on short-lived climate pollutants and appropriate measures that can bring rapid multiple benefits for climate, air quality, health and sustainable development in the near-term. The document in your hands is the first such assessment.

This assessment, developed by 90 authors and lead by experts from the region, identified six technical and policy measures targeting methane, nine addressing major sources of black carbon, and six for hydrofluorocarbons which can reduce regional emissions of these pollutants by 45%, 69%, and more than 80% respectively by 2030.

The resulting reductions of particulate matter air pollution will provide significant immediate benefits for public health, especially amongst women and children, and reduced tropospheric ozone will improve staple crop production by as much as 4.5 million tonnes per year. Global implementation of all identified measures can avoid between 0.6 and 0.7 degrees Celsius of global warming by 2050. And, many parts of the Latin American and Caribbean region would enjoy even larger temperature benefits, such as up to 0.9˚C of avoided warming in northern Mexico.

There are also positive examples of all measures already in place across the region, as well as strong leadership, both in the region and globally for greater ambition to address short-lived climate pollutants. Of the three countries that included black carbon in their intended Nationally Determined Contributions, two, Mexico and Chile, are from the region.

This comprehensive assessment of short-lived climate pollutants in the Latin American and Caribbean region meant to serve as a guide for policy makers and implementers to identify which measures are most important for delivering the maximum near-term multiple-benefits in the region. It also an opportunity and invitation for countries to strengthen national action and regional cooperation that will lead to widespread reductions of short-lived climate pollutants with large near-term benefits for the climate, health, agriculture, and sustainable development.

Helena Molin Valdes
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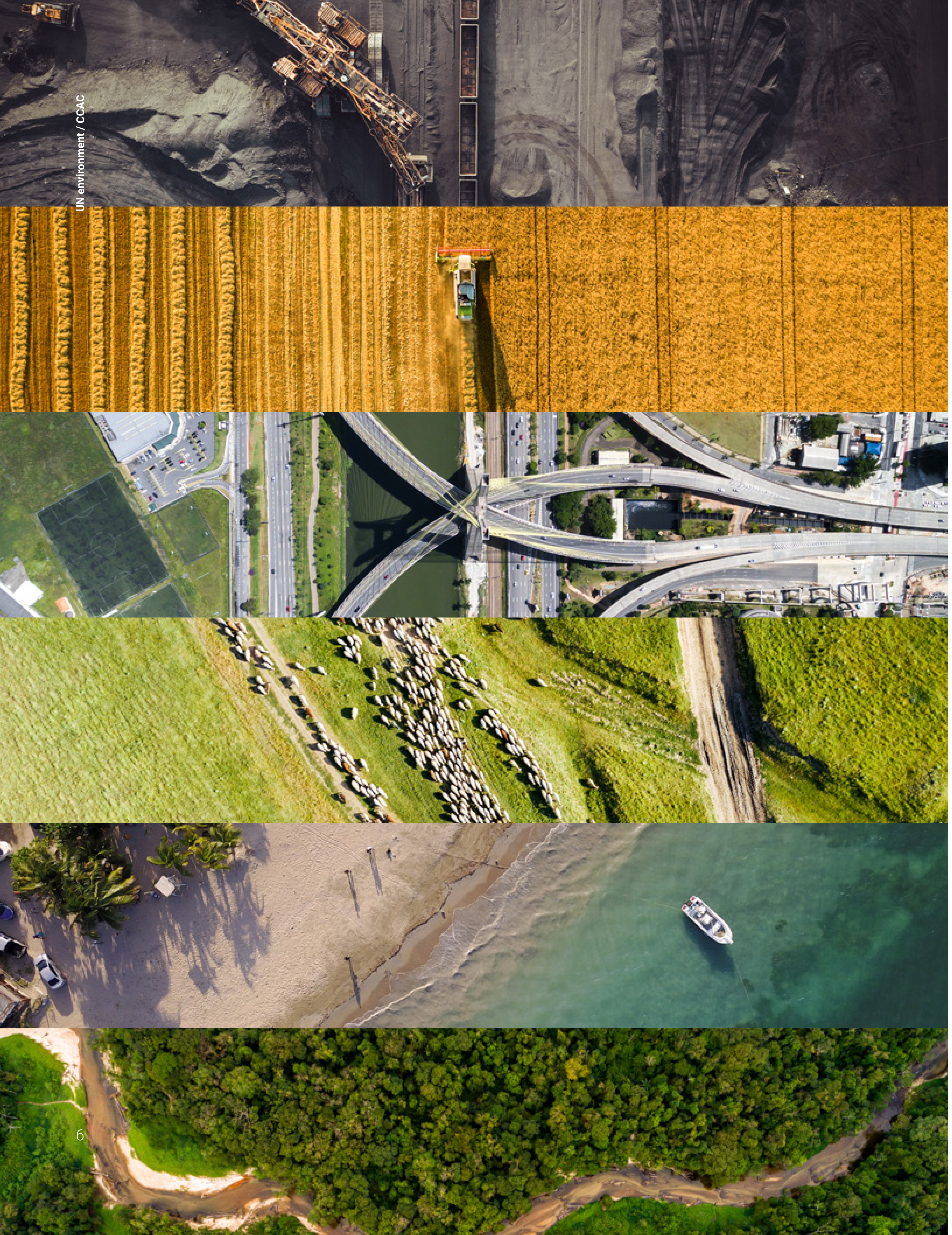

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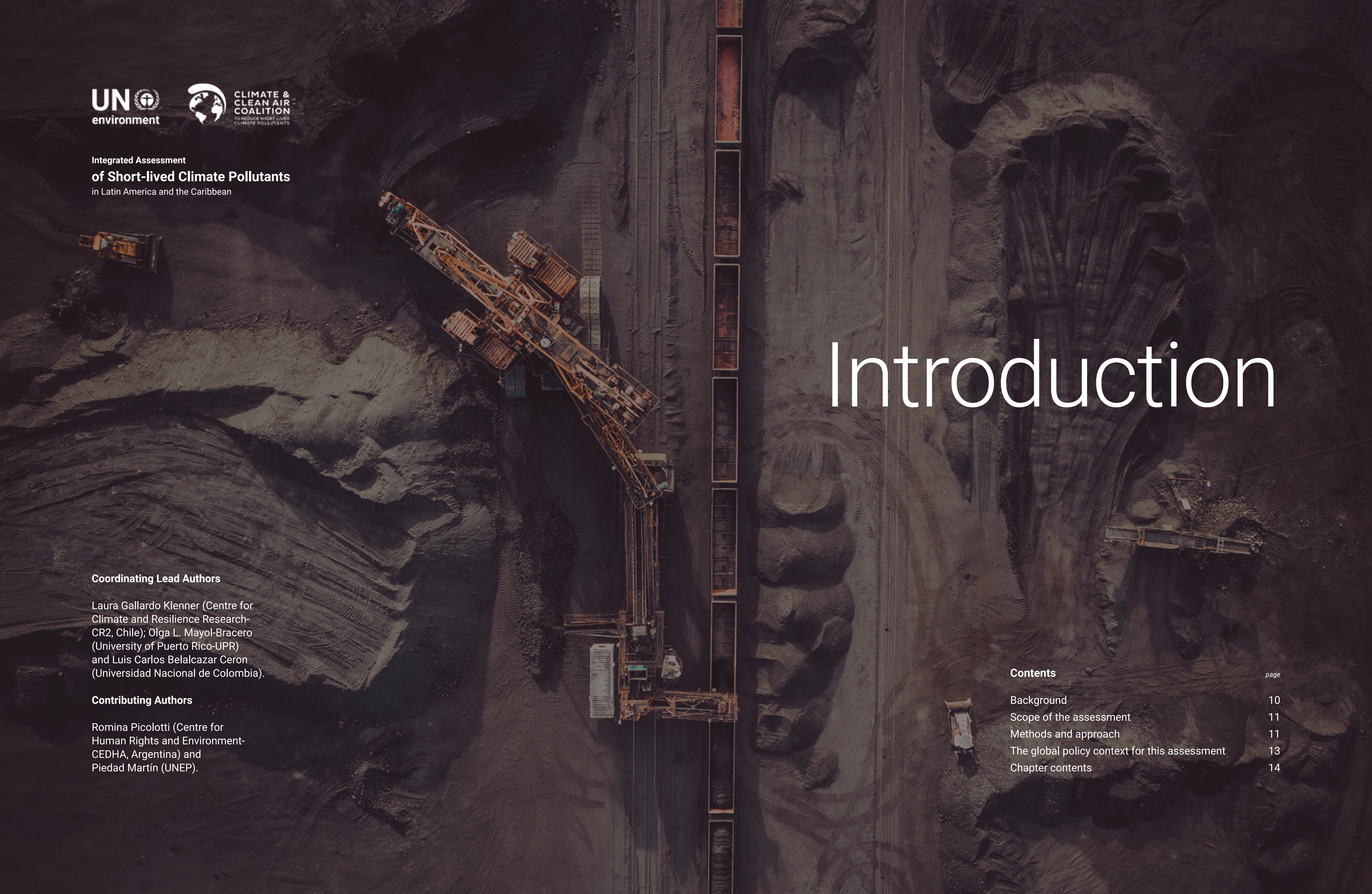

Introduction

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Background

Short-lived climate pollutants (SLCPs) are agents that reside in the atmosphere for a relatively short period of time – from a few days to two or so decades – and have a warming influence on climate. The main SLCPs are particles that contain black carbon (BC) and tropospheric ozone (O_3), which have lifetimes of a few days to a few weeks, and methane (CH_4), which has a lifetime of about 12 years. These are the most important contributors to the global greenhouse effect after carbon dioxide (CO_2), are responsible for a substantial fraction of the climate forcing experienced to date, and will have a significant effect on the rate of warming in the next few decades.

Additionally, hydrofluorocarbons (HFCs) are a collection of very potent climate-warming greenhouse gases with a combined average atmospheric lifetime of approximately 15 years (Oxford Martin School, 2012). Mainly used in refrigeration and insulating foam, HFCs were only commercialized in the early 1990s, and while they represent less than 1 per cent of the current total of greenhouse gases, global production, consumption and emissions of these human-made gases are growing at a rate of 10–15 per cent per year, a pace at which HFCs could account for nearly 20 per cent of climate pollution by 2050 (Molina, 2009; UNEP, 2011). In late 2016, however, 197 countries agreed the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, which will see an 85 per cent reduction in the production and consumption of HFCs by 2036 in developed countries and an 80 per cent reduction by 2045 in the majority of developing ones.

An SLCP strategy has the potential to reduce warming in the near term, reduce disruption of rainfall and weather patterns, and reduce the impacts of fine particulate matter ($PM_{2.5}$) and O_3 pollution on human health (WHO, 2016), crop yields (Tai *et al.*, 2014) and ecosystems. Global assessments have indicated significant benefits from developing such a strategy. This regional assessment for Latin America and the Caribbean has examined the potential in more detail.

Two reports on SLCPs at a global scale (UNEP, 2011; UNEP-WMO, 2011) were published in 2011. The *Integrated Assessment of Black Carbon and Tropospheric Ozone* (UNEP-WMO, 2011), which draws on work by the Climate and Clean Air Coalition (CCAC), first developed the SLCP approach and included concrete measures at the global level with the potential to mitigate climate warming. The assessment reviewed the scientific literature available up to 2011 on the emissions, atmospheric processes and impacts of BC, tropospheric O_3 and CH_4 to provide findings relevant to policy making. It also integrated a range of global-scale models to evaluate the multiple benefits of implementing a carefully identified set of measures to reduce emissions of these SLCPs.

The UNEP-WMO global assessment made a significant contribution by focusing on measures rather than on substances. It provided clear evidence that fast action on SLCPs might help limit near-term global temperature rise, although climate change will only be fully controlled if emissions of the principal long-lived greenhouse gas (CO_2) are substantially and significantly curbed. The assessment also attracted a lot of interest because it demonstrated that many lives could be saved, human health improved, crop yields boosted and climate change delayed by the implementation of a limited number of discrete and available measures using existing technology. Generalizations and aggregations that were done at the global scale now, however, need to be downscaled to the regional level to provide a more detailed understanding of the issue and the identification of opportunities and priorities.

This is particularly necessary for Latin America and the Caribbean. Owing to the coarse scale of the UNEP-WMO assessment and the limited availability of data on, for example, emissions and observations, much of the region was either unrepresented (Caribbean) or underrepresented.

UNEP's report *HFCs: A Critical Link in Protecting Climate and the Ozone Layer* (UNEP, 2011) investigated the potential for HFC emission reductions and avoidance to reduce near-term warming. This report describes the links between HFC emissions, climate protection and protection of the O_3 layer. It suggests that HFCs could be responsible for emissions equivalent to 3.5–8.8 million tonnes of CO_2 equivalent (CO_2eq) by 2050, an amount comparable to current total emissions from transport, estimated at around 6–7 million tonnes CO_2eq annually. The report suggests several options for reducing the impacts of emissions of HFCs including, for example, through improved building design, reducing the need for air conditioning, and the substitution of non-HFC substances.

For the first time, authors from Latin America and the Caribbean, under the leadership of renowned experts and institutions from the region and in collaboration with experts from other regions, have assessed current knowledge and undertaken new research to deliver an assessment specific to the region that identifies some important issues.

The Latin America and Caribbean region is heterogeneous in terms of its physical and human geography. It covers an area of about 200 million square kilometres (km^2), with, by mid-2015, a population of 630 million people, 79 per cent of whom live in urban areas (PRB, 2015).

Although over the last few decades economic growth has been accompanied by increased life expectancy, educational attainment and income as measured by the Human Development Index (UNDP, 2016), the region is still subject to severe inequality as expressed by the Gini Index (World Bank, 2014), which measures income distribution, and empirical evidence indicates that climate change is already affecting the region's economy (Samaniego, 2014). Vulnerability to climate change is significant (Magrin *et al.*, 2014; Marengo *et al.*, 2014), and its effects – increased extreme weather events, droughts, urban floods, sea-level rise and biodiversity loss – will all impact the region's development, with vulnerable populations likely to be disproportionally affected by a changing climate.

Scope of the assessment

Specific objectives

This assessment has been developed to enable the potential benefits of adopting an SLCP approach in Latin America and the Caribbean to be better quantified and assessed. Through it, it will be possible to identify which emission reduction measures are most important for delivering near-term benefits; a better quantification and understanding of relevant emissions in the region; the reductions in regional $PM_{2.5}$ and O_3 that could be achieved by implementing certain measures, with associated health and crop-yield benefits; and measures taken in Latin America and the Caribbean that can serve as an example to other regions.

Benefits to human health and vegetation are felt fairly immediately after emissions are reduced, which responds to current demands on policy to improve people's health and the environment. The assessment also allows further estimation of the near-term climate benefits that would accrue from implementing identified measures. This near-term framing – focusing on likely climate changes over the next few decades – is important for Latin America and the Caribbean because climate impacts are already apparent and are projected to increase in intensity. So a better understanding of the potential improvements that could be achieved through an SLCP policy could help influence policy focus for the benefit of the people of the region.

This assessment has been specifically designed to provide:

- A vehicle for a regional focus for high-level cooperation between policy makers, scientists, practitioners and other key stakeholders on scaled-up SLCP mitigation;
- Regionally specific and relevant information and guidance, as well as proposals for addressing uncertainties, knowledge gaps and capacity development, as a basis for more scientifically robust and effective action on SLCPs in Latin America and the Caribbean;
- A regionally owned scientific and policy assessment to support national action, and help ensure that the priorities and needs of the region are properly understood in international initiatives; and
- A basis for developing public information to enhance public understanding of the issue and engagement in expanded meaningful action.

Methods and approach

This assessment is a scientifically independent and free-standing exercise, owned by and reflective of the interests of Latin America and the Caribbean, with leadership provided by scientists and expert institutions representative of the entire region. It builds upon and complements UNEP-WMO's global assessment, *Integrated Assessment of Black Carbon and Tropospheric Ozone* (UNEP-WMO, 2011), to allow comparison and aggregation of important elements of the work. While it is regionally owned and led, the assessment draws upon the best available international resources and expertise.

This assessment links with the variety of existing initiatives and processes across the region that relate to air pollution, climate change, public health and other relevant sectors. The assessment concept, for example, was developed in close harmony with Latin America and the Caribbean's *Regional Plan of Action on Atmospheric Pollution*, approved at the XIX Meeting of the Forum of Ministers of Environment of the region, held in Los Cabos, Mexico in March 2014.

The current assessment uses the same methods and approaches as those deployed by the global assessment (UNEP-WMO, 2011), in particular and most fundamentally, the same integrated assessment analysis techniques. Data on measurements, emissions and impacts throughout the region were obtained when available, and a comprehensive data set of emissions was developed by supplementing national information with model estimates.

The assessment also uses:

1. The **DPSIR** framework – **D**rivers, for example gross domestic product (GDP) and population; **P**ressure, emissions; **S**tate, concentrations; **I**mpact, on health, agriculture, etc.; **R**esponse, policy, measures, case studies – extensively used by the UNEP *Global Environment Outlook* (GEO) reports; and
2. Work by the International Institute for Applied Systems Analysis (IIASA) for emission scenarios, the US National Aeronautics and Space Administration Goddard Institute for Space Studies (NASA-GISS) and the European Commission Joint Research Centre (JRC) for the modelling of climate and other impacts.

For the first time, a LAC-specific assessment has been undertaken to review current knowledge and propose **mitigation strategies tailored to the region.**

The global policy context for this assessment

In 2015, the 193-member United Nations General Assembly adopted the 2030 Agenda for Sustainable Development. This commits the global community to “achieving sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner” (UN, 2015), and comes along with a set of 17 bold new Sustainable Development Goals (SDGs), which are universal, integrated and reflect a transformative vision for a better world.

The 2012 United Nations Conference on Sustainable Development (Rio+20) was one of the fundamental bases for the establishment of the 2030 Agenda for Sustainable Development. Its political outcome document (UN, 2012) highlighted the importance of building on the Millennium Development Goals (MDGs), but with a stronger focus on clear and practical measures for introducing sustainable development.

Although the MDGs constituted an important alliance for the eradication of poverty, hunger and unfulfilled basic needs such as education and universal access to health, water and shelter, environmental issues were not considered in a broad way, limiting the possibility of improving understanding of the underlying causes of damage and degradation or developing integrated and sustainable solutions.

The SDGs, however, through their 169 specific targets, consider a greater number of issues in an integrated manner. The environmental elements and their connections with poverty eradication and other development priorities offer a significant opportunity to strengthen global efforts to achieve environmental sustainability and improve human well-being. In particular, and following this approach, air pollution is linked to priorities related to public health, sustainable cities, production patterns and the mitigation of climate change. Further analysis of this is presented in Chapter 6, nevertheless it is important to highlight the link between mitigation strategies for SLCPs, other air pollutants and development at this point.

The Latin America and Caribbean region has in fact made significant progress, halving the fraction of its population living in extreme poverty between 1990 and 2010. It remains, however, the most inequitable region in the world, with rapidly increasing CO_2 emissions (ECLAC, 2005) in spite of its vulnerability to climate change (Magrin *et al.*, 2014).

The evidence of human interference with the climate system is clear (Stocker *et al.*, 2013). This has consequences and impacts that act as amplifiers of risks for natural and human systems, which are generally greater for the less advantaged people in society. Effective action must, therefore, be taken now across the world and in Latin America and the Caribbean if the costs and conflicts that will emerge in a changing climate are to be avoided (Samaniego, 2014).

The countries of Latin America and the Caribbean have been active in promoting a global agreement to reduce CO_2 emissions under the United Nations Framework Convention on Climate Change (UNFCC). The majority of the region’s countries have committed to significant emission reductions to be accomplished by 2020 by means of Nationally Appropriate Mitigation Actions (NAMAs) and Intended Nationally Determined Contributions (INDCs). In fact, Chile and Mexico have also included separate sections on SLCPs in their INDCs and specifically mention particles that contain BC. Other countries have included specific action to reduce emissions from the transport sector (diesel), waste management, etc., all of which are relevant to SLCP mitigation, in their INDCs. Many of these actions are backed by an increase in the use of renewable energy sources, including wind and solar as well as hydropower, in domestic energy matrices (Varas *et al.*, 2013; Vergara *et al.*, 2013; Valencia *et al.*, 2017).

In this regional framework, in addition to reducing CO_2 emissions, limiting SLCPs is a key step for mitigating near-term climate change and improving human health and food security. The information that can be provided by a regional assessment, as well as providing a more effective basis for appropriate regional and national decision making, is needed to help ensure that the circumstances and priorities of the region can be taken more effectively into account in wider international strategies and initiatives. Equally, as policies are developed, Latin America and the Caribbean will benefit from the continuous building of a shared and agreed information base on which common regional policies can be developed and common positions agreed. In addition, building on the existing UNEP assessments, an integrated regional assessment will allow for a detailed discussion of opportunities and barriers to policy implementation in support of successful policy and planning at regional and sub-regional scales.

The 2016 Paris Agreement set the framework for the implementation of INDCs, and aims to limit the global temperature increase to 2°C above pre-industrial levels, with a desirable target of 1.5°C. Recent studies show that even if all INDCs were fully implemented, the possible increase in temperature would be around 2.7–3.5°C. Further emission reduction is necessary, and the measures suggested in this report for SLCPs could contribute to limiting the temperature increase to 2°C or less.

Chapter contents

Chapter 1

Short-lived climate pollutants: drivers, regional emissions and measurements

This chapter highlights the factors that set Latin America and the Caribbean apart from other regions of the world with respect to SLCPs and their impact, by:

1. summarizing the socio-economic drivers that modulate the pollutants that are emitted within the region;
2. comparing the emission rates of pollutants from each of the 13 countries/sub-regions within Latin America and the Caribbean;
3. comparing the emission rates of pollutants within Latin America and the Caribbean to those of other regions of the world;
4. documenting available data sets of *in situ* and remote-sensing measurements that validate emissions inventories; and
5. providing examples of emissions validation with the measurements.

Chapter 2

Impacts of short-lived climate pollutants on climate, water and food security, human health, biodiversity and ecosystem services

The impacts of SLCPs are analysed in terms of climate change, as well as of increased tropospheric O$_3$ and PM$_{2.5}$ concentrations. Their impacts are considered, in turn, on water and food security, human health, and biodiversity and ecosystem services. The impact on water yield and availability and its implications for agricultural, mining, industrial and domestic users and ecosystem productivity are highlighted. There is a special focus on food security across the entire region, where, along with climate change impacts, the additional effect of tropospheric O$_3$ is explored. The latter is also considered, along with PM$_{2.5}$, to be the main SCLP-derived hazard identified in the section on human health. All these impacts on biodiversity are considered in an integrated evaluation of potential changes in ecosystem services.

Chapter 3

Measures on short-lived climate pollutants, the potential reduction in emissions, and benefits for near-term climate and air quality

This chapter develops an assessment of the technical potential for emission reductions related to implementing SLCP strategies in Latin America and the Caribbean and links such reductions to human health improvements from reduced PM$_{2.5}$ and O$_3$ exposure, to enhanced crop yields and vegetation from reduced tropospheric O$_3$ levels, and to reduced near-term warming. These benefits are assessed using global and regional applications of several global and regional atmospheric models.

The emission reductions follow from the implementation of a number of key measures, with significant regional reduction potential in emissions of CH$_4$; in the products of incomplete combustion, including BC; and in HFCs. Several scenarios were developed based on implementation of the identified SLCP measures.

It is important to highlight that the analysis focuses on measures that reduce emissions of several pollutants from different sources, rather than concentrating on the reduction in emissions of one particular pollutant. This assessment goes beyond the global assessment (UNEP-WMO, 2011) by, amongst other things, including a specific analysis of the likely development of HFC emissions in Latin America and the Caribbean, and identifies respective mitigation opportunities.

Chapter 4

Implementation of identified measures across Latin America and the Caribbean: progress and opportunities

Chapter 5 provides an overview of progress and opportunities in implementing identified SLCP mitigation measures across the region, covering a range of sectors, including transport; energy, including coal mining, oil and gas production; municipal solid waste and wastewater treatment; agriculture – livestock rearing and open burning; residential heating and cooking; and small industrial sources. The chapter addresses the feasibility of implementing the identified measures and policies in key sectors, and that may be replicated or scaled up to achieve air quality improvement and near-term climate protection. The chapter provides examples of initiatives and measures that have been successfully implemented and addresses the challenges of facilitating widespread adoption of available technologies and practices, both nationally and regionally. The effectiveness of implementation depends on several factors, including consideration of local circumstances, the existence of robust policies and programmes, the availability of advanced technologies, adequate human resources, and appropriate financial support and incentives.

Chapter 5

From assessment to action

The concluding chapter draws on the modelling and analysis, and on the assessment of current policies and measures, to suggest a strategic framework for reducing the impact of SLCPs in the region and, in particular, strategic priorities that could be pursued in the next 5–10 years. The priorities proposed are at sub-regional, regional and national scales. What distinguishes them is not just their potential contribution to medium-term climate mitigation and health improvement, but more widely to sustainable development, poverty alleviation and protection of the ecological wealth and diversity of the region in the longer term.

This Latin America and Caribbean SLCP assessment is not expected to be a one-off exercise, but could, as appropriate, represent the start of a continuing regional process, with work periodically updated and extended. Furthermore, the network of scientific and policy institutions and individuals brought together for the assessment could be a continuing element of the science and policy landscape of the region.

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Limiting SLCPs is a **key step for mitigating** near-term climate change **and improving** human health and food security

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Image: Combine harvester agriculture machine harvesting golden ripe wheat field. LALS STOCK, Shutterstock.

1

Short-lived climate pollutants

Drivers, regional emissions and measurements

Contents *page*

1.1

Introduction

In the 2011 UNEP-WMO *Integrated Assessment of Black Carbon and Tropospheric Ozone* (UNEP-WMO, 2011), estimates of anthropogenic emissions of a number of pollutants were generated by the International Institute for Applied Systems Analysis Greenhouse Gas and Air Pollution Interactions and Synergies (IIASA GAINS) model for the major regions of the world (Figure 2.1). As well as carbon dioxide (CO_2), these include black carbon (BC), organic carbon (OC) and other fine particulate matter with a diameter of 2.5 micrometres (μm) or less ($PM_{2.5}$); the $PM_{2.5}$ precursors sulphur dioxide (SO_2) and ammonia (NH_3); the ozone (O_3) precursors carbon monoxide (CO), methane (CH_4) and non-methane volatile organic compounds (NMVOCs); and nitrogen oxides (NO_x), which are precursors to both O_3 and $PM_{2.5}$. The Latin America and Caribbean region is a relatively small contributor to global emissions overall. The accuracy of the region's emissions estimates at that time, however, was not well known and the assessment had limited specific activity and emission data or observational support.

This chapter discusses the current state of knowledge of emissions of CH_4, NO_x, NMVOCs, CO, SO_2, NH_3, $PM_{2.5}$ and PM_{10} (including BC, OC, and non-carbonaceous components) and hydrofluorocarbons (HFCs), by sector and country. It brings together the nationally reported emissions collected from governmental and regional agencies (section 1.2) and the GAINS model estimates (section 1.5), focusing on the key emission sources of short-lived climate pollutants (SLCPs).

The second component of the chapter, complementary to the emissions information, is a detailed presentation of the database of measurements that have been archived from long-term monitoring stations or focused field projects targeting specific sources of SLCPs (section 1.3). These data sets are critical sources of information for validating the combination of emission estimates and atmospheric model simulations, as well as for assessing the impact of SLCPs on health and climate. A brief discussion of the key atmospheric processes relevant to SLCPs and their impacts in Latin America and the Caribbean is provided in section 1.4.

The last part of the chapter (section 1.5) deals with the integrated assessment model, GAINS, including details of the approach employed to estimate emissions for historical periods, their comparison with national and other modelling estimates, and development of the baseline emission projections used in the assessment. Further, brief characteristics of the atmospheric models – GISS, GEOS-Chem and TM5-FASST – used in the assessment are provided along with estimates of the atmospheric concentrations of various pollutants, which were calculated using the GAINS emission estimates for past years. These concentrations are then compared to the ambient measurements described in section 1.3.

1.2

Nationally reported emissions in Latin America and the Caribbean

Thirteen Latin American and Caribbean countries/sub-regions were chosen for the GAINS model simulations (Figure 1.2). The selected resolution is a compromise balancing economic importance, population size, the availability of principal activity data on energy use, production, transport activities and the contribution to total SLCP emissions in the region, and the information available from emissions inventories. Country representatives provided official national emissions estimates, as well as the respective documentation (Tables 1.1, 1.2 and 1.3).

Table 1.1 summarizes the availability and completeness of emissions inventories across the region as collected in this assessment. Most of the countries appear to report key air pollutant and greenhouse gas emissions (green cells) but there is rather less information for PM (red cells). This reflects the relative paucity of efforts to prepare integrated greenhouse gas and pollutant inventories. Moreover, updated pollutant emissions inventories are scarce even for major cities and sources, which also negatively affects national efforts to quantify these emissions. In addition, in a number of cases important elements of the inventories are missing or incomplete. The dark green cells in Table 1.1 indicate countries and pollutants for which the initial analysis found reliable data, although more analysis will be needed to assess its quality. A more exhaustive discussion of the completeness of the reported emissions is provided in the following sections.

1.2.1

Emissions of short-lived climate pollutants and their precursors

The main SLCPs are O_3, CH_4, HFCs and BC. Combined, they are the most important contributors to anthropogenic climate change after CO_2. Hence, measures to limit these pollutants are potentially important to slow

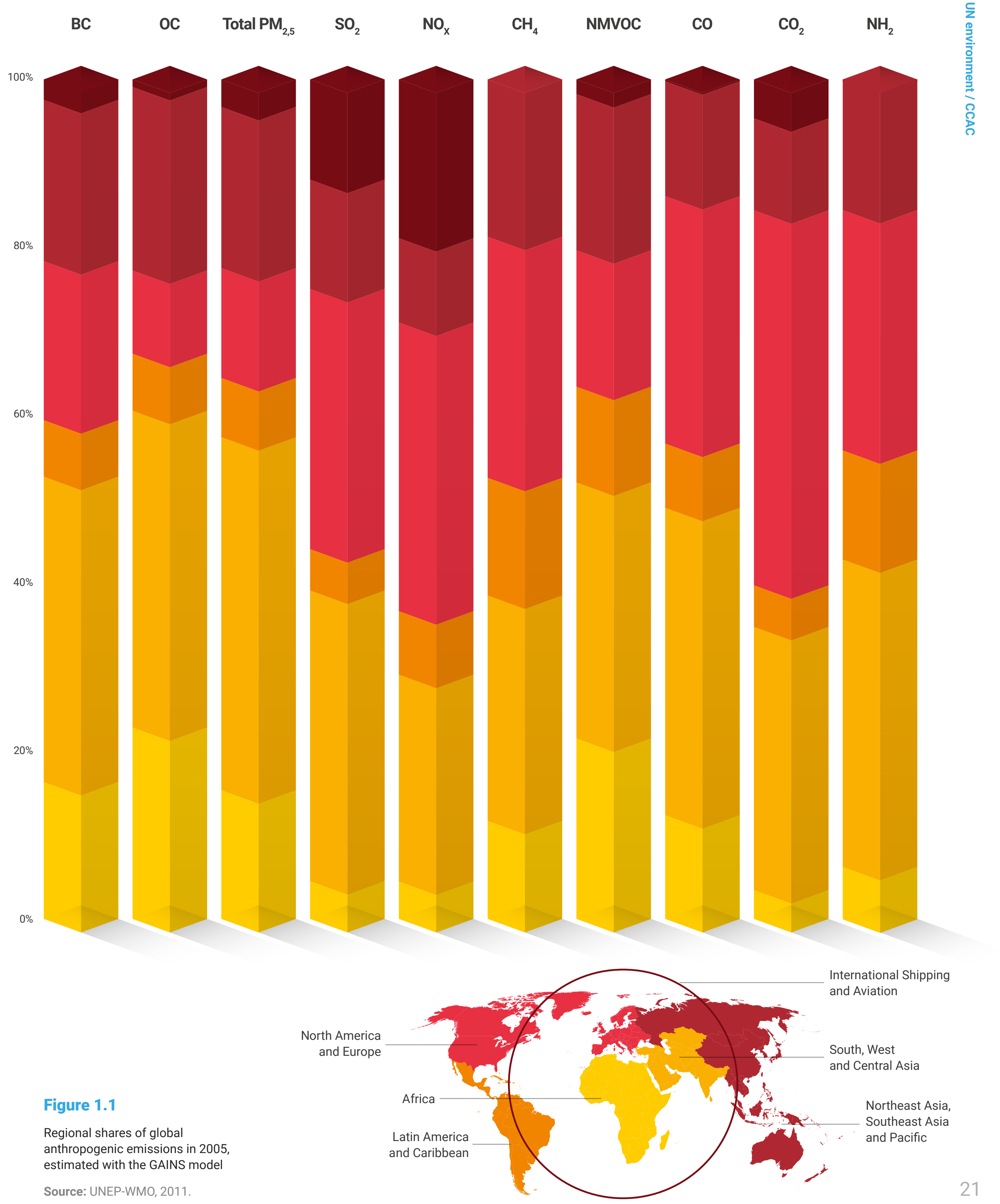


Figure 1.1

Regional shares of global anthropogenic emissions in 2005, estimated with the GAINS model

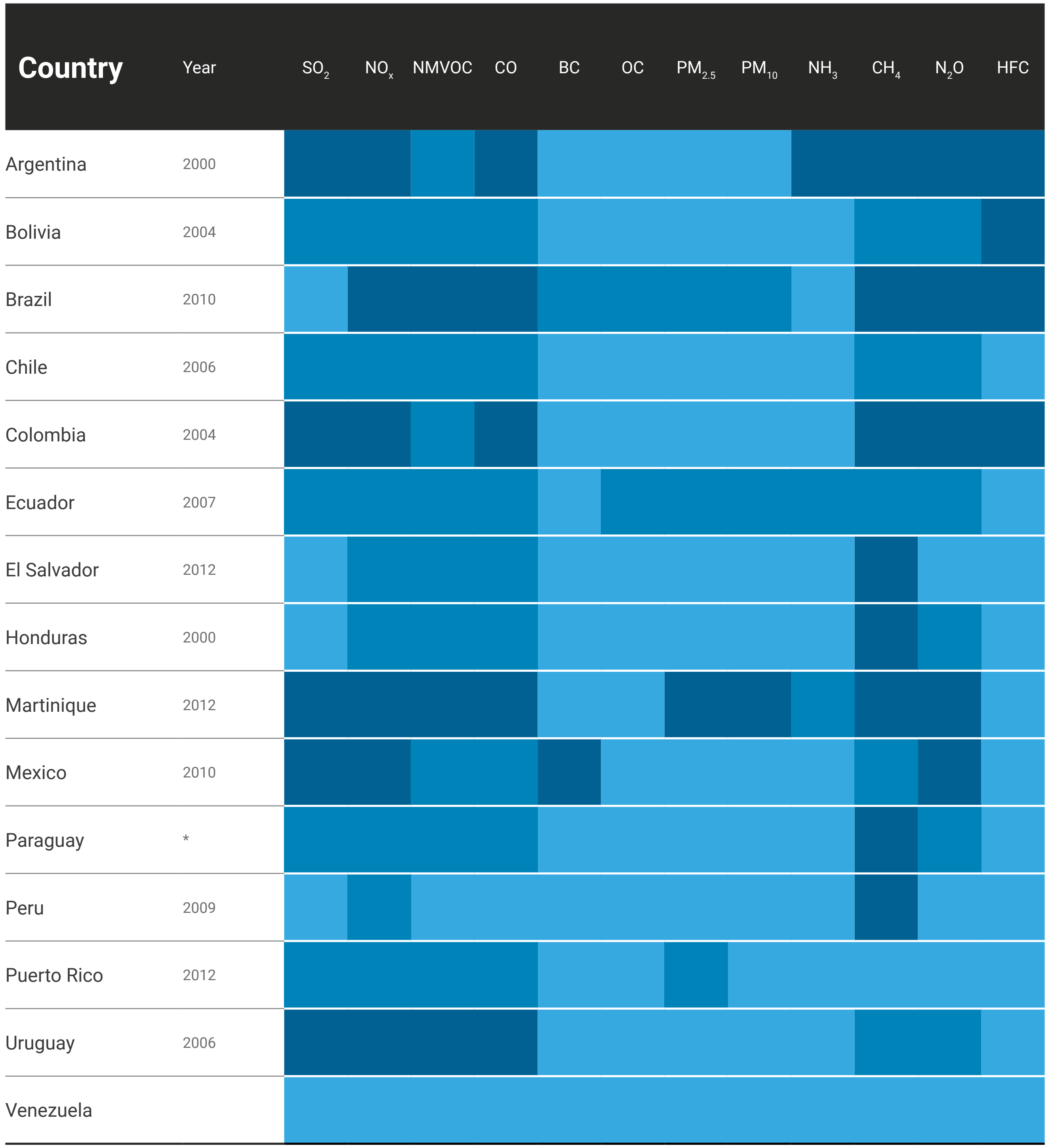
Source: UNEP-WMO, 2011.

Figure 1.2

Latin American and Caribbean countries/sub-regions selected for use in the assessment and GAINS model emission estimates

global warming, especially since they have short lifetimes in the atmosphere. Black carbon and OC are primary constituents of $PM_{2.5}$, and NO_x, SO_2, and NH_3 are important precursors from which secondary $PM_{2.5}$ is formed. Although CO is a minor greenhouse gas, it is an important tracer of combustion processes with strong indirect effects on global warming, as well as a health hazard. In addition, CO, as well as CH_4, NO_x and NMVOCs, is a precursor to O_3 formation.

It is important to emphasize that the national inventories, from which emissions data (reported in this section, Table 1.2, and Tables A1.1-A1.8 in the Appendix 1) are extracted, are produced by each country using methods, standards and categories that are not necessarily comparable across the 13 selected countries/sub-regions of Latin America and the Caribbean. Countries have been using a variety of internationally established methods and sources of emission factors, but there is no ongoing effort to harmonize these nor to estimate and systematize emission factors that could be more representative of national conditions. Information on the spatial distribution of emission sources is also limited. Furthermore, in several inventories, a number of important emission sources are missing, making them incomplete and difficult to compare with other independent sources.



Country	Year	SO_2	NO_x	NMVOC	CO	BC	OC	$PM_{2.5}$	PM_{10}	NH_3	CH_4	N_2O	HFC
Argentina	2000	■	■	▨	■	□	□	□	□	■	■	■	■
Bolivia	2004	▨	▨	▨	▨	□	□	□	□	□	▨	▨	■
Brazil	2010	□	■	■	■	▨	▨	▨	▨	□	■	■	■
Chile	2006	▨	▨	▨	▨	□	□	□	□	□	▨	▨	□
Colombia	2004	■	■	▨	■	□	□	□	□	□	■	■	■
Ecuador	2007	▨	▨	▨	▨	□	▨	▨	▨	▨	▨	▨	□
El Salvador	2012	□	▨	▨	▨	□	□	□	□	□	■	□	□
Honduras	2000	□	▨	▨	▨	□	□	□	□	□	■	▨	□
Martinique	2012	■	■	■	■	□	□	■	■	▨	■	■	□
Mexico	2010	■	■	▨	▨	■	□	□	□	□	▨	■	□
Paraguay	*	▨	▨	▨	▨	□	□	□	□	□	■	▨	□
Peru	2009	□	▨	□	□	□	□	□	□	□	■	□	□
Puerto Rico	2012	▨	▨	▨	▨	□	□	▨	□	□	□	□	□
Uruguay	2006	■	■	■	■	□	□	□	□	□	▨	▨	□
Venezuela		□	□	□	□	□	□	□	□	□	□	□	□

Table 1.1

Availability and completeness of national emissions data in Latin America and the Caribbean

Note: data were provided by regional authorities and include all countries that responded to the request.

* No information provided about the reference year

■ National inventory provided and complete

▨ National inventory incomplete

□ National inventory not provided

The information gathered from the different countries, as well as from agencies working in the sub-regions, has been used to improve the activity data and emission factors in the GAINS model. These data and factors are used in section 1.5 to provide a consistent data set for emissions of all relevant substances, enabling an SLCP assessment to be made for the sub-regions.

Historical emission estimates for recent years

The pollutant emissions submitted by countries in this assessment are listed in Table 1.2. Tables 1.1 and 1.2 highlight the issue of national inventory completeness. While the quality of reporting on greenhouse gases can be quite good, PM species ($PM_{2.5}$, PM_{10}, BC, OC) are poorly reported by most countries. Key missing source sectors include residential combustion, which was omitted by six countries; agricultural waste burning, again omitted by six countries; transport, by three; agriculture, by three; waste, by two; and fossil fuel extraction and distribution, for which eight countries submitted no relevant data.

Reporting of NO_x, SO_2 and CO, as well as CH_4 and nitrous oxide (N_2O) emissions, appears to be more complete than for other pollutants, although HFC reporting is also complete for the few countries that did report it. Data for PM are very scarce, which is consistent with the overall summary in Table 1.1 and the sectoral data provided in the Appendix 1; Tables A1.1-A1.8.

As noted earlier, inventories range over the period 2000–2012; a complete set for any given year covering the whole of Latin America and the Caribbean is not available. All the emission data provided is included in Appendix 1 (Tables A1.1–1.8). It appears that most countries report air pollutant emissions from power plants, industrial boilers, industrial processes and transport, while residential combustion is missing in nearly half of the provided data. Agriculture is reported for CH_4, but almost none of the countries included this source in the NH_3 estimates. Several other sectors appear sketchy and are often missing in several inventories. One of the true surprises is that even for the transport sector, not all countries report emissions of some key pollutants. This might be explained by the fact that most efforts have focused on estimating CO_2 and other greenhouse gases rather than other pollutants, in addition to the large gaps in sectoral data at a national level. Section 1.5.4 compares the reported data with the GAINS calculations for selected pollutants and countries where a fairly complete sectoral coverage was provided.

Owing to rather variable source coverage in the submitted inventories it is not possible to discuss the regional importance of a given pollutant or sector, as the totals for the region as a whole are incomplete and therefore not representative. However, such discussions are possible for specific countries that have developed more accurate and complete emissions inventories, such as Mexico (section 1.5).

Large-scale combustion including power plants and industrial boilers

Large-scale combustion mostly relates to oil- and coal-fired electrical power plants, but many large industries incorporate their own power sources, which can burn a variety of fuels including natural gas, diesel or petroleum. These sources are difficult to document because industries may not accurately report them. The differences in the relative magnitude of pollutants emitted in each country reflect the type of fuel used to produce energy. Because much of the energy in Brazil and Paraguay is hydroelectric, for example, they rely less on the oil- and coal-fuelled power plants on which other Latin American and Caribbean countries depend. In contrast, Mexico's power generation is largely based on fossil fuels and detailed information is available, including for comparison with Canada and the United States of America (CEC, 2011).

Industrial processes including brick kilns, smelters and refineries

A wide variety of industrial processes use combustible materials. This emission source is particularly difficult to document with reliable estimates since many activities, such as brick production and smelting, utilize a variety of materials, including tyres, discarded construction materials or waste oil, whose emissions of CO, CH_4, NO_x and NMVOCs are poorly characterized. In Mexico, most BC emissions associated with industrial processes relate to combustion in sugar mills. In contrast, Brazil attributes practically no emissions to industrial processes due to its lack of industrial SLCP inventories.

Residential-commercial combustion: cooking and heating

Biomass has been used extensively in many developing countries to cover domestic energy needs such as cooking and heating. In rural Mexico and many other Latin American and Caribbean countries, cooking is typically performed on open fires surrounded by three stones or with U-shaped enclosures usually built by the users out of mud or clay (Berrueta *et al*., 2008). Although open fire is highly polluting and often fuel-inefficient, its versatility is much appreciated: it can be made easily, anywhere, anytime, by anyone, at nearly zero cost; uses fuel of nearly any kind; and requires no long-term maintenance (Troncoso *et al*., 2007). To some extent, improved cookstoves have been disseminated to replace traditional devices and improve quality of life for rural inhabitants. However, any resulting effectiveness and impacts on emissions and health still need to be assessed. Well-designed cookstove programmes also help reduce the greenhouse gas emissions associated with traditional open fires. More detailed information on cookstove emissions is given in Appendix A1.3.1.

Transport

This emissions category covers a broad variety of cars, motorcycles, trucks, buses and ships. At 22 per cent of the total reported emissions in this survey, transport is second only to agriculture as a source of pollution in Latin America and the Caribbean. In Chile, Colombia, Ecuador and Mexico it produces more than 60 per cent of the CO and more than 50 per cent of the total NO_x. In the case of Mexico, this might seem surprising since Mexico City, one of the largest megacities in the world, has strict regulations and vehicle inspection measures designed to minimize emissions of CO and NO_x. Nonetheless, transport is the largest source of urban air pollutants and the fastest-growing source of greenhouse gas emissions across the region. In addition, vehicle air-conditioning systems are a large source of HFCs, but have not been factored in by countries reporting on emissions from the transport sector.

Country	Pollutant ('000 tonnes per year)										
	SO_2	NO_x	NMVOCs	CO	BC	$PM_{2.5}$	PM_{10}	NH_3	CH_4	N_2O	HFCs
Argentina (2000)	88	762	906	8 834	nr	nr	nr	nr	4 286	308	1
Bolivia (2004)	13	58	70	1 124	nr	nr	nr	nr	709	2	18*
Brazil (2010)	nr	2 593	5 417	14 016	nr	18	74	nr	16 110	544	8
Chile (2006)	893	909	354	281	nr	nr	nr	nr	79	1	nr
Colombia (2004)	99	280	428	2 450	nr	nr	nr	nr	2 573	111	1
Ecuador (2007)	34	91	76	286	nr	6	11	2	176	1	nr
El Salvador (2005)	nr	39	49	435	nr	nr	nr	nr	160	2	nr
Honduras (2000)	nr	59	564	1 024	nr	nr	nr	nr	270	8	nr
Martinique (2011)	5	25	3	16	nr	1	1	0.1	8	0.1	nr
Mexico (2010)	2 197	1 519	1 074	6 933	79	nr	nr	nr	3 893	195	nr
Paraguay **	0.2	39	59	466	nr	nr	nr	nr	546	0.02	nr
Peru (2009)	nr	75	nr	nr	nr	nr	nr	nr	1 161	75	nr
Puerto Rico (2012)	37	80	67	367	nr	5	nr	nr	nr	0.1	nr
Uruguay (2006)	40	36	44	298	nr	nr	nr	nr	884	36	nr

Table 1.2

Total emissions in Latin America and the Caribbean, by country and pollutant

Note: values are rounded to the nearest integer; nr = not reported; Venezuela is not listed because no information was provided.

* This may be an overestimate and is currently being investigated.

** Reference year not provided.

Fossil fuel extraction and distribution

The mining of coal, mostly in Colombia, and the extraction of oil and natural gas are the activities that contribute the most to emissions in this pollution category. In general, with the exception of Colombia, the extraction of coal is a minor emission source in Latin America and the Caribbean. The oil and gas industry is predominant in Bolivia, Brazil and Chile. Although not reported, Venezuela is also believed to contribute significantly to this component (Heede and Oreskes, 2016). Mexico, a major producer of petroleum, reports no emissions from this source in the 2010 emissions inventory, although the large oil fields in the southern part of the country and the Gulf of Mexico have to be major contributors of CH_4 and other pollutants.

Waste and landfill including open garbage burning

Emissions from waste and landfill are also considered a relatively small source of pollutants in the region. In Brazil, this source is estimated to produce only a tenth of the amount of CH_4 emitted by Brazilian agriculture; in Peru, however, the waste sector is believed to account for at least a third of the country's CH_4 emissions. Even though other countries do not report this source in their national inventories, it is likely that it could be much more significant than currently estimated, particularly in large urban areas where garbage, sewage and other waste products are not adequately treated or disposed of. In addition, refrigerators, which contain HFCs as a refrigerant, that are deposited in landfill are likely sources of HFCs that have until now not been taken into account.

Agriculture

Agriculture is a key source of CH_4, contributing nearly 70 per cent of the total emissions in Latin America and the Caribbean, according to reported estimates (Table A1.5 in the Appendix 1). The model estimates used in this assessment indicate a lower share (about 50 per cent; Figure 1.5), mostly because of higher emissions from oil and gas production. In fact, national and model estimates often allocate sources into different sectors. For example, several countries report emissions from the operation of farm equipment under agriculture (see emissions of CO_2 NO_X and NMVOCs in Argentina, Bolivia and Peru in Appendix A1.3.2), while in the GAINS model (section 1.5) these are categorized as non-road machinery. Similarly, the open burning of crop residues may be accounted under open biomass burning or under agriculture, as was the case in the UNEP global assessment (UNEP-WMO, 2011) and the GAINS model.

Open burning of biomass including crop residues

The use of fire in deforestation processes and in maintaining areas for agricultural use is a very common practice in the tropics. At the same time these fires are a major contributor to atmospheric trace gases and aerosols, including BC. Rosário *et al*. (2013) modelled changes in atmospheric optical depth caused by smoke aerosols and determined that there is a reduction in area-averaged radiative forcing of around 4 per cent in South America, with large contributions of OC and BC. According to Bond *et al.* (2004), emissions of OC from biomass burning in Latin America can be six to seven times greater than from other anthropogenic sources. Based on the reported emissions, the contribution to the total varies strongly between species – from less than 2 per cent for SO_2 to more than 35 per cent for CO_2, with a large variation between countries (Appendix A1.3.2).

Uncertainties

The completeness and quality of information in emissions inventories varies across the region and between countries and pollutant species. For some pollutants, especially aerosols, the underlying information about key sources, such as residential solid fuel combustion and informal sectors including brick production and residual waste burning, is of poor quality or non-existent. This applies to both activity data and local emission factors.

In order to create a comprehensive data set of emissions, national information has to be supplemented with model estimates that often rely on default parameterization; in fact, many of the national inventories draw on the international data sets of emission factors because of a lack of local measurements. Finally, the level of enforcement of existing laws, as well as the real-life performance of control technology, is often insufficiently known. The assumption that enforcement works as planned may be over-optimistic (Xu *et al.*, 2009; Xu, 2011; Stoerk, 2016), as illustrated by the example of the 2015 Volkswagen emissions scandal (Davenport and Ewing, 2015). Consequently, the level of uncertainty, or confidence, varies widely across pollutants, sectors and countries.

No formal uncertainty analysis for emission estimates has been performed in this assessment (developed with the GAINS model); results, however, from the analysis of regions outside Latin America and the Caribbean are helpful and indicative of the expected uncertainties for various species and countries/sub-regions within Latin America and the Caribbean. For example, the TRACE-P emissions inventory for Asia (Streets *et al.*, 2003) includes uncertainty analyses for greenhouse gases and air pollutants for both developed and developing countries. The lowest uncertainties were estimated for pollutants whose emissions are largely constrained by elemental concentrations in the fuels – sulphur in SO_2 and carbon in CO_2. Uncertainty in activity data (energy use) is also relevant and for commercial fuels it is estimated to vary from 2–3 per cent for countries belonging to the Organisation for Economic Co-operation and Development (OECD) to 5–10 per cent for non-OECD countries (IPCC, 2006). The final uncertainties were estimated at 9–44 per cent for SO_2 and 7–91 per cent for CO_2, with the lower bound representative of Japan and the upper one representative of the South Asian developing countries (Streets *et al*., 2003). A somewhat similar range of uncertainties was also estimated for NO_X emissions, while for CO_2, NMVOCs and PM including BC and OC, the uncertainties are much larger, driven by poorly known local emission factors. The emission factors for these species depend strongly on combustion conditions and are in general more uncertain. Additionally, they originate from sources for which there is much less activity data, especially on the combustion of often poor-quality fuels in cookstoves or brick kilns, and the characteristics of local vehicle fleets. The highest uncertainties were estimated for carbonaceous aerosols: 160–500 per cent for the developing countries of Asia and 80–180 per cent for the developed ones (Streets *et al*., 2003).

The global BC and OC inventories developed by Bond *et al.* (2004) include a formal uncertainty analysis of total global emissions providing regional low–high estimates for 1996. For Latin America and the Caribbean, uncertainties for BC emissions from anthropogenic sources range from -30 to +120 per cent and for OC from -40 to +130 per cent. Estimates from the GAINS model used in this assessment sit well within these parameters. For open biomass burning, the ranges estimated by Bond *et al.* (2004) for BC emissions were -45 to +185 per cent and for OC they were -40 to +110 per cent. There are only limited local measurements reported for BC and OC and, even when data are available, all such measurements face the challenge of reproducing the field emission factors in laboratory tests (Roden *et al.*, 2006, 2009).

For some of the pollutants – including NH_3, NMVOCs and CH_4 – non-combustion and fugitive sources represent a large share of emissions. According to the *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), while greenhouse gas emission-factor uncertainties are of the order of 10–30 per cent for stationary combustion sources and 20–60 per cent for mobile ones, fugitive sources such as CH_4 from coal, oil and gas production or agriculture are associated with uncertainties of 100–300 per cent. In addition, emission factors have typically been established on the basis of measurements in the developed world and are not necessarily representative of countries in Latin America and the Caribbean. Consideration of local data and knowledge about emission sources and their factors can significantly reduce uncertainties (Zhang *et al.*, 2009).

National-level HFC production and consumption data are lacking in Latin America and the Caribbean, as they are for much of the rest of the developing world. This is because developing countries are not required to report on HFC consumption and production under the United Nations Framework Convention on Climate Change (UNFCCC). On 15 October 2016, the Parties to the Montreal Protocol agreed to a gradual phase-down of HFC production and use under the Kigali Amendment that includes a larger number of HFC species, and considers more of the subtleties of transition to climate-friendlier alternatives (UNEP, 2016a). For HFCs, large uncertainties exist for activity data and leakage rates in refrigeration, air-conditioning and other industrial sectors. Total HFC emission estimates are most affected by uncertainty in estimates of stationary air conditioning, followed by commercial refrigeration and mobile air conditioning (Purohit and Hoglund-Isaksson, 2017). At the same time, the efficiency assumptions used in this assessment might be conservative in view of the continuous development and increasing market share of alternative refrigerants and more efficient technologies in this sector (US EPA, 2013). The distribution of HFC consumption in different sectors will become available as the inventories and studies under way progress, but in order to quantify emissions, more information is required than is currently available in most developing countries. According to a recent study in Chile (Anthesis-Caleb, 2015), data considered essential are: time series of *hydrochlorofluorocarbon* (HCFC)/HFC consumption by substance; qualitative assessment of sub-sector patterns of use by substance; and information on equipment stocks and average charges.

Estimates of activity data and actual emission factors from open biomass burning, including forest fires and savannah and agricultural residue burning (Reddington *et al*., 2015), are associated with significant uncertainties including, among others, on the amount of biomass burned and inter-annual variability (van der Werf *et al*., 2006; Wiedinmyer *et al.*, 2011; Chen *et al.*, 2013; Ometto *et al.*, 2014a, 2014b), the drivers and impact of change in agricultural fires (Morton *et al.*, 2008), and emission factors (Castellanos *et al.*, 2014). Castellanos *et al.* (2014) found that the widely used global emission factors based on the work of Andreae and Merlet (2001) might lead to overestimation of NO_X emissions from deforestation fires in South America by about 30 per cent, at the same time as underestimating emissions from agricultural fires by a factor approaching two.

The uncertainties in emission estimates developed with the integrated assessment models like GAINS are similar to those of the bottom-up inventories discussed above, at least on a regional scale, or they could be even lower, as they typically rely on a harmonized data set and include a simultaneous calculation of emissions of several species using the same principal activity and technology data. Error compensation can lead to a further reduction in emission uncertainty (Schöpp *et al.*, 2005). The GAINS model uncertainties, calculated in Schöpp *et al.* (2005), are consistent with the values reported by Streets *et al.* (2003) for developed countries. This analysis has also shown that at a finer scale the understanding of local circumstances is critically important for reducing uncertainty. Whereas the emission factors were estimated to be the key determinant of uncertainty in historical emissions, at least for aerosol emissions, the uncertainty in activity assumptions becomes more important for projected emissions.

Finally, it has been shown that one of the best ways of addressing uncertainties in mid- to long-term emission projections is by developing alternative scenarios (Nakicenovic and Swart, 2000; Streets *et al.*, 2004; Amann *et al.*, 2011). A number of factors affect such projections, because future developments in complex systems are either inherently unpredictable or have significant scientific uncertainties (Rotmans and van Asselt, 2001; Amann *et al.*, 2011; UNEP-WMO, 2011; Amann *et al.*, 2013)enhance the acceptance of mitigation measures for long-lived greenhouse gas (GHG. Beyond uncertainties in drivers and emission factors, the development of further mitigation policies and their efficiency, as well as the availability of new technologies, affect future emission trajectories.

1.3

Observational data for complementing and refining emission estimates

The GAINS model produces gridded emission rates that are used as input to atmospheric models, which then calculate pollutant concentrations, for example for $PM_{2.5}$ and O_3. The GISS, GEOS-Chem and TM5-FASST models used in the current assessment produce mass concentrations of the gas and particles within the grid spacing of the model at the surface and selected pressure levels. The accuracy of these modelled concentrations needs to be evaluated using *in situ* and remote sensors that measure the concentrations of the target species – O_3, CO, BC, $PM_{2.5}$ and CH_4 – as well as precursor gases like CO, NO_X and NMVOCs. These measurements are available from air quality monitoring stations and field campaigns, and from vertical profiles made with balloon sondes and remote sensors, as described in the following sections and in Appendix A1.5.

1.3.1

Ground-based monitoring

A thorough review of ground-based, urban air quality monitoring facilities in Latin America and the Caribbean is outside the scope of this section, given the differences in information availability and data quality between cities in the region, even between cities within the same country. Nevertheless, different sources of information were reviewed to provide a rough idea of air quality monitoring availability. On the basis of an analysis of the Ambient Air Pollution Database compiled and published by the World Health Organization (WHO) in 2014 (WHO, 2014), a raw estimate of the number of cities across the region that have air quality monitoring stations suggests than PM is regularly measured in 109 cities across 15 countries. Table A1.9 in Appendix 1 summarizes where these cities are located.

The database was compiled with $PM_{2.5}$ and PM_{10} as reference pollutants, but does not include information about other pollutants monitored in the listed cities. Although this database is not comprehensive, it shows remarkable dissimilarities between countries: for large or mid-size countries such as Argentina, Peru and Venezuela, for example, only one or two cities are included, whereas for Jamaica, with a comparatively small population, three cities with monitoring stations are listed. The completeness and reliability of the reported data have not been assessed.

In a more detailed, though not comprehensive, overview of air quality monitoring capacities in Latin America, Green and Sánchez (2013) analysed data from 22 cities in 12 countries, some of which are not included in the WHO Ambient Air Pollution Database. Their report summarizes the number of stations that were active and measured $PM_{2.5}$, PM_{10}, NO_2, SO_X and O_3 between 1997 and 2011. Data from a number of other cities were discarded since they did not comply with the completeness and other criteria needed to perform a sound assessment. According to their report, the most complete networks are in Quito (Ecuador), São Paulo (Brazil), Monterrey and Mexico City (Mexico), and Bogota and Santiago (Chile), with all the relevant pollutants monitored. In contrast, Panama City (Panama) and Santo Domingo (Dominican Republic) only measure PM_{10}. The reliability and accessibility of information vary widely between cities and are the main issues to be addressed by air quality network managers in the region; $PM_{2.5}$ measurements are still scarce. Table A1.10 in Appendix 1 lists the air quality stations measuring PM, SO_2, NO_2 and O_3.

A review of air quality information reported on the Beijing Air Pollution website (http://aqicn.org), which continuously collects information from automatic air quality monitoring stations worldwide, shows that real-time monitoring of pollutants is performed in cities included in neither the WHO database (2014) nor by Green and Sánchez (2013). This site, however, does not assess the reliability of such data, which has been identified as a major issue in the region. The cities include a significant number of Chilean cities, from Arica to Punta Arenas, a number of Mexican cities, Bahía Blanca in Argentina, São Paulo in Brazil and the Caribbean islands of Martinique and Guadeloupe, together with French Guiana. Many of the cities included in the WHO database, however, are not included on that Chinese website.

1.3.2

Field projects

Black carbon is not included in the air quality networks of Latin America and the Caribbean with the exception of one station in the Mexico City network that began measuring BC routinely in 2013, the National Institute for Environment and Climate Change (INECC) National Black Carbon Network comprising another 11 stations across Mexico, and a few stations in São Paulo city, Brazil. There have, however, been several field projects of relatively short duration in which BC has been measured along with many other gas and particle properties. Although covering a short period, the data from these field programmes provide information that is usually well documented and published in open literature. Table A.1.11 in Appendix 1 is an extensive, but incomplete, list of field projects that measured various SLCPs over the past 25 years, along with publications that present the results from these projects.

1.3.3

Ozonesondes

Information on the vertical profile of pollutants is important for assessing how accurately the atmospheric models used in the assessment (GISS, GEOSChem) distribute these pollutants spatially and temporally. The measurements from ozonesondes provide details on the vertical structure of O_3 that can be directly compared with the output of the model in selected regions, taking into account that the coarse resolution of the model will average out the finer details detected by the sondes. Accordingly, this section is devoted to reviewing the projects of ozonesonde measurements in Latin America and the Caribbean, which provide detailed profiles up to an altitude of about 30 kilometres (km).

The Southern Hemisphere Additional Ozonesonde Network (SHADOZ) was established in 1998 and included two locations in South America: San Cristobal (Ecuador) and Natal (Brazil). In 1999 and 2005 Paramaribo (Surinam) and San José (Costa Rica), respectively, were added to the network. These stations aim to provide insights into tropical chemistry and dynamics (Thompson *et al.*, 2012). On Rapa Nui (Easter Island, Chile), the National Weather Service has been operating an ozonesonde observation programme since 1995, in collaboration with the World Meteorological Organization (WMO). In Punta Arenas (Chile), launches were made between 2009 and 2011. Also in Chile, between 2010 and 2012, the first ozonesonde programme was conducted over Santiago Basin and the surrounding valleys to explore the mechanisms that control regional O_3 formation and transport across the basins (Seguel *et al.*, 2013). A new programme initiated in 2014 aims to determine the contribution of stratosphere-troposphere exchange to the lower troposphere of central Chile. The Global Atmospheric Watch (GAW) station in Ushuaia (Argentina), operating since 2008, recorded the influence of the south polar vortex over the southern tip of the South American continent. The first ozonesonde programme in continental Ecuador was initiated at Cumbaya Valley, on the outskirts of Quito, in 2014 (Cazorla, 2016). Ozonesondes were launched in 2006 in São Paulo, Brazil to determine the effect of biomass burning on O_3 concentrations over the metropolitan area of São Paulo (Andrade *et al.*, 2012). Table A1.12 in Appendix 1 lists the locations and dates of ozonesonde projects along with useful links and associated references.

1.3.4

Remote sensing

The output of atmospheric models can be used to calculate aerosol optical depths and column concentrations of gases such as O_3, CO, NO_2 and CH_4 that are also measured with ground-based photometers and space-borne, multi-wavelength radiometers. Ground-based remote sensing techniques like DOAS and FTIR are used to retrieve ground-level and vertical profiles of some of these gases (Andrade *et al*. 2016). The measured column values can be directly compared with the model output. Vertically resolved information is also available from some of the satellite products.

A number of AERONET stations in Latin America and the Caribbean measure aerosol optical depth and can provide useful comparisons with the GAINS simulations. These are shown in Figure A1.2 in Appendix 1. Table A1.13 lists the AERONET, LiDAR and radiosonde stations that measure vertically resolved column concentrations or optical depths of the various SLCPs and other trace gases and particles.

1.4

Atmospheric processes

Regional heating and cooling

Short-lived climate pollutants have been identified as contributors to total anthropogenic radiative forcing. In contrast to the well-mixed greenhouse gases, SLCPs do not accumulate in the atmosphere at decadal to centennial scales, rather their impact on climate lasts for around a decade after they are emitted. Depending on the particular species, the short-lived substances may have opposing effects. Particles of OC, sulphates and nitrates, for example, produce negative forcing; while BC, CO, HFCs, and CH_4 lead to positive forcing. Regional heating associated with SLCPs and cooling related to aerosols can only be identified if the emissions information is available for all substances (IPCC, 2013); hence the GAINS model was used to develop emissions for all species and the GISS global climate model was used to estimate their impact on warming. The effect on regional climate is discussed in further detail in Appendix 1.

Cloud formation and precipitation

Clouds and precipitation are affected indirectly by O_3 and CH_4 because of their absorption of terrestrial radiation, which leads to changes in the thermodynamic structure of the atmosphere and subsequently drives local and regional dynamics. Black carbon, which absorbs all wavelengths like elemental carbon, and brown carbon, which absorbs shorter, UV wavelengths like organic carbon, also absorb terrestrial and solar radiation, inducing surface heating, affecting evaporation, and altering convection and cloud formation. In addition, BC as well as other particles may act as cloud condensation nuclei and ice nuclei, affecting the formation and concentration of cloud particles in both liquid and ice phases. The effect of SLCPs on cloud formation and precipitation is discussed in much greater detail in Appendix 1.

Cryosphere

All the SLCPs, and in particular BC, have the potential to accelerate the loss of snow and glacier ice, particularly in the mountains of the South American cordillera. As mentioned, BC particles can serve as cloud condensation nuclei and ice nuclei that may alter cloud microphysics depending on their concentration (Rosenfeld *et al*., 2008). They act to decrease precipitation if they compete for the available water vapour, affecting the formation of snow. There is also strong evidence in other parts of the world that BC on top of or mixed with snow cover absorbs solar radiation and promotes sublimation or melting (Ming *et al*., 2009; Menon *et al*., 2010; Ménégoz *et al*., 2014).

1.5

The GAINS model and comparison with measurements and other models

The drivers of SLCP emissions and other pollutants in Latin American and the Caribbean vary widely from country to country with respect to the relative importance of urban to rural activities, agricultural to industrial sources or small-scale to large-scale processes. Mirroring other parts of the world, as populations migrate to urban areas, emissions from transport, both private and public, continue to increase and become more concentrated in these population centres. Moreover, Latin America and the Caribbean is the world's most urbanized area, with almost 80 per cent of its population living in towns and cities. Nowadays, small and medium-sized cities are growing faster than large ones (UNEP, 2016b). In rural areas, open burning of biomass for disposing of crop debris in preparation for planting or for land clearance remains a major source of pollutant emissions. Because of the large variability in both the quantity and quality of emissions inventories and spatial distributions of key measurements, the impact of Latin American and Caribbean emissions on local, regional and global climate cannot be accurately assessed without employing models to fill gaps in the information. The GAINS model (Amann *et al*., 2011) is one such model that was employed for the present assessment. The remainder of this section provides a summary of its features. Greater detail is found in Appendix A1.7.

1.5.1

Overview of the GAINS model

The GAINS model (Amann *et al*., 2011) provides emissions of long-lived greenhouse gases and short-lived species in a consistent framework. It holds essential information about key sources of emissions, environmental policies, and further mitigation opportunities for 170 countries/regions at a global level, including the 13 countries and sub-regions of Latin America and the Caribbean (Figure 1.2). The emission calculation in GAINS draws on the available literature and has been reviewed by experts from academia, governments and industry, and it applies emission factors that reflect country-specific conditions such as fuel quality, combustion technologies, fleet composition, maintenance levels or the application of control technologies. The model relies on exogenous projections of energy use, industrial production and agricultural activity for which it distinguishes all key emission sources and control measures. More than 2 000 technologies to control air pollutant emissions and at least 500 options to control greenhouse gas emissions are included.

Estimation of HFC emissions in GAINS follows the same principles as previously outlined but includes modifications to account for the wide range of global warming potential (GWP) for different HFCs. Emission factors are converted to CO_2 equivalents by multiplying by the respective GWP over 100 years, as presented in the *IPCC Fourth Assessment Report* (AR4) (IPCC, 2007). Wherever data availability allows, source-specific emission factors are taken from published references.

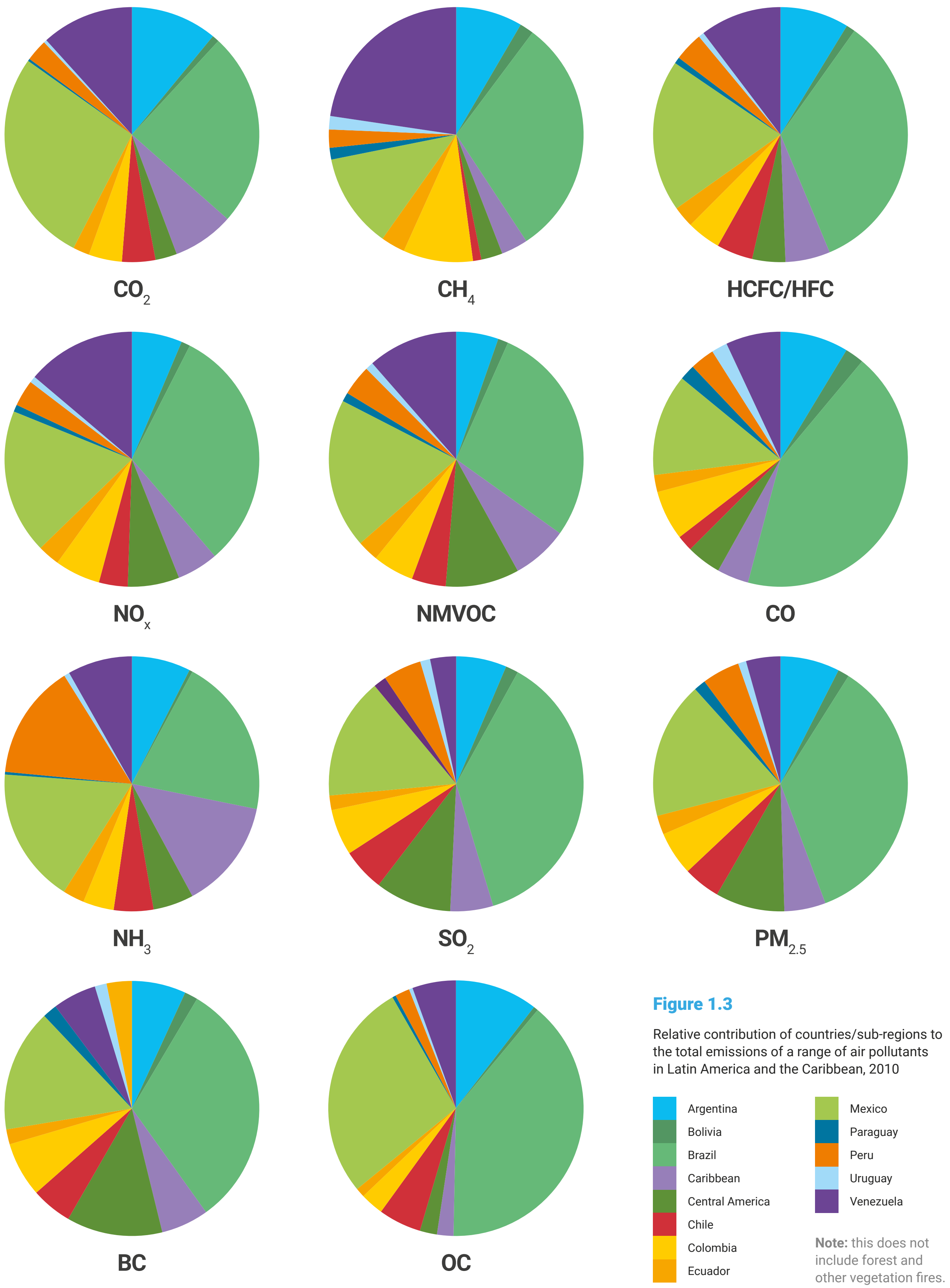


Figure 1.3

Relative contribution of countries/sub-regions to the total emissions of a range of air pollutants in Latin America and the Caribbean, 2010

Note: this does not include forest and other vegetation fires.

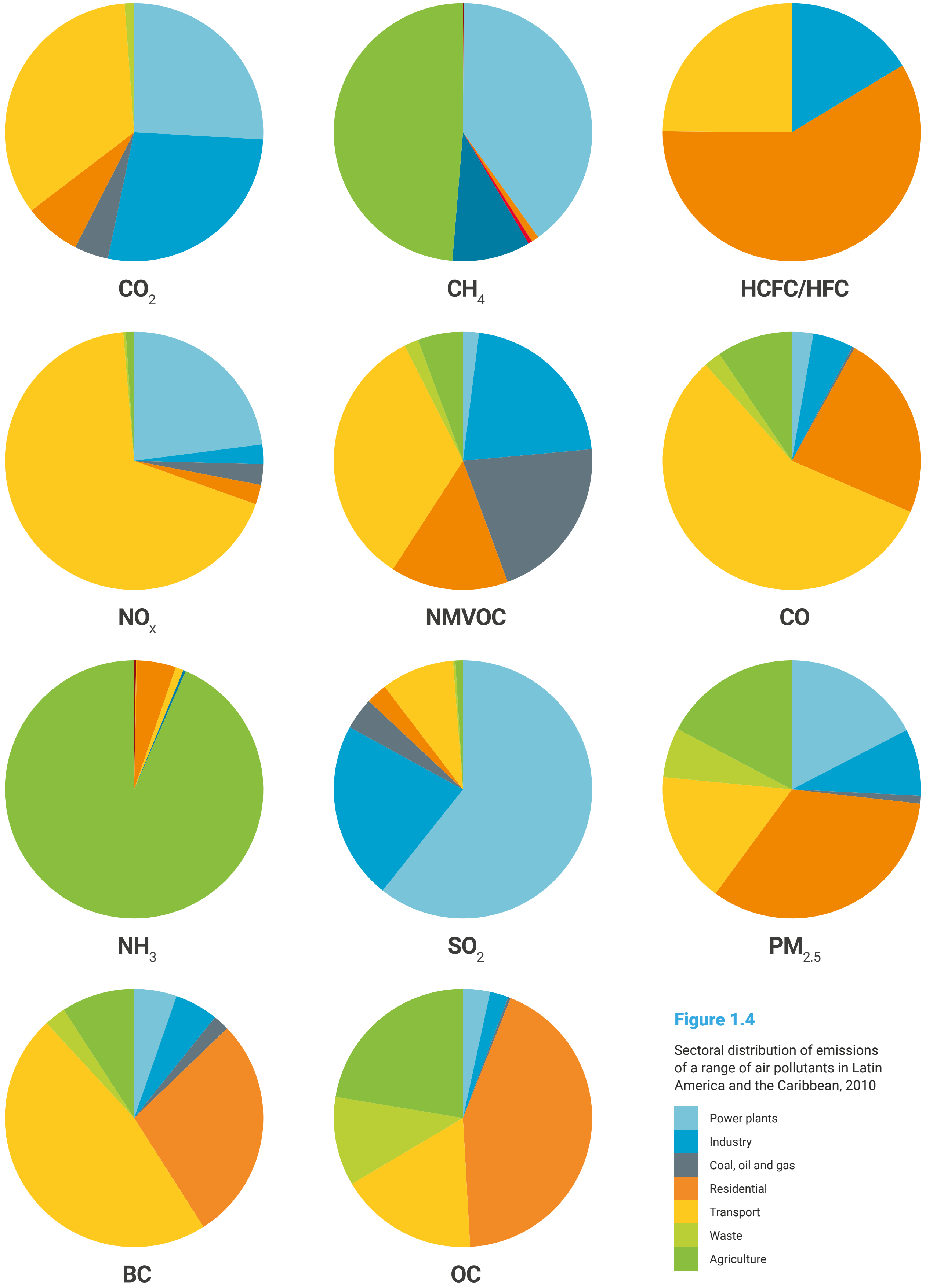


Figure 1.4

Sectoral distribution of emissions of a range of air pollutants in Latin America and the Caribbean, 2010

Sector-specific emission rates are taken from several sources (IPCC/TEAP, 2005; Tohka, 2005; Gschrey *et al*., 2011; Schwarz *et al*., 2011; UNFCCC, 2012). Sector-specific GWP is determined based on the shares of different types of commonly used HFCs and their GWP.

The latest set of global scenarios (Klimont, 2015) draws on international and national statistical data for past years and on studies that project the development of energy use and agricultural activity into the future (Alexandratos and Bruinsma, 2012; IEA, 2012). The current assessment relies on the same principal data sources, reviewed and updated in GAINS for specific sectors, as discussed below.

All emission data were gridded consistently to a resolution of 0.5°x0.5° longitude-latitude. The spatial proxies used in GAINS are consistent with those applied in the representative concentration pathway (RCP) projections as described in Lamarque *et al.* (2010) and as further developed in the Global Energy Assessment project (IIASA, 2012). They were, however, modified to accommodate more recent year-specific information where available, including on population distribution, open biomass burning, location of oil and gas production facilities, and livestock category-specific spatial production patterns (Klimont *et al.*, 2016). Emissions were also temporally allocated; monthly distribution was provided for all sources.

1.5.2

Emission estimates for historical years

The regional distribution of anthropogenic emissions of greenhouse gases and several air pollutants estimated with the GAINS model for 2010 is shown in Figure 1.3. It is the first attempt to quantify Latin American and Caribbean emissions at a country and sub-regional level using a consistent framework, and more reliable regional data on emissions inventories and related information are needed to improve current estimates and enhance reliability. The larger countries, including Brazil and Mexico, appear to dominate the emissions of most species and, in the case of CH_4, Venezuela produces a very significant share. For several pollutants, the pattern looks similar to that of CO_2; however, for SO_2 and PM the patterns vary owing to the important role of non-ferrous smelters and the reliance of residential emissions on solid fuels or exclusively on liquid and gaseous fuels. In the case of NH_3, emissions are dependent on the importance of livestock production and therefore not aligned with the CO_2 pattern. For HFCs, Argentina, Brazil and Mexico represent nearly 80 per cent of emissions, with a major contribution from residential applications (about 60 per cent) followed by transport (about 25 per cent) and specific industrial uses (Figure 1.4).

Figure 1.4 shows the sectoral contribution of different pollutants across the whole region. For some of them, such as CH_4 or NMVOCs, the distributions are fairly typical. For BC and NO_x, the share of transport is unusually large; typically, a higher share of BC would come from the residential sector and a higher share of NO_x from power and industry. These features are, however, compatible with the activity data for the region. At the same time, this has implications for SLCP mitigation opportunities. The expected evolution of these emissions and more details on the methodology are presented in section 1.5.4.

Two of the key SLCPs addressed in this analysis are CH_4 and BC. The region's CH_4 emissions – more than half of which originate in Brazil and Venezuela (Figure 1.5) – are estimated to represent about 15 per cent of the global total. Virtually all emissions come from three sectors: agriculture (nearly 50 per cent), coal, oil and gas production and distribution (nearly 40 per cent) and waste. At the regional level, the importance of specific source sectors varies strongly but, with the exception of Venezuela, agriculture represents a major part, ranging from about 30 per cent in Ecuador to about 90 per cent in Paraguay. The oil and gas industry dominates emissions in Venezuela (nearly 90 per cent), but is also important in several other countries including Ecuador and Mexico, where it contributes 40–60 per cent; coal mining is truly significant in Colombia. Waste management typically represents about 10–20 per cent, with the exception of Chile (40 per cent) and Venezuela (3 per cent).

The region's anthropogenic BC emissions (Figure 1.6), of which more than 60 per cent originate in Brazil and Mexico, represent less than 10 per cent of the global total. Transport and the combustion of solid fuels in the residential-commercial sector are responsible for about three-quarters of total emissions, with the transport sector being the most important in nearly all countries. While brick manufacturing is estimated to contribute up to 10 per cent of BC in several countries, open field burning of agricultural residues appears even more important in a number of countries/sub-regions, accounting for an overall share of about 15 per cent.

1.5.3

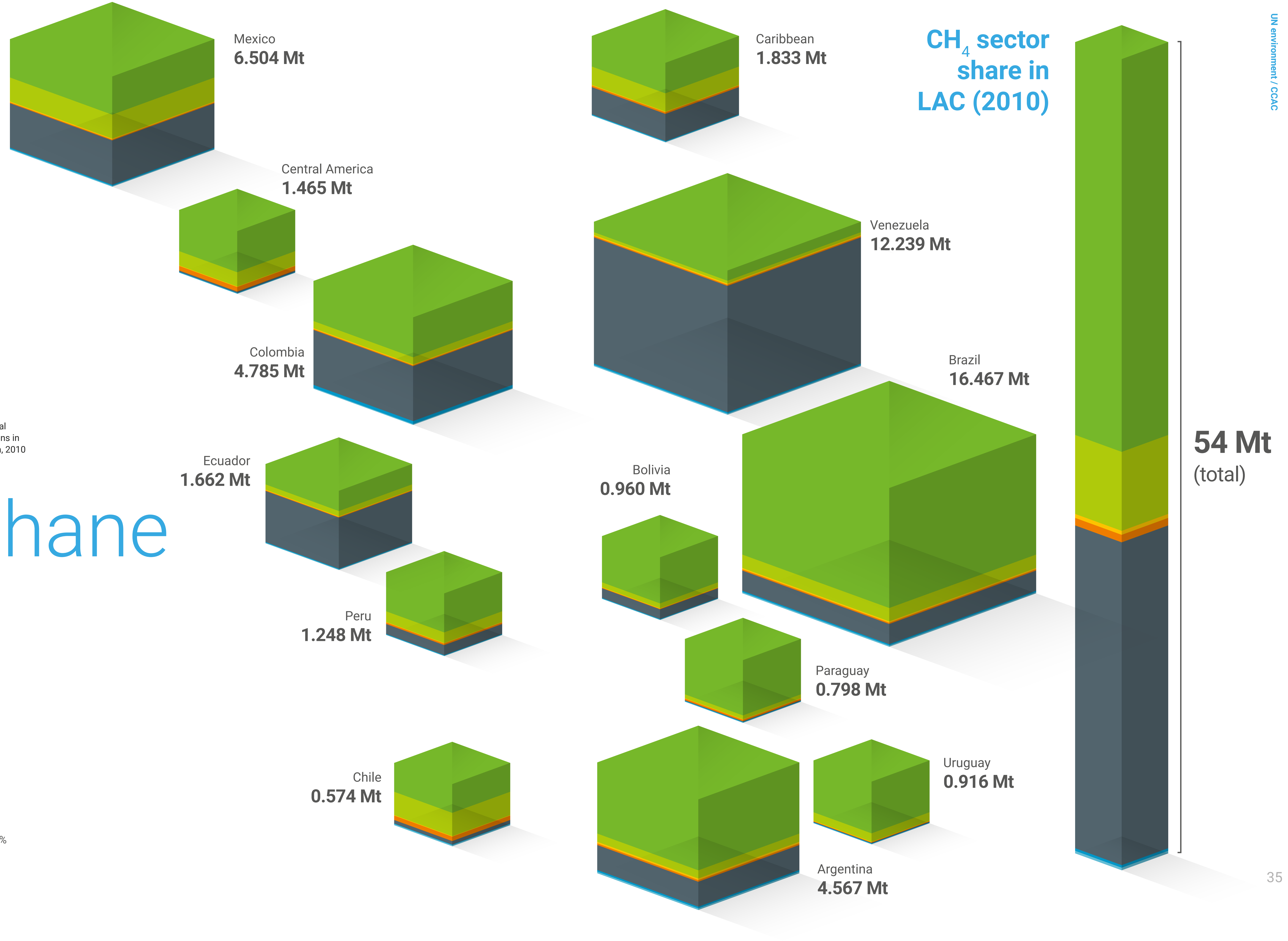
Comparison of GAINS emissions and other estimates

As shown in Figure 1.7, the updated estimates of emissions in this assessment are compared to those presented in the global assessment (UNEP-WMO, 2011). There are several well-understood differences that stem from better national representation of activities and emission factors as well as developments in the GAINS model, including re-evaluation of CH_4 from fossil fuel production and of the whole agriculture sector, which resulted in changes for NH_3. Total CO_2 emissions remain close, as only small adjustments occurred to the total energy use across the region.

Figure 1.5

Sectoral and country/sub-regional contribution to methane emissions in Latin America and the Caribbean, 2010

Methane



- 🟩 Agriculture
- 🟨 Waste
- 🟨 Transport
- 🟧 Residential
- ⬛ Coal, oil and gas
- 🟦 Industry
- 🟦 Power plants

CH$_4$ 100%

Black carbon

Figure 1.6

Sectoral and country/sub-regional contributions to black carbon emissions in Latin America and the Caribbean, 2010

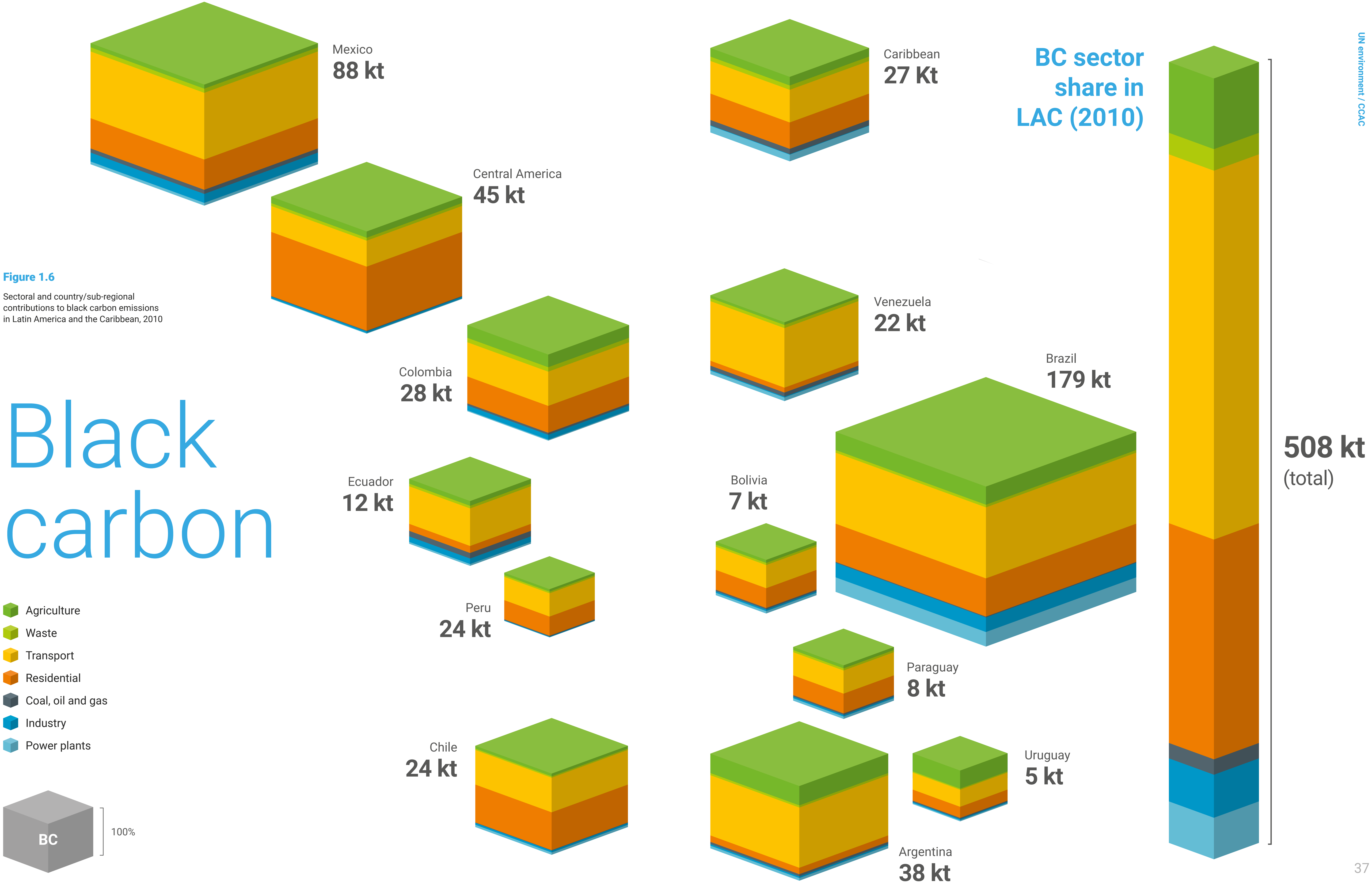
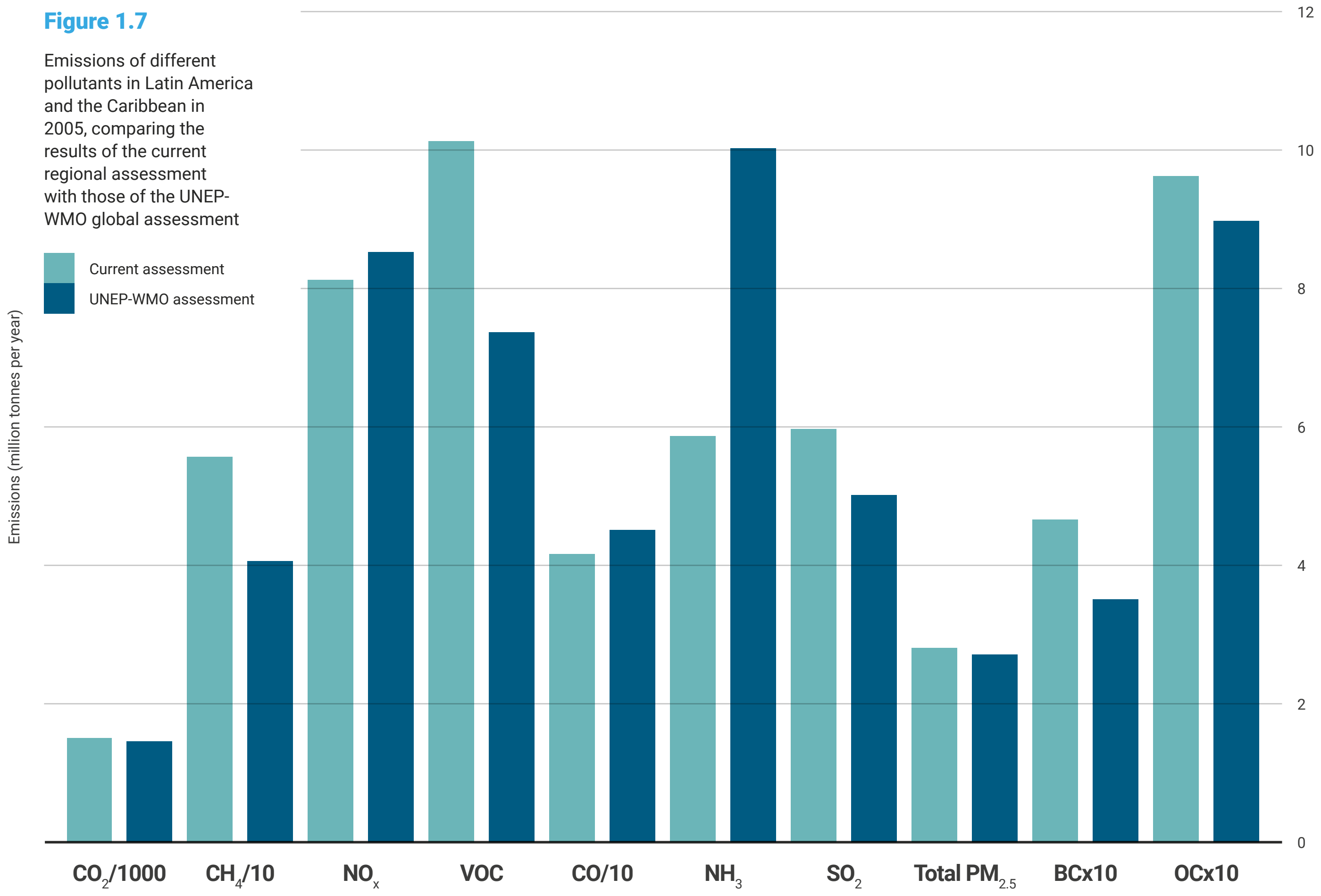


Figure 1.7

Emissions of different pollutants in Latin America and the Caribbean in 2005, comparing the results of the current regional assessment with those of the UNEP-WMO global assessment



A closer comparison of national estimates in the GAINS model is provided in Appendix A1.7; the current section is constrained to a few examples with a reasonably complete national inventory. For CH_4 emissions (Figures A1.3 and A1.4) there is a relatively good agreement at a total level as well as for the agriculture and waste sectors, although for the latter, national estimates are consistently higher than the model. Another result from this comparison is that GAINS is systematically higher due to the estimates for oil and gas industry losses, where several countries, including Bolivia and Mexico, do not report any emissions and others seem to underreport. GAINS estimates were documented by Höglund-Isaksson (2013) and re-evaluated for Latin American countries in the current assessment.

The comparison for NO_x (Figure A1.5) shows a reasonable match for several countries, with GAINS typically estimating slightly higher emissions, possibly because GAINS includes a systematic assessment of high-emitting vehicles, which are absent from national inventories. For some countries, the differences are larger. For example, Chile's national estimate is significantly higher than the GAINS estimate, but a close look at reported emissions from the transport sector suggests that they represent virtually 100 per cent of the reported total, and are even higher than the total transport emissions of Mexico. This is unlikely and needs further investigation.

1.5.4

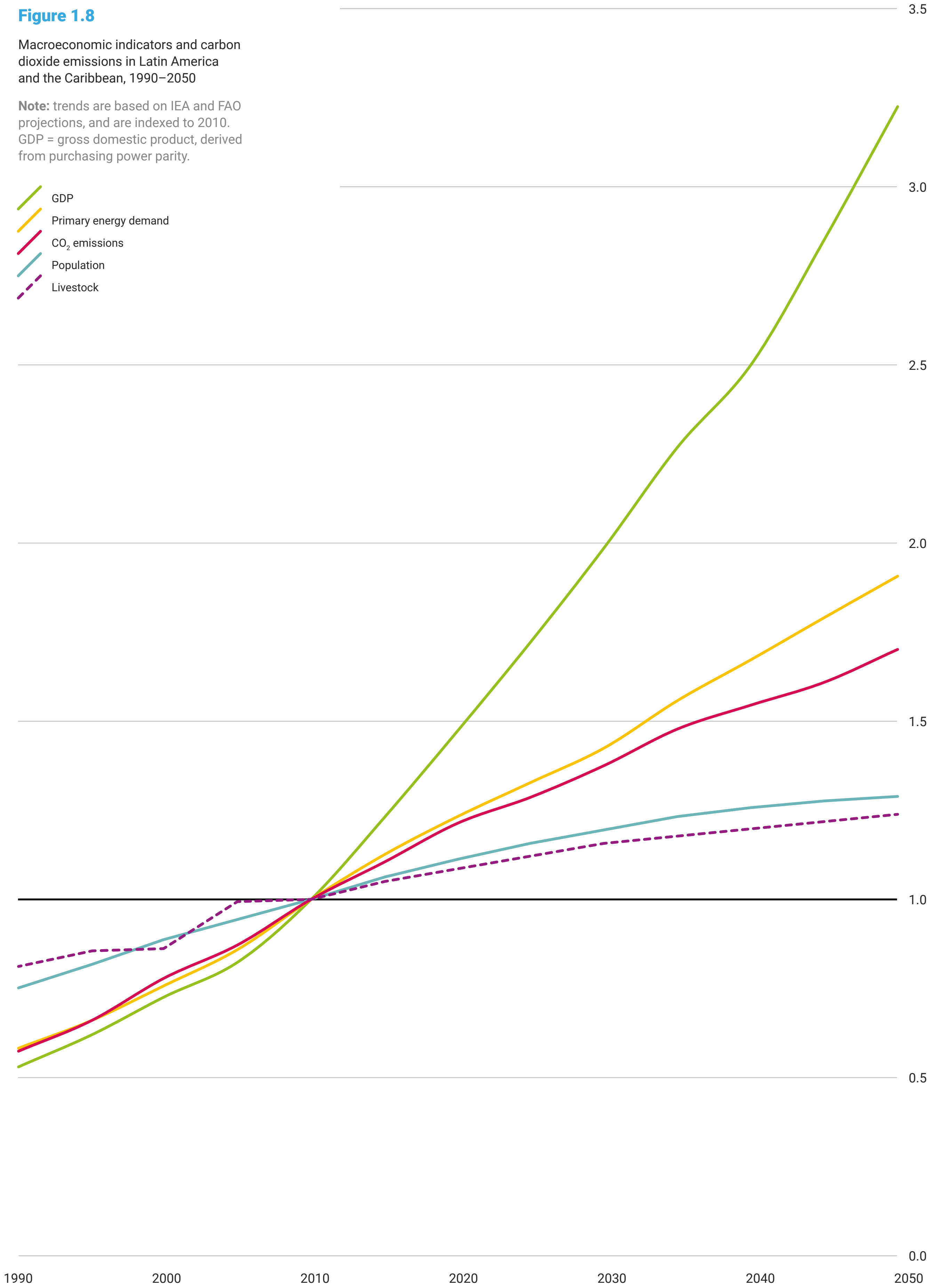
Reference (baseline) scenarios

After establishing the base-year emissions, the reference scenario was developed with the GAINS model. This scenario is based on the energy drivers derived from the International Energy Agency (IEA) energy projections (IEA, 2012) and the projections for agriculture developed by the Food and Agriculture Organization of the United Nations (FAO) (Alexandratos and Bruinsma, 2012). While the energy projections are at a relatively coarse spatial and sectoral resolution, specifically not including each country in the region, the respective data was distributed into GAINS model structures using detailed information from the historical statistics and national databases. Figure 1.8 summarizes key indicators of growth in this scenario for the whole region, relative to 2010. While a moderate population growth of about 30 per cent by 2050 is assumed, gross domestic product (GDP) per person is expected to grow in real terms by more than a factor of three. Primary energy consumption is expected to nearly double, but with a slight reduction in CO_2 intensity as emissions are estimated to grow rather less – by about 70 per cent over the same period.

Figure 1.8

Macroeconomic indicators and carbon dioxide emissions in Latin America and the Caribbean, 1990–2050

Note: trends are based on IEA and FAO projections, and are indexed to 2010. GDP = gross domestic product, derived from purchasing power parity.



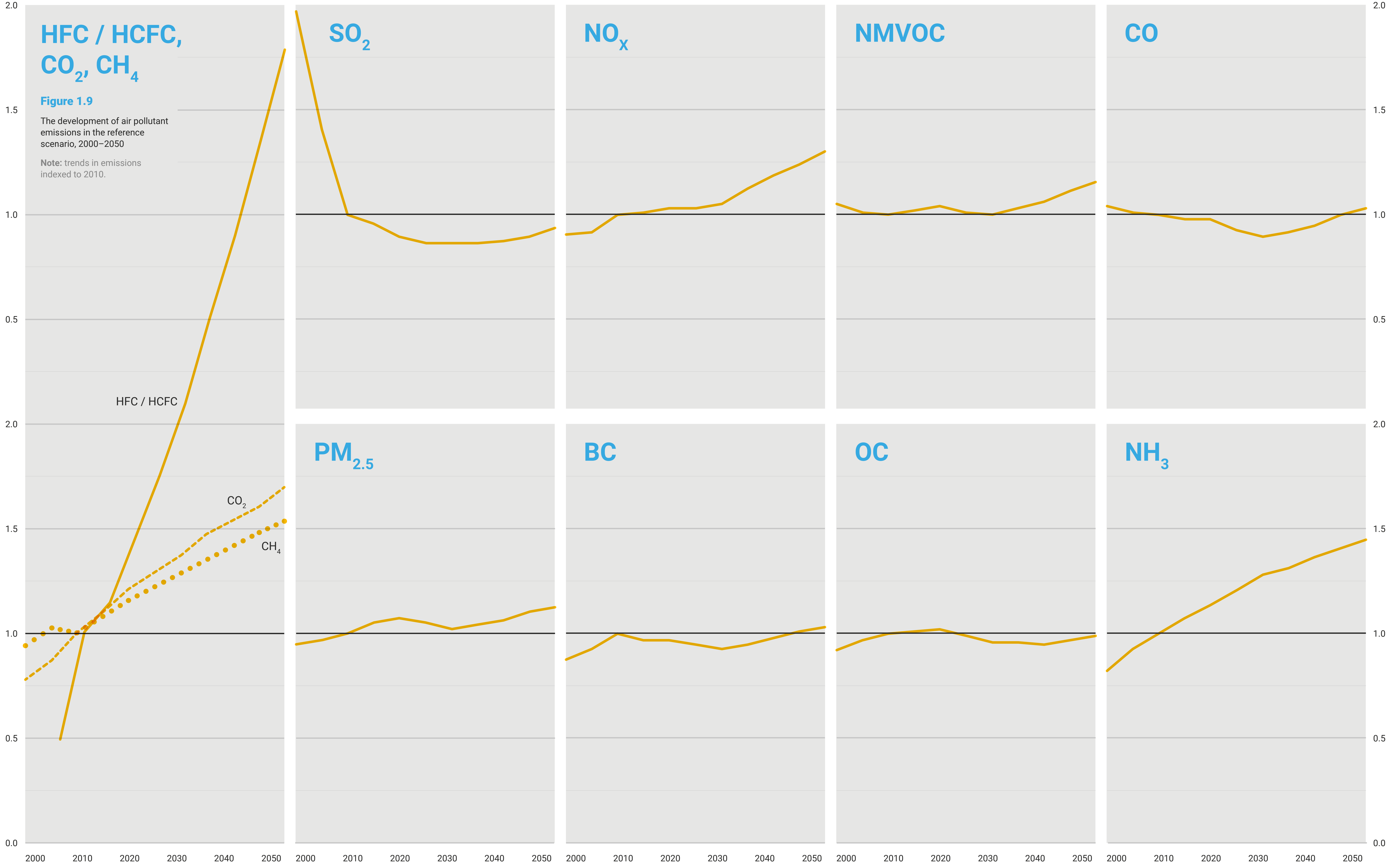


Figure 1.9

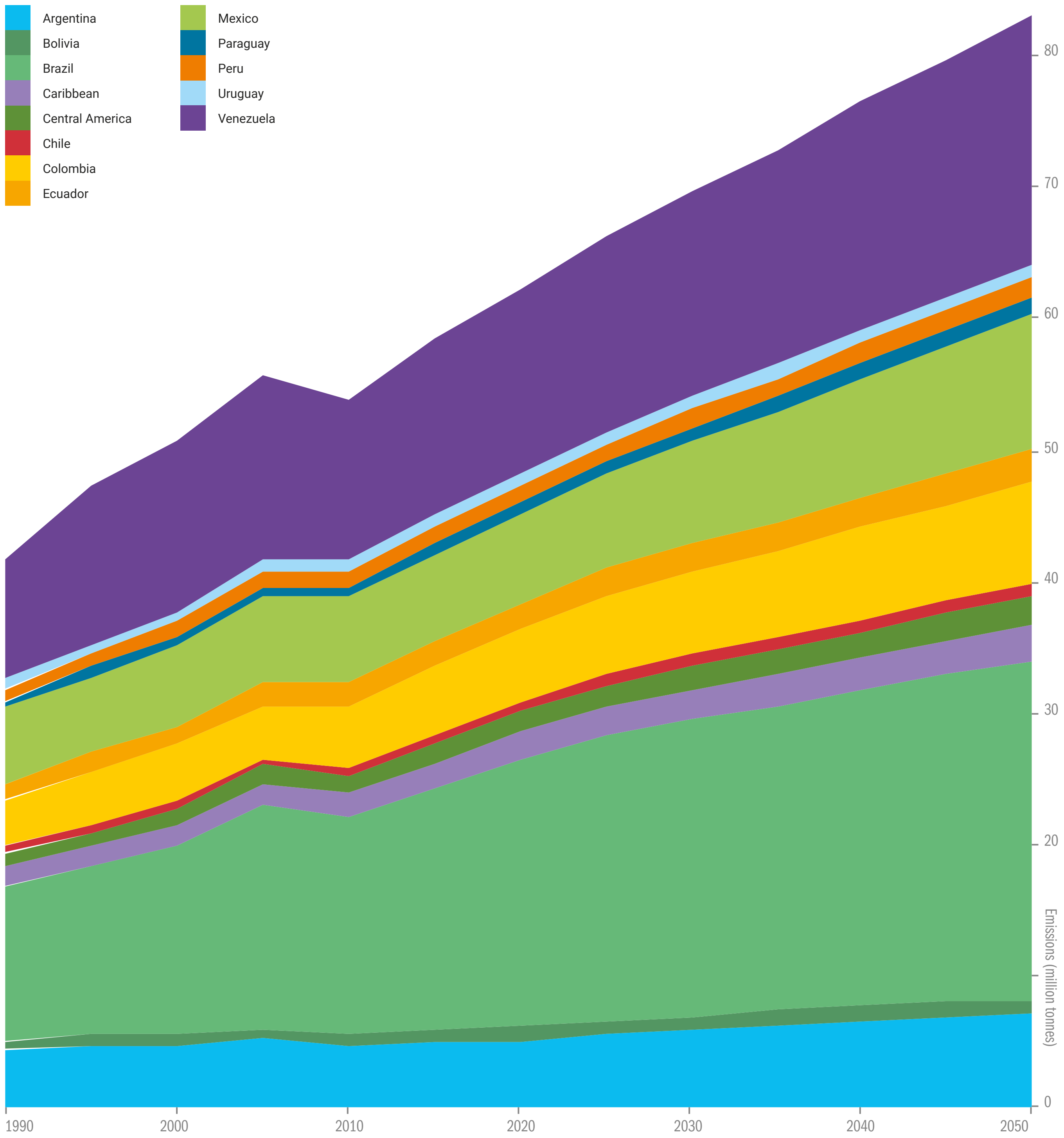
The development of air pollutant emissions in the reference scenario, 2000–2050

Note: trends in emissions indexed to 2010.

Methane

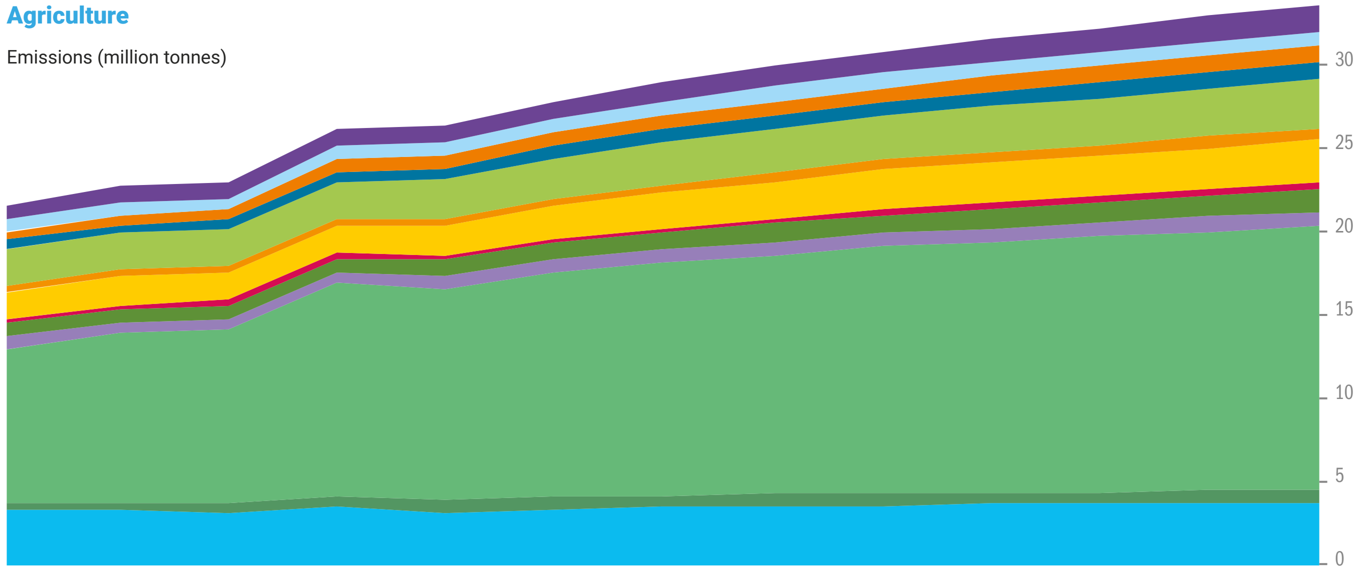
Figure 1.10

Reference scenario for methane emissions in Latin America and the Caribbean, by country/sub-region and for key sectors, 1990–2050



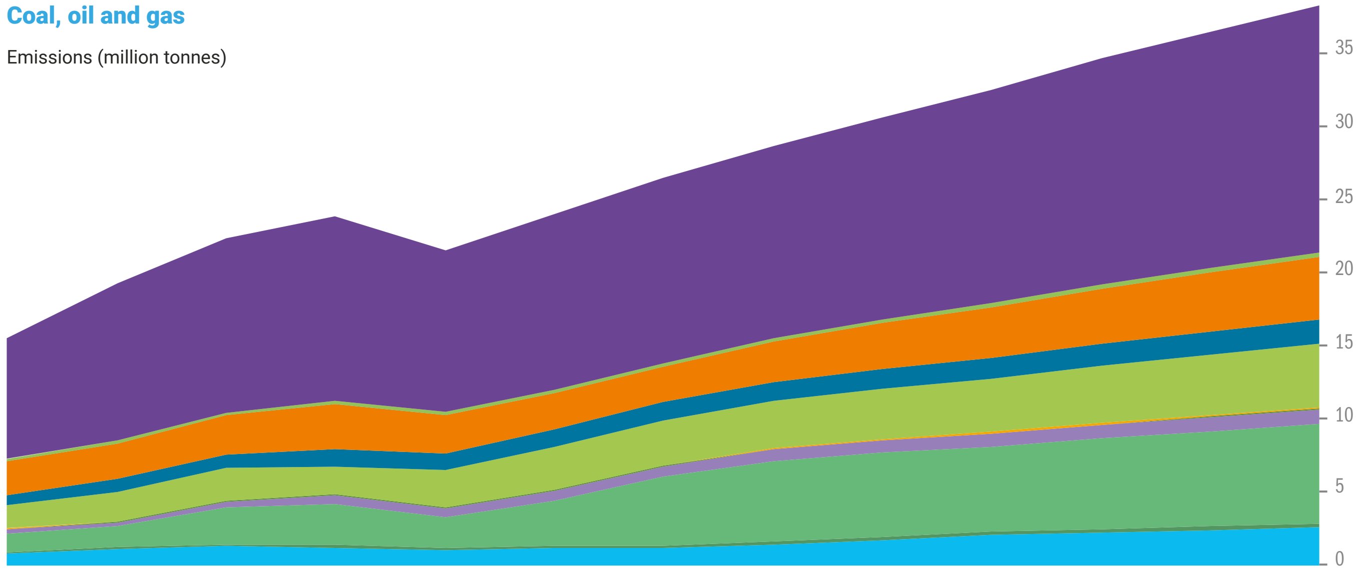
Agriculture

Emissions (million tonnes)



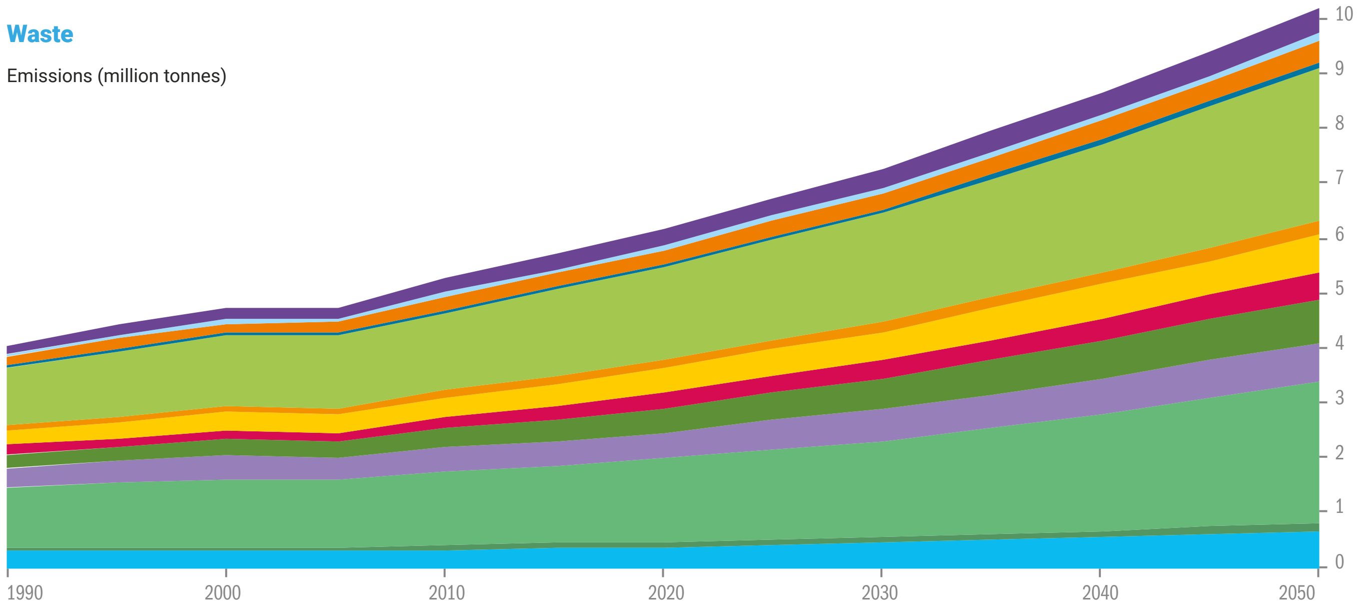
Coal, oil and gas

Emissions (million tonnes)



Waste

Emissions (million tonnes)

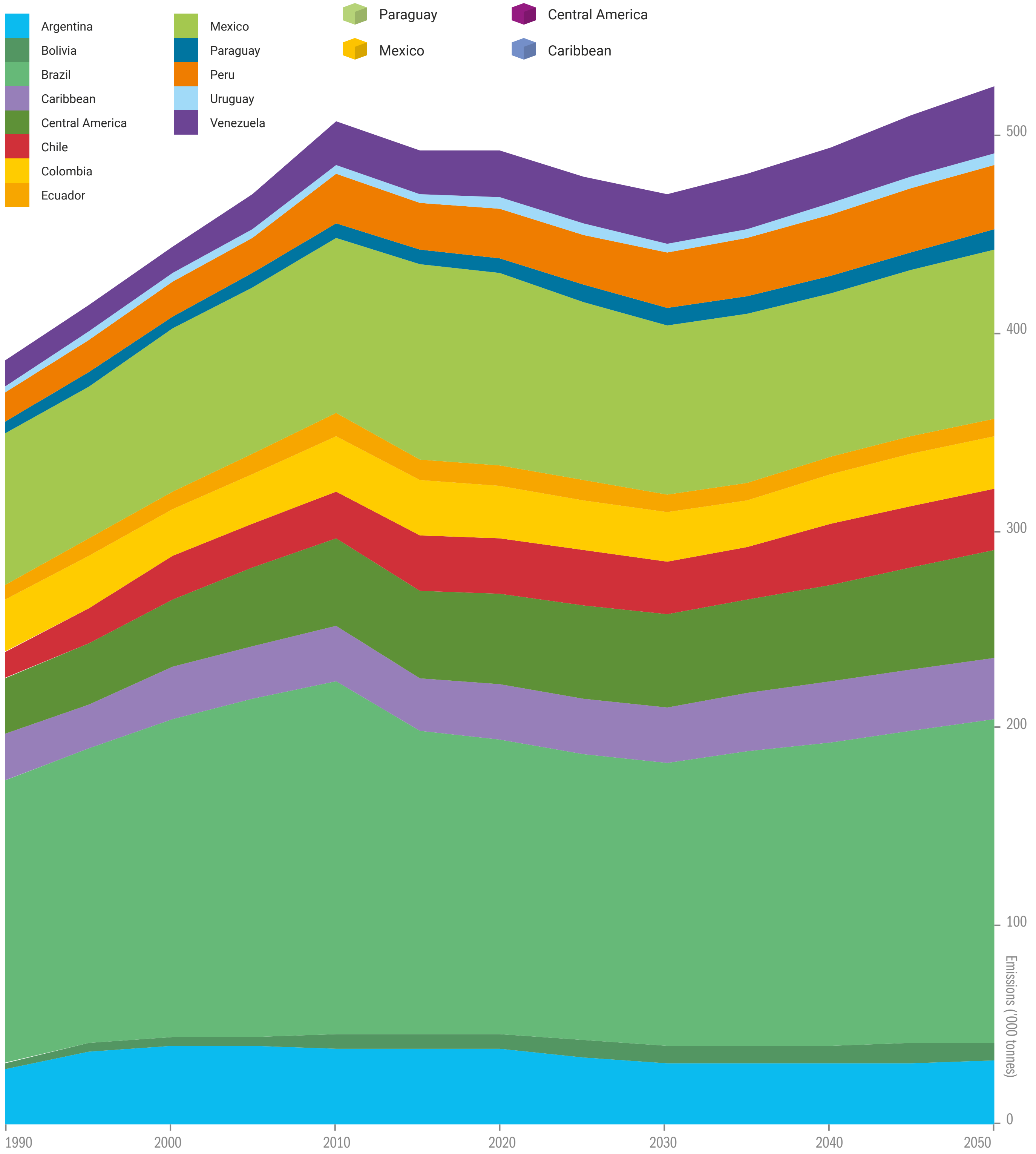


Black carbon

Figure 1.11

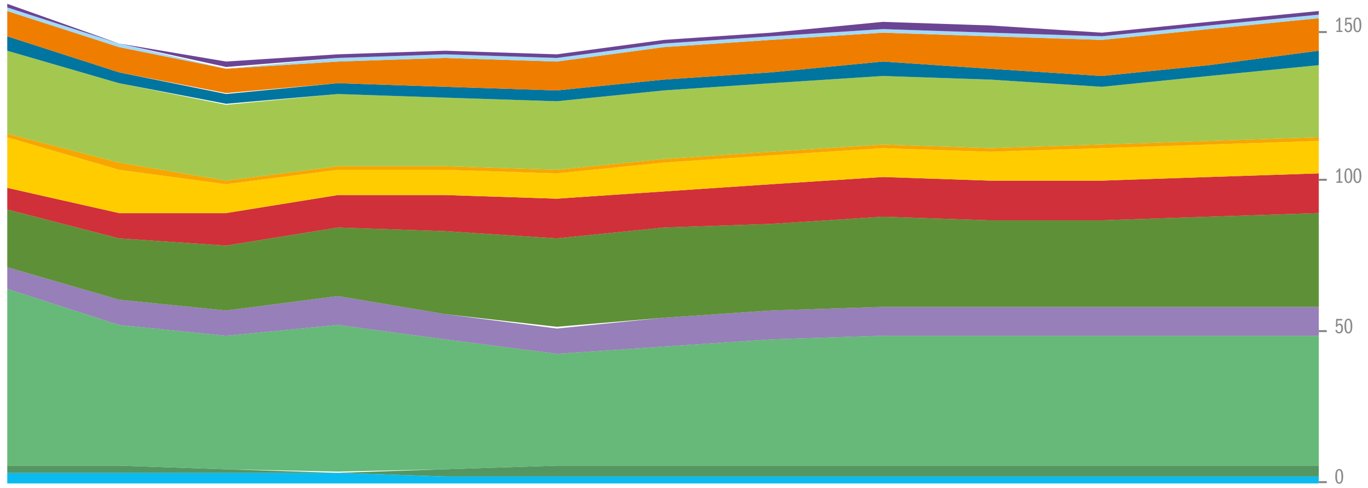
Reference scenario for black carbon emissions in Latin America and the Caribbean, by country/sub-region and for key sectors, 1990–2050

Venezuela
Uruguay
Peru
Paraguay
Mexico
Ecuador
Colombia
Chile
Central America
Caribbean
Brazil
Bolivia
Argentina



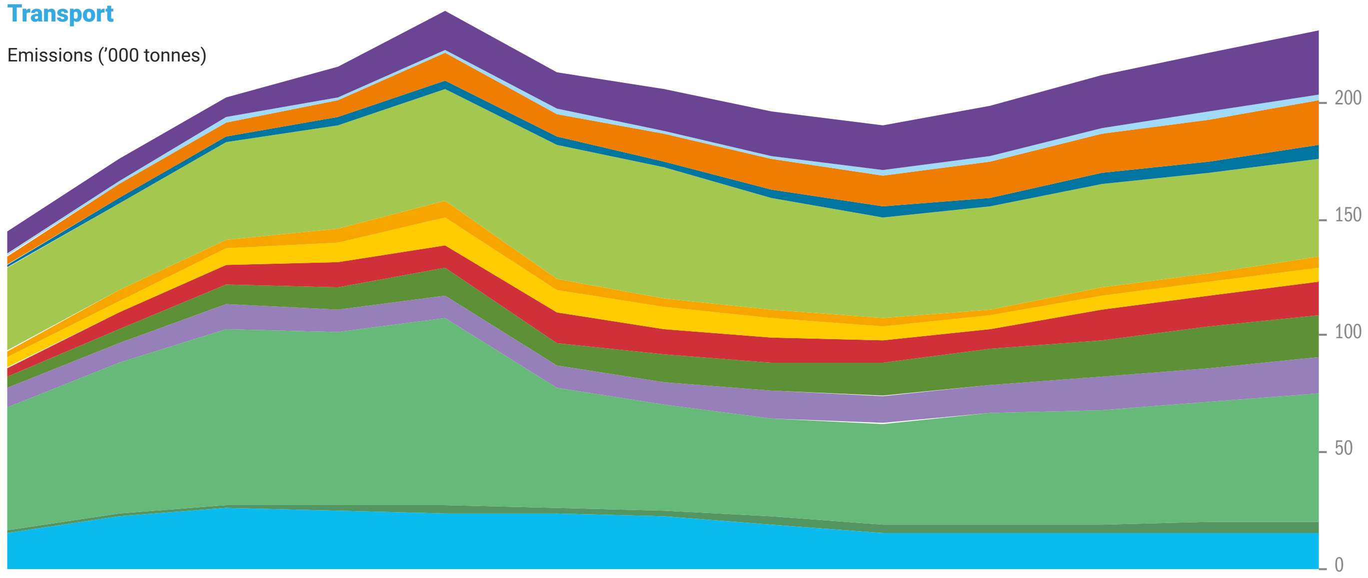
Residential combustion

Emissions ('000 tonnes)



Transport

Emissions ('000 tonnes)



Agriculture

Emissions ('000 tonnes)

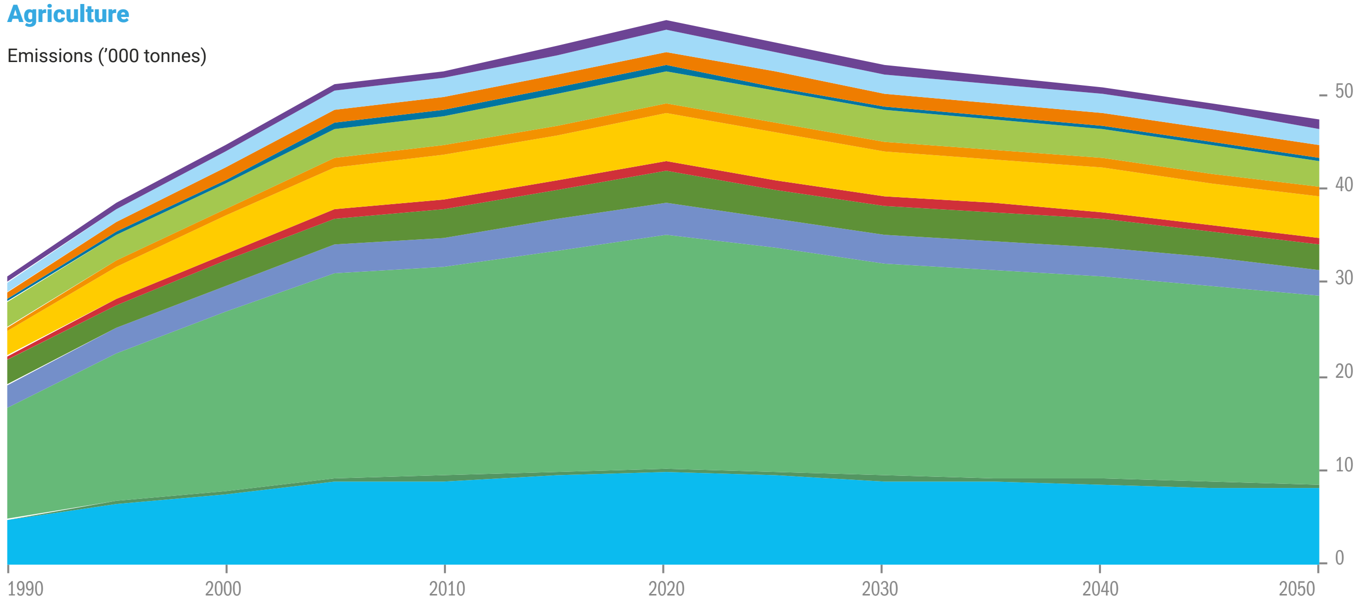
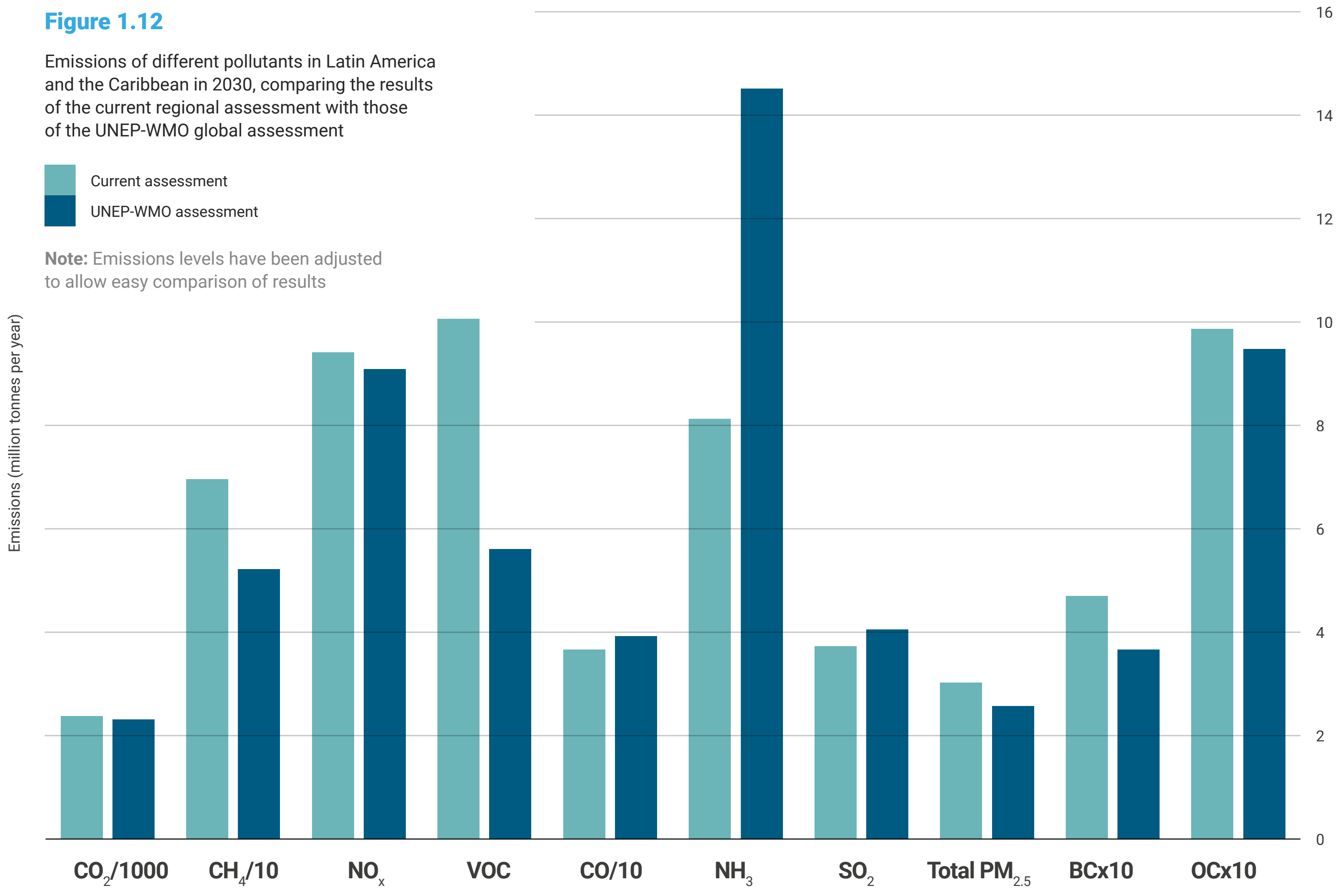


Figure 1.12

Emissions of different pollutants in Latin America and the Caribbean in 2030, comparing the results of the current regional assessment with those of the UNEP-WMO global assessment



Note: Emissions levels have been adjusted to allow easy comparison of results

The reference scenario assumes that current legislation (environmental laws as of 2014), documented in the international and national publications available from the literature or provided within the project activities, is timely and efficiently implemented.

An overview of reference scenario emissions in Latin America and the Caribbean is presented in Figure 1.9. Overall, a strong decoupling of CO_2 from SLCPs is expected, as the latter increase only slightly in the near term while CO_2 emissions continue to grow significantly. Since the transport sector is one of the dominant sources of air pollution in much of the region, the introduction of ever-more stringent legislation in several countries/sub-regions brings a decline or stabilization of NOx, NMVOCs, CO and PM species including BC. Rebound effects then begin to emerge, however, especially for NOx, CO and BC, which start to follow the CO_2 trend, indicating that current legislation is not sufficient to constrain growth in emissions over the long term.

Methane emissions grow similarly to CO_2 at the regional level, although a large part of that growth is due to increasing livestock production as shown in the trajectory for NH_3 emissions; more detailed discussion of the baseline scenario for CH_4 is provided further in the text. By far the strongest relative growth is estimated for HFC emissions.

More detailed analyses of CH_4 and BC reference scenario emissions by sector and country/sub-region are shown in Figures 1.10 and 1.11, respectively; in short, the projections show continued growth in CH_4, while BC is expected to stabilize at the current level. The strong growth in CH_4 emissions is primarily driven by a significant expected increase in the oil and gas sector as well as the waste sector. The latter is driven by population growth and economic development, though waste generation per person rises more slowly than per person GDP.

The reference scenario trajectories show that there is mitigation potential for CH_4 in the oil and gas production, waste and agriculture sectors, and for BC in the residential combustion and transport sectors. At the same time, however, mitigation opportunities vary between countries/sub-regions.

A comparison of the 2030 baseline developed in this study with that of the 2011 UNEP-WMO global assessment (Figure 1.12) reveals some important differences. Whereas the energy demand is nearly the same, as indicated by the CO_2 emissions, a number of species diverge considerably. For example, CH_4 emissions are larger in the current assessment, primarily due to a new evaluation of emissions from the oil and gas industry, including explicit consideration of shale gas resources, but also because the new model resolution allows for better representation of regional emissions and results in a different total. Emissions of NH_3 are significantly lower in the new estimates as a result of the introduction of country-specific characteristics; however, NH_3 does not play a role in the SLCP mitigation strategy. A re-estimation of NMVOCs results in significantly higher emissions in the new scenario, driven by improved assessment of solvents as well as revised transport legislation.

For PM, including BC and OC, the differences are not very large at the regional level but there is a change in the ratio of BC to OC, with new estimates showing a higher share of BC in PM emissions. Additionally, the new estimates reflect a more realistic distribution across countries/sub-regions and sectors, which is of high relevance for the assessment of mitigation opportunities.

Baseline scenario for emissions of hydrofluorocarbons and hydrochlorofluorocarbons

Ongoing emissions of HFCs – primarily as alternatives to ozone-depleting substances but also, in the case of HFC-23, as a by-product of hydrochlorofluorocarbon (HCFC) production – will have an immediate and significant effect on the Earth's climate system. Without further controls, it is predicted that this could partially negate the climate benefits achieved under the Montreal Protocol (US EPA, 2014). While the global assessment (UNEP-WMO, 2011) did not include dedicated HFC projections, this regional one includes explicit projections for HFC emissions in Latin America and the Caribbean; some details on the method are presented in this section.

The GAINS model estimates future emissions by varying activity levels along exogenous projections of anthropogenic driving forces and by adjusting the implementation rates of emission control measures (Höglund-Isaksson *et al.*, 2012). The key emission sources and activity drivers for emission projections are summarized in Appendix 1 (Table A1.14). Activity data for chlorodifluoromethane (HCFC-22) are based on production levels for previous years reported to the Ozone Secretariat (http://ozone.unep.org). Activity data for HFCs in the years 2005 and 2010 are derived from publicly available literature (UNEP, 2011a, 2011b, 2012; GIZ, 2014; UNDP, 2014a, 2014b) and Purohit and Höglund-Isaksson (2017). The reference scenario for future HFC emissions takes into account the future emission controls expected under national and international legislation adopted before May 2016. Hence, the reference scenario does not account for the effects of the amended Montreal Protocol agreed in Kigali, Rwanda, in October 2016 (UNEP, 2016a). More details about historical production and the refrigerant bank in Latin America and the Caribbean, and a comparison of estimates in this study with other sources for 2005, are presented in Appendix A.1.5.5.

Emissions from refrigeration and air conditioning are split between those that result from equipment leakage during use and those resulting from scrapping the equipment at end-of-life. In addition, for each emission source the fraction of HCFC to HFC in use is identified and modelled following the phase-out schedule for HCFCs in the 1999 revision of the Montreal Protocol (UNEP, 2007). The phase-out schedule for HCFCs in the 1999 revision of the Protocol (UNEP, 2007) is detailed in Appendix 1 (Table A1.15) for both Article 5 (developing) and non-Article 5 (developed) countries. In addition to the phase-out of the production and consumption of HCFCs, the Protocol also requires the production and sales of HCFCs for servicing to end completely by 2040.

The resulting baseline projections for total HCFC/HFC emissions in Latin America and the Caribbean are illustrated in Appendix 1 (Figures A1.6–A1.8), with the evolution of emissions for key sectors showing a strong increase from stationary and mobile air conditioning. By 2050, air conditioning will account for nearly 60 per cent of the total, followed by commercial, residential and industrial refrigeration at nearly 30 per cent.

In 2005, HFC emissions are attributed primarily to HCFC-22 production and the mobile air-conditioning sectors, with other sectors predominantly relying on HCFCs (GIZ, 2014; UNDP, 2014a, 2014b). The HCFC and HFC factors were estimated using the 2010 baseline for HCFC consumption in Latin American and Caribbean countries (UNEP, 2007) and reported consumption of HFCs in several sectors (UNEP, 2011a, 2011b, 2012; GIZ, 2014; UNDP 2014a, 2014b). In 2050, 78 per cent of HFC emissions are produced by Argentina, Brazil and Mexico.

In 2010, stationary and mobile air conditioning accounted for 45 per cent of HFC emissions, followed by commercial refrigeration. In 2050, HFC emissions from stationary air conditioning will account for 41 per cent, followed by mobile air conditioning at 19 per cent and commercial refrigeration at 18 per cent.

The results from the GAINS model suggest that in the reference scenario – with no further adoption of legislative or voluntary control – HFC emissions in the region will grow almost seven-fold between 2010 and 2050, from 39 million tonnes of CO_2 equivalent (Mt CO_2eq) in 2010 to 261 Mt CO_2eq in 2050. In particular, a sharp increase in emissions from air conditioning and refrigeration contributes to increased emissions.

Major uncertainties affecting the above results relate to emission factors and activity pathways, as well as the future penetration of mitigation technology such as low-GWP substances in mobile and stationary air conditioners and refrigerators. There is also a general lack of data on reported emissions to verify modelled estimates.

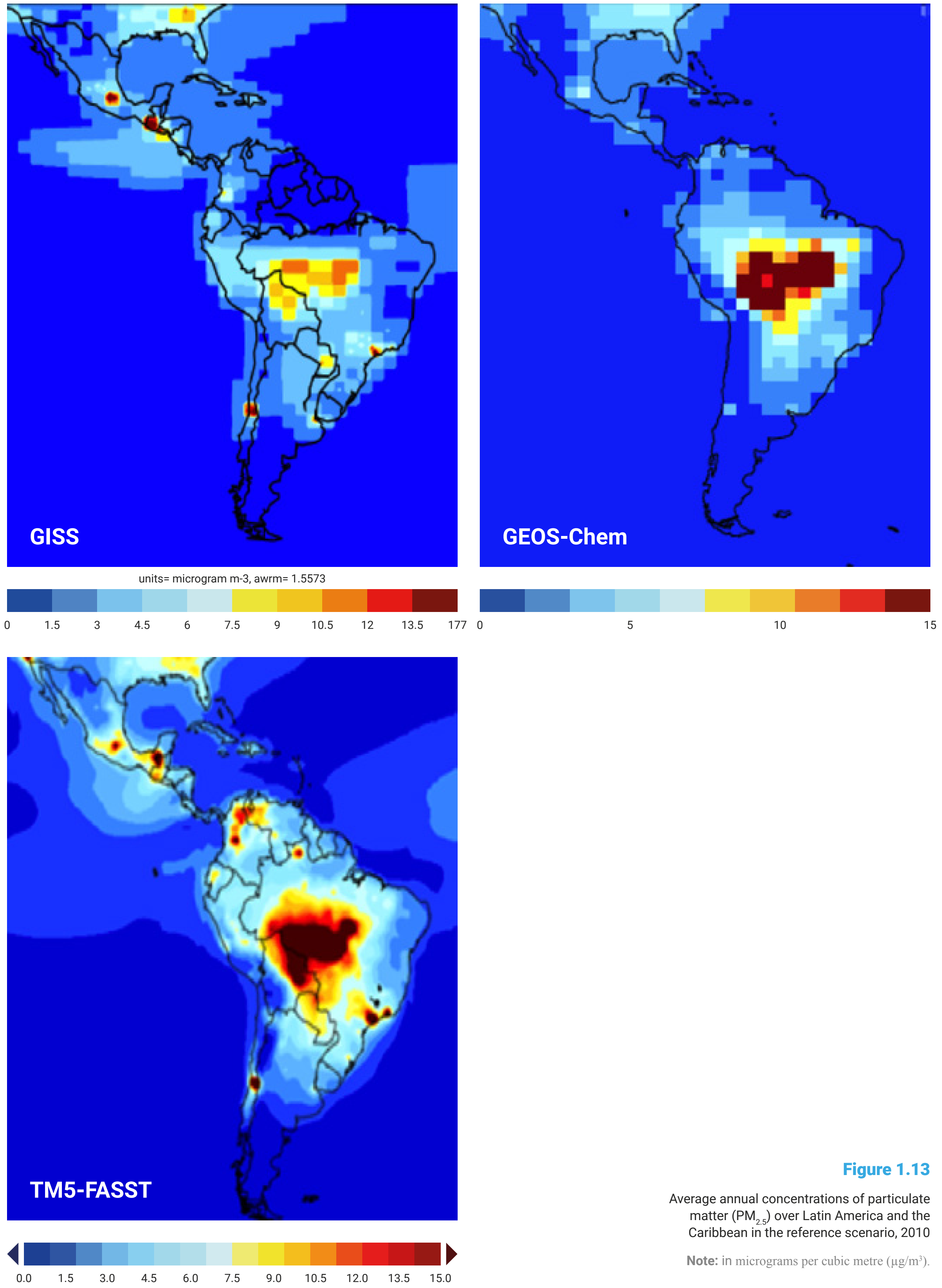


Figure 1.13

Average annual concentrations of particulate matter ($PM_{2.5}$) over Latin America and the Caribbean in the reference scenario, 2010

Note: in micrograms per cubic metre (µg/m³).

1.5.5

Modelling atmospheric concentrations

In order to link emissions with impacts, the baseline emissions and scenario from GAINS have been used as inputs for further modelling the concentrations of a range of different pollutants, including BC, tropospheric O_3 and $PM_{2.5}$. As chemical transport and transformations are complex, resulting in different atmospheric chemistry models providing different outcomes, three were used for this assessment: GISS, run by Drew Shindell at Duke University (Schmidt *et al.*, 2014); GEOS-Chem, run by Daven Henze at the University of Colorado (Henze *et al.*, 2007); and TM5-FASST, run by Rita Van Dingenen at the European Union Joint Research Centre (Leitao *et al.*, 2013). TM5-FASST uses coefficients from the TM5 atmospheric model (Krol *et al.* 2005). In addition, the GEOS-Chem Adjoint model has produced coefficients for Latin America and the Caribbean that have then been used to calculate impacts. The GISS model, as well as producing offline calculations of equilibrium temperature, has been run using a long equilibrium simulation to provide temperature and other climate variables.

These are all global-scale atmospheric models that calculate concentrations and deposition in grids varying from 1ºx1º (TM5-FASST) to 2ºx2.5º (GISS and GEOS-Chem). Some pollutants are fairly homogeneous over large distances – such as O_3 and secondary PM – so the large grids are more appropriate to the scale of the pollution; the coarse resolution is less likely to capture differences in directly emitted particles that vary over smaller distances. However, the GISS and GEOS-Chem Adjoint results also include satellite down-scaling, whereby the $PM_{2.5}$ concentrations for the grid are redistributed according to estimated $PM_{2.5}$ concentrations using satellites down to a 10x10 km resolution. These are then used to improve the population-weighted concentration estimates by correlating these concentrations with 10x10 km population data. The details of these atmospheric models are described in Appendix 1 (A1.9).

The estimates of pollutant concentrations produced by the models are used to calculate the impacts of all relevant species on climate, health and crop yields (Chapter 2). An analysis of the $PM_{2.5}$ and O_3 concentrations calculated by the different models illustrates how the models perform. The results can be compared with measured data from the same altitudes, as well as at ground level (section 1.5.7).

Figure 1.13 shows the average annual gridded $PM_{2.5}$ concentrations calculated by the GISS, GEOS-Chem and TM5-FASST models for 2010. Absolute levels of $PM_{2.5}$ are generally quite low in comparison to other regions such as Asia, except in urban areas and across the Amazon where there is burning of biomass and concentrations of $PM_{2.5}$ exceed 10 micrograms per cubic metre (µg/m³). In most areas (in blue), concentrations average less than 7.5 µg m³ across the grids. The three models show similar patterns, though they differ in some urban zones, where TM5-FASST shows the highest concentrations and GEOS-Chem the lowest.

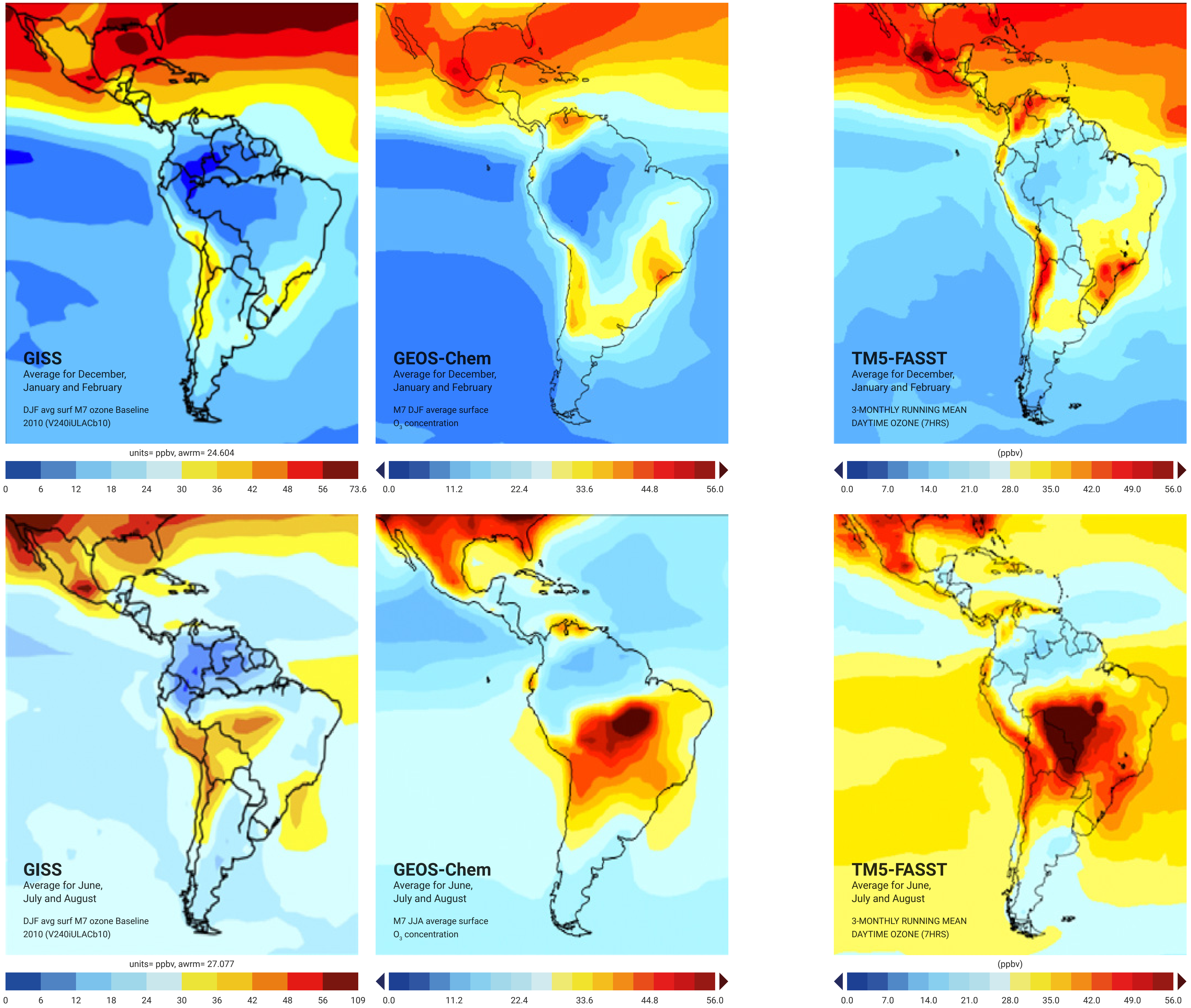


Figure 1.14

Average daily ozone concentrations over Latin America and the Caribbean in the reference scenario, 2010

Note: in parts per billion by volume (ppbv) over seven daylight hours between 9.00am and 4.00pm (M7).

Figure 1.14 shows O_3 concentrations calculated by the three models, represented as the average daily O_3 concentration for two three-month periods: December, January and February, and June, July and August. Estimates for O_3 pollution show great similarity between the three models. Comparisons between the average concentrations from December to February show that the highest O_3 concentrations occur close to cities and areas of greatest economic activity.

Patterns of O_3 formation across the region are similar for the three models although there are differences in absolute concentrations, with TM5-FASST estimates rather higher. Results for the months of June, July and August show higher concentrations over South America, as expected, with peak concentrations over the Amazon. Again, the three models show similar patterns of O_3 exposure, with the concentration estimates highest for TM5-FASST and lowest for GISS.

The emission projections from GAINS in the reference scenario show increases in CH_4, NO_x and NMVOCs, all precursors of O_3 formation. It is therefore no surprise that O_3 concentrations are projected to increase in all three models as shown by comparing the concentrations in 2050 (Figure 1.15) with the 2010 values (Figure 1.14).

Caribbean in the reference scenario, 2050

ts per billion by volume (ppbv) over seven hours between 9.00am and 4.00pm (M7).

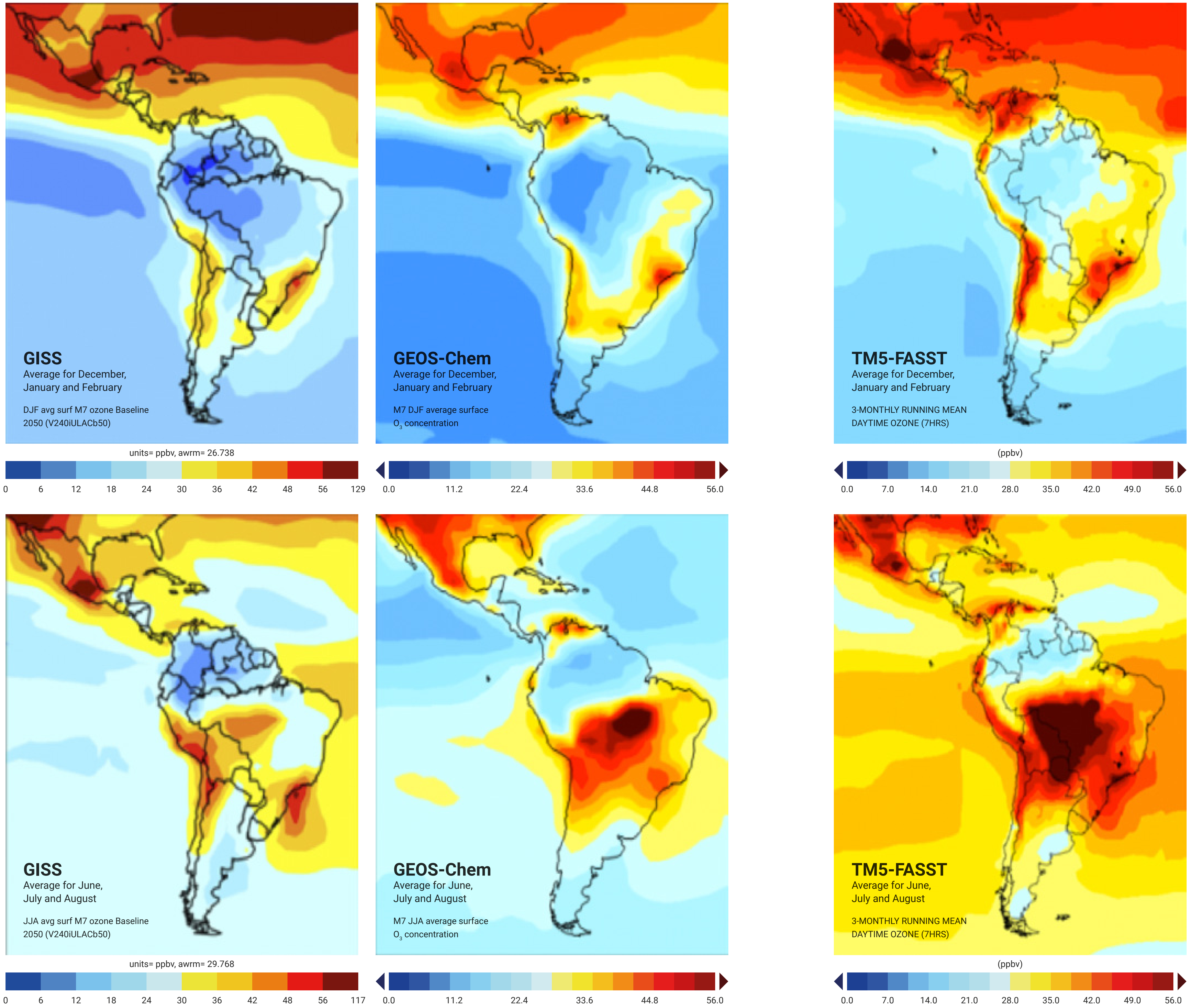


Figure 1.15

Average daily ozone concentrations over Latin America and the Caribbean in the reference scenario, 2050

Note: in parts per billion by volume (ppbv) over seven daylight hours between 9.00am and 4.00pm (M7).

1.5.6

Comparison of modelled and measured concentrations

Using models to estimate atmospheric concentrations is complex, including movement vertically and horizontally and with substances undergoing chemical transformation. It is therefore inevitable that models differ, but also reassuring that they show similar concentration patterns. One important way to test how well the models are performing is to compare their results with observations. The GISS model, for example, has been found to perform well in identifying $PM_{2.5}$ concentrations in some grids while underestimating in others, so it can be concluded that real values are likely to be higher. This is an important consideration when assessing the magnitude of the health impacts caused by $PM_{2.5}$.

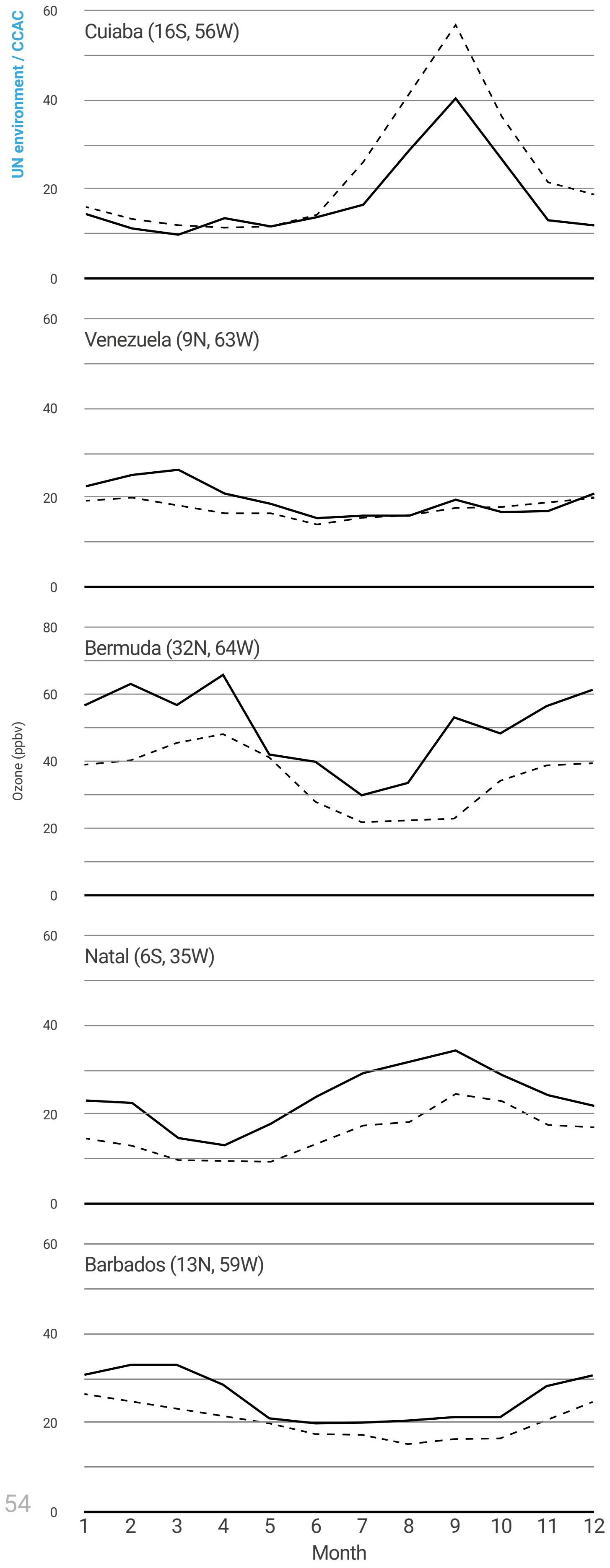


Figure 1.16

Comparison of GISS model monthly mean surface ozone values (solid line) with observations at selected stations in Latin America and the Caribbean

Source: Logan, 1999; Thompson *et al.*, 2007.

With O_3, a comparison of the GISS estimates with monitoring reveals similar patterns of O_3 concentrations over the year (Figure 1.16), though at particular stations the model estimates may be higher or lower than the monitored values.

1.6

Identified gaps in knowledge and priorities for further work

- National inventories in Latin America and the Caribbean are often incomplete, especially for PM.
- Efforts must be made to harmonize national inventories across the region, requiring exchange of information on key emission sources, available measurements and air quality networks.
- The models lack sufficient validation with observational data. This needs to be a priority before model results are cast in stone.

1.7

Summary

The current state of knowledge of emissions of SLCPs and associated precursor gases has been discussed in the context of information made available by governmental and regional agencies in individual Latin American and Caribbean countries. In addition, emission estimates from the GAINS model have been discussed, including several scenarios. Complementing the discussion of emissions is an overview and summary of the observational data available from long-term air quality monitoring stations and from short-term targeted field programmes, including ozonesonde launches.

Although 13 of the 15 countries included in the inventory provided partial or complete reports on emissions of greenhouse gases, SLCPs and several other air pollutants, data on PM emissions were noticeably lacking. Only four countries provided reports on emissions of $PM_{2.5}$, two provided reports on BC and only one provided a (partial) inventory for OC. Given that BC is a significant SLCP and that $PM_{2.5}$ concentrations are directly linked to health impacts, greater efforts should be made to encourage countries to expand their inventories to include these species.

Although greenhouse gas emissions were more widely covered in most of the inventories, there is inhomogeneity with respect to the completeness of the information. Optimum inventories provide emissions by sector (industrial, transport, agriculture, etc.), but very few countries reported at that level, and the lack of such stratification is a crucial obstacle when planning and recommending mitigation strategies. Although emission models can partially compensate for these types of information gaps, actual observations lend greater credence to results from simulations.

A preliminary evaluation of the GAINS model emissions, and their use with three atmospheric models to simulate O_3 and $PM_{2.5}$, was conducted by comparing climatologies of surface O_3 at six locations with simulated values. A comparison of the atmospheric model outputs with measured $PM_{2.5}$ suggests that the model underestimates concentrations in some regions. The results, while encouraging, underscore the need for much further validation, not only for O_3 but also for other SLCPs, at many more locations and in different seasons.

On the basis of the results obtained with the GAINS model, larger countries such as Brazil and Mexico appear to dominate the emissions of most species; in the case of CH_4, Venezuela contributes a significant share.

With respect to how emissions are stratified by sector, the transport sector accounts for large proportions of BC and NO_X. In several countries/sub-regions, the residential sector is typically responsible for a larger proportion of BC emissions, whereas the power and industry sectors are responsible for the largest proportions of NO_X. For HFCs, Argentina, Brazil and Mexico account for nearly 80 per cent of the total emissions in Latin America and the Caribbean, with major contributions from residential applications (approximately 60 per cent) followed by transport (25 per cent) and specific industrial uses.

The region's emissions of CH_4 are estimated to account for approximately 15 per cent of the global total, with more than half of the emissions coming from Brazil and Venezuela. Virtually all CH_4 emissions come from three sectors: agriculture (nearly 50 per cent); coal, oil and gas production/distribution (nearly 40 per cent); and waste (about 10 per cent). In most countries, the agricultural sector plays a major role, its contribution ranging from approximately 30 per cent in Ecuador to approximately 90 per cent in Paraguay. The exception is Venezuela, where the oil and gas industry dominates emissions, accounting for nearly 90 per cent. The oil and gas industry is also important in Mexico and Ecuador, where its contribution is 40–60 per cent, whereas coal mining plays a truly significant role in Colombia.

Finally, the region's BC emissions, 60 per cent of which originate from Brazil and Mexico, account for less than 10 per cent of the global total. Transport and the combustion of solid fuels in the residential-commercial sector are responsible for approximately three-quarters of total emissions, the transport sector being the most important in nearly all countries of the region.

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CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Integrated Assessment
of Short-lived Climate Pollutants
in Latin America and the Caribbean

2

Impacts of short-lived climate pollutants

on climate, water and food security, human health, biodiversity and ecosystem services

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Image: Top view of the most famous bridge in the city of Sao Paulo, Brazil. Filipe Frazao, Shutterstock.

Contents

2.1

Introduction

The objective of this chapter is to evaluate the near-term impacts on climate, health and ecosystems in Latin America and the Caribbean of changes attributable to changes in emissions of short-lived climate pollutants (SLCPs) from anthropogenic sources. A secondary objective is to identify gaps in knowledge and suggest ways of filling them. The chapter highlights known issues that are of importance today and explores others that may become increasingly important in the future. The impacts of SLCPs and their co-emitted substances have so far mostly been studied with regard to atmospheric physical-chemical properties, with implications for climate and human health, and the impact of ozone (O_3) on crop yields. As the chapter shows, the wider impacts of SLCPs and co-emitted substances on ecosystems, water and food security have not been addressed explicitly, as such impacts are largely mediated by the climate. An emerging area relates to the direct impact of black carbon (BC) and other co-emitted particulate matter (PM) on the cryosphere (glaciers and snow) which changes the albedo and melt rates of ice and snow when BC and other particles are deposited on them. The health effects of BC and other fine particulate matter ($PM_{2.5}$), and O_3, which are of major relevance in Latin America and the Caribbean, are discussed in detail.

The focal impacts of SLCPs on atmospheric physical chemistry include climate warming and projected changes in tropospheric O_3 and $PM_{2.5}$ concentrations in the absence of mitigation measures (see the reference scenario, Chapter 1). The modelled impacts, in turn, are interpreted in relation to human health (exposure to $PM_{2.5}$ and O_3) and agricultural crop yields (O_3). Further considerations concern indirect impacts on water and food security, biodiversity and ecosystem services, especially related to regional changes in temperature and precipitation that could occur under different emission scenarios. The impacts on water yield and availability, their implications for users (e.g. agriculture, mining, industry and domestic supply) and ecosystem productivity are discussed.

Impacts on the cryosphere, and, in turn, on sustained water yield, and the implications for users and crop productivity are highlighted in the context of the Andes-Pacific coastal desert where vegetation, agriculture, and urban domestic and industrial water supply are almost entirely dependent on water that originates in the Andes. The Andes-Amazon connection is also explored. There is a special focus on food security across the entire Latin American and Caribbean region, where, along with the modelled impacts of tropospheric O_3, climate change impacts are examined. All these impacts and those on biodiversity are considered in an integrated evaluation of how ecosystem services are affected by changes in emissions of SLCPs and their co-emitted pollutants.

2.2

Current and projected impacts of emissions on climate, crop yields and human health, according to different models

In Chapter 1, the GAINS model (section 1.5.1), updated with data for Latin America and the Caribbean, provides emission estimates for all the gases and particles under consideration: all substances that affect radiative forcing, temperature and rainfall patterns, and contribute to climate change; ground-level O_3 that induces changes in crop yields; and $PM_{2.5}$ and ground-level O_3 concentrations that affect human health.

In addition, the GAINS model was used to develop a reference scenario for the region, projecting the likely particle and trace gas emissions that are expected to result from current trends and the implementation of existing legislation (Chapter 1). Changes in the climate, agricultural yields and health that might result from current emissions or future emission variations according to the reference scenario are estimated in this chapter, using a number of different models. There are several steps in this analysis:

1. reference emission projections were developed using GAINS (section 1.5.4) for all climate forcing agents or their precursors; O_3 precursor emissions and directly emitted $PM_{2.5}$ and precursors of secondary $PM_{2.5}$;
2. global atmospheric models, incorporating the above projected emissions, were used to calculate the resulting concentrations of all relevant substances in the atmosphere, as well as surface concentrations of O_3 and $PM_{2.5}$ (section 1.5.5), and these models also calculated climate forcing and temperature change;
3. impact analyses for climate and air quality changes that affect crop yields and human health (sections 2.2.2, 2.5.1 and 2.6.3).

Projected climatic changes are first explored with reference to the climate and impacts modelling that was undertaken for the Intergovernmental Panel on Climate Change's *Fifth Assessment Report* (IPCC AR5) (IPCC, 2013); and subsequently with reference to the specific modelling carried out for this assessment, using three different global climate composition models and the emissions according to the reference scenario.

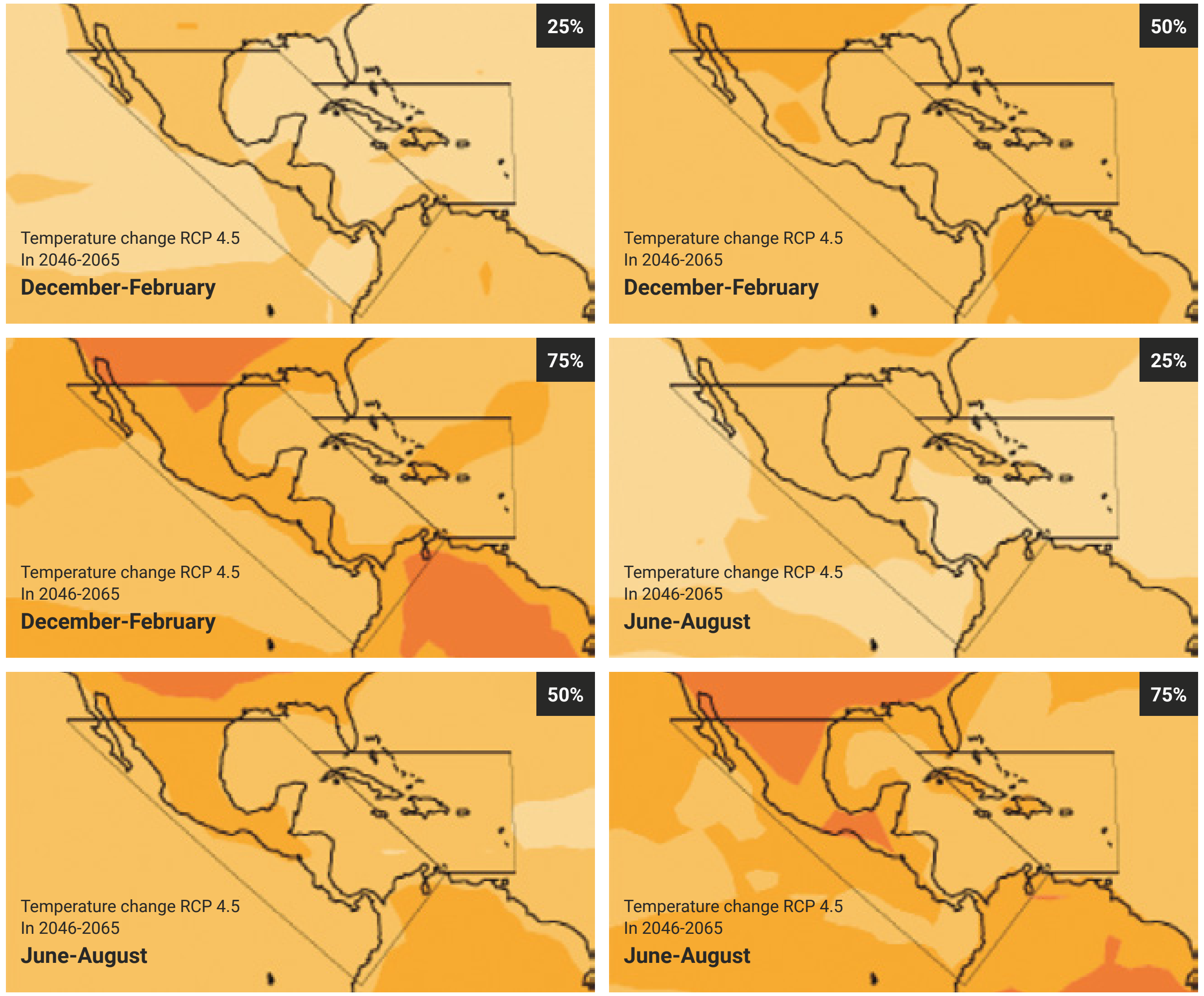


Figure 2.1

Temperature

Projected changes in seasonal temperature and precipitation under IPCC AR5 climate model simulations for 2046–2055

Note: results show the median response (centre column) and 25th (left) and 75th (right) percentiles across the suite of model outputs for change relative to the 1986–2005 period. **Source:** IPCC, 2013: Annex I.

2.2.1

Findings of the IPCC AR5 modelling for the progression of climate change in Latin America and the Caribbean

The IPCC AR5 (IPCC, 2013) included analyses of projected climate change under multiple scenarios for the 21st century. These results were generated from 45 models, some of which were variants of one model, allowing an assessment of both the median and range of model outputs.

Results for surface temperature tended to be consistent in both sign and spatial pattern, although there were variations in overall magnitude across the models for a given scenario. The magnitude of the response was also proportional to the forcing applied in the various scenarios. Temperature changes projected for the mid-21st century in Central America and northern South America, for example, were fairly consistent (Figure 2.1). The median temperature change projection in accordance with the IPCC's representative concentration pathway (RCP) 4.5 scenario was 1.5–2ºC (the 25th percentile was 1–1.5ºC; the 75th percentile was 2–3ºC for large parts of Latin America and the Caribbean). Land areas warm faster than the ocean, giving a distinctive spatial pattern

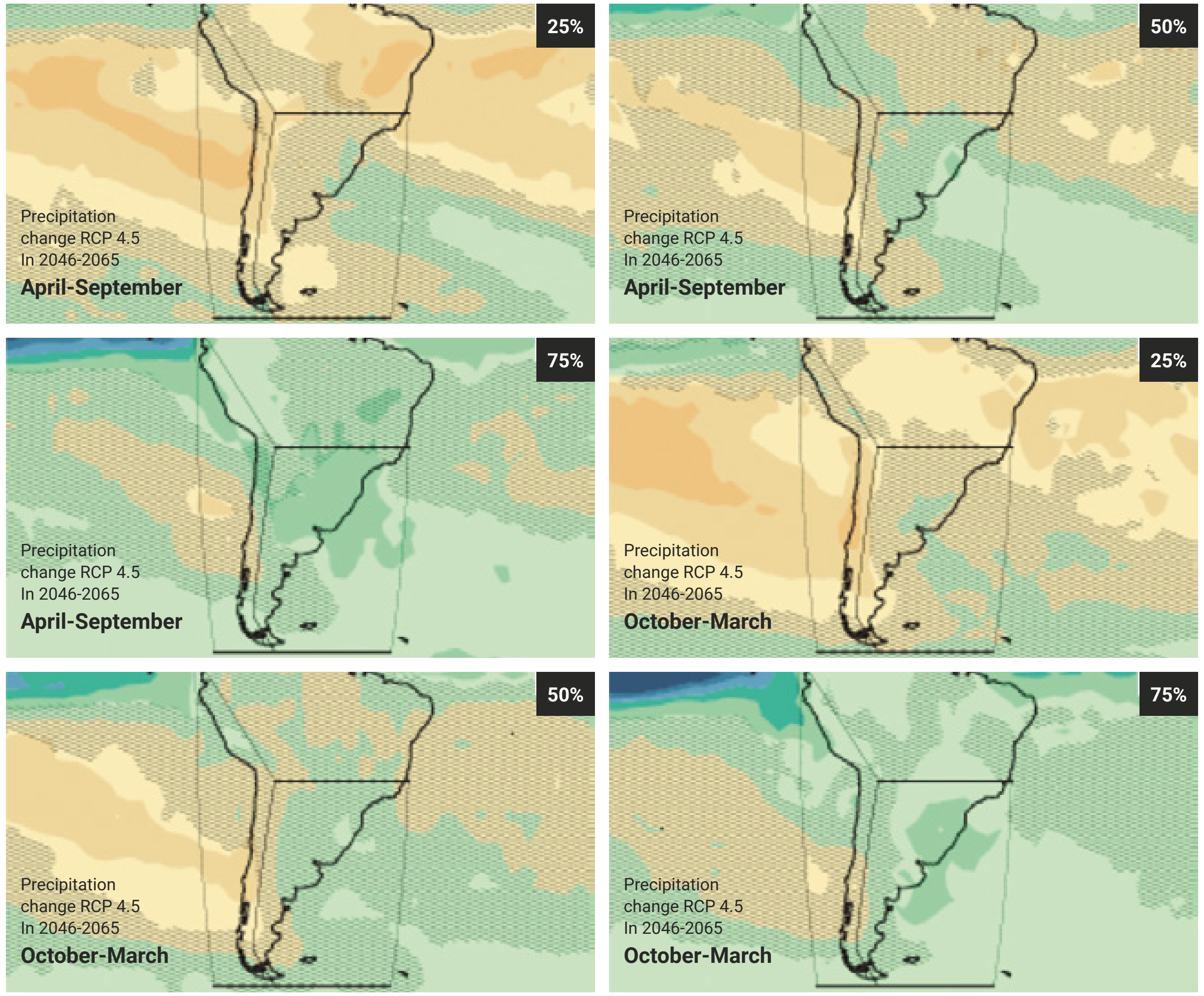


Figure 2.1

Precipitation

Projected changes in seasonal temperature and precipitation under IPCC AR5 climate model simulations for 2046–2055

-50 -40 -30 -20 -10 0 10 20 30 40 50 [%]

Note: results show the median response (centre column) and 25th (left) and 75th (right) percentiles across the suite of model outputs for change relative to the 1986–2005 period. **Source:** IPCC, 2013: Annex I.

to warming. The magnitude of warming largely follows the overall climate sensitivity in a particular model, and the uncertainty in climate sensitivity is roughly a factor of two, suggesting a comparable uncertainty for the magnitude of the warming change associated with this distinctive pattern. These general features are similar for other scenarios and other regions (IPCC, 2013: Annex I).

The projected response to forcing of precipitation, in contrast, is far less reliable (IPCC, 2013). Hence, different model projections often do not agree even on the sign of projected changes, let alone the magnitude or spatial pattern (Figure 2.1), with the exception of a few areas.

2.2.2

Trends in climate response to changes in emissions over the next few decades, according to the reference scenario

Expected climatic changes in Latin America and the Caribbean include those in regional temperatures and rainfall patterns. The response of the climate will be related to the global impact caused by the well-mixed gases such as CO_2 and methane (CH_4), which have long lifetimes; regional climatic changes will also occur owing to changes in aerosol, BC and O_3 concentrations close to the sources of emission, as these have short lifetimes and so their effect is regional or local. These include temperature changes and local or regional adjustments in the distribution and amount of rainfall. Such regional shifts in rainfall are related to the horizontal and vertical changes in heating within a region, with consequences for the transport of water vapour.

The modelled changes in the emissions and concentrations of different pollutants, using the reference scenario, were used to calculate the likely changes in climate in two ways: by using the GISS and GEOS-Chem Adjoint global climate models, and by using TM5-FASST to estimate changes in radiative forcing. From this, temperature change was calculated offline, as was done in the UNEP-WMO global assessment using the GISS and ECHAM models (UNEP-WMO, 2011). In addition, the GISS model was fully run to calculate climatic changes (as was also done in Shindell *et al.*, 2012), including changes to temperature and rainfall distribution and intensity.

Global temperature response due to emission changes under the reference scenario, according to offline calculations

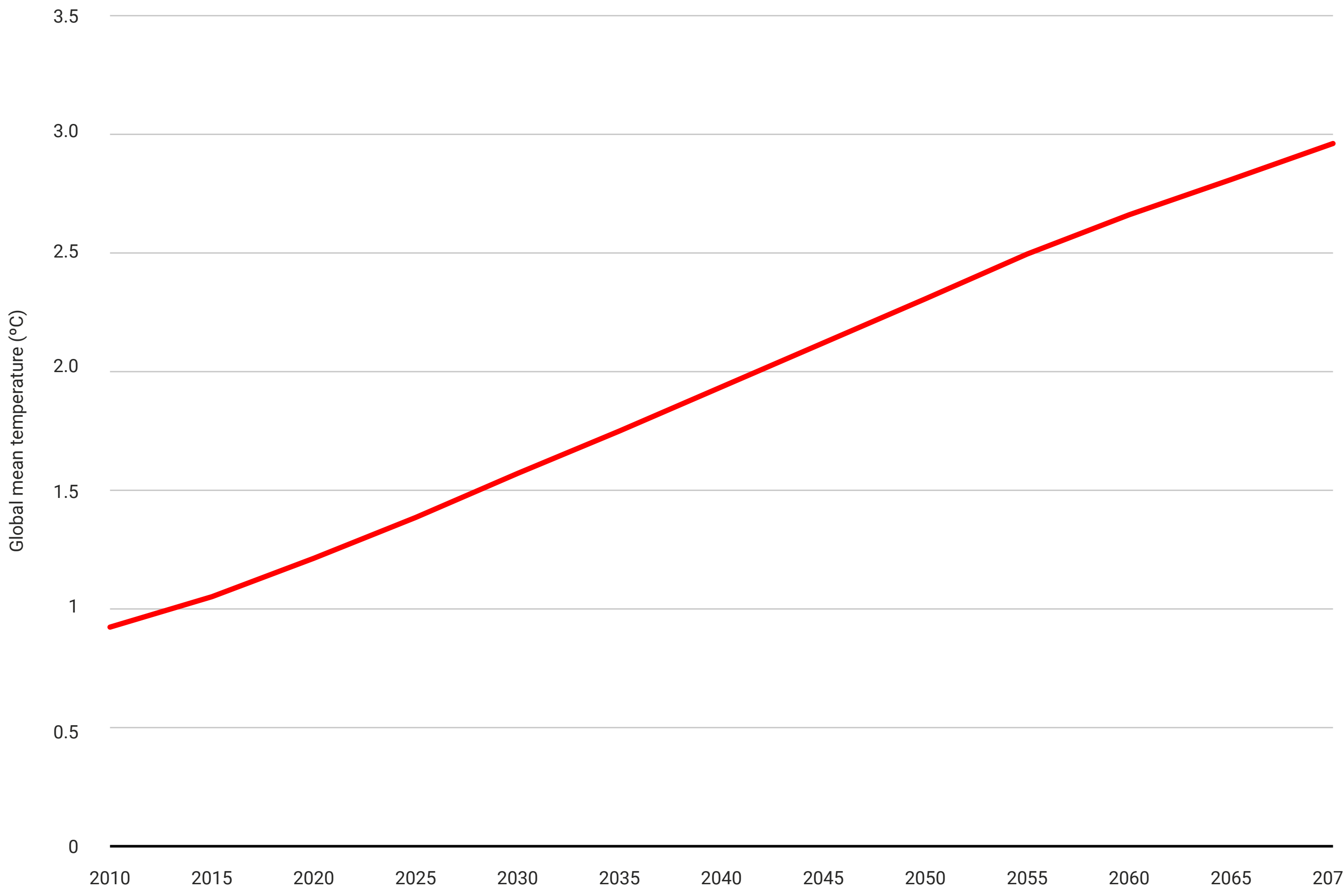
The concentrations of BC, O_3, CH_4 and other substances that affect radiative forcing have various impacts on the climate system. Impacts include changes in global and regional temperatures, storminess, frequency and intensity of heatwaves and other extreme events. In addition, BC and aerosols have an impact on the formation and development of clouds that drive rainfall patterns. Aerosols also cause surface dimming, reducing the radiation fluxes at the surface, affecting evapotranspiration and photosynthetic rates, among other effects.

Annual average global mean temperature is often used in the development of policy goals and can fairly readily be estimated from the degree of forcing and knowledge of climate sensitivity to that forcing. Climate sensitivity is a measure of how much temperature changes per unit of radiative forcing, given the time required for the climate to fully adjust. The climate impact of forcing due to BC has been shown to vary substantially, depending on the altitude at which the BC is located in the atmosphere. As substances such as BC, organic carbon (OC) and O_3 are

Figure 2.2.

Global mean temperature progression under the GAINS reference scenario, 2010–2070

Note: offline response calculations are based on the forcing calculated in the GISS model relative to the observed 1890–1910 temperature.



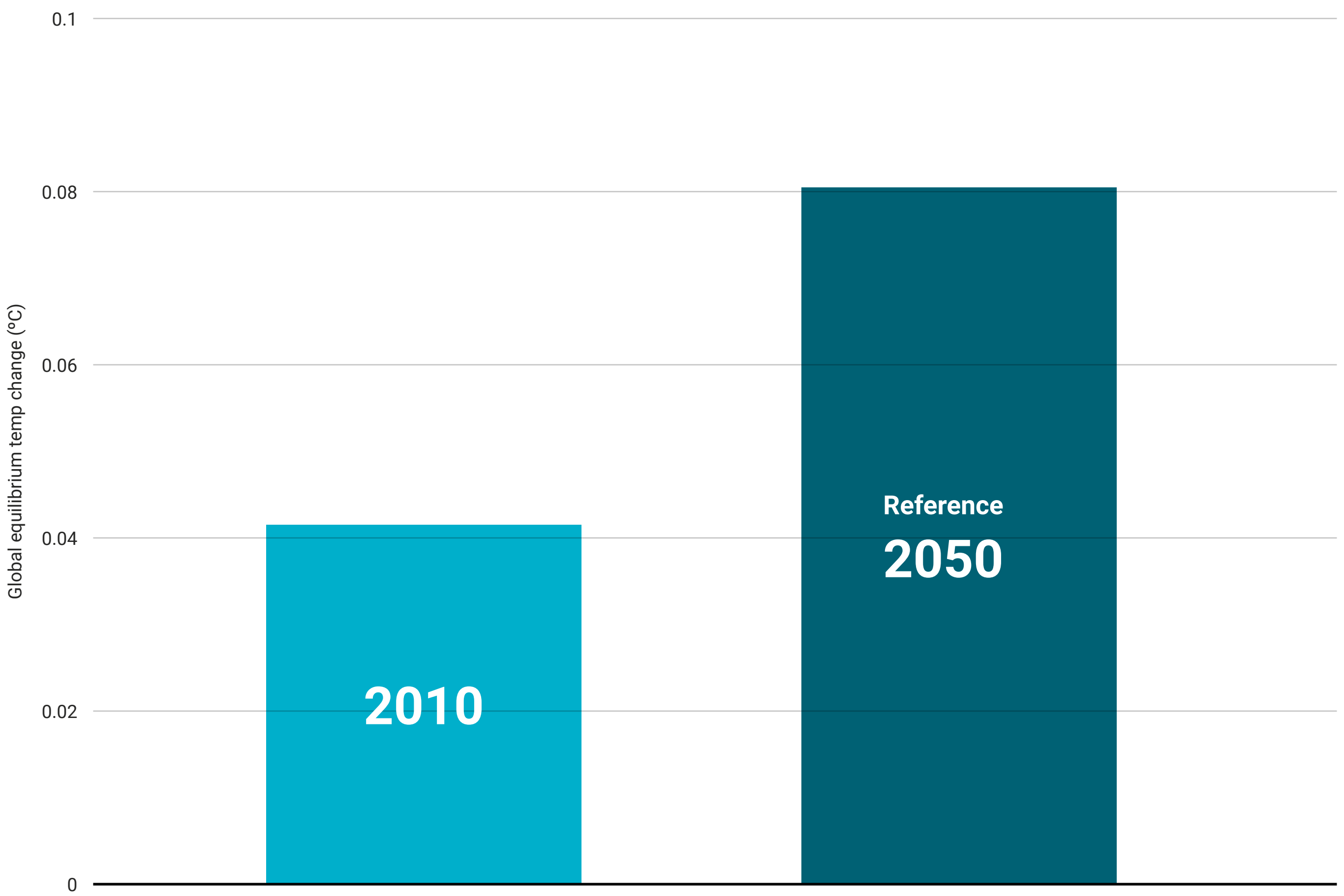


Figure 2.3

Modelled global equilibrium temperature change resulting from Latin American and Caribbean emissions, 2010 and 2050

Note: the change, according to the GEOS-Chem Adjoint model, is relative to the 1890–1910 temperature for 2010 and for the reference scenario in 2050. This includes emissions of CH_4, primary PM and precursors of secondary PM and O_3, but does not include emissions of CO_2 or HFCs.

short-lived and therefore not homogeneously distributed, having higher concentrations close to the sources of emission, they have a larger impact on forcing close to the regions in which they are emitted.

As mentioned, changes in temperature were calculated by three different models: GISS, GEOS-Chem Adjoint and TM5-FASST. The equilibrium temperature response to the changes in forcing was calculated using global and regional temperature potentials (Shine *et al.*, 2005; Shindell and Faluvegi, 2010) that relate forcing to temperature change.

The GISS model was used with global emissions derived from the GAINS model, which incorporates Latin American and Caribbean emissions developed in this assessment, and also recent GAINS emission estimates for all other regions of the world. The result is shown in Figure 2.2, which illustrates that under the reference scenario emissions, the global temperature will increase by about 1.3°C by 2050 relative to present-day temperatures, or 2.3°C above the 1890–2010 temperature. The projected calculations based on the GISS model forcings were made up to 2070, and under the reference scenario, which includes a considerable increase in hydrofluorocarbon (HFC) emissions, the increase rises to 3°C above the 1890–2010 temperature.

The GEOS-Chem Adjoint and TM5-FASST models were used to estimate the impact of Latin American and Caribbean emissions only on global equilibrium temperatures – the temperature of the world that would result when it reaches equilibrium at some date in the future. Figure 2.3 shows the result of applying the GEOS-Chem Adjoint model estimates, indicating that the region's emissions – from the 2010 reference scenarios – would be expected to lead to a net increase in global temperature, but it is important to note that this is a very small change compared to the global temperature change already experienced, or expected by 2050. In 2050, it is projected that the region's reference scenario emissions will more or less have doubled in their impact on global temperatures compared with 2010, although in absolute terms this is still a very small change in comparison to the overall expected warming from global emissions.

Results of running the full GISS climate model

In addition to running the GISS model in an offline mode to calculate temperatures, the version that has a fully coupled climate-ocean system was also run. The results from this complement the offline modelling described in the previous sections and present further information on possible climate impacts related to all emissions in the reference scenario. It must be borne in mind, however, that this is only one model, and in general it is considered best practice to use the results of many different climate models to examine the likely effect of changes in forcing by different substances on warming, patterns of rainfall and other important climatic parameters. The recent IPCC modelling exercise using around 40 models, CMIP5, can be used to put the GISS modelling results into context for interpretation.

While global mean temperatures provide some indication of climate impacts, and their simplicity makes them widely used indicators, temperature changes can vary substantially across the world. Over Latin America and the Caribbean they are related to the regional influences of globally mixed gases, due to differing response times between land and ocean, and the influence of changes in atmospheric circulation and ocean currents in response to forcing at both regional and global scales. The forcing of aerosols and O_3 is very unevenly distributed and hence can cause even greater regional contrasts in temperature. Though effects from regional aerosols can be important, under the reference scenarios forcing from well-mixed greenhouse gases, in particular CO_2, dominates to such an extent that regional effects are less relevant. Hence climate changes under the reference scenario used here are likely to be rather similar to those under the reference scenarios used in the CMIP5 analyses of IPCC AR5 (IPCC, 2013: Chapter 12). The regionally heterogeneous forcings are, of course, paramount for consideration of the effects of SLCP mitigation. It is possible to expect regional effects on relatively small spatial scales and effects that change the seasonality of precipitation, for instance.

The GISS model, in comparison with the broader set of CMIP5 models, has a lower climate sensitivity, but its calculated temperature is well within the range estimated from paleoclimate and modern data and climate modelling (Collins *et al.*, 2013). The spatial patterns of response in most of the world, and in particular in Latin America and the Caribbean, are quite similar to those seen in the multi-model ensemble. For example, under RCP 4.5, the GISS model shows warming of about 1.2–2.0°C over most of Central America and tropical South America, with values from about 0.5°–1.2°C over extra-tropical South America (Figure 2.4). These results are consistent with those in the broader CMIP5 ensemble, which also shows greatest warming over eastern Amazonia and least warming over extra-tropical South America, with similar, though slightly greater, magnitudes for the median of the 45 models used in the IPCC AR5 report (Figure 2.4) (IPCC, 2013: Annex I). The reference scenario used in this assessment leads to forcings fairly similar to those under RCP 8.5, which has a similar pattern of surface temperature change but a slightly greater magnitude (Figure 2.4).

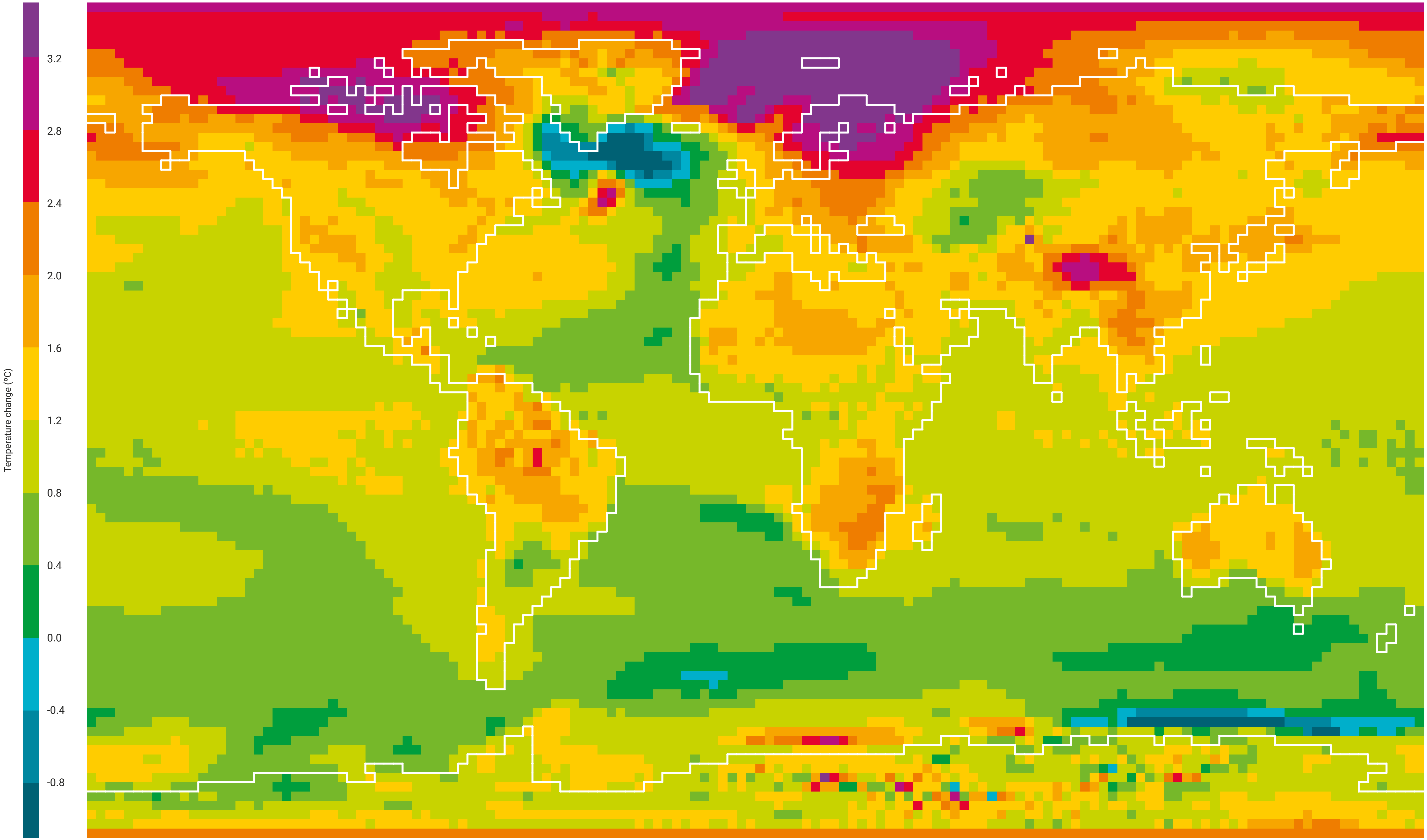
2.2.3

Impact of emissions on cloud cover and rainfall

Ozone and aerosols can influence many of the processes that lead to the formation of clouds and precipitation events. This can change surface temperature due to the associated influence on forcing, or influence the amount of radiation that reaches the surface, changing evaporation. By absorbing sunlight in the atmosphere, O_3 and aerosols can change the vertical temperature structure of the air, and thus convection and cloud formation. Aerosol particles can also act as cloud condensation and ice nuclei, affecting the formation and concentration of cloud particles in both liquid and ice phases. The non-homogeneous aerosol spatial distribution can change wind patterns by altering the regional temperature contrasts that drive the winds, and thus influence where water vapour is distributed and precipitation falls. As these localized effects can influence large-scale atmospheric circulation, they can also affect temperature, cloudiness and precipitation far away from the regions in which the forcing due to aerosols was concentrated.

The impact of global forcing by well-mixed greenhouse gases – mainly CO_2 – on rainfall patterns was modelled in IPCC AR5 (IPCC, 2013: Chapters 10 and 12) and the results are consistent across models at the global scale and in some regions, such as at high latitudes, where rainfall generally increases as the planet warms. Rainfall also tends to increase near the equator and decrease in the subtropics as the Hadley cell broadens. Some other regional patterns, such as a northward shift in wintertime storm tracks across the North Atlantic, are also fairly consistent across models. Nonetheless, many of the smaller-scale spatial patterns of rainfall change are inconsistent across models. This applies to most of Latin America and the Caribbean, as discussed previously (Figure 2.1). Furthermore, as changes due to reductions in aerosols and O_3 are likely to have distinctly different impacts on regional rainfall, comparison of rainfall changes under the reference scenario with those seen in other models would have only minimal relevance to putting into context the rainfall changes projected under an SLCP mitigation strategy.

These model outputs are yet to be explored by scientists in the context of hydrological models, crop suitability and yield models, dynamic vegetation models or species distribution models. As a result, the sections that follow on the above topics should be read bearing in mind the



RCP 4.5

Figure 2.4

Projected surface temperature change in 2070 relative to 2010, under the IPCC RCP 4.5 and RCP 8.5 scenarios

Note: both scenarios are from an ensemble of five simulations with the GISS-E2R model.

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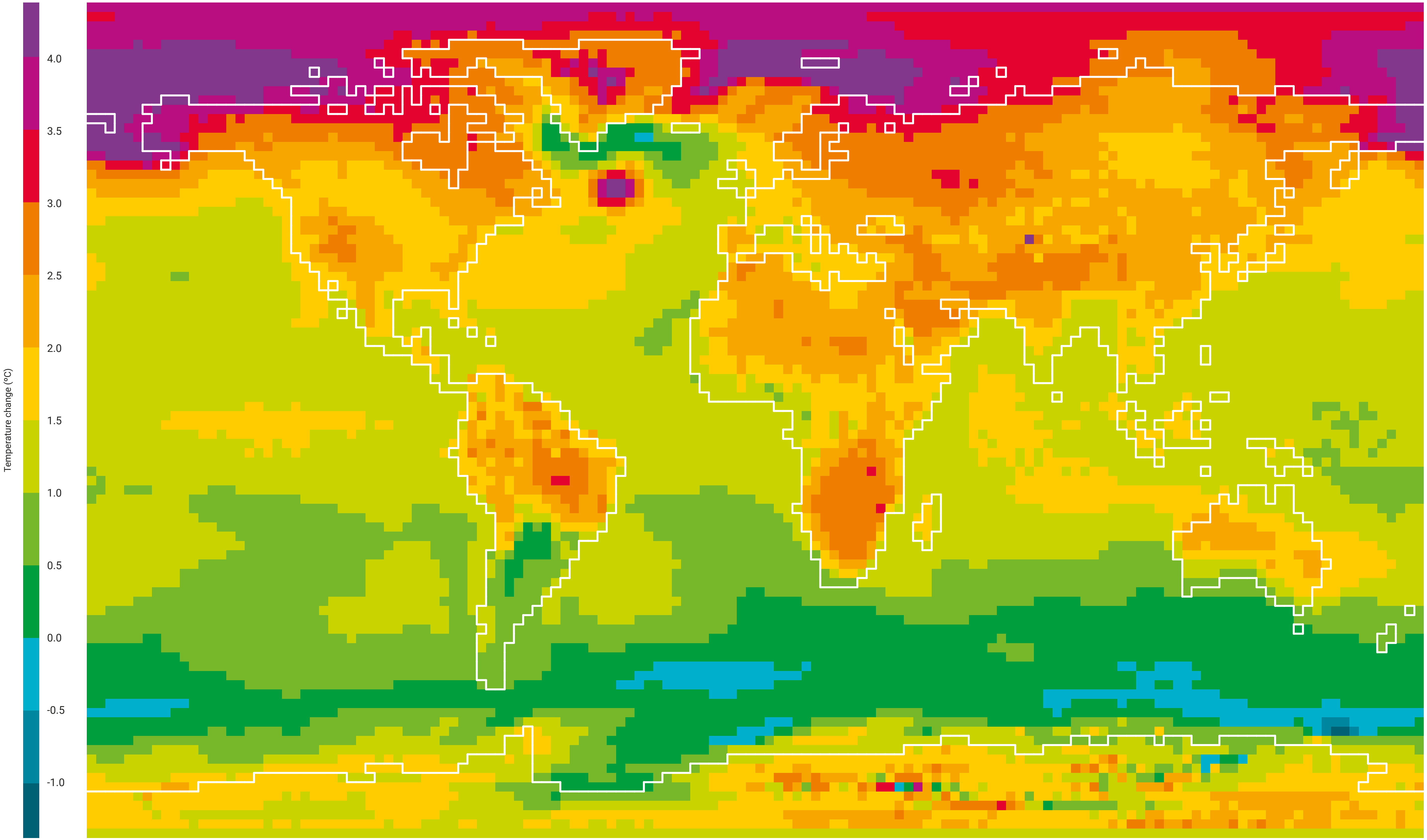

RCP 8.5

Figure 2.4

Projected surface temperature change in 2070 relative to 2010, under the IPCC RCP 4.5 and RCP 8.5 scenarios

Note: both scenarios are from an ensemble of five simulations with the GISS-E2R model.

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climate-modifying impacts described above. Care needs to be taken not to assume linearity in the impacts. In other words, relatively small changes in temperature, precipitation and their combination can result in organisms reaching threshold conditions that can lead to cascading effects.

2.3

Regional sensitivities and impacts–spatial climate variability and distribution of biomes

The Latin America and Caribbean region is very diverse in its climates and associated biomes, reflected in the climatic adaptations of its plants and animals. A relatively simple and traditionally applied system to visualize the broad climatic division of Latin America and the Caribbean is provided by the Köppen-Geiger classification system (Kottek *et al.*, 2006; Rubel and Kottek, 2010). This divides Latin America and the Caribbean into various combinations of climate-vegetation types (Appendix 2). Projected changes from the present day to 2100, based on ensemble modelling of five global circulation models projected on to the Köppen-Geiger system (Rubel and Kottek, 2010) and on the basis of an ensemble of 20 global climate models as part of CMIP5 projected on to the modified Köppen-Trewartha system (Feng *et al.*, 2014), indicate an increase in tropical (type A) and arid (type B) climates and a decrease in subtropical (type C) climate (Rubel and Kottek, 2010; Feng *et al.*, 2014).

Biome models, precursors of dynamic vegetation models, were based on the physiological tolerances of groups of plant species (functional types) that can be further grouped into prevalent life forms, for example trees, shrubs and herbs, which, in turn, characterize large climatically contiguous areas and thereby circumscribe biomes (Box, 1981; Box, 1996; Cramer, 2002). For most biomes in Latin America and the Caribbean, land use and climate change are the highest-ranked drivers of biodiversity change (Sala *et al.*, 2000, 2001; Hassan *et al.*, 2005). The latest IPCC regional report for Central and South America provided a break-down of observed recent trends in drivers for seven sectors (Magrin *et al.*, 2014); in general, there has been an increase in temperature, inter-regional differences in the seasonality and amount of precipitation, a decrease in forest cover in most regions, and an increase in agricultural land use along with economic growth. The biomes in Latin America and the Caribbean most sensitive to climate change appear to be those at high elevation and high latitude, such as the high Andean *páramos* and *puna* and the alpine vegetation of the central and southern Andes, along with the remaining glaciers (see online Appendix for details on ecosystems).

2.4

Climate change implications for water security

2.4.1

Climate impact on hydrological connectivity: Andes–arid Pacific coastal lowlands

The Andes has two macroslopes, one forming a mega watershed that drains into the Pacific Ocean, and the other into the Atlantic after crossing large expanses of lowland South America. The Pacific macroslope is the exclusive supply of fresh water for the Pacific lowlands of arid South America, where agricultural, domestic and industrial water use relies on water of mountain origin. In Peru, for example, only about 1 per cent of freshwater resources originate in the arid coastal plain and Altiplano areas where most of the Peruvian population lives (Casimiro *et al.*, 2012). Stream flow from snow and ice melt and precipitation over highlands far away are therefore key for water supply in this region (Table 2.1).

The observed changes in the Andean cryosphere in the last 50–60 years have included significantly increased rates of recession of glaciers, higher meltwater contributions to stream flow and, in some cases, decreased dry-season discharge in the tropical Andes, with largely identical trends in the southern Andes (Vuille, 2013; Magrin *et al.*, 2014: Table 27.3). The potential effect on local hydrology, however, is less understood. In general, it is expected that a drier and warmer future climate will shift the snow line to higher elevations and reduce the number of days with precipitation falling as snow at any given elevation. Extreme precipitation and corresponding extreme stream-flow events are expected to become more frequent (Halloy *et al.*, 2013; Cortés *et al.*, 2014).

The paucity of observations and the complex nature of energy and mass balance processes make the interpretation of historical records challenging. For example, although warming has been documented at high elevations in Chile over the last 40 years (Falvey and Garreaud, 2009), Cortés *et al.* (2011) did not find matching trends in annual river flow rates, unlike those observed in the Cordillera Blanca, Peru. This apparent disconnection between trends in glacier melt and hydrological yield is one of the key open research questions that needs to be addressed if adequate public policy is to be implemented to mitigate the effects of climate change. Pellicciotti *et al.* (2014) have suggested some avenues of research to better address this challenge, namely:

a. transitioning from documenting glacier volume changes to predicting ice mass through physics-based models;
b. continuing the expansion of observational networks (glaciological and climatic), such as are currently being developed by authorities and research centres in Chile and other countries in the Andes;
c. continuing and deepening an understanding of snow redistribution processes, which apparently contribute disproportionately to glacier mass balance; and
d. assessing explicitly uncertainty in water resource predictions under climate change scenarios, stemming from global circulation models, downscaling and modelling errors.

Country	Region	Cryospheric system	Population (million people)
Argentina	San Juan/Mendoza	Extratropical Andes	2
Bolivia	La Paz	Chacaltaya	2
Chile	Central Chile (Santiago, Valparaíso, Rancagua)	Extratropical Andes	8
Colombia	Páramos	El Cocuy	10
Ecuador	Quito	Cotopaxi-Antezana	2
Peru	Pacific coastal	Cordillera Blanca	10
Total			**34**

Table 2.1

Regions depending on snow/glacier melt for water resources in South America

Source: Barnett *et al.*, 2005; Bradley *et al.*, 2006.

Projections for most major watersheds with glaciers suggest that the glaciers will have disappeared before the end of the 21st century and that most river basins in South America will have been affected by reduced annual or dry-season flows (Vergara *et al.*, 2011; Magrin *et al.*, 2014: Table 27.4).

Many arid coastal populations depend on water supply from Andean glacier ice meltwater (Table 2.1). Several recent studies have evaluated the potential impacts of climate change on water and food security in the context of the Andes and arid Pacific lowlands, in view of the high dependence of the latter and the sensitivity of highland-lowland hydrological connectivity. Two large glaciated watersheds that drain into the Pacific in Peru have shown contrasting potential future patterns (Box 2.1) (Vergara *et al.*, 2011). To address water security in an integrated manner in arid Latin America and the Caribbean, it has been suggested (Scott *et al.*, 2012, 2013) that water management should be based on a framework that conceptually and practically links the components of the climate/hydrology/ecosystems/use-of-ecosystem-services complex. Such an approach would help identify extreme conditions and thresholds in each of the components, and allow planning for water security in a collaborative way between decision makers and Earth system scientists.

2.4.2

Climate impact on hydrological connectivity: Andes–Amazon basin

The Andean slopes of the Amazon basin are the wettest of the entire basin, with rainfall reaching some 5000 millimetres (mm) per year in some places. There are two large uncertainties in relation to the hydrological connectivity between the Andes and the Amazon basin:

Box 2.1

Arid coastal capital cities depend on Andean water

Ministerio del Medio Ambiente de Chile

Water management for the populations living in coastal arid-climate cities, including Lima, Peru, and Santiago, Chile, is crucial. In general, water management systems operate on the assumption of no change in water availability, but climate change simulations indicate that this premise is untenable, and that water availability may change to different degrees owing to the possible impacts of shifts in temperature and precipitation on stream-flow volume and seasonality. Basins dominated by glacial and snow meltwater, for example, are particularly sensitive to such changes, which make human populations and economic activities in such watersheds vulnerable.

Simulated results for the Santa river basin conform to the pattern of reduction in stream flow, while analysis of the complex Mantaro-Rimac system, the supplier of water for Lima and Callao, Peru, indicate lower flow in the Mantaro but not in the Rimac basin. Low stream flow is expected to intensify during the warm and dry months, thereby threatening to cause an interruption in water supply (Demaria *et al.*, 2013). Such trends have already been detected, for example in the Mataquito river basin between 1976 and 2008 (Vicuna *et al.*, 2013).

The Maipo watershed supplies water for 6 million urban inhabitants in central Chile. Bonelli *et al.* (2014) and Delgado *et al.* (2013) considered adaptation measures in the Maipo valley to maintain current water security standards. They suggested the purchase of water rights and improvements in water-use efficiency as probable effective measures. An integrated assessment of the impacts of climate change on meeting the water demands of major water users in the Maipo basin indicated that urban and agricultural sectors are sensitive to climate change, particularly to greater changes in precipitation. Of the two, the urban sector appears less sensitive because it holds a greater fraction of water-use rights compared to actual withdrawals. For urban supply, groundwater pumping is an additional source of water to meet population demands. However, this would change if climate change affected aquifer recharge dynamics (Meza *et al.*, 2014).

a. the actual contribution to stream flow of glacial and snow meltwater; and
b. how precipitation patterns and quantities will alter in the future as a result of climate change.

The patterns in projected precipitation and discharge appear to show little consistency among the watersheds of Andean rivers draining into the Amazon basin in Peru (Casimiro *et al.*, 2011). In the study by Casimiro *et al.* (2011), annual modelled discharge showed an increasing trend in four rivers and a decrease in three, with overall discharge on a decreasing trend. The seasonal increases or decreases in discharge could also vary from watershed to watershed. In a more recent study on the Vilcanota river, Andres *et al.* (2013) confirmed the likely decreasing trend found by Casimiro *et al.* (2011): more total runoff during the rainy season from January to March, and temporary storage indicate that less water will be available during the dry season. Sensitivity to water stress may be exacerbated by changes in precipitation brought about by climate change, but population growth appears to be the main driver of increased water stress; van Soesbergen and Mulligan (2014) found the influence of precipitation on water stress to be greater in parts of the Andean highlands and Amazonian lowlands where water demand is higher.

2.4.3

Pollution impacts on the cryosphere

As discussed, hydrological models that explore projected climate change impacts do not routinely, if at all, explore the contribution of SLCPs to climate change and to the hydrological properties of basins. An emerging field in which BC, one of the SLCPs, is attracting attention is how it affects the melt rates of ice and snow in the cryosphere in Latin America and the Caribbean – and also snow duration and vegetation dynamics in North America.

Air pollution from biomass burning, urban emissions and mining activities (Codelco, 2013; Siekierska and Roberts, 2013) affects large areas of South America, and although it has been a primary concern due to its detrimental health effects, other impacts, such as those on the cryosphere and water yield, are becoming focal issues. The Andes straddle parts of seven countries in South America with a population of around 85 million. Scientific evidence indicates that the Andean cryosphere has already shown the impacts of rapid climate change, with receding glaciers and snow cover that could have potentially large implications for water resources, agriculture and energy production in western South America.

Contributing factors include increasing temperatures, changes in precipitation patterns, and the deposition of BC, which are inherently linked; their relative importance may vary in different Andean regions. Despite the paucity of systematic observations along the Andes, the few existing studies have detected BC on the region's snow and glaciers. These, in addition to existing and projected emissions and weather patterns, suggest a possible contribution of BC to the observed retreat of the Andean cryosphere. Given these concerns, an international scientific programme, Pollution and its Impacts on the South American Cryosphere (PISAC, www.mce2.org/activities/pisac), was launched in October 2013 in Santiago, Chile, to address the issue. The PISAC initiative is a collaboration of researchers with expertise ranging from atmospheric and cryospheric science to policy making. The overall goal of PISAC is to identify the key sources and impacts of BC and co-pollutants in the Andean region, to initiate research activities at dedicated observation sites to close knowledge gaps, and to address mitigation measures for near-term climate protection and air quality improvement (Molina *et al.*, 2015).

2.5

Impacts of climate change and pollution on food security

Food security and how it may be affected by projected climate-change driven changes in crop yields has been a significant concern for Latin America and the Caribbean. A prominent focus of research has been temperature impacts, as the uncertainties associated with projecting long-term precipitation changes are rather challenging. Little focus has been on O_3 impacts as, apart from the megacities and their environs, the concentration of ground-level O_3 is low. The current integrated modelling assessment provides some estimates on potential yield losses attributable to the impacts of O_3 on some main crops (section 2.5.2).

It should be borne in mind that, with the exception of O_3, the SLCP contribution to climate change in many regional assessments is not separated out, and that the reported modelled climate change (temperature) impacts include any assumed impacts of SLCPs on crop yields (Box 2.2).

2.5.1

Potential climate change impacts on agricultural crop yields

Climate change – temperature, water availability and CO_2 fertilization impacts – and continuing population growth

Box 2.2

Food security in Brazil in future climatic scenarios

Several studies, which have used current and future agricultural risk zoning, have considered the potential impacts of climate change on food security in Brazil (Assad *et al.*, 2004; Pinto and Assad, 2008; Lopes *et al.*, 2011; Zullo Jr. *et al.*, 2011). Agro-ecological zoning, introduced in 1996, is based on the sensitivity of the growth phases (phenological stage) of each crop to drought stress, flood risk and extreme temperatures. Crop suitability is determined by temperature and contemporaneous soil moisture data (evapotranspiration) in sensitive crop phenophases (Affholder *et al.*, 1997).

Several recent works have evaluated potential climate change impacts on Brazilian agriculture. For example, Assad *et al.* (2004) examined coffee production, considering its future displacement due to potential changes in climate suitability. Zullo Jr. *et al.* (2011) studied the possibilities of relocating coffee production to the south of the country, a region where climate traditionally had been deemed too cold for coffee cultivation.

More recently, Assad *et al.* (2016) made new simulations of crop suitability, incorporating in the agricultural simulator (Affholder *et al.*, 1997) the projections of the HadGEM2-ES climate model and the RCP 4.5 and 8.5 scenarios (IPCC, 2013). These results indicate identical trends to those obtained by earlier studies (Margulis *et al.*, 2010; Santana *et al.*, 2010; Assad *et al.*, 2013). In terms of vulnerability assessments, the main projected impacts in the next 50 years are:

- global warming could have large impacts on food production in Brazil, leading to yield losses of up to 42 per cent for maize (Figure A) and 48 per cent for soybean (Figure B), under the RCP 4.5 scenario;
- beans and soybean are expected to be most affected;
- beans, maize, rice and soybean are likely to suffer extreme reductions in suitable areas in their current low-risk areas in the northeast of Brazil, with a significant fall in production.

Table A

Global warming impacts on the area suitable for crops in Brazil, 2025, 2055 and 2085

Crop	Scenario RCP 4.5 Area remaining at low risk, and change vs 1990						Scenario RCP 8.5 Area remaining at low risk, and change vs 1990					
	2025 ('000 ha)	Change (%)	2055 ('000 ha)	Change (%)	2085 ('000 ha)	Change (%)	2025 ('000 ha)	Change (%)	2055 ('000 ha)	Change (%)	2085 ('000 ha)	Change (%)
First bean crop	1 226	-37.4	1 126	-42.5	1 186	-39.4	1 124	-42.6	1 064	-45.6	839	-57.1
Second bean crop	506	-50.4	615	-39.7	530	-48.1	423	-58.5	396	-61.2	287	-71.9
First maize crop	6 895	-9.2	7 197	-5.2	7 010	-7.7	6 662	-12.3	6 647	-12.5	5 909	-22.2
Second maize crop	2 143	-71.3	4 243	-43.2	2 214	-70.4	1 752	-76.5	1 129	-84.9	204	-97.3
Rice	2 307	-4.4	2 330	-3.5	2 316	-4.0	2 238	-7.2	2 233	-7.5	2 0774	-13.9
Soybean	10 905	-56.3	12 849	-48.6	11 539	-53.8	8 901	-64.4	8 557	-65.7	4 694	-81.2
Wheat	1 567	-18.1	1 646	-14.0	1 630	14.8	1 502	-21.5	1 596	-16.5	1 458	-23.8

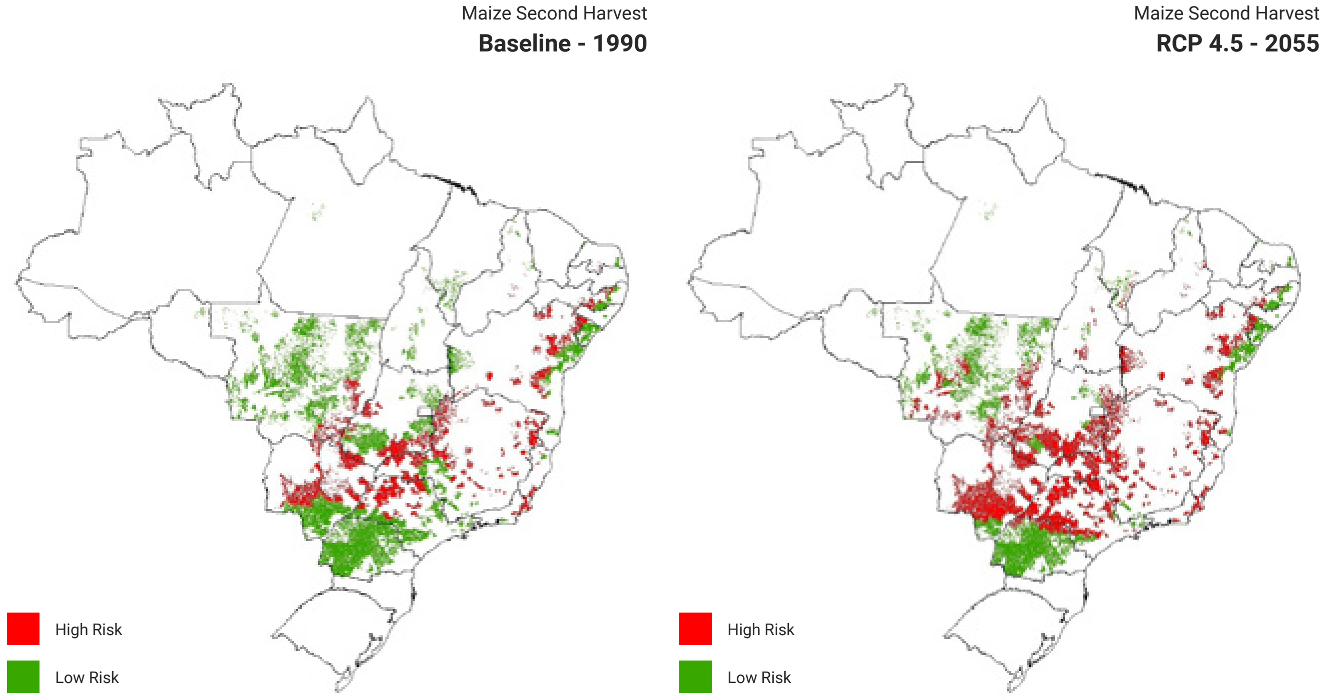

Figure A

Impact of global warming on second maize harvest in Brazil, baseline 1990

Note: simulation with the outputs of the regional Model ETA, with global simulations from CMIP5 and HadGEM2, using scenario RCP 4.5.

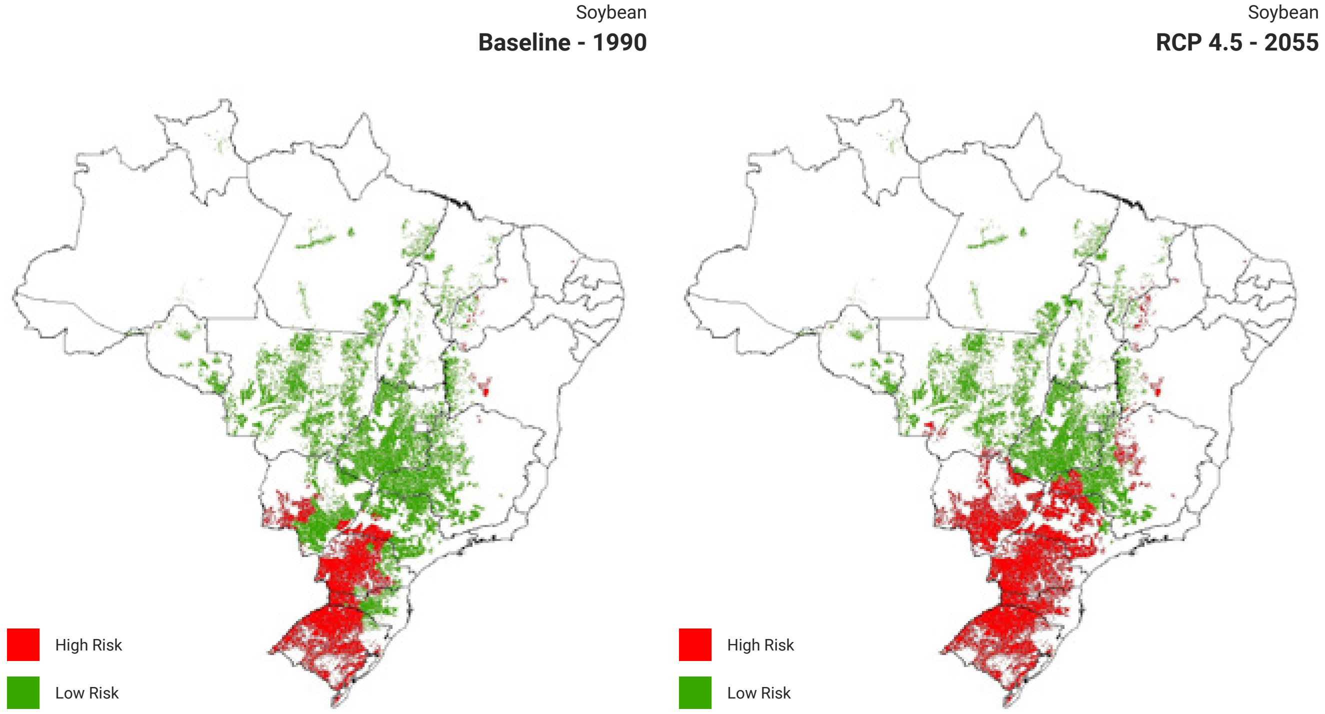

Figure B

Impact of global warming on soybean in Brazil, baseline 1990

Note: simulation with the outputs of the regional Model ETA, with global simulations from CMIP5 and HadGEM2, using scenario RCP 4.5.

will substantially affect food security and the price of agricultural commodities across the globe (Lewis and Witham, 2012). Food security within Latin America and the Caribbean varies from country to country. This offers opportunities for region-wide collaboration to reduce economic losses through concerted action, be it by policy measures or by supporting crop diversification research and climate adaptation, instead of an indiscriminate expansion of agricultural production at the expense of other environmental services (Halloy *et al.*, 2005; Perez *et al.*, 2010; Lambin et al., 2013).

The climate in Latin America and the Caribbean changed during the 20th century, and this has had regionally variable responses in terms of crop yields, the cultivation potential of crops, and weeds and pests (Maletta and Maletta, 2011). Overall, for example, there has been a trend of increasing total annual rainfall over 57 per cent of central Argentina, significantly reducing aridity; however, cultivation potential for soybean appeared spatially heterogeneous between 1940 and 2010 and with notable temporal variation (de la Casa and Ovando, 2014). The Pampas of Argentina have shown some of the most consistently increasing trends in precipitation during the 20th century, with the additional rainfall partly contributing to a significant expansion of area under cultivation (Magrin *et al.*, 2005; Podesta *et al.*, 2009; Asseng *et al.*, 2013). These changes also contributed to changes in crop yields: increases attributable to changes in climate from 1950–1970 to 1971–1999 were 18 per cent for maize, 38 per cent for soybean, 12 per cent for sunflower and 13 per cent for wheat, while mean observed yield increases were 110 per cent for maize, 102 per cent for sunflower and 56 per cent for wheat.

Predicted climate change impacts in the tropics, however, usually signal reduced yield and/or suitability for crops (Jarvis *et al.*, 2011; Lewis and Witham, 2012). Current understanding indicates small yield increases in some of the major commodities including soybean and cassava, but reductions in most other crops including bananas, beans and potatoes.

Regardless of the emission scenario or model used, wheat yields could be significantly affected by climate change (Fernandes *et al.*, 2012). Percentage yield declines are projected to be greatest in Brazil, Colombia and Mexico. Yield reductions are predicted due to a shortening of the crop cycle that will result in fewer days to fill grains. The projected yield declines by 2020 and 2050 due to pests and diseases could also be significant. With few exceptions, insufficient water supply is likely to affect wheat productivity more than any other factor.

For soybean, yields could be reduced by climate change by 2020 and more so by 2050, though by varying magnitudes across the region. Yield losses could be large in Brazil – more than 30 per cent from the baseline (Box 2.2) – but less pronounced in Argentina, Bolivia, Colombia and Uruguay. This can be explained by the greater impact of climate change in Brazil, where the crop cycle is projected to become shorter than in other parts of Latin America, and likely to result in a markedly reduced soybean grain-filling period.

For maize, climate change could reduce yields throughout Latin America, regardless of the emission scenario or global climate model. This is mainly due to the shorter grain-filling period not being compensated for by higher daily biomass accumulation rates and the CO$_2$ fertilization effect. The countries most affected are likely to be Brazil, Ecuador and Mexico, and the Caribbean countries, where maize is one of the main crops.

For rice, the Agroecological Zones Simulation (AZS) estimates have shown that productivity could, on average, increase across the region. A major reason for this positive outlook appears to be related to the fact that rice is a wetland/irrigated crop.

The projections for 2020 and 2050 are encouraging, with higher productivity foreseen in many cases. In Brazil, Mexico and the Caribbean, however, where a strong temperature rise is likely, the expected increased water deficit could reduce production, mainly in Brazil, for maize and soybean, and to a lesser extent coffee could also be affected.

In low-temperature areas, especially southern Brazil and Uruguay, climate change could reduce the incidence of pre-flowering cold shocks that induce sterility. Except for Rio Grande do Sul, Brazil and the Caribbean, rice blast disease pressure could ease, because temperature and rainfall conditions would become less favourable for the pathogen *Pyricularia grisea*, which causes the blast.

2.5.2

Potential ozone impacts on agricultural crop yields

Worldwide, O$_3$ has been estimated to contribute to major losses in crop productivity to affect ecosystem services in (semi-) natural ecosystems (Ainsworth *et al.*, 2012), and have the potential to affect highly biodiverse areas such as tropical Latin America. These impacts are associated with O3 being a climate forcer and thus contributing to climate warming and due to the direct impact of O$_3$ acting as an oxidant once it is taken up into leaves through the stomata, which affects plant growth with no external symptoms (invisible injury) and can also lead to killing of leaf cells (necrosis) with visible injury.

The differential sensitivity to O$_3$ of different species and varieties can lead to changes in the composition of natural and semi-natural ecosystems. In addition, O$_3$ can reduce net primary production and thus reduce net carbon sequestration in terrestrial ecosystems.

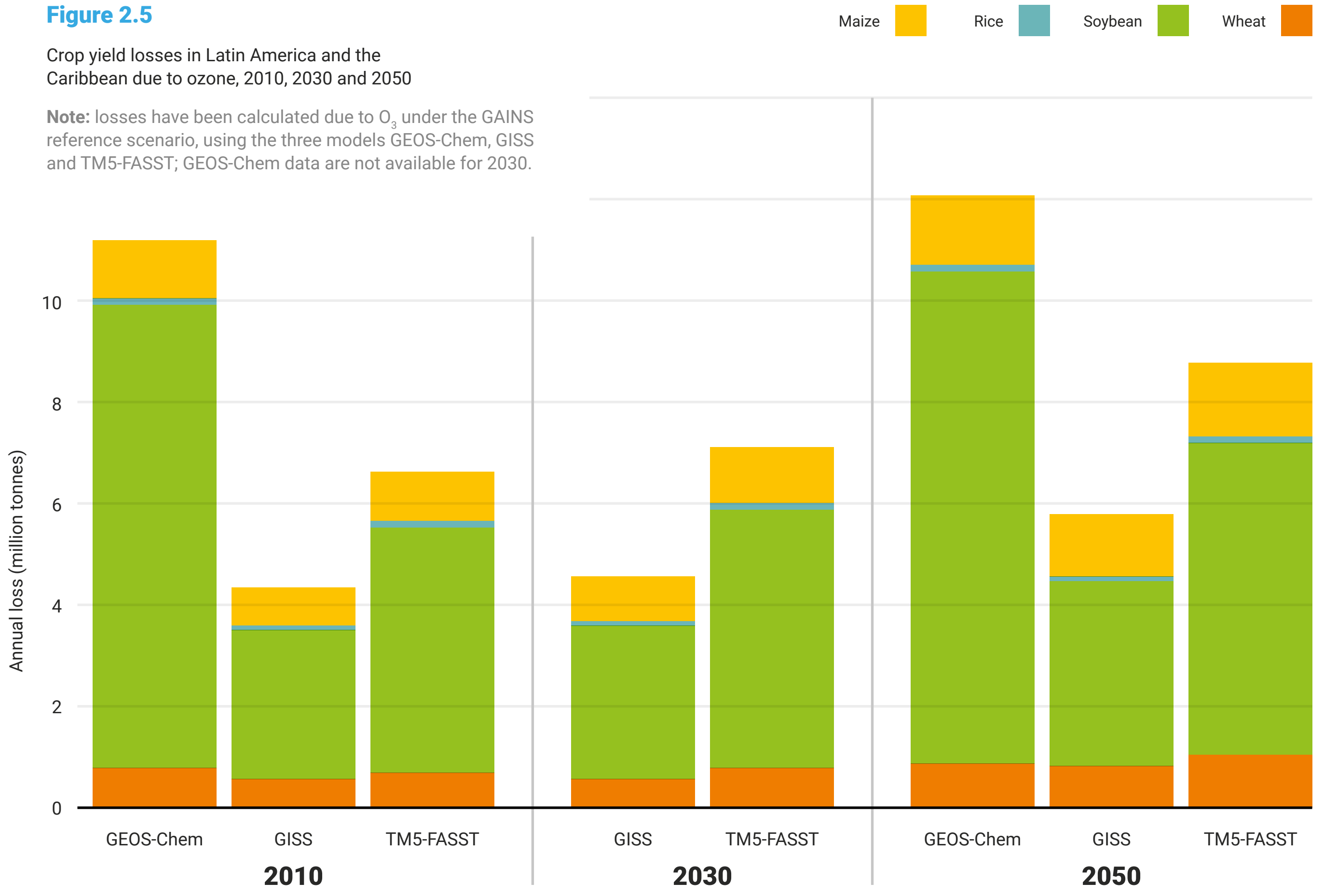

Figure 2.5

Crop yield losses in Latin America and the Caribbean due to ozone, 2010, 2030 and 2050

Note: losses have been calculated due to O$_3$ under the GAINS reference scenario, using the three models GEOS-Chem, GISS and TM5-FASST; GEOS-Chem data are not available for 2030.

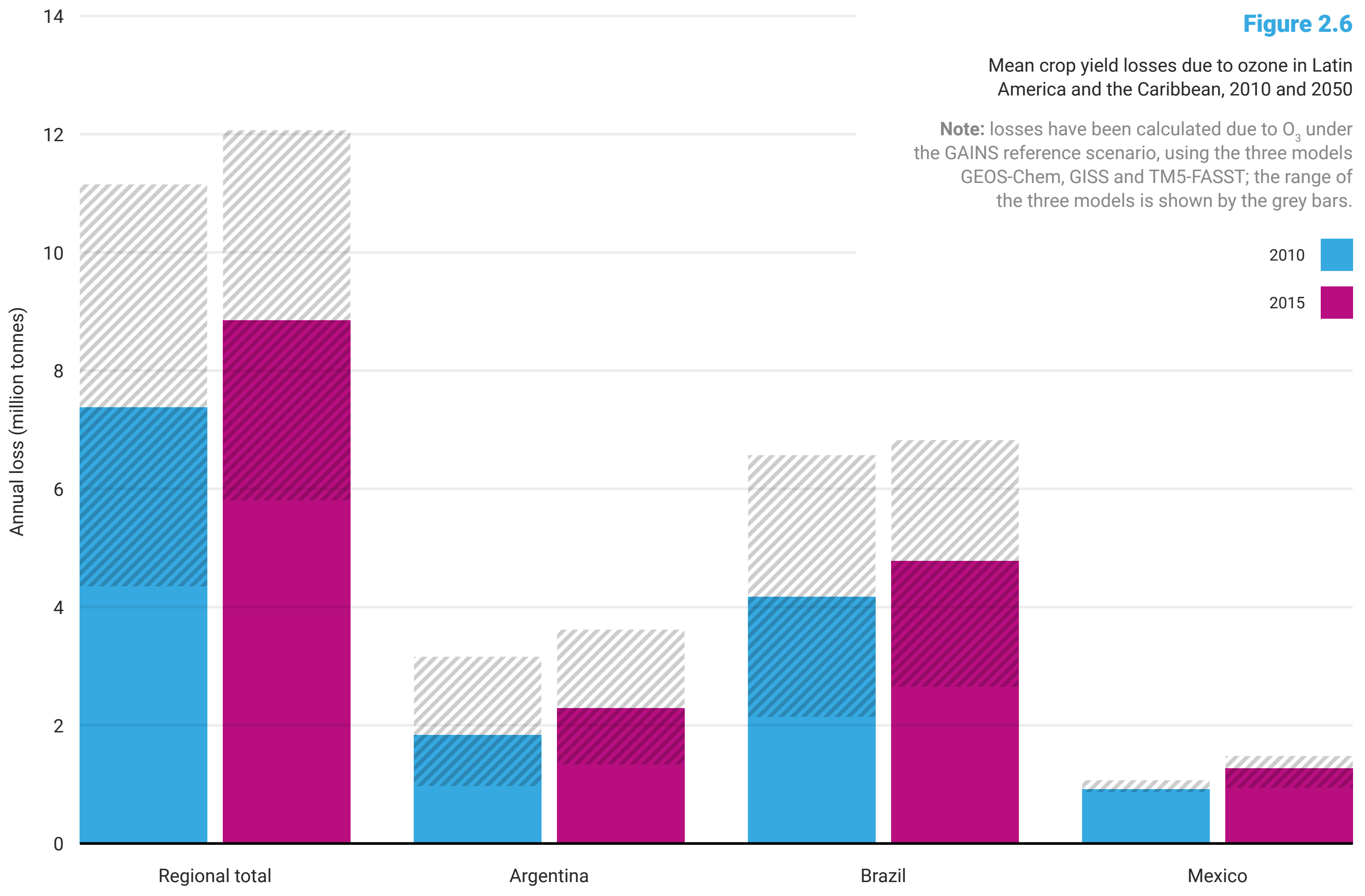

Figure 2.6

Mean crop yield losses due to ozone in Latin America and the Caribbean, 2010 and 2050

Note: losses have been calculated due to O$_3$ under the GAINS reference scenario, using the three models GEOS-Chem, GISS and TM5-FASST; the range of the three models is shown by the grey bars.

Region/ country	Crop	2010 ('000 tonnes)				2050 ('000 tonnes)			
		GEOS-Chem	GISS	TM5-FASST	*Mean*	GEOS-Chem	GISS	TM5-FASST	*Mean*
Latin America and the Caribbean	Maize	1 151	769	967	***868***	1 364	1 216	1 425	***602***
	Rice	124	61	106	***97***	141	102	149	***111***
	Soybean	9 109	2 944	4 835	***634***	9 701	3 652	6 144	***537***
	Wheat	781	573	700	***685***	865	823	1 047	***639 639***
Argentina	Maize	152	36	71	***86***	189	63	103	***100***
	Rice	5	2	3	***3***	6	4	4	***4***
	Soybean	2 599	804	1 208	***507***	2 972	1 087	1 494	***516***
	Wheat	396	108	164	***223***	465	183	242	***254***
Brazil	Maize	413	102	304	***273***	485	183	422	***312***
	Rice	60	31	57	***49***	68	59	76	***57***
	Soybean	6 041	1 963	3 351	***455***	6 230	2 351	4 304	***338***
	Wheat	50	20	61	***44***	60	54	92	***54***
Mexico	Maize	512	593	515	***540***	601	912	781	***636***
	Rice	3	4	3	***3***	3	7	6	***4***
	Soybean	72	47	59	***59***	71	50	75	***62***
	Wheat	269	387	341	***332***	268	501	505	***372***

Table 2.2

Crop yield losses for four different crops, 2010 and 2050

Note: the different atmospheric models are based on the 2010 and projected 2050 GAINS reference scenario emissions.

Two of the most widely grown crops in Latin America, maize and soybean, have been estimated to have suffered a yield loss attributable to O_3 of 5 per cent and 10 per cent in the United States of America between 1980 and 2010 (McGrath *et al.*, 2015). Projections suggest that it is likely that these crops will suffer a similar negative impact in Latin America (Ainsworth *et al.*, 2012). Soybean has been shown in experiments to be particularly sensitive to O_3 pollution.

How other concomitant environmental changes may mitigate or exacerbate O_3 impacts is subject to speculation. There have been reports that with elevated atmospheric CO_2 concentrations, the yield reductions are lower (Mulchi *et al.*, 1992; Morgan *et al.*, 2003). But this, of course, needs to be compared to the impact of elevated CO_2 concentrations in the absence of elevated O_3. Soybean, and other important crops such as coffee, sugarcane and wheat, are known to respond to elevated CO_2 with increased growth, and therefore future studies should establish if this may to some extent compensate the O_3 impact.

Estimating the impact of changes in ozone on crop yields for historical emissions and emissions under the reference scenario

Ozone has been shown in experiments to be the main pollutant that affects crop yields (Mills *et al.*, 2013). The methods used in this assessment are identical to those used in the UNEP-WMO global assessment (UNEP-WMO, 2011). This approach uses the relationship between crop responses and average daylight O_3 concentrations. For maize, rice, soybean and wheat, there are two O_3 concentration indices: M7 and M12[1], averaged over the three months of the growing season, which are applied in exposure-response functions to produce estimates of relative yield loss for each relevant crop in the target country. The relative yield loss values are then combined with annual national crop production numbers for each crop for the relevant year, from, for example, FAOSTAT[2], to obtain the amount of crop production lost.

The results of the modelling are shown in Figure 2.5 and the average of these models in Figure 2.7. Table 2.2 shows the results in more detail for selected countries. These estimate that tropospheric O_3 caused an annual yield loss of about 7.5 million tonnes in 2010, and the changes in emissions of O_3 precursors in the reference scenario imply an increase in annual crop yield loss to about 9 million tonnes in 2050. Figure 2.6 shows that there is most difference for the yield loss for soybean, due to the differences in O_3 concentrations estimated by the models in the region where soybean is grown. The crop yield losses in Argentina, Brazil and Mexico comprise a very large proportion of the total estimated losses in Latin America and the Caribbean.

2.6

Climate change and pollution impacts on human health

This section explores estimates of air pollution-associated premature death derived from different global burdens of disease (GBD) and World Health Organization (WHO) studies developed and published over the period 2014–2016. In the overview of the different health impacts that follows, the tables present national estimates of premature mortality from the first GBD project report to use the integrated exposure-response (IER) (Lim *et al.*, 2012). There follows a comparison of the estimates made by using modelling and satellite approaches in this analysis, and a presentation of the premature death estimates of the GBD 2013 study and WHO ambient air pollution report (Forouzanfar *et al.*, 2015), and a more recently published WHO report (WHO, 2016). Generally, these results are higher for Latin American and Caribbean countries than those in Lim *et al.* (2012), and also higher than the estimates developed by the modelling and satellite imagery for this assessment. They were, however, derived using an estimate of the $PM_{2.5}$ counterfactual concentration consistent with the estimates calculated in this report (in contrast to the GBD 2015 estimates (Forouzanfar *et al.*, 2016)). All the results are generally similar in terms of the relative size of impact on countries, and differences reflect the uncertainty in the estimation of health impacts of air pollution, specifically regarding $PM_{2.5}$ concentrations (Box 2.3), in the relationships between $PM_{2.5}$ and different causes of death, and the level of knowledge about these functions, which is improving over time.

Human activities result in the emission of a wide range of substances into the atmosphere; some of these, greenhouse gases and aerosols, impact climate, and through it ecosystem services and human well-being – and indirectly human health – while others have direct impacts on human health. Urban centres are point sources of high concentrations of emissions of gaseous and particulate pollutants such as O_3 and $PM_{2.5}$ that affect air quality and human health.

The projected increase in temperatures may result in a general increase in illness rates (Delfino *et al.*, 2003), death from heat stroke (Gan *et al.*, 2011) and dehydration. Additionally, injury, illness and death caused by projected increases in extreme weather events, such as tornadoes,

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1. M7 = 3-monthly growing season mean of hourly O3 concentrations during the 7-hour period [09:00 – 15:59] local time; M12 = as for M7, but for the 12-hour period [08:00 – 19:59] local time.
2. Food and Agriculture Organization of the United Nations – Statistics Division, http://faostat3.fao.org/download/Q/QC/E

Box 2.3

Methods for estimating premature mortality linked to exposure to particulate matter (PM$_{2.5}$)

Global estimates for premature mortality have been calculated using IER concentration-response functions relating annual PM$_{2.5}$ exposure to five diseases (ischaemic heart disease, chronic obstructive pulmonary disease (COPD), stroke, lung cancer and acute lower respiratory infection in children) since 2012 (Lim *et al.*, 2012; Burnett *et al.*, 2014; WHO, 2016). The methods used for international assessments of ambient PM$_{2.5}$ health impacts continue to evolve, and these IER functions have been updated in later assessments, incorporating new epidemiological evidence of the effect of PM$_{2.5}$ on different health outcomes (Forouzanfar *et al.*, 2015, 2016; WHO, 2016). These revisions of the IER functions have, in the latest GBD 2015 analysis (Forouzanfar *et al.*, 2016), resulted in a revision of the counterfactual PM$_{2.5}$ concentration below which the excess risk of death from exposure is set to 1 (no excess risk). In previous analyses (Lim *et al.*, 2012; Forouzanfar *et al.*, 2015; WHO, 2016), the counterfactual was defined according to the lowest PM$_{2.5}$ exposures in a large US prospective cohort study (Krewski *et al.*, 2009), between 5.8 and 8.8 micrograms per cubic metre (µg/m^3), but in GBD 2015, the counterfactual PM$_{2.5}$ level was revised to less than half these values, between 2.4 and 5.9 µg/m^3 (Forouzanfar *et al.*, 2016). Additionally, different methods have been used in these global assessments to estimate ambient PM$_{2.5}$ exposure, using combinations of modelled, satellite-derived, and *in-situ* monitoring data (Brauer *et al.*, 2012, 2016; WHO, 2016).

These variations in health impact assessment methods result in variation in the outdoor air pollution disease burden estimates for Latin America and the Caribbean. For example, using the new PM$_{2.5}$ estimates for Latin America and the Caribbean has increased the number of premature deaths estimated for the region. The different methods (Brauer *et al.*, 2016; WHO, 2016) have used updated satellite data, linked with the results of the TM5 atmospheric transport model, and modified according to monitored data in cities in Latin America and the Caribbean and other world regions. The urban monitoring data, in particular, seems to have led to higher overall population-weighted PM$_{2.5}$ estimates being made for the different countries, compared with using satellite data and modelling alone. In addition, the reduction of the PM$_{2.5}$ counterfactual concentration in Forouzanfar *et al.* (2016) has increased the range of PM$_{2.5}$ concentrations at the low end of the concentration distribution which contribute to premature death. This has therefore also increased the estimates of PM$_{2.5}$-associated premature deaths across Latin America and the Caribbean, especially in those countries where population-weighted PM$_{2.5}$ concentrations were relatively close to the 5.8–8.8 µg/m^3 counterfactual concentration used in previous analyses.

floods and winter storms, are likely to increase. Climate change could have important indirect health effects through an increase in vector-borne diseases including malaria, dengue and yellow fever, as the geographic distribution of the vector insects is closely related to the amount and seasonality of precipitation, humidity and temperature. Vector-borne diseases are important globally and it is acknowledged that "the ongoing trends of increasing temperature and more variable weather threaten to undermine progress against these diseases" (Campbell-Lendrum *et al.*, 2015). Health is related to nutrition, which, in turn, is related to the availability and quality of food. The agricultural impacts of climate change can negatively affect food security and food safety, which may increase the prevalence of under- and malnutrition in vulnerable populations, and cause health insecurity due to social disruption and migration (WHO, 2003; IPCC, 2013).

Although all populations are affected by air pollution, the distribution and burden of consequent ill-health are unequal. The poor and disempowered, including slum dwellers and those living near busy roads or industrial sites, are often exposed to high levels of air pollution. Women and children in households that use polluting fuels and technologies for basic cooking, heating and lighting are those most affected by indoor air pollution (WHO, 2015). Children, the elderly with health conditions, and outdoor workers, particularly those in agriculture, are especially vulnerable to increasing temperatures and O$_3$ concentrations. Children are likely to suffer disproportionately from both direct and indirect adverse health effects from climate change. They are particularly sensitive to illness in the short term and harm in the long term because they are developing and growing, and they breathe at a higher rate than adults (WHO, 2016). People in disadvantaged socio-economic positions are also more vulnerable to climate change as they have less access to resources for the prevention of, response to and mitigation of impacts on their health.

2.6.1

Urban air pollution

Air pollution is associated with a range of significant short-term and long-term adverse health effects. It is estimated that the combined effect of air pollution resulted in 5.5 million deaths and 141.5 million disability-adjusted life years (DALYs) in 2013. There were about equal contributions from household air pollution (2.9 million deaths and 81.1 million DALYs) and ambient PM pollution (2.9 million deaths and 69.7 million DALYs) (Forouzanfar *et al.*, 2015). Of these deaths, about 138 000 occurred in Latin America and the Caribbean (WHO, 2014b).

More than 150 million people in Latin America and the Caribbean live in cities that exceed WHO air quality standards (CAI, 2012). Various measures of air pollution – concentrations of nitrogen dioxide (NO$_2$), PM$_{10}$ and PM$_{2.5}$, and elemental carbon filter reflectance – have been shown to have a strong correlation with observed short- and long-term health effects. Short-term fluctuations in ground-level O$_3$ and PM concentrations are linked to weather conditions, which may increase illness related to exposure to air pollution (US EPA, 2009).

Particulate matter

PM$_{2.5}$ has been linked to a series of major health issues, including neuroinflammation, neurodegeneration and cognitive deficits, premature death in adults with heart and lung disease, heart attacks, low birth weight, childhood pneumonia, chronic respiratory disease such as bronchitis, aggravated asthma and other respiratory symptoms including coughing and wheezing (Calderón-Garcidueñas *et al.*, 2008, 2011; Gehring *et al.*, 2010; Romieu *et al.*, 2010; Barraza-Villarreal *et al.*, 2011). Fine PM is a complex mixture of particles, and recent research has shown different health effects linked to individual components (Gehring *et al.*, 2015). As BC is emitted with other pollutants that make up PM, mitigation strategies aimed at reducing emissions of PM will have the co-benefit of reducing BC (UNECE, 2010). A major fraction of PM$_{2.5}$ is constituted by carbonaceous material, which accounts for 31–57 per cent of the PM$_{2.5}$ mass in urban areas (Na *et al.*, 2003; Russell and Allen, 2004; Upadhyay *et al.*, 2011; Martinez, 2012). Black carbon harms human health and can cause or contribute to a number of adverse health effects, including asthma and other respiratory problems, low birth weight, heart attacks and lung cancer (Kulkarni *et al.*, 2006; Janssen *et al.*, 2012). A literature review on the health effects of BC points to its association with cardiovascular impacts. Anenberg *et al.* (2012) estimated that, for PM$_{2.5}$ and O$_3$, respectively, fully implementing 14 specific emission control measures could avoid 0.6–4.4 and 0.04–0.52 million annual premature deaths globally in 2030. Mitigation measures on BC would avoid around 98 per cent of the deaths if all BC and CH4 mitigation measures were implemented (reduced BC and associated reductions of non-CH$_4$ O$_3$ precursor and organic carbon emissions as well as stronger mortality relationships for PM$_{2.5}$ relative to O$_3$). The GBD study has shown that PM$_{2.5}$ may cause about 0.8 million premature deaths (1.2 per cent) and 6.4 million years (0.5 per cent) of life lost globally (IHME, 2015).

A report of the Convention on Long-range Transboundary Air Pollution (CLRTAP) Joint Task Force on the Health Aspects of Air Pollution observed that there was sufficient evidence from epidemiological studies to confirm that chronic exposure to air pollution increased mortality and morbidity – heart disease, stroke, respiratory disease (CLRTAP, 2015). The Integrated Science Assessment of the US Environmental Protection Agency (US EPA, 2009) also concluded that there was a causal relationship between short- and long-term exposure to PM$_{2.5}$ and mortality and cardiovascular impairment.

Country	Deaths per 100 000 of the population			
	O$_3$	CI (95%)	Ambient PM$_{10}$ pollution	CI (95%)
Antigua and Barbuda	0.13	0.00041–0.36	23.54	20.51–26.68
Argentina	0.57	0.13–1.42	17.85	15.49–20.74
Bahamas	0.39	0.13–0.75	21.89	19.15–24.61
Barbados	0.093	0–0.33	33.25	29.05–38.01
Belize	0.29	0.09–0.6	3.06	1.83–4.64
Bolivia	0.84	0.29–1.49	7.03	5.76–8.49
Brazil	1.05	0.38–1.96	18.1	16.99–19.5
Chile	0.45	0.13–0.93	17.94	16.89–19.86
Colombia	0.74	0.23–1.52	13.1	11.99–14.33
Costa Rica	0.2	0.011–0.58	7.72	6.6–9.08
Cuba	0.91	0.28–1.77	20.73	15.62–26.14
Dominica	0.14	0–0.42	25.5	23.07–28.7
Dominican Republic	0.33	0.087–0.68	21.69	19.23–24.56
Ecuador	0.1	0.0067–0.31	12.66	11.33–14.2
El Salvador	1.33	0.43–2.23	17.12	15.94–18.31
Grenada	0.08	0–0.33	31.42	29.19–34.88
Guatemala	0.74	0.25–1.25	14.13	12.86–15.42
Guyana	0.00094	0–0.0082	8.47	5.88–11.4
Haiti	0.16	0.048–0.31	22.28	19.53–25.31
Honduras	0.71	0.18–1.48	12.01	9.08–15.18
Jamaica	0.34	0.076–0.74	17.61	14.98–20.45
Mexico	1.49	1.23–1.77	11.2	10.43–11.96
Nicaragua	0.18	0.021–0.48	3.53	2.33–4.89
Panama	0.26	0.035–0.65	0.76	0.22–1.7
Paraguay	0.5	0.17–0.9	17.44	15.6–19.58
Peru	0.26	0.071–0.59	10.36	9.01–11.92
Saint Lucia	0.13	0–0.43	28.52	25.06–32.18
Saint Vincent and the Grenadines	0.074	0–0.24	26.47	24.06–28.79
Suriname	0.0025	0–0.024	17.85	15.2–20.51
Trinidad and Tobago	0.089	0–0.31	24.35	21.91–27.04
Uruguay	0.21	0.015–0.7	6.83	4.47–9.46
Venezuela	0.42	0.12–0.79	17.06	15.94–18.11
TOTAL	**0.93**	**0.66–1.26**	**15.08**	**14.05–16.21**

Table 2.3a

Deaths attributable to ozone and particulate matter (PM$_{10}$) pollution in Latin America and the Caribbean, by country, 2010

Source: IHME, 2015.

Pollutant	PM$_{2.5}$ (mg/m^3)		PM$_{10}$ (mg/m^3)		O$_3$ (mg/m^3)			SO$_2$ (mg/m^3)				NO$_2$ (mg/m^3)			CO (mg/m^3)	
Averaging time	24-hr	Annual	24-h	Annual	1-hr	8-hr	Annual	10 min	3-hr	24-hr	1-hr	1-hr	24-hr	Annual	1-hr	8-hr
World Health Organization	25	10	50	20	-	100	-	500	-	20	-	200	-	40	-	-
WHO Interim target 1	75	35	150	70	-	160	-	-	-	125	-	-	-	-	-	-
WHO Interim target 2	50	25	100	50	-	-	-	-	-	50	-	-	-	-	-	-
WHO Interim target 3	38	15	75	30	-	-	-	-	-	-	-	-	-	-	-	-
United States of America	35[a]	15[b]	150	-	-	147[c]	-	-	1310	-	197	188[a]	-	100	40	10
European Union	-	25[b]	50[d]	40	-	120	-	-	-	125[e]	350[f]	200[g]	-	40	-	10[h]

Table 2.3b

Ambient air quality guidelines and standards, of the World Health Organization, the United States of America and the European Union

Note: [a] 98th percentile averaged over 3 years; [b] averaged over 3 years; [c] annual fourth highest daily maximum 8-hr concentration averaged over 3 years; [d] 35 exceedances allowed; [e] 3 exceedances allowed: [f] 24 exceedances allowed; [g] 18 exceedances allowed; [h] 25 days exceedances allowed averaged over 3 years.

Source: CAI, 2012.

Ozone

O$_3$ is a common air pollutant associated with adverse health impacts, including mortality (Bell *et al.*, 2004; Romieu *et al.*, 2012). It has been estimated, for example in the GBD study, that almost 2.5 million DALYs were attributable to O$_3$ in 2010 worldwide, including about 0.93 deaths per 100 000 inhabitants in Latin America and the Caribbean (Table 2.3a). The figure for Latin America and the Caribbean was 23.1 DALYs per 100 000 (confidence interval (CI) 95 per cent: 16.1–31.9) (Table 2.4). Both PM and O$_3$ have important short- and medium-term mortality effects that are age related. Socio-economic level and demographic variables also influence the susceptibility of the population to air pollution; socio-economically disadvantaged people apparently have a higher risk of death from respiratory causes, especially COPD (Bell *et al.*, 2004). However, the variability within the country or region, the susceptibility of individuals and those individual issues that generate a different response to exposure to O$_3$ have not been quantified in these studies (CLRTAP, 2015).

Even at relatively low levels, air pollution poses risks to health, and, because of the large number of people exposed, it causes significant morbidity and mortality in all countries. Heart disease and stroke are the cause of 80 per cent of the deaths attributable to outdoor air pollution, and respiratory illness and cancer are responsible for 20 per cent. More than one-third of deaths from COPD are attributed to both household and ambient air pollution. For household pollution, acute respiratory diseases in children and COPD are the most serious

Country	DALYs per 100 000 of the population			
	O_3	CI (95%)	Ambient PM_{10} pollution	CI (95%)
Antigua and Barbuda	5.41	0.017–15.2	475.52	416.88–537.78
Argentina	11.54	2.61–27.86	323.92	286.12–368.03
Bahamas	18.99	6.05–37.99	494.13	428.56–563.93
Barbados	3.88	0–13.58	625.83	555.65–704.71
Belize	10.34	3.19–21.45	71.05	43.46–106.05
Bolivia	26	8.72–46.83	201.31	161.26–247.42
Brazil	26.14	9.43–48.73	405.23	381.4–438.04
Chile	14.58	4.36–31.07	336.31	319.37–363.75
Colombia	16.27	5.16–32.94	287.64	260.99–316.18
Costa Rica	4.71	0.27–13.41	144.99	126.54–167.07
Cuba	24.89	7.41–48.64	346.64	271.34–426.74
Ecuador	3	0.19–8.72	338.75	296.83–382.81
El Salvador	28.16	9.69–47.89	344.06	319.47–372.42
Dominica	4.85	0–15.06	529.39	473.65–597.7
Dominican Republic	10.66	2.81–21.66	487.68	430.9–555.07
Grenada	2.53	0–10.22	627.4	579.18–692.78
Guatemala	20.74	6.98–36.23	490.67	430.08–553.72
Guyana	0.042	0–0.37	239.28	162.35–326.62
Haiti	8.51	2.55–16.37	713.78	614.82–835.18
Honduras	14.65	3.68–30.87	289.23	207.23–377.28
Jamaica	10.46	2.23–22.92	318.95	268.71–373.78
Mexico	35.78	27.83–44.04	252.79	236.33–270.02
Nicaragua	4.21	0.45–11.49	83.38	54.77–118.83
Panama	6.59	0.88–17.13	14.82	4.87–29.95
Paraguay	17.3	5.67–32.17	396.47	355.55–443.58
Peru	8.39	2.23–18.81	238.45	206.09–276.16
Saint Lucia	4.08	0–13.68	544.35	483.77–617.13
Saint Vincent and the Grenadines	3.29	0–11.27	563.71	512.76–617.9
Suriname	0.099	0–0.92	432.77	363.05–501.14
Trinidad and Tobago	3.74	0–12.75	537.69	481.38–602.99
Uruguay	4.71	0.36–15.46	112.27	79.37–149.86
Venezuela	12.48	3.3–24.5	394.09	368.87–421
TOTAL	**23.14**	**16.1–31.91**	**345.45**	**322.11–371.25**

Table 2.4

Disability-adjusted life years associated with air pollution (PM_{10}) in Latin America and the Caribbean, 2010

Source: IHME, 2015.

consequences, followed by heart disease and stroke (WHO, 2015). Air pollution is also classified as a cause of lung cancer by the International Agency for Research on Cancer (IARC) (Straif *et al.*, 2013; IARC, 2015). Around 30 per cent of all lung cancer deaths can be attributed to the joint effects of household and ambient air pollution.

The Clean Air Institute's report on air quality in Latin America (CAI, 2012) obtained PM_{10} concentrations from 12 countries, and $PM_{2.5}$ concentrations from nine of them. The PM_{10} annual standards of these countries are less stringent than WHO air quality guidelines (Table 2.3b). According to a study undertaken by the Climate and Clean Air Coalition (CCAC, 2012), the annual average concentrations for PM_{10} and $PM_{2.5}$ were higher than WHO recommendations in all the cities where these were measured. A more recent paper presented an overview of the mean annual PM_{10} levels for 104 cities and the mean annual $PM_{2.5}$ levels for 57 cities in Latin America and the Caribbean (Riojas-Rodríguez *et al.*, 2016). It appears that only five cities complied with WHO air quality guidelines for the annual mean of PM_{10}, and four complied for $PM_{2.5}$ (Riojas-Rodríguez *et al.*, 2016).

Mitigation of particulate matter (PM_{10}) and ozone pollution by vegetation in urban areas

Urbanization in Latin America is expected to increase to 90 per cent of the population by the mid-21st century (Magrin *et al.*, 2014). Thus, urban vegetation – parks, gardens, street trees, and native forest and planted green belts around cities – will become increasingly important for human well-being (see online Appendix). Plants act as passive filters of pollutants, and, although they emit volatile organic compounds which are precursors of O_3, they bring net benefits to air quality in urban environments. Establishing and managing urban forests for PM_{10} and O_3 removal is effective in mitigating pollution; however, plants have physiological limits determined by their capacity to filter out pollution, beyond which other pollution reduction measures, technologies and policies are required (Escobedo *et al.*, 2011). Pollution removal by trees, at 7.9 grams (g) of PM_{10} per square metre (m^2) of tree cover, appears similar to that by shrubs (8.5 g PM_{10}/m^2) (Escobedo and Nowak, 2009). Modelled relative PM_{10} air quality improvement by trees ranged from 1.6 per cent in areas with 26 per cent tree cover to 6.1 per cent in areas of 100 per cent tree cover in Santiago de Chile (Escobedo and Nowak, 2009) (actual tree cover varied between 12 per cent and 26 per cent and PM_{10} concentrations ranged from 59 to 84 µg/m³). These measured values of PM_{10} are high when compared with those in Mexico City, which is considered one of the most polluted cities in Latin America. Removal of PM_{10} and O_3 by vegetation in Mexico City was estimated by Escobedo and Chacalo (2008) at 2 per cent and 1 per cent, respectively, and removal by peri-urban forest was estimated by Baumgardner *et al.* (2012) at about 2 per cent for PM_{10} and 1 per cent for O_3, of their annual concentrations. Such reductions can have important implications for improving air quality for healthier cities.

2.6.2

Household air pollution

Methane and BC emitted by inefficient stove combustion are powerful climate pollutants. Almost half of the world's people use fire to cook indoors and more than a third, 2.5 billion people, use biomass-based fuels for cooking and heating; with coal this number reaches 3 billion. It is estimated that by 2030 the number of people who cook with biomass-based fuels will reach 2.7 billion (WHO, 2007). In Latin America and the Caribbean, around 90 million people rely on solid fuels for cooking and heating, mostly the poorest, and indigenous and rural populations. More than half of these people live in Guatemala, Haiti, Honduras, Mexico, Nicaragua, Paraguay and Peru. There has been a sustained trend in decreasing the use of solid fuels for cooking over the last 30 years in Latin America and the Caribbean. However, while many countries (Argentina, Ecuador, Uruguay and Venezuela) have practically eliminated solid fuels, others, including Haiti and Guatemala, have made little progress (Table 2.5) (Bonjour *et al.*, 2013). Additionally, about 10 per cent of the population in Latin America and the Caribbean lack electricity and many use kerosene lamps for lighting, which among other health risks emits very high levels of $PM_{2.5}$. The poor may spend a substantial part of their income on fuel and their relative fuel consumption is high (CEPAL, 2009).

2.6.3

Estimating the impact of changes in particulate matter ($PM_{2.5}$) and ozone on human health for the reference scenario

The impact on human health of pollutant emissions and concentrations (Chapter 2) was estimated by using modelled concentrations of $PM_{2.5}$ and O_3 as an input to the epidemiologically derived $PM_{2.5}$ or O_3 concentration-response functions for different causes of premature mortality.

The concentration-response functions used to assess premature mortality are the integrated exposure-response (IER) functions for lung cancer, stroke, ischaemic heart disease, and COPD. For the $PM_{2.5}$ concentrations modelled with the TM5-FASST tool, estimates were also made for deaths among children under five years of age from acute lower respiratory infection. These IER functions are described by Burnett *et al.* (2014), and were the basis for

Country	1990	2000	2010
Argentina	17	6	0
Belize	29	19	12
Bolivia	45	36	29
Brazil	19	11	6
Chile	24	14	6
Colombia	26	19	14
Costa Rica	26	13	6
Cuba	7	6	9
Dominica	42	20	1
Dominican Republic	37	20	7
Ecuador	27	13	2
El Salvador	50	35	22
Grenada	31	11	0
Guatemala	64	59	57
Guyana	26	15	7
Haiti	98	94	91
Honduras	68	58	51
Jamaica	38	23	11
Mexico	25	18	14
Nicaragua	77	64	54
Panama	25	20	18
Paraguay	54	50	49
Peru	62	48	36
Saint Kitts and Nevis	27	19	14
Saint Lucia	37	14	0
Saint Vincent and the Grenadines	69	35	3
Suriname	30	19	12
Uruguay	11	4	0
Venezuela	15	3	0

Table 2.5

Percentage of population using solid fuel in Latin America and the Caribbean, by country, 1990, 2000 and 2010

Source: WHO Global Health Observatory (http://www.who.int/gho/database/en).

Country	Deaths	CI (95%)	DALYs	CI (95%)
	per 100 000 of the population			
Antigua and Barbuda	1.69	1–2.64	38.65	23–60.49
Argentina	6.55	3.3–11.72	115.75	58.98–205.39
Bahamas	11.2	6.34–18.6	281.73	157.79–464.01
Barbados	0.12	0.058–0.22	2.5	1.22–4.56
Belize	11.52	8.92–14.39	292.73	225.65–369.13
Bolivia	16.76	12.44–22.13	495.1	357.15–649.53
Brazil	10.98	6.23–17.56	246.43	141.15–389.84
Colombia	17.29	13.48–21.9	374.42	293.76–468.93
Costa Rica	4.43	2.99–6.14	84.7	57.19–117.74
Chile	5.88	2.84–10.02	118.56	56.87–207.34
Cuba	4.5	2.94–6.56	83.4	53.85–121.16
Dominica	10.27	5.66–17.23	232.82	130.34–388.94
Dominican Republic	13.96	9.87–18.85	0	0
Ecuador	4.6	2.78–7.03	126.85	75.15–199.35
El Salvador	17.25	11.83–23.64	350.62	241.21–480.56
Grenada	3.9	2.17–6.27	84.49	46.36–138.21
Guatemala	29.11	21.31–37.17	1 032.75	741.43–1 344.42
Guyana	10.64	7.44–14.48	322.15	223–445.42
Haiti	61.14	51.7–71.37	2 076.24	1 728.28– 2 460.23
Honduras	42.33	31.16–54.67	980.64	688.73–1 290.25
Jamaica	9.54	5.3–15.28	194.55	106.95–317.54
Mexico	9.86	8.01–11.95	222.98	181.6–271.84
Nicaragua	25.15	19.24–30.97	629.28	475.36–787.92
Panama	10.85	7.63–15.23	226.18	158.6–318.72
Paraguay	28.44	23.34–34.1	690.28	566.2–824.65
Peru	20.68	16.25–25.75	507.11	400.67–641.04
Saint Lucia	9.46	5.08–15.79	197.02	107.71–331.19
Saint Vincent and the Grenadines	6.37	3.9–9.43	152.7	93.68–231.83
Suriname	12.49	9.63–16.14	328.59	248.63–423.86
Trinidad and Tobago	0.27	0.14–0.48	6.52	3.3–11.86
Uruguay	3.45	1.73–6.34	60.55	30.08–108.38
Venezuela	0.24	0.12–0.44	5.78	2.9–10.83
TOTAL	**13.49**	**10.88–16.79**	**332.52**	**270.08–408.04**

Table 2.6

Mortality and disability-adjusted life years associated with household air pollution in Latin America and the Caribbean, by country, 2010.

Source: IHME, 2015.

the premature mortality estimates compiled by the WHO (WHO, 2014a) and the GBD study (Lim *et al.*, 2012). The $PM_{2.5}$ results from the three models – TM5-FASST, GISS and GEOS-Chem Adjoint coefficients – were used to estimate premature mortality. For 2010, instead of using the GEOS-Chem Adjoint coefficients, premature mortality was calculated using the latest satellite-derived estimates for $PM_{2.5}$ (van Donkelaar *et al.*, 2016). The GEOS-Chem Adjoint coefficients were then used to calculate the change in $PM_{2.5}$ concentration from the 2010 satellite-derived data, in different scenarios for 2030 and 2050. TM5-FASST was also used to estimate mortality from O_3 concentrations.

The inputs to the calculations were as follows.

1. Annual average $PM_{2.5}$ concentrations.
2. Baseline mortality rates described in the GBD study (Lim *et al.* 2012) were used by TM5-FASST with satellite data from van Donkelaar *et al.* (2016), and WHO/GBD baseline mortality (WHO 2008) was used for the GISS runs. The same data were used to provide the baseline mortality rate for 2030, and this was also used for 2050 as there was no estimate given for that year.
3. Estimated and projected national populations for 2010, 2030 and 2050 (total number and age structure). Premature mortality estimated by TM5-FASST and using the van Donkelaar (2016) satellite data used the population data from the United Nations Statistics Division including projections (UNDESAPD), and also UN population projections matched to the CIESIN Gridded World Population of the World, v3 (NASA SEDAC). The GISS model used the population data from NASA SEDAC and the United Nations Population Division.

There are some important factors that affect the results of this type of modelling: first, the choice of counterfactual $PM_{2.5}$ concentration, which is the concentration below which there is no evidence of impacts according to the studies from which the IER functions are derived. As Burnett *et al.* (2014) state, “although we set the counterfactual concentration … with a lower bound of 5.8 μg/m³ and an upper bound of 8.8 μg/m³, we are not suggesting that there is convincing evidence that $PM_{2.5}$ mortality and ALRI [acute lower respiratory infection] risk is zero below any specific concentration based on biological considerations”. In Canada, evidence of impacts at concentrations as low as 2 μg/m³ have been noted. In Latin America and the Caribbean, which as a region has relatively low $PM_{2.5}$ concentrations, although some cities have moderate to high levels, the value of the counterfactual concentration has a large impact on estimates of premature mortality. Anenberg *et al.* (2010) have calculated the global impact of $PM_{2.5}$ exposure on premature mortality using a counterfactual concentration of 0 μg/m³ – as well as the higher counterfactual concentration advised for the concentration-response function – to show the range of premature deaths. Natural emissions, from sea salt, soil dust and natural vegetation fires, contribute to the $PM_{2.5}$ concentration observed in any location, and cannot be reduced by any measures or policies discussed in this assessment; this natural component of total $PM_{2.5}$ is lower than 5.8 μg/m³ in most cases. Therefore, the likely best estimate for premature deaths could be higher than that using the internal counterfactual concentration of 5.8–8.8 μg/m³, but lower than using the zero counterfactual concentration. As this study only shows the results for the internally set counterfactual concentrations in the IER, the numbers can be assumed to be conservative.

Second, integrated exposure-response functions have been developed for application to the entire adult population for the four causes of death, but for stroke and ischaemic heart disease, age-stratified IER functions have also been developed – separate IER functions for five-year age groups. The IERs for all adults were applied in this study as this was used by all models, but by using the age-stratified IER functions, substantially higher premature mortality was calculated. Therefore, the selection of all adult IER functions may have led to conservative estimates. Finally, a third reason why the estimates can be considered conservative is the global scale of the modelling in comparison to the city scale where most people in Latin America and the Caribbean are exposed.

Premature mortality from particulate matter ($PM_{2.5}$) pollution

To summarize the impact on premature mortality of $PM_{2.5}$ exposure, the $PM_{2.5}$ concentrations from the GISS and TM5-FASST models and the satellite data for 2010, and from the GISS, TM5-FASST and Geos-CHEM Adjoint models for 2030 and 2050, using the IER and the built-in counterfactual concentrations for the different health outcomes, were averaged. The average for premature mortality from $PM_{2.5}$ exposure for all countries in Latin America and the Caribbean and a range for the years 2010, 2030 and 2050 using the GAINS baseline emission projections are shown in Figure 2.7. Figure 2.8 shows the results for selected countries and country groups.

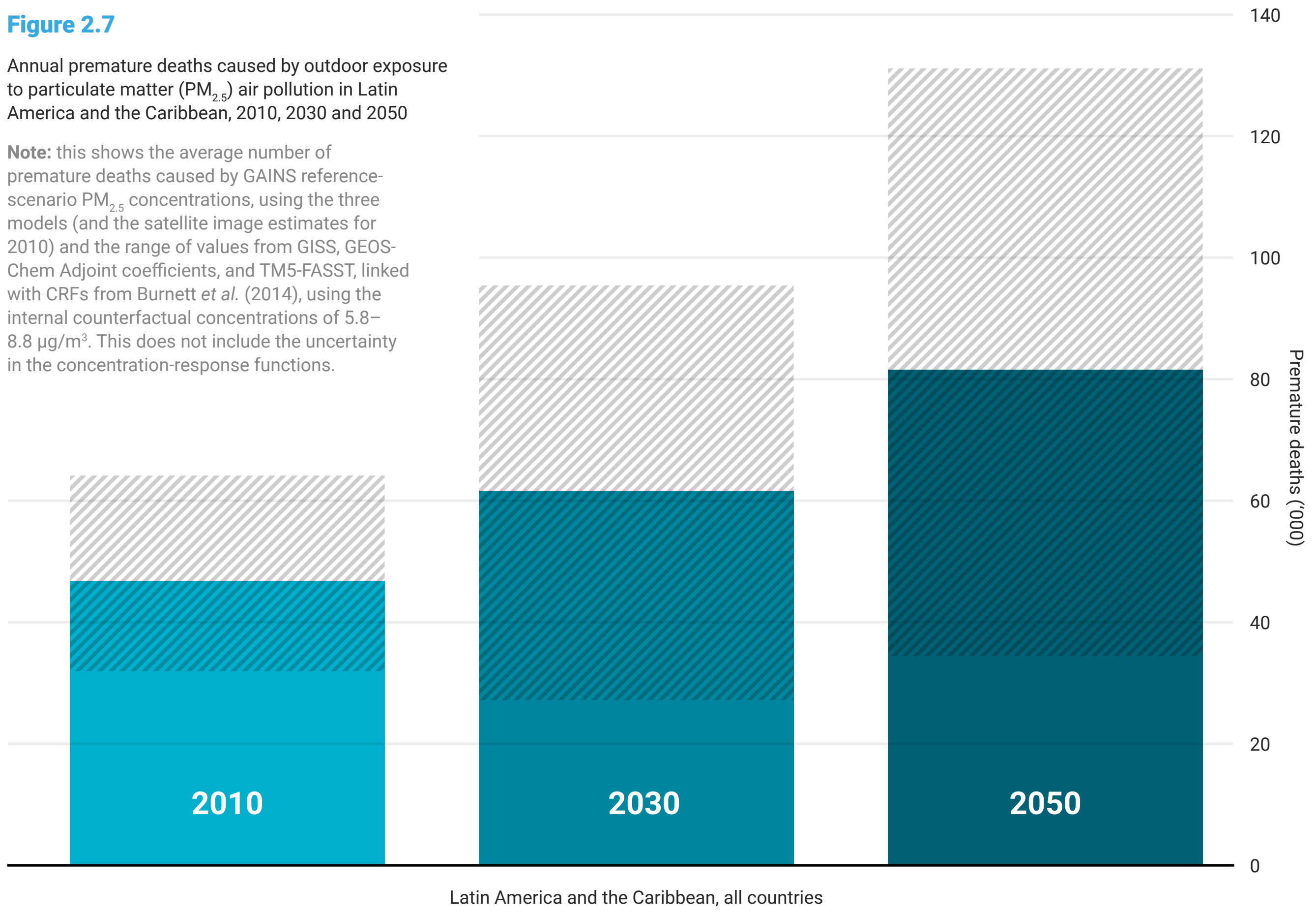
The average modelled number of premature deaths in Latin America and the Caribbean in 2010 was 46 585, (range between 31 933 and 64 170). As shown in Figure 1.13, however, the GISS and TM5-FASST models tend to underestimate the $PM_{2.5}$ concentrations in cities of Latin America and the Caribbean. This estimate of the number of deaths in 2010 is therefore likely to be very conservative, with actual premature mortality due to $PM_{2.5}$ concentrations in outdoor urban air likely to be higher.

The number of deaths in 2030, estimated at about 61 626 (range between 31 933 and 95 403), is about 30 per cent higher than the number in 2010. The number of deaths in 2050 is 81 564 (range: 34 328 and 131 205), a further increase on 2030, and the average number of

Figure 2.7

Annual premature deaths caused by outdoor exposure to particulate matter ($PM_{2.5}$) air pollution in Latin America and the Caribbean, 2010, 2030 and 2050

Note: this shows the average number of premature deaths caused by GAINS reference-scenario $PM_{2.5}$ concentrations, using the three models (and the satellite image estimates for 2010) and the range of values from GISS, GEOS-Chem Adjoint coefficients, and TM5-FASST, linked with CRFs from Burnett *et al.* (2014), using the internal counterfactual concentrations of 5.8–8.8 μg/m³. This does not include the uncertainty in the concentration-response functions.



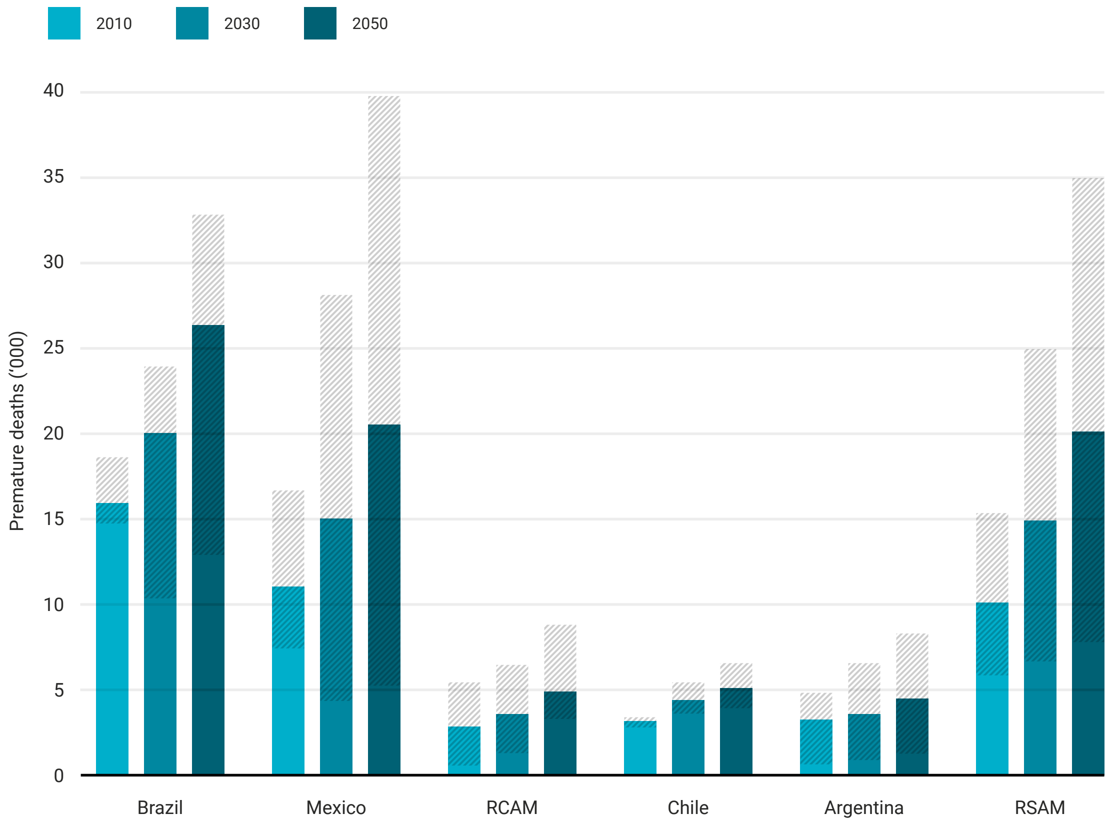


Figure 2.8

Annual premature deaths caused by outdoor exposure to particulate matter ($PM_{2.5}$) air pollution in selected countries and sub-regions of Latin America and the Caribbean, 2010, 2030 and 2050

Note: this shows the average of the number of deaths caused by GAINS reference-scenario $PM_{2.5}$ concentrations, using the three models and the range of values from GISS, GEOS-Chem, and TM5-FASST (and satellite imagery from van Donkelaar *et al.* (2016) for 2010), linked with CRFs from Burnett *et al.* (2014), using internal counterfactual concentrations of 5.8–8.8 μg/m³. This does not include uncertainty in the concentration-response functions. RCAM = Caribbean countries, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama; RSAM = Bolivia, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, and Guyana and Suriname.

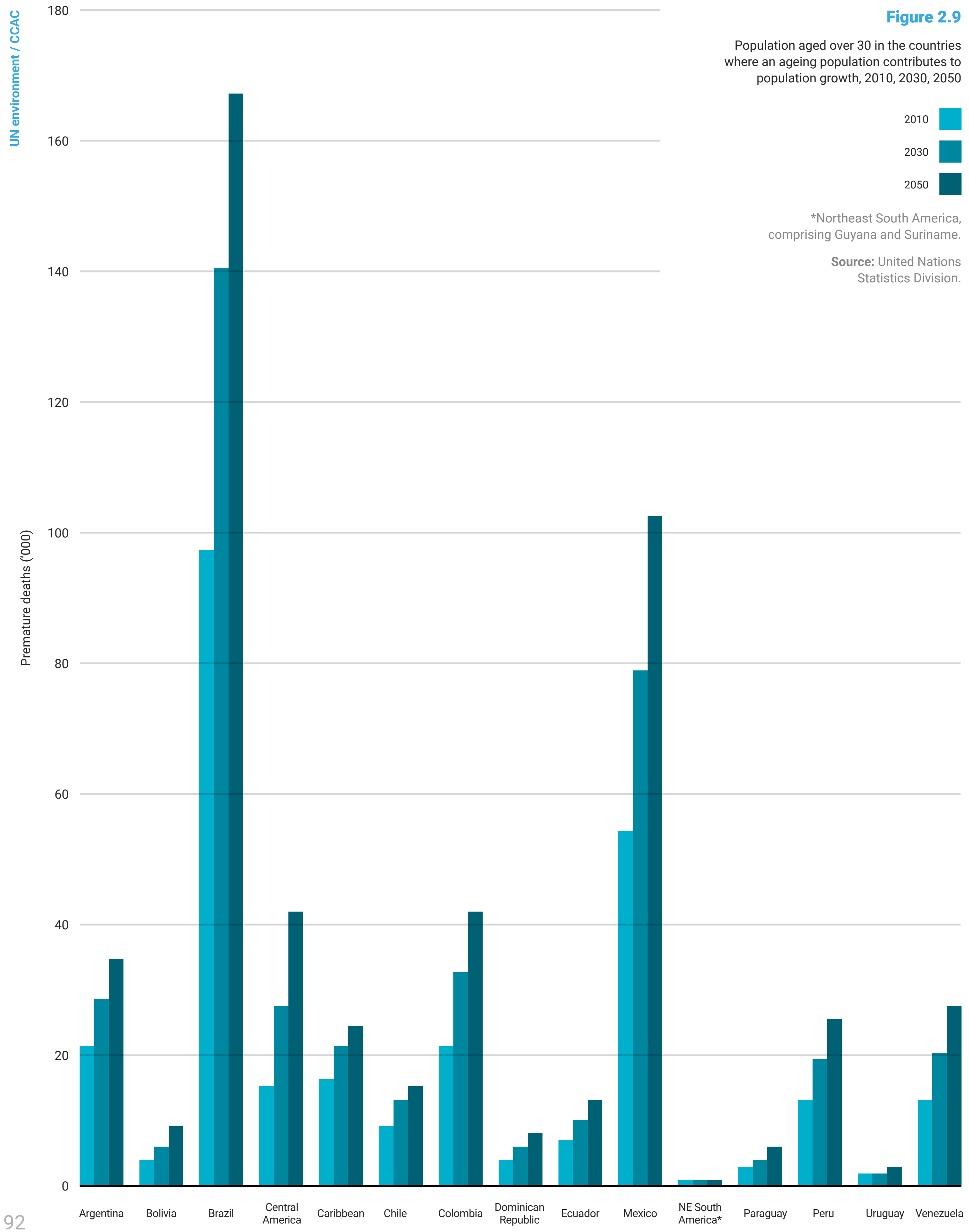


Figure 2.9

Population aged over 30 in the countries where an ageing population contributes to population growth, 2010, 2030, 2050

*Northeast South America, comprising Guyana and Suriname.

Source: United Nations Statistics Division.

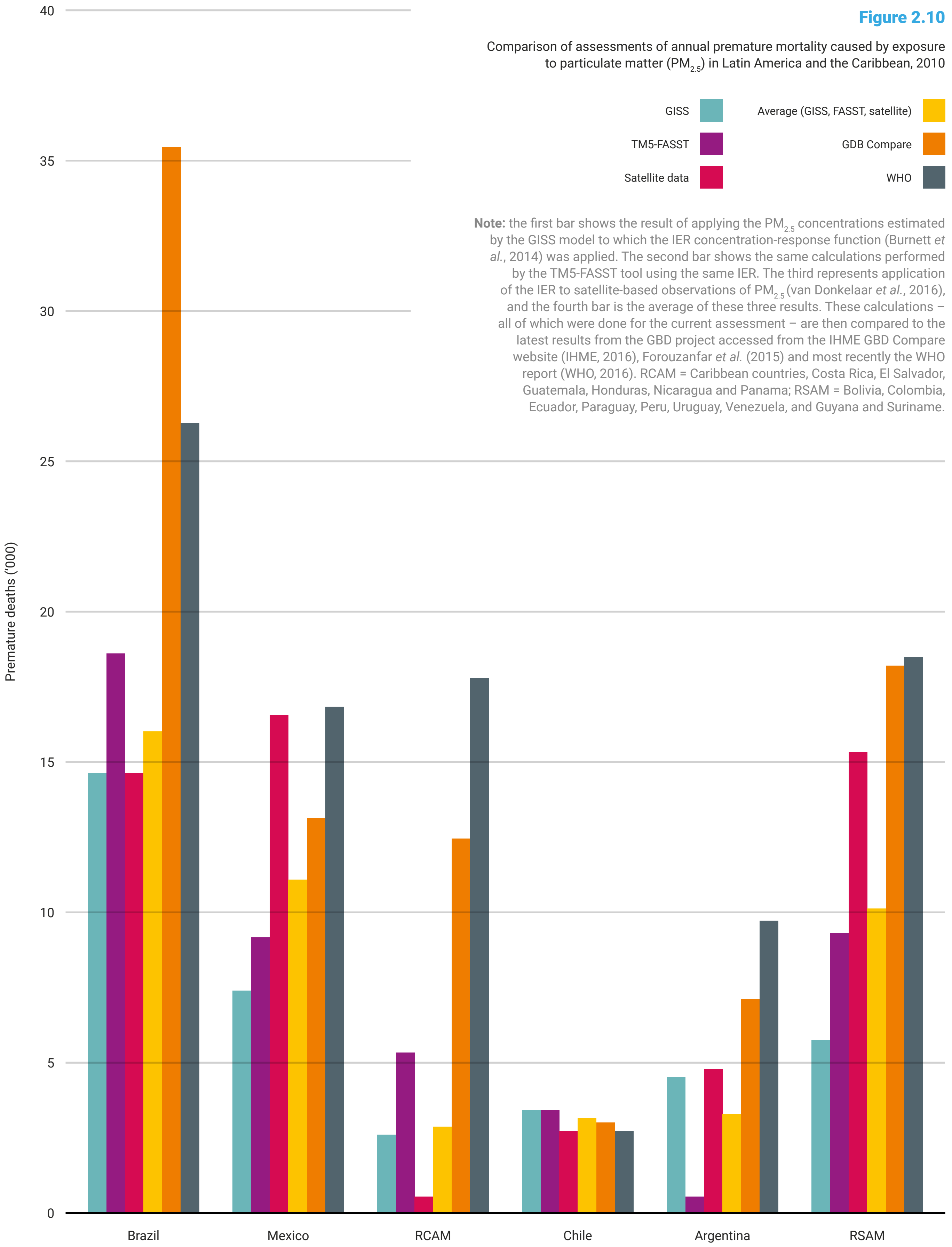


Figure 2.10

Comparison of assessments of annual premature mortality caused by exposure to particulate matter ($PM_{2.5}$) in Latin America and the Caribbean, 2010

Note: the first bar shows the result of applying the $PM_{2.5}$ concentrations estimated by the GISS model to which the IER concentration-response function (Burnett *et al.*, 2014) was applied. The second bar shows the same calculations performed by the TM5-FASST tool using the same IER. The third represents application of the IER to satellite-based observations of $PM_{2.5}$ (van Donkelaar *et al.*, 2016), and the fourth bar is the average of these three results. These calculations – all of which were done for the current assessment – are then compared to the latest results from the GBD project accessed from the IHME GBD Compare website (IHME, 2016), Forouzanfar *et al.* (2015) and most recently the WHO report (WHO, 2016). RCAM = Caribbean countries, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama; RSAM = Bolivia, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, and Guyana and Suriname.

deaths in 2050 is about 75 per cent higher than in 2010. This is due to three main factors:

1. the emissions leading to $PM_{2.5}$ and the subsequent increase in concentrations of $PM_{2.5}$ in the reference scenario (Chapter 1);
2. increases in population in the region between 2030 and 2050; and
3. population aging, with a large increase in the number of people over the age of 30 (Figure 2.9), which leads to higher mortality rates from air pollution.

It is noteworthy that the models resulted in different projections of premature mortality from $PM_{2.5}$ concentrations. The TM5-FASST and GEOS-Chem Adjoint models showed an increase in premature deaths in both 2030 and 2050, with GEOS-Chem Adjoint showing a more than doubling of premature deaths in 2050 compared to 2010. But the GISS model showed a slight decrease in 2030 (see the lower range of results for 2030, Figure 2.7), and only a slight increase for 2050 compared to 2010. As the health impacts were all calculated by using the IER function, then the differences must be due to differences in projections for $PM_{2.5}$ concentrations (see Chapter 1 for details of estimated spatial distribution of modelled $PM_{2.5}$ concentrations) and the different datasets used by the different modellers for population and baseline mortality rates.

The country values (Figure 2.8) showed similar patterns for the whole of Latin America and the Caribbean, but there was a larger range of values for Mexico than other countries; the GISS model indicated reductions in mortality, whereas the other two models projected increases in mortality in all countries. There is more agreement between the models in Argentina, Chile, Central America and the Caribbean, and a number of countries in South America.

It is important to compare the results of this assessment with other recent health impact assessments. The GBD project has been developing new estimates for health impacts from ambient air pollution; for Latin America, estimates have increased considerably since the previous study (Lim *et al.*, 2012). In addition, the WHO has released a report (WHO, 2016) showing country totals for premature mortality from ambient $PM_{2.5}$ air pollution. The WHO has developed exposure using a Data Integration Model for Air Quality (DIMAQ) incorporating data from multiple sources: ground measurements from 6 003 monitoring stations around the globe; satellite remote sensing data; and results from global chemical transport models. These have used the IER concentration-response function, as was also used in this assessment. The GBD project has developed an assessment of the 2010 and 2013 health impact of ambient $PM_{2.5}$ levels, and these have been developed from satellite imagery, modelling using the TM5-FASST atmospheric model and comparing these estimates with monitoring data (Brauer *et al.*, 2016). Figure 2.8 shows the results for 2010 from using the three models in this assessment. In addition, we show the estimates made as part of the GBD project as accessed from the website GBD Compare (IHME, 2016) and the results from the 2016 WHO report (referring to impacts in the year 2012). The WHO (2016) estimate for total deaths from $PM_{2.5}$ in 2012 for Latin America and the Caribbean is 96 757 premature deaths.

The results of this assessment show a similar pattern to those of the GBD and WHO, except for Central America and the Caribbean, where the GBD and WHO include an estimate of about 10 000 premature deaths in the Caribbean countries, which was not calculated by the models and satellite data used in this assessment (Figure 2.10).

With the exception of Chile, the estimated premature mortality in this assessment tends to be lower than the GBD or WHO estimates. As stated previously, a number of factors suggest that this assessment's estimates are conservative and on the low side, and this would seem to be reflected in that comparison. Excluding the large discrepancy in the Caribbean, it would seem that this assessment's average estimate for premature mortality is lower by a factor of two or less than the GBD and WHO ones, but quite close in some countries, including Mexico and Chile. Therefore, it can be said that the premature mortality estimates for 2010 resulting from this assessment are likely to be lower than the reality, which could be twice as high. This implies that the estimated numbers of premature deaths in 2030 and 2050 are also underestimates, and, finally, that opportunities for reducing those deaths might be greater than the values calculated in the scenarios in Chapter 3.

Given that we reproduce the pattern of impact in the GBD and WHO, if not the magnitude, it is understood that this adds credibility to the scenario modelling in Chapter 3, but that the benefits could be higher than estimated.

2.6.4

Impacts of ground-level ozone on health in Latin America and the Caribbean

The GISS, GEOS-Chem forward runs and TM5-FASST models provided the O_3 estimates. The models were used to estimate O_3 concentrations and deliver the O_3 metric used for the concentration-response function – the average of the highest daily O_3 concentration over the six-month period with the highest O_3 concentration. Premature mortality was developed using the concentration-response function according to Jerrett *et al.* (2009).

The results for Latin America and the Caribbean, from applying the TM5-FASST model only, are shown in Figure 3.11. The total number of deaths from O_3 was estimated as 4 933 in 2010, 7 129 in 2030 and 10 369 in 2050. The values are lower than the estimates for premature mortality caused by exposure to ambient $PM_{2.5}$ – about 11–13 per

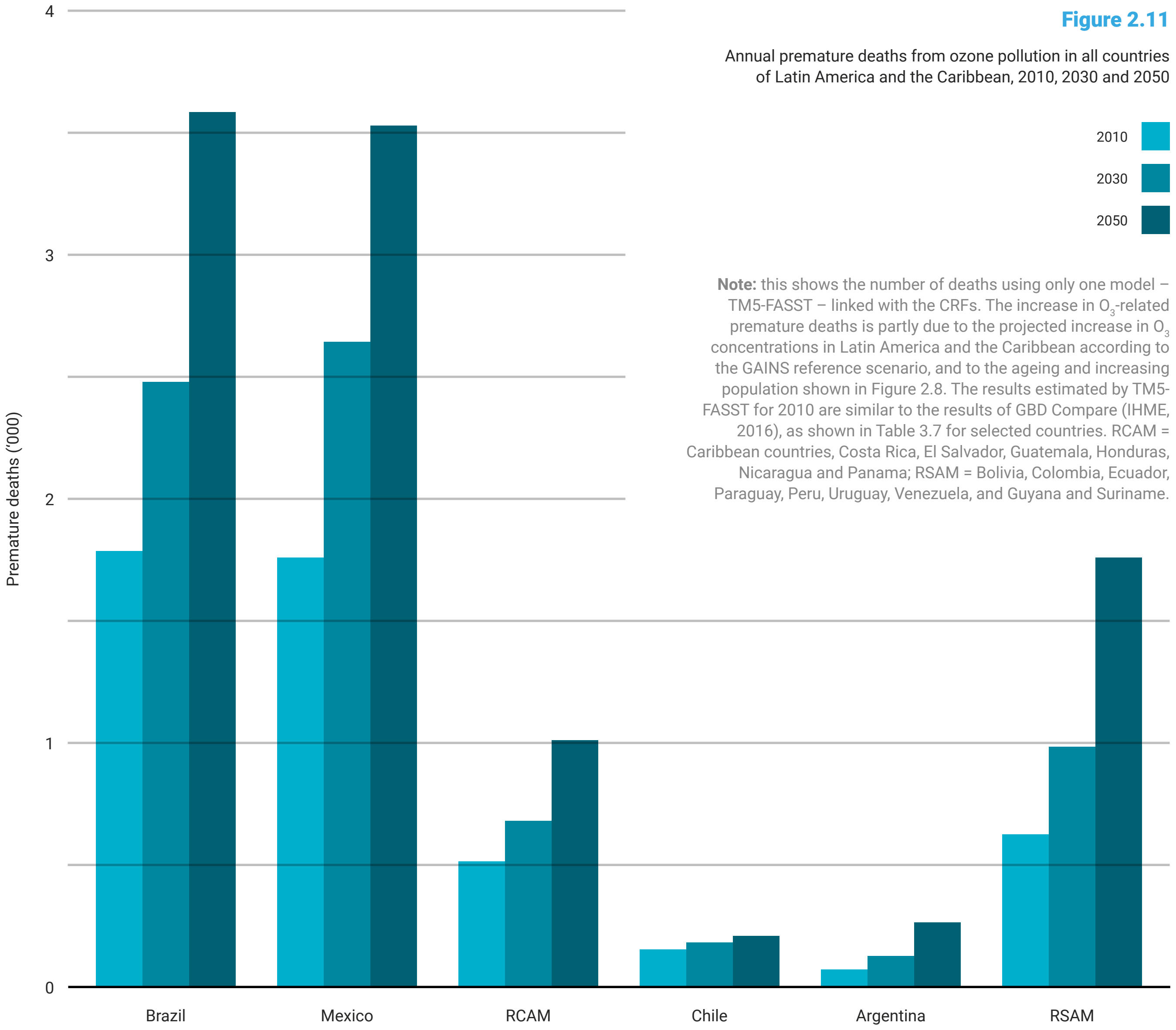


Figure 2.11

Annual premature deaths from ozone pollution in all countries of Latin America and the Caribbean, 2010, 2030 and 2050

Note: this shows the number of deaths using only one model – TM5-FASST – linked with the CRFs. The increase in O_3-related premature deaths is partly due to the projected increase in O_3 concentrations in Latin America and the Caribbean according to the GAINS reference scenario, and to the ageing and increasing population shown in Figure 2.8. The results estimated by TM5-FASST for 2010 are similar to the results of GBD Compare (IHME, 2016), as shown in Table 3.7 for selected countries. RCAM = Caribbean countries, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama; RSAM = Bolivia, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, and Guyana and Suriname.

Country	Annual number of premature deaths	
	TM5-FASST	GBD
Argentina	73	232
Brazil	1 801	2 063
Chile	145	77
Mexico	1 767	1 761

Table 2.7

TM5-FASST premature mortality results compared with GBD results, 2010

Source: IHME, 2016 (for GBD figures).

cent of total $PM_{2.5}$ mortality. The O_3-related premature mortality was not calculated using the O_3 results from the other two models, but, as can be seen from the maps in Chapter 1, all models have similar O_3 concentration estimates.

Uncertainty in the estimates of health impacts

The use of the IER functions of Burnett *et al.* (2014) used in this health impact assessment resulted in a fairly large uncertainty. These uncertainties were due to: (1) the scarcity of information available on actual exposure from second-hand smoke (SHS), which affected the estimation of $PM_{2.5}$ concentrations; (2) potential misclassification of exposure; (3) the variable duration of exposure; and (4) for several of critical assumptions, including the relative toxicity per unit mass of $PM_{2.5}$ of different types, the temporal pattern of exposure was not accounted for nor was considered any potential interaction between kinds of particles produced by different forms of combustion.

2.7

Conclusions

Globally, the emissions according to the reference scenario would lead to an increase in global temperature of about 2.3°C above the 1890–1910 temperature by 2050 and 3°C by 2070, which is compatible with IPCC average results for RCP 8.5. The emission changes in Latin America and the Caribbean under the reference scenario would also cause an increase in temperature, but their influence on global temperatures would, overall, be very small.

The reference scenario results for warming over Latin America and the Caribbean using the GISS model were similar to those obtained with the use of the GISS model with RCP 8.5 emissions which, for the year 2070, has warming of 0–3.5°C over the whole of Latin America and Caribbean, with regional differences. Warming is greater over the Amazon than over north-eastern Brazil, extratropical Latin America, with the IPCC AR5 providing a robust result across models (IPCC, 2013), with an increase of about 2–4°C over the Amazon and 0.5–2.5°C elsewhere in Latin America and the Caribbean. That the northern half of the Andes is projected to warm more than the southern half is another robust result. Results for the response of precipitation patterns to scenarios are not very robust in the suite of models used in the IPCC AR5 scenarios (IPCC, 2013), with different models not agreeing on the sign of the change. Nothing definitive can therefore be said about likely changes in precipitation patterns.

Climate change – affecting temperature, water availability, and CO_2 fertilization – and continuing population growth will substantially affect food security in Latin America and the Caribbean, as well as worldwide. The climate in Latin America and the Caribbean changed during the 20th century, and this has had regionally variable responses in terms of crop yields, the cultivation potential of crops, and impacts on weeds and pests. Current understanding indicates small increases in some of the major commodities, but reductions in most crops.

Even though the first-order effects of global warming on the cryosphere and cryosphere-dependent hydrological systems have been documented and are reasonably well understood, many uncertainties remain that make it difficult to extrapolate the changes observed during the last few decades into the future. The rapid retreat of glaciers throughout the region in some cases has not been mirrored in significant streamflow changes, and the relative influence of precipitation and temperature anomalies and trends needs to be better quantified in order to develop more reliable projections of water availability in Andean catchments. Furthermore, the feedbacks stemming from broadband albedo changes due to warming and pollution can currently only be hypothesized due to the lack of a robust database of observations across different latitudes. Many agencies and institutions are taking steps to bridge these knowledge gaps, but efforts are still scattered and not necessarily well coordinated. A network of long-term research sites documenting the rapid changes affecting the Andes cryosphere would be a welcome development for establishing regional estimates of future cryosphere evolution and its impacts on hydrological systems.

Ozone is already affecting crops across Latin America and the Caribbean. According to the modelling undertaken for this assessment, an annual amount of about 7.4 million tonnes of the yield of four crops – maize, rice, soybean and wheat – were lost in 2010. This is mainly made up of losses of yield from soybean, but there are also significant losses of maize and wheat. Under the reference scenario emissions, the projection estimates a slight increase in annual crop yield losses to about 8.9 million tonnes per year.

Air pollution is affecting health from exposure to outdoor concentrations of $PM_{2.5}$ and O_3, and from exposure to high concentrations of $PM_{2.5}$ indoors, where solid fuels are used. Under this assessment three models have been used to estimate outdoor $PM_{2.5}$ concentrations, and the mean estimate using these with the GAINS emissions is 47 000 premature deaths in 2010. This is expected to increase under the reference scenario to about 80 000 in 2050 using these models. This is caused by a combination of changes to pollutant concentrations and an expanding and ageing population. On comparing these results to the latest GBD estimates for 2010, or the WHO estimates for 2012, the models here tend to provide lower estimates, and there are reasons to believe that these are rather conservative and could be more than twice as high. However, the modelling used here and in Chapter 3 shows similar patterns of premature mortality, in relation to $PM_{2.5}$ concentrations in different countries and regions of Latin America and the Caribbean, to the GBD and WHO estimates.

The impact of O_3 concentrations on premature death in Latin America and the Caribbean leads to a lower number of deaths in comparison to $PM_{2.5}$ pollution – about 5 000 premature deaths in 2010. According to the TM5-FASST model, these deaths double to about 10 000 in 2050, using emissions in the reference scenario. Ozone concentrations represent a smaller cause of premature mortality than exposure to $PM_{2.5}$, and, according to the modelling used in this assessment, the number of O_3-related deaths in the region is about 13 per cent of those caused by $PM_{2.5}$.

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3

Measures on short-lived climate pollutants,

the potential reduction in emissions, and benefits for near-term climate and air quality

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Image: Aerial Drone View Of Sheep Herd Feeding On Grass. Radu Bercan, Shutterstock.

Contents

3.1

Introduction

The purpose of this chapter is to assess the technical potential for emission reductions through strategies on short-lived climate pollutants (SLCPs) in Latin America and the Caribbean, and to link such reductions to human health improvements from reduced exposure to fine particulate matter ($PM_{2.5}$) and ozone (O_3), to enhanced crop yields and vegetation health from reduced tropospheric O_3 levels, and to reduced near-term warming. The emission reductions follow from the implementation of a number of key measures with significant reduction potential for methane (CH_4), products of incomplete combustion including black carbon (BC), and hydrofluorocarbons (HFCs).

This analysis starts with identification of the measures that are likely to maximize the benefits for Latin America and the Caribbean. The measures were determined according to the impact they have on emissions of all relevant substances, as assembled in the GAINS model (Amann *et al.*, 2011), which is described in more detail in Chapter 1. The choice of measures was also harmonized with the analysis in Chapter 4, where factors important to emissions in Latin America and the Caribbean were identified, such as the relevance of location when emissions are released close to densely populated areas or other vulnerable locations such as glaciers. The analysis is constrained by the GAINS model structure to an assessment of the impact of technical abatement measures, while emission reduction potential from broader structural changes in the economy, consumption patterns or institutions are not investigated, although such changes could have significant impacts on emissions. Chapter 4 discusses examples of policies that are not explicitly included in Chapter 3, such as urban form and planning measures affecting mobility and transport choices, or the retrofitting of trucks.

The impact of measures to reduce emissions is calculated against a reference trajectory developed in the GAINS model, where the growth in energy use and industrial and agricultural activity follows the projections of the International Energy Agency (IEA, 2012) and the Food and Agriculture Organization of the United Nations (FAO) (Alexandratos and Bruinsma, 2012). This forms the assessment's reference scenario (Chapter 1).

Beyond the reference scenario, several additional emission scenarios were developed for assessing the impacts of identified measures on SLCP emissions under the reference scenario, and emissions that would occur under a climate scenario that aims to restrict temperature rise to the 2°C limit of the United Nations Framework Convention on Climate Change (UNFCCC) (IEA, 2012). These mitigation scenarios are referred to in the text and charts as SLCP mitigation scenarios, including specific mention of either "reference" or "climate". Both SLCP mitigation scenarios show the result of full implementation of all measures identified in this analysis across Latin America and the Caribbean, a similar assumption that was made in the global *Integrated Assessment of Black Carbon and Tropospheric Ozone of 2011* (UNEP-WMO, 2011). Note that the current assessment also includes HFC emissions and measures, which were not assessed in the global report.

A further scenario shows the emissions resulting from partial implementation of measures for cooking and heating, both regionally and in the rest of the world, taking into account barriers to implementation and the likely potential to overcome them. Both strategies, full and partial implementation, are applied to the reference as well as climate scenarios.

For all emission scenarios, Chapter 3 explores the benefits to health, crop yields and near-term climate. The GISS, GEOS-Chem and its Adjoint, and TM5-FASST models used to estimate atmospheric concentrations are described in Chapter 1. The use of these along with assessment models to estimate impacts and benefits is described in Chapter 2 for historical emissions and for the Latin America and Caribbean reference scenario. There are several important impacts specific to the region that are understood by science but which are difficult to quantify using numerical models. In those cases, the likely effects in relation to current knowledge are discussed.

It is important to highlight that the analysis focuses on measures that reduce the emissions of several pollutants from different sources, rather than focusing on the reduction of a particular one. For example, most sources of incomplete combustion emit a mixture of pollutants, and mitigation measures applied to these sources will simultaneously reduce a number of co-emitted species. Therefore, it is important to understand that whilst BC is an important focus for abatement, the full benefits of implementing these measures are calculated in relation to the net impact of all species controlled. However, the major sources of CH_4 emit mainly CH_4 and HFC sources emit almost only HFCs; therefore, controls targeting these two pollutants do not really affect emissions of other species.

3.1.1

Rationale for the selection of measures

In the reference scenario (Chapter 1), emissions of several air pollutants and greenhouse gases continue to grow (Figure 1.9) in spite of implemented legislation. Several technological measures exist that would allow emission reductions in the future. As discussed in Chapter 2 and in earlier publications (UNEP, 2007, 2011; Unger *et al.*, 2010; UNEP-WMO, 2011; Shindell *et al.*, 2012; Bond *et al.*, 2013), emissions of various substances have different climate impacts and there are virtually no measures that reduce one specific pollutant, except for those targeting CH_4 or HFCs.

The present analysis draws on the GAINS model (Chapter 1) database, follows the same principles in selecting mitigation measures as the UNEP-WMO global assessment (2011), and determines the net effect on radiative forcing resulting from the reduction of all co-emitted and abated pollutants. Emission reduction measures with a beneficial impact on air quality were ranked according to their expected climate benefit, estimated using the chosen climate metric, that is, the sum of all reduced SLCP species and greenhouse gases multiplied by the respective metrics. A subset of measures achieving more than 90 per cent of total forcing mitigation potential was used to define the SLCP mitigation scenario. This analysis also includes the mitigation potential for HFCs, which were not specifically addressed in the global assessment. It is important to note that whilst climate response to mitigation was used to select the SLCP measures, all the measures, except for those focusing on HFCs, also reduce air pollution – by reducing the $PM_{2.5}$ concentrations that have the largest impact on human health, and O_3 precursors that influence the formation of O_3 and its impacts on human health and vegetation, including crops.

There are some important updates to the analysis undertaken in the UNEP-WMO assessment, including different metrics used for evaluation of the measures. In the UNEP-WMO assessment, global warming potential over 100 years (GWP100) was used. This assessment, however, relies on the recent metrics developed for global temperature potential over 20 years (GTP20), in which the region-, season- and species-specific GTP20 values were calculated (Aamaas *et al.*, 2015). This new metric considers a gradual introduction of measures over a period of about 15 years, starting in 2015 and running to 2030, by when the maximum potential will be achieved, and then assumes that the reduction is maintained up to 2050.

3.2

Measures to reduce emissions in Latin America and the Caribbean

The UNEP-WMO global assessment (2011) presented measures that were selected and evaluated from a global perspective, and highlighted that more detailed regional analyses were necessary to better capture local mitigation opportunities in terms of reduction potential and benefits achieved, and also of specific measures that might be more appropriate for different regions. The process by which these region-specific measures have been identified is outlined in this section, starting with pollutant sources already highlighted in the international literature, followed by the sources identified by authors in the present assessment. These were all considered as additional or adjusted measures in the analysis of the key measures that maximize the temperature benefit in Latin America and the Caribbean (section 3.6).

GAINS model updates and extensions since the UNEP-WMO global assessment

A report by the World Bank and the International Cryosphere Climate Initiative (ICCI) focusing on the cryosphere (World Bank-ICCI, 2013) identified further mitigation measures such as the reduction of gas flaring and open biomass burning, especially in the vicinity of snow-covered areas.

Recent work highlighted the use of kerosene for lighting (Lam *et al.*, 2012) as an important source of BC – a source that was largely neglected in previous assessments. Diesel generators are also now included as a separate sector with dedicated control measures in the GAINS model. Finally, the brick sector has been redefined, now including many more categories of brick kiln in response to the critique that vertical shaft brick kilns are not necessarily a universal solution across all regions, and so the GAINS model now also includes Marquez (MK) and zig-zag kilns.

For CH_4 emissions, a number of changes were introduced in the analysis including explicit consideration of shale gas production, and new regional characteristics of oil and coal production and the waste sector. In contrast to the UNEP-WMO global assessment, the present analysis uses country-specific emission factors[1] to estimate the amount of associated waste gas vented from oil production, and to a much lesser extent from gas production. For shale gas an average leak factor of 4.3 per cent has been assumed, which falls in the range of 2–9 per cent published in peer-reviewed literature (Hughes, 2013; Tollefson, 2013; Lyon *et al.*, 2015). The model also spe-

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1. The factors were derived from country-specific data on the amount of associated gas generated, the amount of waste gas currently being recovered for utilization or reinjection, and the amount of unrecovered waste gas that is flared; waste gas that is not recovered or flared is assumed to be being vented; see Supplement in Höglund-Isaksson (2012) for further details. The mitigation option is to extend recovery, including utilization or flaring, to at least 95 per cent of the associated waste gas generated.

cifically considers losses of CH_4 during the transmission and distribution of natural gas, including distinguishing different factors for industrial and residential use.

For coal production, a structural update was made to allow for the separate estimation of emissions and mitigation potentials from pre-mining operations (de-gasification), mining operations (ventilation air CH_4 oxidation), and post-mining activities (no mitigation option identified).

For industrial wastewater, the unit for this activity changed from cubic metres (m^3) of wastewater to kilotonnes (kt) of chemical oxygen demand (COD) in the wastewater as the dilution of the wastewater can differ considerably in different production processes. Estimates of kt COD were derived from FAO statistics on the amount of product produced coupled with the default factors for COD per tonne of product, used by the Intergovernmental Panel on Climate Change (IPCC); for details see supplementary materials in Höglund-Isaksson (2012).

In this assessment, an updated version of the GAINS model is used with a higher regional resolution (Chapter 1) developed specifically for this study, and an enhanced list of measures for both air pollutants and CH_4. These updates allow a better representation of regional emission characteristics as well as mitigation opportunities.

3.2.1

Considering specific regional circumstances to identify relevant measures

Oil and gas

Emissions from oil and gas exploitation are estimated for three distinct sources.

1. **Venting of associated waste gas.** Estimated amounts of CH_4 released through the venting of associated waste gas are derived from information on a number of country-specific factors. There is a generic assumption that the fraction of unrecovered associated gas vented, rather than flared, is considerably higher for heavy oil than for conventional oil treatment facilities. For conventional oil, it is assumed that 71 per cent of the unrecovered associated gas is flared and 29 per cent vented, while for heavy oil the respective assumptions are 12 per cent and 88 per cent. These assumptions are for heavy oil treatment facilities in the Canadian province of Alberta (Johnson and Coderre, 2011) and, in the absence of region-specific estimates for Latin America and the Caribbean, have been assumed to be representative of such facilities in Latin America. These are likely to be the upper estimates[2] and could be improved if flux measurements of CH_4 become available from Latin American oil treatment facilities.
2. **Incomplete combustion of flared associated waste gas.** This is typically a minor source of CH_4 emissions and is derived on the assumption that the combustion efficiency of flares is on average 98 per cent. This means that 2 per cent of the CH_4 content of flared waste gas is released; recent observations indicate that CH_4 emissions might be temporarily higher if measures to reduce soot formation, such as steam injection, lead to near-extinguishing of flame in the flare (Conrad and Johnson, 2017). Gas flaring is, however, considered likely to be an important source of BC. Efforts to quantify, regulate and mitigate BC emissions have been limited by a lack of *in-situ* measurement techniques. A new technique for quantitatively measuring soot emission rates in flare plumes under field conditions has been reported by a group at Carlton University (Johnson *et al.*, 2011). This new approach was tested in a gas flare at a turbocompressor station in Mexico, where a soot mass emission rate of 0.067 grams per second (g/s) was recorded. The new version of the GAINS model, used in this assessment, includes a mitigation measure simulating operation with reduced flaring and improved flare efficiency that simultaneously reduces emissions of several pollutants, including CH_4 and BC.
3. **Unintended leakage from equipment.** Estimates of the amount of CH_4 released by unintended leakage from equipment are highly uncertain as such leakage occurs irregularly and may differ substantially from one well to another. The GAINS model applies default factors (IPCC, 2006) for this type of leakage, including for Latin America and Caribbean.
4. **Distribution losses.** Methane leaks during pipeline transmission and distribution. GAINS distinguishes specific leak factors differentiated between long-distance and local distribution networks as well as industrial and residential consumers; for the latter the losses are significantly higher (Dennet and Vallender, 2011; McKain *et al.*, 2015).

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[2] Apparently, the characteristics of Latin American heavy oil differ from other heavy oils in that its viscosity is lower than usual despite a high density (Dusseault, 2001; Xiaofei *et al.*, 2013). This type of oil is often referred to as "foamy" oil because of the gas bubbles that are trapped in the extracted oil, which contribute to enhancing its flowability and reduce the volumes of free gas released (Xiaofei *et al.*, 2013; Santos *et al.*, 2014). A comparison of the characteristics of Venezuelan and Canadian heavy oil indicated that the amounts of gas in the oil are extremely similar and yet the mobility of Venezuelan heavy oil is two to three times greater than the Canadian equivalent (Dusseault, 2001).

Livestock

The assumption is that the majority of Latin American dairy and beef cattle graze outdoors. Hence, the majority of CH_4 emissions originate from enteric fermentation and less from manure management, limiting the potential use of biogas digesters. While it is expected that further intensification of beef production will occur, leading to higher numbers of large farms, no assumptions about such developments are made.

Solid waste

It is assumed that there is no large-scale organized source-separation of municipal solid waste (MSW) for recycling, composting or energy recovery in Latin America. It is, however, also assumed that some household food and kitchen waste is treated in backyard composting. While landfill gas recovery and electricity generation have been pursued at some sites, it was assumed in this assessment that all other MSW is deposited in landfill without landfill gas recovery, hence creating opportunities for abatement. The open burning of waste is discussed further in section 3.2.1.7.

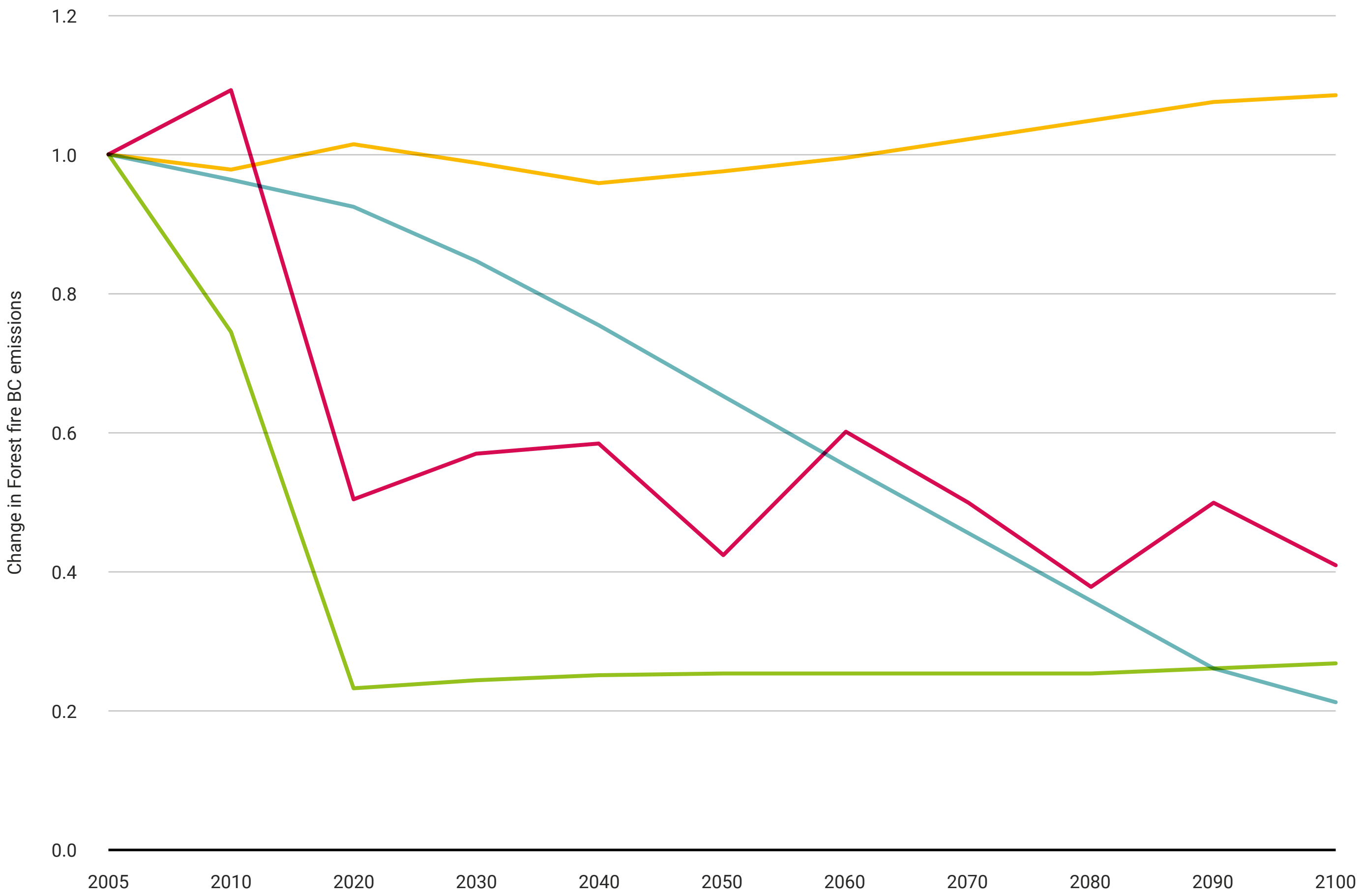
Coal mining

Some of the largest open-pit mines in the world are in Colombia (Huertas *et al.*, 2012), producing a large share of the country's coal; Colombia also accounts for about 80 per cent of South America's coal output. In Brazil, nearly half of coal production originates from surface mines. For all other Latin American and Caribbean countries, the assumption in GAINS is that all coal mining is underground. Default emission factors (IPCC, 2006) were applied for surface and underground mining. All underground mines are assumed to have a CH_4 concentration of 0.3 per cent, except Mexico with 0.5 per cent, in the ventilation air, which makes it technically possible to equip mine ventilation shafts with CH_4 oxidizers.

Figure 3.1

Relative change in emissions from forest and savannah fires in Latin America, as developed in the RCP scenarios, 2005–2100

Note: changes in emissions are indexed to 2005.



Open biomass burning

Key sources of emissions can be grouped into two major categories: open field burning of agricultural residues, and forest and savannah fires. The latter group includes land-clearance, wildfires, and burning for pasture revitalization; a global assessment by van der Werf *et al.* (2010) justifies grouping emissions in these two categories. In the UNEP-WMO global assessment, emissions from burning agricultural residue were reduced by assuming a well implemented ban on this activity. The rationale was to show the impact that stringent policies would have, and was justified by the success of such a policy in several countries of the European Union (EU) where remote sensing data indicate a decrease of nearly 100 per cent in agricultural burning. There are, however, regions in the EU where the ban faced strong opposition from farmers and enforcement is poor. Similar policies also exist in Argentina, Brazil, Mexico and Central America. As there is a shortage of quantitative information about the enforcement of burning bans, the efficient long-term implementation of the ban is assumed, as it was in the UNEP-WMO assessment.

For forest and savannah fires it is assumed that they mainly relate to land clearance, which is a process driven by agricultural development of previously forested land, and shows inter-annual variability due largely to climate (van der Werf *et al.*, 2010). The sensitivity analysis can therefore be performed using comparable assumptions to those in the IPCC's Representative Concentration Pathway (RCP) 6.0 scenario (the assumptions used in the reference scenario) and the RCP 4.5 scenario where a significant reduction is achieved and sustained to the end of the modelling period (Figure 3.1).

Cookstoves

Information about region-specific shares of different cookstove technologies has been collected and applied to the model, allowing for better representation of mitigation opportunities. The assumptions draw on the data from Mexico and Central America (Masera *et al.*, 2007; Berrueta *et al.*, 2008; Johnson *et al.*, 2008; Pine *et al.*, 2011; Troncoso *et al.*, 2011) as well as from local studies in several other South American countries (Ruiz-Mercado *et al.*, 2011).

The scenarios considered here include revised penetration rates for Latin American and Caribbean countries in the reference scenario as well as the potential for mitigation options; see section 3.4.4 for a more detailed discussion of specific assumptions for improved cookstove penetration and its potential future evolution.

Garbage/trash burning

Activity data and emissions are estimated in the GAINS model. Activity data is estimated from the statistics and assumptions on MSW generation rates (IPCC, 1997; Neurath, 2003), the fraction of MSW for which a treatment is unspecified (Höglund-Isaksson, 2012), and assumptions about the percentage burned (Neurath, 2003). Additionally, there are significant uncertainties in the estimates of all the above factors because recycling rates are not well documented and are often included under the heading "MSW unspecified treatment".

Emission factors are derived from studies that measured open burning of residential waste in Mexico (Christian *et al.*, 2010; Li *et al.*, 2012). The estimates of emissions, and even more so of BC, are highly uncertain but the contribution to total $PM_{2.5}$ concentrations in some areas could be as high as 15 per cent (Li *et al.*, 2012), although much lower at the regional scale.

Open burning of residential waste is illegal in most countries but enforcement is far from satisfactory. The current GAINS model estimate for BC emissions suggests that about 2–3 per cent originates from this source. However, lacking any information about the potential for efficient mitigation and owing to a very uncertain emission profile – the BC/organic carbon (OC) ratio and co-emitted species – there are no specific reduction options assumed in the mitigation scenarios developed in this assessment. As indicated above, emissions might be higher locally, and in some regions practices of disposing of old tyres by burning might aggravate the situation further, and obviously should be targeted as several hazardous air pollutants are emitted (Lemieux *et al.*, 2004; Solorzano-Ochoa *et al.*, 2012). A recent assessment of global emissions of trace gases from open burning of domestic waste (Wiedinmyer *et al.*, 2014) suggests much higher burning rates than assumed in this analysis. If confirmed, this provides one more argument to target this source of pollutants, including BC.

Brick production

With respect to brick production, the UNEP-WMO global assessment focused on South Asia, which did not correctly reflect the structure of this sector in Latin America and the Caribbean and relevant region-specific technologies.

The GAINS model has been extended and updated to include the most recent production data (Bellprat, 2009; EELA, 2011; PRAL, 2012; Stratus Consulting, 2014; Swisscontact, 2014b), information about the structure of the sector in key producing countries (EELA, 2011; Erbe, 2011; PRAL, 2012; Stratus Consulting, 2014; Swisscontact, 2014a), and the efficiency of and emissions from new categories of kilns specific to the region (Bruce *et al.*, 2007; Bellprat, 2009; EELA, 2011; Maíz, 2012; Márquez, 2011a, 2011b; Stratus Consulting, 2014; Swisscontact, 2014a).

Important factors in determining the emissions and mitigation opportunities in this sector include brick kiln technology and the type of fuel used. This varies across the region; the regional information available (Bellprat, 2009; Erbe, 2011; Stratus Consulting, 2014) was used to the extent possible.

While many countries in the region have emission standards covering maximum permissible concentrations of several pollutants, including PM, nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO) (Stratus Consulting, 2014), enforcement is difficult because there are relatively few measurements available, especially outside Mexico. For BC the available measurements (Christian *et al.*, 2010; Cardenas *et al.*, 2012; Maíz, 2012) cover several types of kiln including MK. The measurements of BC/OC ratios for traditional kilns appear comparable to data from India (Maithel *et al.*, 2012).

Sector	Low-GWP alternatives
Aerosol	HFO-1234ze, *R-290 (propane)**
Commercial refrigeration	R-290, R-600a, R-1270, *R-744*
Domestic refrigerators	R-600a
Fire extinguishers	*FK-5-1-12*, FM200, R-744 (CO_2), ABC powder
Foam	*R-744*, R-290, HFC-152a, HFO-1234ze
Ground-source heat pumps	R-744, *R-290*
Industrial refrigeration	*R-717 (NH3)*, R-744
Solvents**	Iso-paraffin/siloxane (KC-6)
Mobile air conditioning	*HFO-1234yf*, R-744
Stationary air conditioning	R-290, R-1270, *R-744*
Transport refrigeration	R-290, R-1270, *R-744*

Table 3.1

Sector-specific options with low global warming potential considered for hydrofluorocarbon abatement in the GAINS model for Latin America and the Caribbean

*Alternatives in italics are used in the maximum technical mitigation potential (MTFR) scenario in GAINS.

** GAINS considers a ban on HFC-based solvents as a control option.

Transport

Compared to the UNEP-WMO global assessment, the status of transport regulations was updated using international sources (DieselNet, 2015) with information available for Argentina, Brazil, Chile, Mexico and Peru. National data provided during this project were also used, specifically for Argentina, Brazil, Chile, Colombia, Mexico and Uruguay, as well as Central America and the Caribbean.

Additional regional information was obtained from Argentina, Brazil and Mexico describing specific regulations as well as fleet characteristics and emissions inventories (Ministério do Meio Ambiente, 2011), which improved representation of the road transport sector in the model.

The acquired information includes both fuel quality and current and planned emission standards, which are essential in modelling the evolution of emissions in the future and for determining mitigation potential. It has been noted that several countries lack air quality standards, for example Uruguay, Central American countries and some Caribbean countries. Consequently, one of the major obstacles is a lack of appropriate low-sulphur diesel, which is necessary to introduce the most efficient control technology such as diesel particulate filters (DPF). Furthermore, the fleet of heavy-duty trucks, buses and light-duty vehicles is often very old, with a slow turnover and a lack of emission certificates. Nonetheless, several countries, including Argentina, Brazil, Chile and Mexico, have set ambitious plans to introduce European Emission Standards (Euro 5/V) for new vehicles.

An old and often poorly maintained vehicle fleet is reflected in measurements of emission factors (Mancilla *et al.*, 2012) as well as the share of so-called high-emitters (McClintock, 1999, 2007; Smit and Bluett, 2011; Yan *et al.*, 2011, 2014).

Taking updated information about legislation, fuel standards and vehicle age distribution into account, the model estimates the feasible pace of implementation of strict emission standards on new vehicles, aligned with the timely availability of fuel of respective quality, and, in parallel, the introduction of programmes to eliminate high-emitting vehicles from the roads. Additionally, similar measures are assumed to be available for off-road machinery but, as actual data on this sector is much sparser, broad assumptions are used.

Hydrofluorocarbon and hydrochlorofluorocarbon mitigation potential

As discussed in Chapter 1, the reference scenario developed with the GAINS model includes the phase-out schedule for hydrochlorofluorocarbons (HCFCs) as agreed by Parties to the Montreal Protocol in September 2007 (UNEP, 2007). However, the reference scenario does not account for the HFC phase-down effects of the Kigali Amendment to the Montreal Protocol (UNEP, 2016), an agreement that is in the process of ratification. In addition to the phase-out of HCFCs, the Montreal Protocol requires the production and consumption of HCFC-22 for servicing existing equipment to end completely after 2040. In spite of this, HCFC/HFC emissions in Latin America and the Caribbean are estimated to increase by a factor of eight between 2005 and 2050 (Chapter 1, section 1.5.4).

At the same time, there are significant opportunities for reducing HCFCs/HFCs.

- Technology conversion of new products/manufacturing lines, with the introduction of alternative or not-in-kind replacements that have lower global warming potential (GWP).
- Increased energy efficiency of new products, with energy savings for consumers. Energy efficiency is a driver of change, especially in the refrigeration and foam insulation markets. Many industry efforts are under way showing that lower-GWP alternatives can achieve equal or better energy efficiency than the high-GWP HFC-based systems. This can be done through good design.
- Introduction of standards for flammable alternatives, training of service technicians and good refrigerant management can also help to introduce practices for the safe handling of alternatives and leak prevention, especially in the refrigeration, air-conditioning and heat-pump sectors.
- Retrofitting with lower-GWP alternatives, provided the equipment allows this to be done safely and without jeopardizing energy efficiency. One example is the retrofit of equipment with large charge sizes in commercial refrigeration systems currently using high-GWP refrigerants such as R-404A, which has a GWP of 3922.
- End-of-life management is another important way to destroy or recover and reuse HFCs from old equipment that has been disposed of or replaced.
- Introduction of bans on imports of products containing high-GWP HFCs, unless essential.

The GAINS model distinguishes several abatement options to reduce HFC emissions from anthropogenic sources. Their removal efficiencies, costs and application potentials were determined based on the available data (Tohka, 2005; UNEP, 2007; Gschrey *et al.*, 2011; Höglund-Isaksson *et al.*, 2012, 2013).

Table 3.1 lists alternatives that are currently used on a commercial scale and are considered in the GAINS model for assessing their mitigation potential. The model, moreover, considers good-practice measures for leakage control during the use and recovery of refrigerants after the end-of-life of refrigeration and air-conditioning equipment.

3.3

Mitigation measures selected for this assessment

Drawing on the discussion of measures previously analysed in global studies (UNEP, 2007, 2011; Unger *et al.*, 2010; UNEP-WMO, 2011; Shindell *et al.*, 2012) and options included in the GAINS model (Höglund-Isaksson, 2012; Höglund-Isaksson *et al.*, 2012, 2013; Klimont *et al.*, in preparation), as well as the specific opportunities for Latin America and the Caribbean (section 3.2.1 and Chapter 4), Table 3.2 presents the set of measures selected for regional SLCP mitigation. The term “measures” is used in this assessment to describe a set of technological options, operating practices and strategies to reduce emissions of SLCPs. The method of selection of SLCP measures from the large database of air pollution and non-CO_2 reduction options defined in the GAINS model is discussed in section 3.1.1. This method was applied to newly developed data on activities and measures in Latin America and the Caribbean in order to identify relevant SLCP mitigation opportunities. The estimated emission reductions, assuming full and efficient implementation of these measures, are discussed in section 3.5, and impacts on climate, human health and crop yields in section 3.6.

Table 3.2

Measures selected in the SLCP mitigation scenario for Latin America and the Caribbean

*Including leakage control, improved components, end-of-life recovery, etc.

Methane measures	
Oil and gas production and distribution	• Recovery and use of vented gas in oil and gas production. • Reduction of gas leakage during distribution.
Waste	• Separation and treatment of biodegradable MSW. • Food industry solid and liquid waste treated in anaerobic digesters with biogas recovery.
Coal mining	• Pre-mine degasification and recovery of CH_4 during mining.
Agriculture	• Anaerobic digestion for biogas production.
Measures addressing incomplete combustion (affecting BC and co-emitted species)	
Households	• Clean cooking and heating stoves.
Transport	• Euro VI/6 on new vehicles, including particle filters (DPF). • Elimination of high-emitting vehicles. • Other measures: improved inspection and maintenance.
Industry	• Modernized coke ovens. • Modernized brick kilns. • High-efficiency PM controls in industrial biomass and waste combustion.
Agriculture	• Enforced ban on agricultural open field burning.
Oil and gas production	• Reduced gas flaring.
HFC measures	
All sectors	• Implementation of good practices*. • Training of service technicians. • Technology conversion to lower-GWP or not-in-kind alternatives. • Reduced charge size and improved energy efficiency. • Ban on imports of products containing high-GWP HFCs, unless essential. • Retrofit/replacement of refrigerants with lower-GWP alternatives provided the equipment allows for this safely and without jeopardizing energy efficiency.

The final set used in the analysis includes 21 measures addressing CH_4, HFCs and options to reduce emissions from incomplete combustion (Table 3.2). Most of the selected measures are the same as those in the UNEP-WMO global assessment except those for HFCs, which were not previously included. However, even though these are principally the same categories, they include parameterization with regional/local circumstances, experience and data sources (section 3.2.1). Additionally, reducing emissions from gas flaring is included. Real-life experience in the application of the proposed measures does exist, including in Latin America and the Caribbean (Chapter 4), but increasing penetration and assuring adoption and enforcement will be a challenge.

While the measures address a wide variety of economic activities, most of the mitigation potential lies in relatively few sectors. Oil production and waste management measures for CH_4, and household (cookstoves) and transport measures for BC, account for most of the achievable emission reductions in Latin America and the Caribbean. A transition to low-GWP and other HFC measures (Table 3.2) needs to be implemented to achieve HFC phase-down targets under the Kigali Amendment to the Montreal Protocol (UNEP, 2016). For HFCs, applications in the transport and refrigeration sectors represent a major opportunity.

3.4

Scenarios used in the assessment

A number of different scenarios have been developed to illustrate the benefits of an SLCP policy focus in Latin America and the Caribbean. The first is the reference scenario against which all mitigation scenarios are evaluated; the second outlines an aggressive CO_2 reduction case, which can be considered as an alternative baseline to the reference scenario, but one linked to a successful transition to a low-carbon world – therefore called the climate scenario. There are several reasons why the mitigation scenarios are also evaluated against the climate case: the climate scenario has co-benefits for SLCP reduction; it potentially is a more realistic future in view of the December 2016 UNFCCC Paris Agreement, and finally, such an approach was used in the UNEP-WMO global assessment.

Two scenarios then focus on SLCP mitigation:

1. a full implementation scenario in which all identified SLCP measures are implemented in all parts of Latin America and the Caribbean, and across the world – this scenario is further referred to as "SLCP mitigation";
2. a more plausible scenario which can show the benefits if only partial implementation of some of the measures identified is achieved – this scenario is further referred to as "SLCP mitigation (partial implementation)" and is discussed in sections 3.4.4 and 4.5.1.

These two mitigation scenarios are compared to both the reference and climate scenarios. However, in the case of SLCP mitigation (partial implementation), only impacts on BC emissions are discussed as there was no capacity to perform full impact assessment including health and climate benefits. All the scenarios include assumptions for all the world's regions as changes in emissions elsewhere can affect Latin America and the Caribbean, in some cases quite considerably.

3.4.1

Reference scenario

The key assumptions employed in the reference scenario have been described in Chapter 1. It is based on expected changes in wealth, population, technology as projected in the Energy Technology Perspectives study (IEA, 2012), and the implementation of existing policy, including all current air pollution legislation. This scenario has been developed within the ECLIPSE project, for which it has been used in several regional and global modelling experiments including air pollution and climate impact analyses (Stohl *et al.*, 2013, 2015; Safieddine *et al.*, 2014; Yttri *et al.*, 2014; Eckhardt *et al.*, 2015; Quennehen *et al.*, 2015; Klimont *et al.*, in preparation). The impacts of the emissions according to the reference scenario are described in Chapter 2. All the mitigation scenarios are compared with the reference scenario, and the benefits of mitigation are calculated as the difference between the impacts expected in 2030 and 2050 in the reference scenario, and the impacts under the respective mitigation scenarios.

3.4.2

Climate scenario

This scenario considers the changes in emissions of all substances associated with CO_2 mitigation measures that restrict CO_2 concentrations to 450 parts per million (ppm) or temperature increase to 2°C. The macroeconomic and energy-use projections underlying this scenario originate from the International Energy Agency (IEA, 2012), while the assumptions on environmental policy, specifically regarding air pollution, are the same as those used in the reference scenario. The climate scenario follows a global CO_2 trajectory similar to RCP 2.6 (Van Vuuren *et al.*, 2011); in view of the outcome of the UNFCCC COP21 at which 195 countries adopted the first universal climate agreement (UNFCCC, 2015), such scenarios become even more relevant.

Achieving climate mitigation goals is associated with important changes in the energy system – a transition to the lower use of fossil fuels and, consequently, a reduction in emissions of CH_4 and air pollutants. However, emissions from some important sources of BC, such as the use of biomass for cooking, are not seen as declining much, leaving large mitigation potential for carbonaceous aerosols.

3.4.3

SLCP mitigation scenario

This SLCP mitigation scenario assumes that all measures identified in sections 3.2 and 3.3 are fully implemented in all Latin American and Caribbean countries, as well as the rest of the world. It is not suggested that this is a realistic scenario as this level of implementation may well be difficult to attain, at least for some sources, but it does identify the window of opportunity that can be approached by a concentration of policy and programme development. This mitigation scenario does not include national commitments made for the UNFCCC COP21 discussions – the so called Intended Nationally Determined Contributions (INDCs) – on the reduction of greenhouse gas emissions and, in some countries, SLCPs such as BC. The INDCs were not available when the data developed for this assessment were processed to establish the reference and mitigation scenarios.

Full implementation does not mean that all measures are introduced immediately to the maximum extent. One of the critical elements is the assessment of constraints limiting application of a given measure in a particular sector and/or region within a given time horizon. There are several factors that contribute to such limitations. Technological and, to the known extent, cultural limitations are considered, while potential economic constraints are ignored – it is assumed that technologies will be accessible and their cost will not limit their application (Klimont *et al.*, in preparation). The constraints diminish over time, leading to increasing mitigation potential in the longer term. For all regions, the lifetimes of mitigation measures, as well as primary technologies, have been considered in building the constraints, since premature scrapping of installations such as cars and industrial plants is not assumed. Since most of the identified technologies that reduce SLCP emissions have technical lifetimes of less than 20 years, full implementation of many of them is technically possible by 2030.

Table 3.3

Assumed level of implementation of clean fuelwood stoves in Latin America and the Caribbean, 2020–2050

[a] The stove types represent categories with different combustion efficiency and emissions. Here, the emissions of $PM_{2.5}$ per unit of fuel used are reduced by 60 per cent, 80 per cent, and >95 per cent for *improved*, *new*, and *fan-assisted* stoves, respectively.

[b] SLCP mitigation (partial implementation).

Stove type[a]	Scenario	Region	2020	2030	2040	2050
			% of total fuelwood use			
Improved	Reference	Mexico, Caribbean, Central America	7	12	15	15
		South America	5	9	15	15
	Mitigation[b]	Latin America and the Caribbean	35	45	15	0
New	Reference	Mexico, Caribbean, Central America	1	3	5	5
		South America	0	2	5	5
	Mitigation[b]	Latin America and the Caribbean	15	35	55	60
Fan-assisted	Reference	Mexico, Caribbean, Central America	2	6	10	10
		South America	0	0	0	0
	Mitigation[b]	Latin America and the Caribbean	10	20	30	40

At the same time, this scenario ignores some of the heavily debated limitations regarding the introduction and roll-out of clean cookstove technologies (Pine *et al.*, 2011; Ruiz-Mercado *et al.*, 2011; Troncoso *et al.*, 2011); a description of the constrained mitigation case is given in section 3.4.4.

Finally, this scenario also considers selected measures that are not primarily technology based, such as the elimination of high-emitting vehicles, the ban on open agricultural burning, reducing gas flaring, and the substitution of coal in the residential sector; the latter is mostly relevant to the world beyond Latin America and the Caribbean.

3.4.4

SLCP mitigation scenario (partial implementation) with alternative cookstove assumptions

This section outlines a level of mitigation for the different SLCP measures that includes a different set of assumptions about the feasibility and pace of implementation of particular options in specific sub-regions (Table 3.3). These assumptions are derived from an analysis of positive and negative experiences with particular implementation programmes (Chapter 4). While such an approach might appear somewhat conservative, it provides an ambitious programme of implementation that achieves a significant proportion of the full potential emission reductions identified in the SLCP mitigation scenario.

In particular, the key element that is different from the full SLCP mitigation scenario is the set of assumptions about the pace and maximum penetration rates for various cooking and heating stoves, including the cleanest available on the market. The issue of how to assure sustained use of clean stoves has been under discussion for a long time (Foell *et al.*, 2011; Ruiz-Mercado *et al.*, 2011) and evidence from various parts of the world suggests that many of the programmes fail in the long term (Foell *et al.*, 2011; Shrimali *et al.*, 2011; Wickramasinghe, 2011). The UNEP assessments (UNEP, 2011; UNEP-WMO, 2011) have devoted separate chapters to the concern, providing both positive and negative examples.

For Latin America and the Caribbean, there are studies analysing local and regional issues associated with the adoption of clean technologies for cooking and heating as well as their real-life efficiencies (McCracken and Smith, 1998; Berrueta *et al.*, 2008; Johnson *et al.*, 2008; Ruiz-Mercado *et al.*, 2011; Troncoso *et al.*, 2011). In this assessment a specific set of assumptions has been developed on how the trajectory for replacing current stove stock with clean alternatives could look over the next few decades, considering regional experience, specifically from Mexico and Central America. These assumptions are used across the region and are illustrated in Table 3.3. Both the full and partial implementation strategies assume the complete replacement of traditional cookstoves with either improved, new or fan-assisted versions, with the difference being how quickly the transition to the least-emitting types of stoves takes place.

There are other sectors in which several implementation issues have been identified, for example in the transport sector where the introduction of stricter emission standards has often been hampered by a lack of fuel of the required quality, specifically low-sulphur fuel. Beyond this, there are several issues related to the monitoring of enforcement of specific legislation in several sectors, which might lead to delays or inferior performance of installed technology. It has been shown, however, that in the longer term these market failures have been successfully removed in developed countries as well as in some developing ones (Xu *et al.*, 2009; Xu, 2011). In informal sectors, such as brick production in the developing world, there are several barriers to implementation, and experience shows mixed results in the transition to cleaner technologies. In this scenario, the residential sector was chosen as a case study since the adoption of clean stove technology has been widely studied and this sector is among the most important SLCP emitters offering significant mitigation potential.

3.5

Effect on emissions of implementing measures in Latin America and the Caribbean

This section focuses on the emission reduction that could be achieved if the measures selected and discussed in sections 3.2 and 3.3 were introduced in the reference and climate scenarios. The discussion includes sectoral and regional issues, highlighting key opportunities that could help to prioritize measures, at least from an emissions mitigation perspective. The resulting emissions were spatially distributed across the region using the same set of proxy data as the reference scenario, thus assuring consistency across the scenarios, and these were subsequently used in the climate and regional air pollution, health and crop impacts models (section 3.6).

Figure 3.2 presents an overview of the estimated emission mitigation potential in the SLCP mitigation scenario compared to the reference and climate scenarios. As discussed in Chapter 1, the reference scenario assumes a strong increase in economic output and energy use, and about a 30 per cent growth in livestock production, which is associated with rising HFC, CO_2 and CH_4 emissions. At the level of the whole of Latin America and the Caribbean, most air pollutant emissions increase more slowly than greenhouse gases due to existing air quality legislation, with the exception of ammonia (NH_3), which increases proportionally to changes in livestock output.

The climate scenario brings about a long-term reduction in CO_2 of more than 55 per cent in 2050 compared to the reference scenario, or about 23 per cent when 2050 emissions are compared to 2010 levels. The changed structure of energy production and use, as well as lower consumption, results in a decline in estimated CH_4 and air pollutant emissions, but to a much smaller degree. For example, CH_4 emissions under the climate scenario are about 25 per cent lower in 2050 than in the reference scenario, if still 16 per cent higher in 2050 than in 2010. Methane emission reductions are only associated with changes in fossil fuel production in this scenario, as it does not assume any specific measures for important sectors such as livestock and waste. A similar magnitude of emission reductions is estimated for NO_x, SO_2, and to some degree CO, as their emissions are strongly linked to fossil-fuel demand. For emissions that lead to PM and non-methane volatile organic compounds (NMVOCs), on the other hand, there are no significant reductions under implementation of the climate scenario. This is primarily due to the fact that large proportions of these emissions originate from the residential sector, where biomass use plays an important role. Consequently, in the climate scenario, without any additional incentives to stimulate access to clean energy for cooking, PM pollution is not reduced and this scenario only delivers small benefits for SLCP mitigation, except in the case of CH_4.

By 2050, the SLCP mitigation scenario brings HFC reductions of more than 98 per cent and of 38–49 per cent for CH_4, relative to the climate and reference scenarios. For the products of incomplete combustion, a reduction of nearly 90 per cent in BC emissions relative to 2010 could be reached when SLCP measures are implemented in both the reference and climate scenarios. For SO_2 and NH_3 there are only insignificant changes in emissions from implementation of the SLCP mitigation strategy. However, NO_x emissions show a strong reduction due to the large share of total emissions from the transport sector, one of the target sectors for the SLCP mitigation strategy because of the strong radiative forcing of BC emitted from diesel vehicles (and low OC). It is worth noting that for several species the mitigation potential increases over time as old vehicles and inefficient stoves are replaced with more efficient models and technology.

The following sections discuss mitigation opportunities in Latin America and the Caribbean in more detail, dividing the measures into those that reduce emissions of the products of incomplete combustion (including BC), CH_4, and HFCs.

3.5.1

Measures addressing the emission of products of incomplete combustion

The SLCP mitigation strategies for reducing the emission of products of incomplete combustion have a significant impact on the situation that would occur under the reference scenario (Figure 3.2). The range of measures for reducing BC emissions brings about varied but significant reductions, as shown in Figure 3.3. The full height of the bars in the figure represents the reference scenario, in which no additional measures are implemented beyond current legislation.

When SLCP mitigation is applied to both the reference and climate mitigation scenarios, the relative potential for emission reduction is broadly similar, and increases significantly over time from about 69 per cent in 2030 to about 88 per cent in 2050. The major reason for this is the increased penetration of measures in the transport sector, which, combined with the expected high growth in transport activities, leads to higher mitigation potential. The second largest opportunity relates to clean cooking and heating stoves, with the reduction potential also increasing towards 2050 because of the assumption that, in the longer term, barriers to the adoption of new technology would be gradually overcome, and more of the inefficient stoves would be replaced.

Open field burning of agricultural residues has been a target of regional policies in several countries in Latin America and the Caribbean, but this source remains an important mitigation opportunity according to the estimates in this assessment. As discussed earlier, a complete ban in countries where there has been a tradition of burning agricultural residues for millennia will be difficult to enforce and will require the introduction of additional policies promoting alternative management practices. The other identified measures comprise a similar potential to addressing agricultural burning in the region but their importance varies significantly between countries (Figure 3.4).

Mitigation of BC in the transport sector by accelerating the introduction of stringent emission standards on new vehicles (Euro VI/6) requiring the installation of DPFs, and the efficient elimination and monitoring of high-emitting vehicles are the most important measures for allowing the countries of Latin America and the Caribbean to achieve 35–75 per cent reductions in BC emissions by 2050

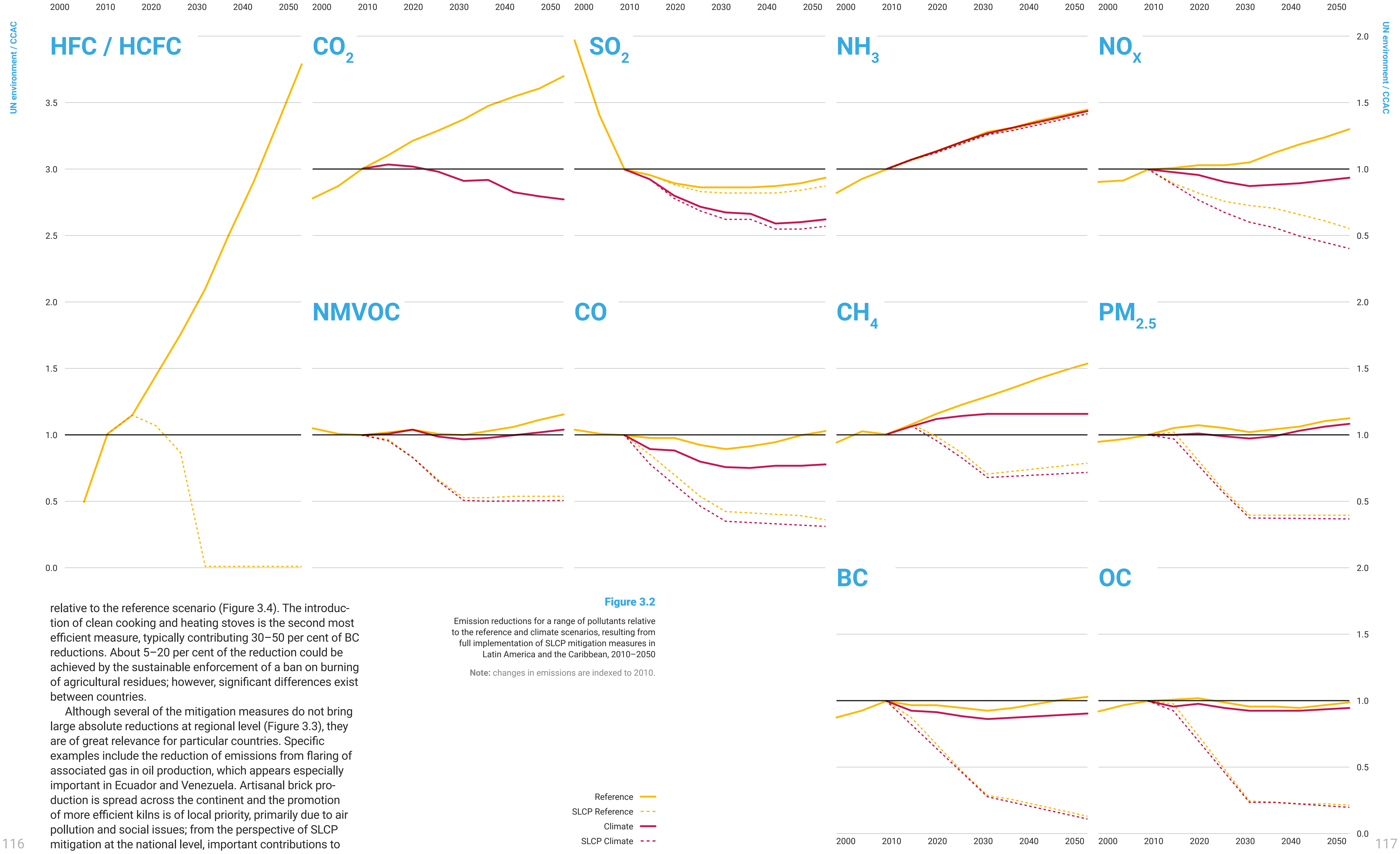


Figure 3.2

Emission reductions for a range of pollutants relative to the reference and climate scenarios, resulting from full implementation of SLCP mitigation measures in Latin America and the Caribbean, 2010–2050

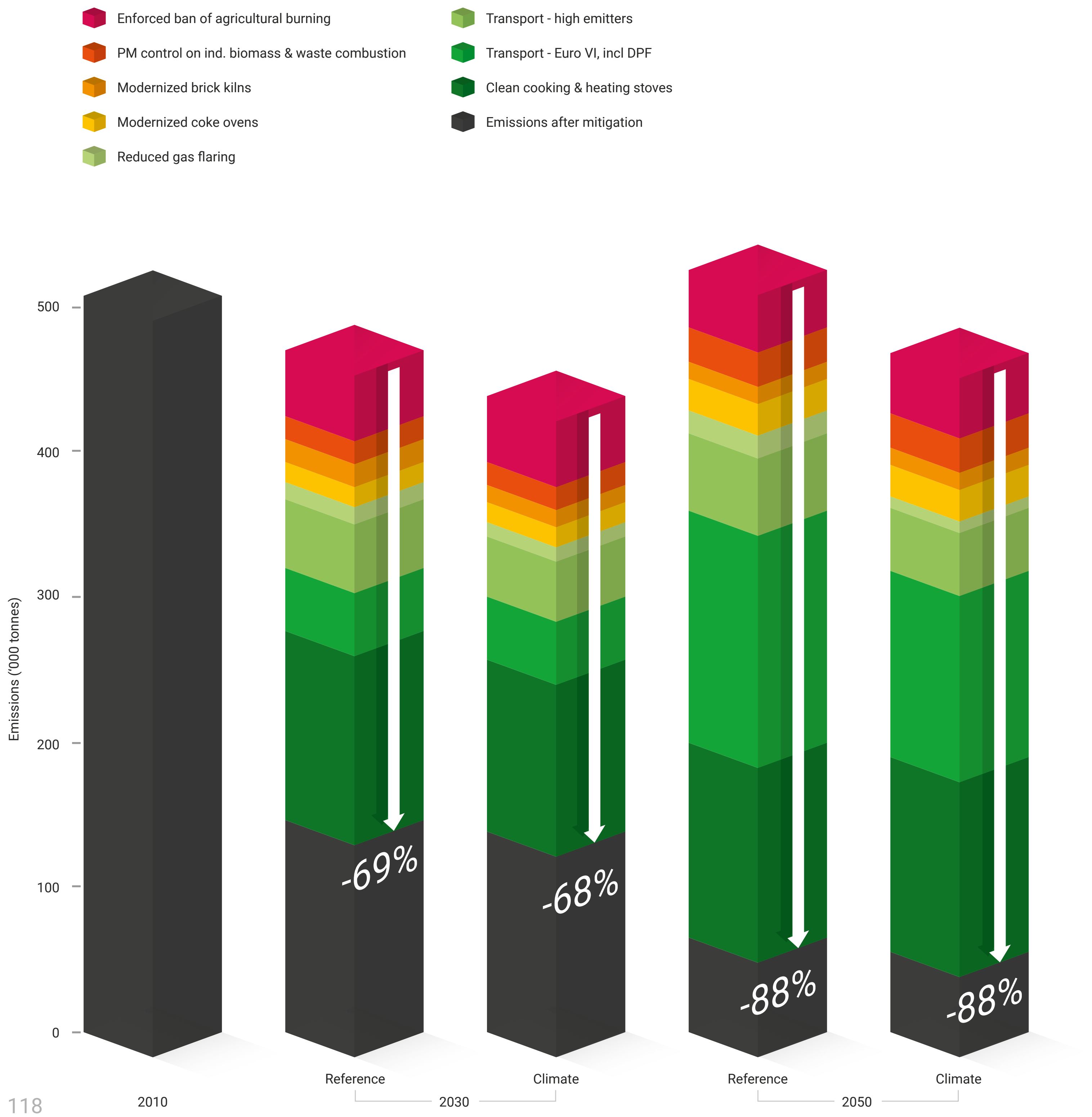
Note: changes in emissions are indexed to 2010.

relative to the reference scenario (Figure 3.4). The introduction of clean cooking and heating stoves is the second most efficient measure, typically contributing 30–50 per cent of BC reductions. About 5–20 per cent of the reduction could be achieved by the sustainable enforcement of a ban on burning of agricultural residues; however, significant differences exist between countries.

Although several of the mitigation measures do not bring large absolute reductions at regional level (Figure 3.3), they are of great relevance for particular countries. Specific examples include the reduction of emissions from flaring of associated gas in oil production, which appears especially important in Ecuador and Venezuela. Artisanal brick production is spread across the continent and the promotion of more efficient kilns is of local priority, primarily due to air pollution and social issues; from the perspective of SLCP mitigation at the national level, important contributions to

Figure 3.3

Reductions in emissions of black carbon in 2030 and 2050 compared to the reference and climate scenarios, resulting from full implementation of SLCP mitigation measures in Latin America and the Caribbean



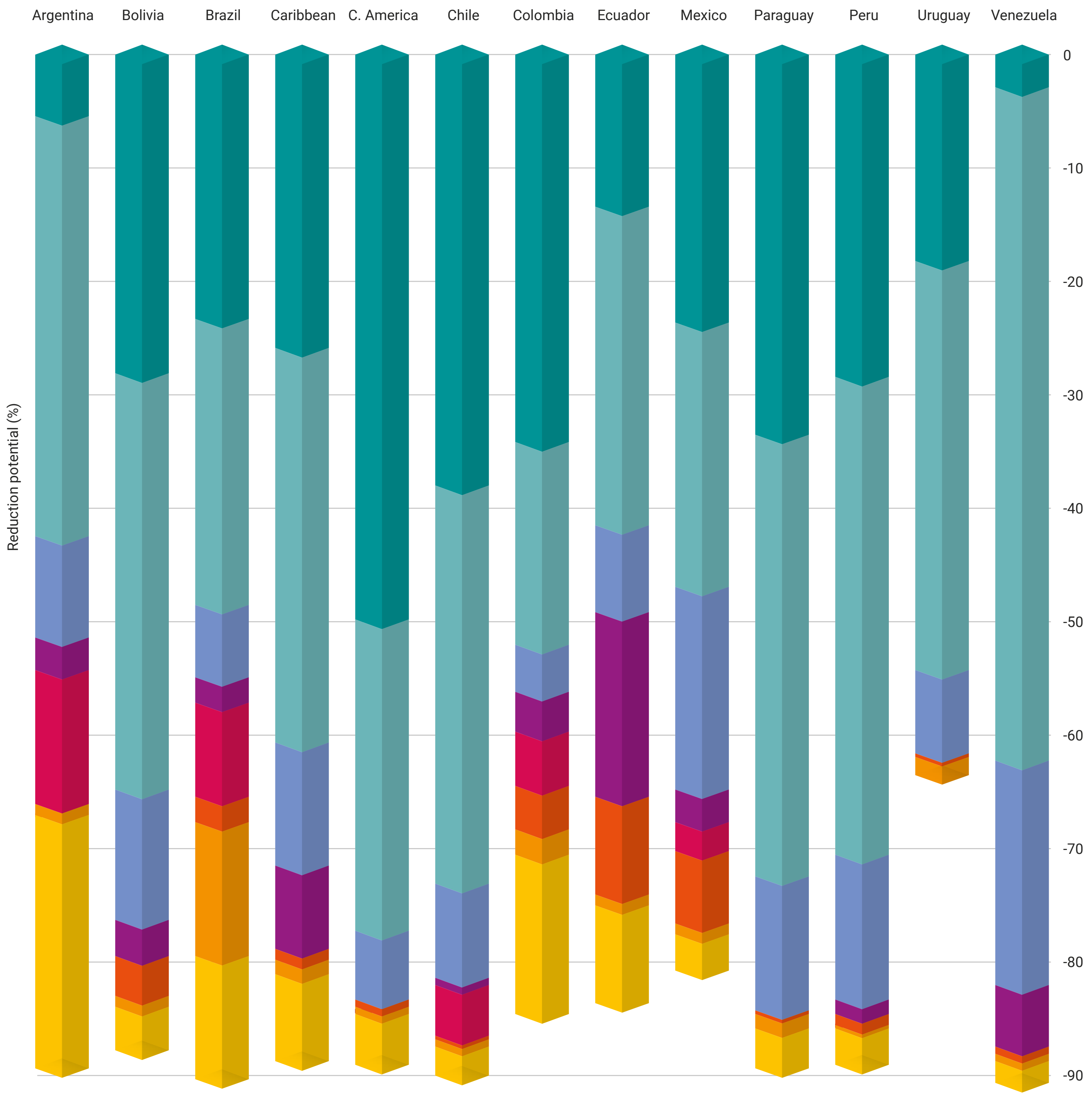


Figure 3.4

Black carbon reduction potential in 2050 from the implementation of different measures addressing incomplete combustion in Latin America and the Caribbean, relative to the reference scenario, by country/sub-region

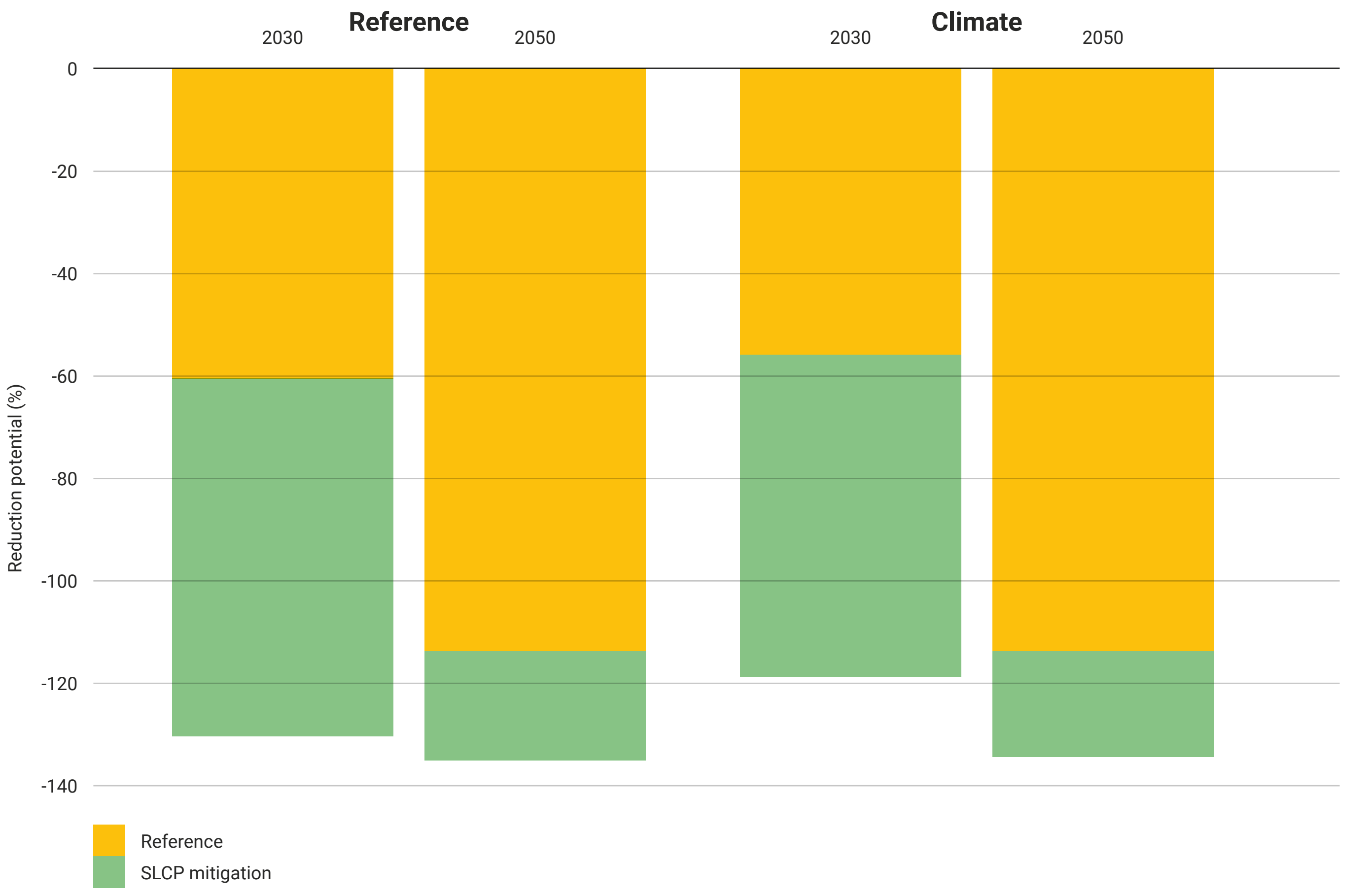


Figure 3.5

Black carbon reduction potential in 2030 and 2050 from partial and full implementation of clean cooking and heating stoves in Latin America and the Caribbean, relative to the reference and climate scenarios

total BC mitigation could be achieved in Bolivia, Colombia, Ecuador and Mexico. Similarly, coke production is of relevance in some countries, but reducing coke oven emissions to state-of-the-art technology levels results in sizeable reductions in only a few, including Argentina, Brazil, Chile and Colombia, contributing 5–20 per cent of overall reduction in these countries.

More detailed results on absolute BC reduction levels for the SLCP mitigation scenario for each country and measures are presented in Appendix A4.1. It should be noted that the reduction of emissions other than BC is important for the characterization of both climate and air pollution impacts and benefits. Addressing incomplete combustion affects the emission of substances that warm and cool the climate, and a number of different emissions that lead to $PM_{2.5}$ and O_3 concentrations.

The discussion presented above refers to the full implementation of mitigation measures and takes the application constraints that stem from the technical characteristics of measures, primarily lifetime, into consideration. As discussed in section 3.4.4, a scenario with partial implementation of clean cooking and heating stoves was also developed. As shown in Figures 3.3 and 3.4, clean stoves offer a significant reduction potential in Latin America and Caribbean, representing nearly 50 per cent of total BC reduction by 2030 and about 30 per cent by 2050 (Figure 3.3).

The analysis performed for the partial implementation of clean stove measures (Figure 3.5) indicates that, when current experience in implementation efficiency is extrapolated, only about half of the full reduction potential is likely to be achieved in the short term. In the longer term, however, the difference between full and partial implementation is much less pronounced. While the role clean stoves can play varies across countries (Figure 3.4), the region-specific conclusions are the same with respect to short- and long-term development since the assumptions about the implementation barriers are similar across the whole region (compare Table 3.3).

From the perspective of total BC mitigation, the partial implementation case for clean stoves shows that the overall BC reduction could be about 20 per cent by 2030, but only a few per cent less than in the full implementation case (SLCP mitigation scenario) by 2050 (Figure 3.6).

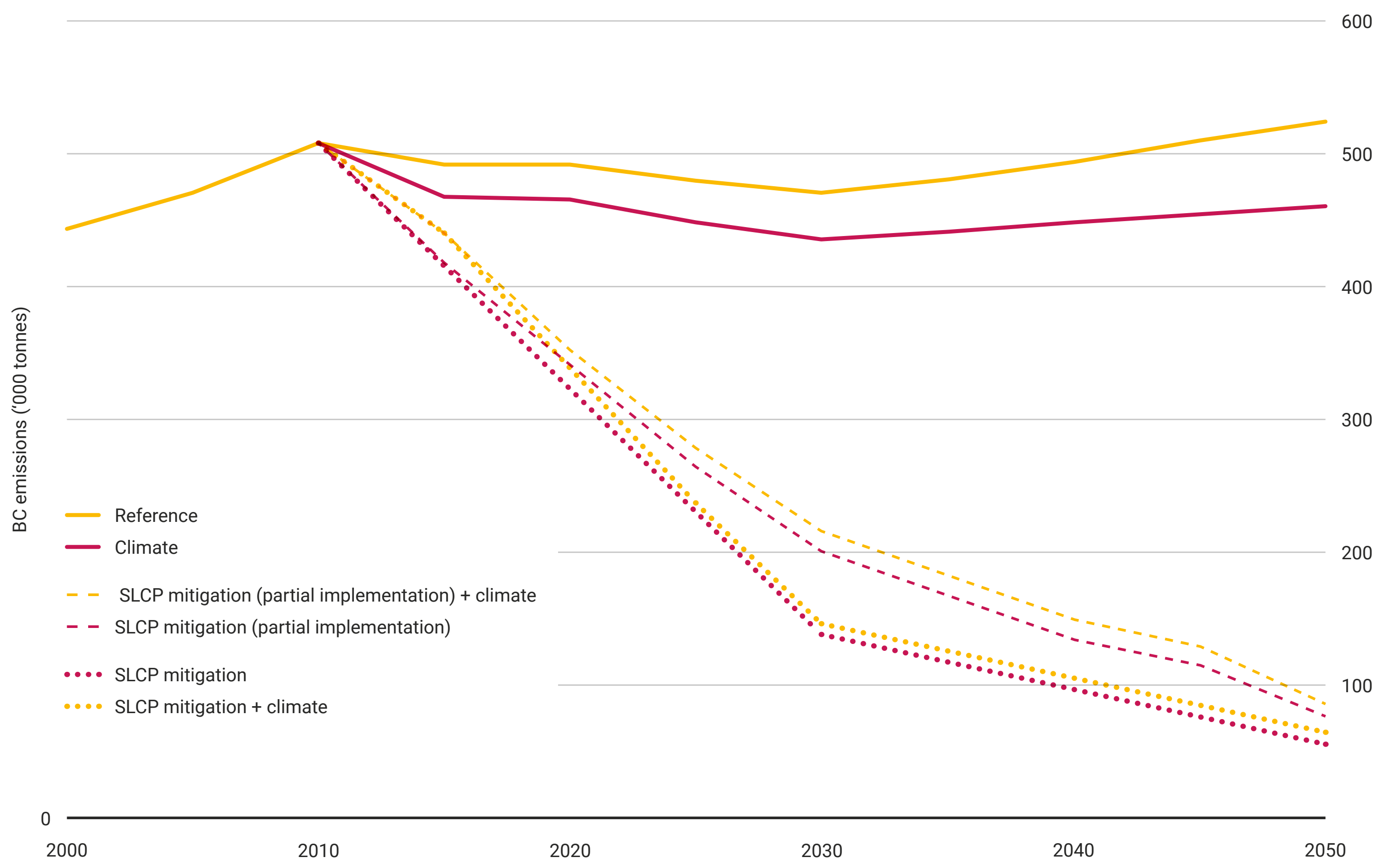


Figure 3.6

Reductions in black carbon emissions in Latin America and the Caribbean with full and partial implementation of measures on clean cooking and heating stoves, compared to the climate and reference scenarios, 2000–2050

3.5.2

Measures addressing methane emissions

In contrast to BC, emissions of CH_4 are projected to increase significantly (Figure 3.7) in the reference scenario, and the selected measures could reduce them by nearly 50 per cent by 2050. The estimated CH_4 mitigation potential in the climate scenario is lower, at about 40 per cent (Figure 3.7). This is because achieving climate mitigation goals is associated with a reduced demand for fossil fuels, which translates into lower oil and gas production in the region and, consequently, lower CH_4 emissions from one of the key sectors.

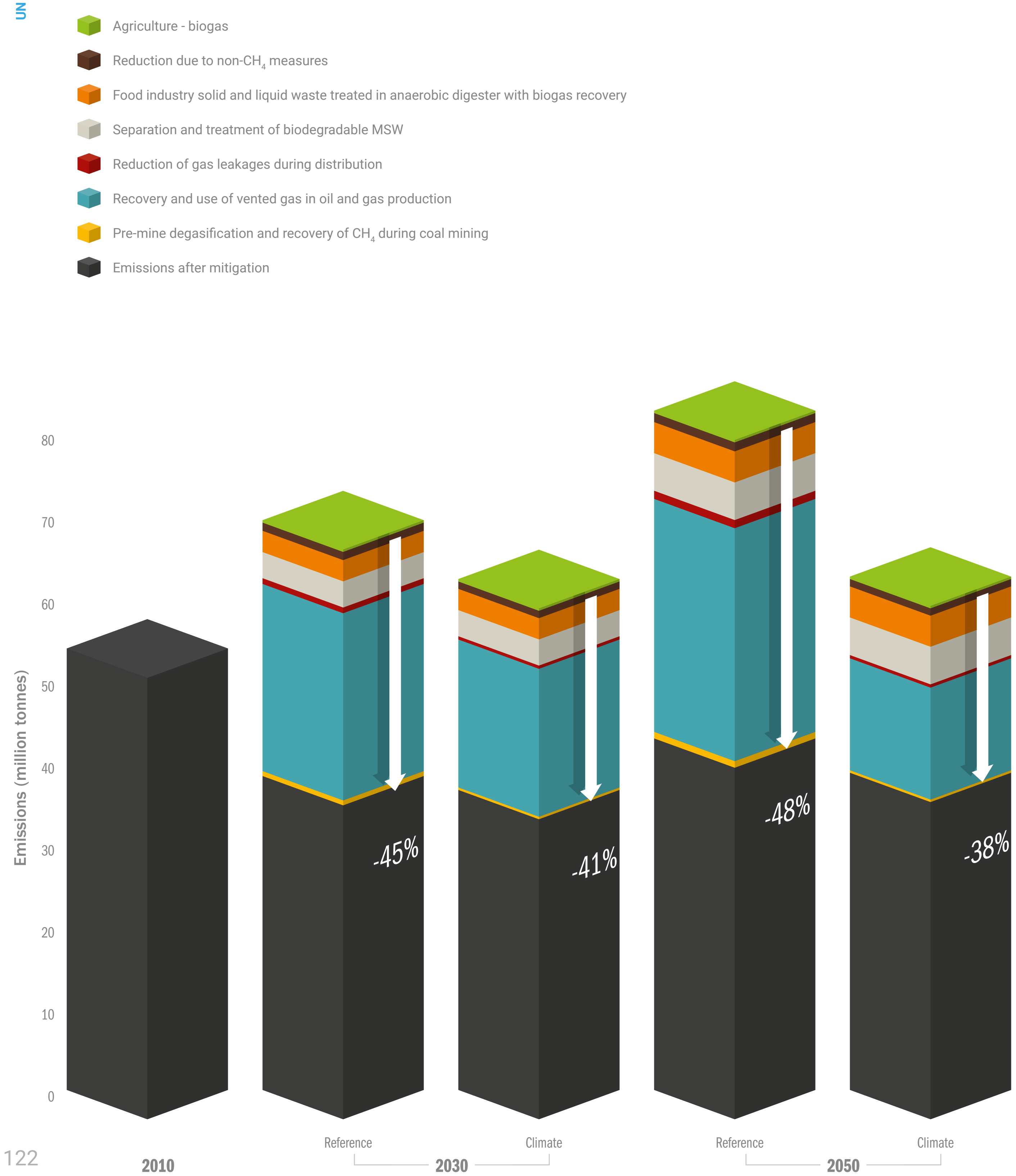
It is assumed that CH_4 measures can be effectively implemented within the next few decades, as appropriate technologies are available for all of them and there is enough relevant experience from other parts of the world (UNEP-WMO, 2011; Höglund-Isaksson, 2012; US EPA, 2013) and to some extent in Latin America and the Caribbean (Chapter 4). The increasing mitigation potential estimated for the period 2030–2050 in the reference scenario is driven by growing activity in key emitting sectors, primarily related to oil and gas production. In the climate scenario, application of CH_4 measures leads to a declining potential for reductions in CH_4 emissions when approaching the year 2050 because of the decreasing production of fossil fuels in the region assumed in the scenario. Overall, full introduction of measures by 2050 would result in CH_4 emissions that are 20–30 per cent lower than in 2010.

At a regional level, mitigation of CH_4 emissions from the oil and gas production sector represents about 60–75 per cent of the total reduction potential, depending on the time period and scenario. The next most important measures are the separation and treatment of biodegradable MSW, with more than a 10 per cent reduction (nearly 20 per cent in 2050 in the climate scenario), and treatment with gas recovery of solid and liquid waste from the food industry, bringing almost a 10 per cent reduction (about 15 per cent in 2050 in the climate scenario). All remaining CH_4 measures combined achieve emission reductions of less than 5 per cent for the whole region. Finally, about a 3 per cent CH_4 emission reduction was estimated under implementation of all the measures addressing incomplete combustion (section 3.5.1), the largest contribution coming from clean stoves.

The overall mitigation potential and importance of identified CH_4 measures varies significantly between countries (Figure 3.8), much more than for measures addressing incomplete combustion (Figure 3.4). For example, for Paraguay and Uruguay the mitigation potential is estimated at only 10–15 per cent, for the Caribbean, Chile, Ecuador and Mexico at 50–60 per cent, and for Venezuela at more than 75 per cent. Such strong differences, of course, are linked to the emission source structure, especially the role of fossil fuel production as

Figure 3.7

Reductions in methane emissions in 2030 and 2050 from full implementation of SLCP mitigation measures in Latin America and the Caribbean, compared to the reference and climate scenarios



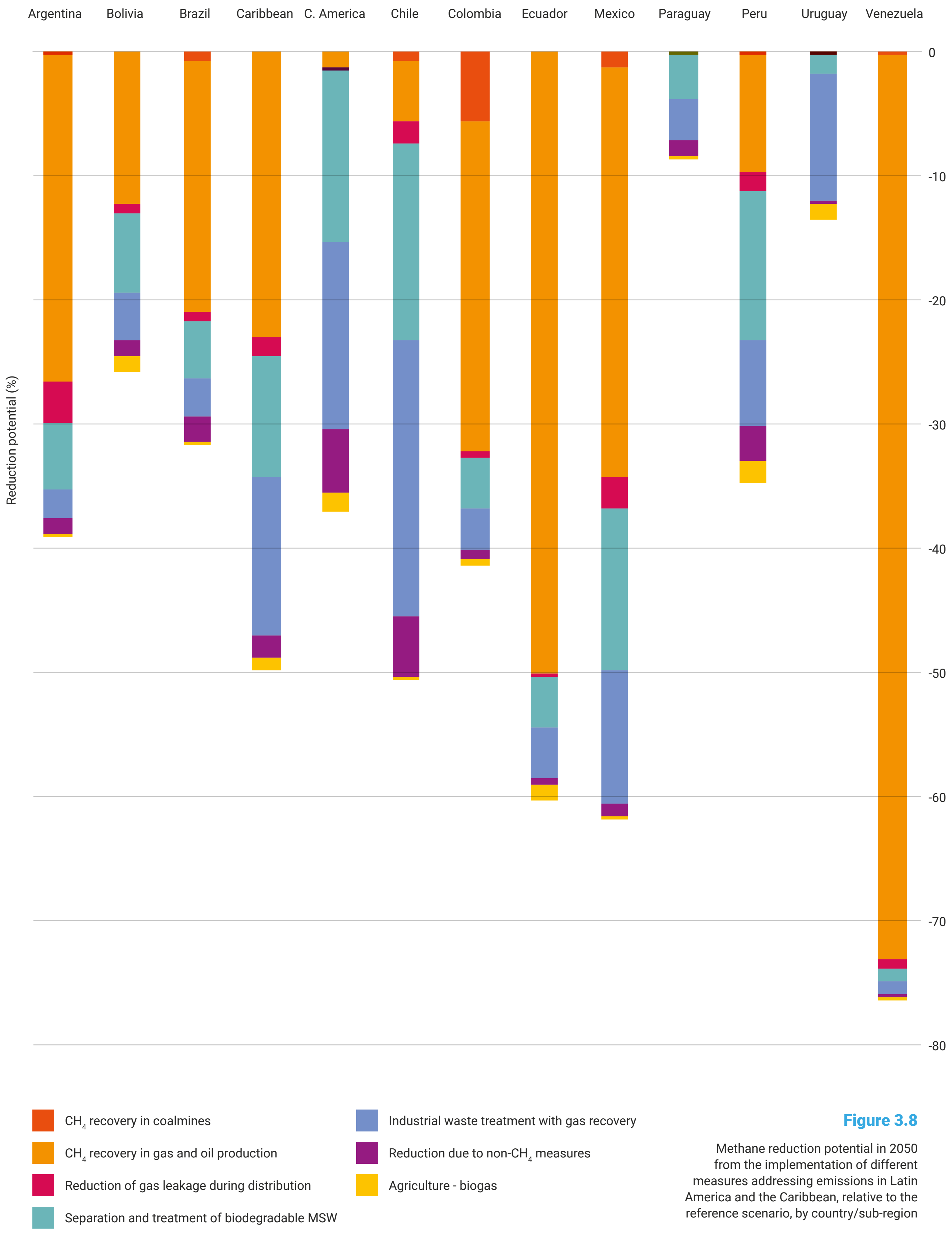


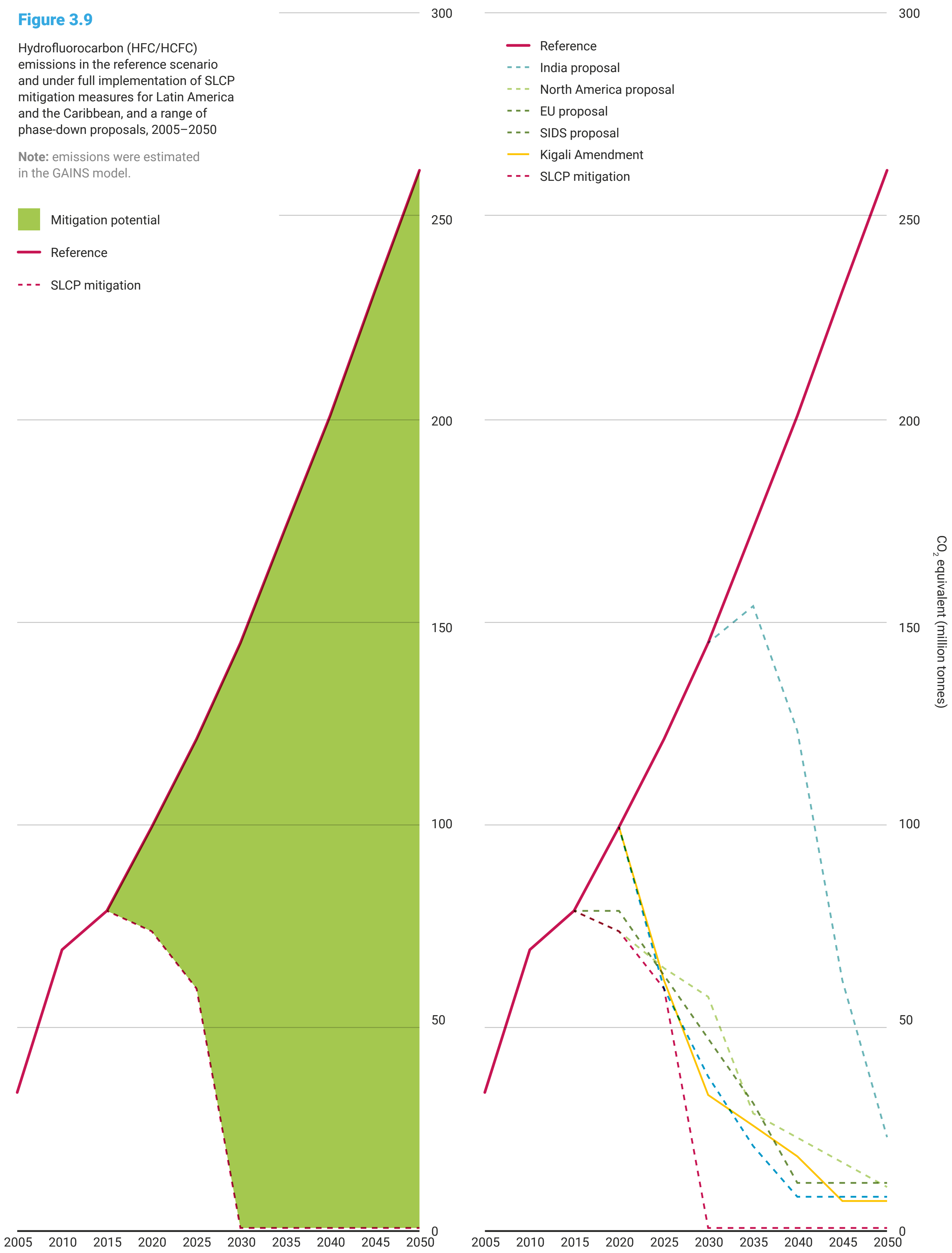
Figure 3.8

Methane reduction potential in 2050 from the implementation of different measures addressing emissions in Latin America and the Caribbean, relative to the reference scenario, by country/sub-region

Figure 3.9

Hydrofluorocarbon (HFC/HCFC) emissions in the reference scenario and under full implementation of SLCP mitigation measures for Latin America and the Caribbean, and a range of phase-down proposals, 2005–2050

Note: emissions were estimated in the GAINS model.



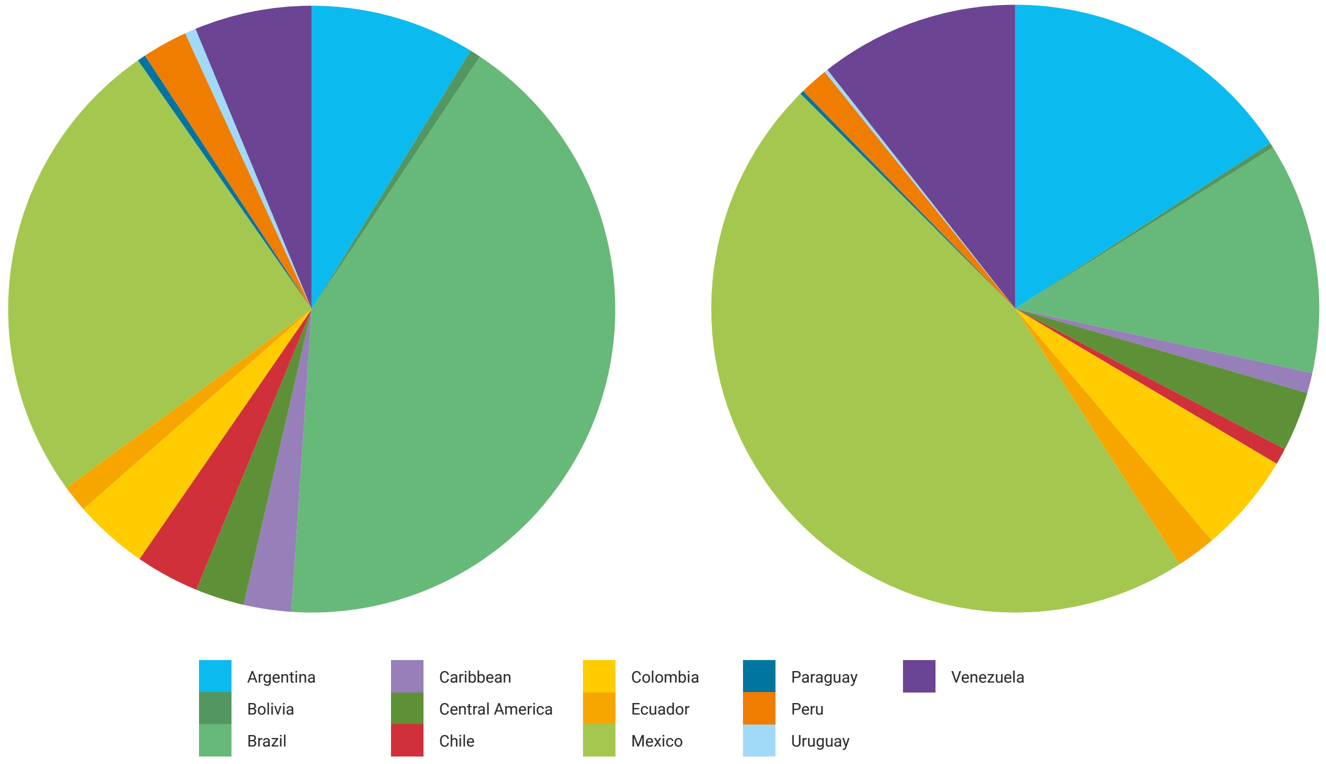


Figure 3.10

Share of total hydrofluorocarbon emissions in Latin America and the Caribbean in 2030, for the reference scenario and under full implementation of SLCP mitigation measures

well as the importance of the livestock sector for which only limited mitigation opportunities exist.

Most countries[3] have an oil and gas production industry and, other than in Central America, Chile and Peru, some 50 per cent to more than 90 per cent of estimated CH_4 mitigation potential originates from this sector. For Venezuela and Ecuador more than 80 per cent of mitigation potential is associated with this sector and for Brazil and Argentina it is estimated at about 70 per cent.

Coal is mined in most Latin American and Caribbean countries but production is concentrated in Colombia, which generates more than 80 per cent of the region's total output, and consequently this is the only country for which CH_4 recovery from coal mining plays a significant role at a national level; for Brazil and Mexico some potential was also identified.

Improved residential and industrial waste management with CH_4 recovery is the second largest opportunity in the region and important for all countries, for many representing the major CH_4 emission mitigation opportunity. For example, in Central America, Chile, Paraguay, Peru and Uruguay more than 70 per cent of total estimated reduction potential is associated with this sector, typically distributed equally between MSW and food industry waste. For the Caribbean and Mexico, nearly 50 per cent of the reduction is estimated to come from waste management.

Remaining CH_4 mitigation opportunities typically represent just a few per cent of the potential and are distributed between the reduction of gas leakage in distribution networks and from using anaerobic digesters to produce biogas from livestock manure.

More detailed results on absolute CH_4 reduction levels for the SLCP mitigation scenario for each country and measure are presented in Appendix A4.1.

3.5.3

Measures addressing hydrofluorocarbon emissions

Significant mitigation potential has been estimated for HFC emissions. The maximum technically feasible reduction in the SLCP mitigation scenario is presented against the reference scenario for Latin America and the Caribbean (Figure 3.9); total HFC emissions in the case of maximum SLCP mitigation are very low.

Recognizing the opportunity presented for fast and effective phasing out of HFCs, several amendment proposals to phase down high-GWP HFCs have been submitted to the Montreal Protocol. In April 2015 the United States of America, Canada and Mexico together submitted a proposal for a phase-down in HFC production and consumption (UNEP, 2015a), and in the same year the European Union (EU) (UNEP, 2015b), India (UNEP, 2015c) and a group of Small Island Developing States (SIDS) of

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[3] Except Paraguay and Uruguay.

the Pacific (UNEP, 2015d) submitted their own proposals to amend the Protocol. In each proposal, the annual production and consumption of HFCs in non-Article 5 (developed) countries and Article 5 (developing) countries are reduced following phase-down schedules relative to specified base levels. In October 2016, the 28th Meeting of the Parties to the Montreal Protocol adopted the Kigali Amendment on HFCs, which commits the world's nations to significantly reduce their consumption and production. Under the Kigali Amendment, Latin America and the Caribbean have agreed to a timeline to reduce the use of HFCs by 80 per cent of their baselines by 2045 (UNEP, 2016). The base level and HFC phase-down schedules for non-Article 5 and Article 5 countries as per the 2015 Montreal Protocol amendment proposals are presented in the proposal documents (UNEP, 2015a-d). All of the proposed amendments to the Montreal Protocol provide a flexible phase-down with financial and technological assistance through the Multilateral Fund to address the needs of different countries (more details on the regional proposals are given in Appendix A4.2).

Figure 3.9 presents HFC emissions in Latin America and the Caribbean in the reference and SLCP mitigation scenarios (left panel) in comparison with alternative policy scenarios as outlined by the different amendment proposals to the Montreal Protocol (right panel). For developing countries, the phase-out schedules are not fully specified in the EU and Indian proposals, therefore some intermediate reduction steps are assumed in the present analysis. It may be noted that HFC emissions in GAINS are modelled in each five-year interval and therefore the HFC phase-down is adjusted accordingly. The EU (consumption) baseline is used in this study. As expected, HFC emissions are phased out significantly in the EU (95 per cent), North America (96 per cent) and SIDS (97 per cent) proposals by 2050 as compared to the Indian proposal (91 per cent) in which HFC consumption and production freeze by 2031.

3.6

Benefits of implementing the emission reduction measures in Latin America and the Caribbean

The changes in emissions for the different scenarios are used to estimate the benefits of implementing the measures for human health, crop yields and climate change. To do this, the emissions of all relevant pollutants are input to a number of global atmospheric climate-composition models, which calculate concentrations of key pollutants that can be used to estimate the impacts and benefits of mitigation. The different models used have been described in Chapter 1.

The climate calculations for forcing and temperature change were run offline for GISS, GEOS-Chem Adjoint and TM5-FASST results, and provided temperature change at a global scale and for four latitudinal bands. In addition, for some of the scenarios, the GISS model was run for multiple years until temperatures approached equilibrium and these runs provide regional temperature variation and precipitation changes. Health impacts are assessed from the modelled $PM_{2.5}$ and O_3 concentrations using the Integrated Exposure Response concentration-response functions from Burnett *et al.* (2014), based on the $PM_{2.5}$ results from GISS, GEOS-Chem and TM5-FASST, and using GEOS-Chem Adjoint coefficients.

No regional model was involved in this exercise and the grid size of the global models is quite coarse at about 2°x2.5° in the case of GISS and GEOS-Chem and 1°x1° for TM5-FASST. Some of the climate impacts work on large scales and so the results are appropriate for Latin America and the Caribbean. But at this scale, some of the changes over smaller distances, especially in mountainous regions, will not be captured, although the level of scientific knowledge may not legitimize finer-scale modelling.

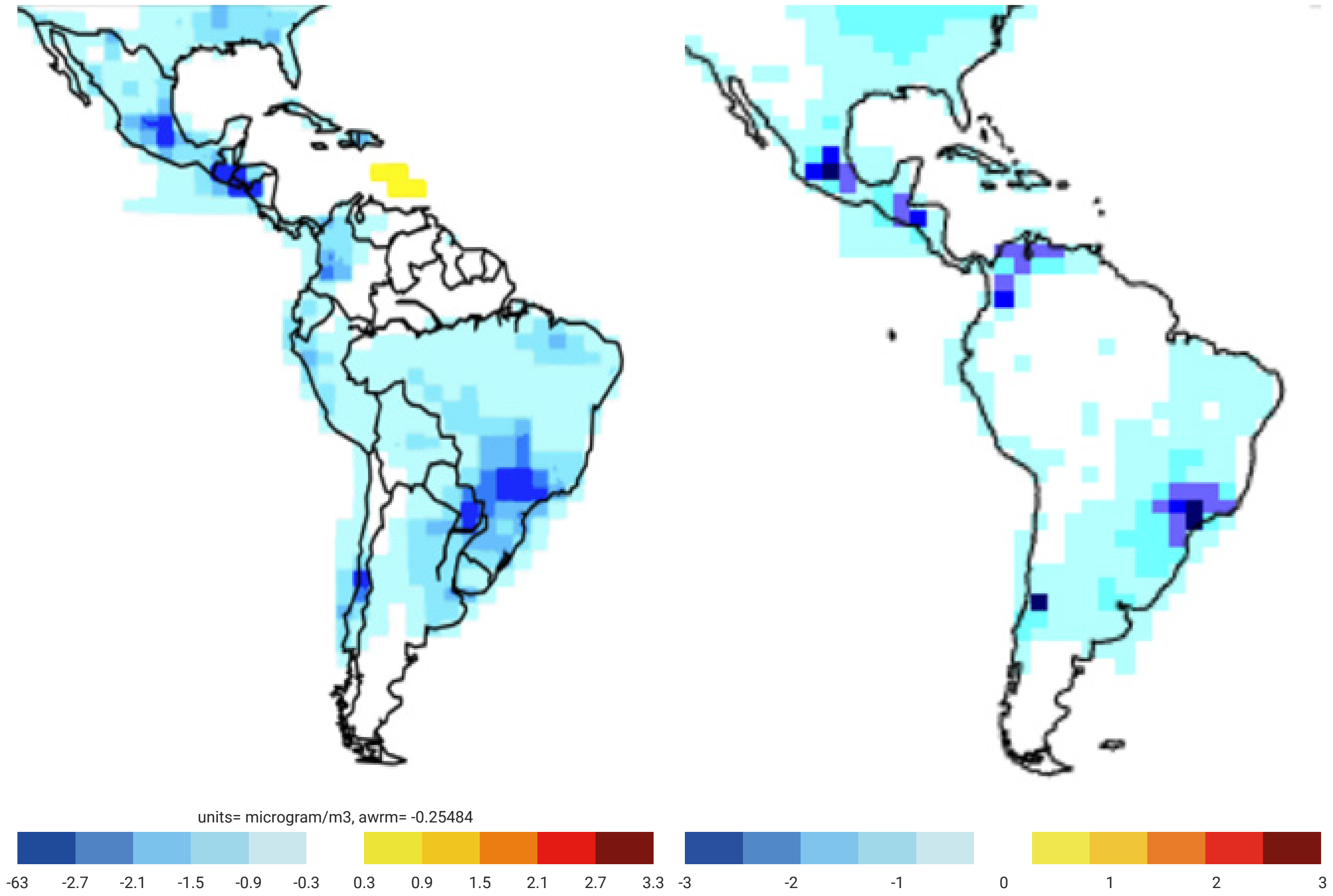
3.6.1

Impacts on health

Chapter 2 discusses the health impacts of air pollution, mainly related to concentrations of $PM_{2.5}$, but also of ground-level O_3, and estimates the change in $PM_{2.5}$ and its health consequences for the reference scenario. On implementation of the SLCP mitigation scenario, all three models estimate lower mean annual concentrations of $PM_{2.5}$ compared to the Latin America and Caribbean reference scenario – the difference in 2050 is shown in Figure 3.11 for the three models. The $PM_{2.5}$ concentrations in 2050 decrease due to the implementation of SLCP measures compared to the reference scenario, especially in cities in Brazil, Chile and Mexico, but also in other areas.

Using the results of the atmospheric models, such as shown in Figure 3.11, and the health impact assessment methods outlined in Chapter 2, the benefit of implementing the different mitigation scenarios has been calculated showing the change in the number of annual deaths attributable to $PM_{2.5}$ in 2030 and 2050 compared to the reference scenario. These only represent the change in deaths from ambient $PM_{2.5}$ concentrations, and do not include mortality from O_3 or the impacts on health of exposure to indoor air pollution, which is discussed later in this section. The different models used with the SLCP mitigation scenario, in relation to reference emissions, show close agreement in the level of reduction in premature mortality, as can be seen by comparing Figure 3.12 to the projections for premature mortality in the reference scenario (Figure 2.7). Premature mortality decreases between 2030 and 2050 due to the greater degree of mitigation in 2050, and also due to the greater number of people and an older population in 2050, which means that the mitigation has a large impact as you are reducing the exposure of a larger number of vulnerable people.

According to these calculations, implementing the SLCP mitigation scenario avoids about 13 200 premature deaths in 2030, with a range of about 10 200–16 200 avoided deaths per year from the different model results using the GAINS emissions data (Figure 3.12). In 2050, the SLCP mitigation



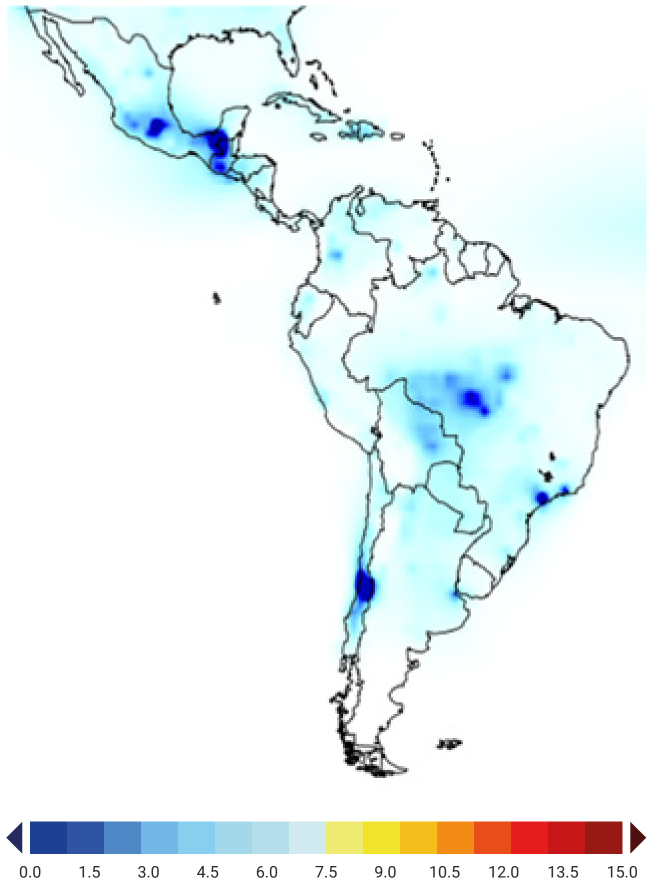


Figure 3.11

Change in particulate matter ($PM_{2.5}$) concentrations in Latin America and the Caribbean in 2050, under full implementation of SLCP mitigation measures compared to the reference scenario

Note: data are shown in micrograms per cubic metre (μg/m³), using the GISS (left), GEOS-Chem (centre) and TM5-FASST (right) models.

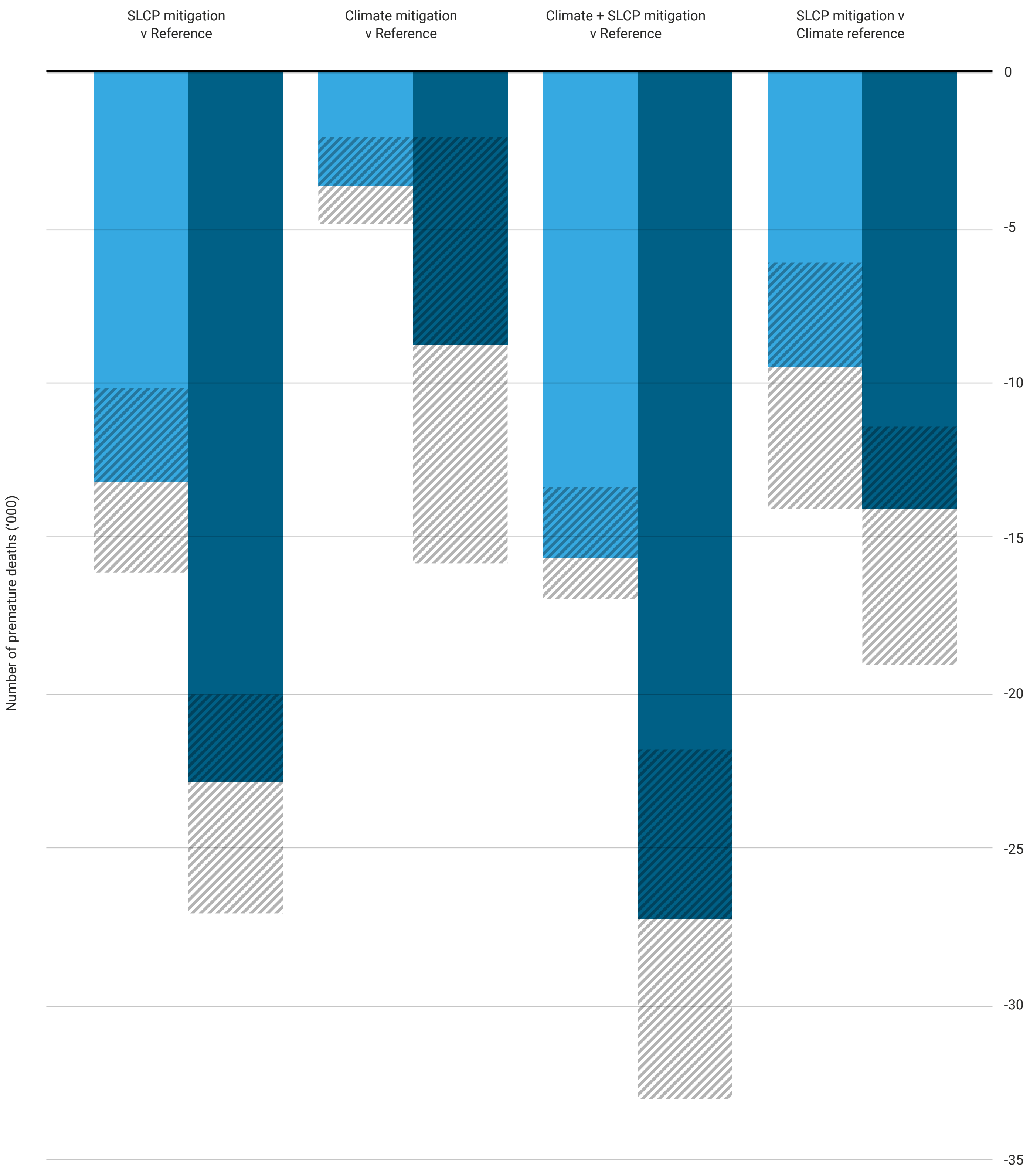


Figure 3.12

Annually avoided premature deaths from particulate matter (PM$_{2.5}$) concentrations in Latin America and the Caribbean due to implementation of mitigation measures, 2030 and 2050

Note: based on an average of the mortality estimates using PM$_{2.5}$ estimates as an average of the GISS, GEOS-Chem Adjoint and TM5-FASST models, and concentration-response functions according to Burnett *et al.* 2014. The range of results from the different models is shown alongside the average avoided mortality.

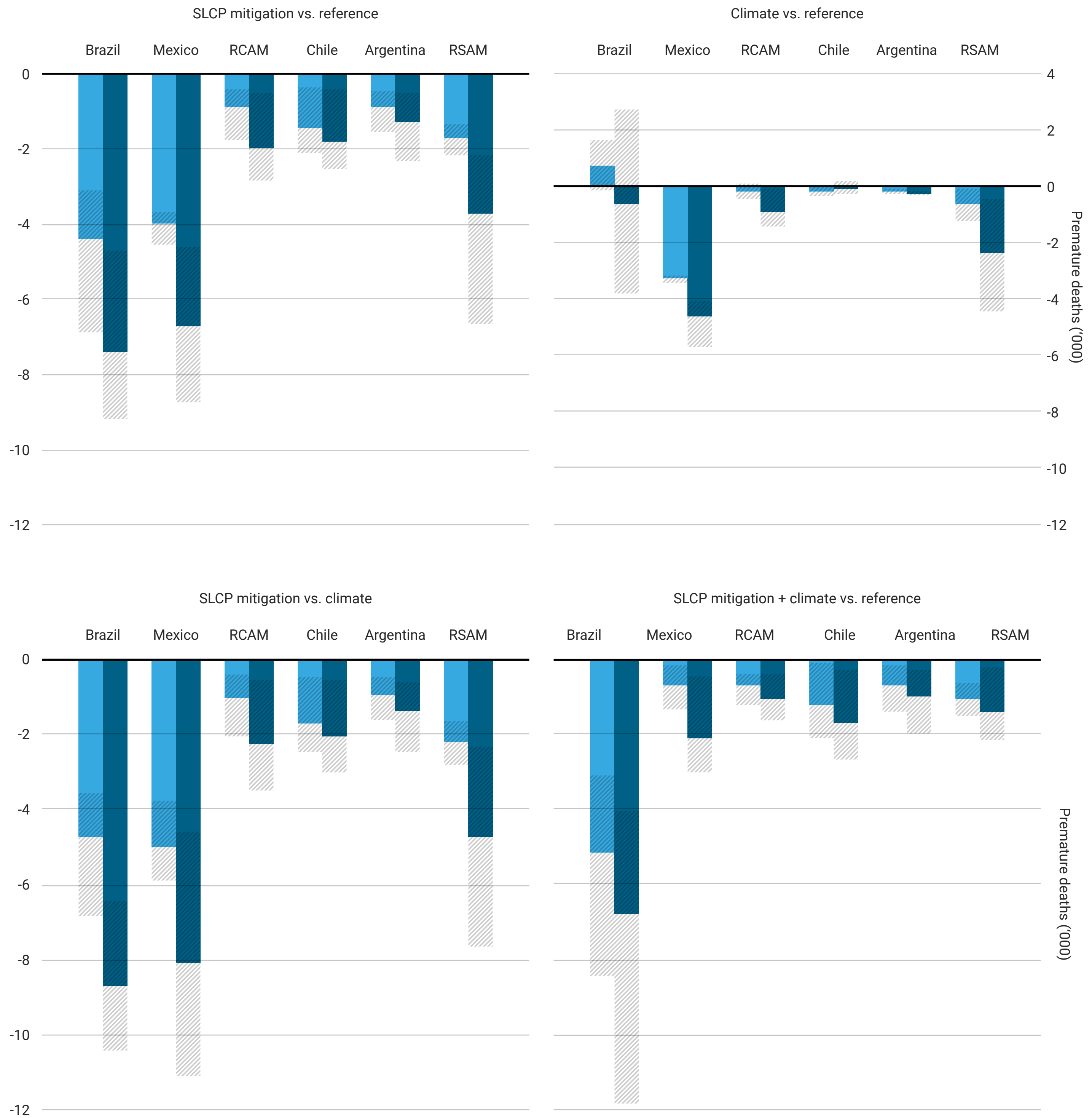


Figure 3.13

Annually avoided premature deaths from particulate matter (PM$_{2.5}$) concentrations in different scenarios, for selected countries/groups of countries in Latin America and the Caribbean, 2030 and 2050

Note: these show an average of the mortality estimates using PM$_{2.5}$ estimates from GISS, GEOS-Chem Adjoint and TM5-FASST, and concentration-response functions according to Burnett *et al.* 2014. The range of results from the different models is shown alongside the average avoided mortality. RCAM = Caribbean countries, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama; RSAM = Bolivia, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela and Northeast South America (French Guiana, Guyana and Suriname).

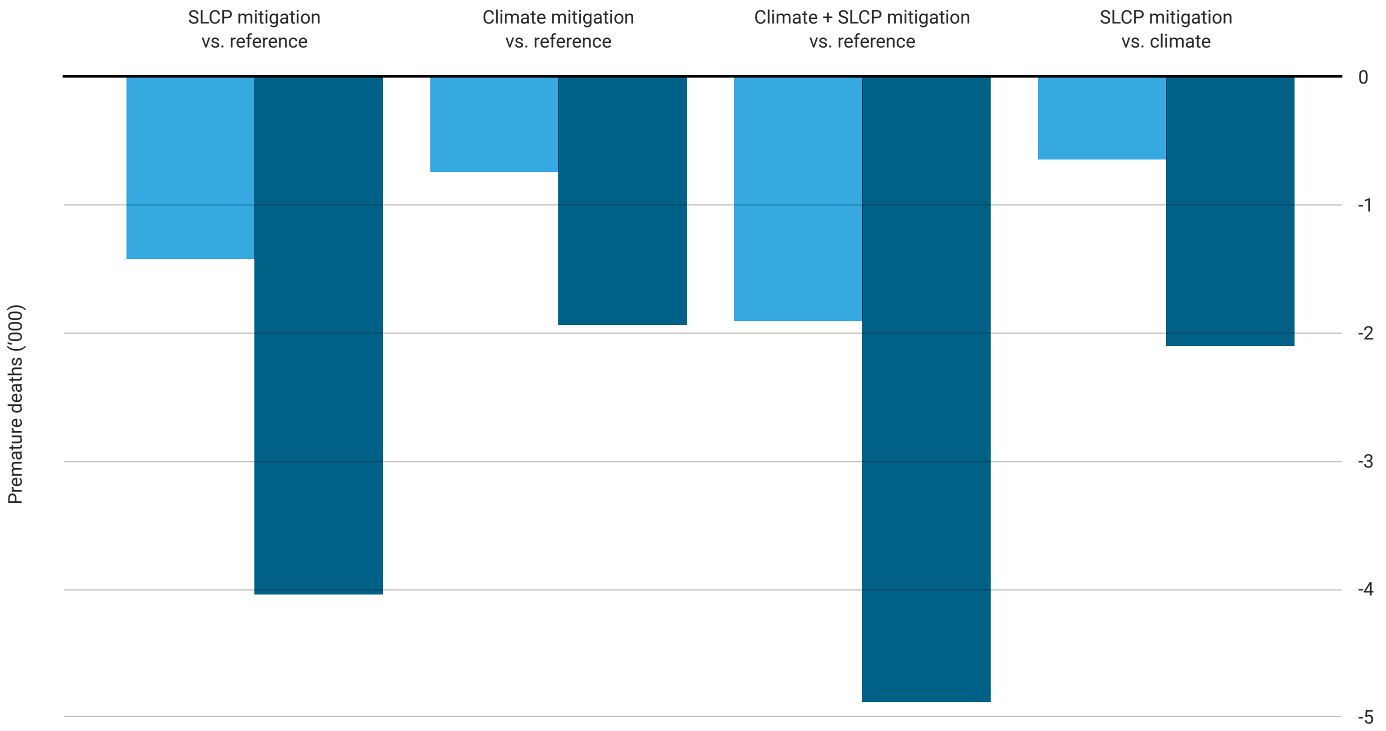


Figure 3.14

Annually avoided premature deaths from exposure to ozone concentrations in Latin America and the Caribbean due to implementation of mitigation measures, 2030 and 2050

Note: based on the TM5-FASST model only.

scenario reduces the number of deaths by about 22 800 in comparison to the reference scenario, with a range of 18 500–25 500. Figure 3.11 gives a very consistent picture of the response in different countries and regions of Latin America and the Caribbean, although the range of different models is still fairly large. It should be borne in mind that these results are likely to be conservative for the reasons outlined in Chapter 2, and this means that the reduction in premature mortality from the implementation of an SLCP strategy could well be considerably larger.

In comparison to the SLCP mitigation scenario, the implementation of the climate scenario – which aims to achieve the target of restricting warming to 2ºC above pre-industrial levels – has a more mixed impact on reducing premature mortality. The overall reduction in deaths is lower (about 3 700 premature deaths avoided with a range of 2 000–5 000 in 2030, and about 8 800 premature deaths avoided in 2050 with a range of 2 100–15 800); in addition, the picture is very variable for different countries and regions, with some models projecting an increase in the number of premature deaths in comparison to the reference scenario for Brazil, Central America and Chile in 2030. It should be noted that under the TM5-FASST model Brazil shows a consistent but small reduction in mortality in the climate scenario, whereas the GISS and GEOS-Chem models show an increase in mortality in 2030; and in 2050 both GEOS-Chem and TM5-FASST show a decrease. It is clear from this that the measures in the climate scenario do not address the emissions that lead to $PM_{2.5}$ concentration in Latin America and the Caribbean as efficiently as the SLCP measures that focus on incomplete combustion, which is a large source of the overall regional $PM_{2.5}$ burden.

Given the relatively low number of premature deaths avoided in the climate scenario, it is not surprising that implementing the SLCP mitigation scenario at the same time as measures under the climate scenario provides a considerable additional benefit, delivering further avoidance of 9 500 premature deaths in 2030 (range of 6 000–14 100) and 13 987 in 2050 (range of 11 300–19 100). This again emphasizes the fact that the climate mitigation proposed in this scenario will not reduce the $PM_{2.5}$ as much as will SLCP mitigation.

In comparison to the reference scenario, implementing both climate and SLCP mitigation measures will lead to the greatest reduction in premature mortality, giving a benefit of about 15 600 fewer premature deaths in 2030 (with a range of 13 400–16 900) and 27 200 in 2050 (with a range of 21 900–33 100), which implies that, while particular opportunities to reduce $PM_{2.5}$ concentrations do arise through the climate mitigation options, the SLCP measures provide the largest health benefit.

Figure 3.13 illustrates that all countries and sub-regions show a reduction in premature mortality under implementation of the SLCP measures in relation to the reference scenario. Brazil and Mexico dominate, with about 60 per cent of the reduction in deaths across the whole region.

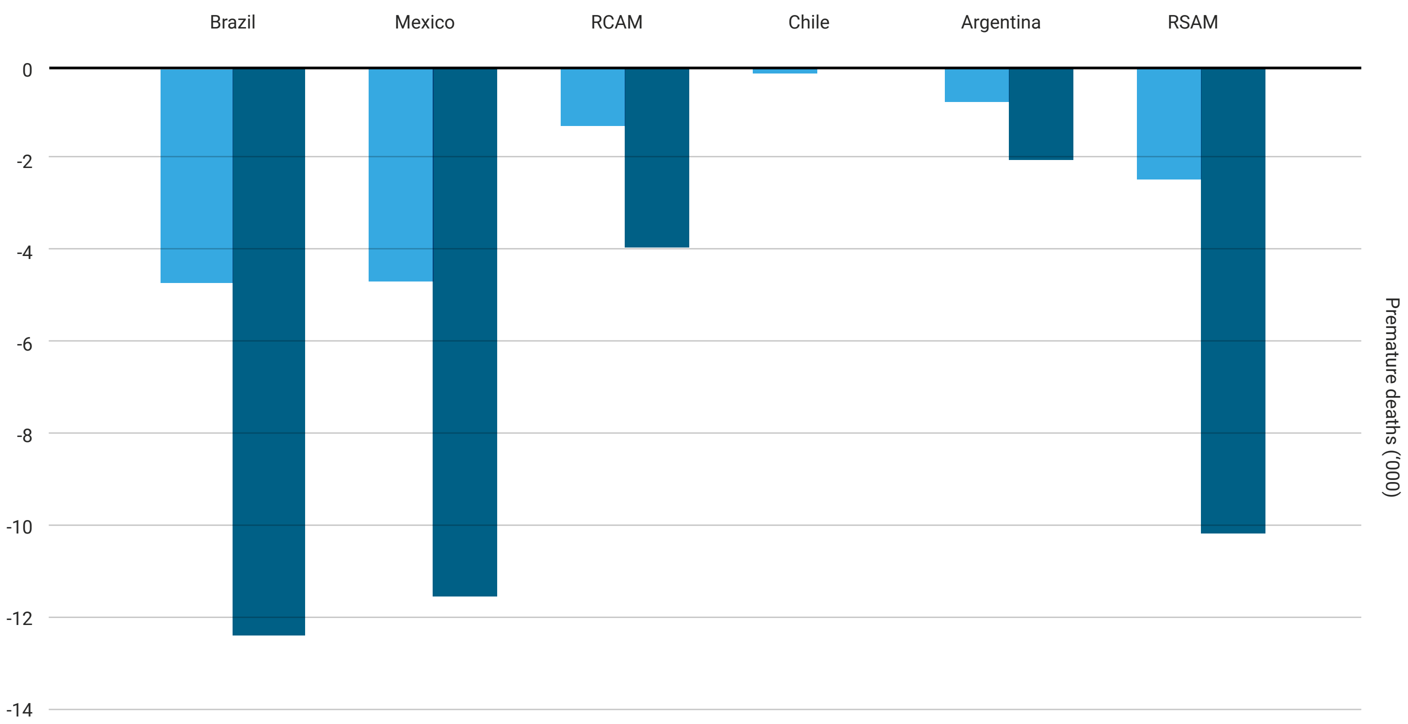


Figure 3.15

Annually avoided premature deaths from exposure to ozone on implementation of SLCP mitigation measures compared to the reference scenario, for different countries/groups of countries in Latin America and the Caribbean, 2030 and 2050

Note: based on the TM5-FASST model only. RCAM = Caribbean countries, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama; RSAM = Bolivia, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela and Northeast South America (French Guiana, Guyana and Suriname).

The SLCP mitigation scenario also measures reductions in the formation of tropospheric O_3 from reduced emissions of O_3 precursors both from measures addressing CH_4 and from those reducing the products of incomplete combustion. The corresponding reduction in premature mortality from the implementation of SLCP measures in Latin America and the Caribbean as calculated by the TM5-FASST model alone is more than 1 400 deaths avoided in 2030 and more than 4 000 avoided in 2050, which is about a 40 per cent reduction on the deaths in the reference scenario. There is a slight further decrease in premature deaths when the SLCP and climate mitigation measures are both implemented, with more than 1 900 deaths avoided in 2030 and almost 4 900 in 2050 (Figure 3.14), with about two thirds of the benefit being realized in Brazil and Mexico (Figure 3.15).

Overall, implementing the SLCP measures would seem to provide a health benefit that leads to about 18 500–30 400 fewer deaths in 2050 due to reductions in $PM_{2.5}$ and tropospheric O_3. It is important to note that the range does not include the uncertainty around the dose-response relationships – which is considerable (Chapter 2). The reduction in premature deaths in this regional assessment is within the range estimated in the UNEP and UNEP-WMO reports (UNEP, 2011; UNEP-WMO, 2011), although it is a bit lower – there was a benefit of about 39 000 in the UNEP report (UNEP, 2011), with a range of 13 000–68 000, for reductions in $PM_{2.5}$ alone – the range here representing the uncertainty related to the dose-response relationship.

As stated in Chapter 2, there are reasons to believe that these are considerable underestimates of the health benefits that could result from reducing emissions. This assessment has only considered the impacts of $PM_{2.5}$ and O_3 exposure on premature mortality. However, exposure to $PM_{2.5}$ and O_3 have also been associated with a range of non-fatal health outcomes that further increase the burden of disease associated with current air pollution levels in Latin America and the Caribbean, and increase the benefits that could be realized from reductions in exposure. For example, studies predominantly conducted in North America and Europe have found associations between $PM_{2.5}$ exposure and hospital admissions, and a range of respiratory and cardiovascular diseases – including non-fatal heart attacks, strokes and heart failure (Dominici *et al.*, 2006; US EPA, 2009; Zanobetti *et al.*, 2009, Brook *et al.*, 2010; WHO, 2013). Additionally, the disproportionate health impacts of air pollution on children indicate that the full burden of disease due to air pollution may not be accounted for here.

This assessment quantified premature deaths from acute lower respiratory infection among children under the age of five, representing a substantially greater loss of human potential than air pollution-associated premature deaths among older people. There is also evidence, however, of additional health impacts that occur from childhood exposure to air pollution that contribute to childhood mortality, as well as lifelong morbidity in survivors. Evidence from studies in North America, Europe and Asia, for example, indicates that maternal exposure to $PM_{2.5}$ results in adverse pregnancy outcomes such as pre-term birth and low birth weight (Shah and Balkhair, 2011; Rich *et al.*, 2015; Sun *et al.*, 2015; Zhu *et al.*, 2015). Globally, complications from pre-term births resulted in 965 000 neonatal deaths in 2013, 35 per cent of all neonatal deaths (Liu *et al.*, 2015), and pre-term birth has also been associated with a range of chronic physical and neurological impairments in survivors (Blencowe *et al.*, 2013a, 2013b). Additionally, childhood exposure to air pollution has been associated with respiratory effects in children, such as asthma symptoms in asthmatic children (Weinmayr *et al.*, 2010), acute bronchitis (Dockery *et al.*, 1996) and lower respiratory symptoms (Schwartz and Neas, 2000; Mehta *et al.*, 2013).

Measures addressing open biomass burning

The results presented in this section refer to mitigation of forest and savannah burning as discussed in section 3.2.1.5 of this report and shown in Figure 3.1. An independent analysis of the mitigation potential for this source has not been made for this assessment but it draws on the assumptions used in the RCP scenarios. It is specifically assumed for Latin America and the Caribbean that the mitigation scenario will follow the assumptions about open burning activity as defined in the RCP 4.5 scenario – a reduction of 75 per cent worldwide excluding agricultural waste burning. The comparison of the impacts on premature mortality is presented in Figures 3.16 and 3.17. These figures show

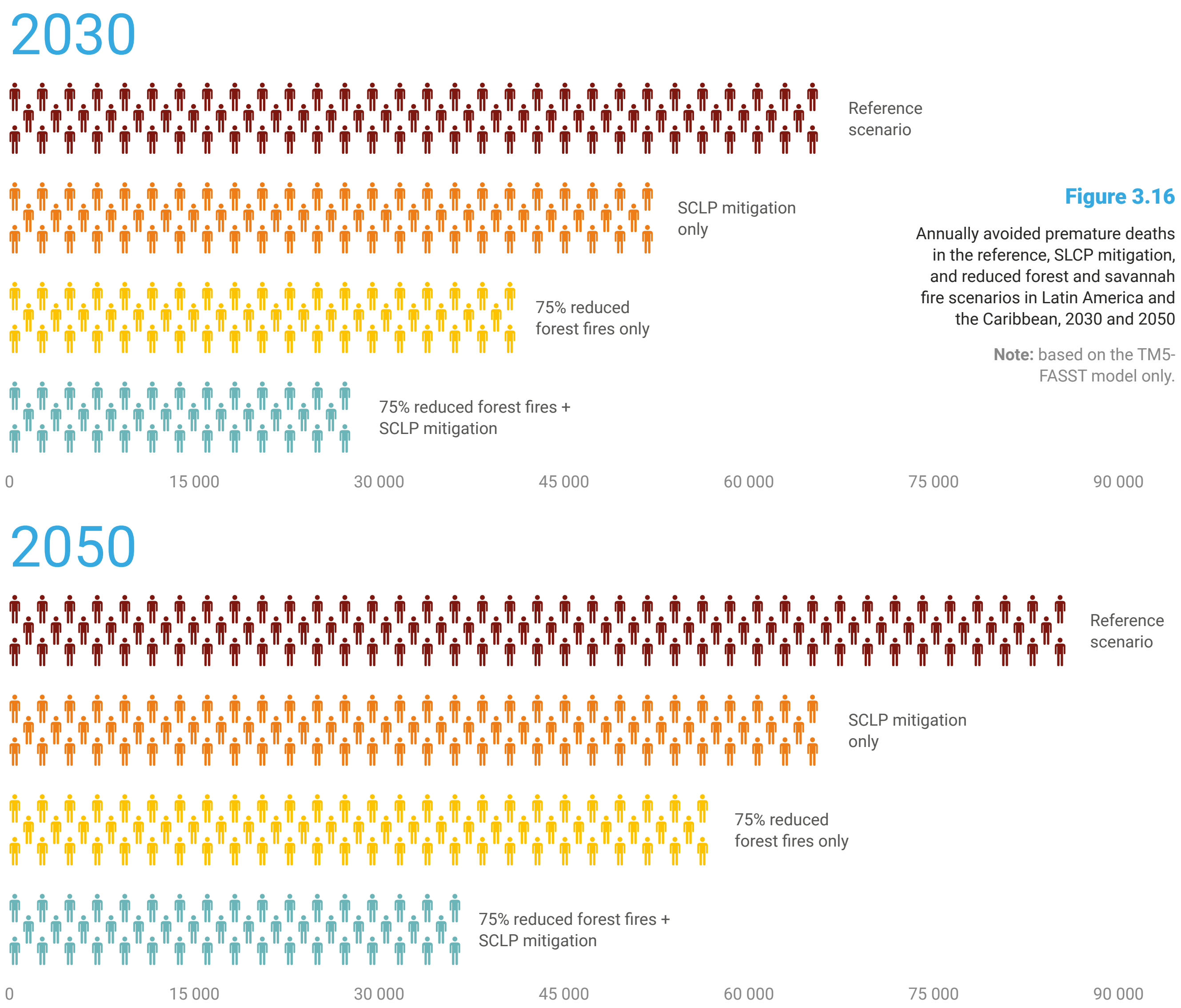


Figure 3.16

Annually avoided premature deaths in the reference, SLCP mitigation, and reduced forest and savannah fire scenarios in Latin America and the Caribbean, 2030 and 2050

Note: based on the TM5-FASST model only.

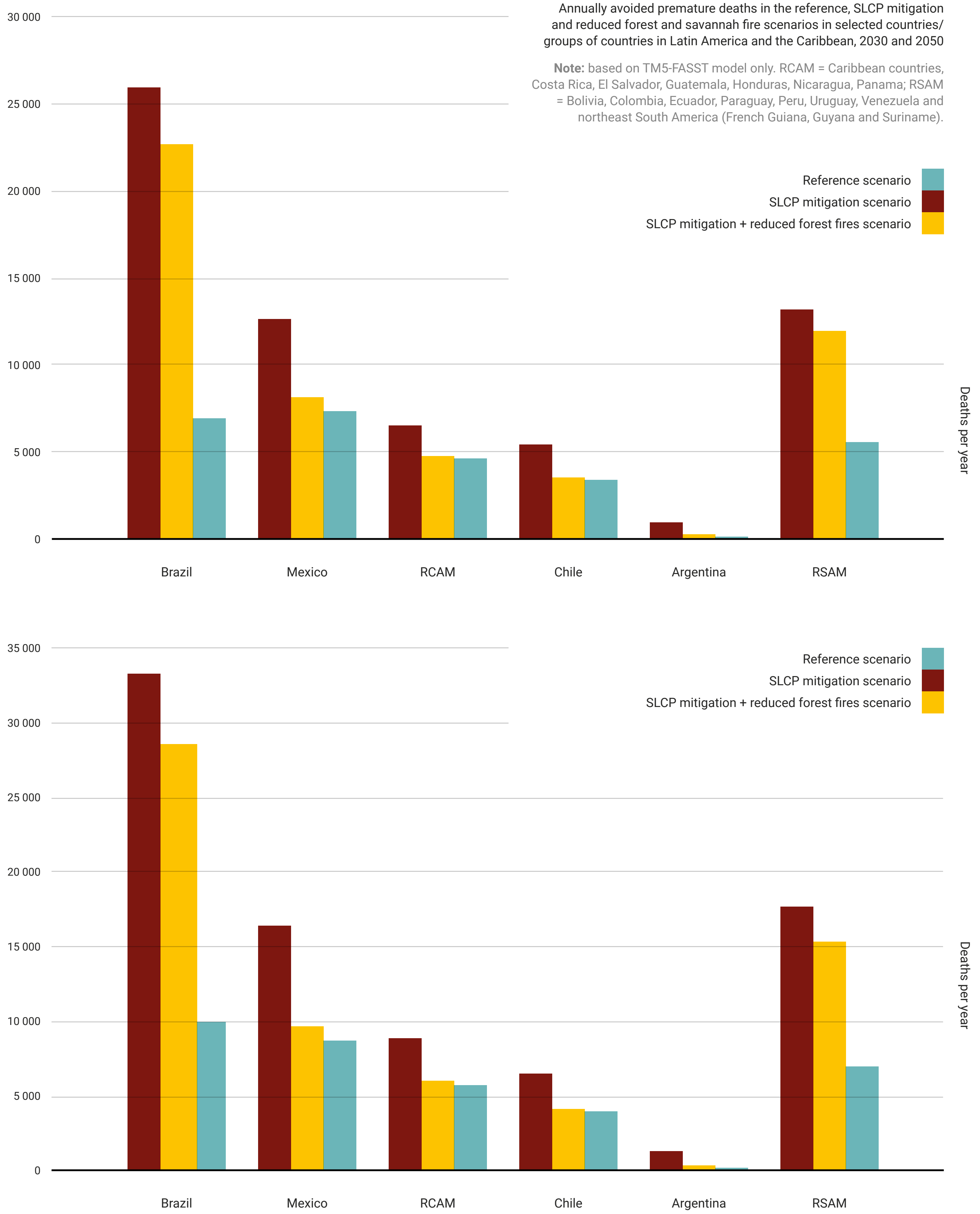


Figure 3.17

Annually avoided premature deaths in the reference, SLCP mitigation and reduced forest and savannah fire scenarios in selected countries/groups of countries in Latin America and the Caribbean, 2030 and 2050

Note: based on TM5-FASST model only. RCAM = Caribbean countries, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama; RSAM = Bolivia, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela and northeast South America (French Guiana, Guyana and Suriname).

estimates for the reference scenario compared with the SLCP mitigation scenario, and a further scenario where additionally a rather optimistic assumption was made of a sustained 75 per cent reduction in burning.

According to the TM5-FASST calculation, mitigation of open burning in Latin America and the Caribbean brings even larger health benefits than the SLCP mitigation scenario, at least at the regional level (Figure 3.16). By 2030, about 20 000 premature deaths can be avoided, and more than 25 000 by 2050; this is nearly doubling the impact of the SLCP mitigation scenario. More than 70 per cent of the health benefits from reducing forest and savannah fires in Latin America and the Caribbean are estimated to occur in Brazil, with most of the remaining health benefits in other South American countries (RSAM) (Figure 3.17). In other countries, the health benefits in the SLCP mitigation scenario are higher than for the case with mitigation of open biomass burning.

While the health impact estimates developed in the World Bank/ICCI study (World Bank-ICCI, 2013) also included a 50 per cent reduction in global open field and forest burning, their estimate for avoided premature mortality, calculated at 27 000 for the case where all measures were included, is not directly comparable, as the study suggested that about half of the health impact mitigation came from the improvement of cookstoves, which is not included here. However, it only related the estimate to the Andes and Patagonia region, defined as Argentina, Bolivia, Brazil, Chile, Ecuador, Peru and Venezuela. Considering that there is no significant impact calculated for Mexico, Central America and the Caribbean (as calculated with the TM5-FASST model in this assessment; Figure 3.17), and that the World Bank/ICCI study assumed a 50 per cent rather than 75 per cent reduction in open burning, one could conclude that the health impacts due to forest and savannah fire reduction are broadly compatible between the two studies, ranging from about 15 000 to 25 000 cases of premature mortality avoided annually.

Impacts from household air pollution

This assessment has not explicitly addressed indoor air pollution and therefore no estimate of health impacts from the mitigation of pollution from cookstoves is discussed. Background information about the relative risk estimates used in the 2013 Global Burden of Disease study (Brauer *et al.*, 2016), however, is provided.

Calculation of the impact of household air pollution on premature mortality in the Global Burden of Disease study (Brauer *et al.*, 2016) firstly calculates the proportion of a national population using solid fuels (Smith *et al.*, 2014). Within this fraction of the population, each woman is assigned a personal total exposure (indoor plus outdoor) of 337 µg/m^3, each man 204 µg/m^3 and each child 285 µg/m^3. These personal exposures are then used in combination with integrated exposure response (IER) functions (Burnett *et al.*, 2014) to calculate the relative risk associated with premature mortality due to ischaemic heart disease, lung cancer and stroke for men and women, and acute lower respiratory infection for children. The impact of household air pollution on mortality due to chronic obstructive pulmonary disease is calculated as a separate relationship derived from Smith *et al.* (2014). These relative risks are then used to calculate the increase in mortality due to household air pollution.

Table 3.4 shows the percentage reduction in the number of deaths associated with a reduction in the personal exposure of men, women and children to $PM_{2.5}$ concentrations. The lower $PM_{2.5}$ personal exposures (200, 160, 80, 40, 35 and 10 µg/m^{-3}) are derived from levels of exposure assigned to conversions to different cooking technologies in default scenarios used in the Household Air Pollution Intervention Tool (HAPIT, https://hapit.shinyapps.io/HAPIT/), as well as two World Health Organization (WHO) air quality guidelines (WHO, 2006). These personal exposures are indicative only, are uncertain, and the preference when assessing the impacts of a conversion from solid fuel use to other technologies is to have measured personal exposures before and after the intervention. Nevertheless, when taken together, the exposures for each intervention technology allow assessment of the benefits that could result from a reduction of personal $PM_{2.5}$ exposure assigned to individuals using solid fuels in Global Burden of Disease assessments (Smith *et al.*, 2014).

A reduction of $PM_{2.5}$ exposure to the WHO air quality guideline of 10 µg/m^3, which would require substantial reductions in ambient $PM_{2.5}$ concentrations in many regions, would achieve the majority of the benefit in terms of lowering premature mortality from ischaemic heart disease, lung cancer, stroke and child acute lower respiratory infection. For females, who have the highest personal exposure to pollution from solid fuels, reductions to 35–40 µg/m^3 – which are comparable with annual average outdoor concentrations in many regions (Brauer *et al.*, 2016) – result in avoiding over half the premature mortality associated with ischaemic heart disease and lung cancer. Similarly for children, reducing personal exposures to these levels achieves more than a 60 per cent reduction in premature mortality associated with acute lower respiratory infection.

3.6.2

Impacts on climate change

The different models estimate the impacts of the scenarios on various aspects of climate change. The GEOS-Chem Adjoint, TM5-FASST and GISS models have all been used to estimate the temperature change caused by implementing the SLCP measures in relation to the reference scenario

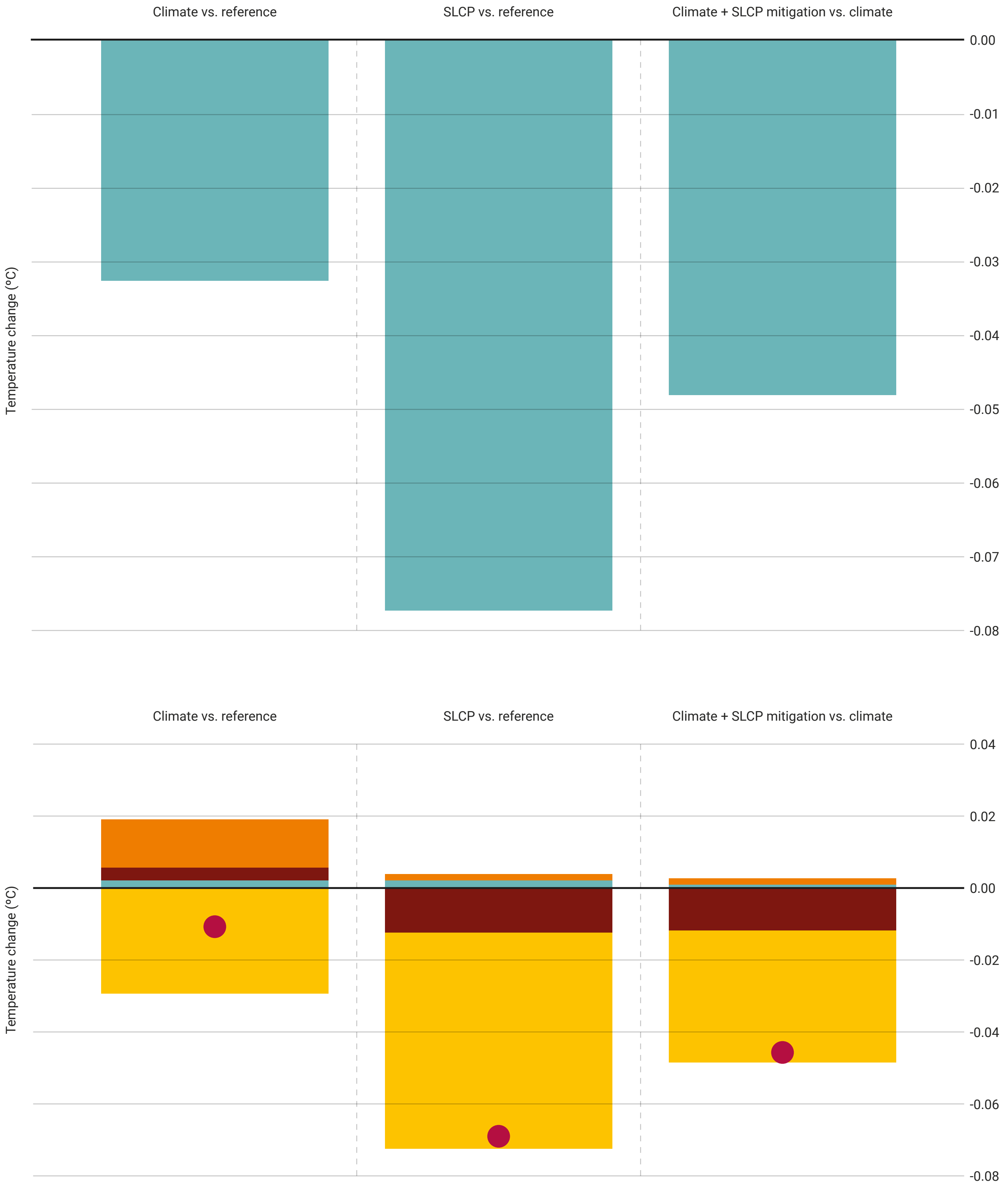
Health outcome	Ischaemic heart disease	Lung cancer	Stroke	Acute lower respiratory infection
Relative risk at 337 µg/m^3 (female personal exposure)	1.98	2.34	2.07	
Relative risk at 204 µg/m^3 (male personal exposure)	1.61	1.91	2.03	
Relative risk at 285 µg/m^3 (child personal exposure)				2.85
Relative risk at 200 µg/m^3 (chimney)	1.61	1.90	2.03	2.62
Relative risk at 160 µg/m^3 (rocket[a] stove)	1.57	1.76	2.01	2.43
Relative risk at 80 µg/m^3 (advanced/fan[b]-assisted stove)	1.44	1.44	1.88	1.80
Relative risk at 40 µg/m^3 (LPG[c]-fired stove)	1.32	1.25	1.59	1.35
Relative risk at 35 µg/m^3 (WHO interim target)	1.30	1.22	1.51	1.29
Relative risk at 10 µg/m^3 (WHO air quality guideline)	1.11	1.04	1.04	1.02
Percentage reduction in deaths (< 200 µg/m^3)	F: 23% M: 0%	F: 17% M: 0.6%	F: 2% M: 0%	C: 5%
Percentage reduction in deaths (< 160 µg/m^3)	F: 27% M: 4%	F: 25% M: 9%	F: 3% M: 1%	C: 9%
Percentage reduction in deaths (< 80 µg/m^3)	F: 38% M: 19%	F: 47% M: 36%	F: 9% M: 8%	C: 32%
Percentage reduction in deaths (< 40 µg/m^3)	F: 51% M: 36%	F: 65% M: 58%	F: 28% M: 27%	C: 60%
Percentage reduction in deaths (< 35 µg/m^3)	F: 53% M: 39%	F: 69% M: 62%	F: 35% M: 33%	C: 65%
Percentage reduction in deaths (< 10 µg/m^3)	F: 80% M: 74%	F: 93% M: 92%	F: 93% M: 92%	C: 97%

Table 3.4

Relative risk associated with different levels of personal exposure to particulate matter ($PM_{2.5}$) from household pollution, and the percentage decrease in premature mortality associated with a reduction in concentrations

Note: a relative risk of 1 equates to non-exposure. The exposure levels here are those assigned in the 2013 Global Burden of Disease study (Brauer *et al.*, 2016). F = female; M = male; C = child.

[a] A rocket stove is an efficient and hot-burning stove using small-diameter wood fuel.
[b] Forced draft.
[c] LPG = liquid petroleum gas.



🟦 Ozone
🟥 PM
🟨 Methane
🟧 Indirect effect
● Total change in temperature

Figure 3.18

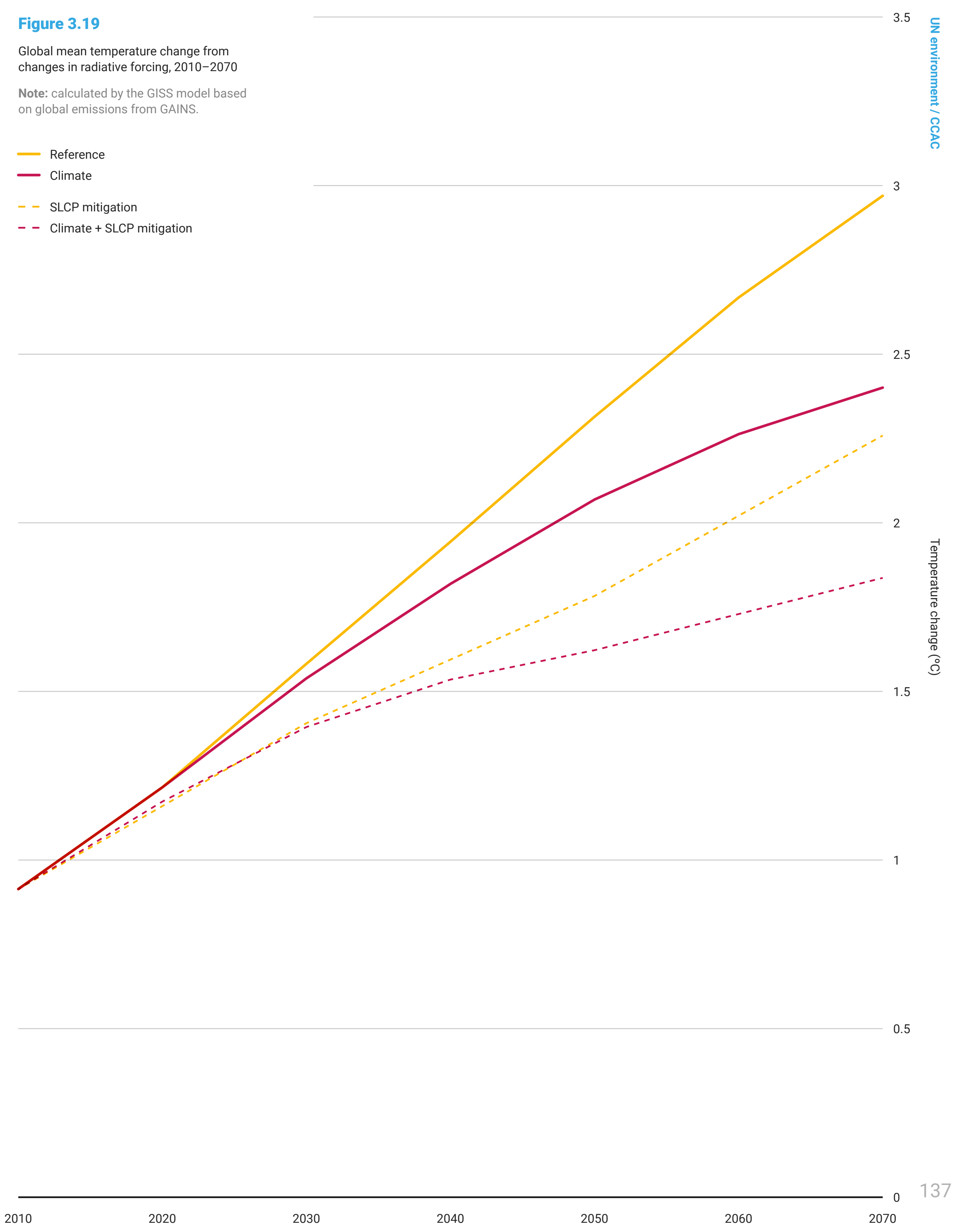
The change in global equilibrium temperature that would result from emissions in Latin America and the Caribbean under the climate and SLCP mitigation scenarios, 2050

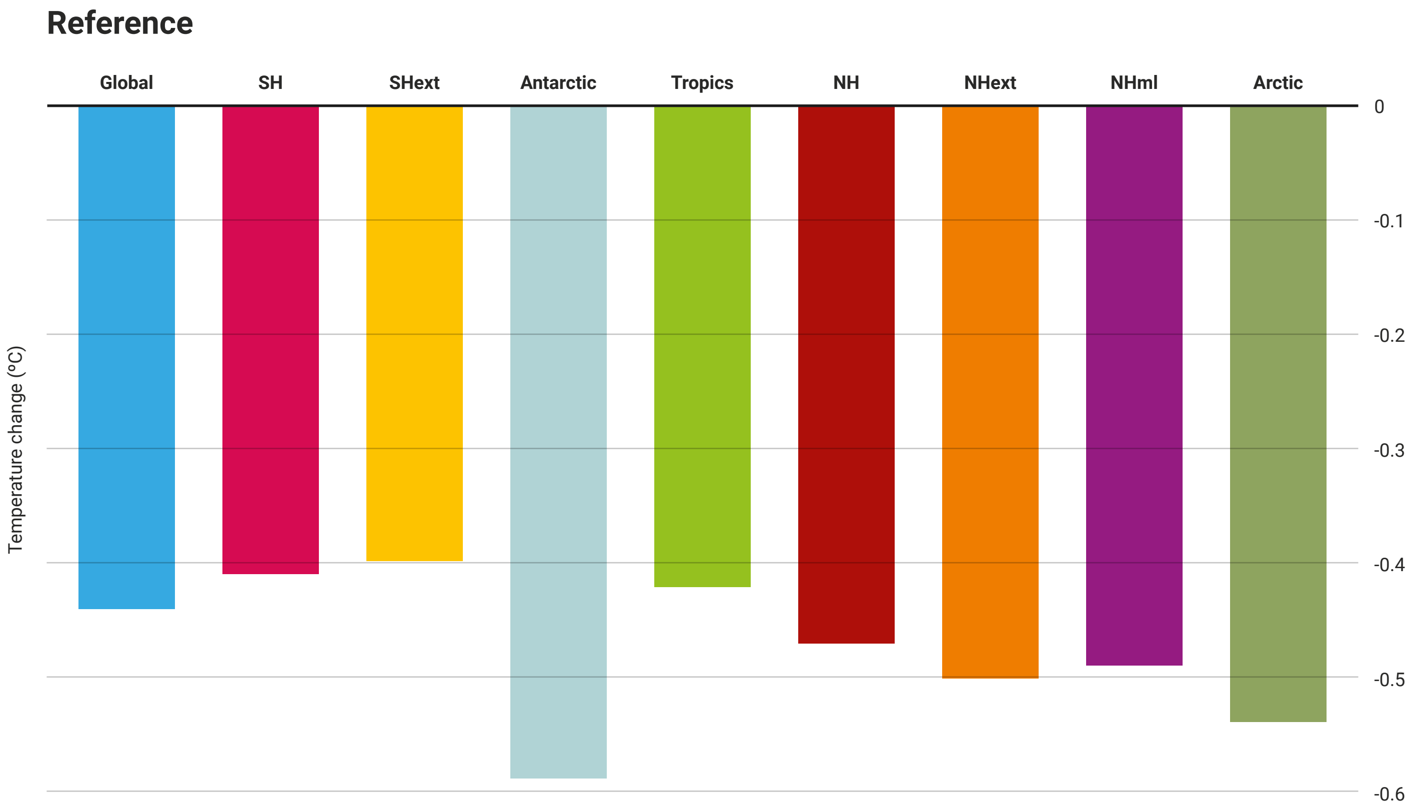
Note: the left-hand panel shows the GEOS-Chem Adjoint model results and the right-hand panel shows the TM5-FASST results. Impacts of CO2 and HFCs are not included.

Figure 3.19

Global mean temperature change from changes in radiative forcing, 2010–2070

Note: calculated by the GISS model based on global emissions from GAINS.




Reference

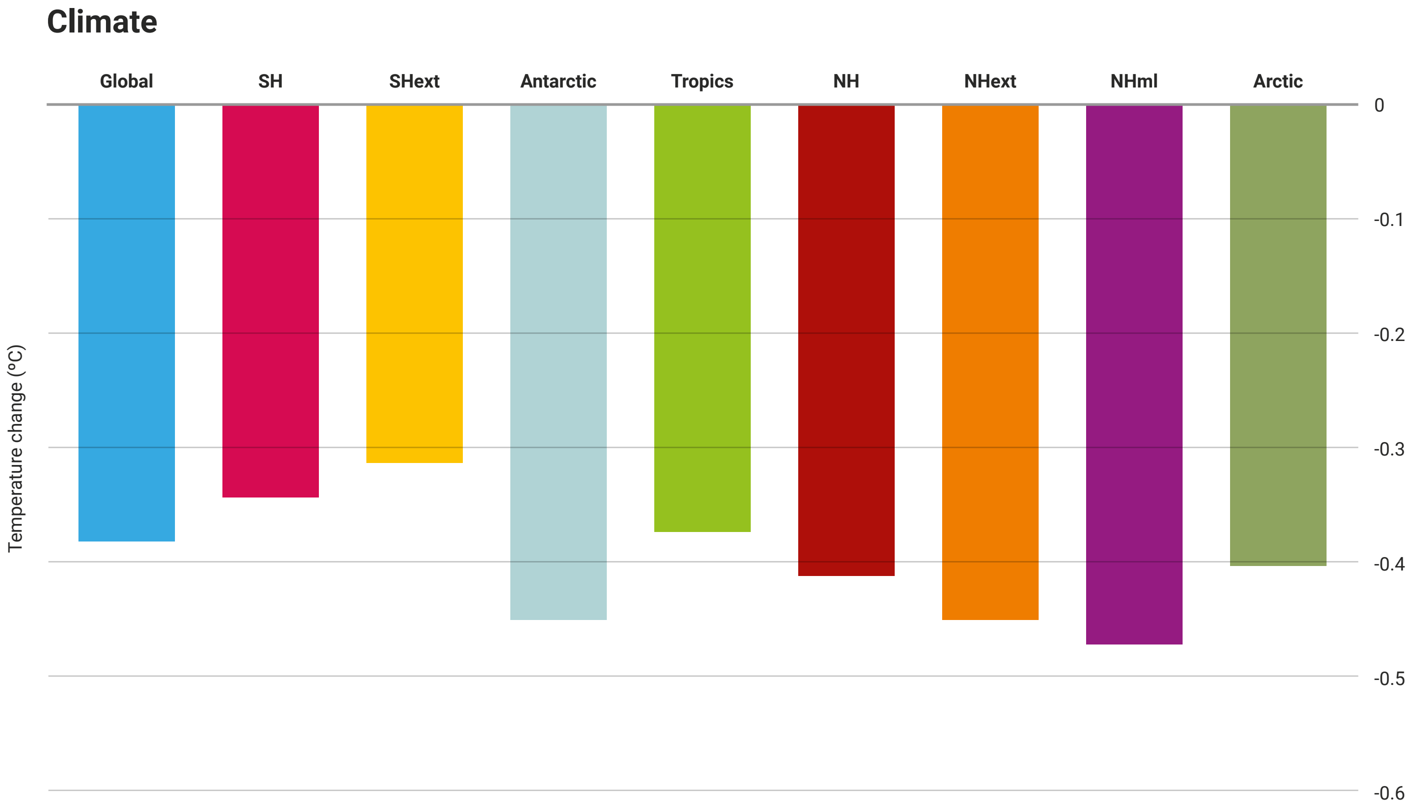

Climate

Figure 3.20

Global and regional temperature changes due to implementation of SLCP mitigation measures under the reference and climate scenarios, 2050

Note: calculated by long-term runs of the full GISS climate model. SH = southern hemisphere; SHext = southern hemisphere extra-tropics; NH = northern hemisphere; NHext = northern hemisphere extra-tropics; NHml = northern hemisphere mid-latitudes.

and also when applied to the climate scenario. These calculations are done offline, based on the concentrations of aerosols and O_3 calculated by the model, the forcing related to these and the emissions of globally mixed greenhouse gases. The GISS model includes HFCs, which are not included in the other two models. The results are changes in radiative forcing, resulting in equilibrium temperature change for the entire globe and for four latitudinal bands. The GISS model results were also used to calculate the annual change in temperature for the globe. Finally, the full GISS climate model was run for multiple years under 2050 conditions to calculate the changes in regional temperature, precipitation and other climate parameters.

Radiative forcing is a measure of the net change in the Earth's energy balance with space – incoming radiation from the sun minus outgoing radiation from the Earth. Ozone, CH_4 and BC all cause positive radiative forcing, and the Earth's temperature will respond until the outgoing radiation balances the incoming solar flux, thus warming the atmosphere. Black carbon will increase the warming at the top of the atmosphere, thus changing the distribution of warming in the vertical profile of the atmosphere. This then reduces the radiation reaching the surface, causing surface dimming.

Emissions from different locations affect radiative forcing to varying extents due to factors that include variations in residence times, background concentrations and the amount of available sunlight. The models have been run with the distribution of emissions and they have calculated the resulting concentrations of different substances in the atmosphere that affect forcing, both by cooling – through the action of, for example, sulphate, OC and nitrate – and warming – by, for example, BC, O_3 and CH_4, and then they calculate overall forcing for the historical emission and also for the projection in the year 2050. It should be noted that, given the fact that sources of BC also emit many other substances, the results of forcing for any one component are not very useful, as it is the overall changes in forcing that are of interest.

The change in global equilibrium temperature that would result in 2050 from SLCP emissions (excluding CO_2 and HFCs) in Latin America and the Caribbean was estimated using the GEOS-Chem Adjoint and TM5-FASST models. The equilibrium temperature is the temperature that would result if the emissions in 2050 were kept constant and the temperature response were allowed to reach an equilibrium value. As such, it is a theoretical value but can be used to estimate the impact of emission scenarios on temperature. Figure 3.18 shows that, by 2050, the global temperature benefit (a reduction of c. 0.08°C) resulting from the SLCP mitigation scenario implemented in Latin America and the Caribbean would be more than double that (c. 0.03°C) for the climate measures scenario only (excluding CO_2) in comparison to the reference scenario. Implementing SLCP measures in addition to climate measures would give rise to an additional global benefit of about -0.05°C (climate + SLCP versus climate). Results from the two models are broadly similar, although for the climate vs. reference scenario the indirect effects – albeit very uncertain – in the TM5-FASST model result in a smaller net reduction compared to the GEOS-Chem Adjoint model.

The influence of emission reductions in Latin America and the Caribbean (Figure 3.2) can be compared to the influence of implementing the SLCP scenario globally. This is shown in Figure 3.19 using the forcing calculated with the GISS model. This was run globally on the emissions from the GAINS model for all regions and the temperature response was calculated for each year. According to this analysis, the global benefit of implementing the SLCP measures in 2050 is a reduction of about 0.6°C, to a maximum of about 0.7°C in 2070. It should be noted that this run includes the HFCs in the reference and mitigation scenarios, which are not included in the other models. The HFC mitigation is responsible for about 33 per cent of the temperature benefit. Without the HFC measures, the global reduction in equilibrium temperature from the implementation of incomplete combustion and CH_4 measures according to the GISS-based calculations is 0.44°C. Under the climate scenario, the impact of the SLCP measures is reduced, but still provides a reduction in global temperature of 0.38°C. It can be seen that though the measures do not prevent an increase in temperature over the next five decades, they have the potential to significantly reduce both the rate and absolute value of the increase.

From Figure 3.20 it can be seen that the temperature decreases due to implementation of the SLCP mitigation scenario are not uniform in different latitudinal bands: whilst the southern hemisphere and southern hemisphere extra-tropics show a slightly lower than average temperature response, the Antarctic has the largest response to the emission reductions.

Impacts on regional temperature

The GISS model has been used in several experiments simulating the climate in 2050 under various emission scenarios with very long runs until temperature approaches equilibrium, and many years of data are available for statistical analysis. These runs are able to simulate changes in regional temperature and the results are shown in Figure 3.21, which indicates the spatial distribution of the changes that would occur in different regions comparing the impact of implementing SLCP measures to the reference scenario for 2050.

The SLCP measures lead to a reduction in the absolute temperature increase in the year 2050 across Latin America (Figure 3.21). The greatest reduction under the SLCP measures, relative to the reference scenario temperature, is of 0.7–0.9°C in northern Mexico, while in South America, the largest reduction is of 0.5–0.7°C in central Brazil and in part of the Andes in Argentina, Bolivia, Chile and Peru. Estimates for most areas of

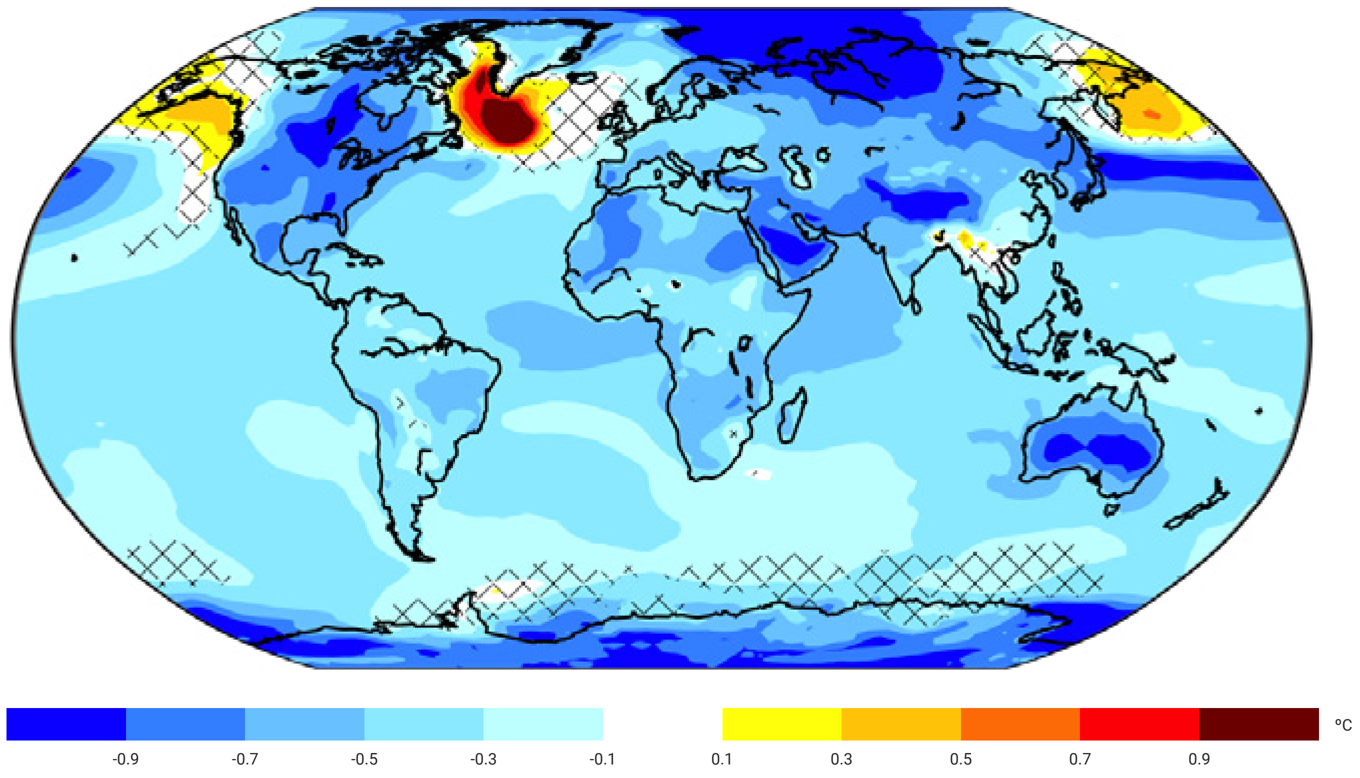


Figure 3.21

Regional temperature change resulting from the implementation of SLCP mitigation measures in relation to the reference scenario, 2050

Note: showing the results of long-term runs of the GISS model using emissions from GAINS. Hatching indicates areas where changes are not statistically significant at the 95 per cent confidence level.

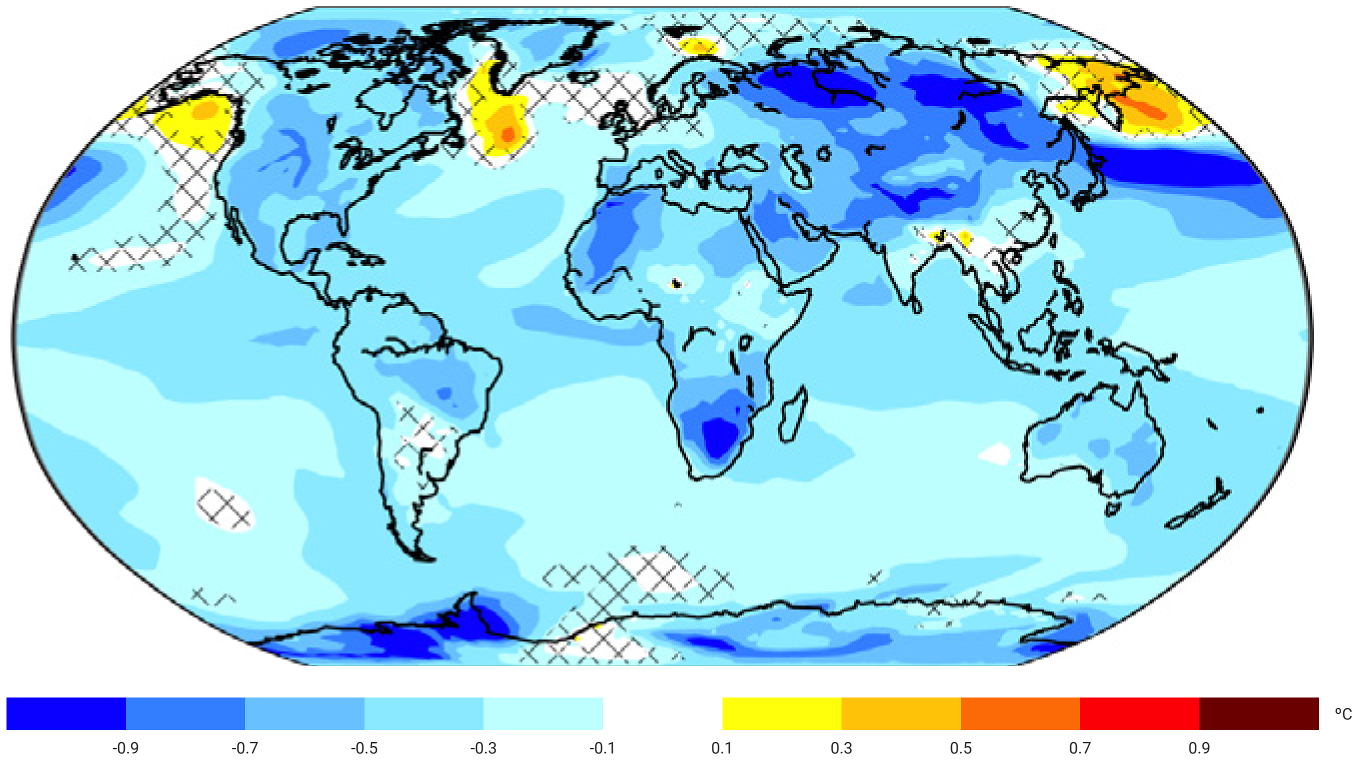


Figure 3.22

Regional temperature change resulting from the implementation of SLCP mitigation measures in relation to the climate scenario, 2050

Note: showing the results of long-term runs of the GISS model using emissions from GAINS. Hatching indicates areas where changes are not statistically significant at the 95 per cent confidence level.

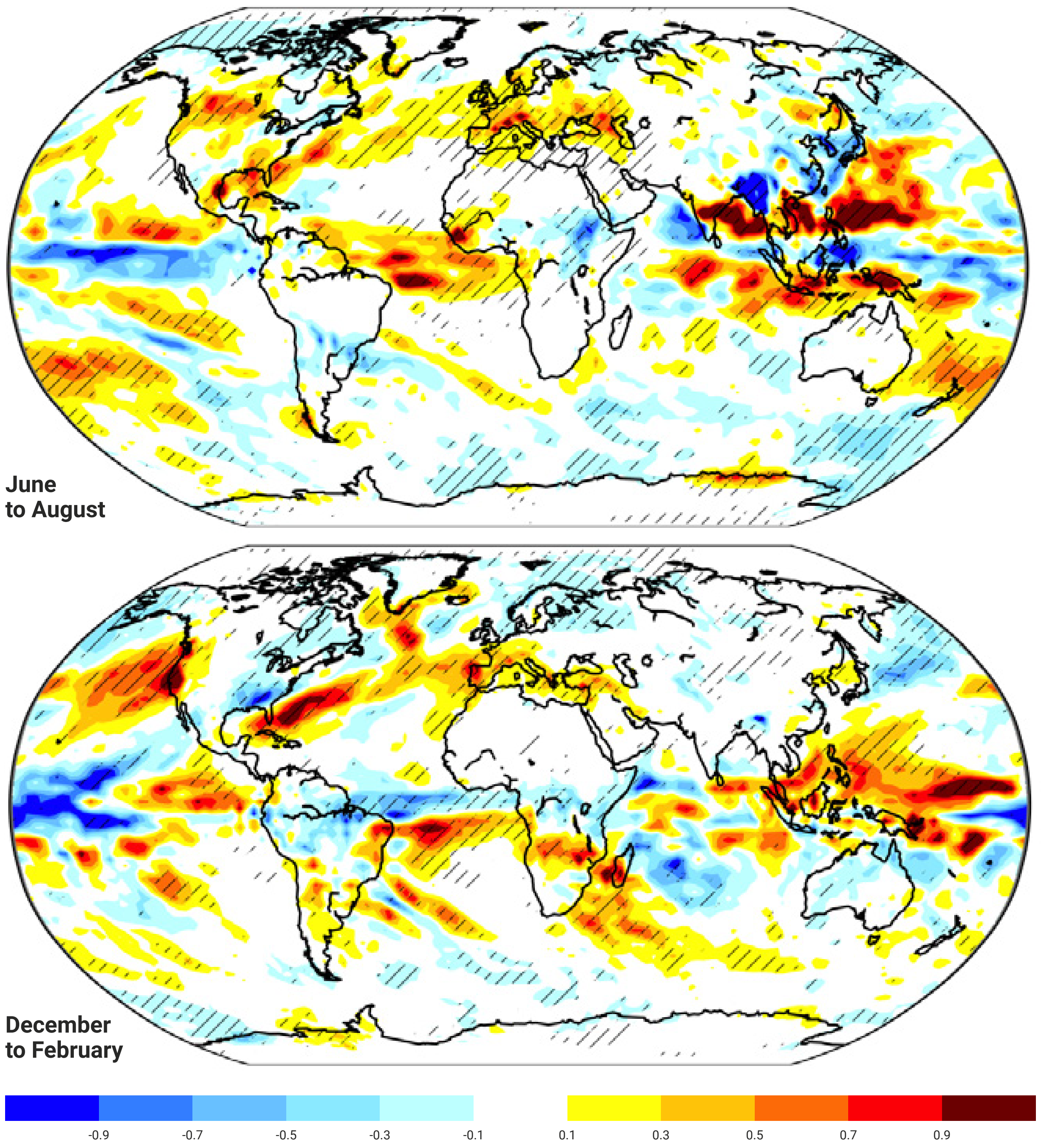


Figure 3.23

Changes in seasonal precipitation under SLCP mitigation measures compared to the reference scenario, 2050

Note: precipitation is given in millimetres per day, calculated by the GISS model. Hatching indicates areas where changes are not statistically significant.

South America indicate a reduction of 0.3–0.5°C from the reference scenario temperature. The lowest reductions are projected to be 0.1–0.3°C in parts of central and northern South America.

In the Caribbean it is estimated that temperatures will be 0.3–0.7°C lower under the SLCP measures than the temperatures projected in the reference scenario. Results are broadly similar under the climate scenario, with spatial patterns generally quite similar but magnitudes of reduced warming slightly less (Figure 3.22).

These reductions in regional temperature change are the result of running only one model and, due to the differences that usually occur between models, care has to be taken in interpreting them. The IPCC in its Fifth Assessment Report (AR5) (IPCC, 2014) used more than 40 models to understand the range of responses as a result of changes, mainly, to different greenhouse gas emission scenarios. The GISS model results can be compared to the results of those models to see how it performs (Chapter 1). Generally, different global climate models tend to agree more on temperature than precipitation over Latin America and the Caribbean, and there is therefore more confidence in the temperature change results.

Impacts in cryosphere regions of the Andes

The GISS model shows that implementing the SLCP measures will reduce the temperature increase in the Andes by 2050 by between 0.3°C and 0.7°C. This can be compared with the current increase in temperature in the region of 0.7°C since 1950; glaciers in the mountain range have shrunk by an average of 30–50 per cent since the 1970s (Menegoz *et al*., 2014).

Impacts on regional rainfall distribution

The GISS model has also been used to estimate potential changes in rainfall and other precipitation under the different scenarios. Figure 3.23 shows the seasonal changes in precipitation resulting from the implementation of SLCP mitigation measures. It can be seen that there are few areas with any significant change in rainfall and other precipitation over Latin America and the Caribbean as inter-annual variability is very large. There are indications of a decrease in parts of Amazonia during December–February and increases in parts of Argentina, Bolivia, Brazil and Uruguay (lower map); and indications of an increase in rainfall in Mexico in June, July and August (upper map). The decreased rainfall in Amazonia, which is statistically significant in this model, would partially offset large increases in rainfall projected for this area during December–February under the reference scenario, though models diverge greatly in projected rainfall changes.

3.6.3

Impacts on crops and vegetation

The measures targeting incomplete combustion reduce emissions of the O_3 precursors CO, NO_x, NMVOCs and some CH_4. The CH_4 measures mainly reduce CH_4 emissions. However, CH_4, and to some extent CO, control background levels of O_3, and NO_x and NMVOCs control the peaks and regional variation of O_3. Therefore, implementation of measures related to both incomplete combustion and CH_4 leads to reductions in O_3 concentrations. As explained in Chapter 2, O_3 is the main pollutant affecting crop productivity and vegetation health. Figure 3.24 shows the results of using the different models to estimate O_3 concentrations and uses these together with concentration-response functions (Chapter 2) to look at changes in

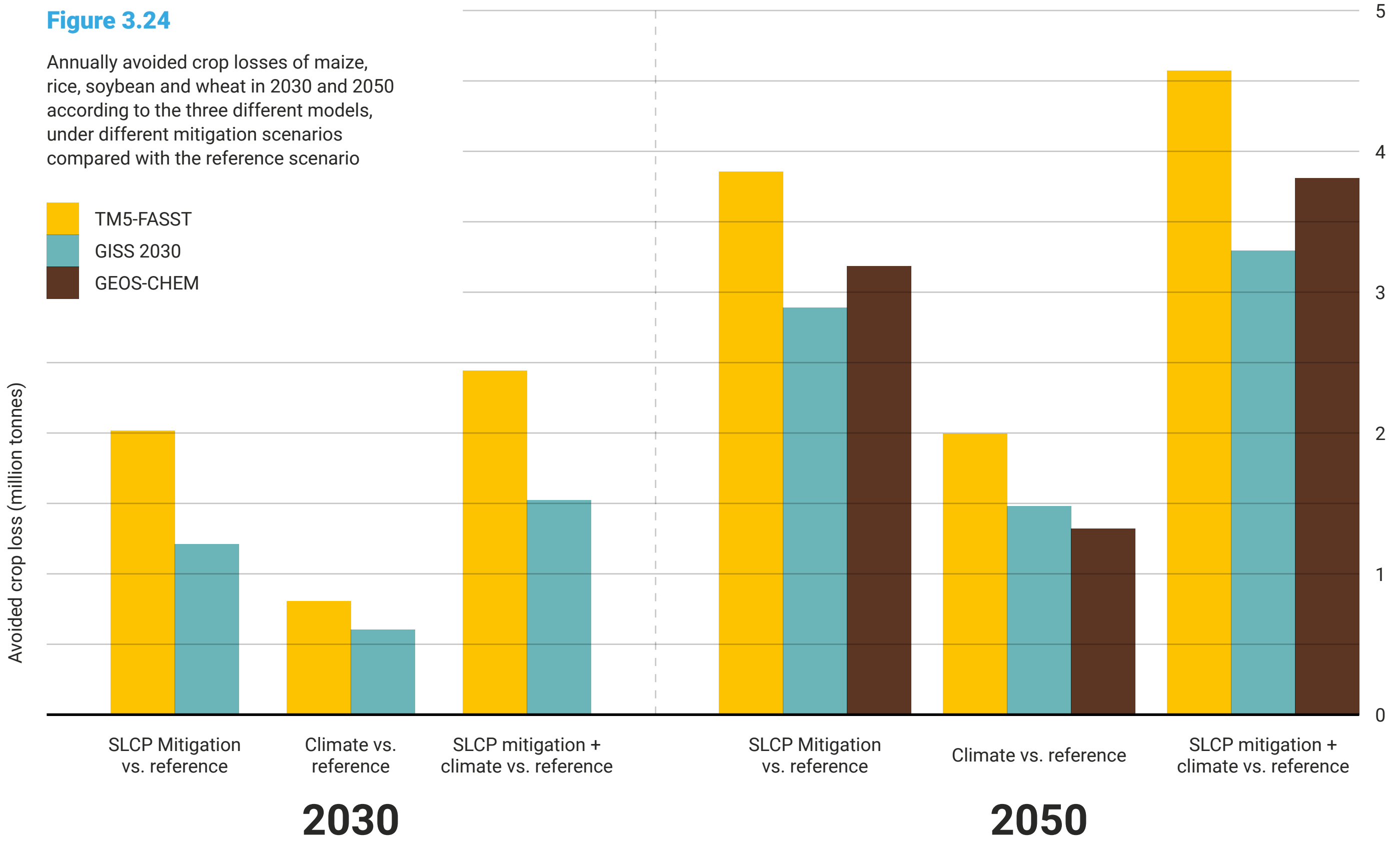


Figure 3.24

Annually avoided crop losses of maize, rice, soybean and wheat in 2030 and 2050 according to the three different models, under different mitigation scenarios compared with the reference scenario

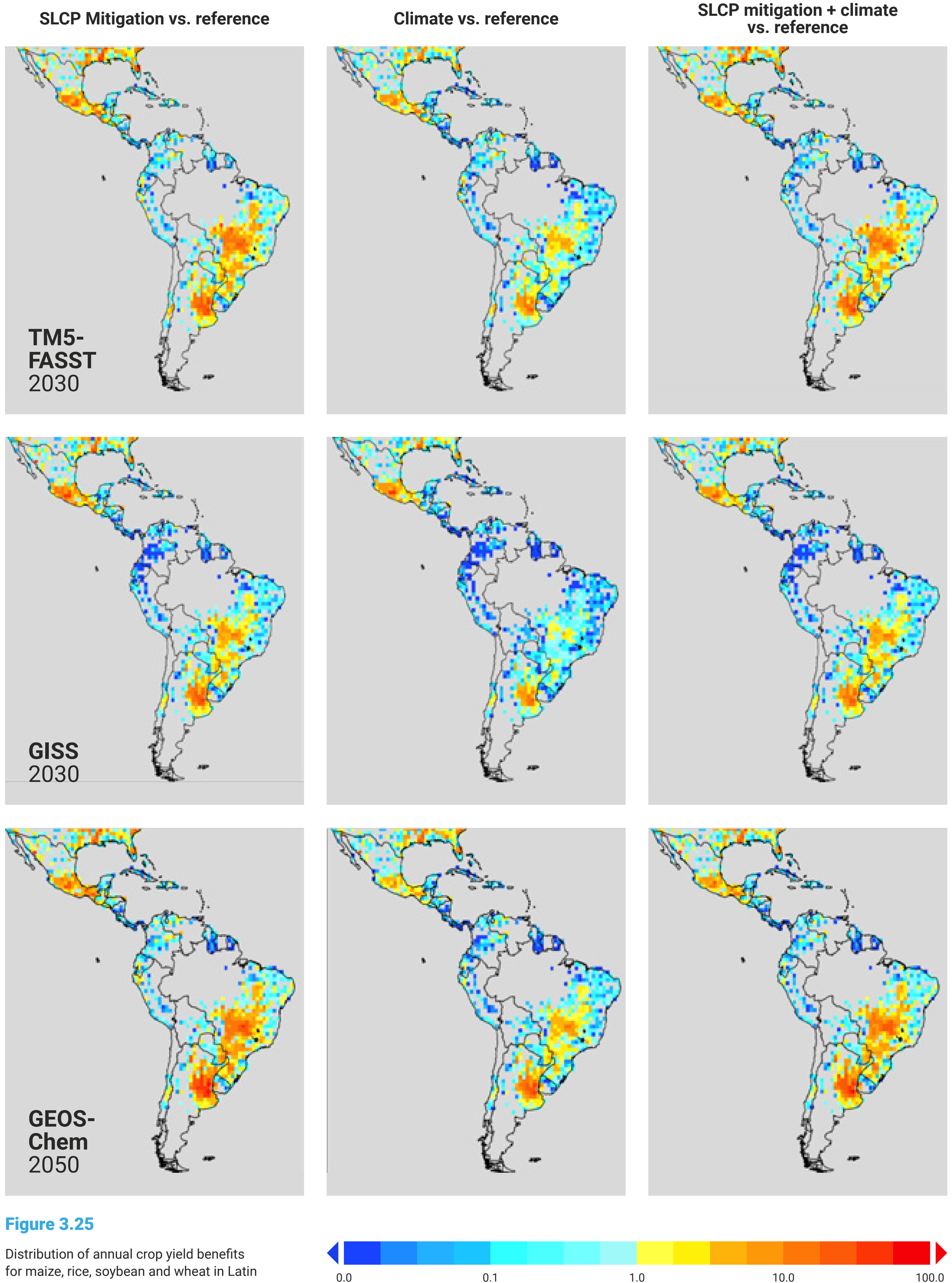


Figure 3.25

Distribution of annual crop yield benefits for maize, rice, soybean and wheat in Latin America and the Caribbean according to the three different models, 2030 and 2050

Note: avoided crop loss is given in '000 tonnes per grid cell. Orange and red show the greatest benefit.

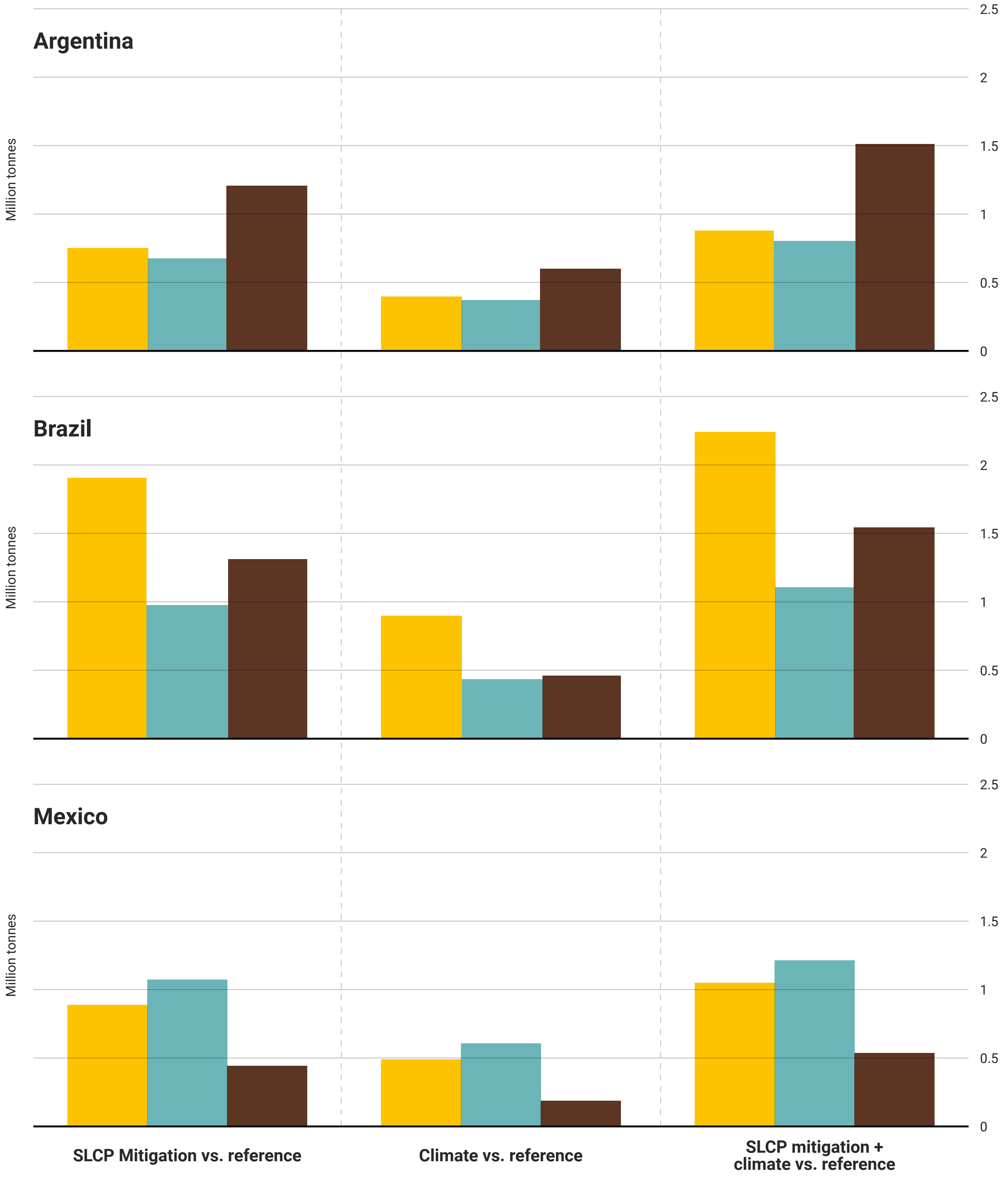


Figure 3.26

Annual yield benefits for maize, rice, soybean and wheat in the three major crop-growing countries of Latin America and the Caribbean in 2050, under different mitigation scenarios and according to the three different models

the crop yield of four staple crops – maize, rice, soybean and wheat. The different models estimate broadly similar crop benefits resulting from O_3 reduction through SLCP measures, representing about 3–4 million tonnes of these four crops for the whole of Latin America and the Caribbean. The climate scenario also results in reduced O_3 impacts on crops, but the benefits – of 1.5–2 million tonnes – are not as large as those achieved by the SLCP measures. The SLCP measures implemented under the climate scenario provide the greatest benefit – of 3.5–4.5 million tonnes – in relation to the reference scenario, but this is not much larger than implementing the SLCP measures alone. The benefits of the O_3 reductions are about twice as large in 2050 as in 2030.

Mapping the benefits of reduced O_3 impacts on crops shows that the greatest benefits are realized in the major crop-growing areas of Latin America and the Caribbean, namely Argentina, Brazil and Mexico. The different models show a similar distribution of benefits (Figure 3.25), but with a greater avoided crop loss in 2050, as also shown in Figure 3.24.

Figure 3.26 shows the degree of crop benefits in the three main crop-growing countries – Argentina, Brazil and Mexico. The models provide broadly similar results at the country scale, with the estimates generally varying by a factor of two.

Impact of climatic changes on crops and vegetation

The most marked climate change, according to the GISS model, is temperature change, which currently varies between 0.5°C and 0.7°C over the region.

As discussed in Chapter 2, temperature changes are inducing long-term alterations in hydrology and ecological processes that could in turn affect agricultural production. Warmer temperatures are affecting evaporation and evapotranspiration rates, as well as water storage in lakes and reservoirs. They are also changing the altitude of dew points, thereby affecting the water balance in mountainous areas.

Warmer temperatures may also result in changes in the geographical distribution of animal and plant species, alterations in their population growth rates and vigour, extensions of the development season, decreased resistance and resilience to disturbances such as drought, fire and flooding, and increased risk of invasive species, including pests and plants.

3.6.4

Additional benefits of hydrofluorocarbon abatement

In addition to the direct climate benefits from HFC mitigation, transitioning away from HFCs could catalyse additional climate benefits through improvements in the energy efficiency of refrigerators, air conditioners and other products and equipment that use HFC refrigerants. These efficiency gains could reduce emissions from

Table 3.5

Peak load reduction (gigawatts) in 2030 from a 30 per cent efficiency improvement and a transition to refrigerants with low global warming potential, selected countries of Latin America and the Caribbean

* **Note:** results for the policies enacted in parallel are better than the simple addition of the effects of the policies in isolation simply because the effects are multiplicative and not additive.

Country	Efficiency improvement alone	Refrigerant transition alone	Combined transition*	Number of avoided 500-megawatt peak-load power plants
Brazil	14–32	2.3–5.4	15.4–36	31–72
Chile	0.44–1.0	0.1–0.2	0.5–1.1	1–2
Colombia	1.9–4.3	0.3–0.7	2.1–4.8	4–10
Mexico	1.8–4.2	0.3–0.7	2.0–4.7	4–9
Total	**18.14–41.5**	**3.0–7.0**	**20.0–46.6**	**40–93**

the generation of electricity, which, depending on the application, generation mix and fuel type, could account for 70–95 per cent of total greenhouse gas emissions attributable to products using refrigerants. Reductions in emissions from fuel have substantial benefits for air quality, human health and fuel security, as well as agricultural yields and ecosystem integrity from less damage by O_3 and other toxic air pollutants.

Furthermore, growth in the use of refrigeration and air-conditioning products could account for 40–60 per cent of peak summer energy load in cities with hot climates, and are the largest contributor to peak load from household appliances. The growth of room air conditioning, particularly in major emerging economies, is increasing pressure on the capacity of power grids, with far-reaching economic and environmental consequences. A transition to super-efficient room air conditioning would reduce energy demand, lower operating costs for businesses and households, and reduce greenhouse gas emissions and air pollution associated with electricity generation.

The phase-out of chlorofluorocarbons under the Montreal Protocol catalysed substantial improvements in air-conditioning and refrigerant energy efficiency as the result of replacing old products and equipment with a new generation of higher-efficiency machines, and comparable energy efficiency improvements are documented for projects demonstrating alternatives to high-GWP HFCs (Carvalho *et al.*, 2014). For example, recent demonstration projects for utilizing low-GWP alternatives to HFCs presented by the Climate and Clean Air Coalition to Reduce Short-lived Climate Pollutants (CCAC) calculated energy savings of 15–30 per cent and carbon footprint reductions of up to 60–85 per cent for refrigeration in commercial food stores (UNEP/CCAC, 2014). As compared to HFC-410A, HFC-32 can improve energy efficiency by 5–10 per cent depending on the model (Daikin, 2016). In addition, companies including Coca-Cola and PepsiCo have reported an almost 50 per cent energy saving by using low-GWP retail refrigerated beverage display cases. Tesco and Unilever have reported approximately 10 per cent energy savings for refrigerated and frozen food cabinets using natural refrigerants compared to high-GWP units.

The achievable energy savings from the replacement of high-GWP HFCs with low-GWP alternatives, paired with technical improvements in the equipment that utilize them, has the potential, in some sectors, to as much as double the climate benefit of either action alone. A study by the US Lawrence Berkeley National Laboratory estimated that a ~30 per cent improvement in the technical energy efficiency of mini-split room air conditioning in parallel with a transition to low-GWP refrigerants has the potential to significantly reduce peak-load energy demand and in four countries in Latin America and the Caribbean has the potential to avoid energy use up to the equivalent of 93 medium-size power plants (Shah *et al.*, 2015).

Another benefit of tackling HFC emissions is the protection of the stratospheric O_3 layer. While HFCs were originally chosen as replacements for O_3-depleting substances under the Montreal Protocol, recent studies by NASA have determined that HFCs still have a small O_3-depleting potential. Thus reducing HFC emissions would avoid the resulting O_3 depletion (Hurwitz *et al.*, 2015).

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4

Progress and opportunities

Implementation of identified measures across Latin America and the Caribbean

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Image: Aerial drone image of Salem Paradise Beach, a beautiful public beach in Salen, northern Jamaica. Mihai-Bogdan Lazar, Shutterstock.

Contents

4.1

Introduction

This chapter reviews examples of initiatives and measures that have successfully reduced emissions of black carbon (BC), methane (CH_4) and some hydrofluorocarbons (HFCs), the short-lived climate pollutants (SLCPs) considered in this assessment of Latin America and the Caribbean. It addresses the feasibility of implementing the identified measures and policies in key sectors, where they could be replicated or scaled up to achieve air quality improvements and near-term climate protection.

The examples profiled include both technical and non-technical measures that reduce BC, CH_4 and HFCs, and cover a range of sectors, including transport; energy, particularly coal mining and oil and gas production; municipal solid waste and wastewater treatment; agriculture, including livestock rearing and open burning; residential heating and cooking; and small industrial sources.

These examples demonstrate the available technologies and practices that are currently in use in various locations of the region. The effectiveness of the examples depends on several factors, including consideration of local conditions, the existence of robust policies and programmes, the availability of appropriate technology, and effective access to financial support and incentives. What remains a challenge is facilitating widespread implementation of existing technologies and practices nationally and regionally.

Where data are readily available, a suite of key drivers and outcomes are described, such as the motivation for the initiative, emissions data, and analyses of air quality and health impacts. These are described in detail in a forthcoming technical report. The examples also include possible institutional arrangements and strategic investment opportunities, which could facilitate the implementation of such measures in different parts of Latin America and the Caribbean, as well as other parts of the world.

The analysis of specific sectors and examples from the region suggest that, despite differences in each country and sector, there are common needs that should be considered as good opportunities for actual improvements. Comprehensive and coordinated policies, laws and regulations are crucial if progress is to be made in all sectors. Unfortunately, however, some sectors and countries in Latin America and the Caribbean still suffer from a lack of appropriate policies, laws and regulations, standard-setting, and even consideration of economic instruments that take the social and environmental costs and benefits of SLCP mitigation into account.

There is also an urgent need to generate information at all levels to promote understanding of the processes and options to mitigate SLCPs. Complete and public information can help raise awareness and improve the participation of stakeholders, creating strong, effective networks and participatory processes.

Reliable and complete information is needed to, among other things, consider local practices and make sure all stakeholders understand their benefits, and avoid delays or limited results. Understanding the site characteristics of CH_4 emissions, such as those from wastewater treatment plants, is essential to having reliable data and certainty about inventories and mitigation. Detailed and local information can also provide previously unknown mitigation opportunities, such as the substitution of native plants as fodder in experiments on the mitigation of CH_4 emissions from enteric fermentation in ruminants in Argentina and Mexico. Furthermore, the adoption of no-till techniques in Argentina, Brazil, Paraguay and other Latin American and Caribbean countries has decreased the need for open agricultural burning, which affects human health as well as contributing to land degradation and climate change.

In addition, all analysed sectors identified the need to build capacity to meet the requirement for scientific and technical expertise to monitor emissions, generate information and implement available technologies. Sectors such as livestock management, brick production and municipal solid waste management all mentioned a lack of capacity among the personnel involved, something that is also related to the informal nature of the sectors. Strengthening networks and sharing lessons learned and good or bad practices are among the elements that the region could exploit to increase capacity.

Improving, developing and introducing technology is another crucial opportunity identified across sectors. Significant advances in technology have already been demonstrated, as in the use of diesel particle filters and the replacement of high-polluting vehicles in the transport sector. In Chile, for example, European Emission Standards (Euro 5/V) have been in place since 2013, which means all medium diesel vehicles must install particle filters (Gobierno de Chile, 2012a). Moreover, the next Decontamination Plan for the city of Santiago will require all public transport (Transantiago) buses to meet the Euro 6/VI standard (MMAa). The following sections present important examples of initiatives that can and do have positive mitigation impacts. These examples are, however, still limited; much wider implementation of successful measures is needed.

Making sure that there are economic incentives in place, with effective financial mechanisms and sufficient resources to promote the changes needed, is crucial for all analysed sectors. Economic instruments such as the increase in fuel prices in Colombia and Mexico and financial support for improved cookstoves, among other initiatives, have been shown to contribute to the necessary advances. Many of the effective measures required for mitigating BC, CH_4 and other SLCPs are new in Latin America and the Caribbean, for example the reduction of emissions of CH_4 by minimizing or eliminating fugitive emissions in the oil and gas sector and the emerging shale gas industry. Therefore, making sure that financial resources are available for the introduction of the necessary technology and infrastructure should be a priority for the region and the international community.

Strengthening networks and **sharing** lessons learned and good or bad practices are among the elements that the region could exploit to **increase capacity**.

4.2

Institutional and legal framework in Latin America and the Caribbean

In the last decade, advances have been made in Latin America and the Caribbean in the development of institutional and legal frameworks for the improvement of air quality and the mitigation of climate change. Chile and Mexico, for example, have recognized SLCPs and their link with public health and the environment, and their national institutions are already integrating measures to improve air quality and reduce the impacts of climate change.

Mexico is the first country in the region to expressly consider SLCPs within its national policies, and to integrate climate change mitigation with improvements in air quality. The reduction of SCLPs was included in the National Development Plan 2013–2018, then in the Programme for the Environmental and Natural Resources Sector, and more recently in the Special Programme on Climate Change 2014–2018 (Gobierno de México, 2013a, 2013b, 2014a). Institutions in charge of policy and implementation, the Ministry of the Environment and Natural Resources (SEMARNAT) and the National Institute for Ecology and Climate Change (INECC) are already coordinating efforts to integrate air quality and climate change issues.

In 2014, Chile merged the Division of Air Quality with the Climate Change Office within the Ministry of Environment, a collaboration that can tackle SLCPs more effectively. The new institution, known as the Division of Air Quality and Climate Change, recognizes SLCPs in its public listing of main duties (MMAb, 2017).

Colombia was one of the pilot countries, together with Mexico, to develop SLCP plans under the Supporting National Action Planning on SLCPs (SNAP) initiative of the Climate and Clean Air Coalition (CCAC) (CCAC-SNAP, 2013). The main objective of the initiative is to support the development of national SLCP planning processes – facilitating action in countries by embedding SLCPs in ongoing activities and policies, and building national capacity to coordinate issues related to SLCPs and identify national priorities. Currently, Chile, Colombia, Mexico and

Peru are participating in Phase II of the SNAP initiative, which also provides regionally coordinated support for institutional strengthening in participating countries.

Furthermore, in the context of the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), held in Paris in December 2015, countries were expected to present Intended Nationally Determined Contributions (INDCs), publicly outlining the actions they intended to put forward in the battle against climate change (UNFCCC, 2015). Only Chile and Mexico, from among the region's countries, mentioned SLCPs in their INDCs. Chile merely outlines the opportunity that addressing SLCPs implies, referring to the relation between BC and fine particulate matter ($PM_{2.5}$), and establishes that the country is open to technical cooperation and international finance to support such measures (Gobierno de Chile, 2015). Mexico also recognizes the opportunities offered by tackling SLCPs and states that their inclusion in its INDCs increases the country's level of ambition; this will be done with national resources and in an unconditional manner. Mexico's commitment is to reduce BC emissions by 51 per cent by 2030 (Gobierno de México, 2015).

Although many countries in Latin America and the Caribbean do not specifically consider SLCPs, some of these pollutants, such as ozone (O_3) and $PM_{2.5}$, are regulated and monitored as part of air pollution control efforts. Other relevant legal frameworks regarding CH_4 and other SLCPs relate to environmental protection and water and waste management, as described below. Effectively, existing regulations need to be reviewed, updated and coordinated to avoid duplication and advance mitigation efforts.

As air pollution issues intensify over the region, there is an urgent need to strengthen the air quality management system, its instruments at local and national levels and its integration in/coordination with the climate change agenda. An effective air quality management and climate change action plan requires the establishment of specific goals, abatement strategies, implementation programmes and ongoing evaluation with clear responsibilities and adequate financial resources, as well as defined timelines for achievement.

4.2.1

Improvement and coordination of policies, laws and regulations

One of the main challenges for a legal framework in Latin America and the Caribbean is that regulations are weak and do not reflect recommended levels, and, in many instances, are poorly enforced. A comparative study of Brazil, Chile and Mexico's legal and policy frameworks for air quality, for example, concluded that the maximum permitted levels for O_3 and particulate matter (PM_{10}) were beyond the guidelines of the World Health Organization (WHO) (AIDA, 2016). Mexico and Chile, in 2005 and 2012 respectively, regulated $PM_{2.5}$, and in 2014 Mexico revised the PM_{10} and $PM_{2.5}$ standards (Gobierno de Chile, 2012b; Gobierno de México, 2014b), although these still fall short of the WHO guidelines (WHO, 2005). And in 2013, Brazil instigated a process of updating its national standards with the target of including $PM_{2.5}$, though this is yet to be approved by the Brazilian National Environment Council (Governo do Brasil, 2013) – a lower standard implies that even if it is complied with, there will be negative impacts on public health and the environment.

As the analysis of the different sectors in this assessment has concluded, clearer and coordinated policies, laws and regulations are essential to promote the required changes. The establishment of stricter standards in Chile and Mexico, for example, along with complementary measures such as positive incentives and the implementation of cleaner technology, has reduced emissions from the transport sector. But to achieve greater fuel economy in the sector, public policies are needed to force economic agents to take account of social costs and benefits in their consumption and production decisions.

One of the main challenges identified by several sectors, including the brick-making and livestock industries and wastewater and municipal solid waste management, is the lack of policies and well-defined laws and regulations, as well as effective enforcement with penalties for non-compliance. The coal, oil and gas sectors have shown the need for policies that require mandatory CH_4 emission reductions to facilitate technology advancement and the implementation of the necessary measures. Without these mechanisms, and considering the cost of the measures, it is unlikely that changes will be achieved.

The biogas programme of the Costa Rican Electricity Institute (ICE), described in the livestock manure management section (section 4.3.4), is a good example of how the establishment and enforcement of policies, along with information, active stakeholder participation and economic incentives, can deliver the needed outcomes.

Another interesting opportunity to increase SLCP mitigation is the incorporation of a rights-based approach in policy and legal framework development and review. Air pollution in the region, mainly in cities, is linked to premature deaths and cardiovascular and other illnesses, largely affecting children, the elderly and other vulnerable sectors of the population (CAI, 2013). Air pollution clearly impacts quality of life, human well-being and the environment.

As international human rights law establishes that all states should protect, promote and respect human rights, states have the obligation to effectively control and monitor all activities that might pose a risk to the enjoyment of human rights, as well as providing special protection to children and others who might be in a more vulnerable situation. Based on a human rights approach, states should, therefore, review and strengthen policies and regulations to promote effective SCLP mitigation measures in different sectors. In addition, as the majority of the region's countries recognize the right to a healthy environment in their constitutions, they are responsible for implementing effective measures to mitigate SLCPs under both constitutional and international law.

4.2.2

Coordination and integration of standards and responsibility

In Latin America and the Caribbean, with a few exceptions, issues related to SLCPs are regulated and controlled by different national authorities, mainly those concerned with climate change and air quality, in addition to authorities responsible for particular sectors such as transport, agriculture, environmental protection, water management, waste management, energy, oil and gas, and health. Coordination and implementation of measures is, as a result, challenging. It is therefore recommended that, as Chile and Mexico have recently done, countries find ways to effectively integrate standards and responsibilities, consistent with national SLCP action plans and strategies.

42.3

Institutional structures and capacity

While important efforts have been made to develop institutional capacity to improve air quality, they are still insufficient to respond to current needs. Brazil, Chile and Mexico have all established monitoring networks, but challenges of adequate equipment, accuracy of data, and effective dissemination of information to the public remain. It is crucial for countries to concentrate on their monitoring networks, which are essential for assessing progress in air quality management, evaluating the effectiveness of applied measures, and taking appropriate action for improvement.

In Chile, the Ministry of the Environment administers more than 200 public air quality stations, providing updated information that is constantly publicized (MMAc, 2017). Private air quality networks controlling emissions from private projects also provide information (MMAc, 2017). In 2012, new stations were opened in all cities with more than 100 000 inhabitants (MMA, 2013). Although not perfect, it is a country with good monitoring providing regularly updated information, and also has mechanisms for sharing information with the community.

In Brazil, the monitoring network covers the main metropolitan areas, which are concentrated in the south, southeast and one state in the northeast, but it covers less than 2 per cent of the country's municipalities and just 9 of the 26 states plus the Federal District that have some means of monitoring air quality (Instituto Saúde e Sustentabilidade, 2014). Mexico has monitoring networks for its major cities, but needs further improvement as only 40 per cent of the population has information about air quality (INECC, 2011). The Air Quality and Protection of the Atmosphere Act (Senado de la República, 2013), which is currently being considered by the Mexican congress, is expected to make progress.

4.2.4

Indicators, compliance and enforcement of regulations

Despite the need to improve policies and regulations, existing laws and regulations could, with adequate enforcement, bring good opportunities for mitigation – Brazil, Chile and Mexico have policies, plans and legal frameworks in place with important goals and objectives. In many cases, however, those policies and plans lack concrete indicators, impeding the measurement of progress, evaluation of results and incorporation of the necessary adjustments. There are also key pieces of legislation that have not been implemented or enforced. Mexico's NOM 086, for example, mandated Petróleos Mexicanos (PEMEX) to distribute ultra-low-sulphur fuel (30 parts per million (ppm) of sulphur on average for gasoline and 15 ppm for diesel) from 2009 as part of the national policy to improve air quality (Gobierno de México, 2006), but implementation is still pending. In contrast, Brazil's Air Pollution Control Programme for Vehicles (PROCONVE), created in 1986, has succeeded in introducing stricter emission limits and low- sulphur diesel – currently diesel with 10 ppm of sulphur is available across Brazil (IBAMA, 2016).

4.2.5

Financial and other resources

The Latin America and Caribbean region has particular challenges in funding activities for SLCP abatement. For example, though their economies are growing, Brazil, Chile and Mexico still face obstacles in implementing the plans and projects as required due to limited financial, technical and even personnel resources. In order to ensure that SLCPs are mitigated, it is vital to identify, assess and prioritize high-impact interventions, define implementation requirements and design funding strategies that ensure access to local, national and/or international financial resources in the short, medium and long term. Models such as the Green Climate Fund and the Mexican Climate Fund could become key players in these processes. Mexico's Climate Fund should start operating soon and, given the fact that Mexico is one of only three countries that have legislated to reduce SLCPs, these resources could be expected to provide funding (SEMARNAT, 2015). It is important, however, to clearly understand the nature, eligibility, requirements and operational procedures of this and other sources of funding.

Brazil, in contrast, already has a National Climate Change Fund in operation, which offers an interesting combination of delivery of grants and loans (Presidência da República, 2009). So far, however, the fund's resources have been little used because of the complexity of accessing them, but it certainly is a starting point for leverage.

Chile, on the other hand, does not yet have a safe and reliable solution for funding resources for climate initiatives. In addition, and considering that air pollution also has an important impact on the Chilean economy, a cost-benefit analysis should be carried out so that the co-benefit to public health could be taken into account.

4.3

Sectoral Description

The following sections provide an overview of each of the major sectors addressed in this assessment. Because of space limitations, more detailed descriptions of each sector, including initiatives and measures that have been successfully implemented in some parts of the region; opportunities for scaling up; and challenges faced in implementing the policy, regulation or initiative will be described in a separate technical report.

4.3.1

Transport sector

The transport sector has a very important role in emissions of BC, CH_4 and HFCs, all of which have negative effects on human health as well as contributing to climate change. The most current global estimates suggest that 19 per cent of BC emissions are emitted by the transport sector, including road transport, non-road transport including locomotives and diesel marine vessels, and agricultural equipment (World Bank, 2014).

Several countries in Latin America have implemented successful measures to reduce emissions of these pollutants, such as:

- vehicle technology improvements;
- stricter environmental regulations;
- more efficient mobility into the cities;
- improvement in fuel quality and economy.

Vehicle technology improvements include the development and implementation of particle filters for diesel vehicles that have demonstrated a more than 90 per cent reduction of PM and BC (World Bank, 2014); these have been introduced in Brazil, Chile and Mexico. However, in order to deploy currently available advanced vehicle technologies, the sulphur content of fuel needs to be reduced. Other reduction measures include the replacement of diesel with natural gas in Peru's buses and the introduction of hybrid and electric vehicles in some cities in Argentina, Brazil, Colombia and Mexico.

Another important reduction measure is the introduction of the strictest available international vehicle emission standards developed by the United States Environmental Protection Agency (US EPA Emissions Standards, 2017) and the European Union (Euro 6/VI). Brazil, Chile and Mexico are among the countries in Latin America that have worked to incorporate these into their national legislation (Gobierno de Chile, 2012a; 2012b; ICCT, 2014). It is, however, important that the regulations are enforced, including through the use of inspection and maintenance programmes.

Some important Latin American cities are working to introduce more efficient mobility through a number of strategies. Bus rapid transit (BRT), which uses restricted lanes to provide passengers with an efficient service, has demonstrated benefits in terms of reductions in emissions and exposure of passengers to pollutants: systems have been implemented in Argentina, Brazil, Chile, Colombia, Ecuador, Guatemala, Mexico and Peru (Transmilenio, 2011; Metrobus Mexico, 2013; Transantiago). Some cities have promoted the use of non-motorized transport and developed infrastructure for walking and bicycling (ECOBICI, 2016). In addition, increasing the efficiency of transport systems necessitates integrating land-use, urban growth and the provision of transport infrastructure.

It is also important to mention that other measures and programmes have been developed to reduce BC, CH_4 and HFCs in Latin America, such as the Clean Transportation Programme implemented in Mexico, which aims to reduce fuel consumption and vehicle operating costs through driver training and discouraging vehicle use, specifically in Colombia and Mexico. Recovery of gasoline vapour at filling stations has been implemented in Mexico City; a nation-wide roll-out is under consideration.

In addition, the promotion of fuel efficiency in the transport sector has great potential to boost low-emission development. To achieve greater fuel economy in this sector, a set of public policies is needed, such as low-emission and energy-efficiency standards that force economic agents to take social costs and benefits from their consumption and production decisions into account.

The freight sector represents a large area of opportunity for emission reductions through improvements in technology and fuel, and the overall enhancement of operational efficiency and logistics along the supply/distribution chain.

4.3.2

Residential cooking

In many regions of Latin America and the Caribbean, while infrastructure for gas and electricity exists in urban zones it is limited in rural areas. However, as an expression of culture and tradition, households in many peri-urban and rural areas with access to gas and electricity still use wood as fuel for cooking and heating. Traditionally the wood is burned in inefficient open cookstoves inside poorly ventilated houses, conditions that expose operators, who are mainly women, often with children, to polycyclic aromatic hydrocarbons (PAHs). Exposure to PAHs is associated with cancer, pneumonia and heart and lung disease (Global Alliance for Clean Cookstoves).

Several other elements, including carbon dioxide (CO_2), O_3 precursors including CH_4, and BC, make up the indoor smoke from solid fuels. In addition to the public health issues associated with indoor smoke, emissions to the atmosphere of BC and CH_4 are currently the centre of international attention because of their capacity to affect the climate system (Anenberg *et al*., 2013; Bond *et al*., 2013). The introduction of improved biomass cookstoves is therefore of great importance as they reduce both emissions of PAHs and SLCPs – those available in Latin America and the Caribbean include Patzari, Ecostufa, Ecozoom, Ludé Bichée Ecocina, Onil, Turbococina, Mimosa, Noya Stove, Justa Metal and Copal Stove, Ecofogón, Chapina, Justa and Justa 2x3, Malena and Inkawasi (Wang *et al*., 2013b).

The use of liquefied petroleum gas (LPG) for cooking has also been widely promoted as a substitute for fuelwood in many of the region's countries. The use of LPG stoves has increased considerably in large urban areas but, in most peri-urban and rural settings, LPG only partially substitutes fuelwood, leading to mixed fuelwood-LPG users. As a result, the promotion of both LPG and improved cookstoves is much more effective in eliminating the use of open fires (Masera *et al*., 2015; Ruiz-Mercado and Masera, 2015).

Introduction programmes, if properly designed, adapted and deployed in communities, demonstrate health, economic and environmental benefits. Indeed, the energy efficiency, health and environmental benefits of some of the stoves mentioned have already been evaluated and show considerable reductions in emissions of PAHs and SLCPs (Johnson *et al*., 2008; Christian *et al*., 2010; Jetter *et al*., 2012; Jeuland and Pattanayak, 2012; Wang *et al*., 2013a), with some studies in Mexico showing a reduction of 61 per cent in total BC emissions when traditional stoves are fully replaced by improved ones (Christian *et al*., 2010; Masera *et al*., 2012).

Across Latin America and the Caribbean, non-profit organizations, the private sector and governments are starting to introduce these stoves to rural and peri-urban communities, but the penetration of programmes is still limited and faces a number of barriers that need to be addressed. Several local programmes, such as the Mirador Project in Honduras, have achieved significant success where users' priorities have been taken into account, stove designs are robust and stoves are monitored. Other programmes, however, have not succeeded due to financial and strategic difficulties, as well as poor design. In general, deficiencies in the supply chain and a lack of penetration have prevented the market from becoming self-sustaining.

Furthermore, in most cases, efforts to disseminate improved cookstoves in the region have not taken enough account of the cultural and social implications, including the multiple functions played by open fires, besides cooking. In this context, new and improved stoves designed to meet well-established standards that allow replacing both cooking and heating functions are needed. Different financial mechanisms and incentives tailored to local circumstances along with economic models to increase penetration will allow programmes to scale up, sustain the dissemination of improved stoves and focus efforts on adoption and use.

International experience suggests that improved cookstove adoption is more successful when fuelwood is not readily available; health issues are clearly understood by the whole family; incentives are in place to reduce the upfront cost of stoves; when stoves are adapted to local cooking practices, and their use does not involve major changes in cooking habits; when tangible fuel and time savings are proven; and finally, when the stoves appeal to the users' desire for "modernity" (Wang *et al*., 2013b).

4.3.3

Brick production

Artisanal brick making is an ancient activity and currently a significant element of the small economies of many communities, especially in developing countries. According to the CCAC, artisanal brick production had diminished in recent years but is now reviving, driven by the adoption and implementation of efficient technologies and processes (CCAC-Brick Production Initiative, 2017). The most recent global artisanal brick inventory shows that Asia is the main brick producer with approximately 100 000 large-scale kilns, of which 2 500 are in India and Bangladesh. In contrast, the total number in ten Latin American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Honduras, Mexico, Nicaragua and Peru) is around 48 000, and they are mostly small-scale kilns (EELA, 2013).

Many of the region's traditional cities, including Bogota and Cartagena, Colombia; Cusco, Peru; and Queretaro and San Miguel de Allende, Mexico still

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preserve their colonial design of buildings with brick walls and tile roofs; these elements are considered noble construction materials. In countries including Argentina, Chile, Ecuador and Mexico, artisanal brick production enterprises are largely part of the informal economy operating in rural and peri-urban areas on leased land, which is periodically displaced by urban sprawl.

Currently artisanal brick producers tend to service the informal construction sector that makes up a significant part of local housing markets, where people live in socially, sanitarily and ecologically unsustainable conditions, causing physical and mental health problems, exacerbating domestic violence and negatively impacting the environment, as elsewhere around the world. In contrast, industrial brick producers mainly supply the formal construction market; in Mexico, for example, industrial brick production supplies the formal construction sector, which represents around 10 per cent of the total market (Kato *et al.*, 2013).

Even in the formal industry, there is a lack of information on the process and emissions. In terms of BC emissions, estimates vary according to the fuel used and the control of combustion processes. In general, artisanal and some industrial brick producers in Latin America and the Caribbean use fuel that has high environmental impacts in low-efficiency kilns. Wood, tyres and plastics, among other fuels, are used to fire bricks and tiles, contributing significantly to air pollution and deforestation as well as climate change (Red Ladrilleras).

To reduce emissions of greenhouse gases, BC, O_3, PM and other pollutants, a step-by-step approach is required. By introducing simple technology that improves combustion, reduces emissions and saves fuel and thereby significantly reduces costs, it should be feasible to move the sector towards cleaner and modern production.

Currently important international efforts, developed by the Programme on Energy Efficiency in Artisanal Brick Kilns in Latin America to Mitigate Climate Change (EELA) and the CCAC-Brick Production Initiative, consider climate change to be a pivotal issue for development, have recognized brick production as an actor, and are therefore strengthening capacity. The EELA Programme has proved that promoting a systemic approach, in which technology suppliers and financial providers promote their products and services to brick manufacturers, can create a win-win situation for all market players. Emission standards can drive the sector to introduce new kilns, as demonstrated in Brazil and Colombia, while more efficient kilns that use less fuel and save money can drive producers to update their equipment. Peru has designed a nationally appropriate mitigation action (NAMA) for the brick sector, which may contribute to sector modernization (Swisscontact, 2016).

Finally, in terms of government efforts, Mexico has been supporting different national institutions with the main objective of obtaining local emission factors in order to improve data and establish emission strategies.

4.3.4

Livestock manure management

In the last decade, beef, pork, poultry and milk production in Latin America and the Caribbean has grown by more than one third, far above the world average (CEPAL/FAO/IICA, 2014). This rapid growth has occurred predominantly in Argentina, Brazil, Chile and Mexico. While it is partly attributable to high rates of land-use change from forest to pasture and cropland, the more important driver has been the introduction of technologies and instruments to restrain growth to areas already designated for livestock, a forest conservation measure leading to intensive production systems associated with increased meat and milk output per animal (FAO, 2014). For rural and peri-urban communities in the region, the growth in the livestock sector has been an important indicator of economic well-being. At the same time, the number of livestock farms that are de-coupled from cropland but associated with higher numbers of livestock has increased, posing new challenges for the management of manure. Among these challenges are the emissions of two potent greenhouse gases, CH_4 and nitrous oxide (N_2O), during manure decomposition (Gerber et al., 2013). Together, CH_4 and N_2O from manure storage, treatment, application and deposition are estimated to account for nearly 30 per cent of total agricultural emissions in Latin America and the Caribbean (FAOSTAT, 2014).

Across the region, much of the national and international investment in initiatives related to manure management has been used to promote CH_4 capture and destruction in on-farm biodigesters, which involves channelling animal excrement into covered lagoons where it undergoes anaerobic digestion and releases CH_4. This is captured and then either flared off or utilized for electricity generation or heating (IDB, 2011). Initiatives to install biodigesters on livestock farms are common in Latin America and the Caribbean, funded both by international development organizations and by national governments, for example under the umbrella of NAMAs. These include the Biogas Programme of the Costa Rican Electricity Institute, which was created when the Costa Rican National Animal Health Service (SENASA) passed a law requiring farms to implement approved systems of manure management (SENASA, 2006); Costa Rica's Watershed Management Commission for the River Reventazón, which includes incentives to install biodigesters amongst measures to reduce waste flow from farms into rivers (COMCURE, 2000); Nicaragua's National Biogas Programme, funded by the Inter-American Development Bank and the Nordic Development Fund (Hivos, 2013); and Chile's NAMA on Self-supply Renewable Energy (CER, 2013).

While cattle in the region have traditionally been raised in pasture-based systems, feedlots have been introduced over the last few decades, especially in Ar-

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gentina (CAF, 2014) and Brazil (Costa Junior *et al.,* 2013; Domingues Millen *et al.,* 2014). Feedlots, also known as confined or concentrated animal feeding operations, are a type characterized by high concentrations of animal numbers in confined spaces. As world demand for milk and meat products rises, most of the increase in production to meet this demand is expected to occur in feedlots (Peterson *et al.,* 2013).

Depending on the animal species and feed composition, 60–95 per cent of livestock nutrient intake from feed is excreted as manure and urine (Teenstra *et al.,* 2014). Manure management thus plays a fundamental role in the nutrient cycle – when nutrients consumed and excreted by animals are returned to productive lands. Manure management practices that attempt to close the nutrient cycle, especially when they provide an alternative to expensive and fossil fuel-intensive synthetic fertilizers, are therefore widely promoted throughout Latin America and the Caribbean. Examples of these practices are slurry irrigation, composting and the drying of manure solids for easier transportation and application as fertilizer.

The region's countries generally do not have specific policies on manure management, but regulations and incentives that affect manure management are a common component of national-level environmental, agricultural, energy and public health policies. For example, the climate change policies of Brazil, Costa Rica and Mexico promote manure management as an approach to reducing emissions. Mexico's Special Programme on Climate Change (2009–2012) set out annual emission reduction targets for the livestock sector, to be achieved in part by implementing manure management measures. Brazil's Sectoral Plan on Low-Carbon Agriculture (2012) provides specific targets and budgets for the treatment of animal waste, the use of biogas as an energy source, and the installation of biodigesters (Brazilian Plan ABC, 2012). Costa Rica's National Action Plan for Climate Change (MAE-Costa Rica, 2012) includes annual targets and budgets both for reducing CH_4 and N_2O emissions from the livestock sector and for increasing the use of emission reduction technologies by 2021. Other policies regulate and incentivize specific manure management practices related to storage, treatment, application and disposal. However, regulations and incentives for improving manure management in many countries are weak, lacking both strong incentives for good practice and clearly defined penalties for non-compliance.

Climate change has created a new context for manure management policy making, in which targets are set for implementing specific manure management practices or achieving certain emission reductions associated with the livestock sector. In Latin America and the Caribbean the availability of technology is not a limiting factor in improving manure management; rather it is that the links between manure management, nutrient flows, the competitiveness of the livestock sector, and SLCPs and other greenhouse gases have not been sufficiently articulated. Accordingly, key opportunities for improvement include information gathering and awareness raising, policy development, and stakeholder network building.

4.3.5

Enteric fermentation in ruminants

Latin American and Caribbean countries contribute less than 9.1 per cent of the world's anthropogenic greenhouse gas emissions, with the region ranking fourth behind Asia, Europe and North America. Agriculture contributes about 13 per cent of the global total, 50 per cent of CH_4 emissions and 60–80 per cent of released nitrous oxide (N_2O) (IPCC, 2014). Most CH_4 emissions originate from ruminant enteric fermentation and flooded rice cultivation. Ruminants are one of the most important sources of CH_4 released into the atmosphere, producing about 33 per cent of all anthropogenic CH_4 emissions (Eckard *et al.,* 2010). It is a normal by-product of the digestive process of ruminants: archaea methanogenic bacteria use the carbon dioxide (CO_2) and hydrogen (H_2) present in the rumen – which originate from the microbial fermentation of fibre from plants – to form CH_4 and reduce the accumulation of H_2 in the rumen. Methane is not used by the animal as a source of energy and is eliminated through the lungs or belched into the atmosphere (Eckard *et al.,* 2010). Nonetheless, CH_4 production in ruminants denotes a loss of energy from the system, which can represent up to 7 per cent of the total daily gross energy intake (Hristov *et al.*, 2013). Therefore, developing strategies to reduce CH_4 production in the rumen can on the one hand contribute to mitigating the effects of the gas on climate change, and on the other hand bring economic benefits to farmers by making animals more efficient in terms of the use of energy from feed.

Currently, most of the efforts in Latin America and the Caribbean to reduce CH_4 produced by ruminants are aimed at quantifying emission volumes, defining emission factors and calculating inventories, whereas little has been done on mitigation. This is because it was only recently that governments and scientists in the region recognized the important role that cattle, sheep and goats play in the production and emission of large amounts of CH_4 into the atmosphere and its influence on climatic variability. The first regional conference on greenhouse gases in agriculture took place in Chile in 2014 (Ministerio de Agricultura, 2014). The first initiatives to address the magnitude of the problem are related to the development of facilities and infrastructure, allowing scientists to measure CH_4 emissions by ruminants and thus generate baseline information on which governments can negotiate mitigation targets within the current international protocols. Improved emissions inventories will reduce current uncertainty and allow the monitoring of livestock production systems before and after the implementation of mitigation strategies, so that emission reduction can be validated and the effectiveness of the strategy evaluated.

The generation of local CH_4 emission factors for ruminants is an emerging challenge for the region's countries because it demands expensive facilities, scientific equipment and a substantial number of experiments with a large number of animals over relatively long periods of time to provide an accurate characterization of emissions. A review of the available literature reveals a rather small number of studies on the subject despite the fact that the agricultural and livestock sectors are two of the main economic actors in Latin America and the Caribbean. One of the first studies on CH_4 emissions in Latin America was conducted in Argentina by Bárbaro *et al.* (2008) using the sulphur hexafluoride (SF_6) technique (Johnson *et al.*, 1994) to measure CH_4 emission by a group of Aberdeen Angus steers, half of which were grazing on native pasture and the other half on cultivated pasture. A similar experiment was carried out by Bualo *et al.* (2014) on beef cattle, half of which had access to a mixed grass-legume pasture and the other half to received sorghum fodder. In Chile, Muñoz *et al.* (2015) conducted one of the first studies to measure enteric CH_4 production by grazing dairy cattle on ryegrass; they observed that increasing the level of concentrate supplementation resulted in an increase in milk yield without affecting CH_4 production per unit of milk produced. Brazil is one of the few countries in the region that has invested in the construction and operation of respiration chambers to measure *in vivo* CH_4 production (Gonçalves de Faria *et al.*, 2014).

Some Latin American studies have been carried out on the reduction of enteric fermentation in ruminants through the use of oils and tanniferous plants, with contrasting results. In Colombia, for example, Rodríguez *et al.* (2014) evaluated the *in vivo* effect of the addition of *Lippia origanoides* oil on CH_4 production by Holstein heifers with negligible effect. In an *in vitro* study in Argentina, Martínez Ferrer *et al.* (2014) reported that oil extracted from *Tagetes* and *Aloysia* produced an effect similar to monensin, an antibiotic that has proven its effectiveness in reducing CH_4 formation in the rumen. In Mexico, Ayala *et al.* (2014) reported that the addition of *Enterolobium cyclocarpum* (parota tree) to the sheep's diet reduced CH_4 emissions by up to 36 per cent. Other mitigation strategies include the use of leguminous trees and shrubs integrated into sylvo-pastoral systems, which is believed to be a more sustainable method of production compared to traditional livestock systems, particularly in the tropical regions. Trees and shrubs improve the nutritional quality of the diet of grazing livestock, normally by increasing the concentration of protein, and help to reduce CH_4 synthesis by the effect of secondary metabolites such as tannins and saponins present in these plants. For example, Mayorga *et al.* (2014) reported the effect of *Guazuma ulmifolia* in reducing CH_4 emissions from zebu steers. *Leucaena leucocephala,* a leguminous tropical tree from Mexico, has also proved to be successful in reducing CH_4 emission by ruminants in tropical regions of Latin America (Moreira *et al.,* 2013). The potential of *Leucaena* to reduce enteric CH_4 production is promising, however more research is needed before arriving at conclusive results, in particular due to its effects on animal performance at high inclusion levels and its potential production of N_2O.

There is an urgent need to expand information on emission factors, inventories and mitigation strategies for the different ruminant species in Latin America and the Caribbean. This information will serve to guide the development of mitigation policies and reduce uncertainty in CH_4 inventories for the region.

4.3.6

Agricultural open burning

Over the last 50 years, the world's agricultural area increased by approximately 10 per cent, but in Central and South America it grew by around 34 per cent, from 111 million hectares to about 125 million hectares in Central America, and from 440 million hectares to 614 million hectares in South America. In the latter region this was mainly due to new technological capacity and agricultural improvements (FAOSTAT, 2015).

Across the region, open burning is commonly used in arable areas as a tool for pest and weed control of wheat, soybean and other grains, as well as for preparing the land for planting. This technique, however, affects soil organic carbon (OC), increases runoff and soil erosion, contaminates watercourses, and affects the climate (Rusu, 2014; Calvin *et al.,* 2016). Although the agricultural area has increased considerably in past decades, the burning of stubble has decreased substantially since the 2000s due to investment in direct drilling, known as no-till (Derpsch, 2008; Friedrich *et al.,* 2012; Rusu, 2014).

The no-till technique is an alternative to agricultural open burning introduced to Latin America and the Caribbean in the 1970s, mainly in Argentina, Brazil and Paraguay (Friedrich et al., 2012; AAPRESID, 2015; FEBRAPDP, 2015). No-till technologies have great potential to increase the organic matter content of the soil and sequester carbon; intensive tillage systems, on the other hand, constantly reduce the carbon content of the soil. The main barriers to no-till adoption, however, which include a lack of know-how, access to appropriate machinery and adequate herbicides, and policies to promote its adoption, need to be overcome.

The growth of the area under no-till has been especially rapid in South America. Argentina and Brazil lead the countries in which the technique is spreading quickly, with it being employed over 29 and 32 million hectares, respectively, corresponding to 70–80 and 86 per cent of the total area under cultivation in these countries (Peiretti and Dumanski, 2014; FEBRAPDP, 2015). Paraguay and Uruguay also have high usage: 90 per cent and 82 per cent of agricultural areas, respectively, use no-till techniques (Kassam et al., 2014), while in Bolivia 72 per cent of the area growing soybean uses no-till. In contrast, in Chile, the technique is used on only 0.2 million hectares of agricultural land, while almost 0.5 million hectares are cleared by burning. In Colombia and Venezuela, only about 0.1 and 0.3 million hectares, respectively, use no-till techniques.

The decrease in open burning of agricultural areas in South America is mainly due to rapid expansion of techniques that seed into untilled soil without removing stubble, restrictions on burning and the use of machinery for harvesting.

Several initiatives are working to reduce agricultural open burning or the expansion of agricultural areas in the Amazon forest. One of the well-known examples showing that it is possible to significantly reduce stubble burning in Brazil is the 2007 Agro-environmental Protocol, also known as the Green Protocol, a voluntary agreement between the São Paulo State Government and the Brazilian Sugarcane Industry Association (SMA-UNICA). In sugarcane areas, fire is used to eliminate up to 30 per cent of sugarcane biomass, including dry and green leaves as well as stubble. To reduce burning, the protocol introduced early phase-out deadlines: 2014 for mechanized areas and 2017 for non-mechanized ones. Between 2006 and 2012, while the cultivated sugarcane area in São Paulo State increased by 45 per cent, the areas in which burning was used decreased to 27 per cent of the total cultivated with sugarcane. Furthermore, with restrictions on burning, the number of properties that use machinery for harvesting has increased considerably. Nationally, a federal decree prohibits pre-harvest field burning as of 2018 on large farms that can be mechanized.

4.3.7
Municipal wastewater treatment

In Latin America and the Caribbean 88 per cent of the urban population and 64 per cent of the rural population, or 83 per cent of the total, have access to centralized sewage systems or in-situ final disposal (WHO, 2015). Municipal wastewater treatment is provided for only 56 per cent of the collected sewage, which represents 38 per cent of the total municipal or domestic wastewater produced in the region. These values are estimated using data from the official documents of six countries that together represent 76 per cent of the region's total population – Argentina, Brazil, Chile, Colombia, Mexico and Peru.

In addition, the operational practices of existing wastewater treatment plants are very different and some of the smaller installations have been abandoned. This precarious situation is evidence of how far the region is from delivering full wastewater treatment. Indeed, the Development Bank of Latin America (Corporación Andina de Fomento, CAF) estimates that an annual investment of US$1.66 billion dollars will be required between 2010 and 2030 if Latin America is to reach 64 per cent treatment of municipal wastewater (CAF, 2012).

The purpose of wastewater treatment facilities is to remove pollutants, and by this means to protect the environment and public health. Nevertheless, if the plants are not correctly conceptualized, designed, maintained and operated, they can have serious environmental impacts, if, for example, CH_4, which is the product of anaerobic decomposition, leaks during the process. In fact, anaerobic degradation and the resulting CH_4 emissions may take place in the sewage network, pumping systems, preliminary treatment and the biological reactor itself. Furthermore, emissions of N_2O from anaerobic systems should be kept in mind due to their high global warming potential (GWP) – N_2O has a GWP 310 times greater than the equivalent mass of CO_2 over a 100-year time horizon – especially when the process incorporates the biological removal of nitrogen.

The baseline for any mitigation policy in the water sector is energy efficiency, either for existing or future systems. This should be regarded as a high-priority mitigation measure, especially where electricity generation is based on burning fossil fuels. Biogas recovery for electricity production has major mitigation potential for conventional municipal wastewater treatment plants with anaerobic sludge digesters. This not only reduces CH_4's global warming contribution by burning it, but can also provide 50–60 per cent of the energy needed in large treatment plants that would otherwise be sourced from the grid (Arnaud and Gricourt, 2015).

In some countries with warm climates, direct anaerobic sewage treatment is increasingly used, mostly based on upflow anaerobic sludge blanket reactors. A recent survey of 2 734 wastewater treatment plants in six Latin American countries – Brazil, Chile, Colombia, Dominican Republic, Guatemala and Mexico – (Noyola *et al*., 2012) found, however, that nearly 60 per cent of the sewage treatment capacity is still provided by activated sludge (extended aeration and conventional) processes.

The adoption of direct anaerobic processing for sewage treatment in developing countries is a more sustainable option than conventional activated sludge or low-cost stabilization ponds. This should be supported by a programme for improving management and training, mainly focused on small municipalities or operators, regardless of the type of treatment process. Moreover, research and technology development should be encouraged to provide small and reliable biogas burners and co-generation units, as well as simple means of capturing or degrading CH_4 dissolved in effluent.

A life-cycle assessment in Mexico showed that stabilization ponds have a higher environmental impact due to CH_4 venting (Noyola *et al*., 2013), while extended aeration contributes to GWP due to indirect emissions generated by the demand for electricity in the aeration tank. The contributions of conventional activated sludge are CH_4 from anaerobic digestion and greenhouse gases from the generation of electricity for aeration purposes. However, co-generation of electricity by burning CH_4 can be an asset, reducing electricity consumption from the grid and decreasing the overall GWP. Finally, the use of upflow anaerobic sludge blankets could also lower GWP impact if efficient CH_4 capture and burning is provided.

Encouraging the adoption of anaerobic treatment technologies for future sewage treatment facilities in developing regions may be an attractively accessible measure (Noyola *et al*., 2016). This would reduce greenhouse gas emissions from the wastewater sector while simultaneously reducing capital investment and operational costs compared to conventional full aerobic treatment options.

A study based on five scenarios for 2030 showed that greenhouse gas emissions from sewage treatment in Mexico could be reduced by as much as 34 per cent compared to a baseline scenario (Noyola *et al*., 2016). This could be accomplished if future facilities were based on combined anaerobic-aerobic processes with 95 per cent CH_4 burning efficiency and electricity co-generation in facilities with treatment capacities above 500 litres per second. If, however, the production of electricity were not considered, the reduction of greenhouse gas emissions would be limited to 14 per cent (Noyola *et al*., 2016). Clearly, the impact of biogas recovery for electricity production is significant. Moreover, the anaerobic-aerobic scenario would result in slightly lower emissions – 10 277 tonnes of CO_2 equivalent in 2030 compared to 10 500 tonnes in 1990. However, if the biogas were used for cogeneration in the anaerobic-aerobic processes, the amount of CO_2 equivalent generated in 2030 would be 75 per cent of the amount produced in 1990. It should be noted that, during that year, only 20 per cent of the collected sewage was treated.

4.3.8
Municipal solid waste

The municipal solid waste sector is the third largest source of anthropogenic CH_4 emissions, generating 800 million tonnes of CO_2 equivalent worldwide annually; BC and CO_2 are also produced by this sector (CCAC-Municipal Solid Waste Initiative).

Municipal solid waste management is important for both public health and the environment. With population growth, the amount of solid waste generated in Latin America and the Caribbean has been increasing. Approximately 50 per cent of this waste is not adequately disposed of, although in recent years collection coverage has increased. One of the main difficulties for waste collection has been observed in urban slums of large cities or in areas that are difficult to access (BID-AIDIS-OPS/OMS, 2011). In Rio de Janeiro, small vehicles such as motorcycles with baskets and low-capacity trucks are able to enter such difficult areas in the slums (*favelas*), facilitating waste collection (CCAC-Rio, 2015).

Sorting at source is not common practice in the region and no appropriate source-sorting incentives or information are available to most people; such practices as waste picking, open burning and uncontrolled landfill are still common (BID-AIDIS-OPS/OMS, 2011). Mexico City's 2003 Law of Solid Wastes includes a chapter on sorting of wastes, stating that it is an obligation of every waste generator, household, business and industry, institution, etc., to separate organic and inorganic waste and to deposit them in differentiated containers. Source sorting grew from 1.68 per cent in 2005 to more than 24 per cent in 2013 in residential areas (SMA-DF, 2014). The city of Cali, Colombia, has designed a municipal source separation policy based on identifying, organizing and providing legal status to waste pickers, who operate as city contractors for gathering, separating and commercializing recyclable materials. Households are urged to separate their waste at source using different coloured bags and large generators of organic waste are targeted for separate collection (CCAC-Cali, 2015).

Landfill is the prevalent solution for the final disposal of solid wastes, with uncontrolled landfill remaining very common, together with the uncontrolled burning of waste in small cities. Open burning of municipal waste is widespread, accounting for 2 per cent of the region's overall wastes, although in some countries up to 7 per cent of municipal solid waste is disposed of in this way (BID-AIDIS-OPS/OMS, 2011). Recycling is not extensive, yet informal recycling supports a large sector of very poor people. Composting has not been developed in Latin America and the Caribbean due to inappropriate evaluation of its economic feasibility.

The region has little experience in generating energy from waste. In Mexico, some projects for capturing CH_4 from landfill have shown good results (BENLESA, 2013). Rio de Janeiro has recently closed its primary disposal site, the Gramacho landfill, where a new biogas purification plant will deliver 10 000 cubic metres (m^3) of high-grade gas per day to one of the country's main refinery complexes through a 5 500-metre pipeline (CCAC-Rio, 2015). In Viña del Mar, Chile, energy is recovered from five landfills that process 50 per cent of all municipal waste (CCAC-Viña, 2015). However, these projects are not free of operational and logistical problems. While anaerobic digestion is a common treatment in developed countries, implementation of municipal solid waste digestion in the region is scarce. Interest has, however, increased as a result of successful measures in both rural and urban areas. Brazil and Mexico have implemented effective projects under Clean Development Mechanism (CDM) schemes (UNFCCC, 2012).

In most countries of the region, the establishment of public policies and financial allocation are the responsibility of governments, while municipalities are tasked with services to collect, transport, treat and dispose of waste. Many countries in the region have set up national waste management programmes for reaching medium- and long-term goals, and relevant policy measures have been implemented, but effective economic and financial regulatory standards are missing.

The CCAC has ongoing programmes addressing municipal solid waste: by 2015, 50 cities around the world had developed and were implementing action plans to reduce SLCPs from the waste sector by 2020 (CCAC, 2015). The aim is to expand the city network to reach 100 additional cities to motivate and lead a further 1 000 cities to take action to implement the most successful practices.

4.3.9

Coal mining

Global coal production in 2013 was 3 830 million tonnes of oil equivalent (TOE). Latin America and the Caribbean produce 70.3 million TOE, approximately 2 per cent of global production, with, over the past three years, Colombia contributing more than 75 per cent of the region's total (BP, 2014).

The three major coal producers in the region – Colombia, Mexico and Brazil – are pioneers in reducing CH_4 emissions from coal mines (GMI, 2015), implementing policies and making technical efforts to capture emissions. In Colombia, the Ministry of Mines and Energy is in the process of establishing technical procedures that mining companies must apply (Ministerio de Minas y Energía, 2014); in Mexico, Minerales Monclova has developed an initiative for extracting CH_4 from three of their mines, the first project in the region that has been approved under the Kyoto Protocol's Clean Development Mechanism (CDM) ($MexiCO_2$, 2014); and in 2009 Brazil implemented enhanced coal-bed CH_4 recovery by injecting CO_2 as a pilot project in Porto Batista (Beck *et al.*, 2011). According to ZEROCO (2011) this project was successfully completed in 2011.

There are several techniques for trapping and disposing of CH_4 in coal mines. One is the use of large-scale ventilation systems that move massive quantities of air through the mines, thereby diluting and removing CH_4 from underground mines. These ventilation systems help maintain safe working conditions for miners, but release large amounts of very low-concentration ventilation air CH_4 into the atmosphere. Policies are required to promote and motivate coal-mining companies to invest in technology, not only to extract the CH_4, but also to use it for energy generation.

At present Colombia has a big challenge in reducing not only CH_4 emissions but also other pollutants that affect the communities living near the mines.

4.3.10

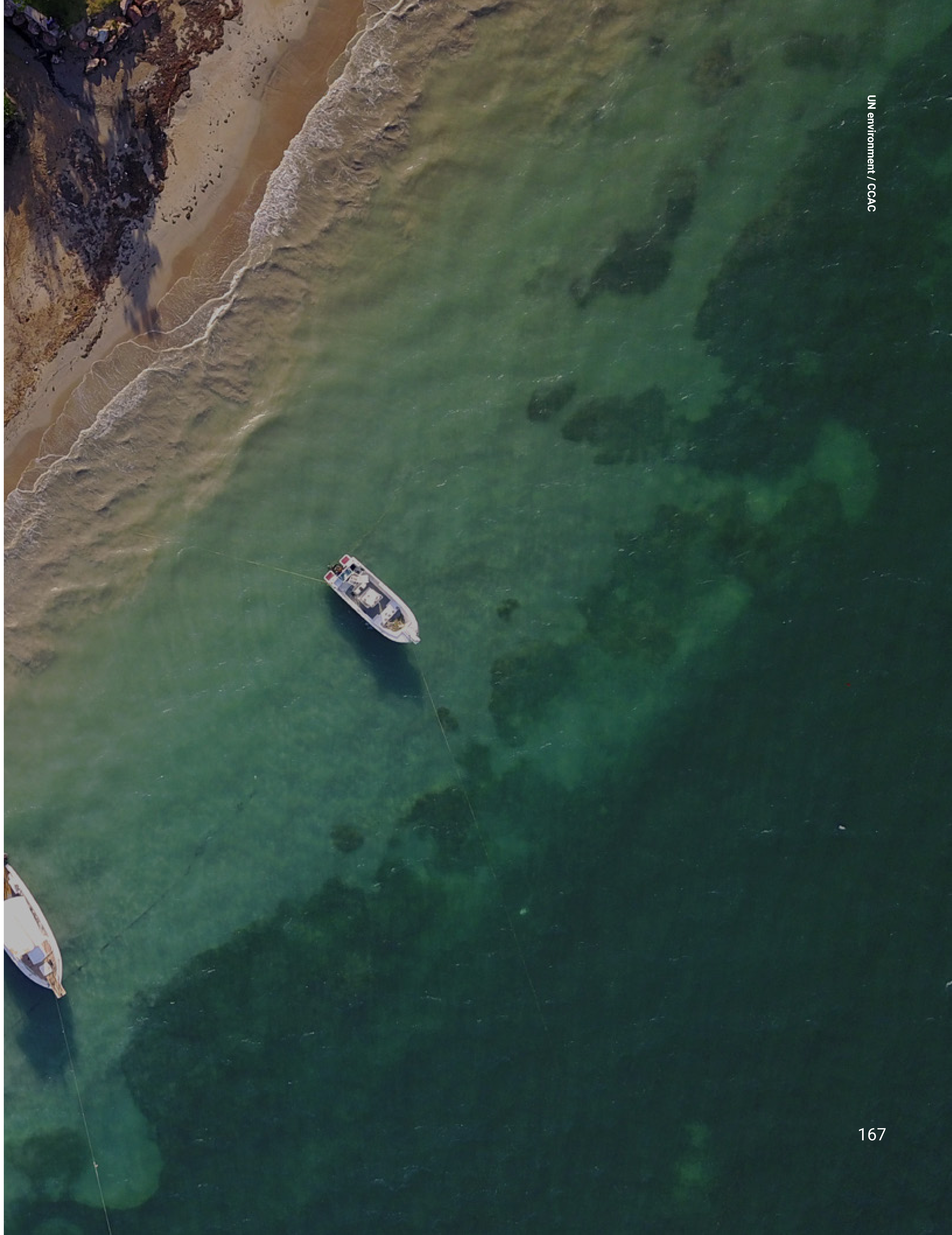
Oil and gas sector

The production, processing and distribution of oil and natural gas are the second largest emitter of anthropogenic CH_4 worldwide, releasing an estimated 1.35 billion tonnes of CO_2 equivalent of CH_4 into the atmosphere in 2010 (US EPA, 2012) – approximately 20 per cent of global CH_4 emissions.

When crude oil is extracted from both onshore and offshore oil wells, raw natural gas associated with the oil is also produced. The gas can be used at the installation as fuel to run compressors, may be transported by pipeline and used or sold elsewhere, or may be injected into the ground to enhance oil recovery. In areas lacking the infrastructure, however, the oil and gas industry disposes of the gas by carefully planned venting or burning (flaring). In emergencies, such as overpressure, equipment malfunction or power outage, unexpected gas emissions are flared as a safety measure to control the risk that it represents to workers, nearby villages, surrounding infrastructure and the environment.

The gas extracted typically consists of multiple hydrocarbon compounds (HCs), CO_2, nitrogen gas and hydrogen sulphide. Gas venting or flaring is currently recognized as an environmental problem that has serious implications for global warming due to the atmospheric emission of greenhouse gases – CO_2 and CH_4, and BC particles. In addition, gas flaring is of itself a waste of natural resources. Among the countries with the highest flaring rates are Russia, Nigeria, Iran, Iraq and the United States of America; these countries represent 57 per cent of the associated gas flaring worldwide (World Bank, 2017).

Venezuela and Mexico are the largest oil exporters in Latin America and the Caribbean, together exporting 3 million barrels per day (OPEC, 2014). At the same time, these two countries have the highest flaring rates – 2.8 and 2.0 billion m^3 per year, respectively (Farina, 2010). In 2013, Colombia flared 0.44 billion m^3 of gas, and vented 0.02 billion m^3 (ACP, 2014). Currently, the volume of gas flared and vented in all the region's countries remains uncertain.



Examining the conservation of natural resources, governmental energy sector authorities have requested the elimination of flaring and venting and the control of leaks in the oil and gas industry. International experience (GGFR 2011; IPIECA and OGP 2011) suggests that, to be successful, this initiative should be implemented as a joint effort between the government and oil and gas companies. Additionally, it suggests that the implementation of these regulations should be performed in three phases. The first of these should aim to promote the spirit of the regulation, the adoption of best practices, the measurement of the gas flared and the development of an action plan to reduce flaring and venting within each company. The second phase should aim to implement the action plan, obtain an accurate inventory of the volume of gas flared and refine the regulation according to local circumstances. The third phase should establish individual annual goals for flare reduction and enforcement mechanisms.

Some countries in the region have strict regulations to control gas flaring and its environmental impact. Implementation and verification of compliance, however, remain challenging (World Bank, 2004). The main barriers include the significant cost of capturing and utilizing the associated gas as there is currently insufficient financing to put the necessary gas infrastructure in place, the domestic gas markets are undeveloped and countries have limited access to international markets (GGFR, 2011).

In recent years, Mexico, through the state-owned petroleum company PEMEX, has focused a number of activities on emission reduction in the oil and gas sector. Since 2006, a key PEMEX greenhouse gas initiative has been its collaboration with the Global Methane Initiative (GMI, 2015) to develop projects for improving CH_4 recovery, reducing flaring and improving energy efficiency.

Recently, Mexico communicated that it aims to reduce its greenhouse gas emissions by up to 40 per cent compared to its business-as-usual scenario by 2030 (Gobierno de México, 2015). It added that the full implementation of its 2009 Special Climate Change Programme (PECC), which includes a set of NAMAs to be undertaken in all relevant sectors, would achieve a reduction in total annual emissions of 51 million tonnes of CO_2 equivalent by 2012, compared with the business-as-usual scenario. This is, however, subject to the provision of adequate financial and technological support from developed countries as part of a global agreement. The central aim of this NAMA is the creation of a programme framework to reduce emissions of CH_4 through the minimization or elimination of fugitive emissions from the processing, transport and distribution of natural gas in Mexico. The estimated emission reduction from this NAMA is approximately 3 million tonnes of CO_2 equivalent per year. Achieving this would improve Mexico's efficiency in processing fugitive emissions and in the transport and distribution of natural gas to levels reached in other countries such as the United States of America and Canada (CO_2-Solutions, 2013).

With regard to non-conventional oil and gas reservoir exploitation, Argentina, Mexico and Brazil have the second, sixth and tenth largest shale gas reserves worldwide, with 23, 15.5 and 7 trillion m^3 respectively (EIA, 2013). Recent reports claim that CH_4 leaks from well completions after hydraulic fracturing may account for 3–10 per cent of total natural gas production in the United States of America (Tollefson, 2013). Undoubtedly, new technology is required to reduce this leakage; otherwise the use of natural gas to fuel industry and transport, considered a strategy towards a low-carbon economy, may be neutralized by CH_4 leaks.

4.4

Managing hydrofluorocarbons in Latin America and the Caribbean

Hydrofluorocarbons (HFCs) are a group of chemicals primarily produced for use in refrigeration, air conditioning, insulating foams and aerosol propellants, with minor uses as solvents and for fire protection. They were developed to replace chlorofluorocarbons (CFCs), which have already been phased out and hydrochlorofluorocarbons (HCFCs), which are currently being phased out under the Montreal Protocol on Substances that Deplete the Ozone Layer in order to put the stratospheric ozone layer on a path to recovery (UNEP, 2011; UNEP, 2016). However, HFCs are very powerful greenhouse gases, trapping thousands of times more heat in the atmosphere per unit of mass than CO_2.

Only commercialized in the early 1990s, HFCs have caused approximately 1 per cent of total global warming to date. However, the production, consumption and emissions of these manufactured gases are growing at a rate of 10–15 per cent per year, effectively doubling every five to seven years (Montzka *et al.,* 2014). The use of HFCs has been accelerating as they replace HCFCs and as demand grows for the appliances that use these refrigerants.

Across Latin America and the Caribbean, some large and medium-sized manufacturing companies utilize HFCs in such countries as Argentina, Brazil, Colombia and Mexico, but the majority of other countries rely on imported products and alternative substances for servicing their equipment and appliances (Koefoed, 2016).

In 2016, the Parties to the Montreal Protocol agreed to the Kigali Amendment to phase down the production and consumption of HFCs. Under the Amendment, Latin American and Caribbean countries must freeze the production and consumption of HFCs on or before 2024 at agreed baseline levels, and begin stepped reductions, reaching 20 per cent of the freeze level in 2045. The global HFC phase-down plan agreed to in Kigali is expected to avoid up to 90 per cent of the warming that HFCs would otherwise have caused by 2100 – up to 0.5°C – and considerably more from fast implementation and parallel efforts to improve the energy efficiency of air conditioners and other products.

The Montreal Protocol's HCFC phase-out presents an opportunity for Latin American and Caribbean countries to move faster than the control schedule of the Kigali Amendment by leapfrogging HFCs and converting to lower-GWP and not-in-kind technologies, avoiding the growth in emissions of these powerful greenhouse gases while eliminating existing sources of HFCs. The region's countries have an excellent opportunity to work in a stepwise way by prioritizing the sectors in which appropriate technology is available, and making transitions to proven technologies that will allow significant reductions in HFC emissions, while benefiting from significant gains in energy efficiency from substantially improved technologies, particularly in the refrigeration and air-conditioning sectors.

There are several opportunities to mitigate the increase in HFC consumption. In summary:

a. ratify the Kigali Amendment to the Montreal Protocol to phase down HFCs;
b. control, regulate, and monitor imports, use, and emissions of HFC products and equipment;
c. technology conversion of manufacturing lines to lower-GWP and energy-efficient alternatives; if feasible, the safe retrofit and/or replacement of existing products and equipment containing high-GWP products;
d. ban imports of products containing HFCs, unless essential;
e. introduce standards and training of service technicians;
f. introduce good practices in refrigerant management as well as end-of-life management;
g. incentivize simultaneous improvements in appliance energy efficiency and low-GWP refrigerant alternatives.

Across the region action is being taken to address growing HFC emissions and the first step has been taken in a large number of countries – mapping their uses in different sectors through HFC country surveys, mostly funded by the Multilateral Fund for the Implementation of the Montreal Protocol and the CCAC. By scrutinizing the selection of energy-efficient and lower-GWP technology during project approval, the Multilateral Fund of the Montreal Protocol and the CCAC are of the utmost importance in global efforts to mitigate climate change.

4.5

Identified measures implemented in Latin America and the Caribbean

A number of mitigation measures for BC, CH_4, and HFCs have been successfully implemented in parts of the region (Tables 4.1–4.3). In addition to the list in Tables 4.1–4.3, there are other sectors and policy options, described in a forthcoming technical report, that have large mitigation potential for SLCP emissions; however, more resources are needed for their implementation. Their application, however, would greatly accelerate the national planning process for SLCPs in Latin America and the Caribbean.

In conclusion, despite some remaining uncertainties about SCLPs, especially BC, that require further research, currently available scientific and technical information has provided a strong foundation for making mitigation decisions and implementing the identified measures through appropriate public-private partnerships, financial incentives, dedicated research funds and legal frameworks to achieve lasting benefits for public health, the environment and climate.

Transport sector	
BC-1	Promote and implement improved vehicle technology: • facilitate the introduction of ultra-low-sulphur (ULS) fuel and advanced emission-control technologies; • catalyse deployment of low- or zero-emission vehicles; • retrofit particle filters for appropriate diesel engines (requires ULS fuel); • replace old diesel buses and trucks with cleaner, more efficient models.
BC-2	Enforce stricter environmental regulations on emissions and efficiency such as low-emission and fuel-economy standards: • strengthen inspection and maintenance programmes; • accelerate the scrapping of old vehicles.
BC-3	Implement more efficient mobility in the cities: • promote high-capacity public transport, such as BRT, and non-motorized transport; • develop integrated land-use and transport policies, travel demand and freight management.
BC-4	Promote clean transport programmes (eco-driving training programmes to reduce fuel consumption and operating costs).
Residential cooking	
BC-5	Substitute traditional cookstoves (open fire) with improved wood-burning cookstoves and modern fuels such as LPG.
BC-6	Develop social and environmental policies and national programmes to incentivize and support the substitution of traditional cookstoves with improved cookstoves.
Brick production	
BC-7	• Promote cleaner production in the brick sector by, for example, switching to cleaner fuels. • Improve fuel efficiency in traditional brick kilns and move gradually to introduce modern brick kilns. • Identify and incentivize alternative construction materials.
Oil and gas sector	
BC-8	Extended recovery and utilization, rather than flaring, of associated gas and improved control of unintended and fugitive emissions from the production of oil and natural gas.
Agricultural open burning	
BC-9	Adoption of no-till technologies and other conservation agriculture.
BC-10	Encourage mechanization of sugar-cane harvesting.
BC-11	Ban or restrict open burning of crop residues and agricultural waste.
Wildfires	
BC-12	Reinforce national programmes for protection against forest fires.

Table 4.1

Identified measures for reducing black carbon emissions in Latin America and the Caribbean

Livestock	
MT-1	Implement integrated livestock manure management: • utilize on-farm biodigesters to harness CH_4 for use as an electricity source, slurry irrigation, and composting; • apply manure to fields as fertilizer for improving the nutrient cycle.
MT-2	Improve dietary and grazing management of cattle: • use tanniferous and saponiferous plants, as well as plant oils, to reduce CH_4 production in the rumen.
Municipal solid waste	
MT-3	Reinforce and promote programmes for the separation of urban solid waste to increase the number of 3R programmes (reduce, reuse and recycle).
MT-4	Promote CH_4 recovery at landfill sites and use it for power generation.
Municipal wastewater treatment	
MT-5	Improve management of existing wastewater treatment facilities to ensure proper operation, energy efficiency and maintenance. Consider as an option the installation of sewage treatment processes consisting of modern anaerobic reactors followed by aerobic or natural systems, particularly in warm regions.
MT-6	Upgrade primary wastewater treatment to secondary and tertiary treatment with gas recovery and overflow control: • in conventional activated sludge processes (medium and large), install anaerobic sludge digesters to process wastewater biosolids and produce biogas for on-site use (in place of using conventional fuel to generate electricity); • install biogas capture systems at existing open-air anaerobic ponds; • install efficient flares and degassing devices at the effluent discharge of anaerobic municipal reactors (upflow anaerobic sludge blanket).
Coal mining	
MT-7	Extend pre-mine degasification and recovery and oxidation of CH_4 from ventilation air from coal mines.
Oil and gas sector	
MT-8	Extend recovery and utilization, rather than venting and flaring, of associated gas and improve control of fugitive emissions from oil and gas production.
MT-9	Apply Reduced Emission Completions (RECs) or “Green Completions” after hydraulic fracturing stimulation and workovers. RECs help to reduce emissions of CH_4, volatile organic compounds and hazardous air pollutants during well clean-up and can eliminate or significantly reduce the need for flaring.
MT-10	Leak monitoring and repair: • reduce CH_4 emissions by utilizing control technologies, for example, low-bleed or no-bleed pneumatic controllers and dry-seal systems.

Table 4.2

Identified measures for reducing methane emissions in Latin America and the Caribbean

HF-1	Ratify and comply with the Kigali Amendment to the Montreal Protocol to phase down HFCs.
HF-2	Control, regulate, and monitor imports, use and emissions of HFC products and equipment.
HF-3	Technology conversion of manufacturing lines to lower-GWP and energy-efficient alternatives; if feasible, the safe retrofit and/or replacement of existing products and equipment containing high-GWP HFCs.
HF-4	Control imports of products containing high-GWP HFCs, unless essential.
HF-5	Introduction of standards and training of service technicians.
HF-6	Introduction of good practices in refrigerant management as well as end-of-life management.
HF-7	Incentivize simultaneous improvements in appliance energy efficiency and low-GWP refrigerant alternatives.

Table 4.3

Identified measures for reducing hydrofluorocarbon emissions in Latin America and the Caribbean

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Integrated Assessment
of Short-lived Climate Pollutants
in Latin America and the Caribbean

5

From assessment to action

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Image: Aerial View of Amazon Rainforest, South America. Gustavo Frazao, Shutterstock.

Contents

5.1

Summary

This final chapter of the assessment brings together the analysis of the data, modelling results and measures already implemented locally, presented in previous chapters, to highlight possible pathways that countries in the region may want to consider to accelerate mitigation of short-lived climate pollutants (SLCPs).

The reduced set of measures identified in previous chapters, if scaled up across the entirety of Latin America and the Caribbean and fully implemented, could significantly reduce SLCP emissions and contribute to an increase in quality of life while reducing impacts on the region's ecosystems.

Moreover, analysis of the isolated measures already being implemented in certain regions highlights common needs and opportunities for achieving a more widespread penetration of the measures. The common challenges that prevent SLCP emission reductions are associated with weak regulatory systems and even a lack of regulations in several Latin American and Caribbean countries. The role of government through enforcement, but also through increased investment in infrastructure such as clean mass transit systems and waste management plants, and through incentives, needs to be strengthened at all levels to increase effectiveness.

There is a need for the development of an integrated framework for coordinated management of climate and air quality mitigation across the region. Strategies need to be driven by the recognition that integrated policies for climate and clean air can significantly reduce the cost of achieving objectives in both cases.

The current crossroads after signing the 2015 Paris Agreement and, more recently, the 2016 Kigali Amendment to the Montreal Protocol, provides a unique opportunity for countries in Latin America and the Caribbean to enhance south-south cooperation and lead in the global effort to mitigate SLCPs, consistent with sustainable development goals.

5.2

Building on regional experience to scale up action

One of the most important goals of this assessment was to explore opportunities to rapidly scale up mitigation of SLCPs in Latin America and the Caribbean and to clearly define the benefits of such action for the region. What this assessment shows is that a package of targeted measures based on existing and emerging technologies and policies, if scaled up, could have a substantial impact on SLCP emissions, provide near-term improvements in the quality of life of the population and foster sustainable development.

There is now clear evidence that air pollution is associated with at least 140 000 premature deaths per year in Latin America and the Caribbean. Chapter 2 (section 2.6) describes the strong correlation between observed short- and long-term health impacts and increasing levels of air pollution, particularly in urban environments. Tropospheric ozone (O_3), formed from precursor gaseous emissions, and black carbon (BC) are both prevalent in urban environments and have severe adverse health impacts. Black carbon, for example, as a substantial component of fine particulate matter ($PM_{2.5}$), can cause or contribute to asthma and other respiratory problems, low birth weights, heart attacks and lung cancer, and is estimated to have contributed close to 47 000 premature deaths in the region annually based on 2010 ambient concentrations, considered a conservative estimate (section 2.6.3.1).

The Latin America and Caribbean region is already predominantly urban, with almost 80 per cent of its population living in cities and towns, and further urban growth is expected in future decades, exposing an ever-increasing proportion of the population to the negative health effects of air pollution. Several countries, including Brazil, Chile, Colombia, Mexico and Paraguay, in their efforts to mitigate urban air pollution, currently have or are contemplating measures to reduce $PM_{2.5}$, which will also lead to decreased BC concentrations. The analysis performed in this assessment suggests that 70–90 per cent of BC emissions associated with the transport sector could be avoided across the region if the measures identified in this report were fully implemented. Since some of the measures are already being considered by the region's countries as part of their air quality management plans for $PM_{2.5}$, prioritizing measures that will maximize benefits by coordinating action at the regional level could bring about significant improvements in quality of life, preventing an annual average of 27 000 premature deaths by 2050 across the region (section 3.6.1).

Measures already implemented or under consideration to reduce emissions of O_3 precursors in urban environments will also benefit the rural regions where the precursors disperse and form O_3, with impacts on natural and agricultural ecosystems and therefore on food security. Implementing the identified SLCP measures could reduce annual losses of the four crops analysed – maize, rice, soybean and wheat – by between 3 and 4 million tonnes (section 3.6.3) due to the reduction in O_3 pollution.

In addition, the analysis and results presented in the previous chapters indicate measures that could reduce anthropogenic methane (CH_4) emissions on average by about 50 per cent by 2050 (Section 3.5.2). Countries in the region are already considering greenhouse gas mitigation action under the Paris Agreement. Prioritizing measures that control emissions by sector represents the best opportunity at the national level, especially in energy, transport, waste management and agriculture.

The measures available for mitigating emissions fall broadly into four categories.

- Incorporating best practices or upgrading to the best available technologies in industrial processes, such as reducing flaring in the oil industry or capturing and utilizing coal-bed CH_4. The advantages of these measures are that they *can be deployed quickly and implemented through sector-targeted policies by incentivizing and regulating the change*.
- Incorporating measures into the large-scale infrastructure programmes of public authorities, especially in the waste sector, such as capturing and utilizing CH_4 emissions from municipal landfill sites. Here the changes may again be *relatively simple as the technology is already available, but needs to be integrated into major public infrastructure development programmes* to control the pace of adoption.
- Implementing sustainable, low-emission urban transport solutions, especially to reduce BC emissions, such as the renewal of the fleet with energy-efficient technology and cleaner fuels, providing alternative non-motorized transport options and freight management. To be successful, the enhancement of urban transport systems requires strong commitment and combined efforts and investment on the part of local authorities and transport operators. *The process may be lengthy but the transformation of urban transport is indispensable to air quality improvements and health benefits, as well as to climate change mitigation.*
- Changing practices, which are often deeply embedded in cultural, economic and social traditions, for domestic cooking and heating; in agriculture, for example halting slash-and-burn agricultural practices; and in some artisanal industries such as small-scale brick production. As broad acceptance and implementation of change will require independent action by very large numbers of individuals or small economically vulnerable groups, *the process of change may be lengthy and complex but will produce immediate benefits to the affected population.*

1. Specific measures identified for black carbon mitigation

The measures selected in the SLCP mitigation scenario bring about large reductions in BC emissions in five sectors: household cooking and heating; transport; agriculture; oil and gas production; and industry, for example coke ovens and brick kilns (Table 3.2). While the SLCP mitigation scenario considers the full implementation of these measures across Latin America and the Caribbean, individual countries might consider a set of measures based on the particulars of their national emissions, as discussed in Chapter 3.

The most efficient action identified at a regional level is a reduction in BC emissions in the transport sector, which can be achieved through two measures: accelerated introduction of stringent Euro 6/VI emission standards on new vehicles, requiring installation of diesel particulate filters and low-sulphur fuel; and the elimination of high-emitting vehicles with full enforcement. Combined, these measures would achieve 35–75 per cent reductions in BC emissions by 2050 in this sector.

The second most efficient measure identified is the effective introduction and adoption of cleaner cooking and heating stove technology, which has the potential to reduce total BC emissions by 30–50 per cent and produce significant improvements in public health.

The third most efficient measure identified is the elimination of burning of agricultural residues, which contributes to both BC and O_3 precursors. This has been targeted by national policies in several countries but due to lack of enforcement remains a large emission reduction opportunity. About 5–20 per cent of total reductions could be achieved through the sustainable enforcement of bans on burning agricultural residues; however, significant differences exist between countries (Figure 3.4).

Although several of the mitigation measures do not bring large absolute reductions in the region as a whole (Figure 3.3), they are of great relevance for particular countries. One such example relates to artisanal brick production. Promotion of more efficient kilns could be considered a local priority, primarily due to air pollution and social issues, and would make an important contribution to the total BC mitigation estimated for Bolivia, Colombia, Ecuador and Mexico (Figure 3.4). Similarly, coke production is of relevance in Argentina, Brazil and Chile, where reducing coke oven emissions to levels associated with state-of-the-art technology would result in sizeable savings, contributing 5–20 per cent of overall emission reductions in these countries.

Other specific examples include reducing emissions from flaring of associated gas in oil production, which is particularly important in Ecuador and Venezuela, and also has potential for CH_4 mitigation, as discussed in the following section.

2. Specific measures identified for methane mitigation

There is more mitigation potential in Latin America and the Caribbean for CH_4 than for BC. Nevertheless, the overall potential varies significantly between countries. For some, such as Chile, Ecuador, Mexico and Venezuela, and the Caribbean islands, CH_4 mitigation potential ranges between 50 and 75 per cent. Two sectors, oil and gas production and distribution, and waste management, have been identified as the main contributors to CH_4 emissions in the region and the few mitigation measures identified all involve medium-to-large capital investment and effective compliance and enforcement mechanisms.

All countries in the region except Paraguay and Uruguay have oil and gas production industries, and between 50 per cent and more than 90 per cent of the estimated CH_4 mitigation potential comes from this sector. For some countries, such as Ecuador and Venezuela, more than 80 per cent of the potential is associated with this sector, and for others, including Argentina and Brazil, it is estimated at about 70 per cent. A number of countries, such as Venezuela, have already pledged to reduce CH_4 emissions from the exploration and production of natural gas (UNFCCC, 2016). Governments should aggressively address leakage in gas transport and distribution systems since in many countries it represents a significant loss of revenue for state-owned companies.

Improved waste management with CH_4 recovery from residential and industrial waste is the second largest opportunity in the region and important for all countries. In Central America, Chile, Paraguay, Peru and Uruguay, for example, more than 70 per cent of the total estimated reduction potential is associated with this sector, typically distributed equally between municipal solid waste and industrial food processing waste. For the Caribbean and Mexico, nearly 50 per cent of the reduction is estimated to come from waste management. Twenty countries in the region have pledged to reduce emissions from this sector in their Intended Nationally Determined Contributions (INDCs) and 10 identified specific actions to reduce CH_4 emissions from municipal solid waste – Barbados, Belize, Costa Rica, El Salvador, Grenada, Guatemala, Haiti, St. Lucia, Uruguay and Venezuela (UNFCCC, 2016).

The recovery of CH_4 from coal mining is of national significance in Colombia, which accounts for 80 per cent of the coal output of the entire region.

3. Specific measures for mitigation of ozone precursors

Tropospheric O_3 is formed in the atmosphere from precursor gases and has serious consequences for human health, particularly in urban areas, and for crops, leading to significant yield losses (Chapter 2). The GAINS model includes many measures that affect several of the gaseous precursors. Particular measures for reducing vehicular emissions, open agricultural burning and gas flaring, discussed above in relation to BC, are also pertinent to O_3 mitigation.

4. Specific measures identified for hydrofluorocarbon mitigation

The projected increase in hydrofluorocarbon (HFC) emissions in the region requires measures such as technology conversion to alternative or not-in-kind systems that have lower global warming potential (GWP): switching to lower-GWP HFC alternatives in mobile air conditioning and refrigeration; banning imports of products containing high-GWP HFCs, unless essential; reducing the refrigerant charge size and improving the energy efficiency of appliances; and training of service technicians. Retrofitting or replacement of refrigerants with lower-GWP alternatives must be done safely and without jeopardizing energy efficiency. In October 2016, agreement to phase down HFCs was reached by the Kigali Amendment to the Montreal Protocol. The Amendment was agreed by all the countries of the world and it mandates concrete HFC phase-down actions in developed and developing countries. It represents the largest near-term climate mitigation measure from a single agreement. Through its implementation, the Kigali Amendment will avoid up to 0.5°C of future warming (UNEP, 2016; Velders *et al*., 2017). It also has the potential to catalyse significant additional climate and development benefits beyond what is already enshrined by increasing energy efficiency while implementing the HFC phase-down.

Recent demonstration projects done in Chile and Brazil by the Climate and Clean Air Coalition (CCAC) on commercial refrigeration, with HFCs replaced by climate-friendly alternatives, showed significant reductions in the carbon footprint of refrigeration operations as well as energy savings. Energy savings range from 15 per cent to 30 per cent and carbon footprint reductions range from 60 per cent to 85 per cent. In one case, for example, reductions in the carbon footprint of a refrigeration operation were estimated at 85 per cent relative to the baseline. Of the 85 per cent reduction, 58 per cent is attributable to reduced energy use while the remaining 27 per cent is attributable to the direct emissions avoided by replacing HFCs with a low-GWP alternative. The phase-out of HFCs is not only possible – as the CCAC case studies have shown – but also presents a unique opportunity for fast mitigation and at the same time makes financial sense (UNEP/CCAC, 2014).

5.2.1

Lessons learned – building on success and experience in Latin America and the Caribbean

1. General observations

Analysis of specific sectors (Chapter 4) has shown that despite differences between countries and sectors, there are common needs and opportunities for improvement. Some of the measures to reduce SLCPs have been implemented with a level of success in a number of countries of the region. In many cases, however, the measures have had limited reach, leaving considerable room to scale up and harvest all the benefits that broader implementation could provide.

The fact that additional climate finance could be available as a consequence of the Paris Agreement offers an unprecedented opportunity to increase the level of implementation of climate change mitigation programmes and projects. Climate finance includes instruments and assistance for mitigation and adaptation activities to facilitate the transition towards low-carbon, climate-resilient growth and development. There are two key aspects, however, that should be kept in mind: SLCPs generally and BC specifically are not explicitly included in the Paris Agreement, which might limit the financial assistance available from the Green Climate Fund and other climate facilities; and international climate funding should be seen as a complement to local and national funding, rather than as a substitute. Sound identification, design and appraisal of large-scale and effective SLCP projects is crucial for getting access to climate finance opportunities.

Comprehensive and coordinated policies and regulations at national and regional levels are crucial for advancement in all sectors, with a corresponding focus on enforcement and compliance. Some sectors and countries in the region still suffer from a lack of appropriate policies, regulations and standards to support rapid scale-up of SLCP measures. The Regional Action Plan for Intergovernmental Cooperation on Air Pollution for Latin America and the Caribbean, discussed below, is one mechanism for exchanging knowledge, disseminating good practice and fostering regional harmonization of policies and regulations.

There is also an urgent need to *raise awareness* at all levels for a full understanding of the processes and options for SLCP mitigation. Complete, accessible and publicly available information can help catalyse the participation of stakeholders in stronger and more effective networks and cooperative processes.

In addition, all analysed sectors have identified the need to *build capacity* in scientific and technical expertise to monitor emissions, generate information and make use of the available technologies. Strengthening networks, sharing of lessons learned and disseminating best practice are among the opportunities that Latin America and the Caribbean could exploit to increase the capacity to act at the regional scale.

Improving, developing and implementing *technology* provides another crucial opportunity identified in all sectors and, if accompanied by holistic approaches to policy, could be a significant source of jobs. Advances in technology have already been demonstrated. The successful examples presented in Chapter 4 need much wider implementation to achieve the desired benefits.

2. Identification of measures for rapid and visible progress

The removal of the relatively small fraction of vehicles that contribute with significant emissions – the *high emitters*: older cars, buses and trucks – is another measure that can have a clear impact on air quality and public health. Such vehicles are usually owned by low-income individuals and transport operators, and success in achieving their removal would likely require direct financial incentives, improved surveillance and political will to enforce emission regulations.

Several countries in Latin America have introduced successful measures to reduce vehicular emissions. Programmes to remove high-emitting buses and trucks have already been implemented in Colombia and Mexico and would be easy to apply in other countries. The replacement of diesel buses with natural gas buses in Peru, and the introduction of hybrid and electric vehicles in some cities in Argentina, Brazil, Colombia and Mexico, have been successful and could be extended to other countries. The implementation of bus rapid transit (BRT) in Argentina, Brazil, Chile, Colombia, Ecuador, Guatemala, Mexico and Peru has led to certifiable benefits in terms of falling emissions and reduced human exposure to pollutants. Such a measure could be readily applied in other countries.

3. Identification of measures requiring more time for visible progress

The adoption and enforcement of more stringent vehicle emission standards is already under consideration in most countries of Latin America and the Caribbean. The introduction of advanced emission-control technologies and ultra-low-sulphur fuels, however, will be gradual given the varying levels of implementation. Particle filters for diesel vehicles have been used in Brazil, Chile and Mexico, for example, but currently available technologies also require a reduction in the sulphur content of fuel, which is more difficult to achieve in the short term. Countries with refineries have an opportunity for government and oil companies to coordinate an investment plan to gradually upgrade installations to produce ultra-low-sulphur fuel. Cost/benefit analyses, including the public health costs of air pollution, are available in some countries, including Mexico, and are important planning tools for adopting such policies.

The introduction of improved biomass cookstoves and/or liquefied petroleum gas (LPG) for cooking in such countries as Guatemala, Haiti, Honduras, Mexico, Nicaragua, Paraguay and Peru would improve public health and increase quality of life in low-income regions throughout Latin America and the Caribbean. The use of LPG cookstoves in the

Dominican Republic has already been a tremendous success in preserving the country's natural environment, which is central to the tourism industry, the country's most important source of revenue. In order to maximize the penetration and acceptance of this measure, users' priorities, such as robust design, need to be taken into account. Moreover, it is important to consider the region-specific cultural and social implications of behavioural change for achieving maximum uptake.

Large expansions in agricultural areas have occurred in the region in recent decades, leading to increases in emissions from open burning of agricultural residues. A greater use of no-till techniques as an alternative to agricultural fires would bring several benefits, including increased organic matter in the soil. Even though the penetration of this measure is growing every year, there is still room for specific policies to remove the main barriers to adoption, including expanding people's knowledge of no-till methods and improving the availability of adequate machines and herbicides.

Municipal solid waste management is important for both public health and the environment, since landfill is the most widespread option for the final disposal of solid waste. Measures that would lead to improved waste management with CH_4 recovery from residential and industrial waste constitute a large opportunity for all countries in the region as a means of CH_4 mitigation. This measure requires considerable investment by local governments as well as time for implementation. While there is little experience of using waste for energy production, some projects for CH_4 capture from landfill in Argentina and Mexico have shown good results and could be explored in other countries that are considering new landfill facilities. A complementary measure to promote and reinforce programmes for the separation of solid waste and recycling can extend the benefits.

Coordination between (federal) government, state authorities and municipalities is essential to improve waste management. In most cases the removal and disposal of waste is the responsibility of the municipality; however, municipal authorities often have insufficient funds to build the landfill infrastructure that could capture CH_4 once a cell is closed. Both the Inter-American Development Bank (IDB) and the World Bank have credit lines that municipalities could access with the support of their national government. There are also many instances where the volume of waste from a single city does not justify the waste management systems necessary for CH_4 capture in economic terms. There has been some success with groups of cities cooperating to create a facility able to jointly manage their waste, making the necessary investment economically feasible. In these cases, coordination between the municipal and state levels of government is key.

5.2.2

The role of policy for scaling up action

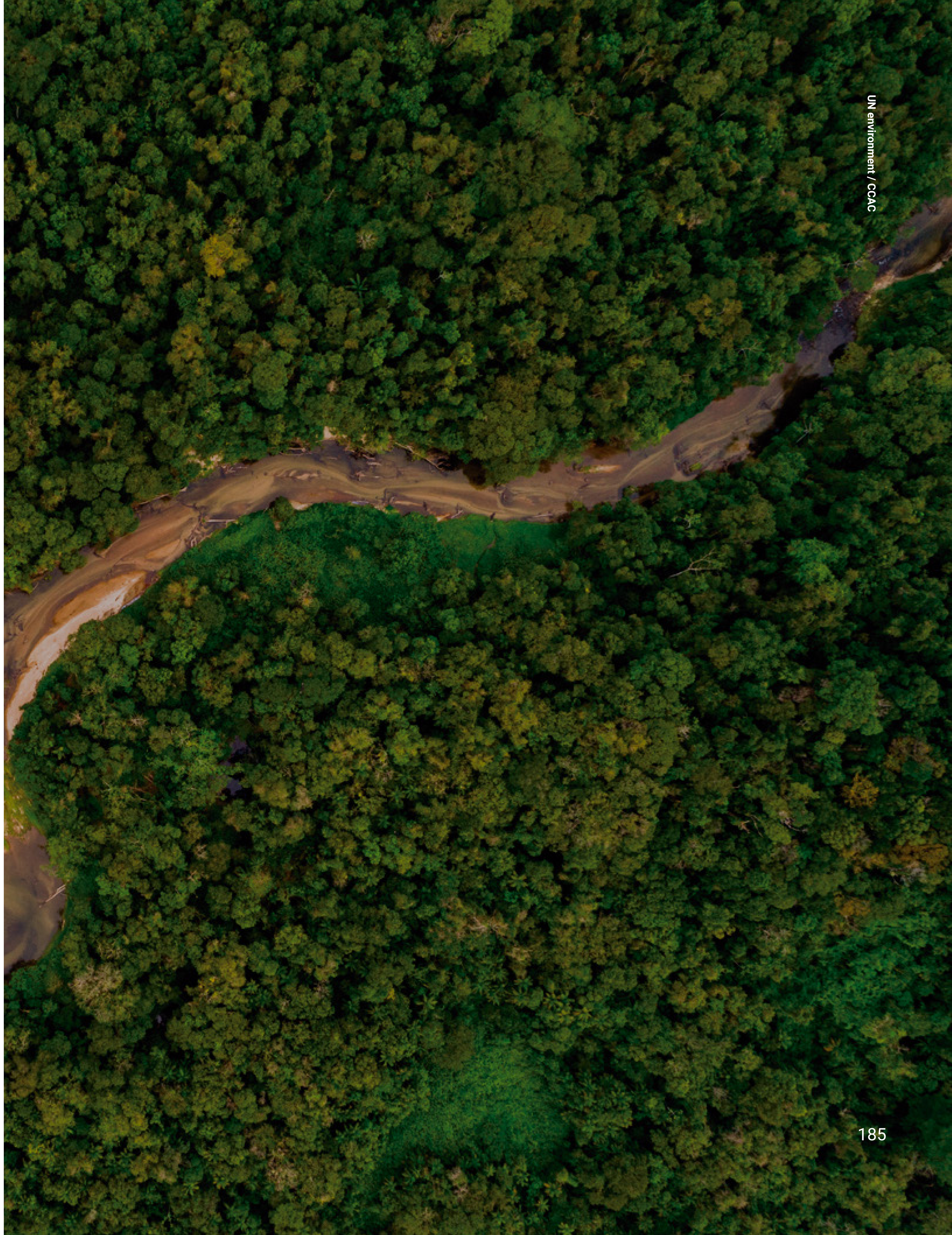
One of the main challenges identified by several sectors is a lack of effective policies and regulations, as well as effective enforcement mechanisms including penalties for non-compliance. The coal, oil and gas sectors, for example, have demonstrated the need for policies requiring mandatory CH_4 emission reduction in order to facilitate technology advancement and ensure implementation of the necessary measures. Without these mechanisms, and taking into account the cost of putting the measures into practice, potential changes are unlikely to be made.

There is also a role for governments to encourage rapid action in particular sectors. It is highly feasible to eliminate high emitters and urban and off-road vehicles that contribute a large proportion of BC, involving few decisions, some incentives and reliable enforcement. Aggressive educational campaigns and citizen participation – such as taking photos with cell phones and uploading them to web pages set up by local government – might be considered to complement enforcement efforts.

Improved financial mechanisms and incentives tailored to local circumstances, along with economic models to increase penetration, will allow programmes to scale up to sustain the dissemination of improved domestic cookstoves and heating options, and focus efforts on stove adoption and use. Again, aggressive educational campaigns could lead the way, allowing whole families to be aware of effective and affordable alternatives, health benefits and savings in cost and time, and could appeal to users' desires to improve their quality of life. Certification of effective cookstoves and sound follow-up programmes are essential to assess the effectiveness of penetration.

Low-emission public transport policies should continue to be implemented across countries in a predominantly urban subcontinent. Some measures are already in place or in the process of being implemented, including bus rapid transit, non-motorized transport programmes and travel-demand and freight management, and have had modest success. But much more needs to be done in terms of both education and setting up urban transport systems, so that the general population, for example, learns not only to accept and respect bicycle users, but to make cycling fashionable, modern and culturally desirable as part of a new urban movement. There is a need for educational campaigns aimed at younger people – elementary school children – to change their views on what urban mobility in the 21st century signifies, consistent with the new mobility paradigms and a diminishing trend in and desire for car ownership.

Additionally, thinking ahead is required in devising new, alternative ways of looking at mobility in the cities of the future, preventing the need for further increases



in emissions from transport while still providing mobility. Collaboration between civil society, the private sector and governments is needed to introduce a new paradigm of urban living and to get the majority of the population behind it.

A complete phase-out of agricultural burning of residues in countries where it has been a tradition for centuries presents a challenge as well as an opportunity. Additional policies and incentives promoting alternative management practices will be required. There are successful models, such as the Agro-environmental Protocol established by the Brazilian Sugarcane Industry Association (UNICA). Since sugarcane is also a major crop in Central America, Mexico and the Caribbean, there is an opportunity to learn from the Brazilian experience and try to implement similar protocols.

To accomplish a better mechanism for waste management it should be acknowledged that in most countries in Latin America and the Caribbean, waste collection, its transport, treatment and disposal are functions of municipalities. National governments are, however, responsible for establishing public policies and allocating the required financial resources. Effective economic and financial regulatory standards that allow management plans to be fully implemented are usually lacking.

5.2.3
Leveraging institutional synergies

It should be recognized that there is a fundamental need for the development of an integrated framework for coordinated management of climate and air quality mitigation. The two are so closely linked, with SLCPs making up such a significant and overlapping part of each, that it no longer makes sense to develop policies separately. Strategies need to be driven by the recognition that integrated policies for climate and clean air can significantly reduce the cost of achieving objectives in both cases.

The integration of policies could be achieved through a variety of systems. Unifying the two functions in a single department – as in Mexico and recently also in Chile – is a logical and effective approach, but it is not the only one. Other processes could include an integrated planning system for climate and air quality, a coordinated assessment and planning mechanism, or indeed a simple oversight and review procedure.

While full implementation of the identified measures across the region may not be a realistic objective in the near term, the results of this assessment are an indication of what could be achieved in terms of climate, health and food security by prioritizing action on SLCPs. Implementing changes within new public infrastructure programmes can involve complex national and local decision making, and the lead-times are likely to be long. The public and private institutions promoting change may need to plan for relatively slow, incremental processes of adaptation, requiring long-term education, maintenance and support programmes. The sooner these processes begin the earlier people will enjoy the benefits of the implementation of these actions at scale.

5.3
Synergies with global and regional platforms

The multiple co-benefits of SLCP mitigation are important tools for driving local and national action to scale up the implementation of SLCP measures. The concrete and synergistic benefits of addressing SLCPs can leverage and mobilize the resources and will of multiple stakeholders and allow them to reach their objectives simultaneously, for example by improving public health for a health ministry while reducing energy consumption for a ministry of energy. Similarly, national action to address SLCPs can be mutually beneficial and supportive of the goals and objectives of regional and global mechanisms, which can be leveraged to mobilize even greater resources and will to scale up SLCP action.

This section looks at three such mechanisms: the Sustainable Development Goals (SDGs); the United Nations Framework Convention on Climate Change (UNFCCC) and Paris Agreement; and the 2014 Regional Action Plan for Intergovernmental Cooperation on Air Pollution for Latin America and the Caribbean.

5.3.1
The Sustainable Development Goals

The impacts and the benefits of reducing SLCPs are directly or indirectly linked to a number of the objectives of sustainable development.

On 25 September, 2015, the world adopted a set of goals to end poverty, protect the planet and ensure prosperity for all as part of a new sustainable development agenda, known as the SDGs. These were developed to replace the Millennium Development Goals (MDGs), which concluded in 2015. While there have been many critics of the MDGs, they did succeed in mobilizing global resources to reduce extreme poverty by half, averted 3.3 million deaths from malaria, gave 2.3 billion people access to improved drinking water, increased the political participation of women, and made substantial progress towards gender parity in school enrolment. Environmental problems, however, were not considered in a broad way, limiting the possibility of understanding the underlying causes and identifying appropriate mechanisms for sustainable and integrated solutions.

The SDGs consider a greater number of matters through an integrated and indivisible approach, and reflect them in 169 specific targets. In particular, the environmental elements and their connections with poverty eradication and other development priorities offer a significant opportunity to strengthen global efforts to achieve environmental sustainability and human well-being. Following this approach, air pollution is linked to priorities related to health, sustainable cities, production patterns and climate change mitigation. Like the MDGs before them, the SDGs are expected to mobilize and direct significant international, regional and national resources over the next 15 years.

Initiatives to reduce SLCP emissions could directly and indirectly support the achievement of many of the SDGs and recognition of their potential contribution could help mobilize resources and increase policy traction. Just as combating sources of SLCP emissions through the measures discussed in this assessment could provide multiple co-benefits to public health, food security and the climate, they could simultaneously contribute directly and indirectly to the achievement of multiple SDG targets.

Policies and measures to reduce SLCP emissions can affect *SDG 1, No poverty* indirectly by increasing crop yields and reducing the economic effects of ill-health due to air pollution. Improving public health by reducing the burden of disease also increases the resilience of populations to environmental shocks and disasters. Reducing the rate of climate change will also affect the increase rate of climate-driven impacts such as extreme weather events and sea-level rise, allowing vulnerable populations critical time to adapt. Reducing near-term warming will also reduce temperature-driven losses in labour productivity, particularly for outdoor workers.

Improvements in air quality from SLCP measures directly contribute to *SDG 2, Zero hunger* by improving ecosystem health and agricultural yields, thereby helping to end hunger and achieve food security; and to *SDGs 3, Good health and well-being* and *11, Sustainable cities and communities*, by reducing indoor and outdoor air pollution and helping ensure healthy lives for people.

Reducing near-term global warming directly contributes to *SDG 13*, *Climate action* but also supports *SDGs 1* and *11* by helping to reduce the exposure of vulnerable populations to climate-related extreme events.

Measures to address SLCPs also promote low- or no-emission alternative practices and technologies across a wide range of sectors, supporting *SDG 7, Affordable and clean energy*; *SDG 9, Industry, innovation and infrastructure*; and *SDG 12, Responsible consumption and production*. Measures to reduce HFC emissions, for example, when paired with technical improvements in appliance efficiency, can provide significant energy efficiency benefits. Replacing traditional biomass cooking and heating stoves with more efficient alternatives can improve resource efficiency and reduce consumer costs by reducing fuel use, which can also contribute to *SDG 1*.

As countries in the region work to implement and achieve the SDGs and their targets over the next 15 years, prioritizing measures that reduce SLCPs provides a means of addressing multiple goals simultaneously.

5.3.2
The Paris Agreement

The Paris Agreement, adopted at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21), is an important achievement for climate action and allows for many mechanisms and processes designed to spur rapid emission reductions, sustainable economic development and poverty reduction.

The Paris Agreement refers for the first time to the widely agreed long-term goals of limiting warming to 1.5–2°C above pre-industrial levels as well as zero net carbon emissions beyond mid-century. The Agreement also contains important signals that fast implementation of technical and policy measures to cut emissions will require adequate and opportune financing, technology transfer, and the identification of synergistic action that would be beneficial for the climate, public health and food security, as well as supporting sustainable development.

One process that began before COP21 and will continue to be an important mechanism for climate action and sustainable development involves the INDCs. These are a tool allowing countries to lay out a specific vision for climate action and identify those measures, sectors and climate forcers that are most important to their development in the context of their national priorities, circumstances and capabilities. The INDCs allow these nationally focused plans to be integrated into a global framework that drives collective action towards a sustainable, climate-resilient future. Within this context, they can be an instrument of mutual support for climate action, SLCP reduction and sustainable development, and can drive policy and investment at local, national and global levels.

Most countries in Latin America and the Caribbean had already strongly signalled the importance of addressing SLCPs for climate mitigation in the INDCs they submitted before COP21. As of February 2016, of the 33 countries in the region, 31 had submitted their INDCs to the UNFCCC Secretariat. The majority identified at least one SLCP or major SLCP emission sector as an important target for mitigation, including 28 countries targeting CH_4 and 15 targeting HFCs. Two countries, Chile and Mexico, also highlighted the importance of reducing BC emissions. Furthermore, Mexico has pledged a 51 per cent reduction on business-as-usual in BC emissions by 2030.

The Paris Agreement formalized the INDC process and established a regular schedule for updates and renewal. Countries that wish to further embed SLCP action in their INDCs, however, can resubmit an updated INDC to the UNFCCC Secretariat. The Agreement also includes provisions to conduct a global stocktaking to assess collective progress towards long-term goals. The first stocktaking will take place in 2023 and will be used to inform the second submission by Parties in 2025.

5.3.3

Kigali Amendment to the Montreal Protocol

On 15 October 2016, the parties to the Montreal Protocol on Substances that Deplete de Ozone Layer reached an historic agreement to phase-down HFCs by more than 80 per cent over the next 30 years, which had been under negotiations since 2009. It will be effective from 1 January 2019, provided that at least 20 parties ratify it, a feat accomplished by November 2017. The number of parties that has currently ratified the Amendment 30 (http://ozone.unep.org/sites/ozone/modules/unep/ozone_treaties/inc/datasheet.php)

The reduction of HFC emissions through a phase-down under the Kigali Amendment would reduce the climate forcing effects of HFCs in 2050 to below their current levels, effectively eliminating a climate threat before it develops.

Furthermore, transitioning away from HFCs could catalyze other climate benefits through improvements in the energy efficiency of refrigerators, air conditioners, and other products and equipment that use HFC refrigerants. Linking a transition away from HFC refrigerants to improvements in the energy efficiency of room air conditioners could significantly reduce peak-load energy demand and has the potential to avoid the use of significant energy in the region.

5.3.4

The Regional Action Plan for Intergovernmental Cooperation on Air Pollution for Latin America and the Caribbean

The Regional Action Plan for Intergovernmental Cooperation on Air Pollution for Latin America and the Caribbean was agreed in 2014 at the XIX Meeting of the Forum of Ministers of Environment for Latin America and the Caribbean and is the first ever regional air pollution agreement covering the region. The Action Plan strives to foster "regional cooperation … to maximize resources, synergies, and co-benefits to simultaneously address the issues of air quality problems related to the short-lived climate pollutants, as well as their social, environmental, and health effects". Through the Action Plan, the region's countries support each other voluntarily to develop flexible national plans to improve air quality, establish mechanisms for strengthening cooperation, and work to align policies, guidelines, legislation, standards, monitoring and data management procedures with respect to air pollution (UNEP, 2014).

The Action Plan includes explicit recognition of SLCPs in terms of both air quality and climate change policies. There are moreover significant mutually reinforcing overlaps between this assessment and the goals and focus of the Action Plan. The Action Plan, for example, calls for the types of studies, increased cooperation and information sharing provided by this assessment to:

a. Identify and assess sources of pollutants and their impacts on human health and the environment, including the climate system;
b. implement and evaluate intervention options to reduce emissions; and
c. quantify the impacts of such intervention options.

The Action Plan identifies a number of priority pollutants to be addressed due to their significant impacts on air quality and climate change, all of which are SLCPs or co-emitted from SLCP sources: particulate matter (PM_{10} and $PM_{2.5}$) with a particular emphasis on BC; tropospheric O_3 and its precursors; hydrocarbons (HC) and volatile organic compounds (VOCs); nitrogen oxides (NO_X); sulphur dioxide (SO_2); carbon monoxide (CO); and other compounds.

The Action Plan also identifies a number of strategic sectors and measures for countries to consider adopting, many of which are also identified in this assessment, including:

- reducing emissions from the transport sector, particularly of BC;
- reducing emissions from brick production;
- replacing inefficient biomass cooking and heating stoves with low-emitting efficient alternatives such as those using LPG;
- reducing CH_4 and BC emissions from oil and gas extraction and distribution;
- establishing comprehensive solid waste management to reduce waste sent to landfill and to capture/incinerate CH_4 emissions;
- implementing wastewater management to harvest CH_4 emissions for natural gas or electricity;
- reducing open burning of biomass.

This assessment on SLCPs has identified all the above as strategic for the reduction of CH_4 and BC emissions. During the XX Meeting of the Forum of Ministers of Environment for Latin America and the Caribbean, held in Cartagena, Colombia, in 2016, there was an explicit call for "the full implementation" of the Action Plan. The Action Plan will be updated every four years, with the first update in 2018 at the XXI Meeting of the Forum. The options for implementing and scaling up measures to reduce SLCPs identified in this assessment provide a clear pathway towards fulfilment of the Action Plan.

5.4

Financing action in Latin America and the Caribbean

The multiple benefits of SLCP reduction measures mean that local and international resources can often be fostered to finance implementation. The efficiencies and cost savings from many measures, particularly for capturing and reusing CH_4 emissions, frequently pay for themselves. And, when the benefits to public health and agricultural production are taken into account, all SLCP measures are cost effective from a public policy perspective. There are many examples in the region of successful SLCP projects implemented entirely with domestic resources (Chapter 4). There are also additional international sources that could provide funding to support SLCP mitigation – such as the Green Climate Fund (GCF), the Climate Investment Funds (CIF) and the Global Environmental Facility (GEF), among others. These funds are implemented through international financial institutions such as the World Bank, the IDB and the Development Bank of Latin America (CAF).

Between 2007 and 2012, approximately 7.7 per cent of World Bank commitments were on projects directly and indirectly relevant to SLCPs, such as energy, transport, agriculture, urban waste and wastewater (World Bank, 2013). In Latin America and the Caribbean, the World Bank has been financing policy reform and investment operations dealing with air pollution in a number of countries, including Brazil, Colombia, Mexico and Peru. The World Bank is a partner in the CCAC.

The GCF was established in 2010 by 194 Parties to the UNFCCC and is designed to operate as its financial mechanism. It offers grants, concessional loans, equity investment and guarantees using the executing and financial intermediation capacity of partner organizations (accredited entities) that will work as implementing entities or intermediaries. One of these implementing entities is UNEP. The Fund is expected to promote the shift towards low-emission and climate-resilient development pathways while promoting environmental, social, economic and development co-benefits and a gender-sensitive approach. To date, US$5.8 billion has been formalized through signed contributions to the Fund. All Latin American and Caribbean countries are eligible to receive funds from the GCF.

Decision No. 9 from the XX Meeting of the Forum of Ministers calls upon the GCF to "prioritize fast action measures that simultaneously support reductions in atmospheric pollution while providing short-term benefits for climate change mitigation and adaptation". Three of its four thematic mitigation priorities relate to measures to reduce SLCPs highlighted in this assessment: low-emission transport; access to low-emission energy and power generation at all scales, which could include cookstoves; CH_4 capture through waste management and upgrading brick kilns; and reduced emissions from buildings, cities, industries and appliances – for example by reducing CH_4 leakage from the oil and gas industry, upgrading brick kilns and coke ovens as well as improving the energy efficiency of appliances while transitioning to lower-GWP alternatives to HFCs. Likewise, some of the measures could also be included under GCF priorities for adaptation such as increased resilience in health, food and water systems and enhanced livelihoods of vulnerable people, communities and regions.

The IDB provides grants, loans and technical assistance in SLCP-relevant sectors such as water and sanitation, health, agriculture, energy, and urban development and planning. In 2015, the IDB pledged to provide up to US$450 million – with additional support from the GCF of up to US$217 million – to this new IDB programme. This involves guaranteeing green asset-backed securitized bonds for refinancing of energy efficiency loans in several Latin American and Caribbean countries. The IDB joined the CCAC in 2015.

The CCAC itself is another very important means of leveraging financial resources, with a trust fund of more than US$50 million. The CCAC is currently funding SLCP mitigation activities in the oil and gas sector, brick kilns, cookstoves, HFCs, transport, waste management, agriculture and health, as well as scientific assessments, national action planning, finance and institutional strengthening. The CCAC currently has more than 100 partners, of which 12 are in Latin America and the Caribbean.

5.5

Scaling regional action into global leadership

As noted in Chapter 2, SLCPs are already significantly affecting Latin America and the Caribbean in important and complex ways, harming public health, reducing agricultural production, devastating the cryosphere, and slowing sustainable development. Without rapid action to address SLCP emissions, these impacts are only expected to increase as global temperatures continue to rise, populations continue to migrate to urban centres, and consumption patterns change. The impacts complicate the achievement of national development priorities and threaten to reverse many of the hard-fought improvements in public health, poverty reduction, education and other development indicators that the region has achieved over the past half century.

The SLCP measures identified in this assessment provide a foundation for countries to combat and reverse many of these current and growing impacts, while at the same time supporting multiple national and local priorities for sustainable development. As described in Chapter 3, by implementing measures to reduce emissions of BC and other pollutants such as O_3 precursors, the countries of Latin America and the Caribbean may prevent more than 13 000 premature deaths annually by 2030 (Figure 3.10), and increase crop production by 3–4 million tonnes annually by 2050 (Figure 3.22). However, avoiding 0.6˚C of additional warming by 2050 can only be achieved through the rapid and global implementation of SLCP measures while assuming that CO_2 mitigation measures are also fully implemented.

The important links between local and national SLCP measures and the ongoing global processes discussed above offer an opportunity to leverage additional resources to achieve nationally relevant goals, but they are also an opportunity for the Latin American and Caribbean region to promote the SLCP agenda globally. As national and regional policies and investments to reduce SLCPs gain momentum, they can spur more ambitious commitments and action at the international level. Ensuring that SLCP measures are embedded in national climate and development strategies and the Regional Action Plan for Intergovernmental Cooperation on Air Pollution will place the region in a position to drive global action to protect and enhance its priorities and development.

The fact that SLCP measures are aligned with development goals represents a unique opportunity to enhance south-south cooperation and promote a near-term climate mitigation agenda globally that will result in direct benefits for the inhabitants of developing countries.

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Acronyms and Abbreviations

A	
AERONET	Aerosol Robotic Network
ALRI	acute lower respiratory infection
B	
BC	black carbon
BRT	Bus rapid transit
C	
CCAC	Climate and Clean Air Coalition
CH_4	methane
CIF	Climate Investment Funds
CLRTAP	Convention on Long-range Transboundary Air Pollution
CMIP5	Coupled Model Intercomparison Project Phase 5
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
COP21	Twenty-first Conference of the Parties to the UNFCCC
COPD	chronic obstructive pulmonary disease
D	
DALY	Disability-adjusted life year
DIMAQ	Data Integration Model for Air Quality
DOAS	Differential Optical Absorption Spectrometry
DPF	diesel particulate filters
E	
EU	European Union
Euro III/IV/VI	European Emission Standards III, IV, and VI
F	
FAO	Food and Agriculture Organization of the United Nations
FTIR	Fourier Transform-Infrared Spectroscopy
G	
g/s	grams per second
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GAW	The Global Atmospheric Watch
GBD	global burden of disease
GCF	Green Climate Fund
GDP	gross domestic product
GEF	Global Environmental Facility
GISS	Goddard Institute for Space Studies
GTP	global temperature potential. GTP20 is GTP over a 20-year timescale.
GWP	global warming potential. GWP20 is GWP over a 20-year timescale. GWP100 is GWP over a 100-year timescale
H	
HAPIT	Household Air Pollution Intervention Tool
HCFC	hydroclorofluorocarbon
HFCs	hydrofluorocarbons
I	
IDB	Inter-American Development Bank
IEA	International Energy Agency
IER	integrated exposure response
INDC	Intended Nationally Determined Contribution
INECC	National Institute for Environment and Climate Change Mexico
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth Assessment Report
K	
Km	kilometer
Kt	kilotonne
L	
LAC	Latin America and the Caribbean
LiDAR	Light Detection and Ranging
LPG	Liquified petroleum gas
M	
M^3	cubic metres
MDG	Millennium Development Goals
Mm	micrometer
MSW	municipal solid waste
Mt	Megatonne
N	
NH_3	ammonia
NMVOCs	Non-methane volatile organic compounds
NOx	nitrogen oxides
O	
O_3	ozone
OC	organic carbon
P	
PISAC	Pollution and its Impacts on the South American Cryosphere programme
PM	particulate matter. $PM_{2.5}$ has a diameter of 2.5µm or less. PM_{10} has a diameter of 10µm or less
R	
RCP	IPCC's Representative Concentration Pathway
S	
SDG	Sustainable Development Goals
SHADOZ	The Southern Hemisphere Additional Ozonesonde Network
SLCPs	short-lived climate pollutants
SNAP	Supporting National Action Planning on SLCPs Initiative
SO_2	sulphur dioxide
U	
UNEP	UN Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
W	
WHO	World Health Organization
WMO	World Meteorological Organization

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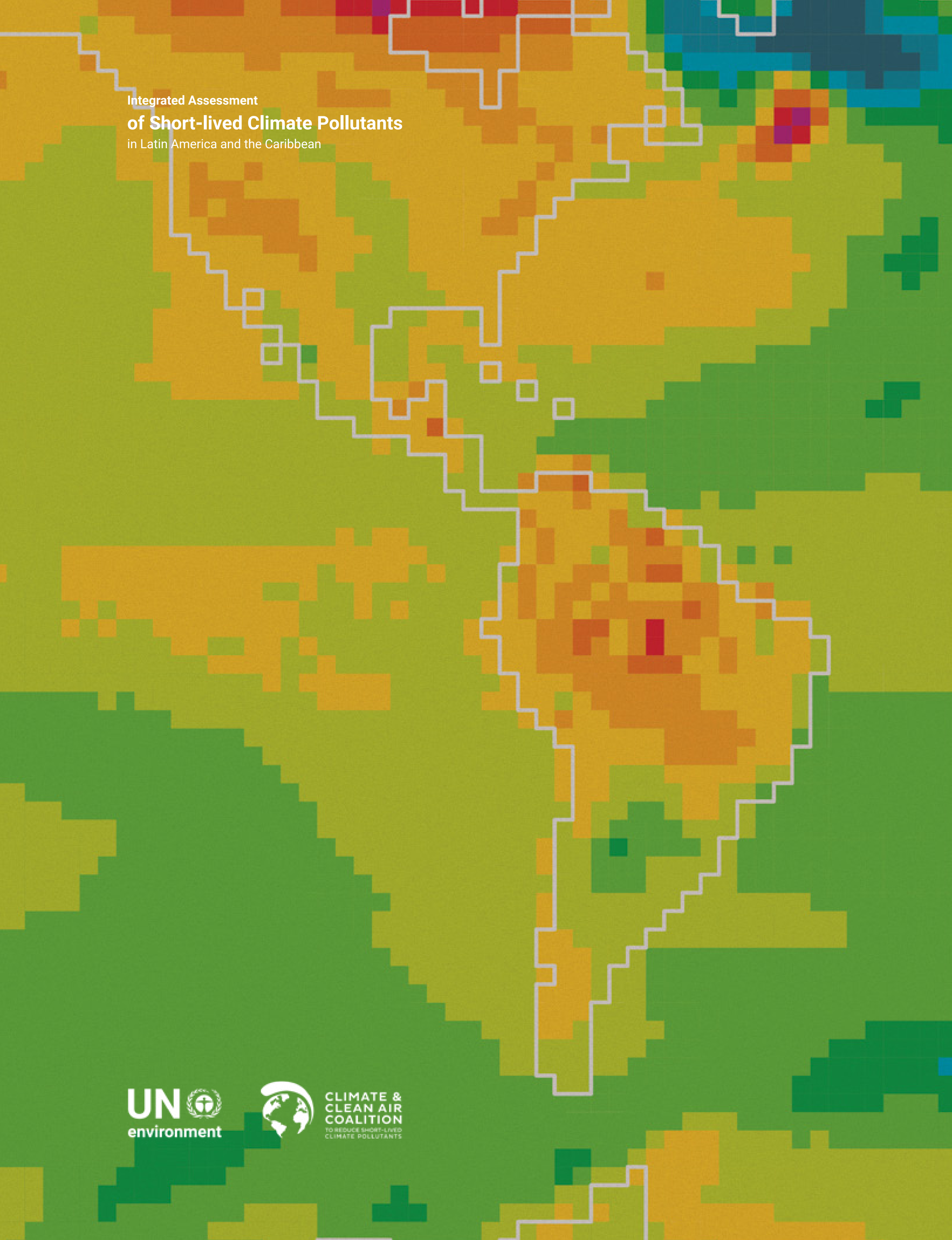
CLIMATE &
CLEAN AIR
COALITION
TO REDUCE SHORT-LIVED
CLIMATE POLLUTANTS



Integrated Assessment

# of Short-lived Climate Pollutants

in Latin America and the Caribbean

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TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS