UN environment programme

Hidden assets

The economic and health case for climate and clean air action.



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

a UNEP convened initiative

Global Economic Assessment of
Integrated Climate and Clean Air Action

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Hidden assets:

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Global Economic Assessment of
Integrated Climate and Clean Air Action

Abbreviations

AAP	ambient (outdoor) air pollution
ACE4ES	Agroecology and Circular Economy for Ecosystem Services in Sub-Saharan Africa
AFOLU	agriculture, forestry, and land use
AMI	acute myocardial infarction (heart attack)
AMOC	Atlantic Meridional Overturning Circulation
AMRUT	Atal Mission for Rejuvenation and Urban Transformation (India)
AQ	air quality
AQG	air quality guidelines
AWD	alternate wetting and drying
BAU	business as usual
BC	black carbon
BCA	benefit-cost analysis
BCR	benefit-cost ratio
BRT	bus rapid transit
BS IV	Bharat Stage IV emission standard (India)
C	carbon
°C	degrees Celsius
CAAQMS	continuous ambient air quality monitoring sites (India)
CapEx	capital expenditure
CCAC	Climate and Clean Air Coalition
CCAP	Center for Clean Air Policy
CCC	Climate Change Council (Mexico)
CCS	carbon capture and storage
CiICC	Intersecretarial Commission on Climate Change (Mexico)
CEA	cost effectiveness analysis
CFE	Federal Electricity Commission (Mexico)
CH_4	methane
CI	Confidence Interval
CICC	Inter-Ministerial Commission on Climate Change (Mexico)
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CMIP	Coupled Model Intercomparison Project
CO	carbon monoxide
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
COP	Conference of the Parties
COPD	chronic obstructive pulmonary disease
CPA	Centrally planned Asia
CPCB	Central Pollution Control Board (India)
CRF	concentration-response function
CTF	common tabular format
DALY	disability-adjusted life years
DCC	Department of Climate Change (Nigeria)
DPC	Department of Pollution Control (Nigeria)
DPF	diesel particulate filter
DRE	decentralised renewable energy
ECOWAS	Economic Community of West African States (Benin, Cape Verde, Gambia, Ghana, Guinea, Guinea Bissau, Cote d'Ivoire, Liberia, Nigeria, Senegal, Sierra Leone, Togo)
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
EEA	European Economic Area – EU27+EFTA+United Kingdom of Great Britain and Northern Ireland
EFTA	European Free Trade Association – Iceland, Liechtenstein, Norway and Switzerland
e.g.	exempli gratia (for example)
EIAPP	Engine International Air Pollution Prevention
EJ	exajoule (10^{18} joules)
EMAPEC	Estimating the Morbidity from Air Pollution and its Economic Costs
ENACC	National Climate Change Strategy (Mexico)
ENCA	National Air Quality Strategy (Mexico)
ENME	National Electric Mobility Strategy (Mexico)
EPR	extended producer responsibility
ERF	effective radiative forcing
et al.	*et alia* (and others)
ETP	Energy Transition Plan (Nigeria)
EU	European Union
EU27	European Union (from 2020) – Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary,

	Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands (Kingdom of the), Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.
EUR	Europe
EV	electric vehicle
FaIR	Finite Amplitude Impulse Response simple climate model
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (India)
FAO	Food and Agriculture Organization of the United Nations
F-gas	fluorinated gas
FGD	flue-gas desulphurization
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GBD	Global Burden of Disease
GCM	General Circulation Model
GDP	gross domestic product
GFED	Global Fire Emissions Database
GISS GCM	Goddard Institute for Space Studies Global Climate Model
GLOBIOM	Global Biosphere Management Model
GHG	greenhouse gas
GMP	Global Methane Pledge
GMST	Global Mean Surface Temperature
GOBARdhan	Galvanizing Organic Bio-Agro Resources Dhan initiative (India)
GRAP	Graded Response Action Plan (India)
Gt	gigatonne (10^9 tonnes)
GW	gigawatt (10^9 watts)
GWP	global warming potential
HAP	household air pollution
HC	hydrocarbon
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
HFO-1234yf	2,3,3,3-tetrafluoropropene
HRAPIE	health risks of air pollution in Europe
IAM	Integrated Assessment Modelling
ICCT	International Council on Clean Transportation
i.e.	*id est* (that is)
IEA	International Energy Agency
IHD	ischemic heart disease
IHME	Institute for Health Metrics and Evaluation
IIASA	International Institute for Applied Systems Analysis
I&M	inspection and maintenance
IMO	International Maritime Organization
INECC	National Institute of Ecology and Climate Change (Mexico)
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	IPCC's Sixth Assessment Report
IPCC AR6 WGIII	IPCC's Sixth Assessment Report Working Group III
IQR	interquartile range
IRR	internal rate of return
JRC	Joint Research Centre (of the European Commission)
KA	Kigali Amendment (to the Montreal Protocol)
kg	kilogram
km	kilometre (1,000 metres)
km²	square kilometre
kW	kilowatt (1,000 watts)
kWh	kilowatt-hour
LAC	Latin America and Caribbean
LAERFTE	Law for the Use of Renewable Energies and the Financing of the Energy Transition (Mexico)
LDAR	leak detection and repair
LED	light-emitting diode
LGA	local government area (Nigeria)
LGCC	General Law on Climate Change (Mexico)
LGEEPA	General Law of Ecological Balance and Environmental Protection (Mexico)
LGPGIR	General Law for the Prevention and Integrated Management of Waste (Mexico)
LIC	lower-income country
LMICs	lower- and middle-income countries
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LRI	lower respiratory infection
LSPEE	Law of the Public Service of Electric Energy (Mexico)
LT-LEDS	long-term low-emission development strategies
LTS	long-term strategy
LYL	Life years lost
m	metre
m²	square metre
m³	cubic metre
MACRO	single sector macro-economic model
MCDA	multi-criteria decision analysis
MEA	Middle East
MEE	Ministry of Ecology and Environment (China)

MEPS	minimum energy performance standards
MESSAGEix	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MIC	middle-income country
MNRE	Ministry of New and Renewable Energy (India)
MoEFCC	Ministry of Environment, Forests and Climate Change (India)
MoHFW	Ministry of Health and Family Welfare (India)
Mt	million tonnes
MW	megawatt (10^6 watts)
µg	microgram, one millionth (10^{-6}) of a gram
NAF	Northern Africa
NAM	North America
NAPCC	National Action Plan on Climate Change (India)
NCAP	National Clean Air Programme (India)
NCCC	National Council on Climate Change (Nigeria)
NDC	Nationally Determined Contribution (to the Paris Agreement)
NDRC	National Development and Reform Commission (China)
NESREA	National Environmental Standards and Regulations Enforcement Agency (Nigeria)
NEV	new energy vehicle
NGFS	Network for Greening the Financial System
NGO	non-governmental organisation
NH_3	ammonia
NIECC	National Institute of Ecology and Climate Change (Mexico)
NMVOC	non-methane volatile organic compound
NPV	net present value
N_2O	nitrous oxide
NOAA	National Oceanic and Atmospheric Administration (United States of America)
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
3-NOP	3-Nitrooxypropanol (synthetic feed additive)
NPPWM	National Policy on Plastic Waste Management (Nigeria)
NRMM	Non-Road Mobile Machinery
NUE	nitrogen use efficiency
O_3	ozone
OC	organic carbon
OCE	Oceania
OECD	Organisation for Economic Co-operation and Development
OpEx	operating expenditure
PAF	Population Attributable Fraction
PAGE	Policy Analysis of the Greenhouse Effect (model)
PAH	polycyclic aromatic hydrocarbon
PE	polyethylene
PFAS	Per- and polyfluoroalkyl substances
PM	particulate matter
$PM_{2.5}$	fine particulate matter with a diameter of 2.5 micrometres or less
PM_{10}	particulate matter with a diameter of 10 micrometres or less
PMPGIRSU	*Programa Municipal para la Prevención y Gestión Integral de los Residuos Sólidos Urbanos* (Municipal Urban Solid Waste Management Programme, Mexico)
PMUY	*Pradhan Mantri Ujjwala Yojana* (Free Gas Cylinder Scheme, India)
PNCC	National Climate Change Policy (Mexico)
ppb	parts per billion
ppm	parts per million
PPP	PPP has two meanings in this report; the meaning is determined by context: (1) purchasing power parity; (2) public-private partnership
PV	photovoltaic
PVC	polyvinyl chloride
pyCIAM	Python Coastal Impacts and Adaptation Model
QALY	quality-adjusted life year
RR	Relative Risk
3Rs	reduce, reuse and recycle
R&D	research and development
REMP	Renewable Energy Master Plan (Nigeria)
REN21	Renewable Energy Policy Network for the 21st Century
RTO	regenerative thermal oxidisers
RTOC	Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee
RUS	Russian Federation
RUWES	Rural Women Energy Security (Nigeria)
SAF	Southern Africa
SAPCC	State Action Plan on Climate Change (India)
SAS	South Asia
ScenarioMIP	Scenario Model Intercomparison Project

SCR	selective catalytic reduction
SDG	Sustainable Development Goal
SEA	Southeast Asia
SEDESOL	Secretariat of Social Development (Mexico)
SEMARNAT	Ministry of Environment and Natural Resources (Mexico)
SENER	Secretariat of Energy (*Secretaría de Energía*, Mexico)
SEP	State Emissions Profile (India)
SINACC	National Climate Change System (Mexico)
SLCP	short-lived climate pollutant
SLR	Sea Level Rise
SO_2	sulphur dioxide
SPCB	State Pollution Control Boards (India)
SOMOX	Sum of Ozone Means Over X ppb (parts per billion ozone concentration)
SSA	Sub-Saharan Africa
SSP	Shared Socioeconomic Pathway
SWM	solid waste management
t	tonne (1,000 kilograms)
TEAP	Technology and Economic Assessment Panel (of the Climate and Clean Air Coalition)
TFA	trifluoroacetic acid
UAE	United Arab Emirates
UK	United Kingdom of Great Britain and Northern Ireland
ULB	urban local bodies
UNDP	United Nations Development Programme
UNCTAD	United Nations Conference on Trade and Development
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
USEPA	United States Environmental Protection Agency
UT	Union Territory
VAT	value-added tax
VOC	volatile organic compound
vs.	versus
VSL	value of statistical life
VSLY	value of statistical life year
W	watt
WAS	West Asia and Eastern Europe
WBK	Western Balkans
WCRP	World Climate Research Programme
WHO	World Health Organization
WG3	Working Group III
WMO	World Meteorological Organization
WRI	World Resources Institute
W2E	waste to energy
YLD	Years lost due to disability
$	United States dollar

Terms and definitions

Active mobility: Walking and cycling instead of commuting using motorised vehicles. Results in reduction of emissions and brings significant health benefits because of exercise.

Acute (health): Either short-term exposure to pollution or short-term health conditions – both with time scales in the order of a few days or weeks.

Acute myocardial infarction (AMI): Heart attacks occur when the blood supply to the heart is suddenly blocked, often by a blood clot, damaging heart muscle with possible significant constraints on lifestyle.

Adipic acid: Adipic acid is the most important dicarboxylic acid, with about 2.5 million tonnes produced annually, mainly as a precursor for the production of nylon. Adipic acid otherwise rarely occurs in nature.

Aerosol: A suspension of fine solid particles or liquid droplets in air or another gas. Aerosols are classified based on how they form.

- **primary aerosols:** emitted directly into the atmosphere, such as sea salt, dust, volcanic ash, and soot;
- **secondary aerosols:** formed in the atmosphere through chemical reactions of precursor gases, such as sulphate aerosols.

Alzheimer's disease: A type of dementia that affects memory, thinking and behaviour.

Ambient (outdoor) air pollution: Pollution that is present at concentrations that affect human health, ecosystems and agriculture. It is primarily measured through the presence of particulate matter (PM_{10} and $PM_{2.5}$), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide in the air.

Anthropogenic (source of pollution): Pollution arising from human activities such as power generation or transport.

Article 6.4 mechanism: A new international carbon market mechanism under the United Nations Framework Convention on Climate Change's Paris Agreement intended to help countries accelerate their climate action and finance to developing countries. For further information, see https://www.sustain-cert.com/news/what-is-article-6-4-of-the-paris-agreement

Asthma: Wheezing, coughing and shortness of breath as a chronic (long-term) condition.

Avoided damage: In economics refers to the financial savings, protected assets, or prevented welfare losses achieved by implementing preventive measures or policies. It is a core metric used in cost-benefit analyses to prove that investing in disaster resilience or environmental protection is cheaper than the cost of inaction.

Barrier: A constraint that delays or prevents the deployment of climate and clean air solutions. Barriers can include financial limitations, technical challenges, institutional weaknesses, and social or behavioural factors.

Benefit-cost analysis (**BCA**): A systematic approach to estimating the strengths and weaknesses of alternatives. It is used to determine options which provide the best approach to achieving benefits while preserving savings in, for example, transactions, activities, and functional business requirements. A BCA may be used to compare completed or potential courses of action, and to estimate or evaluate the value against the cost of a decision, project, or policy. It is commonly used to evaluate business or policy decisions (particularly public policy), commercial transactions, and project investments. For example, the U.S. Securities and Exchange Commission must conduct BCAs before instituting regulations or deregulations.

Benefit-cost ratio (BCR): A financial metric used to evaluate a project's viability by comparing expected monetary benefits to projected total costs. Calculated as:

$$BCR = \frac{\text{Present value of benefits}}{\text{Present value of costs}}$$

Bharat stage emission standards (BSES): Emission standards instituted by the Government of India to regulate the output of air pollutants from compression ignition engines and spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment, Forest and Climate Change. The standards, based on European regulations, were first introduced in 2000, Bharat VI, the equivalent of Euro standard 6, introduced and applied nationwide from 2020. For further information, see https://www.iea.org/policies/7454-bharat-stage-bs-vi-emission-standards.

Billion: 1,000,000,000 (10^9).

Capacity building: The process of strengthening the technical, institutional, administrative and human resources needed to design, implement, monitor and enforce policies and programmes effectively.

Capital expenditure (CapEx): Money spent on major, long-term physical assets such as buildings, equipment and machinery. These purchases provide value for over a year and are depreciated over time.

China diesel emissions standards: Released in June 2018, the standard is equivalent to, or in some aspects even more stringent, than the current European standards (Euro VI). The new standard makes it mandatory for all new diesel heavy-duty vehicles introduced to the market after July 2021 to be fitted with diesel particulate filters (DPF). If effectively implemented, it will transition all new heavy-duty vehicles in China to soot-free emission levels. For further information, see https://www.ccacoalition.org/content/china-diesel-emissions-standards

China III emissions standard: Vehicular and non-road engine regulations that correspond roughly to European **Euro 3** standards. Adopted broadly in the mid-2000s and rolled out through 2010, they set caps on pollutants like carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NO_x), and particulate matter (PM).

Chronic (health): Long-term exposure to pollution or long-term health conditions – those which individuals may experience typically for years or for the rest of their lives.

Chronic obstructive pulmonary disease (COPD): Covers both chronic bronchitis (long-term inflammation of the airways) and emphysema (damage to the air sacs in the lungs). Main symptoms are shortness of breath, a persistent chesty cough with phlegm, frequent chest infections and persistent wheezing.

CMIP: A project of the World Climate Research Programme (WCRP) providing climate projections to understand past, present and future climate changes. For further information, see https://wcrp-cmip.org/cmip-phases/cmip7/

Co-benefits: The positive outcomes that occur in addition to the primary objective of a policy, intervention or action. Measures to reduce greenhouse gas emissions may also, for example, improve air quality and public health.

Conference of the Parties (COP): The COP is the supreme decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC). All States that are Parties to the Convention are represented at the COP, at which they review the implementation of the Convention and any other legal instruments that the COP adopts and take decisions necessary to promote the effective implementation of the Convention, including institutional and administrative arrangements. For further information, see https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop

Confidence Interval: A range of values that likely contains a true population average. A 95 per cent CI would contain the true value in 95 per cent of cases if the analysis were repeated many times.

Damage: A technical term in environmental economics, meaning reductions in population-scale welfare due to market and non-market losses.

Deadweight costs: Deadweight costs are aggregate reductions in economic productivity driven by mismatches between supply and demand. In this work, deadweight costs occur when carbon pricing shifts supply chains away from the economic efficiencies found in the baseline.

Dementia: Degeneration of the brain affecting memory communication, thought, feelings and behaviour.

Diabetes (type 2): Under-regulation of glucose in the bloodstream through impacts on insulin production or utilisation. Increases the risk of various other problems including heart attacks, strokes, and damage to the kidneys. Quantification here relates specifically to type 2 (T2) diabetes.

Disability adjusted life year (DALY): A measure of the health burden that combines the loss of life expectancy, that is, the number of life years lost due to early death, and the loss of number of healthy life years free of disease because of living with disability (YLD). For further information, see https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/global-health-estimates-leading-causes-of-dalys

Discount Rate: A discount rate means that future money is worth significantly less today.

Disutility: A decrease in utility (valued quality of life) caused by a specific symptom or complication. These values are often expressed negatively to reflect the impact of symptoms or disease.

EAT-*Lancet* Commission: The 2025 EAT-*Lancet* Commission on healthy, sustainable, and just food systems presents new evidence-based insights on nutrition and human health, within safe and just planetary boundaries. For further information, see https://www.thelancet.com/commissions-do/EAT-2025

Economic cost: The combination of losses of any goods that have a value attached to them by any one individual. Economic cost is used mainly by economists as means to compare the prudence of one course of action with that of another. The comparison includes the gains and losses precluded by taking a course of action as well as those of the course taken itself. Economic cost differs from accounting cost because it includes opportunity cost.

Elasticity: The elasticity between income and pollution measures how much pollution levels change in response to a percentage change in income. This relationship is not constant.

Enabler: A condition, policy, or action that helps overcome barriers and accelerates the implementation of climate and clean air solutions. Cross-cutting enablers refer to sets of mostly institutional reforms that strengthen implementation across multiple sectors by improving governance, capacity, and stakeholder engagement. Sector-specific enablers are sets of targeted reforms that address the technical, policy, social, and financing barriers for individual sectors or technologies.

Enabling environment: The institutional, economic, social, technical and policy conditions that facilitate the implementation of solutions and reforms. An enabling environment helps overcome barriers by creating incentives, capacities, resources and governance arrangements that support action.

Engineering costs: Engineering costs in air pollution mitigation refer to the financial expenditures required to design, implement, and maintain technical measures that reduce emissions. These costs are primarily divided into three categories: capital costs (hardware and installation), operational and maintenance (O&M) costs, and auxiliary fuel or energy expenses.

The European Commission: The European Union's main executive body. It proposes legislation, upholds EU treaties and ensures Member States apply EU law and policies.

European emission standards (Euro standard): Vehicle emission standards (Euro 1–7) that regulate pollution from the use of new land-surface vehicles sold in the European Union and European Economic Area Member States and the United Kingdom of Great Britain and Northern Ireland, and ships in European territorial waters. These standards target air pollution from exhaust gases, brake dust and tyre rubber pollution, and are defined through a series of European Union directives that progressively introduced stricter limits to reduce environmental impact.

Externality: In economics, a cost or benefit to an uninvolved third party that arises as an effect of another party's (or parties') activity. Many externalities can be considered as unpriced components that are involved in either consumer or producer consumption. Air pollution from motor vehicles is one example. The cost of air pollution to society is not paid by either the producers or users of motorised transport. Water

pollution from mills and factories are another example. All (water) consumers are made worse off by pollution but are not compensated by the market for this damage.

Fluorinated gases (**F-gases**): A term used by regulators to refer to fluorinated greenhouse gases. Major classes include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). They are used in refrigeration, air conditioning, heat pumps, fire suppression, electronics, aerospace, magnesium industry, foam, and high voltage switchgear. Their use is regulated due to their strong global warming potential.

Global Burden of Disease (GBD): The GBD study, produced by the Institute for Health Metrics and Evaluation (IHME) is the largest and most comprehensive effort to quantify health loss across places and over time, so health systems can be improved and disparities eliminated. For further information, see https://www.healthdata.org/research-analysis/gbd

Global Methane Pledge (GMP): Participants joining the GMP agree to take voluntary actions to contribute to a collective effort to reduce global methane emissions by at least 30 per cent from 2020 levels by 2030. This is a global, not a national reduction target. Meeting the GMP would reduce methane emissions to a level consistent with 1.5 °C pathways while delivering significant benefits for human and ecosystem health, food security and economies. It has the potential to reduce warming by at least 0.2 °C by 2050 and prevent annually 26 million tonnes of crop losses, 255,000 premature deaths, 775,000 asthma-related hospitalizations and 73 billion hours of lost labour due to extreme heat. The GMP was launched at COP26 of the UNFCCC by the European Union and the United States of America and today has 159 participating countries and the European Union. Today, co-convenors are Canada and the European Union. The CCAC Secretariat provides secretariat services to the GMP. For further information, see https://www.globalmethanepledge.org/

Global North: The Global North broadly comprises Northern America and Europe, Israel, Japan, Republic of Korea, Australia, and New Zealand.

Global South: Broadly comprises Africa, Latin America and the Caribbean, Asia excluding Israel, Japan, and Republic of Korea, and Oceania excluding Australia and New Zealand.

Global warming potential (GWP): A measure of how much heat a greenhouse gas traps in the atmosphere over a specific time period, relative to carbon dioxide. It is an index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2). The GWP thus represents the combined effect of the differing duration these substances remain in the atmosphere and their effectiveness in causing radiative forcing.

Gross Domestic Product (GDP): The total monetary value of all finished goods and services produced within a country's borders during a specific period. It serves as the primary indicator to gauge the size and state of an economy.

Greenhouse gas (**GHGs**): The gases that trap heat in the atmosphere, raising the surface temperature of the Earth. The most abundant greenhouse gases in Earth's atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Other greenhouse gases of concern include chlorofluorocarbons (CFCs and HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (C_xF_y), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

- **Well-mixed greenhouse gases** are those with atmospheric residence times substantially longer than the roughly 1–2-year timescales for mixing by winds throughout the troposphere, leading to quasi-uniform horizontal distributions within the troposphere.

Healthcare costs: The costs of treating a disease or health condition over its full duration, including time spent by healthcare professionals (doctors, nurses, carers, etc.), hospital stays, medication, residential care, etc.

Horizontal coordination mechanism: An institutional arrangement that promotes collaboration, information sharing, and policy coherence among ministries, agencies, or sectors operating at the same level of government.

Horizontal Integration: Aligning climate and clean air goals across different government agencies and sectors, such as energy, transport, health, environment, and finance. This involves strengthening coordination, creating shared incentives, and supporting joint planning to deliver solutions that achieve multiple benefits.

Household (indoor) air pollution: Household air pollution exposure results from burning solid fuels for cooking, heating or other domestic tasks.

Implementation barrier: An economic, institutional, social (behavioural), or technical factor that hinders the adoption, scaling, implementation or effectiveness of a policy, technology or intervention.

Incidence (of a disease): The number of newly diagnosed cases of a disease occurring in a specified population during a specified period.

Integrated planning: A planning approach that coordinates objectives, policies and investments across sectors and policy domains to achieve multiple outcomes simultaneously, such as improvements in air quality, public health, climate mitigation and sustainable development.

Internal rate of return (IRR): A method of calculating an investment's rate of return. The term internal refers to the fact that the calculation excludes external factors, such as the risk-free rate, inflation, the cost of capital or financial risk.

International dollar: A hypothetical currency unit used by economists to compare living standards and economic data across countries. It holds the exact same purchasing power that a US dollar had in the United States of America at a given base year.

Interquartile Range (IQR): A statistical measure of spread that describes the middle 50 per cent of a dataset. It is calculated by ordering the data from smallest to largest and subtracting the first quartile (Q_1) from the third quartile (Q_3).

Ischemic heart disease: Heart damage caused by narrowed heart arteries. This is also called coronary artery disease and coronary heart disease. When arteries narrow, less blood and oxygen reach the heart muscle. This can lead to heart attacks. For further information, see https://www.heart.org/en/health-topics/heart-attack/about-heart-attacks/silent-ischemia-and-ischemic-heart-disease

Kigali Amendment: An amendment to the Montreal Protocol, adopted in October 2016 and currently ratified by 173 countries, is an international agreement to gradually reduce the consumption and production of hydrofluorocarbons (HFCs). It is a legally binding agreement designed to create rights and obligations in international law. For further information, see https://treaties.un.org/Pages/ViewDetails.aspx?chapter=27&clang=_en&mtdsg_no=XXVII-2-f&src=IND

Levee: An elevated ridge or embankment built alongside a river or body of water to prevent flooding.

Life years: Typically refers to life expectancy, the statistical average number of years a person is expected to live at a given age.

Livestock unit: The **livestock unit** is a reference unit which facilitates the aggregation of livestock from various species and age as per convention, through the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal – bovine animals, goats, sheep, Equidae (horses, etc.), pigs, poultry and female breeding rabbits. The reference unit used for the calculation of one livestock unit is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs. For further information, see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)

Long-term: Impacts estimated to arise beyond those in the near-term.

Loss aversion: In cognitive science and behavioural economics, loss aversion is a cognitive bias in which the same situation is perceived as worse if it is framed as a loss, rather than a gain.

Lost productivity: Loss of economic activity arising from sickness or death. In this study, wage rates have been used as a proxy for productivity.

Lung cancer: Cancer in the lungs and airways. Symptoms often appear only when lung cancer is well developed, leading to very high mortality rates (around 90 per cent).

Market costs/damage: The value of outcomes that are traded on markets. In the case of health impacts this includes healthcare costs and labour productivity.

Montreal Protocol: The Montreal Protocol on Substances that Deplete the Ozone Layer is the landmark multilateral environmental agreement that regulates the production and consumption of nearly 100 man-made chemicals referred to as ozone depleting substances (ODS). When released into the atmosphere, those chemicals damage the stratospheric ozone layer, Earth's protective shield that protects humans and the environment from harmful levels of ultraviolet radiation from the sun. Adopted in September 1987, the Protocol is one of the rare treaties to achieve universal ratification. For further information, https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol

Morbidity: Morbidity is quantified as the incidence or the number of people newly suffering from a disease either per year or summed over a period of years. Hence an incident of asthma does not refer to an asthma attack, but an individual developing asthma.

Mortality: Expressed here as reduction in life expectancy ('life years lost') accumulated over the population *or* the equivalent number of deaths brought forward ('premature deaths').

Nationally Determined Contribution (NDC): National climate action plans submitted by countries under the Paris Agreement that outline their targets, policies, and measures to reduce greenhouse gas emissions and, in many cases, strengthen adaptation and resilience.

Natural (source of pollution): Pollutants present in the atmosphere but originating from natural sources, such as sea salt or desert dust, or sulphur dioxide (SO_2) from volcanoes.

NDC-LTS scenario: A climate and energy projection that evaluates the combined impact of countries' medium-term Nationally Determined Contributions (NDCs) and long-term Long-Term Strategies (LTS or LT-LEDS) under the Paris Agreement.

Near-term: In the early years (e.g. first decade) of action being taken.

Net present value (NPV): A method for assessing whether future amounts of money are worth more or less than the cost of an investment made today. It is widely used in finance, economics, and project evaluation to judge whether a planned activity is expected to create value.

Net nodal costs and engineering costs: Represent two fundamentally different approaches to evaluating financial requirements in power and utility systems. Net nodal costs deal with wholesale electricity market pricing and grid efficiency, whereas engineering costs refer to the physical, upfront construction and hardware budgets.

Nitrogen oxides (NO_x) Regulation 13 (International Maritime Organization): The control of diesel engine NO_x emissions in vessels is achieved through the survey and certification requirements leading to the issue of an Engine International Air Pollution Prevention (EIAPP) Certificate and the subsequent demonstration of in-service compliance in accordance with the requirements of the mandatory regulations. For further information, see https://www.imo.org/en/ourwork/environment/pages/nitrogen-oxides-(nox)-%E2%80%93-regulation-13.aspx

Non-market costs/damage: The value of outcomes that are not traded on markets (and hence are outside of GDP) and affect well-being generally. For health, relating to freedom from pain and suffering and the ability to undertake whatever activities one wishes to do. For ecosystems this can cover both the value people place on their use and the value they place on their existence.

Norm: An accepted standard, model or pattern of behaviour that is considered typical, expected, or required.

NORSOK: A set of industry guidelines developed by the Norwegian petroleum sector to ensure safety, cost-effectiveness, and efficiency in offshore operations. For further information, see https://standard.no/en/sectors/petroleum/norsok-standards/

Numeraire: A basic standard by which value is computed. In mathematical economics it is a tradable economic entity in terms of whose price the relative prices of all other tradeables are expressed. In a monetary economy, one of the functions of money is to act as the numeraire, i.e. to serve as a unit of account and therefore provide a common benchmark relative to which the value of various goods and services can be measured against.

Operating expenditure (OpEx): Day-to-day running costs such as rent, utilities and salaries, which are fully deducted in the year incurred.

Overshoot, peak and decline pathways, sometimes abbreviated as **Overshoot pathways**. Pathways that first exceed a global warming level (e.g. 1.5 °C) and then return to or below that level again before the end of a specified period (e.g. before 2100). Sometimes the magnitude and likelihood of the overshoot are also characterised. The overshoot duration can vary but typically lasts for at least multiple decades (adapted from IPCC).

A 1.5 °C overshoot, peak and decline pathway comprises a multidecadal sequence involving four distinct stages:

- **Exceedance of 1.5 °C:** the period in which global warming surpasses 1.5 °C but before it reaches its peak.
- **Plateauing stage:** the period when global warming reaches and plateaus at its maximum level above 1.5 °C for a period before starting to decline. The maximum level is called **peak warming**.
- **Decline stage:** the period in which global temperatures begin to decline from their peak level.
- **Stabilization stage:** reached once global temperatures return below 1.5 °C after peak and reversal, and stabilise at a level at or below 1.5 °C.

Paris Agreement: A legally binding international treaty on climate change. It was adopted by 195 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Currently, as of 27 January 2026, there are 194 Parties to the Paris Agreement. For further information, see https://unfccc.int/process-and-meetings/the-paris-agreement

Per- and polyfluoroalkyl substances (PFAS): A group of synthetic organofluorine chemical compounds that have multiple fluorine atoms attached to an alkyl chain. The high chemical and thermal stability of PFAS leads to these compounds having long environmental lifetimes, hence their being known as forever chemicals. For further information, see https://www.efsa.europa.eu/en/topics/per-and-polyfluoroalkyl-substances-pfas

Planetary Health Diet: A global reference diet based on the best available science. It represents a dietary pattern that supports optimal health outcomes and can be applied globally for different populations and different contexts, while also supporting cultural and regional variation. The diet is rich in plants: whole grains, fruits, vegetables, nuts, and legumes comprise a large proportion of foods consumed, with only moderate or small amounts of fish, dairy, and meat recommended. The diet is based entirely on the direct effects of different diets on human health, not on environmental criteria. The diet's name arose from the evidence suggesting that its adoption would reduce the environmental impacts and nutritional deficiencies of most current diets. For further information, see https://eatforum.org/eat-lancet/the-planetary-health-diet/

Policy coherence: The systematic alignment of policies, objectives and action across sectors and levels of governance to minimise trade-offs, maximise synergies and support the achievement of shared goals.

Prevalence (of a disease): Total number of existing cases of an illness at a given time or over a period, including new and old cases from prior years, usually expressed as percentage of the population with the illness or cases per 100,000 persons.

Purchasing power parity (PPP): A measure of the price of specific goods in different countries and is used to compare the absolute purchasing power of the countries' currencies. PPP is effectively the ratio of the price of a market basket at one location divided by the price of the basket of goods at a different location. The PPP inflation and exchange rate may differ from the market exchange rate because of tariffs and other transaction costs.

The PPP indicator can be used to compare economies regarding their GDP, labour productivity and actual individual consumption, and in some cases to analyse price convergence and to compare the cost of living between places. The calculation of the PPP, according to the Organisation for Economic Co-operation and Development (OECD), is made through a basket of goods that contains a "final product list [that] covers around 3,000 consumer goods and services, 30 occupations in government, 200 types of equipment goods and about 15 construction projects".

Quality-adjusted life year (QALY): A generic measure of disease burden, including both the quality and the quantity of life lived. It is used in economic evaluation to assess the value of medical interventions. One QALY equates to one year in perfect health. QALY scores range from 1 (perfect health) to 0 (dead).

Radiative forcing: The Intergovernmental Panel on Climate Change Sixth Assessment Report defines *radiative forcing* as "the change in the net, downward minus upward, radiative flux, expressed in watts per square metre, due to a change in an external driver of climate change, such as a change in the concentration of carbon dioxide, the concentration of volcanic aerosols or the output of the Sun".

Rock weathering: The in-place breakdown of rocks and minerals by physical, chemical and biological processes. It breaks down the Earth's crust into sediments and creates soil. While natural weathering takes millions of years, the process is increasingly harnessed for agricultural improvement and atmospheric carbon removal.

ScenarioMIP-CMIP7: The Scenario Model Intercomparison Project (ScenarioMIP) carries out earth system model simulations driven by alternative plausible futures of emissions and land use. The primary objectives of ScenarioMIP are to:

1. Facilitate integrated research leading to a better understanding of the physical climate system consequences of future scenarios and their impact on natural and social systems, including adaptation and mitigation considerations.

2. Provide a basis for addressing targeted science questions about the climate effects of aspects of forcing relevant to scenario-based research.

3. Provide a basis for various international efforts that target improved methods to quantify projection uncertainties based on multi-model ensembles.

ScenarioMIP is part of the Coupled Model Intercomparison Project organised by the World Climate Research Programme, and integrates research across the climate science, integrated assessment modelling (IAM), mitigation, and impacts, adaptation and vulnerability (IAV) communities. For more information, see https://wcrp-cmip.org/mips/scenariomip/

Science-policy interface: The processes, institutions and mechanisms that facilitate the back-and-forth exchange of knowledge between researchers and policymakers, helping to ensure that policy decisions are informed by the best available scientific evidence and that evidence is relevant to policy.

Shared Socioeconomic Pathways (**SSPs**): Climate change scenarios of projected socioeconomic global changes up to 2100 as defined in the IPCC Sixth Assessment Report on climate change in 2021. Five scenarios are used to derive greenhouse gas emissions scenarios with different climate policies, providing narratives describing alternative socio-economic developments. The five scenarios are:

- SSP1: Sustainability ("Taking the Green Road")
- SSP2: "Middle of the Road"
- SSP3: Regional Rivalry ("A Rocky Road")
- SSP4: Inequality ("A Road Divided")
- SSP5: Fossil-fueled Development ("Taking the Highway")

SSP2: Middle of the road narrative is: "The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain". For further information, see https://unfccc.int/files/science/workstreams/research/application/pdf/part1_iiasa_rogelj_ssp_poster.pdf

Short-lived climate pollutants (SLCPs): Short-lived climate pollutants are powerful climate forcers that remain in the atmosphere for a much shorter period of time than carbon dioxide, yet their potential to warm the atmosphere can be many times greater. Certain short-lived climate pollutants are also air pollutants that have harmful effects for people, ecosystems and agricultural productivity. The short-lived climate pollutants black carbon, methane, tropospheric ozone, and hydrofluorocarbons (HFCs) are the most important contributors to anthropogenic global warming after carbon dioxide, responsible for up to 45 per cent of current global warming. If no action to reduce emissions of these pollutants is taken in the coming decades, they are expected to account for as much as half of the warming caused by human activities. For further information, see https://www.ccacoalition.org/content/short-lived-climate-pollutants

Social Cost of Carbon: The social cost of carbon (SCC) is an estimate of the economic damage caused by emitting one additional metric tonne of carbon dioxide into the atmosphere. By quantifying climate change in monetary terms, it provides governments and businesses with a standard metric to calculate the benefits of reducing emissions and to weigh the costs of environmental policies.

SOMO20: The annual sum of daily 8-hour maximum ozone concentrations above a threshold of 20ppb.

Stern Review: The Stern Review on the Economics of Climate Change is a 700-page independent review by economist Nicholas Stern released for the Government of the United Kingdom of Great Britain and Northern Ireland in 2006. The Review states that climate change is the greatest and widest-ranging market failure ever seen, presenting a unique challenge for economics. It provides prescriptions including environmental taxes to minimise the economic and social disruptions. The Review's main conclusion was that the benefits of strong, early action on climate change far outweigh the costs of not acting. For further information, see https://www.lse.ac.uk/granthaminstitute/publication/the-economics-of-climate-change-the-stern-review/

Stroke: Occurs when blood stops flowing to part of the brain, impacting e.g. speech and movement. Recovery times can be long and effects may be permanent.

Super pollutant: A group of atmospheric pollutants that have greater impacts on warming than carbon dioxide per tonne and can have other environmental and human health effects. Super pollutant mitigation measures that focus on methane, tropospheric ozone, black carbon, and hydrofluorocarbons (HFCs) deliver the largest near-term climate benefits. Additional atmospheric pollutants that are considered super pollutants in various contexts are nitrous oxide, other fluorinated gases (F-gases; such as sulphur hexafluoride), and tropospheric ozone precursors (carbon monoxide, non-methane volatile organic compounds [NMVOCs], and hydrogen; also known as indirect greenhouse gases). Further, while black carbon is considered a super pollutant, it is an aerosol and a component of $PM_{2.5}$ air pollution. For further information, see https://www.ccacoalition.org/content/short-lived-climate-pollutants

Tail risk: The financial risk of an asset or portfolio of assets moving more than three standard deviations from its current price, above the risk of a normal distribution.

Three types of capital: The sustainability revolution is based on the fundamental recognition that there are three forms of capital essential to the creation of genuine prosperity. These are **economic (financial and manufactured), natural and social capital**.

Trillion: 1,000,000,000,000 (10^{12}).

Triple planetary crisis: The triple planetary crisis refers to the three main connected issues that humanity currently faces: climate change, pollution and biodiversity loss. Each of these issues has its own causes and effects and each issue needs to be resolved if humanity is to have a viable future on this planet. For further information, see https://unfccc.int/news/what-is-the-triple-planetary-crisis

Unit Cost: The unit cost in the burden or impact calculation is the cumulative lifetime cost per case of illness (including market and non-market contributions) or the economic value (disutility) associated with mortality.

Utility: Refers to the benefits (satisfaction or happiness) consumers derive from a good, and it can be measured based on individuals' choices between alternatives or preferences revealed in their willingness to pay.

Vegan (diet): A vegan diet is based on plants (such as vegetables, grains, nuts and fruits) and foods made from plants. Vegans do not eat foods that come from animals, including dairy products and eggs.

Vegetarian (diet): A vegetarian diet is devoid of the flesh of any animal – red meat, poultry, seafood, freshwater fish, insects, etc.

Vertical coordination mechanism: A governance arrangement that promotes alignment, cooperation and accountability across different levels of government, such as national, provincial, and local authorities.

Vertical Integration: Aligning climate and clean air goals across levels of government – from international and national commitments to regional and local action. This involves coordinating policies, building local capacity, and providing finance and other support to help lower levels of government implement shared objectives.

Well-mixed greenhouse gases: Those GHGs with atmospheric residence times substantially longer than the roughly 1-2 year timescales for mixing by winds throughout the troposphere, leading to quasi-uniform horizontal distributions within the troposphere.

WHO Air Quality Guidelines: The WHO guidelines offer guidance about these air pollutants, updated in 2021. WHO has also established **interim targets** to promote a gradual shift from high to lower concentrations and their associated health benefits as follows: **WHO Interim Targets:** Interim targets for $PM_{2.5}$ are designed as indicators marking progress towards the Guideline as follows:

		Interim target				AQG
Pollutant	**Averaging time**	**1**	**2**	**3**	**4**	**level**
$PM_{2.5}$ µg/m³	Annual	35	25	15	10	5
	24-hour	75	50	37.5	25	15
PM_{10} µg/m³	Annual	70	50	30	20	15
	24-hour	150	100	75	50	45
O_3 µg/m³	Peak season	100	70	–	–	60
	8-hour	160	120	–	–	100
NO_2 µg/m³	Annual	40	30	20	–	10
	24-hour	120	50	–	–	25
SO_2 µg/m³	24-hour	125	50	–	–	40
CO µg/m³	24-hour	7	–	–	–	4

For further information, see https://www.who.int/publications/i/item/9789240034228

Xietong kongzhi: In economics and management, the Chinese term *Xietong kongzhi* (collaborative co-control or cooperative control) describes supply chain or organisational coordination in which (multiple) autonomous actors work together to achieve a shared objective.



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Foreword

The world is heading for a period of global temperature rise above 1.5 °C, known as overshoot. Every extra fraction of a degree above 1.5 °C, and every extra year we stay there, will bring escalating and perhaps irreversible climate impacts. At the same time, air pollution is cutting short around seven million lives each year and holding back human and economic potential in ways we are only beginning to fully understand.

These two crises are deeply interconnected, often resulting from the same sources, such as the burning of fossil fuels and biomass. We can and must act on them with the urgency they deserve – to get back below 1.5 °C, save lives and protect the nature upon which we depend. This Assessment shows that integrated action on the two crises is not only the fastest way to deliver greatest impact, it is one of the most compelling economic opportunities of this century.

At the heart of the opportunity is a package of 25 scalable solutions – from moving to renewable energy for power generation and transport to reducing methane emissions from fossil fuels, agriculture and waste to increasing energy efficiency in industry, homes and vehicles. These solutions address all greenhouse gases, from CO_2 to super pollutants such as methane and black carbon. This package could deliver an approximate fifteen-fold return on investment – with economic gains equivalent to 4.5 per cent of global GDP by 2050, and substantially more thereafter. Accelerating implementation could unlock up to US$ 10 trillion in health benefits by 2040. Those gains go first, and fastest, to the countries that act early – with the highest returns in the regions that carry the heaviest burden today.

We have a clear choice. On one trajectory, without following these solutions, action remains slow and fragmented. Emissions continue to rise. The burden of disease grows. Economic losses accumulate, stressing public finances at a time when fiscal space is already sharply constraining development. On the other trajectory, we act early and in an aligned way, combining long-term climate strategies with solutions that deliver immediate clean air, climate and health benefits, while investing in the enabling conditions that determine whether solutions are delivered.

We have the technologies and policies. The only difference between these two pathways is how quickly and effectively we choose to act and achieve results. For too long we have treated climate action as a cost to be managed and air pollution as the unfortunate outcome of development. This report shows that clean air is a key driver of development. It is an asset that we need to invest in. The evidence for action and the solutions presented in this report are strong and clear. I call on policymakers, the private sector and all actors with a role to play to implement these solutions at the pace and scale this moment demands – and address climate change and air pollution together.

Inger Andersen

UNEP Executive Director

Preface

We chose to lead this Assessment because the moment demanded it. In an increasingly fragmented world, governments, cities, businesses and financial institutions are being asked to do more with less, including cutting emissions faster, protecting more lives, and delivering on climate and clean air commitments while public finances are stretched and patience for analysis without action is wearing thin. We believe the evidence in this report can change what is possible. This Assessment was designed for this new reality. It shows where integrated action on climate and air quality can deliver the greatest returns around the globe.

Three features of this Assessment are, to our knowledge, without precedent. First, it quantifies the combined economic value of climate and air quality actions within a single, internally consistent framework allowing feedback between these environmental changes, rather than adding together separate estimates produced by different models with different assumptions. Second, it captures a broader spectrum of the full burden of illness caused by air pollution, not only premature deaths but also the diabetes, dementia, stroke, heart disease and childhood asthma that diminish the lives of hundreds of millions of people who are alive today. This is where economics and lived experience meet: a benefit-cost ratio is, in the end, a statement about real people, lost days, constrained choices and avoidable suffering, and we have tried to make that connection impossible to ignore. Third, it makes the economic case for investing in the enabling environment itself, including the institutions, finance, coordination, enforcement and public trust that determine whether commitments translate into results. At a moment when the global conversation is shifting from what must be done to how to do it faster and fairly, we believe this Assessment can be of value to the people who must decide.

None of this would have been possible without the sustained support of the Climate and Clean Air Coalition, whose Secretariat, along with the team at the Stockholm Environment Institute in York, coordinated this effort from its earliest conception to final draft, and the United Nations Environment Programme, whose stewardship gave this work its home, legitimacy, and reach. We are grateful to the authors, reviewers, modelling teams and partners whose expertise and persistence made this Assessment possible.

We offer this Assessment not as the final word, but as the most complete evidence base yet assembled for decisions that cannot wait. In a period of constrained finances and competing priorities, the choice is not whether the world can afford integrated climate and clean air action. It is whether it can afford to miss the benefits such action would deliver. We hope it is read, argued with, and above all, used.

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Audience and focus

This Assessment is a global analysis that brings together climate change and air pollution within a single economic framework. It provides new evidence on the scale of economic, health and development benefits from acting on these challenges, intended to inform fiscal policy, public investment decisions, and economic planning, particularly for ministries of finance. It also serves as a resource for policymakers, development partners, the private sector, the scientific community and other stakeholders.

Building on previous Climate and Clean Air Coalition (CCAC) assessments and related global analyses, this report advances understanding by quantifying the combined economic impacts of climate change and air pollution, and the benefits of integrated action in the near, medium and long-term.

The Assessment draws on state-of-the-art integrated assessment, atmospheric and health impact models to estimate the economic, health and environmental impacts of a package of mitigation solutions. These include solutions targeting long-term climate outcomes, and those targeting air pollution and near-term climate. It significantly expands the analysis of health impacts to include outcomes such as asthma, diabetes and dementia, alongside their economic valuation. For the first time, it also quantifies how the enabling environment influences the speed of implementation, and the resulting impacts on emissions reductions and associated economic and health benefits.

The findings of this Assessment have been reviewed by a wide range of international experts through a formal peer review process.

Executive summary

This Assessment provides the most complete picture to date of the benefits and costs of integrated climate and clean air action, complemented by an empirically grounded analysis of how these benefits can be delivered quickly enough to avoid premature deaths and disease and improve the lives of many of the world's most vulnerable people. The world has entered a new phase of planetary and economic challenges. Exceeding 1.5 ºC of warming is now widely assessed as unavoidable (UNEP 2026), and governments face mounting economic costs from climate change and air pollution simultaneously, at a time when fiscal space is sharply constrained and returns on public investment are under intense scrutiny. The policy debate is also shifting: the question is no longer only what needs to be done to reduce emissions, but how to implement proven solutions quickly enough to avert planetary and economic crises, and how to generate returns that justify private investment. This Assessment demonstrates how the response to these challenges can be transformed into an economic opportunity.

One of the keys to unlocking that economic opportunity is recognizing that climate change and air pollution are inextricably linked. They share many of the same drivers and sources, above all fossil-fuel combustion, and certain agricultural practices and industrial processes. Many pollutants cause both climate change and air pollution, and their impacts compound one another, harming human health, ecosystems and economic activity. Despite these linkages, climate change and air pollution are often analysed separately, leading to incomplete assessments of their economic costs and benefits and, in many cases, avoidable trade-offs. In consequence, heads of state, finance ministers, business leaders, and affected communities often have a partial picture of the massive economic benefits of integrated solutions and the enabling reforms needed to achieve these gains.

This Assessment draws on the latest science and models and evaluates a package of 25 proven solutions based on existing technologies and practices spanning energy and fossil fuel systems, industry, transport, agriculture and food systems, residential cooking and heating, and waste management (Table ES2). The 25 integrated solutions have been assessed by previous United Nations Environment Programme (UNEP)/ Climate and Clean Air Coalition (CCAC) integrated assessments at global and regional levels, but in different combinations and not in a full economic context as in this Assessment. They comprise four long-term climate actions targeting deep carbon dioxide reductions, delivering co-benefits for air pollution and large longer-term benefits, and 21 solutions targeting super pollutants that deliver rapid improvements in air quality, health outcomes and near-term climate impacts. The analysis finds that integrated action delivers greater economic and health benefits than acting on climate change or air pollution alone, and that these benefits materialise quickly enough to outweigh costs within the first decade. It further shows that the chief obstacles to capturing these gains are often neither technical nor economic but institutional: reforms of enabling frameworks that determine the speed, scale and effectiveness of implementation are frequently overlooked in economic assessments because they are difficult to quantify. This Assessment addresses that gap directly.

Unless otherwise stated, ranges in parentheses represent 95 per cent confidence intervals for economic and temperature estimates, and interquartile ranges for health estimates. Ranges are shown alongside central estimates in the text, figures and tables.

Integrated action on climate and clean air is one of the highest-return investments available to governments today

Every dollar invested in the 25 solutions generates around 15 dollars of economic benefits, with market returns exceeding implementation costs within ten years and an internal rate of return of 60 per cent.

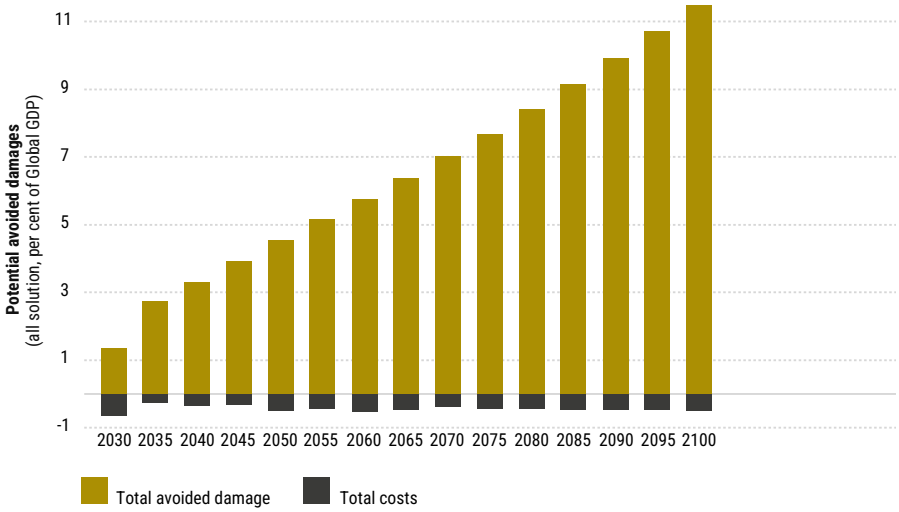
The 25 solutions, if implementation begins immediately, could generate economic benefits equivalent to about 2.8 (2–4) per cent of global gross domestic product (GDP) by 2035, 4.5 (3–6) per cent by 2050, and approximately 11.4 (8–14) per cent by 2100 (Figure ES1). Implementation costs are approximately 0.7 per cent of global GDP in the coming decade, declining to approximately 0.5 per cent by the end of century, meaning global economic benefits exceed implementation costs by a ratio of 15 to 1. For context, global spending on explicit fossil fuel subsidies was 2.18 per cent of GDP in 2022, and total government spending on education was 3.5 per cent and on health care was 9.3 per cent of GDP in 2023.

Even excluding non-market welfare gains entirely and counting only measurable market benefits, such as reduced healthcare spending, higher labour productivity, and avoided physical damage, the 25 solutions return approximately US$ 4 for every dollar invested.

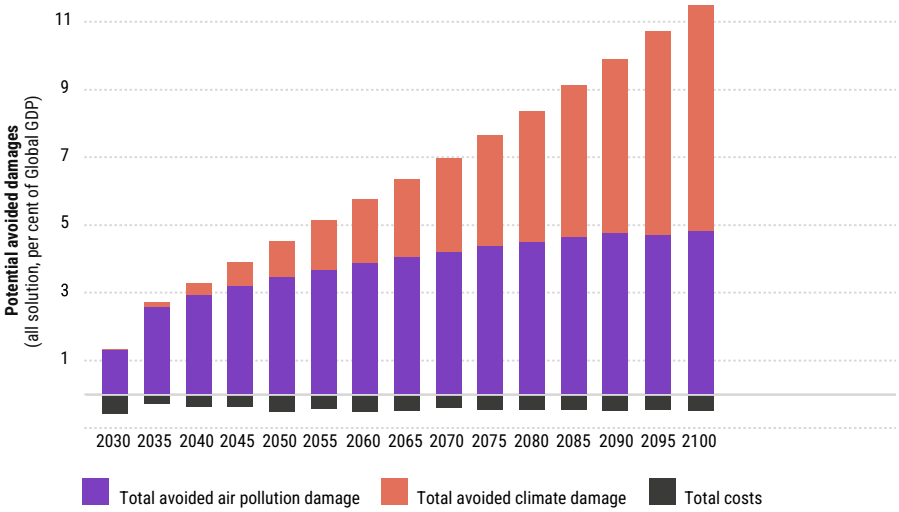


Figure ES1:
Avoided damages, shown in total (top, gold), split into air pollution (purple) and climate change (pink) benefits (middle), and into market (light brown) and non-market (dark brown) damages (bottom), alongside total implementation costs (dark blue), 2025–2100, per cent of global gross domestic product.

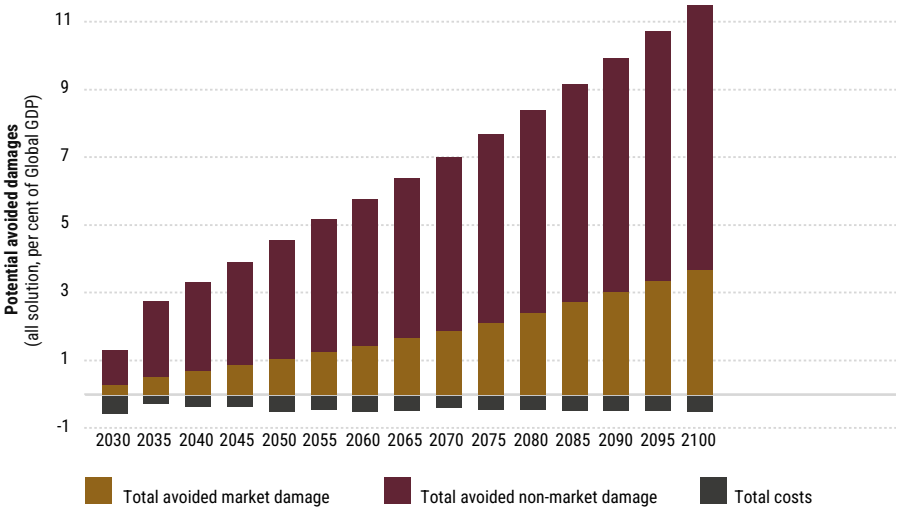
Total avoided damages against total costs
Economic Benefits outweigh implementation costs immediately



Avoided damages split by air pollution and climate
Reduced air pollution benefits begin to accrue immediately with climate benefits accumulating more slowly, but reaching a higher level in 2100



Avoided damages split by market and non-market
Market benefits including reduced healthcare costs and higher productivity exceed implementation costs within a decade

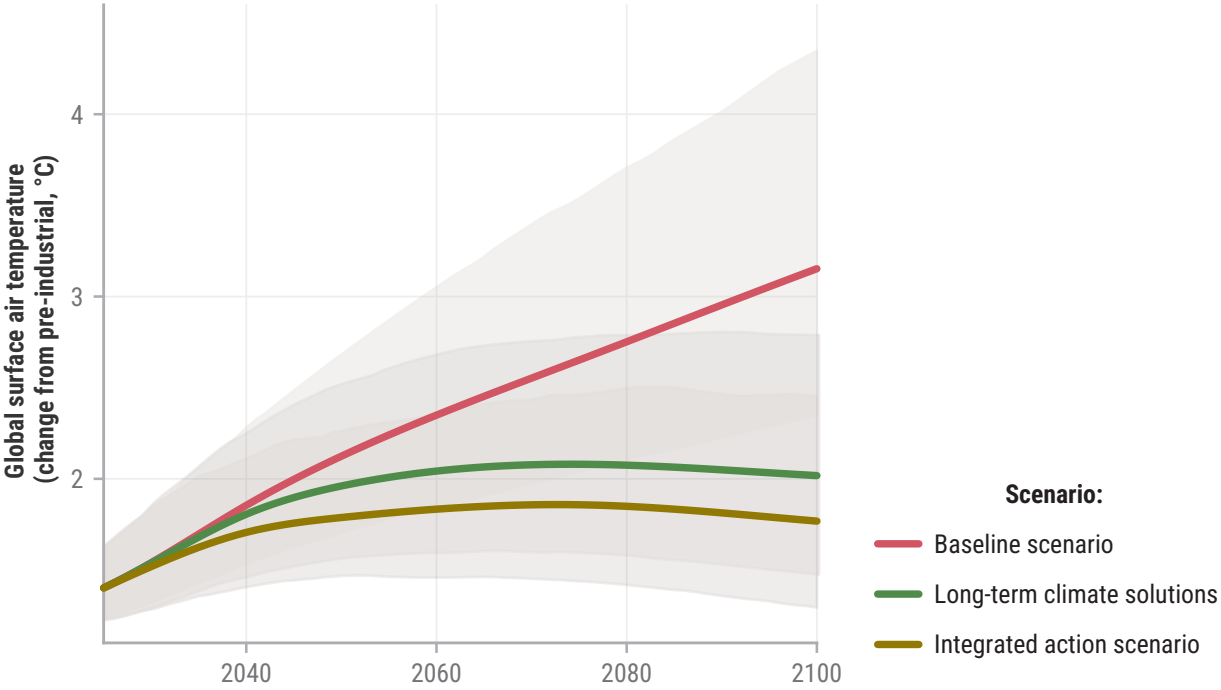


The economic value of avoided air pollution damage exceeds that of avoided climate damage in early years after the implementation of the 25 solutions and remains nearly 45 per cent of the total economic benefit in 2100 (Figure ES1). Considering only the costs of climate impacts therefore misses almost half of the economic benefits of action, underlining the importance of the integrated approach.

Pursuing climate and air quality action together rather than separately generates approximately 0.2 per cent of GDP in additional economic benefits. These gains arise because many benefit channels – avoided climate damage, reduced healthcare expenditure, higher labour productivity and quality-of-life improvements linked to reduced morbidity and mortality – only materialise fully when the climate and clean air agendas are pursued together. These benefits are captured (but not shown) in Figure ES1.

The 25 solutions could avoid approximately 0.34 °C (0.1–0.6) of warming by 2050 and approximately 1.4 °C (0.9–2.1) by 2100 (Figure ES2). Since temperatures over land rise faster than the global average, the benefits of the 25 solutions are larger at the regional level than global figures suggest, with avoided warming of approximately 0.1 °C in 2035, 0.5 °C in 2050 and 1.5–2 °C in 2100 in most regions.

Figure ES2: Changes in global surface temperature for the baseline, the four long-term climate solutions and the full 25 integrated solutions (integrated action scenario) relative to pre-industrial levels, 2020–2100, degrees Celsius.



Note: bands show the 95 per cent confidence interval.

Air pollution is a macroeconomic risk, not an environmental add-on

The morbidity and mortality effects of air pollution, including through lost productivity and rising healthcare costs, already represent several percentage points of GDP annually and are projected to grow without stronger action.

This Assessment finds that in 2025, anthropogenic ambient (outdoor) fine particulate matter ($PM_{2.5}$) and ozone together caused an estimated 6.4 (5.2–7.3) million premature deaths worldwide. Indoor $PM_{2.5}$ contributed an additional estimated 2 (1.8–2.2) million premature deaths, 300,000 (260,000 to 330,000) of which were children. Ambient $PM_{2.5}$ exposure alone is associated annually with millions of new cases of childhood asthma, millions of heart attacks, chronic obstructive pulmonary disease (COPD), diabetes, stroke, dementia, and lung cancer (Table ES1).

Table ES1: Number of new cases of disease linked to anthropogenic fine particulate matter exposure and proportion of all instances globally, 2025.

Disease	New cases Millions	Per cent of all new cases
Childhood asthma	5.5 (4.7–6.2)	22 per cent
Heart attacks	4.2 (3.3–4.9)	20 per cent
Chronic obstructive pulmonary disease (COPD)	3.8 (3.2–4.3)	21 per cent
Diabetes	3.3 (2.6–3.9)	15 per cent
Stroke	2.5 (2.0–2.9)	20 per cent
Lung cancer	0.5 (0.4–0.6)	19 per cent
Dementia	2.0 (1.6–2.3)	19 per cent

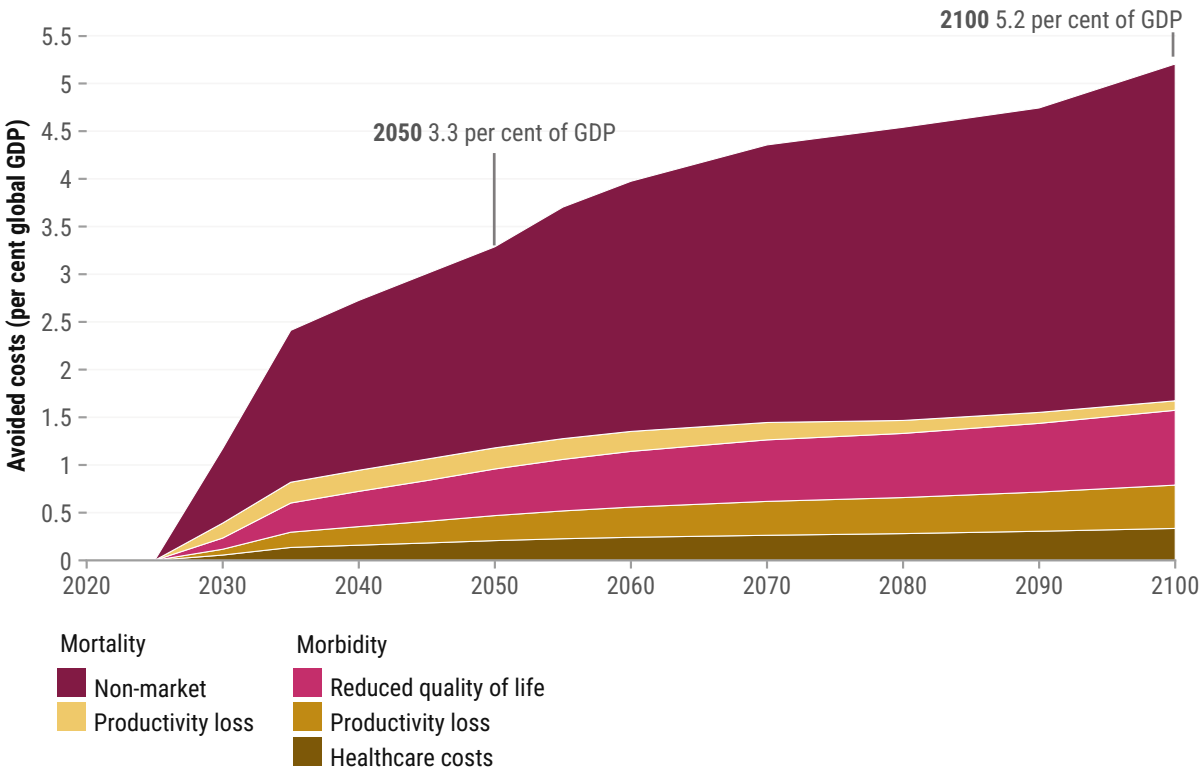
Note: numbers in brackets show the Interquartile range (IQR).

Cumulatively, by 2050, the 25 integrated solutions would avoid hundreds of millions of cases of chronic diseases and an estimated 144 million premature deaths from ambient and household $PM_{2.5}$ exposure plus ozone exposure. This is made up of an estimated 62 (37–77) million cases of childhood asthma, 87 (65–103) million acute myocardial infarctions (heart attacks), 63 (50–73) million cases of COPD, 56 (39–68) million cases of diabetes, 45 (37–51) million cases of stroke, 36 (29–42) million cases of dementia, 7 (5.4–8.2) million cases of lung cancer, 96 (80–109) million premature deaths attributable to ambient $PM_{2.5}$, 43 (38–48) million premature deaths from household $PM_{2.5}$ exposure, and 5 (4.0–5.8) million premature deaths from exposure to ozone (See Figure ES4).

Many prior economic assessments of air pollution have focused on premature mortality, leaving the broader costs of illness unvalued. This Assessment incorporates the latest evidence across a substantially expanded set of health conditions and breaks down their cost implications, making the costs and benefits of action more visible and directly comparable. By 2050, the 25 solutions could avoid market healthcare expenditures and productivity losses equal to 0.7 per cent GDP. These benefits increase markedly when the quality-of-life (non-market) benefits of reduced morbidity and mortality are also considered (Figure ES3). The avoided market costs are comparable in magnitude to the full cost of implementing all 25 solutions, and the economic case strengthens further once non-market welfare losses are included.

Without further action, emissions of greenhouse gases, air pollutants and their precursors are projected to keep rising globally, particularly in rapidly developing regions. Without additional policy, the share of the global population exposed to the most dangerous $PM_{2.5}$ concentrations rises from 27 per cent in 2025 to 34 per cent by 2050. Combined with ageing populations, this will increase the disease burden from air pollution and raise pressure on public finances and constrain economic growth in exactly the countries that can least afford it. Full implementation of the 25 solutions would avoid 60 to 70 per cent of the total air pollution health burden annually.

Figure ES3: Annual morbidity and mortality air-pollution-related costs avoided by implementing all 25 solutions, 2025–2100, per cent of global gross domestic product.



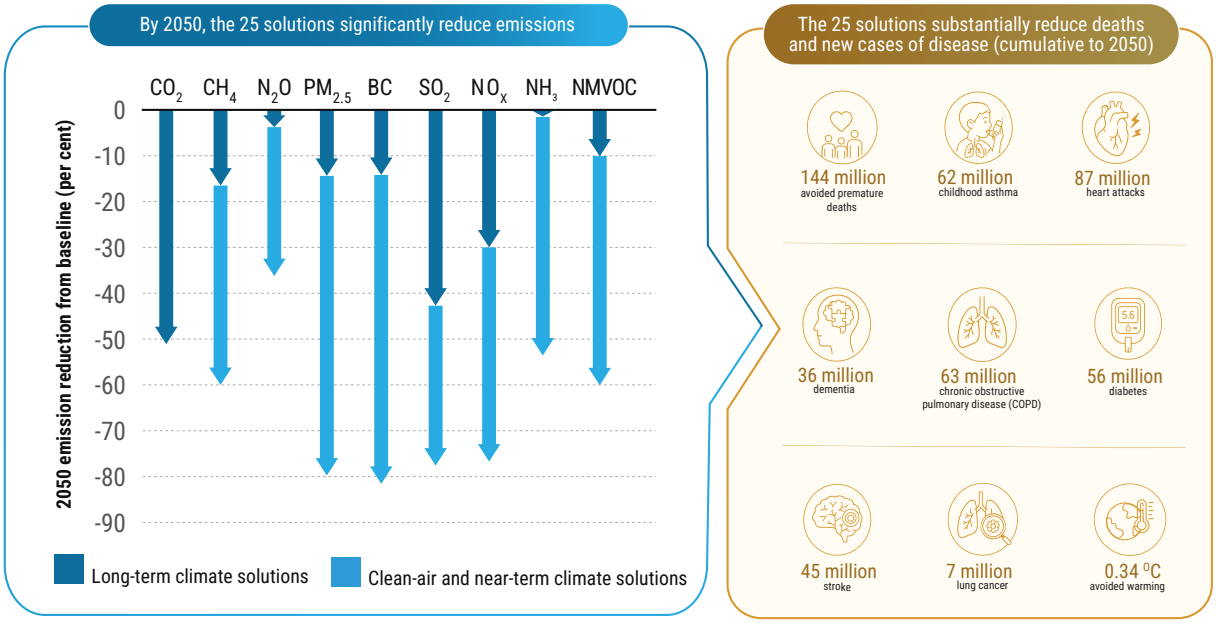
Greater than the sum: integration increases returns

Tackling shared sources of climate change and air pollution through an integrated package boosts net economic benefits to approximately 11.4 per cent of global GDP by 2100, more than either achieves alone.

Because climate change and air pollution share partly the same emission sources, the 25 integrated solutions can simultaneously reduce greenhouse gases, cut air pollution, and generate compounding economic returns across health, productivity and avoided climate damage (Figure ES4). Integrating the two agendas means that in all regions the combined benefits of action offset costs in the near term, and substantially more so over the long term. Integrated action allows impacts to be reduced more quickly, effectively and at a lower overall cost compared to the situation pursuing each of the agendas separately with uncoordinated timelines and stakeholder involvement hampering fast progress and transformation needed to implement it.

By 2050 the 25 solutions cut global carbon dioxide emissions by half, methane by 60 per cent, and black carbon and $PM_{2.5}$ precursors including sulphur dioxide and nitrogen oxides by 70 per cent (Figure ES4). By 2100 carbon dioxide emissions are net-negative and $PM_{2.5}$ precursors fall by up to 85 per cent. Solutions targeting air pollution and near-term climate impacts complement long-term decarbonization by delivering immediate economic gains, including reductions in public healthcare costs, productivity gains, and increased workforce participation.

Figure ES4: Global emission reductions attributed to the implementation of (i) the long-term climate solutions and (ii) the clean-air and near-term climate solutions of key greenhouse gases and air pollutants in the integrated action scenario compared to the baseline (left) in 2050 (as per cent), and the associated health and climate benefit (right) compared to the baseline in 2050.



Time is money: delay locks in avoidable costs

Near-term action on fast-acting solutions reduces warming, starts to save lives immediately, and generates returns that delayed action cannot recover.

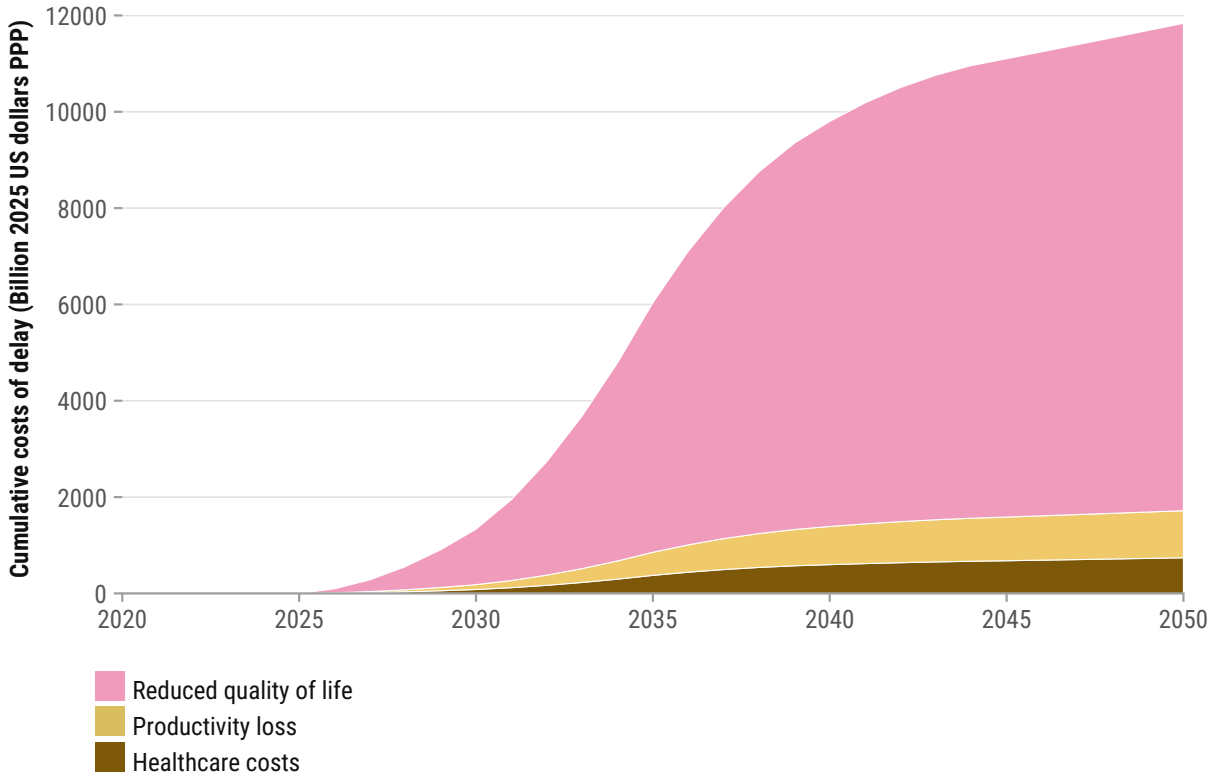
Every year of delay raises cumulative emissions, increases long-term costs and locks in health burdens that cannot be reversed. In terms of health impacts, emissions reductions not achieved in the near-term cannot be compensated for later in the absence of fundamental changes to socio-economic factors such as demand preferences or population relative to the scenarios used in this Assessment, however strong the action that follows. Each year of delay foregoes more than 0.5 per cent of global GDP in benefits, equivalent to more than US$ 1.5 trillion in combined market and non-market value.

This Assessment quantifies what more rapid implementation is worth. Strengthening enabling conditions – economic, social, technological and institutional – can bring all 25 solutions fully into place up to a decade sooner, substantially boosting reductions in $PM_{2.5}$ and ozone precursors over the 2025–2050 period. Implementation delays of 7.5 to 8 years are expected globally on average, with institutional barriers the single largest contributor, accounting for approximately 2.4 years (Figure ES7) over a notional 15-year implementation window. A delay of this scale roughly halves the emissions reductions achievable by 2035. Market and non-market morbidity benefits from enabling reforms that accelerate implementation alone could total up to a cumulative US$ 10 trillion in savings by 2040 (Figure ES5). This is roughly equivalent to one full year of total global spending on health, which reached US$ 10.6 trillion in 2023 (WHO 2025).

The effects of delay are real. In Delhi, India, achieving current national air quality standards on schedule from 2026 would reduce the cumulative $PM_{2.5}$ exposure burden by 20 per cent by 2040. With an eight-year delay, the global average, the reduction is only 10 per cent. Half the benefit is lost.

Investment in sustained capacity-building programmes, air quality monitoring systems, interagency coordination mechanisms and other enabling reforms that accelerate implementation is an often overlooked economic priority in its own right.

Figure ES5: Cumulative costs of delay accounting for air pollution only, morbidity and mortality because of barriers to implementation, 2025–2050, billion 2025 United States dollars, purchasing power parity.



Note: for this cumulative result, future costs are discounted to 2025 at 3 per cent per year.

The benefits materialise everywhere, across all regions and over different timescales

The economic and health returns from integrated action vary substantially across the 15 regions analysed, but every region benefits, and no solution is wasted.

The 25 integrated solutions do not deliver uniform benefits across the world. Benefit-cost ratios (BCRs) range from three in high-income regions such as the European Union, the European Free Trade Association and the United Kingdom of Great Britain and Northern Ireland to 26 in Southern Africa, reflecting the concentration of health and climate risk in lower-income countries in which approximately 95 per cent of premature deaths attributable to air pollution occur. Regions in South Asia, Sub-Saharan Africa and the Middle East face combined pollution and climate risks equivalent to more than 5 per cent of regional GDP by 2100. Even excluding non-market benefits entirely, benefits exceed costs in 8 of the 15 regions. No region should wait for others to move first.

Within the 15 regions analysed, the solutions delivering the largest near-term benefits differ substantially, reflecting each region's energy system, pollution profile and stage of development (Figure ES6). In 2035, five broad groupings emerge where countries gain the most benefit: for high-income regions with mature pollution controls it is from dietary change and emissions controls for international shipping; for developing regions with high indoor air pollution exposure, including Latin America and the Caribbean, South Asia and Sub-Saharan Africa, it is from clean cooking; for oil and gas producing regions in the Middle East, North Africa and Russian Federation it is from controlling methane leakage and flaring; and for rapidly developing regions across Asia it is from power generation and household energy transitions.

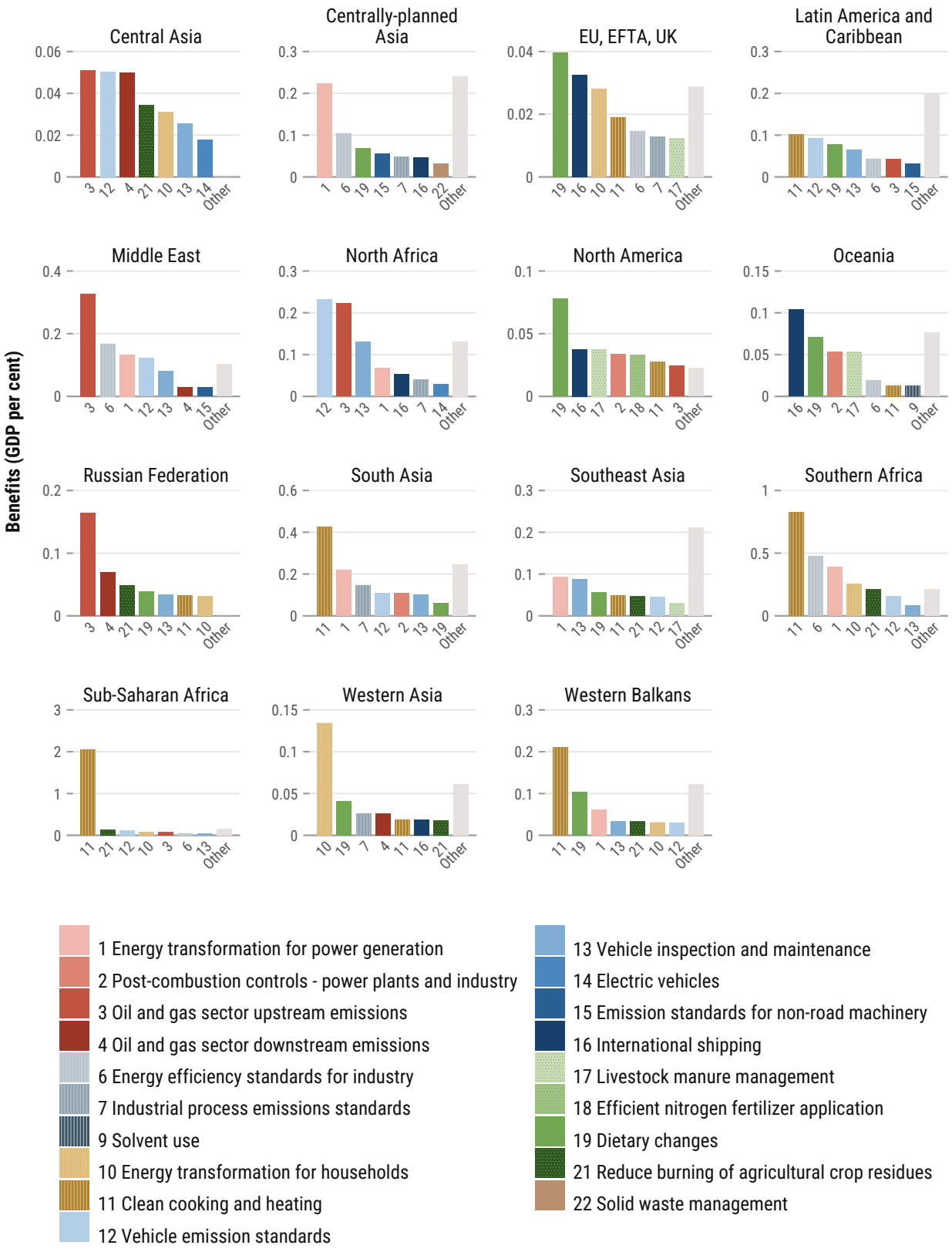
These groupings remain broadly stable in 2050, but the relative importance of the four long-term climate solutions grows as near-term air pollution benefits are progressively captured, and dietary change and energy-efficiency standards rise in prominence across most regions. This variation in the benefits that the measures give does not reduce the case for implementing all

25 solutions simultaneously: the synergistic benefits identified only materialise when the full package is pursued.

Well-designed policies amplify these gains; poorly designed policies risk undermining them. For example, in some communities, policies such as targeted transfers, subsidised access to cleaner technologies, and gender-responsive planning may be essential for capturing the full benefit at the community level, not optional additions. Ensuring implementation explicitly reaches vulnerable populations is both an equity imperative and a precondition for realizing the full economic returns that this Assessment identifies.



Figure ES6: Priority solutions by region in 2035 considering air pollution and climate policies, ranked by total market benefit, per cent of regional gross domestic product.



Note: The figure shows the seven solutions delivering the greatest market benefits in each of the 15 regions by 2035, expressed as a percentage of regional GDP and accounting for both air-pollution and climate benefits. The grey bar shows 'other' - the combined effect of the rest of the 25 measures.

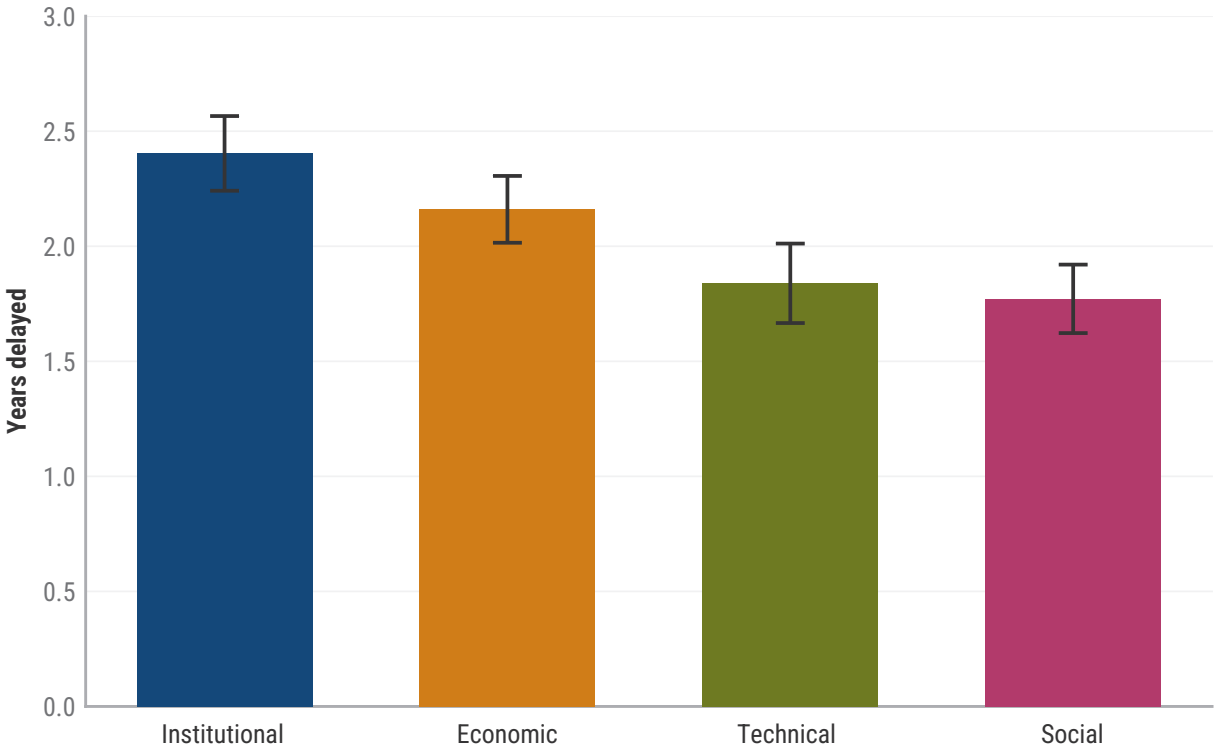
Enabling conditions are as important as technology choices

Access to finance, institutional capacity, governance, and coordination challenges explain why the same policies deliver different outcomes across contexts. Investment in a well-designed enabling environment is essential to bringing full implementation forward by up to a decade.

Most previous economic assessments have focused on which solutions need to be adopted by when, with limited attention on what makes implementation succeed or fail over different time periods. This Assessment addresses that gap directly. It also shows that barriers to implementation are not primarily technical. Siloed decision-making, limited enforcement capacity, inadequate financing and weak cross-ministerial coordination are the constraints that are cited most frequently to explain why proven solutions are not adopted at the speed or scale predicted in models and fail to achieve their technical potential (Figure ES7).

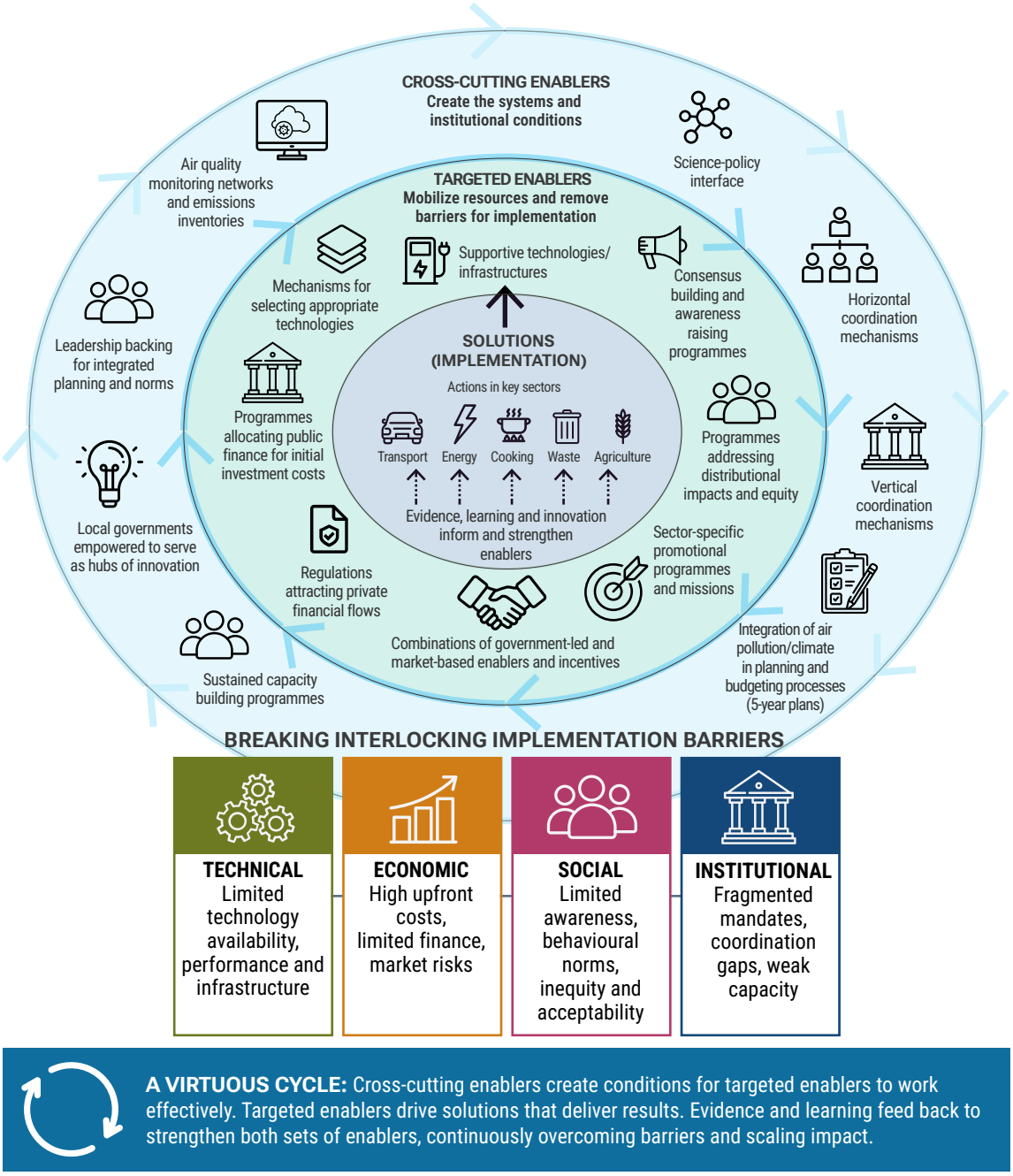
Addressing these barriers through a suite of broader cross-cutting institutional enablers and narrower-sector specific reforms can accelerate implementation substantially (Figure ES8). The 25 solutions span six sectors, each governed by different ministries, regulatory frameworks and financing channels. Realizing the full package of benefits requires institutional architecture capable of coordinating across all of them – and this Assessment shows, for the first time, the economic value of strengthening institutional coordination and equipping regulators with the tools and resources to enforce policies.

Figure ES7: The relative importance of different barriers, years delayed.



Note: The error bars reflect upper and lower ranges of 95 per cent confidence intervals for all solutions for each type of barrier for the 4 countries, China, India, Mexico and Nigeria.

Figure ES8: 16 enablers that break the four implementation barriers to accelerate action.



Country experience shows this is achievable, not aspirational. At the institutional level, China's co-control strategy for air pollution and climate change, Mexico's Intersecretarial Commission on Climate Change, and Nigeria's integration of short-lived climate pollutants into its Nationally Determined Contribution (NDC) illustrate how policy frameworks can be designed to strengthen cross-sectoral implementation.

At the programme level, China's expansion of electric vehicle charging infrastructure, India's clean cooking access programme and solar mission, Mexico's national cookstove projects and national strategy for electric mobility and Nigeria's awareness-raising initiative on open burning and its Rural Women Energy Security programme show that well-designed interventions can drive social as well as technological change.

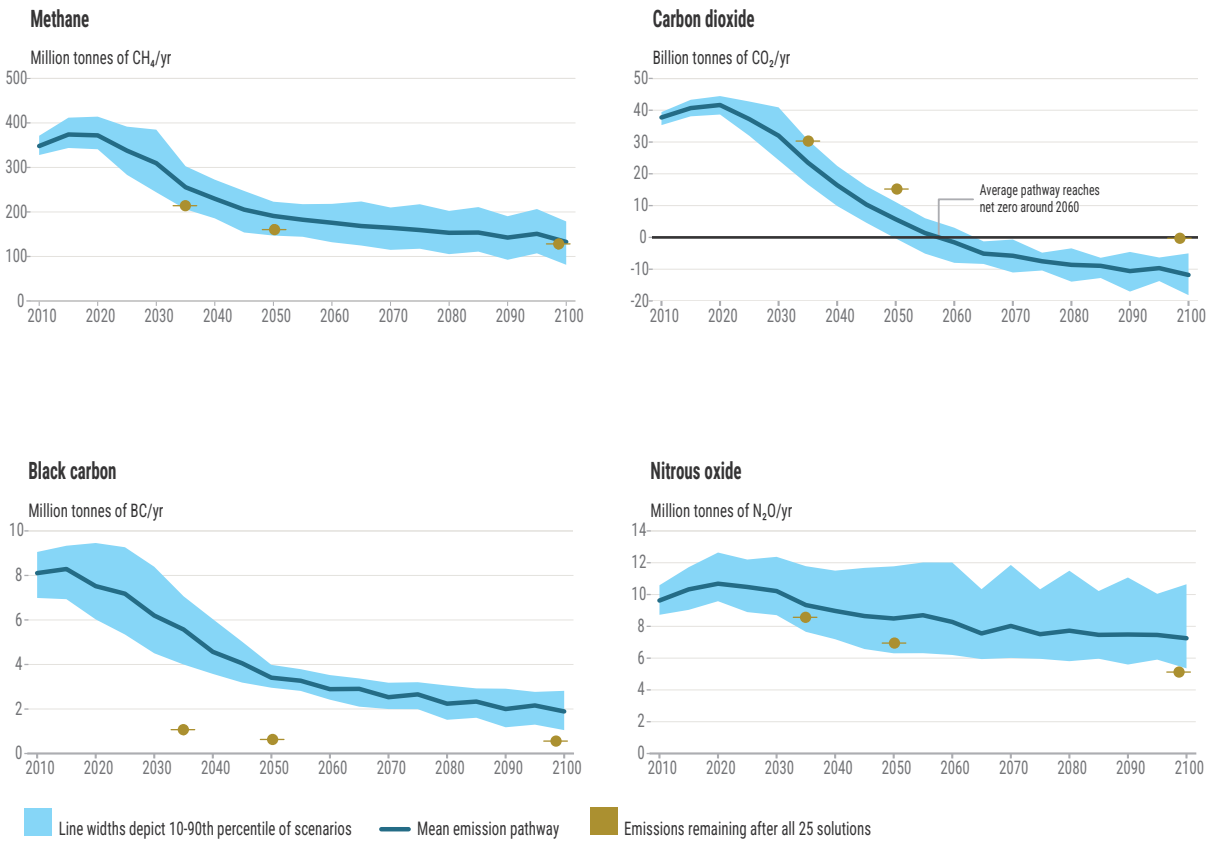
The 25 solutions deliver on governments' existing commitments, not just future aspirations

Full adoption exceeds the pace required to meet the World Health Organization (WHO) 2040 air-quality mortality target and is consistent with Intergovernmental Panel on Climate Change (IPCC) pathways for limiting peak warming.

In May 2025, the World Health Assembly adopted a voluntary target of halving mortality attributable to anthropogenic air pollution by 2040, relative to 2015. Meeting it requires average annual reductions in attributable mortality of approximately 3.3 per cent. Global implementation of the 25 integrated solutions delivers approximately 4 per cent per year over the same period, exceeding the pace the target demands.

In the 2015 Paris Agreement, parties agreed to limit global warming to well below 2 °C and ideally to 1.5 °C. Exceeding the 1.5 °C climate target of the Paris Agreement is now widely assessed as unavoidable; the central challenge is to limit peak warming, reduce the duration of exceedance, and return temperatures below 1.5 °C. For the super pollutants that determine the peak and pace of overshoot – methane, tropospheric ozone, HFCs and black carbon – the 25 integrated solutions reduce associated emissions to levels consistent with, or well below, IPCC overshoot, peak and decline pathways limiting warming to 1.5 °C (Figure ES9). For carbon dioxide, the solutions achieve substantial reductions, reaching net-negative emissions after 2080, but closing the remaining gap to the net-zero by 2060 required by these pathways will require additional decarbonization, land-use change and carbon capture measures that do not meet the criteria for inclusion in the package of 25 solutions. In an era of overshoot, the 25 solutions deliver across all three stages of the response: rapid near-term reductions that slow warming now, sustained decarbonization that limits the peak, and the net-negative carbon dioxide and continued super pollutant reductions that help bring temperatures back down while delivering immediate benefits for public health and the economy.

Figure ES9: Comparison of the key greenhouse gas emissions reduction between the integrated scenario and the Intergovernmental Panel on Climate Change overshoot pathways, 2010–2100, methane, black carbon and nitrous oxide, million tonnes; carbon dioxide, gigatonnes.



Call to action

This Assessment makes a more comprehensive economic case for integrated action on climate and clean air than any previous global analysis. Capturing these returns, at speed and scale, requires deliberate choices across five areas.

- **Make integrated climate and clean air policy a core economic strategy.** Governments should embed air quality and climate action jointly in national growth plans, fiscal frameworks, and investment strategies. Avoided health costs, productivity gains, and reduced fiscal exposure to climate damage are economic objectives in their own right and should be reflected in budget and planning processes.

- **Invest early and consistently in enabling conditions.** Governments should prioritise spending that shortens implementation delays, including affordable finance and risk-sharing instruments, institutional capacity and cross-ministerial coordination, and planning, budgeting and enforcement systems.

- **Target rapid wins to meet near-term commitments.** Solutions including clean cooking, methane controls addressing leaks, venting and flaring, organic waste, and transport and air quality measures are largely within national control and deliver direct economic and health returns in less than a decade. Accelerating these alongside longer-term decarbonization is not only fiscally sound – it is a direct path to meeting the WHO 2040 voluntary target of halving air-pollution mortality and keeping peak warming as low as possible during a period of 1.5 °C overshoot. Governments that move quickly on these solutions will capture near-term fiscal space, build the political foundation for sustained climate action, and demonstrate measurable progress against commitments already made.

- **Align international cooperation with realities of implementation and finance needs.** Global and regional frameworks should be designed to reflect significant differences in impacts and abatement costs across regions. International partners should mobilise finance for institutional strengthening, policy development, technology transfer, and infrastructure investment to address the higher relative burdens and implementation constraints facing developing regions.

- **Invest in the data and monitoring infrastructure that decisions depend on.** This Assessment demonstrates that expanding the health evidence base materially changes the economic conclusions. Governments should treat air quality monitoring networks, emissions inventories and sex-disaggregated health data as core economic infrastructure, not scientific overhead. Future assessments should extend this approach to under-counted damage in agriculture and ecosystems, additional pollutants, and biodiversity and natural capital as well as additional health impacts including mental health. Systematic collection of sex-disaggregated data should be treated as a core evidence investment alongside modelling capacity.

Integrated action on climate and clean air is one of the rare policy agendas that delivers rapid domestic returns, reduces fiscal risk, improves equity outcomes and strengthens long-term growth and prosperity. The 25 solutions make the economic case for taking rapid action with precision. What is required now is moving at a speed and scale that matches it.

Table ES2: The 25 solutions implemented in the 'integrated action scenario'. This includes the two groupings (i) 4 long-term climate solutions ( ) and (ii) 21 clean air ( ) and near-term climate ( ) solutions. For each measure the primary mitigation objective is indicated with as well as the mitigation co-benefit.

Measure	Brief description	Primary mitigation objective	Mitigation co-benefit
Energy and fossil fuel systems			
Energy transformation for power generation	Energy transformation for power generation. Transition to use of wind, solar and hydro power for electricity generation		
Post-combustion controls – power plants and industry	Application of high efficiency flue gas cleaning technology to reduce air pollutants		
Oil and gas sector upstream emissions	Recovery of associated gas to eliminate routine venting and flaring, reduce unintended leaks		
Oil and gas sector downstream emissions	Reducing leaks in long-distance and consumer gas transmission pipelines, and in refineries		
Coal mining	Ventilation air CH_4 oxidation and extended pre-mining recovery of coal mine gas		
Industry			
Energy efficiency standards for industry	More ambitious energy efficiency standards and extended electrification		
Industrial processes emission standards	Improvements in process technology, including adipic acid production		
Efficient brick kilns	Improved efficiency and emission standards		
Solvent use	Low-solvent products, leak detection, etc.		
Residential cooking and heating			
Energy transformation for households	Improved energy efficiency of buildings, lighting, and household appliances		
Clean cooking and heating	Clean alternatives for traditional cooking and solid fuel heating		
Transport			
Vehicle emission standards	More stringent emission limit values and efficiency standards		
Vehicle inspection and maintenance	Early recognition and elimination/repair of high emitting vehicles		
Electric vehicles	Transition to use of electric vehicles		
Emission standards for non-road machinery	More stringent emission limit values and efficiency standards		
International shipping	Low-sulphur fuels, control of particulate matter and NO_x		
Agriculture and food systems			
Livestock and manure management	Control of ammonia and CH_4 from livestock production, including manure application, enteric fermentation, and anaerobic digestion		
Efficient nitrogen fertilizer application	Improving timing and dose, urease inhibitors, etc.		
Dietary changes	Shift to less meat protein in diets		
Rice paddies	Encourage intermittent aeration of continuously flooded paddies		
Reduce burning of agricultural residues	Effective bans and alternatives to burning		
Waste management			
Solid waste management	Efficient waste collection with source separation and recycling. Gas recovery from landfills		
Wastewater treatment	Well-managed two-stage anaerobic followed by aerobic treatment with biogas recovery		
Others			
Prevention of forest and peatland fires	Improved forest, land and water management and fire prevention strategies		
Phasing down the use of hydrofluorocarbons (HFCs)	Further mitigation beyond the Kigali Amendment		

01 Rationale for this Assessment



Caption: © Farm worker handling straw bundles near agricultural threshing machine. Photo: AdobeStock/Sumita

Integrated action on climate change and air pollution is one of the highest-return investments available to governments today. The same measures that reduce greenhouse gas emissions can cut healthcare expenditure, raise labour productivity, strengthen energy security and extend millions of lives, and the returns begin within years, not decades.

Capturing these returns, however, requires acting against a challenging backdrop. Governments face growing fiscal pressure from climate change and air pollution. Healthcare expenditure, lost labour productivity, damaged infrastructure and constrained growth are already material items on national balance sheets, and both sets of costs are projected to rise. More than a decade since the Paris Agreement was adopted, global efforts to address these challenges have grown in scope and ambition, but the scale of the challenge continues to grow. The past decade was the warmest on record, and 2024 was confirmed as the first single calendar year in which global mean temperature exceeded 1.5 °C above the 1850-1900 average. The atmospheric concentrations of the major well-mixed greenhouse gases (GHGs) are also growing at or near record rates (FSIN 2024; WMO 2025). At the same time, nine out of ten people worldwide breathe air that exceeds the World Health Organization (WHO) guidelines, making air pollution the second-largest health risk factor after high blood pressure (Brauer *et al*. 2024). Demographic change is adding to this vulnerability. As the population ages, more people face heightened risk from air pollution and heat, so achieving targets such as halving air-pollution-related mortality by 2040 will require progressively larger reductions in exposure. Together, these trends underscore the urgent need to reduce emissions of GHGs and air pollutants to keep climate, air quality and development goals in reach. Left unaddressed, they increase the economic and health consequences of these emissions and raise the cost of meeting those goals as action is deferred.

Climate change and air pollution are more than parallel crises. They share many of the same emission sources, particularly fossil fuel combustion and agricultural activity, and many of the same consequences for human health, economic productivity and ecosystem stability. Because the sources overlap, solutions that target one problem can impact the other simultaneously, generating compounding returns that neither issue captures alone. Yet prior economic analyses have tended to focus on one of the two

issues independently of the other. The Stern Review, for example, targeted a stabilised atmospheric concentration of carbon dioxide equivalent and did not formally account for the benefits of reducing local air pollution (Stern 2007), while analyses by the OECD and World Bank have explored the effects of air pollution without considering the economic effects of the climate change caused by the same emission sources (OECD 2016; Damania *et al*. 2025). Analysing the two issues separately omits the interactions between them, and as a result understates the total returns to action.

The health costs of air pollution illustrate the scale of what separate analyses omit. Air pollution causes not only premature death but a wide range of serious chronic conditions, including diabetes, dementia, stroke and lung cancer, that drive up healthcare costs, reduce labour productivity and diminish well-being for hundreds of millions of people. Yet most prior economic assessments have captured only a fraction of this burden, valuing premature mortality while leaving the broader costs of illness largely unquantified. A more complete accounting, one that integrates both climate and air pollution and captures the full range of health consequences, provides decision-makers with a more accurate basis for evaluating the returns on public investment.

This Assessment provides that accounting. Building on earlier Climate and Clean Air Coalition (CCAC) assessments, it delivers a consistent, integrated analysis of the economic impacts associated with changes in both climate and air pollution, and of the benefits of solutions that reduce air pollution, mitigate climate change, or do both. For the first time, it quantifies these combined benefits within a single economic framework and makes them directly comparable with the costs of action. It quantifies and compares mitigation costs and benefits over time and across impact pathways, compares the costs and effectiveness of immediate relative to delayed action, and analyses implementation barriers and the reforms that address them.

Climate change is already causing large and growing economic damage, and air pollution exacts a toll on economic development that falls most heavily on lower-income countries. This Assessment provides the most complete economic evidence to date on the combined costs of these challenges and the returns available from addressing them together.

1.1 Introduction to an integrated approach

Air quality and climate change are closely linked, with important implications for policy design and the implementation of mitigation solutions. They share many of the same drivers, unsustainable patterns of production and consumption, and originate from many of the same emissions sources (Box 1.1, Figure 1.1). Several pollutants contribute to both air pollution and climate change, and the impacts of each can reinforce the other, compounding harm to human and planetary health (Box 1.1). Despite these connections, policymakers frequently address climate change and air pollution separately through legal and policy frameworks. This fragmentation occurs at international, national and sub-national levels, where limited cross-agency coordination and institutional practices frequently inhibit integrated action.

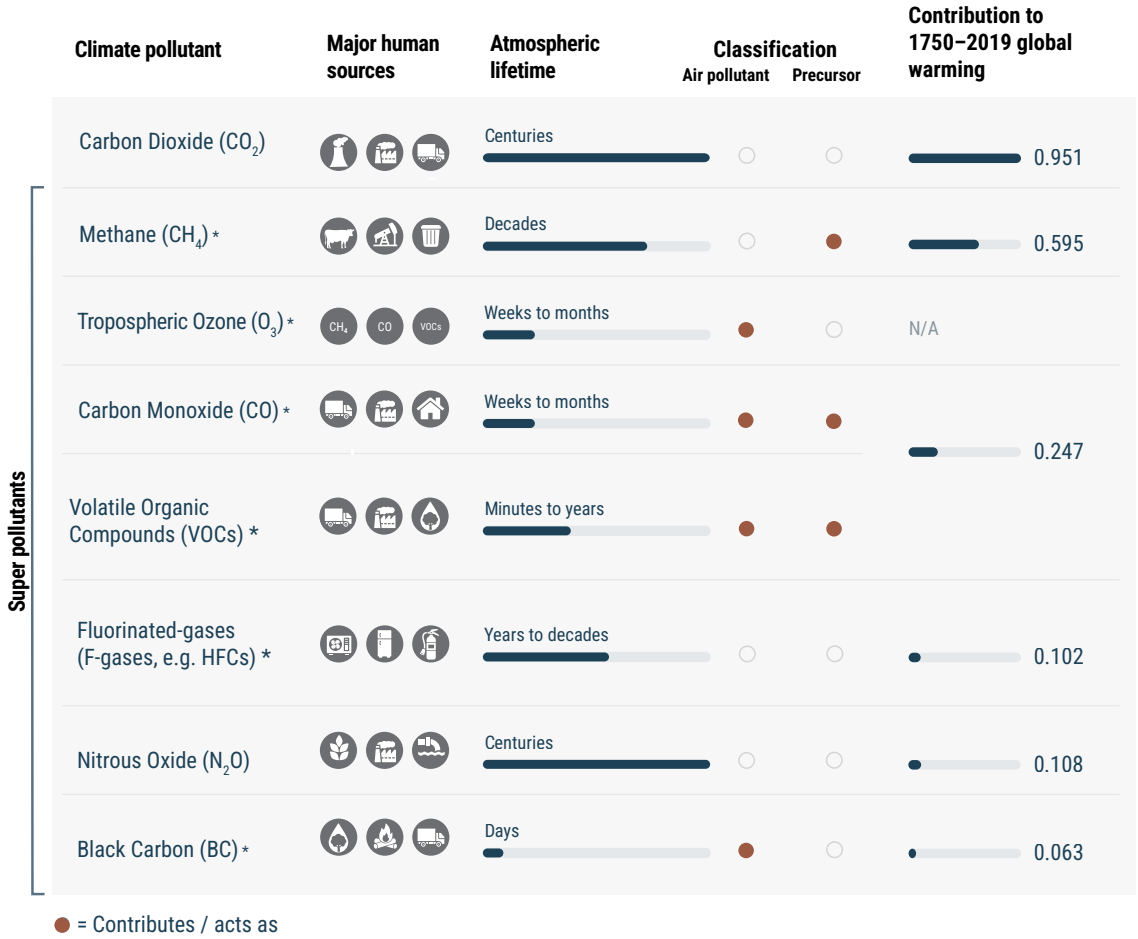

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Box 1.1 Climate and air pollutants that drive warming

Climate-active pollutants fall into two broad categories. Long-lived greenhouse gases, principally carbon dioxide (CO_2) and nitrous oxide (N_2O), persist in the atmosphere for centuries, reducing them in the near-term is essential for limiting end-of-century warming but produces climate benefits only gradually. Super pollutants are atmospheric pollutants that warm the climate more powerfully than CO_2 per unit of emissions and can cause additional environmental and human health harm. They include methane, black carbon, tropospheric ozone, hydrofluorocarbons (HFCs) and N_2O. Most super pollutants are also short-lived climate pollutants (SLCPs): they cause warming and cycle through the atmosphere within a decade or less, meaning emission reductions translate into measurable cooling primarily within years to decades rather than over decades to centuries. The four SLCPs that deliver the largest near-term climate benefits are methane, black carbon, tropospheric ozone and HFCs, which together account for up to 45 per cent of current global warming. Paired reductions in super pollutants alongside CO_2 can triple avoided warming by mid-century compared to decarbonization alone. Critically, most SLCPs also degrade air quality directly or as precursors of fine particulate matter and ground-level ozone, which means reducing them simultaneously advances climate and public health goals, generating the compounding returns that addressing either challenge in isolation cannot capture (all other than HFCs; Figure 1.1).

Additional pollutants that contribute to air pollution cause cooling, including sulphur dioxide, nitrogen oxides, organic carbon and ammonia, making it important to carefully consider how specific policies can optimally align air pollution and climate goals, especially given that these pollutants share many of the same sources.

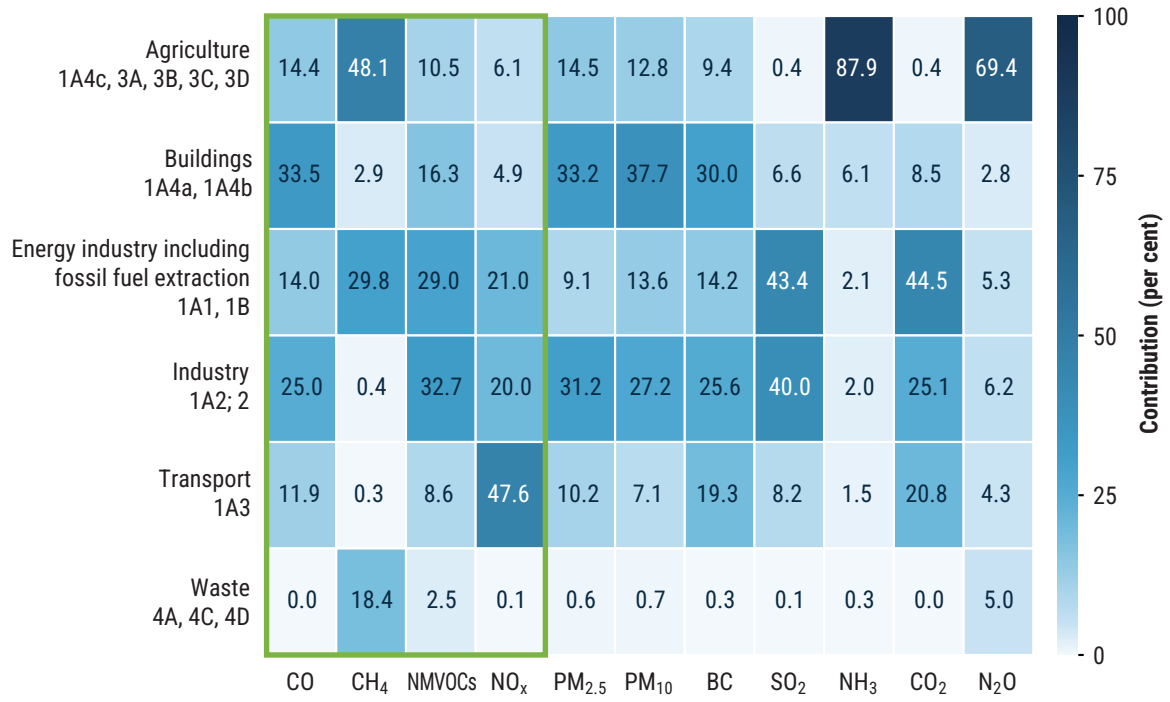
Figure 1.1: Climate pollutants, their major human sources, atmospheric lifetime, role as air pollutants or air pollutant precursors, and contribution to 1750–2019 global warming.



**Indicates SLCPs, though for F-gases only some are SLCPs whereas others have longer lifetimes. Contribution to global warming is based on calculations of the change in global mean surface air temperature from the IPCC AR6 (Table 6.SM.2). Figure modified from CCAC "Super Pollutant Factsheet"*

All major economic sectors contribute to emissions of a broad range of GHGs, SLCPs and air pollutants (Figure 1.2). Because many sources of air pollutants are also sources of greenhouse gases, control strategies can simultaneously reduce air pollution and climate impacts. These interlinkages provide an opportunity to amplify the benefits of action and catalyse greater mitigation ambition, while knowledge of how air pollution and climate change interact can be used to design policies that avoid trade-offs.

Figure 1.2: Sectoral contributions (per cent) to emissions of major greenhouse gases (CO_2, CH_4 and N_2O) and of air pollutants including aerosols and their precursors (PM, BC, SO_2, NH_3, some NO_x and NMVOCs) and tropospheric ozone precursors (CO, NMVOCs, NO_x). Data from EDGARv8.1.





Caption: © Farmer using a smartphone to monitor smart farming data with IoT technology. Photo: AdobeStock/waragron

An integrated approach to climate and air quality addresses these challenges by recognizing shared drivers, common sources, and interacting impacts across temporal and spatial scales. Considering climate and air quality outcomes together supports more coherent and cost-effective policy decisions, maximises multiple benefits, and reduces trade-offs among climate, air quality and sustainable development objectives. This Assessment takes this approach, building on integrated analysis in previous CCAC Assessments (Box 1.2).

This Assessment focuses on outcome-based strategies that target clean air and near-term warming reductions, reduced long-term climate change, or an integrated approach covering both, rather than on specific pollutants. Given the strong overlap between the emissions that drive warming and degrade air quality, these strategies tend to greatly reduce many of the super pollutants and nearly all of the SLCPs (Box 1.1). Strategies targeting clean air and near-term climate goals deliver rapid reductions in these pollutants, while those focused on long-term climate outcomes place greater weight on decarbonization and mitigation of long-lived GHGs. Methane mitigation is central across all strategies due to its strong climate impacts and its role as an air pollutant precursor (Box 1.1).

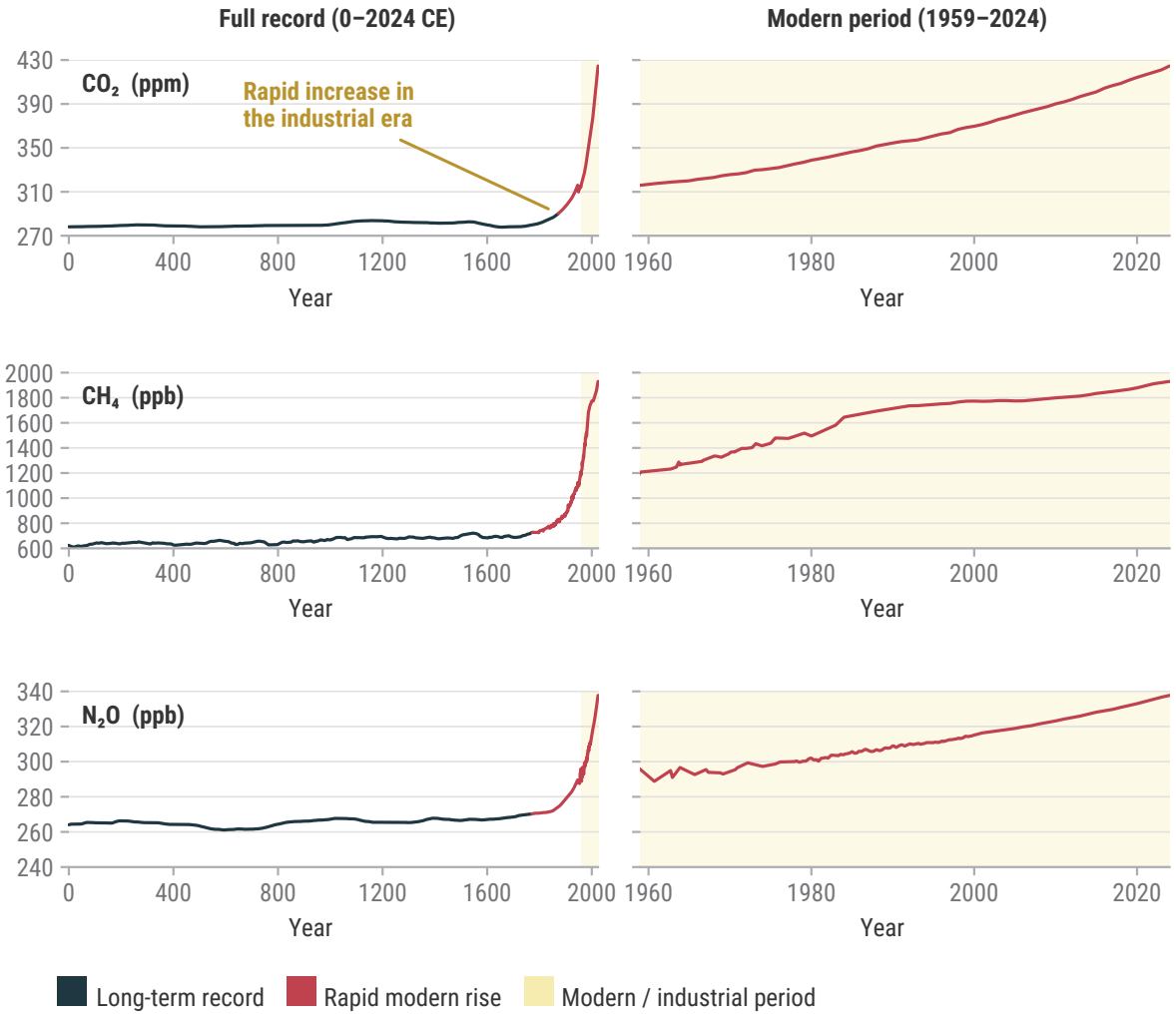
The distinction between decarbonization and SLCP mitigation is not always clear, particularly for energy-sector methane. In addition, actions to reduce emissions of some pollutants, notably CO_2 and N_2O, can lower co-emitted cooling aerosol precursors, improving air quality but also introducing modest near-term climate trade-offs. These interactions motivate an outcome-based framing rather than a focus on single-pollutant strategies. Accordingly, subsequent chapters classify scenarios by their primary outcomes (for example, clean air and near-term climate or long-term climate). The analysis of specific solutions highlights their contributions to reducing key pollutants, even though the scenarios are not organised by pollutant.

1.2 Historic emissions and concentrations

Emissions of the main well-mixed GHGs, CO_2, methane, and nitrous oxide, have grown tremendously since the industrial revolution, leading to marked increases in their atmospheric concentrations over the past two centuries (Figure 1.3). These increases have continued since the 2015 Paris Agreement, with growth rates at or near their highest in the modern period. Those increases have, in turn, been the primary driver of the global temperature rise observed during the 20th and 21st centuries (IPCC 2021) which has seen annual average temperatures rise by approximately 1.5 °C relative to the preindustrial period (Figure 1.4).

Concentrations of tropospheric ozone, a short-lived GHG, have similarly risen throughout the period since industrialization, though in contrast to the well-mixed GHGs, the growth rate appears to have slowed somewhat during the last approximately 25 years relative to the 1950-1980 period of fastest growth (Szopa *et al*. 2021). In contrast, while emissions of aerosols and their precursors also increased greatly following the industrial revolution, they have declined in many parts of the world over the past several decades thanks to clean-air policies. Given that several aerosols cause cooling by increasing the reflection of sunlight away from the Earth (Box 1.1), the net effect of these aerosol increases has been to partially mask GHG-induced warming. Global mean masking by aerosols peaked around 1980 and has since decreased due to air-quality regulations, particularly in Europe and North America, with substantial regional variations (Szopa *et al*. 2021; Figure 1.5). The decline in aerosols has therefore contributed to the apparent acceleration of observed global temperature rise in recent decades (Figure 1.4).

Figure 1.3: **Global concentrations of the primary well-mixed greenhouse gases over the last approximately 2000 years (blue lines), with the shaded areas (yellow) indicating the time period since the Paris Climate Agreement (2015). The timescale (x-axis) for left panel spans 2000 years; the timescale for right spans only the past 65 years. Data in the left panels are from ice cores (Ahn, Brook and Buizert 2023) while data in the right panels are from NOAA observations (Lan, Thoning and Dlugokencky 2022; United States, National Oceanic and Atmospheric Administration 2025).**





Caption: © Electric city bus at a charging station. Photo: AdobeStock/alpegor

Figure 1.4: Observed global mean annual average temperature relative to the 1850–1900 average for the indicated datasets. Data Source: Copernicus Climate Change Service (C3S). Climate Indicators – Global surface air temperature.

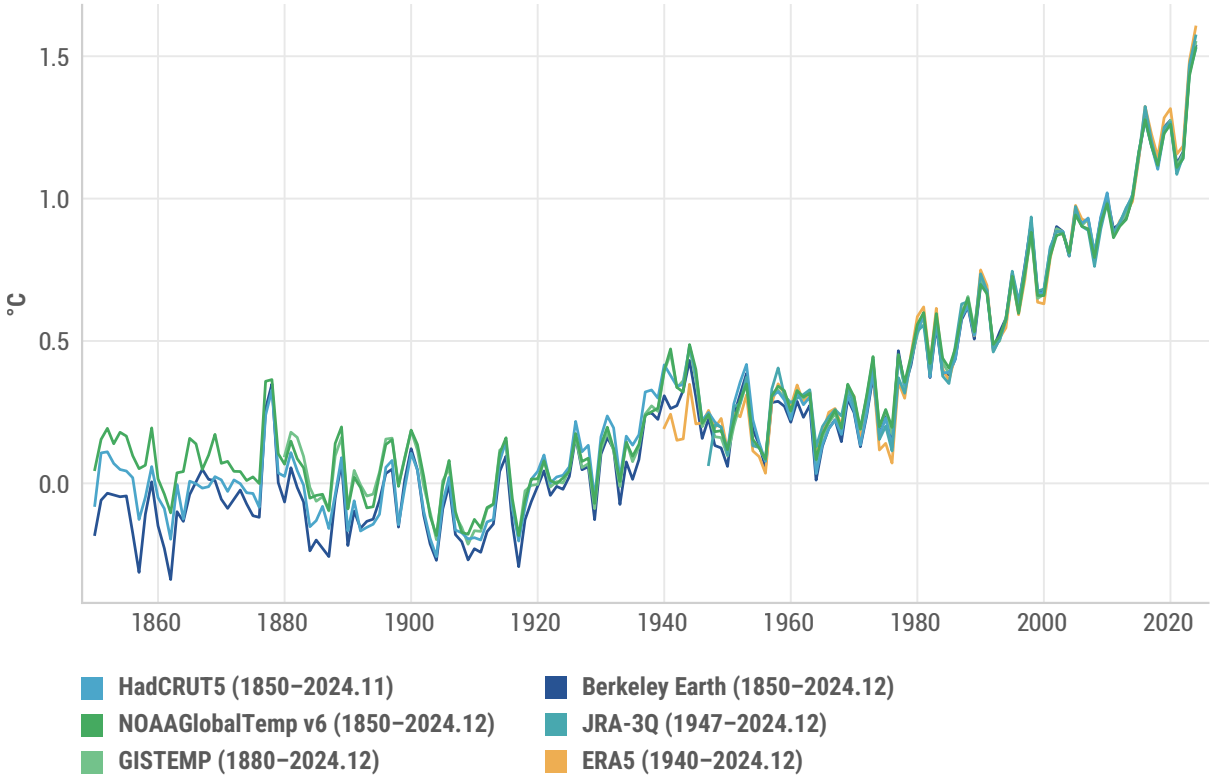
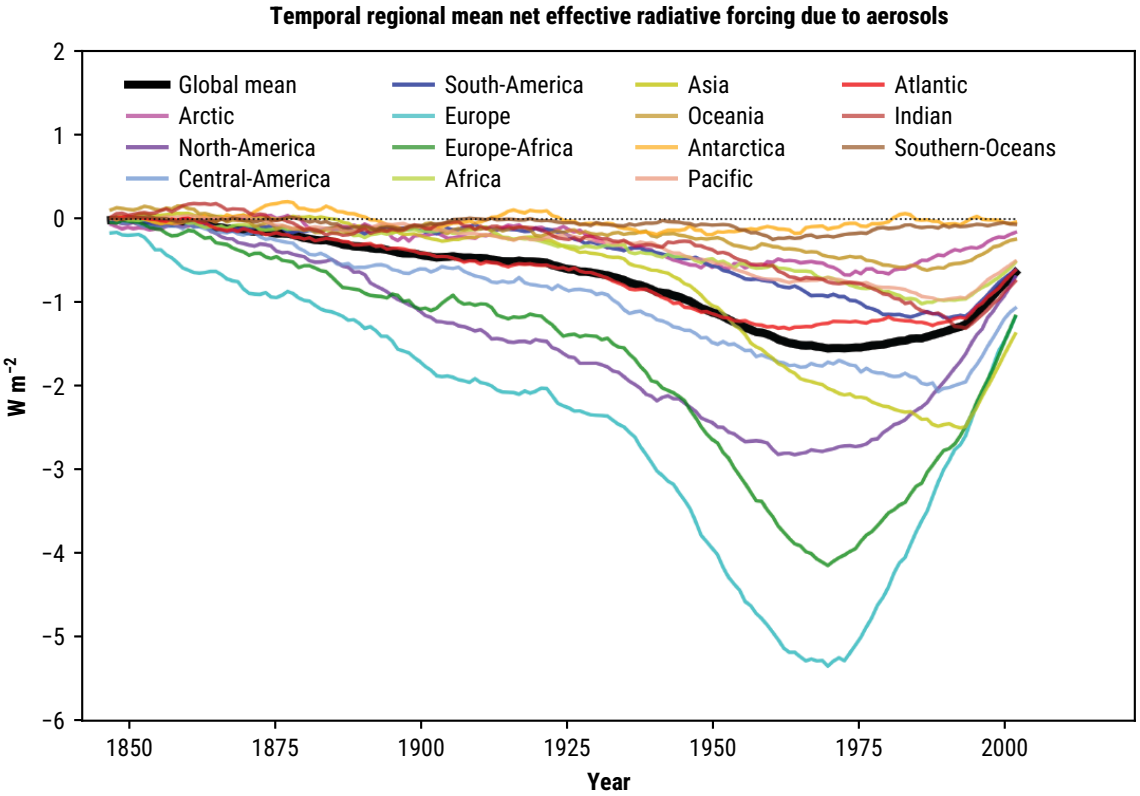


Figure 1.5: Observed global mean annual average temperature relative to the 1850–1900 average for the indicated datasets. Data Source: Copernicus Climate Change Service (C3S). Climate Indicators – Global surface air temperature.



1.3 Economic Impacts of Climate Change and Air Pollution

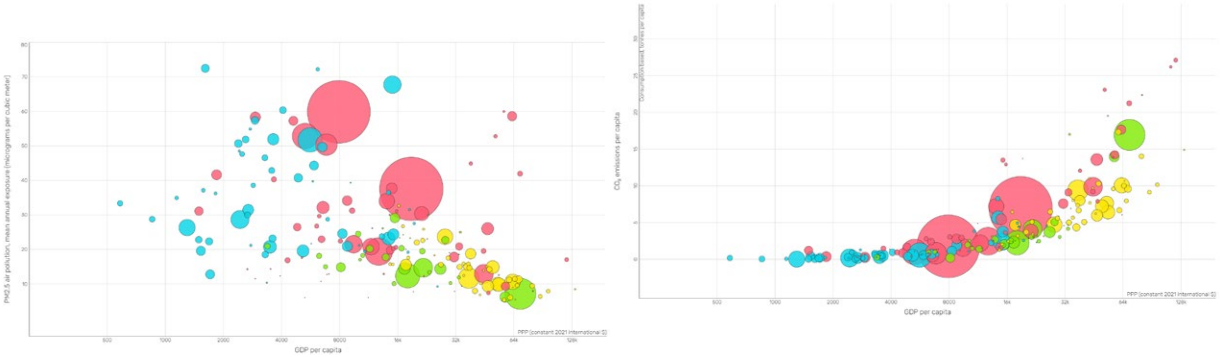
1.3.1 Cost and benefit valuation

Air pollution and GHG emissions share many of the same sources, particularly the combustion of fossil fuels in industry, transport, and power generation. Policies that support reductions in long-lived GHGs will therefore have large, direct implications for air pollution, as fossil fuel use is phased out. These reductions in air pollution will have benefits for human health and natural ecosystems that begin to accrue immediately.

Similarly, action on SLCPs, particularly methane reduces not only air pollution but also radiative forcing, resulting in lower warming. Because the residence time of methane in the atmosphere is short, policies that combat methane emissions will produce avoided warming within a decade (UNEP and CCAC 2021; Dreyfus *et al*. 2022; Shindell *et al*. 2024b). Cutting warming today will save lives, reduce natural disasters, and benefit economic growth. This report is motivated by these tight linkages between air pollution and climate change.

After a long history of air pollution management in OECD countries, the countries with the worst air pollution are no longer the countries with the highest GHG emissions. As shown in Figure 1.6, population-weighted $PM_{2.5}$ exposure falls with rising income, while per capita CO_2 emissions are still highest in the countries with the highest incomes. Air pollution was more evenly distributed across the world 30 years ago, but it has fallen consistently in OECD countries since 1990. This shows both the effectiveness of environmental policy and the long-term sustained effort that it has historically required.

Figure 1.6: $PM_{2.5}$ ambient exposure (left) and CO_2 emissions per capita (right). Points represent countries, with colours according to world regions and sizes proportional to population. Results shown for 2019.



Source: GapMinder (https://www.gapminder.org/tools/).

Environmental policy has costs as well as benefits, and as an economic assessment, this report aims to consider both. To compare the costs of environmental policy with benefits like longer life and greater productivity, the assessment needs to put a wide range of consequences for human well-being on the same footing. In practice, this means that, in addition to estimating direct market benefits such as higher labour productivity or reduced healthcare spending, the assessment needs to include benefits that accrue beyond the reach of markets for private goods, such as higher quality of life. This Assessment draws on techniques from welfare economics, based on measuring how people make decisions that trade money for non-monetary benefits. For example, if people are willing to pay more for safer cars, this provides an important indication of the value they place on their lives. This Assessment constructs the full economic costs and benefits of policies by translating non-monetary costs and benefits into "willingness to pay" estimates. The table below lists the policy costs and benefits included in this Assessment.

Table 1.1: Climate and air quality policy costs and benefits

Policy Costs	Policy Benefits
• **Direct technology costs:** Construction and maintenance of green technology. • **System transformation costs:** Cost of supporting infrastructure (e.g., chargers, batteries). • **Deadweight loss:** Reduction in economic production under higher costs.	• **Market benefits:** Benefits that increase financial outcomes, such as increased productivity and lower healthcare costs. • **Non-market benefits:** Benefits that improve welfare in non-financial ways, such as improved quality of life and reduced risk of death.

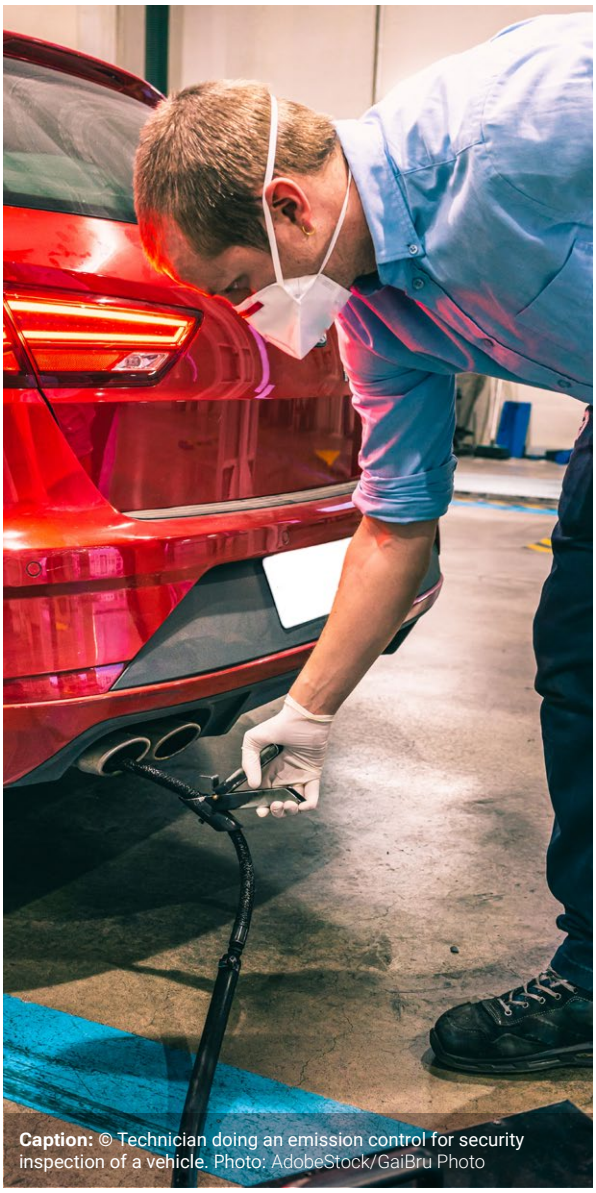
Chapter 3 reports these market and non-market economic costs and benefits as fractions of global or regional gross domestic product (GDP). GDP is thus used here as a numeraire to express estimated costs and benefits in units that are understandable and can be meaningfully compared. Reporting costs and benefits in terms of GDP does not imply that only GDP matters for human well-being. On the contrary, establishing the GDP equivalence of non-market benefits is precisely motivated by the limited scope of GDP.

Larger economies (measured in GDP terms) have more to spend on policies and less to lose from any given monetary impact. A policy that costs 1 per cent of GDP or an impact that causes damages equivalent to 10 per cent of GDP is more comparable across regions than absolute monetary costs and benefits. This extends to the time dimension. This analysis considers impacts to 2100, by which time many developing economies are expected to be much larger. Reporting outcomes in terms of GDP removes the large, distinct, and uncertain changes that will happen over the next 75 years.

1.4 Past assessments of air pollution and climate change impacts

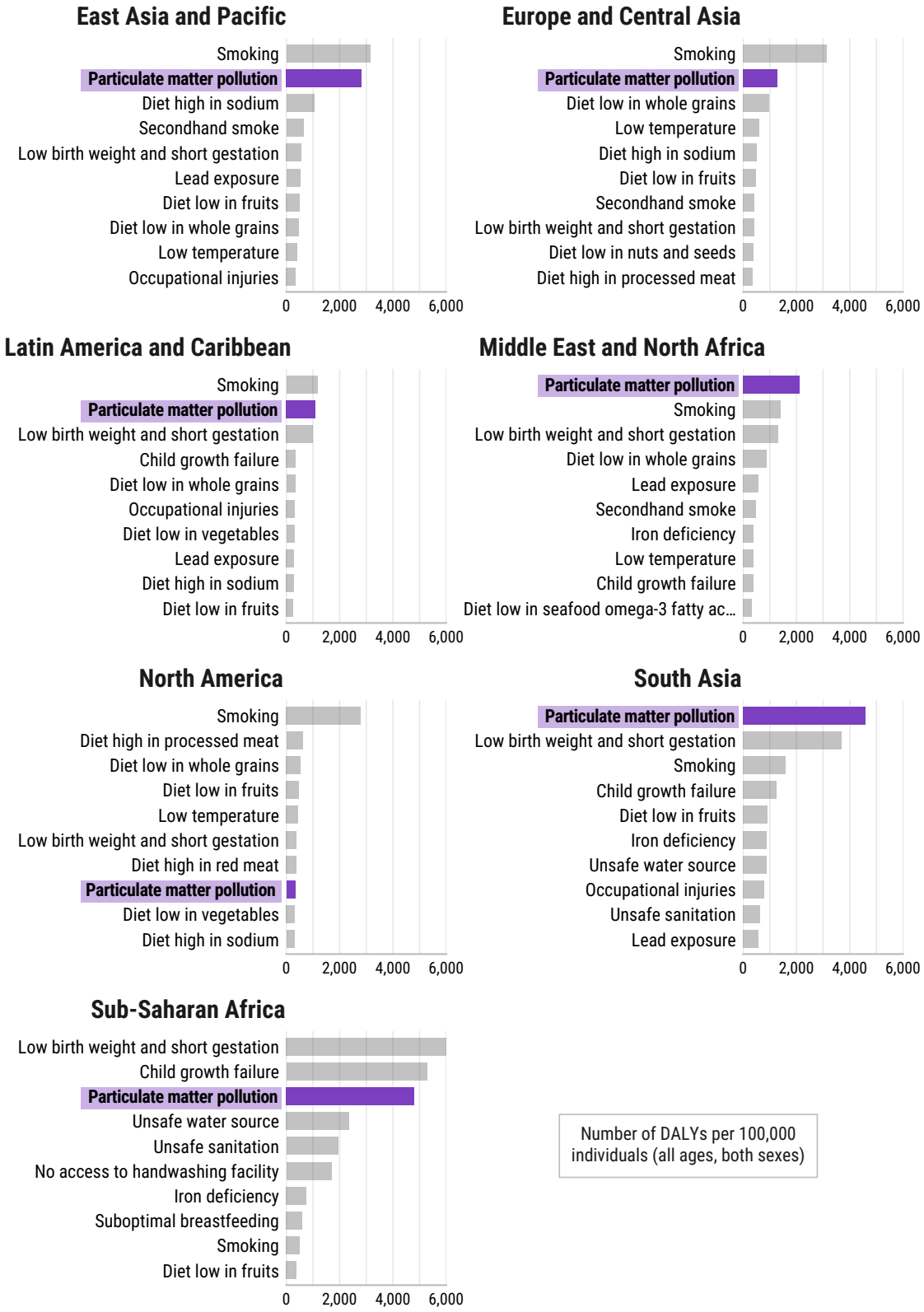
1.4.1 Health impacts of air pollution

Exposure to outdoor and indoor air pollutants is the foremost environmental health risk factor in all world regions (Figure 1.7). Exposure to air pollutants contributes to both acute (short-term) and chronic (long-term) health effects. Acute effects occur in vulnerable individuals within days of exposure, while chronic exposure, over periods ranging from months to multiple years, contributes to the onset (incidence) or progression (prevalence) of disease, reduced life expectancy and early death.



Caption: © Technician doing an emission control for security inspection of a vehicle. Photo: AdobeStock/GaiBru Photo

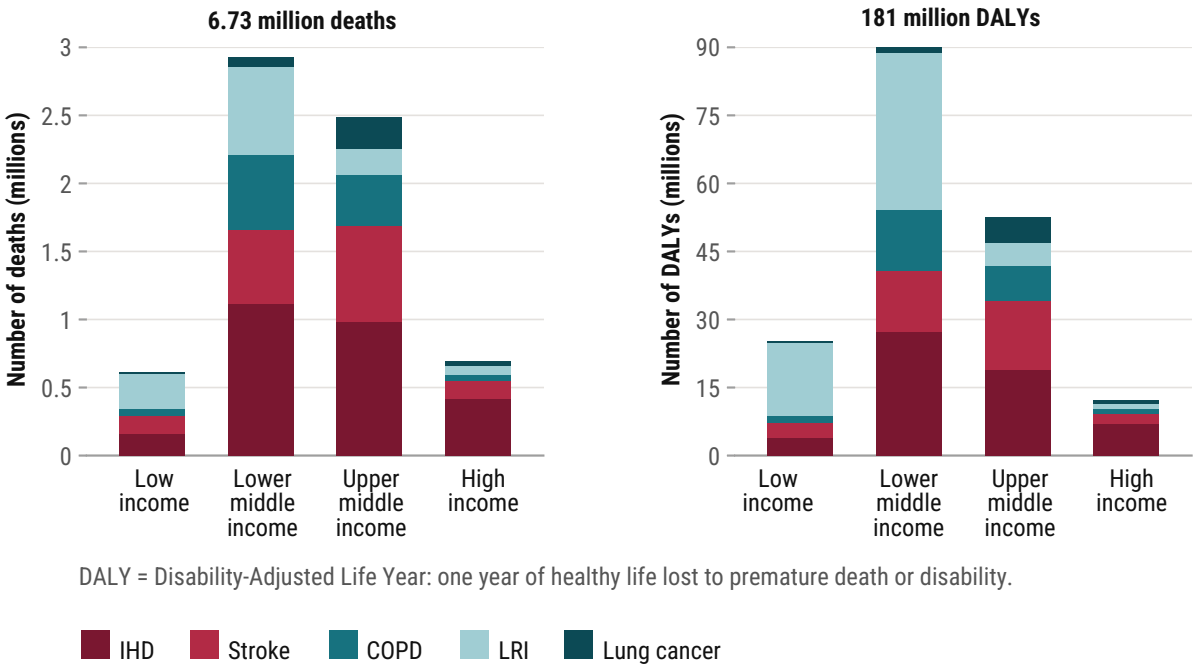
Figure 1.7: Top ten health risk factors by World Bank regions in 2019, DALYs per 100,000 persons; the health risk from the joint exposure to indoor and outdoor $PM_{2.5}$ is highlighted in purple.



Source: Elaboration based on Global Burden of Disease results (GBD 2021 Risk Factors Collaborators).
Note: DALY, disability adjusted life year, is a measure of the health burden that combines the loss of life expectancy (that is, the number of life years lost due to early death) and the loss of number of healthy life years (free of disease) because of living with disability (YLD).

Degraded air quality is linked to a wide range of adverse health effects, including increased respiratory, cardiovascular and metabolic diseases, neonatal disorders, and reduced life expectancy due to premature mortality. In 2019, 6.73 million deaths were linked to air pollution exposure globally (Figure 1.8) (WHO 2024).

Figure 1.8: Global burden of disease due to both ambient and household air pollution by income group and cause in 2019: Mortality (left) and DALYs (right).



Source: WHO Ambient Air Quality Database (Update Jan 2024).

Historically, the economic consequences of air pollution have been calculated by valuing changes in life expectancy, measured as premature deaths or years of life lost, or by estimating losses in future wages resulting from early death (e.g. WHO Regional Office for Europe 2015; OECD 2016; World Bank and IHME 2016; Lelieveld *et al*. 2020; World Bank 2020). In a global analysis, the World Bank estimated that, in 2019, the combined effects of indoor and outdoor exposure to $PM_{2.5}$ caused a total economic burden of 8.1 trillion US dollars (valued at purchasing power parity prices), equivalent to 6.1 per cent of global GDP for that year. Exposure to outdoor air pollution accounted for nearly 80 per cent of this total burden. Premature mortality accounted for approximately 85 per cent of the overall impact, while morbidity accounted for the remaining 15 per cent (World Bank 2022). Evidence consistently shows that socially disadvantaged populations, particularly those in low- and middle-income countries (LMICs), bear a disproportionate share of environmental health burdens, both physically and economically, compared with wealthier groups (Hajat, Hsia and O'Neill 2015; United Kingdom, Office for National Statistics 2025). Approximately 95 per cent of premature deaths attributable to air pollution occur in LMICs. As a percentage of GDP, South Asia experiences the highest annual economic burden from air pollution among all world regions, reaching 10 per cent of regional GDP, six times higher than North America (1.7 per cent of GDP), which has the lowest burden (World Bank 2022).

Additional global studies have examined mortality attributable to ambient $PM_{2.5}$ exposure and its associated economic burden, including the study by (Yin *et al*. 2021), which estimated global mortality in 2016 at 8.42 million premature deaths. Unlike the World Bank (2022) and WHO (2024) health impact assessments, Yin and colleagues considered a broader set of causes of death, including all noncommunicable diseases and lower respiratory infections. The estimated global economic burden of these diseases ranged from US$ 3.9 to 8.3 trillion (2011 purchasing power parity adjusted prices), corresponding to 3.4-7.3

per cent of global GDP. A key contribution of this study was its adjustment of economic valuation parameters to account for individual-level confounders, including life expectancy, wealth status, and quality of life. More recent health risk assessments have increasingly incorporated morbidity outcomes, reflecting improvements in the availability of morbidity data and exposure-response functions for estimating non-fatal health effects of air pollution (e.g. Forastiere *et al*. 2024; Corso *et al*. 2025; WHO 2025).

1.4.2 Major impacts of climate change

Economic impacts from climate change have been quantified for a wide range of channels, including reduced agricultural yields, losses in labour productivity, impacts on tourism, damage to infrastructure and displacement of populations by natural disasters, and increased risk of premature mortality.

Premature mortality has emerged as one of the largest economic risks. Carleton *et al*. (2022) find that, on average, a 35 °C day increases mortality rates by 10 deaths per 100,000 people for people over 65. By the end of the century, this would imply over 200 deaths per 100,000 people under a high-emissions scenario. However, populations later in the century are also expected to adapt to higher temperatures, and combined with further economic growth, this is expected to reduce excess mortality to 70 deaths per 100,000 people. Cromar *et al*. (2022) do a meta-analysis of climate-health impacts and found that a 1 °C increase produces an increase in all-cause mortality risk of 1 to 4.5 per cent.

Since the Stern Review (Stern 2007), there have been many integrated assessments of climate change losses. These generally fall into "bottom-up" assessments, which quantify the risk from individual sectors and aggregate them, and "top-down" assessments, which use macro-economic evidence or expert elicitation to relate warming levels to total losses to society. Bottom-up approaches tend to provide more detailed insights into specific impacts, such as agriculture or health, but may miss interactions across sectors, while top-down approaches capture economy-wide effects but often rely on broader assumptions.

Few academic studies have integrated climate change and air pollution, and the effects of air pollution on economic growth are particularly under-studied. Important previous studies have examined the air pollution benefits of decarbonization solutions (e.g. Vandyck *et al*. 2018), as well as the damage caused by the air pollution effects of emissions reduction policies, and part of the damage caused by their climate effects (e.g. Shindell *et al*. 2021, 2024a; UNEP and CCAC 2021). Finally, a recent World Bank analysis modelled a different set of scenarios but found qualitatively similar results for several health and economic impacts of air pollution, and similarly showed that an integrated approach to air pollution and climate change is more efficient than addressing them separately (World Bank 2025). This analysis used only one of the two methodologies applied in this Assessment, excluding the effects of air pollution on economic growth and not explicitly analysing the economic effects of avoided climate change, so its results capture a narrower set of channels than the estimates presented here.

1.5 Introduction to the enabling environment

Realizing the full environmental and economic benefits of the mitigation solutions identified in Chapter 2 and evaluated in Chapter 3 depends not only on the technical performance of those solutions but also on the conditions that enable their implementation. Growing recognition of the gap between what is technically achievable and realistically feasible has highlighted the importance of understanding the economic, technical, social, and institutional factors that determine whether mitigation measures are deployed at speed and scale. Applying the same scientific rigour used to identify mitigation opportunities and quantify their multiple benefits to questions of implementation can help identify the enabling actions needed to bridge this gap.

Implementation barriers are not external to mitigation analysis; they are embedded within it. All scenarios make assumptions, often implicitly, about the conditions under which measures are deployed. Scenarios that assume rapid implementation effectively assume that barriers are overcome, while more conservative scenarios assume that some constraints remain. Systematically understanding these conditions and the actions required to address them is essential for translating technical potential into tangible outcomes.

To better understand these conditions and bring them explicitly into scenario modelling, this Assessment applies a novel, data-driven approach that combines expert surveys and literature reviews to evaluate the influence of economic, technical, social, and institutional factors on the implementation of key solutions over the next two decades. Drawing on evidence from four countries, the analysis examines how different enabling conditions affect the speed, scale, and effectiveness of solutions. In doing so, it helps answer the question of how mitigation solutions can be implemented in diverse contexts.

By directly addressing the implementation challenge, the analysis underscores the critical role of institutional enablers. Establishing strong institutional foundations is particularly important because institutions can serve as enablers of enablers, exerting cross-cutting influence over whether technologies are suited to local contexts, public finance is mobilised to reduce upfront costs, market-based and regulatory instruments are effectively combined, and the voices of women, informal workers, and vulnerable populations are meaningfully reflected in policy decisions.

The assessment not only quantifies how institutional and other enabling reforms can strengthen implementation but also illustrates these effects through case studies focusing on embedding solutions in targeted and crosscutting enabling reforms from China, India, Mexico, and Nigeria. These examples include mechanisms for matching technologies to local needs, such as Mexico's national cookstove programmes; investments in supportive infrastructure, such as China's expansion of electric vehicle charging networks; and initiatives designed to expand access to clean cooking technologies among low-income households by centering gender and equity considerations, such as India's Pradhan Mantri Ujjwala Yojana (PMUY).

Chapter 4 also sheds light on the powerful effects of combining multiple enablers. Illustrative examples include Nigeria's awareness-raising initiatives on open burning and its Rural Women Energy Security (RUWES) programme, which couples public support with efforts to accelerate the uptake of clean cooking solutions. At the broader institutional level, countries are strengthening cross-cutting enablers through complementary reforms that create incentives for action across multiple levels of governance. Examples include China's co-control strategy for air pollution and climate change, Mexico's Intersecretarial Commission on Climate Change, Nigeria's integration of short-lived climate pollutants into its Nationally Determined Contribution (NDC), and India's expansion of air quality monitoring networks. Together, the quantitative analysis and case studies demonstrate how combinations of enabling actions can reinforce one another, create virtuous cycles of reform, break technological and institutional lock-ins, and maximise environmental, economic, and social benefits.

1.6 Scope and objectives of the Assessment

While much is known about the impacts of strategies to mitigate climate change and improve air quality, evaluations of the economic consequences of those impacts tend to be incomplete. This Assessment aims to fill this gap by providing a more complete and consistent analysis of the economic impacts of emissions reductions, comparing the latter with the costs of that abatement. Incorporating both climate and air quality impacts within a single, internally consistent framework allows this Assessment to explore how the costs and benefits compare across the wide variety of spatial and temporal scales that are potentially of interest. In particular, air quality impacts are typically localised and rapid, whereas climate impacts are typically global and many decades are typically required for mitigation policies to produce climate benefits via long-lived GHGs.

This Assessment aims to answer several questions, including:

- What are the economic consequences of early ambitious emission reductions versus late or minimal action, and who benefits?
- How feasible is the implementation of the different emission reduction solutions, and what barriers must be overcome to achieve early, ambitious, and comprehensive action?
- What actions are necessary, and who must take them to enable progress at the scale and speed required to implement the near-term benefit solutions?

- What are the economic benefits of solutions focused on achieving long-term temperature targets and how do those solutions simultaneously help achieve clean air targets?

This Assessment includes several advances in modelling and analysis that deliver more consistent and complete answers to these questions than prior studies. These include:

- The analysis considers the impacts of both air pollution (outdoor and indoor) and climate change, and this report integrates these effects to assess the near- and long-term benefits of policies targeting air pollutants and decarbonization. Climate actions can yield both near-term and long-term benefits through reductions in air pollution and in the rate and magnitude of warming, and similar dual benefits arise from solutions to control air pollution.

- Evidence on the health consequences of air pollution has evolved substantially over recent years. Air pollution causes a wide range of serious diseases and health conditions, such as asthma, chronic obstructive pulmonary disease (COPD), diabetes, dementia, lung cancer, acute myocardial infarction (heart attack) and stroke. These conditions simultaneously increase healthcare costs and reduce labour productivity, putting a brake on economic development. They also diminish human well-being, affecting many millions of people. This Assessment draws on this expanded evidence base to quantify the health and associated economic benefits of 25 integrated solutions.

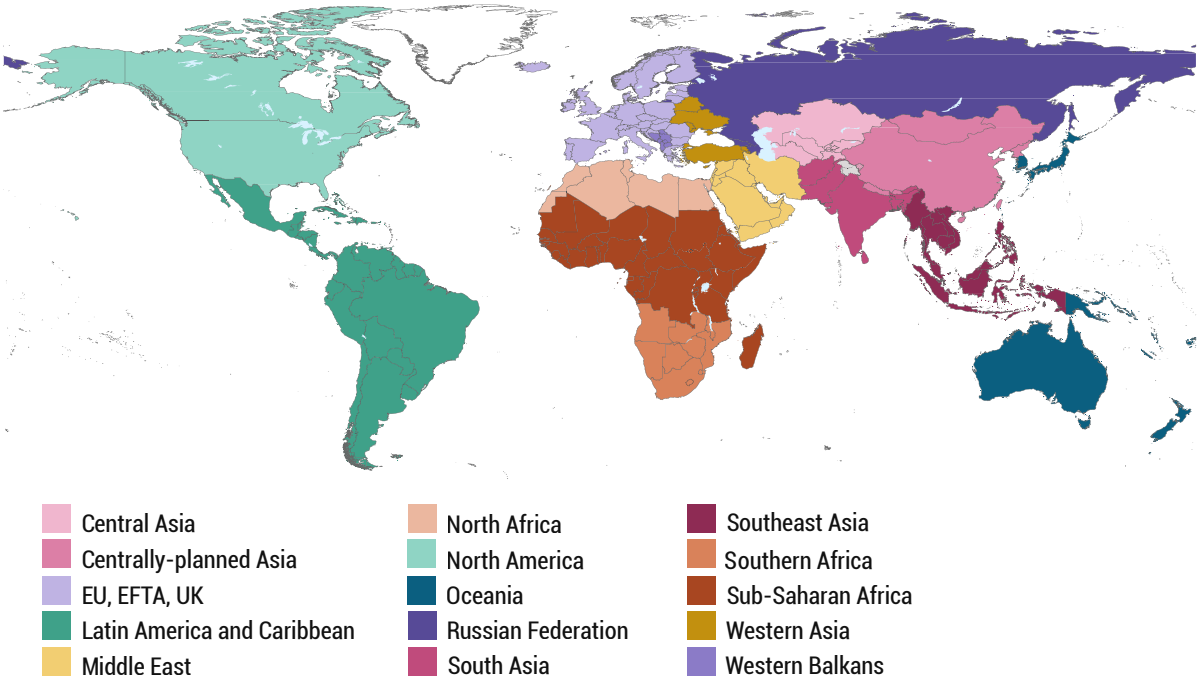
- For the first time in a CCAC Assessment, this report analyses the costs of implementing solutions alongside the resulting benefits, translating social and environmental impacts into economic terms so that market and non-market costs and benefits can be compared, including across regions at different income levels. Avoided market costs from reduced morbidity along are comparable to the total costs of mitigation solutions; once non-market benefits are included, the benefits of action far exceed the costs.

- Finally, the analysis uses a novel modelling approach that includes the effects of air pollution-related impacts on long-term economic growth. This aligns the treatment of air pollution-related economic impacts with climate-related economic impacts (Box 1.2).

This Assessment aims to quantify the costs and benefits of actions aimed at providing clean air and near-term climate benefits, long-term climate benefits, or an integrated scenario with both goals. The scenarios included here examine the effects of these packages of solutions relative to a Baseline Scenario, with all cases incorporating consistent projections of socio-economic factors, including GDP, population, consumption preferences, baseline vulnerability rates for diseases, and technological developments. These scenarios therefore do not capture the same level of uncertainty associated with those projections in the way that efforts such as the Shared Socio-economic Pathways (Riahi *et al*. 2017) attempt to for socio-economic factors. Additionally, these scenarios rely upon a single projection of future technological developments and deployment options from MESSAGEix-GLOBIOM (Huppmann *et al*. 2019; Krey *et al*. 2020; https://iiasa.github.io/GLOBIOM/) to provide relevant analysis for current and future challenges, numerical models of human and earth systems need to support higher spatial and temporal resolution, facilitate integration of data sources and methodologies across disciplines, and become open and transparent regarding the underlying data, methods, and the scientific workflow. This manuscript presents the building blocks of a new framework for an integrated assessment modelling platform; the "ecosystem" comprises: i and do not explore alternative possible projections, for example, as can be seen in the scenario database analysed by IPCC AR6 WGIII (Riahi *et al*. 2022). Those include possibilities such as a much larger deployment of small modular nuclear reactors, large increases in the use of hydrogen in the energy system or ammonia in shipping, or substantial deployment of enhanced rock weathering. Though the results of this work are qualitatively robust to differing projections about such future developments, quantitative values could vary substantially from those presented here.

This Assessment presents results for 15 world regions (Figure 1.9). The grouping considers geophysical features such as airsheds, topographic and climatic conditions, as well as income levels according to the World Bank classifications (World Bank 2025). The regions are used for scientific convenience only and have no official or administrative significance.

Figure 1.9: The 15 emission source regions used for modelling purposes in this analysis.



An important advance in this Assessment is the expanded scope of health impact valuation; there are nevertheless limitations to both the analysis of costs and benefits. On the cost side, the spending required for some policies, such as dietary shifts, has not been analysed in this work, as this is more challenging to characterise relative to technological controls such as methane capture from fossil fuel systems. Similarly, transaction costs are not fully accounted for (Chapter 4). On the benefit side, some impacts have been identified in scientific studies but their valuation remains quite challenging, such as the value of losses in cognitive development in children exposed to air pollution or the effects of pollution on allergies, eczema, and skin ageing (Academy of Science of South Africa *et al*. 2019), whereas others have been quantified in many studies but the evidence is not as conclusive and so those are largely excluded here, such as the effects of long-term ozone exposure on cardiovascular diseases. As several of the likely but uncertain and/or difficult to value benefits omitted are expected to be large, the benefits presented here are likely to be systematically underestimated.



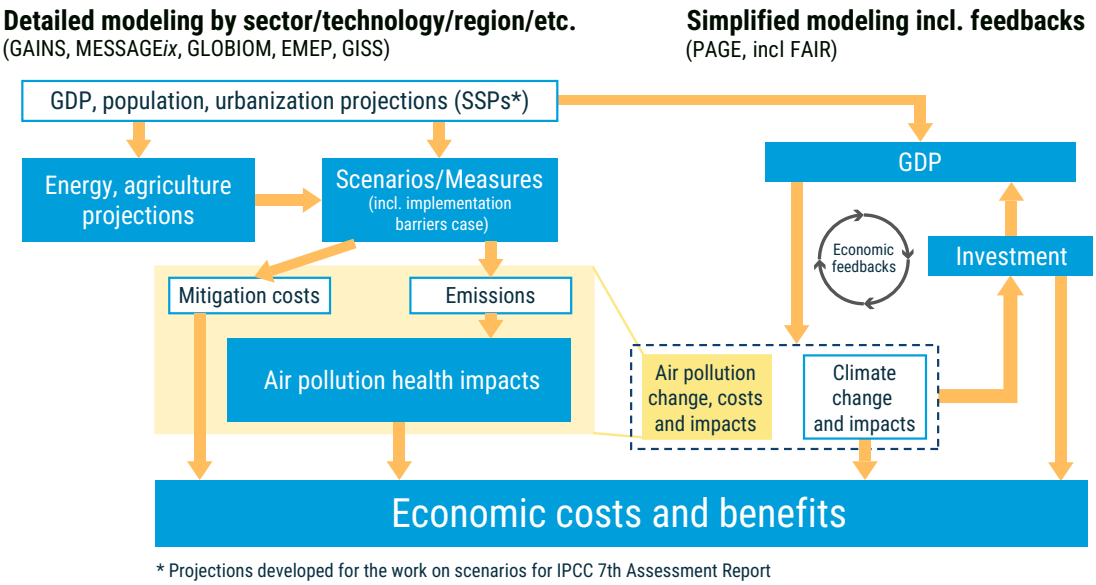
Caption: © Agricultural biogas and biomass processing facility with large circular concrete digesters, membrane-covered gas storage tanks, technical buildings. Photo: AdobeStock/Maik

Box 1.2: Modelling approach

Figure 1.10. shows a schematic diagram of modelling framework used in this Assessment, integrating two IAM approaches: (i) detailed spatially but not interactive with the economy and (ii) PAGE model – less detailed spatially but interactive with economic growth, i.e., allowing to calculate economic feedbacks for mitigation scenarios. The left stream relies on the GAINS-MESSAGEix-GLOBIOM models developing key scenarios, calculating emissions, health impacts, mitigation costs and benefits, including use of EMEP and GISS models results for estimation of ozone concentrations and health impacts. The results are passed to the right-hand stream as indicated by the green lines. The statistical emulators used by the PAGE model are shown on the right side. PAGE uses pollution policy costs and health benefits from MESSAGEix and GAINS to determine total economic consequences for the Baseline and Integrated Action scenarios (see Boxes 2.1 and 3.1). While native resolution of the models is relatively fine, the outputs are aggregated into 15 world regions.

Both streams are informed by input socio-economic projections (upper left box; Dellink *et al*. 2024 and K. C. *et al*. 2024) that underlie the scenarios explored here. The PAGE model was used in the Stern Review (Stern 2007), but for the first time has now been expanded to include air pollution-related economic impacts based on the more detailed air pollution emissions, transport and impact modelling from the left-hand modelling stream. Chapter 2 provides key assumptions and outcomes of the scenarios as well as a brief description of the IAM modelling framework.

Figure 1.10: Schematic diagram of the modelling framework used in this Assessment



* Projections developed for the work on scenarios for IPCC 7th Assessment Report

1.7 Guide to the Assessment

The analytical core of this Assessment spans Chapters 2 through 5, moving from describing emissions trends and scenarios, to quantifying economic impacts, to examining how implementation can be accelerated. Chapters 2, 3, and 4 are supplemented by technical Annexes which provide greater detail on methodologies, results and analysis.

Chapter 2 sets out the emissions landscape, introduces the Baseline and Integrated Action scenarios used throughout the Assessment, and presents the associated mitigation costs and their distribution over time and across regions. Chapter 3 quantifies, in comparable terms, the damage caused by climate change and air pollution, and the benefits of implementing solutions under each scenario, showing that these benefits can outweigh costs within the first decade. Chapter 4 examines implementation feasibility, drawing on country case studies to introduce a framework for identifying and addressing implementation barriers. Finally, Chapter 5 addresses the remaining challenges and the way forward, identifying where the evidence is strong, where uncertainties remain and what is needed to accelerate equitable action.



Caption: © Application of water-soluble fertilizers, pesticides or herbicides in the field. Photo: AdobeStock/CreativeSuburb

02 Scenarios and solutions


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Key messages

This chapter identifies 25 solutions, broadly applicable across most global regions, that together form an Integrated Action Scenario. Implemented as a complete package, the 25 solutions help reduce near-term air pollution and climate change and limit long-term climate change to well below 2 ºC by the end of this century. A Baseline Scenario is developed first to which the 25 solutions are applied in an Integrated Action Scenario. This is followed by an assessment of the economic costs of action and the benefits of economic, technical, social and institutional factors that enable faster implementation of the measures.

- Without new policy action beyond current commitments, methane and nitrous oxide emissions rise throughout the century, driven by continued agricultural growth, waste growth and fossil fuel production. Fine particulate matter ($PM_{2.5}$) and its precursors, including sulphur dioxide, nitrogen oxides, and ammonia, also increase, despite some decoupling of energy-related carbon dioxide from gross domestic product (GDP) growth. In rapidly developing regions, notably parts of South and Southeast Asia and Africa, emissions of most pollutants continue to grow, driven by economic and demographic expansion and slower policy strengthening. In regions with mature control policies, including China, the European Union, Japan and the United States of America, air-pollutant emissions decline but greenhouse gas trends remain a concern.

- Emissions fall into two structurally distinct clusters, each requiring its own mitigation strategy. Energy and combustion-related species, including carbon dioxide, nitrogen oxides, sulphur dioxide, black carbon and $PM_{2.5}$, are dominated by power generation, industry, transport and residential energy use. Non-combustion and biogeochemical species, including methane, nitrous oxide, and ammonia, are dominated by agriculture, which accounts for more than 40 per cent of current methane emissions, approximately three-quarters of nitrous oxide emissions, and more than 90 per cent of ammonia emissions. Solutions that effectively reduce energy-related emissions deliver little reduction

in agricultural emissions, and vice versa. An integrated strategy must address both clusters simultaneously.

- A package of 25 proven solutions can deliver deep, rapid reductions across all major greenhouse gases and air pollutants simultaneously. Implemented together as the Integrated Action Scenario, they reduce carbon dioxide emissions to net negative, but methane by approximately 75 per cent, nitrous oxide by about 62 per cent, and key air pollutants by 65–85 per cent by 2100.

- Global costs of implementing current policies in the baseline scenario are estimated at US$ 10 trillion in 2030 (constant 2025 US dollars). Air pollution control costs represent approximately 10 per cent of the total. These costs are estimated to be equivalent to approximately 4.5 per cent of GDP in 2030 but decline to 1.5 per cent by the end of the century.

- The costs of full implementation of the 25 integrated solutions are manageable and decline as a share of GDP over time. Total implementation costs reach approximately US$ 1.5 trillion per year in the coming decade, equivalent to about 0.7 per cent of global GDP, declining to approximately 0.5 per cent by end of century. The costs of the 21 clean-air and near-term climate solutions remain stable at approximately US$ 500 billion per year throughout the century. The additional cost of air-pollution measures above the baseline falls to zero by 2050, as long-term decarbonization progressively eliminates the need for separate pollution controls by transforming the energy system and phasing out combustion sources.

- The timing and speed of implementation determine how much of the benefit is captured. Implementation delays of 7.5–8 years are expected on average globally, with institutional barriers the single largest contributor at approximately 2.4 years out of a notional 15-year implementation window. A delay of this scale roughly halves the emissions reductions achievable by 2035. Foregone near-term reductions cannot be recovered: additional warming, premature deaths and crop losses accumulated during slower implementation cannot be fully offset by stronger action later.

2.1 Introduction to scenarios and solutions

A robust integrated economic assessment of air-pollution and climate solutions requires an understanding of four issues: the assumptions underpinning the baseline and integrated action scenarios; the effects of those scenarios on key emissions globally and across regions, the costs of implementation; and the impacts of enabling reforms that accelerate implementation. This chapter addresses each of these areas, supported by an Annex 1 reviewing assessment methods in greater detail. Together, they provide the foundation for the cost and benefit assessment in Chapter 3 and the case studies in Chapter 4.

Two scenarios anchor this Assessment (Table 2.1). The *baseline scenario* projects the expected trajectory of emissions under current and already-planned climate and air-pollution policies, with no new measures added. The *integrated action scenario* builds on this baseline by adding a portfolio of 25 solutions: four long-term climate solutions that drive deep carbon dioxide reductions consistent with limiting warming to well below 2 °C, these also have co-benefits for methane and air pollutant reductions, and 21 clean-air and near-term climate solutions that target methane, black carbon and other short-lived climate pollutants (SLCPs) and air pollutants. Together, the two scenarios isolate the additional benefit of deliberate, integrated action and allows this Assessment to quantify both how much further action is needed beyond current policies, and how the timing and sequencing of that action shape the benefits achieved.

The 25 solutions are not new, but have been assessed by previous UNEP/CCAC integrated assessments at global (e.g. UNEP and WMO 2011, UNEP and CCAC 2021, UNEP and FAO 2024) and regional level (e.g. UNEP 2011, UNEP and CCAC 2018, UNEP and CCAC 2019, UNEP 2023b, UNEP and CCAC 2025), but in different combinations and not in a full economic context as in this Assessment. Similar measures have also been covered by other assessments such as

Amann *et al*. (2020) and World Bank (2025) at global level, World Bank (2022) in South Asia and on HFCs from refrigeration and air conditioning (UNEP 2023a).

Table 2.1: The Baseline and Integrated Action scenarios used in the assessment of economic costs and benefits, and the different groups of solutions in the Integrated Action scenario focussed on achieving (i) long-term climate benefits and (ii) air pollution and near-term climate benefits.

Scenario	Brief description	Relevant solutions	Solution sub-categories	Policy focus	Included solutions
1. Baseline	Expected trajectory consistent with the Shared Socioeconomic Pathway 2 (SSP2) narrative	N/A		Implementation of current climate and air pollution policies, consistent with the SSP2-Medium objectives (see main text)	
2. Integrated action	Population and economic growth projections as in the baseline, but includes implementation of all solutions enabling a pathway reducing air pollution, providing near-term climate benefits, and limiting warming over the long term	All 25 solutions, covering four long-term climate solutions and 21 clean air and near-term climate solutions	Long-term climate solutions	Upscaling and accelerating the introduction of solutions that focus primarily on carbon dioxide emission reduction to limit warming and climate change over the long term; consistent with the SSP2-Low objectives (see main text)	Four of the 25 solutions focusing on Energy transformation for power generation; Energy efficiency standards for industry; Energy transformation for households; and Electrification of vehicle fleets
			Clean air and near-term climate solutions	Promotion and effective implementation of solutions designed to reduce emissions of short-lived (in the atmosphere) pollutants that cause air pollution and warming	21 of the 25 solutions focusing on reducing SLCPs like methane, black carbon and hydrofluorocarbons as well as key precursors of air pollutants from various sectors (see Table 2.2).

2.1.1 Key features of the baseline scenario

The baseline scenario is defined by the following key drivers and policy assumptions. It builds on scenario work developed for the Seventh Intergovernmental Panel on Climate Change (IPCC) Assessment Report, that is for the Scenario Model Intercomparison Project of the Coupled Model Intercomparison Project (ScenarioMIP-CMIP7) (Van Vuuren *et al*. 2026) and recent assessments of progress under existing methane and air-quality policies (Wang 2021; EU 2025; IEA 2025; UNEP 2025; World Bank 2025).

The Assessment uses an integrated modelling framework combining three global models: the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS), the Global Biosphere Management Model (GLOBIOM) and the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE*ix*) (Box 2.1). GLOBIOM and MESSAGEix are coupled integrated assessment models - MESSAGE*ix* projected energy demand, technology deployment, fuel use, and GHG mitigation pathways, while GLOBIOM generated land-use and biomass supply pathways while MESSAGE*ix* projected energy demand, technology deployment, fuel use and greenhouse gas mitigation pathways. GLOBOIM outputs were fed into MESSAGE*ix* as an emulator, ensuring energy pathways remained consistent with land-use and biomass constraints. Combined outputs from MESSAGEix and GLOBIOM then served as inputs to GAINS, which estimated air pollutant emissions. Together, the three models produce a consistent set of scenarios, spanning climate, air pollution, and development policies, driven by shared socio-economic projections, considering climate, air pollution, and development policies (Dellink *et al*. 2024; K. C. *et al*. 2024).

The baseline scenario adopts policy assumptions consistent with the SSP2 scenario narrative (O'Neill *et al*. 2017; Riahi *et al*. 2017; Van Vuuren *et al*. 2026), incorporating the current implementation status and likely outlook for air-pollutant and SLCP policies (Purohit and Höglund-Isaksson 2017; Rao *et al*. 2017; Amann *et al*. 2020; Gómez-Sanabria *et al*. 2022; UNEP 2025; World Bank 2025). The SSP2's "middle-of-the-road" narrative, often characterised as a continuation of historical trends, remains broadly applicable today. Recent geopolitical developments have tested globalization and multilateralism, but other key indicators continue to track historical trends or exceed them, such as deployment of low-carbon energy technologies such as the deployment of low-carbon energy technologies such as solar photovoltaics (PV) and wind, and demand-side technologies such as electric vehicles (EVs) and heat pumps, is advancing faster than projected several years ago (IPCC 2022; IEA 2023).

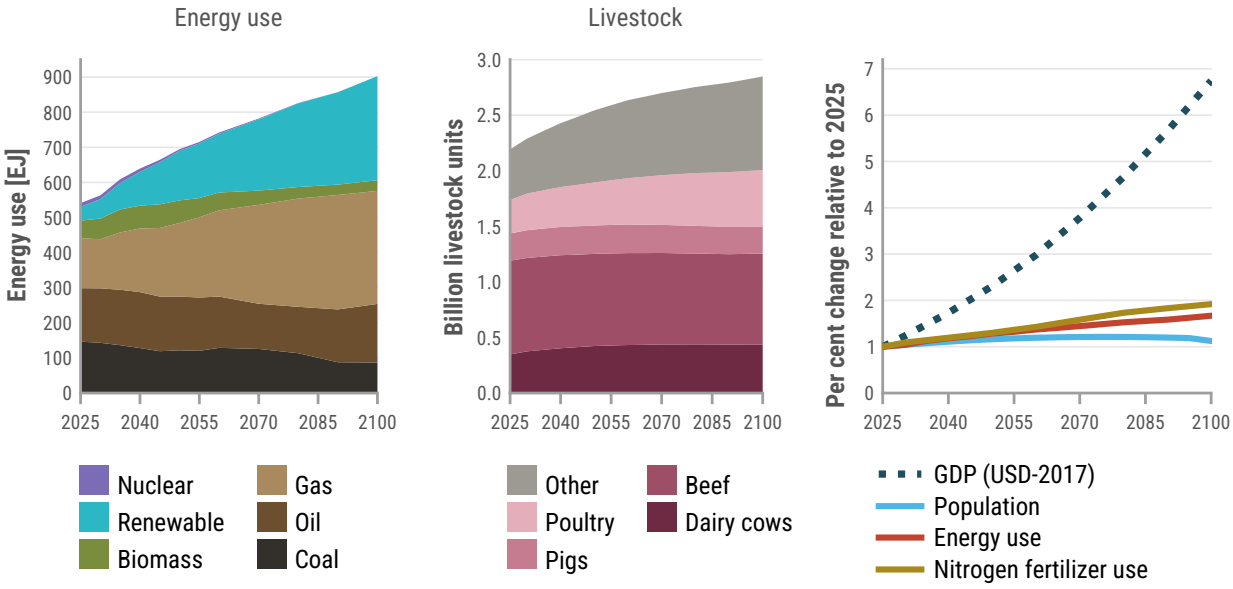
The baseline scenario builds on an updated version of SSP2 - the SSP2-Medium scenario - incorporating three key changes from the original (Riahi *et al*. 2017):

- socio-economic projections have been updated to reflect the demographic and economic impacts of recent crises, including the COVID-19 pandemic.
- technical and economic assumptions have been revised to account for advances in key low-carbon technologies in line with current AR7 modelling developments.
- the scenario reflects today's more challenging geopolitical environment through a fragmented climate policy design, starting from currently implemented and planned policies across countries and assuming only modest continuation of these efforts.

The baseline scenario assumes full implementation of already-planned air pollution policies, but introduces no new policies, making it a conservative projection. Where derogations or delays in meeting prescribed emission limit values are known and documented, the baseline incorporates these.

In the baseline scenario, global energy use increases steadily throughout the century but much more slowly than GDP (Figure 2.1). The energy mix remains diversified but fossil-fuel intensive, with oil, gas, and coal continuing to play a substantial role. Coal use declines gradually over time but remains present in the system, while oil and gas continue to supply a large share of final energy demand. Although renewable energy expands significantly, its growth occurs largely in addition to, rather than as a replacement for, fossil fuels. Projected development of global livestock populations and the demand for synthetic nitrogen fertilisers are projected to increase steadily throughout the century as illustrated in Figure 2.1.

Figure 2.1: Global energy use in the baseline scenario – SSP2-Medium (MESSAGEix model results). Global developments in livestock sector (GAINS-GLOBIOM). Change in population and GDP (Dellink et al. 2024; K. C. *et al.* 2024), energy use, and nitrogen fertilizer use are shown on the right, relative to 2025.





Caption: © Technician and homeowner discussing solar panel on porch. Photo: AdobeStock/wavebreak3

Box 2.1: Models used to develop the scenarios

MESSAGEix (Huppmann *et al.* 2019) represents the core of the International Institute for Applied Systems Analysis (IIASA) Integrated Assessment Modelling (IAM) framework and its main task is to optimise the energy system so that it can satisfy specified energy demands at the lowest costs (https://docs.messageix.org/projects/models/en/latest/global/overview/index.html). MESSAGE carries out this optimization in an iterative setup with MACRO, a single sector macro-economic model, which provides estimates of the macro-economic demand response that results from energy system and services costs computed by MESSAGEix. For the six commercial end-use demand categories depicted in MESSAGE, based on demand prices MACRO adjusts useful energy demand, until the two models have reached equilibrium. This iteration reflects price-induced energy efficiency adjustments that can occur when energy prices change. MESSAGE can represent different energy- and climate-related policies.

GLOBIOM (https://iiasa.github.io/GLOBIOM/) provides MESSAGEix with information on land use and its implications, including the availability and cost of bioenergy, and the availability and cost of emission mitigation in the agriculture, forestry and other land use (AFOLU) sector. To reduce computational costs, MESSAGE iteratively queries a GLOBIOM emulator which provides an approximation of land-use outcomes during the optimization process instead of requiring the GLOBIOM model to be rerun iteratively. Only once the iteration between MESSAGEix and MACRO has converged, are the resulting bioenergy demands, along with corresponding carbon prices, used for a concluding analysis with the full-fledged GLOBIOM model. This ensures full consistency of the results from MESSAGE and GLOBIOM and allows a more extensive set of land-use related indicators, including spatially explicit information on land use, to be produced.

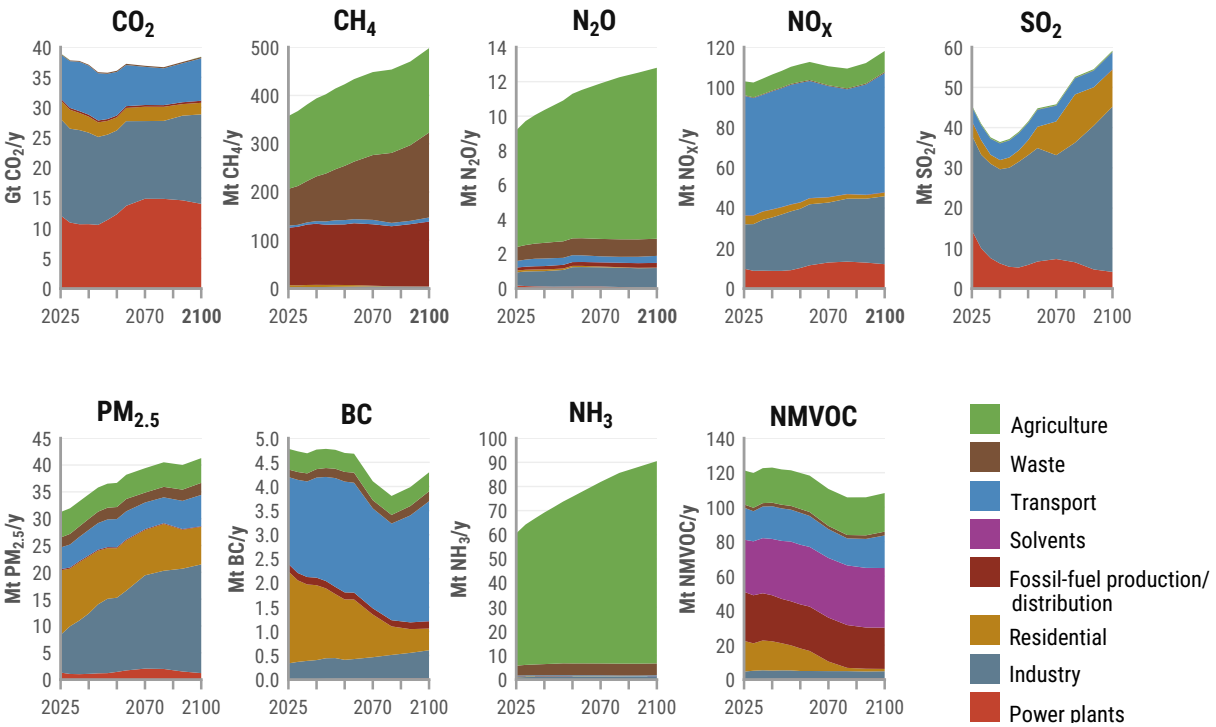
The GAINS (Greenhouse gas-Air Pollution Interactions and Synergies) model explores cost-effective multi-pollutant emission control strategies that meet environmental objectives on air quality impacts (on human health and ecosystems) and greenhouse gases. GAINS brings together data on economic development (inputs from MESSAGE-GLOBIOM), the structure, control potential and costs of emission sources, the formation and dispersion of pollutants in the atmosphere, and an assessment of environmental impacts of pollution (https://gains.iiasa.ac.at/models/). Emissions and costs are estimated using both national and international data on source- and technology-specific emission and cost factors; more than 1000 control options are represented. The model computes the atmospheric dispersion and formation of secondary pollutants for each scenario, including specific response to each major solution analysed in the report. This allows the quantification of $PM_{2.5}$ concentration changes from application of each measure/solution at the fine scale. As an indicator for population exposure to particulate matter, the annual average population-weighted mean exposure to ambient $PM_{2.5}$, accumulated over the whole population, is used.

2.2 Emission outlook under the baseline scenario

The baseline scenario projects that global carbon dioxide emissions decline and stabilise by the end of the century (Figure 2.2), slowly decoupling from population and economic growth. Methane and nitrous oxide emissions, however, are projected to continue increasing, driven by continued agricultural growth, rising gas production and limited methane regulation Figure 2.1. While current climate and air-quality policies decouple emissions from projected economic growth at the global level (Figure 2.2), $PM_{2.5}$ and its precursors (sulphur dioxide, nitrogen oxides and ammonia) are still projected to increase (Figure 2.2).

Emissions of sulphur dioxide, currently declining, are projected to rebound by mid-century if no further policies are introduced, driven by strong growth in industrial production and fossil fuel use in the industrial and residential sectors, primarily across the Global South. Anthropogenic black carbon and non-methane volatile organic compound emissions are projected to decline, mainly due to reduced solid-fuel use for cooking and heating – policies targeting this source are already in place in several regions and are expected to accelerate even under the baseline scenario.

Figure 2.2: Global anthropogenic emissions of selected greenhouse gases and air pollutants in the baseline scenario (SSP2-Medium) by key sectors, 2025–2100, gigatonnes (carbon dioxide) and others million tonnes per year.



Note: nitrogen oxides (NO_X) are shown as million tonnes of nitrogen dioxide (NO_2).

The baseline scenario projects stable or increasing emissions of the GHGs that mainly drive long-term climate change. In regions with mature control policies, such as China, the European Union, Japan and the United States of America, air-pollutant emissions continue to decline. In rapidly developing regions, notably parts of South and Southeast Asia and Africa, emissions growth persists, driven by economic and demographic trends alongside slower policy strengthening.

Power generation, industry and energy use in transport collectively account for 90 per cent of anthropogenic carbon dioxide emissions throughout the century, and the sectoral distribution changes little over time. This reflects strong inertia in energy-related emission sources. Stable carbon dioxide emissions are only achievable because renewables, including those supporting EV fleets, expand significantly in the energy mix over time (Figure 2.1). Nitrogen oxides and sulphur dioxide follow a similar pattern, with fossil-fuel use as

the primary driver, though industrial processes play a growing role over the longer term and transport remains a particularly important source of nitrogen oxides.

Agriculture trends dominate emissions of nitrous oxide and ammonia and is a major driver for methane. Agriculture, led by enteric fermentation, represents slightly more than 40 per cent of current methane emissions, followed by fossil-fuel production and distribution, and steadily growing emissions from waste management. Rapid projected growth in waste generation and inadequate policies in many regions, however, make waste an increasingly important source which will supersede agricultural methane emissions by the end of the century. Agriculture drives approximately three-quarters of nitrous oxide emissions through fertiliser application and soil processes throughout the century, while other sectors contribute comparatively little. More than 90 per cent of ammonia emissions originate from agriculture, primarily livestock manure and the application of synthetic fertilisers, with only marginal contributions from waste and other sectors. The contribution of nitrogen oxides from agricultural soils is projected to grow, particularly in regions where combustion-source reductions are expected.

Transport and residential energy use are the most important sources of black carbon and $PM_{2.5}$ throughout the century, with industrial process emissions playing a growing role for $PM_{2.5}$ reaching half of anthropogenic emissions by the end of the century. Transport dominates black carbon emissions, reflecting the lasting impact of diesel combustion. Solid fuel use for cooking and heating is a key source over the next few decades, but its contribution declines as policies expanding access to clean residential fuels take effect. Open burning of agricultural residues remains an important source throughout the century, as enforcement of existing bans consistently falls short.

Emissions of non-methane volatile organic compounds come from multiple sources including combustion and evaporative losses from fossil-fuel production and use, solid-fuel combustion in inefficient residential stoves, agriculture and solvent use. Most of these sources remain significant throughout the century. The main exception is residential cooking and heating, from which emissions gradually decline due to improved access to clean fuels, pulling total non-methane volatile organic compound emissions slightly downwards overall.

Sectoral emission patterns fall into two broad clusters. Energy- and combustion-related greenhouse gases and air pollutants, including black carbon, carbon dioxide, nitrogen oxides, $PM_{2.5}$ and sulphur dioxide, are dominated by power generation, industry, transport and residential energy use. Biogeochemical and non-combustion species, such as methane, nitrous oxide and ammonia, are dominated by agriculture and an increasing importance of waste for methane. These differences demand sector-specific mitigation strategies, as solutions that effectively reduce energy-related emissions will deliver little to no reduction in agricultural emissions, and *vice versa*.

2.3 Key features of the integrated action scenario

Proven, scalable solutions to reduce greenhouse gas and SLCP emissions, including $PM_{2.5}$ and ozone precursors, already exist and have been successfully applied at local and regional scales. The integrated action scenario consists of a portfolio of 25 solutions, addressing long- near-term climate and air-pollution benefits, that result in deeper and faster reductions in all air pollutants and SLCPs than is possible with a climate only approach.

The 25 integrated solutions forming the integrated action scenario (Table 2.2) are broadly applicable across most global regions, and cost and efficiency data are available for most. Full descriptions of all 25 measures appear in Annex 1. The terms measure and solution are used interchangeably here to refer to:

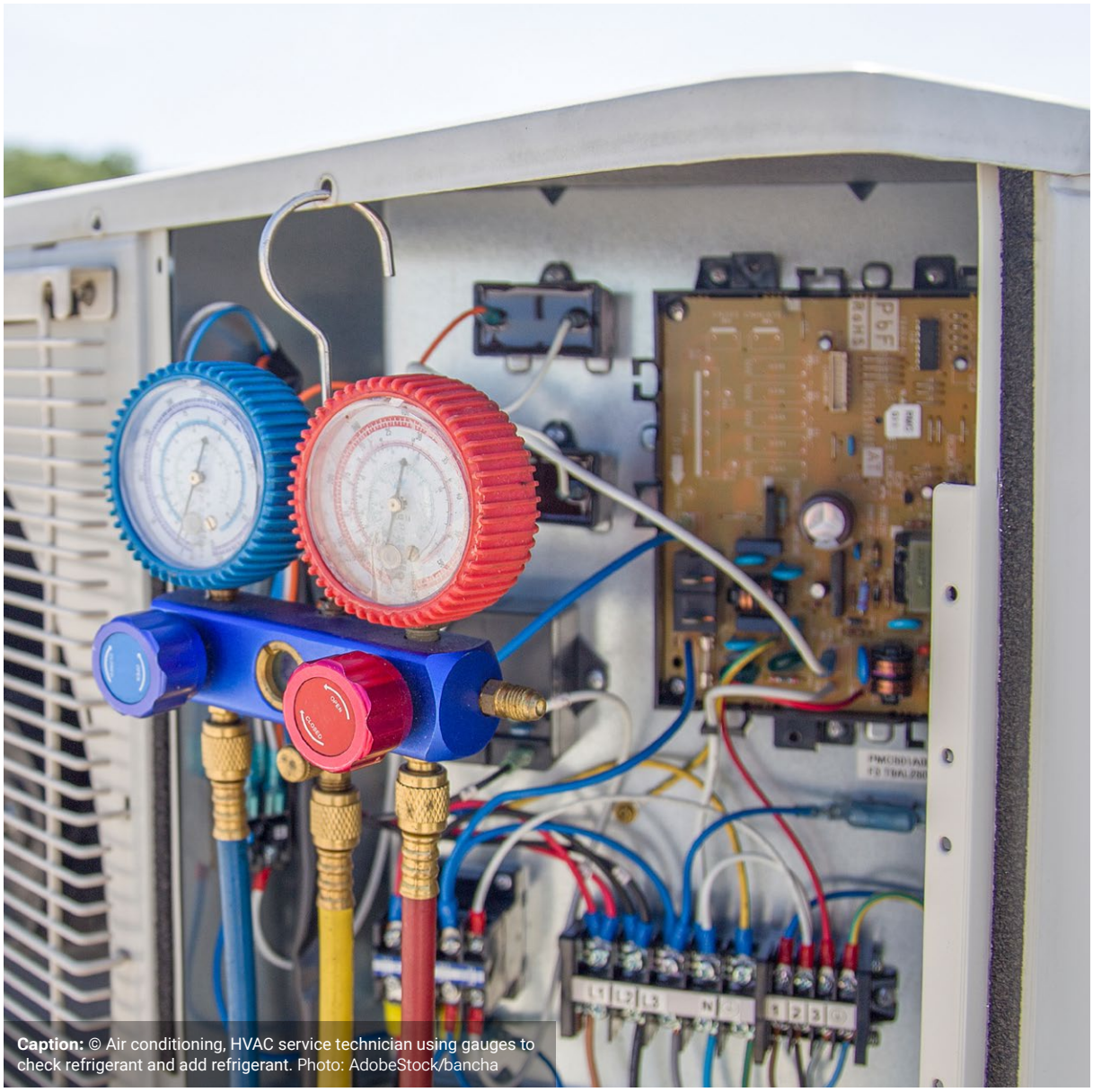
- energy or agricultural system transformations, typically targeting long-term objectives;
- changes in operating practices; and
- technological options that reduce emissions of greenhouse gas, SLCPs and air pollutants.

The 25 integrated solutions were selected to maximise near- and long-term benefits for both climate change and air quality, and comprise the following two types of interventions:

- Four long-term climate solutions: these proven solutions address long-term climate objectives, focusing on carbon dioxide reduction through energy system transformation and agricultural development needed to limit global warming to well below 2 °C by the end of the century. They draw from scenario analysis using the MESSAGE*ix* and GLOBIOM models, and their mitigation impact is calculated as the difference between the baseline (SSP2-Medium) and the climate mitigation (SSP2-Low) scenario.

- 21 air pollution and near-term climate solutions: these, which were assessed using the GAINS model, target sources of air pollution and methane. For air pollutants, the mitigation potential captures 90–95 per cent of technically feasible reductions, excluding the most expensive options that deliver only marginal air-quality improvements. For methane, the mitigation potential excludes solutions with average abatement costs greater than US$ 15,000 per tonne of methane.

This Assessment's approach differs from that of a recent World Bank study (World Bank 2025), which aimed to halve the population exposed to $PM_{2.5}$ levels above the World Health Organization (WHO) Interim Target II guideline of 25 micrograms per cubic metre (µg/m^3) by 2050. Although both studies use the GAINS model, the World Bank study relies on a different set of underlying scenarios from the International Energy Agency (IEA 2023).



Caption: © Air conditioning, HVAC service technician using gauges to check refrigerant and add refrigerant. Photo: AdobeStock/bancha

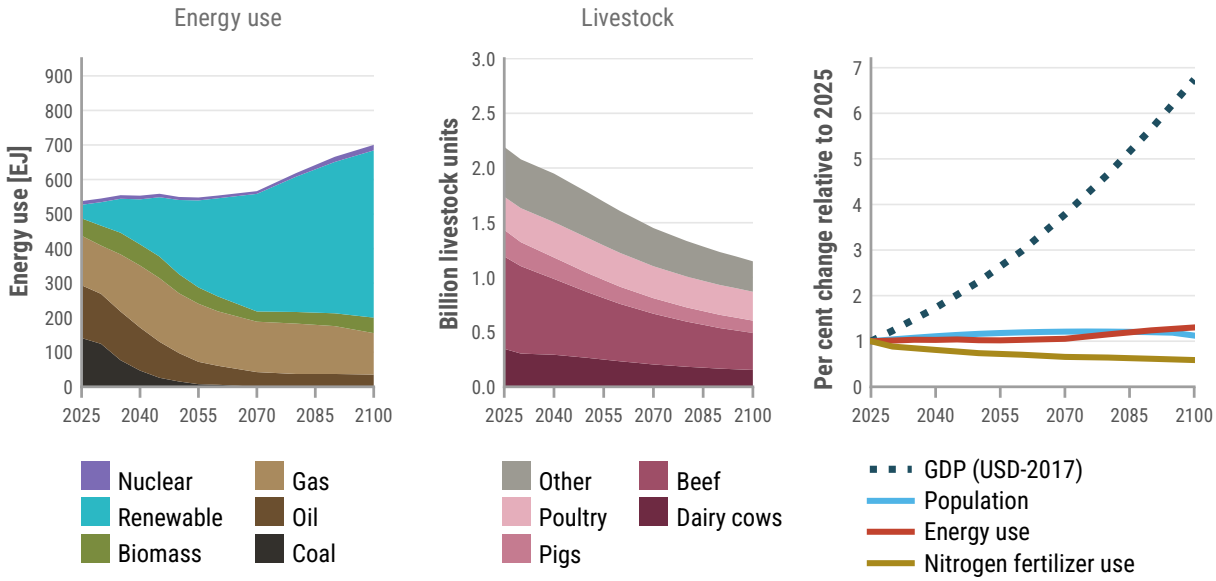
Table 2.2: The 25 solutions implemented in the 'integrated action scenario'. This includes the two groupings (i) 4 long-term climate solutions ( ) and (ii) 21 clean air ( ) and near-term climate ( ) solutions. For each measure the primary mitigation objective is indicated with as well as the mitigation co-benefit. More information on the measures is given in Annex 1.

Measure	Brief description	Primary mitigation objective	Mitigation co-benefit
Energy and fossil fuel systems			
Energy transformation for power generation	Energy transformation for power generation. Transition to use of wind, solar and hydro power for electricity generation		
Post-combustion controls – power plants and industry	Application of high efficiency flue gas cleaning technology to reduce air pollutants		
Oil and gas sector upstream emissions	Recovery of associated gas to eliminate routine venting and flaring, reduce unintended leaks		
Oil and gas sector downstream emissions	Reducing leaks in long-distance and consumer gas transmission pipelines, and in refineries		
Coal mining	Ventilation air CH_4 oxidation and extended pre-mining recovery of coal mine gas		
Industry			
Energy efficiency standards for industry	More ambitious energy efficiency standards and extended electrification		
Industrial processes emission standards	Improvements in process technology, including adipic acid production		
Efficient brick kilns	Improved efficiency and emission standards		
Solvent use	Low-solvent products, leak detection, etc.		
Residential cooking and heating			
Energy transformation for households	Improved energy efficiency of buildings, lighting, and household appliances		
Clean cooking and heating	Clean alternatives for traditional cooking and solid fuel heating		
Transport			
Vehicle emission standards	More stringent emission limit values and efficiency standards		
Vehicle inspection and maintenance	Early recognition and elimination/repair of high emitting vehicles		
Electric vehicles	Transition to use of electric vehicles		
Emission standards for non-road machinery	More stringent emission limit values and efficiency standards		
International shipping	Low-sulphur fuels, control of particulate matter and NO_x		
Agriculture and food systems			
Livestock and manure management	Control of ammonia and CH_4 from livestock production, including manure application, enteric fermentation, and anaerobic digestion		
Efficient nitrogen fertilizer application	Improving timing and dose, urease inhibitors, etc.		
Dietary changes	Shift to less meat protein in diets		
Rice paddies	Encourage intermittent aeration of continuously flooded paddies		
Reduce burning of agricultural residues	Effective bans and alternatives to burning		
Waste management			
Solid waste management	Efficient waste collection with source separation and recycling. Gas recovery from landfills		
Wastewater treatment	Well-managed two-stage anaerobic followed by aerobic treatment with biogas recovery		
Others			
Prevention of forest and peatland fires	Improved forest, land and water management and fire prevention strategies		
Phasing down the use of hydrofluorocarbons (HFCs)	Further mitigation beyond the Kigali Amendment		

In the integrated action scenario, the four long-term climate solutions engender a marked transformation of the energy system. Total energy demand grows more slowly than in the baseline scenario and eventually stabilises (compare Figure 2.1 and Figure 2.3), despite continued strong GDP growth, reflecting substantial gains in energy efficiency and reductions in energy intensity. Renewables expand rapidly and become the dominant energy source by mid-century, increasingly displacing rather than supplementing fossil fuels. Coal and other solid fossil fuels are largely phased out by mid-century, and reliance on oil and gas declines alongside them. The scenario assumes countries have not backtracked on ambitious climate pledges made under the United Nations Framework Convention on Climate Change (UNFCCC) process, continue implementing unconditional Nationally Determined Contributions (NDCs) until 2030, and follow through on net-zero commitments (the approach follows the NDC-LTS scenario described in Hooijschuur *et al*. (2025).

Dietary change acts as an upstream structural reform, enabling large reductions in livestock numbers and demand for nitrogen fertiliser. When combined with climate mitigation, it drives system-level transformation in the agricultural sector, simultaneously addressing greenhouse gas emissions and nitrogen pollution (Figure 2.3). These results show that dietary change substantially enhances the effectiveness of climate mitigation, delivering nitrogen management benefits that supply-side solutions alone cannot achieve. This underlines the importance of integrating demand-side interventions, such as dietary shifts, into long-term mitigation strategies. New solutions targeting agricultural greenhouse gas emissions may also emerge, providing additional mitigation options and supporting broader sectoral transformation.

Figure 2.3: (Left) global energy use in the integrated action scenario - SSP2-Low, 2025–2100, exajoules. (centre) global developments in livestock sector used in the integrated action scenario of this Assessment. (right) change in population, gross domestic product, energy use, and nitrogen fertiliser use, relative to 2025.



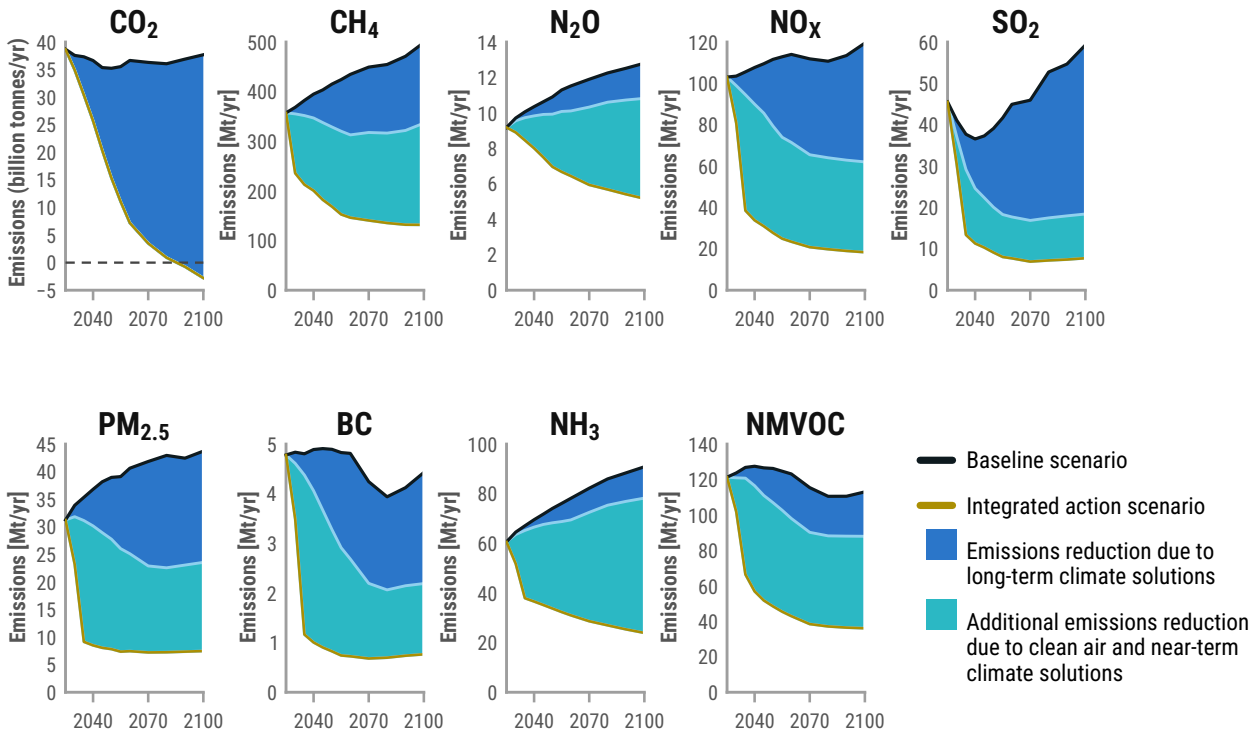
Sources: (left) MESSAGEix model results. (centre) GAINS-GLOBIOM; (right) Dellink et al. 2024; K. C. et al. 2024; GLOBIOM-GAINS.

The integrated action scenario does not include all solutions with potential benefits for public health, climate mitigation, and the economy as, in several cases, the benefits cannot yet be robustly quantified at scale or incorporated into the modelling framework. Some of these solutions are discussed in Annex 1. Chapter 3 (Section 3.6; Annex 2.7) presents illustrative studies and local and regional evidence for selected cases.

2.4 Emissions outlook under the integrated action scenario

The integrated action scenario significantly reduces emissions relative to the baseline. Compared to the baseline, carbon dioxide emissions turn net negative, methane is reduced by approximately 75 per cent, nitrous oxide by approximately 62 per cent, and air pollutants by 65–85 per cent (Figure 2.4).

Figure 2.4: Global emission pathways of key greenhouse gases and air pollutants from anthropogenic sources in the baseline and integrated action scenarios, showing the reduction in the integrated action scenario that can be attributed to (i) the four long-term climate solutions and to (ii) the additional reduction associated with implementation of the 21 clean-air and near-term climate solutions, 2025–2100, carbon dioxide billion tonnes per year, others million tonnes per year.



The four long-term climate solutions prioritise carbon dioxide reduction (Figure 2.4) through an accelerated transformation of the energy system by expanding power generation from renewable sources for industry and households, electrifying vehicle fleets, and improving energy efficiency in industry and households, including housing, lighting and appliances. In the first decades after 2025, natural gas remains important where renewable capacity is not yet sufficient to meet demand, but its consumption plateaus as coal use is rapidly phased down. Additionally, carbon dioxide is reduced by growing application of carbon capture and storage (CCS) solutions in power and industrial sectors and these reductions contribute to the decline in carbon dioxide shown in Figure 2.4. Finally, while changes of agricultural, forestry, and land-use emissions in the baseline and the integrated action scenario are not discussed, emissions from this sector also change and play a role in reduction of carbon dioxide in the SSP2-Low scenario.

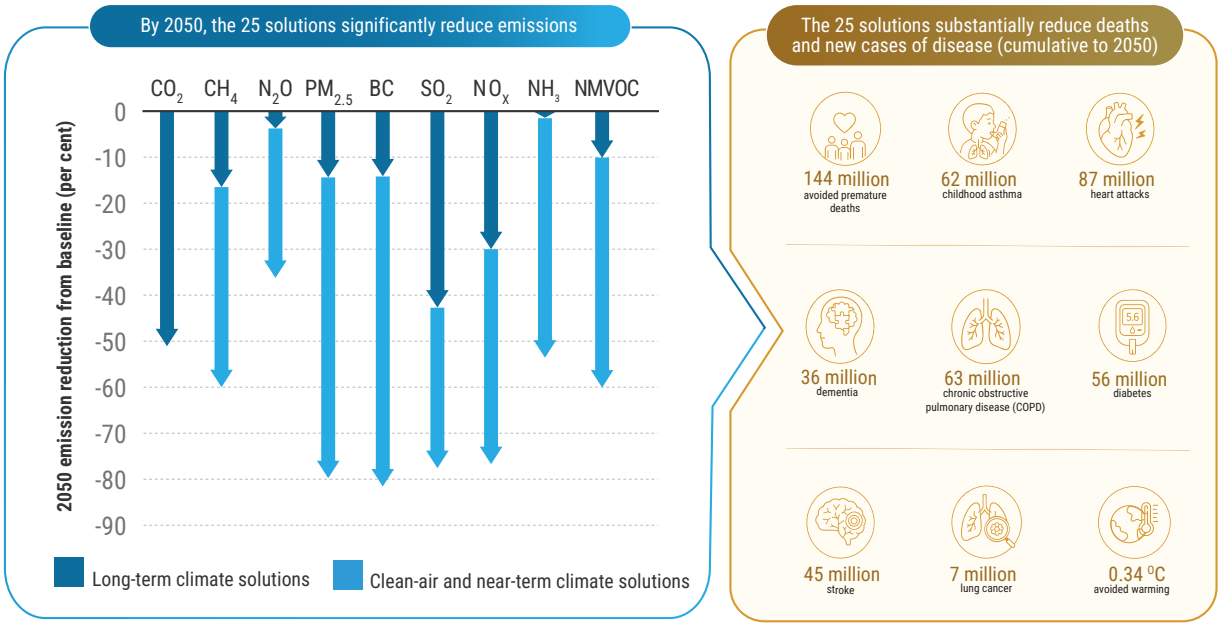
The four long-term climate solutions deliver important air-quality benefits, particularly through reductions in combustion-related air pollutant – black carbon, nitrogen oxides, $PM_{2.5}$ and sulphur dioxide (Figure 2.4) – yet these benefits remain underrecognised

and underutilised in climate-policy discussions, despite their potential to deliver significant health and economic gains (Chapter 3). These solutions have a more moderate impact on agricultural nitrous oxide and ammonia emissions but drive methane down to below current emission levels by end of century, a reduction of about 30 per cent relative to the 2100 level in baseline, driven primarily by the near-elimination of the use of coal by mid-century, continued reductions in oil use, and some reduction in agricultural emissions.

The 21 clean air and near-term climate solutions drive the deepest and fastest reductions across all air pollutants and SLCPs (Figure 2.4). The largest additional mitigation potential lies in methane, nitrous oxide and ammonia, for which agricultural sources offer significant reductions, partly through dietary shifts. Reduced livestock production lowers demand for synthetic nitrogen fertilisers (Figure 2.3), directly cutting nitrous oxide and ammonia emissions, and reducing nitrogen oxides through lower emissions (Figure 2.3 and Figure 2.4). Solutions targeting transport, industrial processes, cooking and heating, and open burning of agricultural residues approximately double the reduction already achieved by the four long-term climate solutions for $PM_{2.5}$, black carbon and non-methane volatile organic compounds (Figure 2.3 and Figure 2.4).

Until mid-century, clean air and near-term climate solutions offer larger mitigation potential than the long-term climate solutions for all species, except carbon dioxide. Figure 2.5 illustrates this for 2050, where transformation of the energy supply and demand offers large mitigation potential for carbon dioxide and sulphur dioxide driven by the near elimination of the use of coal, while the greatest reduction opportunities for all other species come from solutions targeting air pollutants, methane and nitrous oxide.

Figure 2.5: Global emission reductions attributed to the implementation of (i) the long-term climate solutions and (ii) the clean-air and near-term climate solutions of key greenhouse gases and air pollutants in the integrated action scenario compared to the baseline (left) in 2050 (as per cent), and the associated health and climate benefit (right) compared to the baseline in 2050.



This speed advantage is most pronounced in the first one to two decades, in which the 21 clean air and near-term climate solutions' emissions-reduction potential is several times greater than under the long-term climate solutions alone. The finding demonstrates that targeted air-pollutant and SLCP mitigation can deliver rapid emissions reductions and air-quality improvements alongside near-term climate benefits, while reinforcing long-term decarbonization. Combining energy-system transformation with sector-specific solutions in agriculture, waste and combustion sources, the integrated action pathway achieves climate–mitigation and air-quality improvements concurrently.

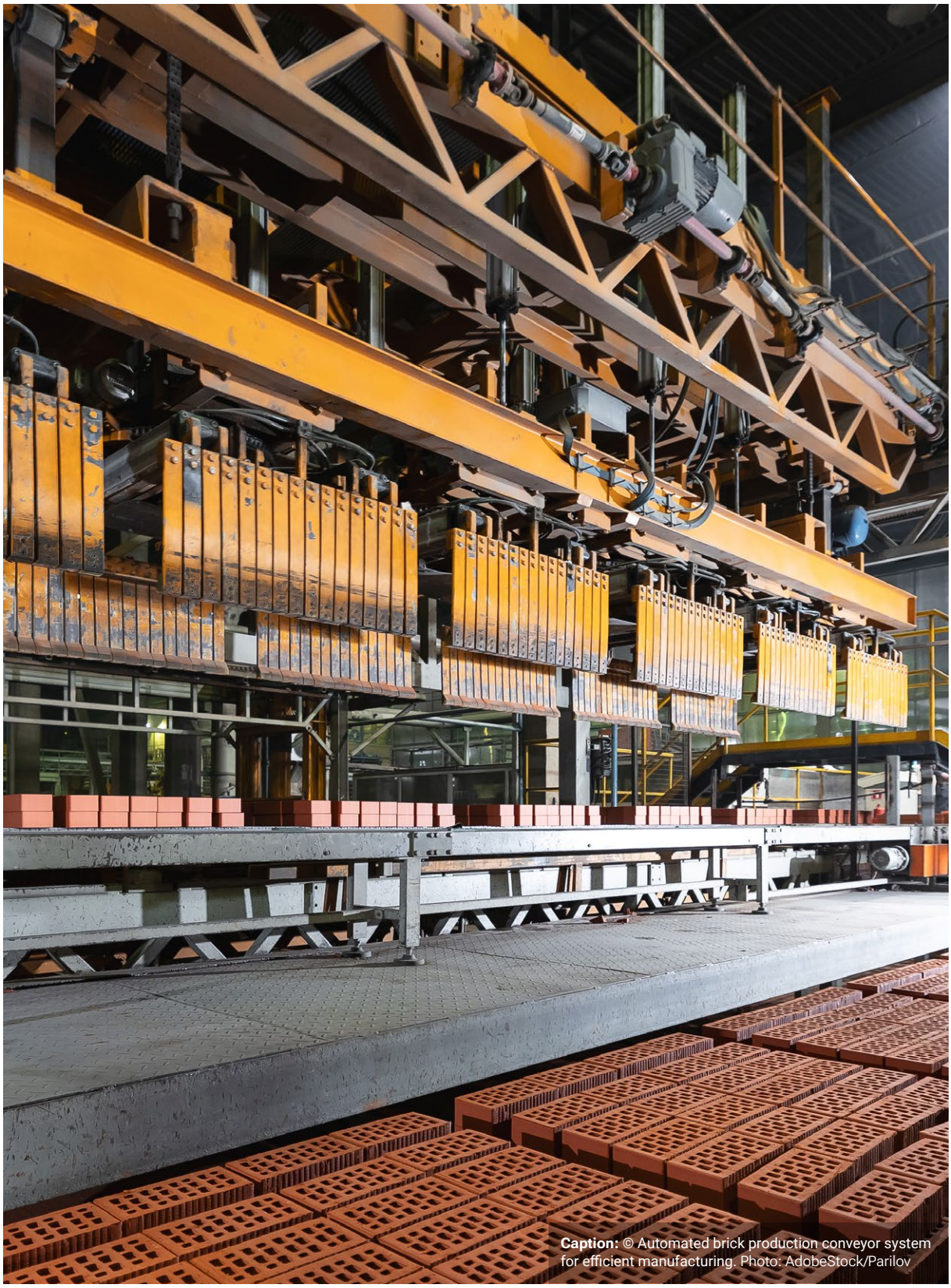
A key strength of this approach is its multipollutant character. Most solutions simultaneously reduce carbon dioxide, non-carbon dioxide greenhouse gases and air pollutants (Table 2.3). Although the relative impact shifts over time and across the regions, as illustrated for black carbon and methane in Figure 2.8 and Figure 2.9, this multipollutant characteristic persistently reduces multiple environmental and human health burdens simultaneously (Chapter 3).

Table 2.3: Relative contribution of individual 25 solutions to global reductions of greenhouse gas and air-pollutant emissions in the integrated action scenario, 2050, (for absolute values and costs of mitigation see Table A1.1 in Annex 1). The '–' in the cell indicates that a particular solution does not result in emission reductions of a given species or that it is negligible.

	Emission reductions *(units: kilotonne (kt) per year, unless stated otherwise)*								
	CO_2 (Mt)	CH_4	N_2O	$PM_{2.5}$	BC	SO_2	NO_x	NH_3	NMVOC
Energy transformation for power generation	9,918	26,217	102	1,130	4	5,115	7,190	153	3,822
Post-combustion controls - power plants and industry	–	1	-5	2,407	131	1,733	7,373	-67	377
Oil and gas sector upstream emissions	161	68,113	–	176	137	17	153	1	12,653
Oil and gas sector downstream emissions	–	17,978	–	–	–	–	–	–	–
Coal mining		1,729	–	4	–	–	–	–	–
Energy efficiency standards for industry	5,932	4,366	81	862	52	8,885	5,091	342	1,724
Industrial process emissions standards	62	40	316	7,570	77	7,744	9,499	216	728
Efficient brick kilns	–	11	0	272	82	670	57	–	14
Solvent use	–	–	–	–	–	–	–	–	20,467
Energy transformation for households	856	2,559	21	2,793	447	2,333	1,003	71	3,331
Clean cooking and heating	–	1,822	–	5,075	695	63	356	-1	7,290
Vehicle emission standards	1,564	4,999	74	1,805	1,002	335	18,219	119	6,131
Vehicle inspection and maintenance	–	–	–	893	481	–	5,860	–	2,338
Electric vehicles	928	10	113	464	158	313	3,327	166	2,970
Emission standards for non-road machinery	474	27	18	491	216	405	4,920	-6	2,018
International shipping	–	-1,128	–	464	47	2,053	16,160	–	-205
Livestock and manure management	–	4,244	33	54	–	–	56	9,739	–
Efficient nitrogen fertilizer application	–	–	–	–	–	–	–	6,363	–
Dietary changes	–	53,962	2,976	174	–	–	3,107	22,516	4,222
Rice paddies	–	6,260	–	–	–	–	–	–	–
Reduce burning of agricultural crop residues	–	3,283	–	3,183	343	236	486	657	4,268
Solid waste management	1	36,051	–	975	73	49	232	–	940
Wastewater treatment		16,558	214	–	–	–	–	–	–
Prevention of forest and peatland fires	–	1,035	–	2,432	134	149	1,361	331	4,842
Phasing down the use of HFCs	–	–	–	–	–	–	–	–	–

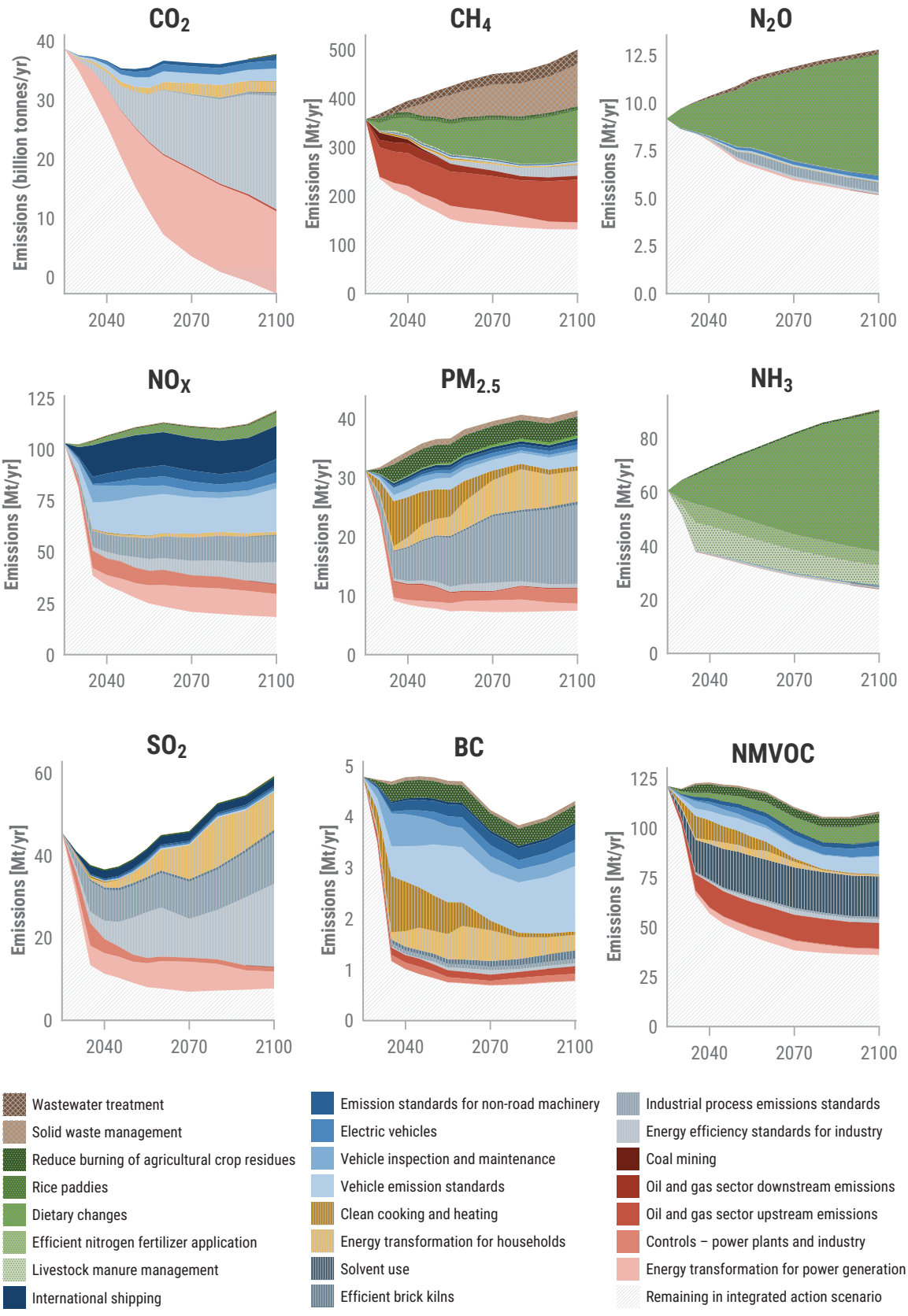
At the global level, a small number of solutions account for the majority of mitigation potential. For carbon dioxide, nitrous oxide and ammonia, just two to three solutions deliver approximately 90 per cent of the reduction potential. For black carbon, methane, nitrogen oxides, non-methane volatile organic compounds and $PM_{2.5}$ full implementation of 5–10 solutions would be needed to achieve comparable reductions. Regional distributions vary; Figures A1.1 and A1.2 in Annex 1.2 illustrate which solutions deliver the greatest share of global mitigation potential in 2050.

The mitigation potential of individual solutions varies over time. For decarbonization of transport, power and industry, solid waste management and dietary change, potential grows over time. For others, including vehicle inspection and maintenance, coal mining, efficient brick kilns, post-combustion controls in power and industry, and clean cooking and heating, the largest potential is concentrated in the first few decades and can be realised quickly. Table 2.3 shows the impact of each solution on key greenhouse gas and air pollutant emissions in 2050, with trends across the full modelling horizon shown in Figure 2.6.



Caption: © Automated brick production conveyor system for efficient manufacturing. Photo: AdobeStock/Parilov

Figure 2.6: Global emissions reduction potential of individual measures in the integrated action scenario, compared to the baseline, 2025–2100, carbon dioxide billion tonnes per year, others million tonnes per year.



Note: Reductions achieved by 23 solutions are shown for global anthropogenic emissions of major greenhouse gases, air pollutants and precursors of fine particulate matter and ozone – the impacts of action addressing forest fires and hydrofluorocarbons are not shown. The estimated impact of solutions addressing the prevention of forest fires is discussed in Box 2.2.

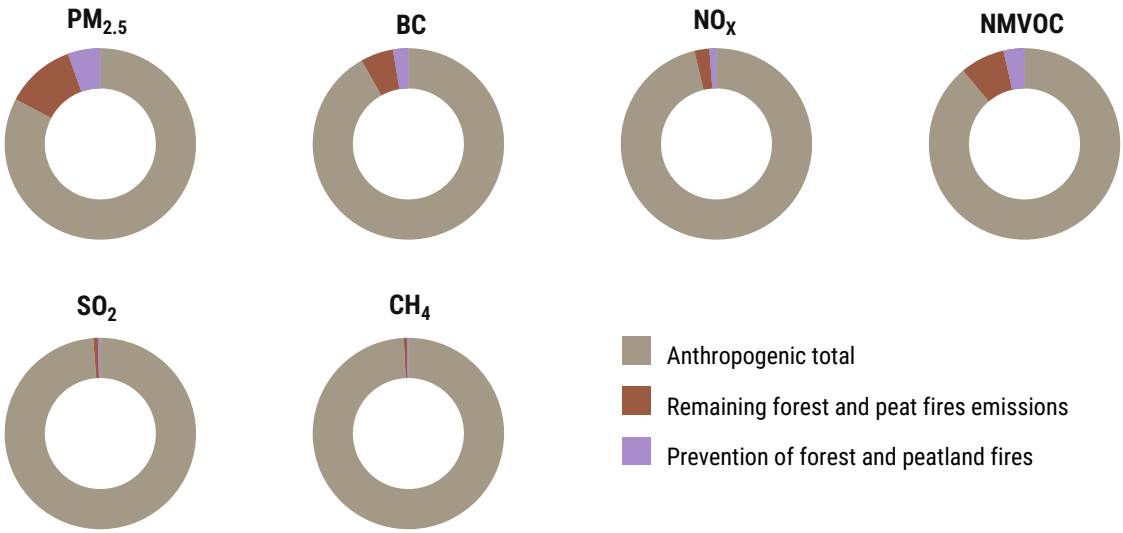
Box 2.2: Reducing emissions from forest fires and peatland fires

Prevention of forest and peatland fires is one of the 25 solutions identified in this Assessment, addressing opportunities to improve forest, land and water management and fire prevention strategies. Because the human contribution to fire emissions is large but regionally variable and difficult to attribute precisely, fire emissions are treated separately from the anthropogenic emissions shown in the charts in this chapter. They are nonetheless included in the impact assessment in Chapter 3.

Fire emissions are projected using remote sensing data (Wiedinmyer *et al*. 2023), with the SSP2 scenario defining the Baseline and SSP1 defining the mitigation potential (van Vuuren *et al*. 2026).

Open burning emissions are not equally significant across all pollutants. As Figure 2.7 shows, the largest contributions in 2050 are to $PM_{2.5}$ (17 per cent of total emissions including anthropogenic emissions and open fires), NMVOC (11 per cent), black carbon (8 per cent), NO_X (4 per cent), with SO2 and CH_4 each accounting for approximately 1 per cent. Based on the SSP1 scenario, the mitigation potential is approximately 30 per cent across these species, shown in Figure 2.7 (van Vuuren *et al*. 2026).

Figure 2.7: Relevance of emissions from forest and peatland fires in total emissions as well as potential for their reduction assumed in this Assessment for selected air pollutants and methane; example for 2050.



Source: GAINS model (IIASA), Wiedinmyer et al. (2023), van Vuuren et al. (2026).

2.4.1 Importance of sectors for mitigation potential and regional variation

The mitigation potential of each of the 25 solutions varies by pollutant (Table 2.3). The relative importance of these solutions also varies by region and changes over time, underscoring the need for pollutant-specific strategies within integrated climate–air quality frameworks. Figure 2.8 and Figure 2.9 illustrate this regional variation, showing how the 25 solutions' contributions to reducing black carbon and methane emissions differ across regions and evolve over time.

Black carbon emissions-reduction potential is greatest in household energy use through the shift to clean cooking and heating; in transport through the implementation of vehicle emission standards, and inspection and maintenance; and industrial combustion processes. This potential is particularly pronounced in developing countries across parts of

East Asia, South Asia, Latin America and sub-Saharan Africa where solid-fuel use in the residential sector remains a dominant source of black carbon, and in Central Asia and other parts of the Global South, in which post-combustion controls and efficiency improvements can deliver substantial reductions from small-scale, outdated, low-efficiency industrial technologies that remain widespread.

The greatest methane mitigation potential is strongly concentrated in oil and gas production and distribution, coal mining, waste management and agriculture (Figure 2.9), sectors largely distinct from those driving black carbon mitigation, though oil and gas is relevant to both. Across most regions and time horizons, mitigation in the oil and gas sector alone accounts or more than a third of total methane reduction potential (and more than two thirds for region where fossil fuel production sector is a key economic activity), reflecting the structural nature of its emissions and the high effectiveness of targeted leak detection and recovery solutions.

The relative importance of solutions shifts over time, driven by factors including feasible mitigation timelines, the pace of decarbonization and economic growth. Understanding how sectoral roles evolve across near- and long-term mitigation objectives is important for effective planning, maximizing benefits, and minimizing costs. While these dynamics vary by region, several patterns recur across multiple regions, as follows:

- Access to clean fuels and efficient cooking and heating stoves plays an important role in reducing emissions of black carbon and other air pollutants in the first decades. This is driven by policies that secure access to clean fuels and electricity while reducing reliance on inefficient solid fuel stoves, combined with long-term climate solutions that reduce energy demand and fossil-fuel use, especially coal, most prominently in Africa and South Asia.

- Transport solutions remain highly relevant across the entire time horizon, despite progressing fleet electrification, since internal combustion engines persist, particularly for heavy-duty engines in both on- and non-road applications.

- Preventing open burning of agricultural residues through the introduction of alternative practices can deliver significant impacts across the entire time horizon.

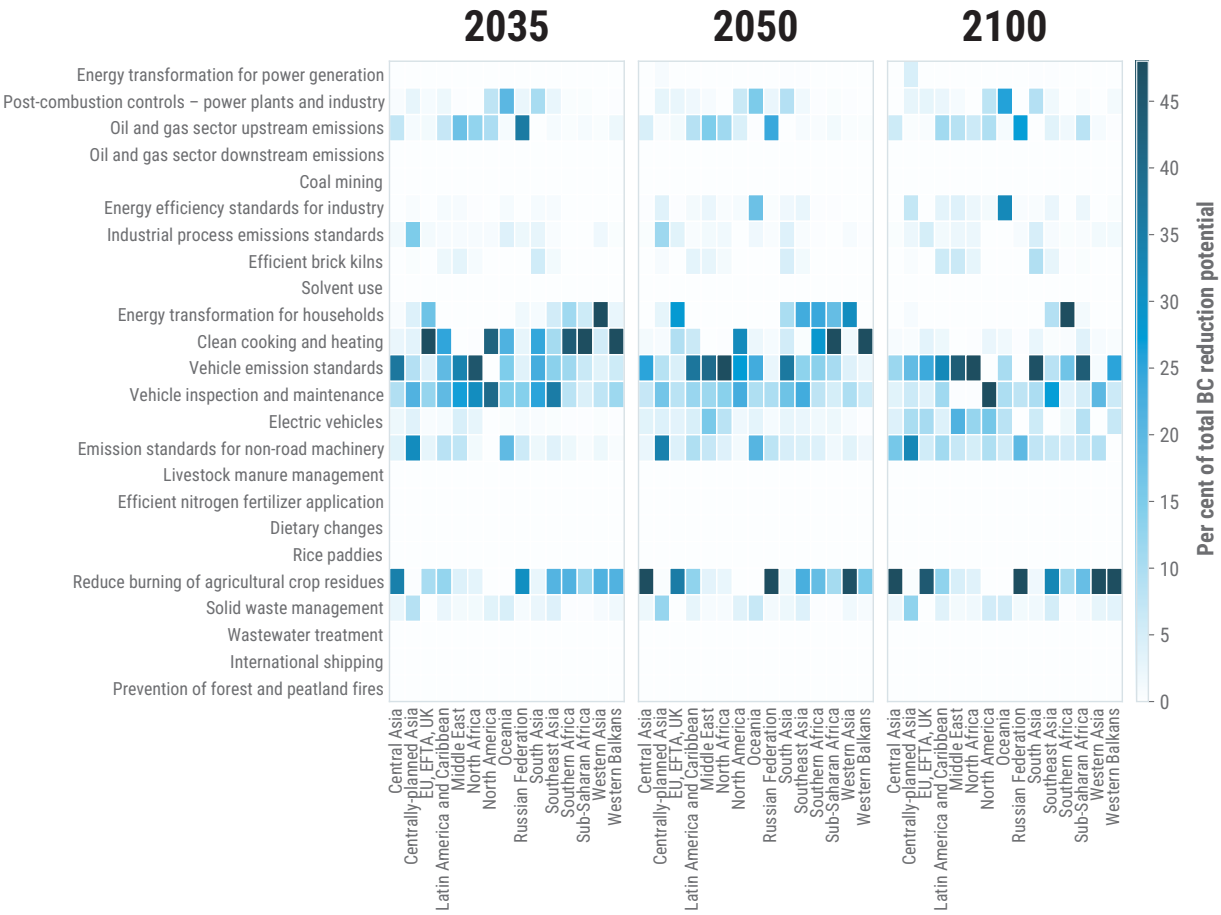
- Solutions targeting methane emissions from fossil fuel production and distribution have the greatest impact in the first few decades, as the transition to a low-carbon economy drives a steady decline in coal and oil use.

- Solid waste and wastewater management, by contrast, plays a role throughout the entire time horizon, delivering both methane and black carbon mitigation, with regional differences shaped by economic development and corresponding waste-generation potential.

Regional differences matter because some mitigation pathways show strong regional specificity. For black carbon emissions, this stems from differences in household access to energy, transport systems, and industrial technologies. Effective black carbon mitigation strategies therefore align with national and sub-national circumstances and are best integrated into country-specific NDCs and air quality management plans.

Methane mitigation, by contrast, displays a more globally consistent sectoral structure, though important regional differences remain in dominant sources and mitigation options. A small number of key sectors offer the largest mitigation opportunities, either available across all regions, such as waste and agriculture, or concentrated among a small number of regional and global operators, such as oil and gas. This concentration enhances the feasibility of international cooperation and coordination, standardised regulatory approaches, and collective initiatives such as the Global Methane Pledge (GMP), alongside emerging coalitions of willing actors, particularly multinational companies, working through pledges, alliances, and similar initiatives.

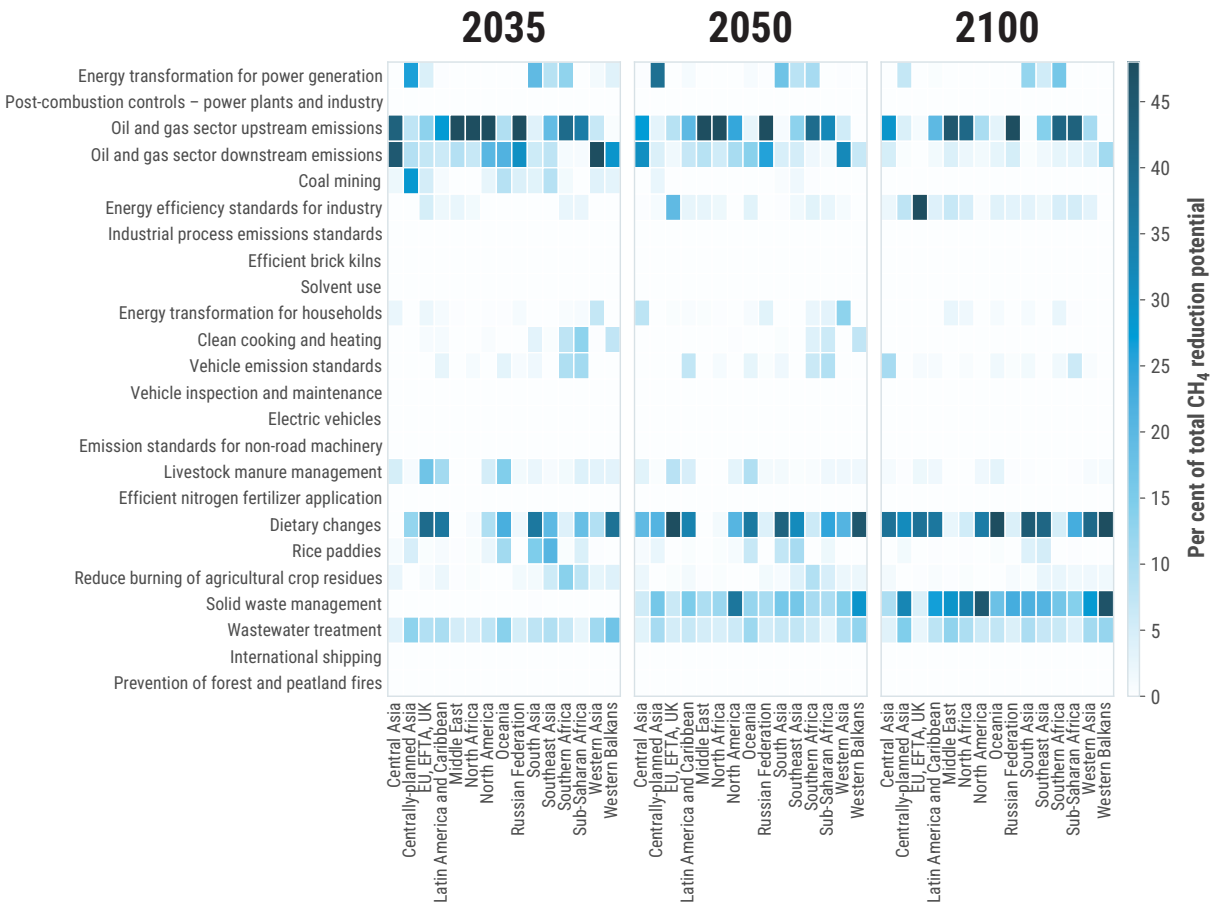
Figure 2.8: **Relative importance of different solutions for black carbon emission reductions as a percentage of the total reduction potential within each region in the integrated action scenario, 2035, 2050 and 2100.**



© AdobeStock/Verin



Figure 2.9: Relative importance of different solutions for methane emission reduction as a percentage of the total reduction potential within each region in the integrated action scenario, 2035, 2050 and 2100.



Black carbon and methane play complementary roles in achieving near- and medium-term climate objectives. Black carbon mitigation offers rapid, regionally targeted opportunities to deliver immediate climate and health benefits (see also Chapter 3), while methane mitigation is essential for stabilizing warming over the medium-term through focused action in a small number of high-impact sectors. An integrated strategy that simultaneously addresses black carbon and methane can enhance the effectiveness, equity, and political feasibility of pathways consistent with the 1.5 °C goal.

While the black carbon and methane are recognised as the key SLCPs, the solutions identified in this Assessment will bring significant reductions to others, including carbon monoxide and non-methane volatile organic compounds, contributing to reduced warming, and benefiting health and crop yields following a decline in ozone concentrations.

2.5 Quantifying implementation costs of the scenarios

Once key mitigation measures have been identified and assessed as part of the integrated action scenario, a crucial question is what the cost will be to governments and businesses implementing them. Although investment and operating costs are needed to achieve the level of mitigation required, this Assessment shows that the magnitude varies over time by sector and region with the overall cost being comparable to that in the baseline scenario and falling as a proportion of GDP over the course of the century. Costs of reducing emissions are also reduced by structural changes to the sectors, such as moving from fossil fuel dependence to energy generated from renewable sources.

The MESSAGEix and GAINS models calculate solution costs including investment costs plus fixed and variable operating costs (often referred to as engineering costs) (Box 2.3). The latter include labour costs, non-labour operation and maintenance costs,

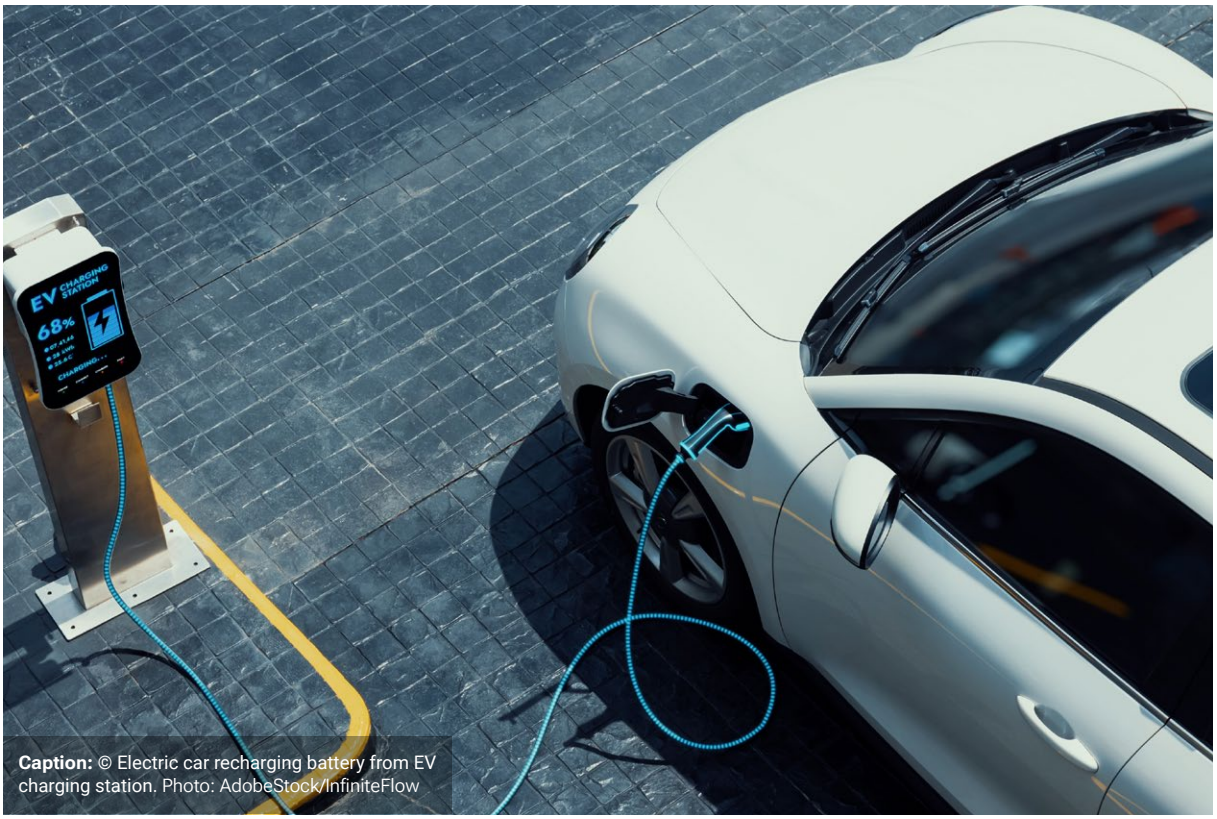
cost-savings from recovered or reduced demand for electricity, heat, or gas, and non-energy cost savings such as avoided landfill fees. Unit costs equal the sum of annualised investment costs (CapEx), calculated over each technology's lifetime, and annual operating costs (OpEx) divided per capacity or activity level of concerned source. These unit costs also vary due to various source specific factors, e.g., plant (also farm) size distribution, utilization factors, fuel quality and technology lifetimes, which can differ across regions (Amann *et al*. 2011; Klimont and Winiwarter 2015; Purohit and Höglund-Isaksson 2017; Winiwarter *et al*. 2018; Huppmann *et al*. 2019; Höglund-Isaksson *et al*. 2020; Krey *et al*. 2020).

Costs are technology- and region-specific and investment costs are incorporated into the modelling based on currently available data. The components of the cost estimates for air pollution and climate mitigation are discussed in Box 2.3.

The general assumption is that a free global market exists for emissions control technologies, making the same technology available to all countries. In reality, some markets are dominated by locally developed technologies available only within a specific region, often with lower efficiency, durability, or safety standards that limit their global applicability. Information on the costs of such technologies is also often unavailable or poorly documented.

Cost uncertainty exists, particularly where data on specific interventions is limited, but overall costs are considered robust, drawing on data compiled over many decades. Costs for technological solutions are typically well documented. For solutions involving management practices or behavioural change, however, data is sparse and often not comparable, making it difficult to produce a representative, broadly applicable estimate. Examples include reducing open burning of agricultural residue, enforcing bans on waste burning, forest fire management, and dietary change. For this reason, this Assessment excludes costs for reducing forest and peat fires and for dietary shift strategies; for the latter, Annex 1.3 contains a discussion of the potential global costs of transformation.

Where cost data are limited or available for only for a small number of countries, such as for ammonia emissions from livestock and non-methane volatile organic compound emissions from industrial solvent, overall costs are estimated by extrapolating from regions where data are available, which can lead to under- or overestimation of costs in some regions.



Caption: © Electric car recharging battery from EV charging station. Photo: AdobeStock/InfiniteFlow

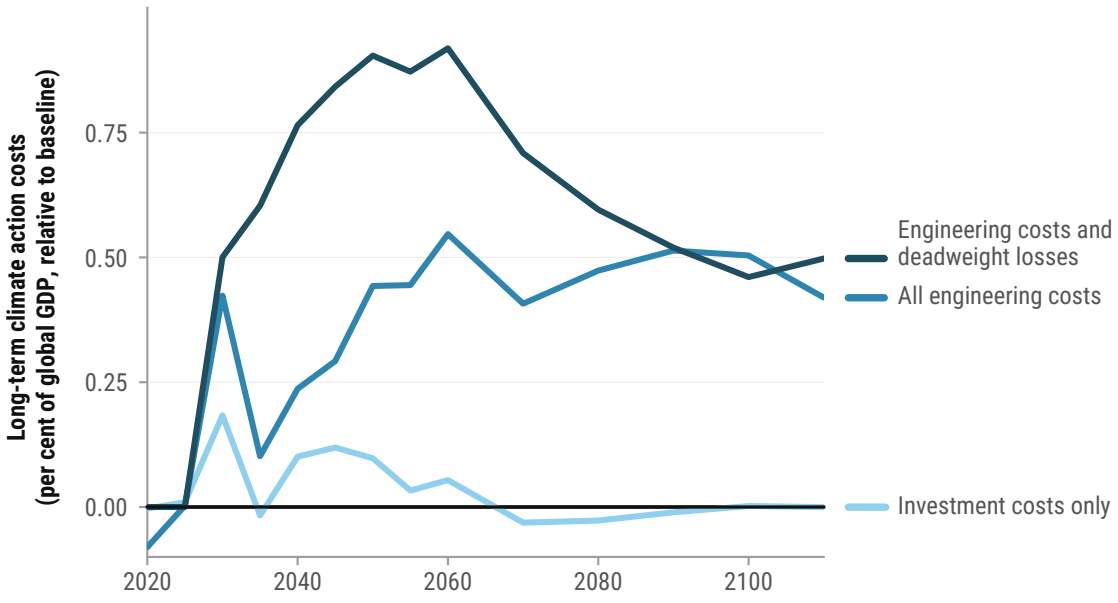
Box 2.3: Components of costs estimates

This Assessment uses engineering costs to measure the cost of implementing the 25 solutions. Engineering costs cover what it actually costs to build, operate and maintain the infrastructure and equipment required, for example, the cost of installing a clean cookstove or upgrading an industrial facility. For climate, these are calculated as net nodal costs: the total construction, operation and maintenance costs across the transport and energy system, which exceed direct investment costs alone because they capture the full system-level expenditure (Figure 2.10).

Engineering costs do not capture broader macroeconomic consequences of policy. When policies raise the price of fossil fuels or high-emission goods, those higher prices reduce demand. Some economic activity that would otherwise have occurred no longer takes place, and the value lost as a result is termed deadweight loss. In the case of climate policy, deadweight losses depend upon the scale of production changes in the economy, revenue recycling practices and the current level of economic efficiency in the economy. It is generally estimated that deadweight losses increase the total costs of environmental policies by around 50 per cent, relative to engineering costs alone (Nordhaus 1991, Czyzewski *et al*. 2020). In this Assessment deadweight losses are only estimated for the four long-term climate solutions, and are not estimated for the 21 clean air and near-term climate solutions. For consistency, engineering costs are used throughout both solution groups. This means the full economic consequences of policies (consisting of both engineering costs and deadweight losses) are somewhat higher than costs reported above. However, full economic costs are still expected to be much lower than the benefits of climate and clean air solutions. The total economic benefits presented in Chapter 3 far exceed full economic costs by 2035.

Figure 2.10 covers policy costs only and does not include the economic benefits of the transition itself, such as the potential for accelerated growth from public investment, reduced healthcare expenditure, or improved labour productivity. Healthcare and labour productivity benefits are quantified separately in Chapter 3.

Figure 2.10: Components of cost analysis.



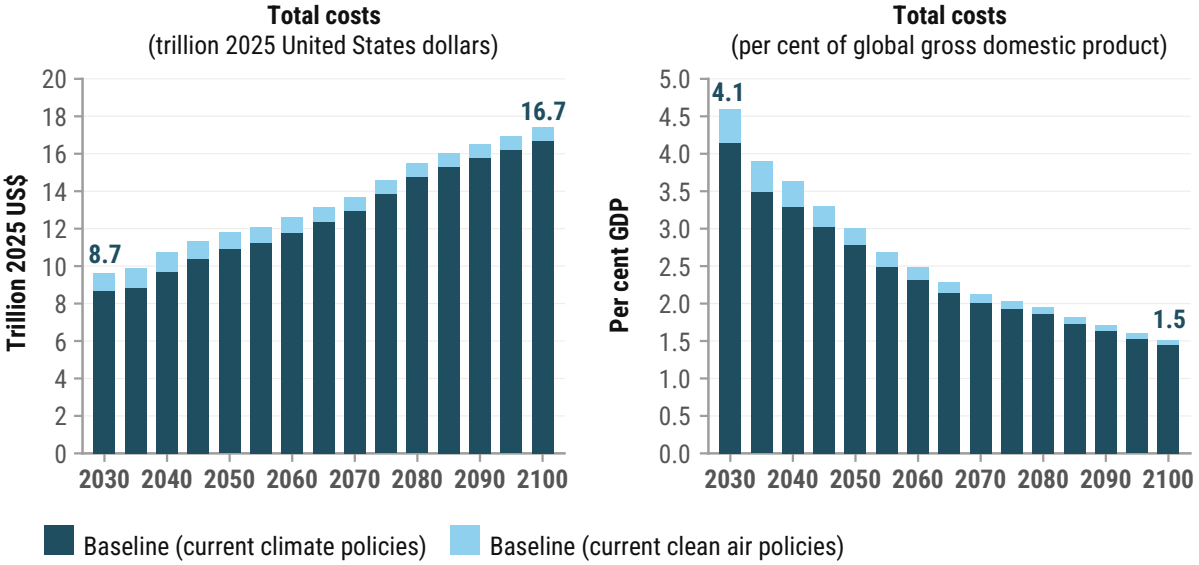
2.5.1 Climate and air pollution control costs in the baseline scenario

As described above, the baseline scenario assumes full implementation of already-planned climate and air pollution policies but introduces no new policies beyond these commitments. Applying the cost methodology, this Assessment calculates that the global costs of implementing solutions to comply with current air pollution legislation and climate commitments will be nearly US$ 10 trillion per year in 2030 at (constant 2025 US dollar prices) (Figure 2.11 left). The cost of implementing just the air pollution policies represents approximately 10 per cent of the total in 2030, approximately US$ 1 trillion per year. These costs are projected to increase steadily, reaching approximately US$ 17 trillion per year in 2100. The growth in total costs is driven almost entirely by increasing investment in climate mitigation, as the costs of air-pollution management remain largely stable, at 2030 levels, throughout the century (Figure 2.11, left).

These costs, however, are expected to decline as a percentage of global GDP from more than 4.5 per cent in 2030 to approximately 1.5 per cent by 2100 (Figure 2.11, right), due to projected GDP growth (Figure 2.11). The costs for air pollution policies alone are equivalent to about 0.5 per cent of global GDP in 2030, declining to about 0.1 per cent by 2100.

Current policies include existing source legislation for stationary, mobile, as well as agriculture sources prescribing emission limit values for air pollutants or types of control measures necessary to receive permit for operation. Such legislation exists in all regions but their stringency varies; review of policies included in the GAINS model has been documented in the past (Klimont *et al*. 2017; Rao *et al*. 2017; Amann *et al.* 2020; World Bank 2025). Similarly, implementation of the baseline scenario in MESSAGE assumes achievement of current climate policies, which are based on the Climate Policy Database (Nascimento *et al*. 2022). The estimated annual costs in the baseline (Figure 2.11) represent current commitments and therefore, in this Assessment these are not additional expenditures.

Figure 2.11: Comparison of global costs of the current clean-air policies and climate policies in the baseline scenario, 2030–2100, (left) trillion 2025 United States dollars and (right) per cent of global gross domestic product.



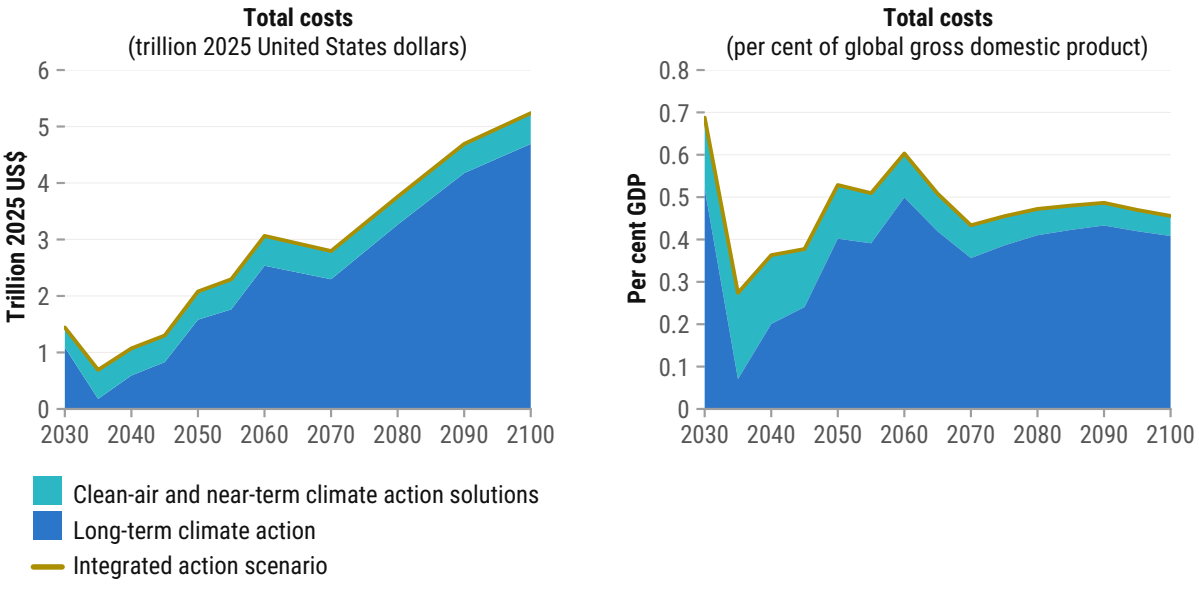
2.5.2 Costs of implementing the 25 integrated solutions

Total implementation costs of the 25 integrated solutions are estimated at approximately US$ 1.5 trillion per year in the coming decade, rising to over US$ 5 trillion per year (constant 2025 US dollars) by end of century. As a share of future GDP, however, these costs are initially equivalent to about 0.7 per cent of global GDP but decline to approximately 0.5 per cent by end of century (Figure 2.12).

Successful implementation of the integrated action scenario requires an initial investment of nearly US$ 1.5 trillion in 2030 (Figure 2.12, left panel). The four long-term climate solutions account for nearly two-thirds of this early investment, with the 21 clean air and near-term solutions making up the remaining one third. Costs decrease quickly following this initial investment to approximately US$ 700 billion per year by 2035, followed by a steady increase for the remainder of the century (Figure 2.12, right panel). In the first decades, the additional costs of the 21 clean air and near-term climate solutions represent up to 50 per cent of the total cost. While they are expected to steadily increase in absolute terms (Figure 2.12, left panel), due to estimated strong increase in cost of long-term climate solutions, their share declines strongly over time to about 10 per cent of total costs at the end of the century.

This initial investment for clean air and near-term action is driven mainly by early spending in waste management, including wastewater treatment, municipal solid waste management, and industrial solid waste management. Although the scenario also includes spending to control methane losses from fossil fuel production and distribution, their impact on total costs remains relatively small, owing to the strong reduction in fossil fuel use driven by the four long-term climate solutions and the relatively low costs of these solutions. The major part of the early additional investments is associated with achievement of the NDCs (UNFCCC 2025); owing to the current geopolitical situation 'weak' NDCs are assumed. The necessary system restructuring and resulting carbon price is typically high but after achieving the 2030 targets there is a slowdown resulting in declining additional investments before they start increasing steeply to achieve the national net-zero targets. These are derived based on the national goals set by the countries, which are then treated cumulatively over time within a given region to finally reach net-zero in 2100. The path from 2030 NDCs is linearly interpolated to the net-zero target, which avoids the model delaying the achievement of net-zero targets until 'the last minute', which would create even larger drops after 2030 and increase the spikes at the time of net-zero.

Figure 2.12: Global additional costs of mitigation in the integrated action scenario compared to the baseline, 2030–2100, (left) trillion 2025 United States dollars and (right) per cent of global gross domestic product.



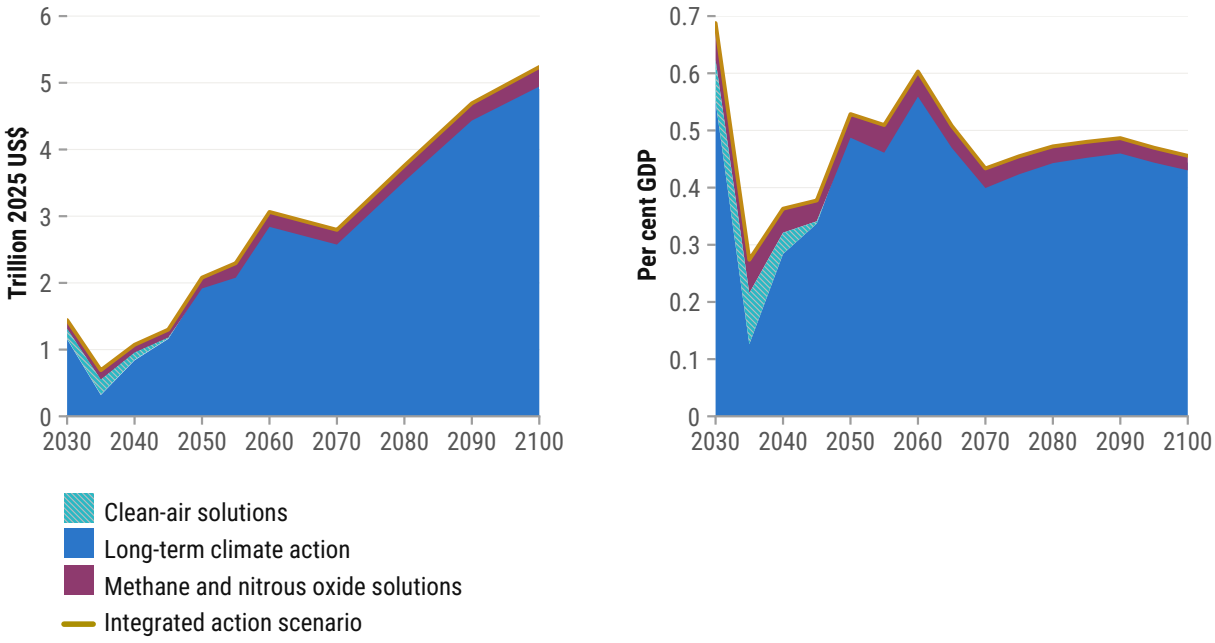
Note: see also Figures in Annex 1.4.

Costs for the 21 clean air and near-term climate solutions, taken together, remain fairly constant throughout the century, estimated in 2025 US dollars at approximately US$ 500 billion per year. Relative to GDP, costs associated with this group are estimated to decline by a factor of approximately five, falling to less than 0.1 per cent of global GDP by end of the century (A1.4 in Annex 1). This stability holds despite strong economic growth, and structural changes in the economy and energy system, including rapid implementation of the long-term climate solutions. The regional distribution of these costs shifts substantially over time, with an increasing share occurring in Sub-Saharan Africa and the Middle East (Figure 2.14).

Dietary transformation ranks among the key solutions for delivering significant reductions in methane, nitrous oxide and ammonia (Figures A1.1 and A1.2 in Annex 1.2), but its costs are not quantified in this Assessment, though discussed in Annex 1.3. As a result, the overall costs shown in Figure 2.13 are likely underestimated.

Within the 21 clean-air and near-term climate solutions, the air-pollution measures alone follow a distinct cost trajectory. Investment to implement them rises initially in the near-term, but absolute spending on air-pollution mitigation falls below expenditure levels in the baseline scenario by 2050. Between 2030 and 2050, these measures account for roughly half of the total cost of implementing the 21 solutions, but their additional cost above the baseline scenario falls to zero by 2050, even as overall global spending on air-pollution control continues (Figure 2.13).

Figure 2.13: Global cost of mitigation in the integrated action scenario discriminating between solutions targeting air pollution, long-term climate objectives, methane and nitrous oxide, 2030–2100, (left) trillion 2025 United States dollars and (right) per cent of global gross domestic product.



Two forces drive this decline. First, the four long-term climate solutions reshape the energy system in ways that directly reduce the need for pollution control technology since the shift toward renewables in power generation and industry, alongside the transition to EVs, is central to this group of solutions. Eliminating coal power plants, for example, eliminates the need for gas cleaning technology altogether and declining sales of new internal combustion engines reduce costs for expensive exhaust treatment. Second, the shift to clean fuels and electrification for cooking directly reduces solid fuel use, lowering the cost of the air-pollution measures that target this source. Together, these effects emerge quickly and grow over time, steadily narrowing the gap between the baseline and the integrated action scenario spending on air pollution control until it closes entirely.

2.5.3 Regional distribution of costs

In the first decades, more than 40 per cent of expenditure occurs in Asia, more than a quarter in

Organisation for Economic Co-operation and Development (OECD) countries, and less than 15 per cent in Africa (Figure 2.14). In the second half of the century, Africa's share rises to about a quarter of total costs, while Asia's share drops below 20 per cent and the OECD share remains the same. The decline in Asia's costs is driven by reduced demand for emission controls from fossil fuels used in power, industry, and transport, alongside a sharp reduction in reliance on biomass for cooking. Africa, in contrast, faces significant population growth, currently has only modest emission controls in power and industry even as it develops substantial processing capacity, and is yet to address waste management.

Figure 2.14: Regional distribution of costs for clean-air and near-term climate solutions in the integrated action scenario, 2035, 2050 and 2100, in billion 2025 United States dollars spent in each region annually. The largest costs for a given region in a particular year shows as the number in each cell, the size of the bars in each column shows costs relative to this highest value.

Region	2035	2050	2100
Central Asia	6	6	8
Centrally-planned Asia	77	50	25
EU, EFTA, UK	19	12	9
Latin America and Caribbean	51	53	65
Middle East	55	57	106
North Africa	20	18	21
North America	70	111	102
Oceania	13	11	11
Russian Federation	37	33	25
South Asia	75	58	40
Southeast Asia	27	21	19
Southern Africa	11	13	19
Sub-Saharan Africa	41	46	87
Western Asia	9	9	9
West Balkans	1	1	0

2.6 Unlocking the mitigation opportunities: why enabling implementation matters

The 25 integrated solutions only deliver results if countries are able to effectively implement them at scale. Early implementation is essential, since foregone near-term emissions reductions cannot be fully recovered later. Strong, effective enabling environments can accelerate implementation by up to a decade and substantially increase reductions in $PM_{2.5}$ and ozone precursors during the 2025–2050 period. Effective implementation means turning policy on paper into fast action on the ground. Yet the factors affecting how rapidly, consistently, and sustainably, countries make that transition are typically given less emphasis in data-driven scenario analyses than the solutions themselves.

Technical, economic, social, and institutional factors determine whether implementation succeeds. These include whether key agencies have incentives to work across sectoral silos, investors are motivated to provide sufficient initial capital, civil society groups can ensure equity and gender considerations are factored into planning, and supportive technologies allow innovation to scale. Gender-responsive implementation also depends on who participates in decision-making, who has access to finance and technologies, who controls household and productive resources, how time burdens are distributed, and how social norms shape adoption and benefit-sharing. Institutional and

social enablers, in particular, are difficult to quantify and are therefore rarely captured systematically in scenario modelling.

This Assessment uses a novel data-driven approach to assess how implementation barriers and enablers could influence the achievement of benefits from the *integrated action* scenario (Box 2.4). The approach draws on *barrier assessment surveys* of 120 experts across China, India, Mexico, and Nigeria, approximately 30 per country, complemented by a literature review of barriers to implementing a subset of eight solutions. The surveys covered solar and wind energy, clean cookstoves and clean fuels for cooking, and different waste management approaches, mapping three of the 25 integrated solutions: energy transformation for power generation; clean cooking and heating; and solid waste management.

The four countries were selected for their population size, varying levels of development, and extensive experience implementing many of these solutions. They also offer valuable insight into building an effective enabling environment (Chapter 4).

The barrier assessment survey evaluates how much technical, economic, social, and institutional barriers (Table 2.4) could slow implementation of solutions over a 15-year horizon, relative to full implementation of the *integrated action* scenario. Combining survey data with a literature review, the assessment estimates how an illustrative set of barriers can delay implementation, while identifying enabling reforms that can bring policymakers closer to the Integrated action scenario's outcomes. This indicative approach allows the assessment to gauge how much the enabling environment matters for maximizing benefits. Box 2.3 provides further details methodological details on estimating delays.

Table 2.4: Description of the implementation barriers (See also Chapter 4 for additional details).

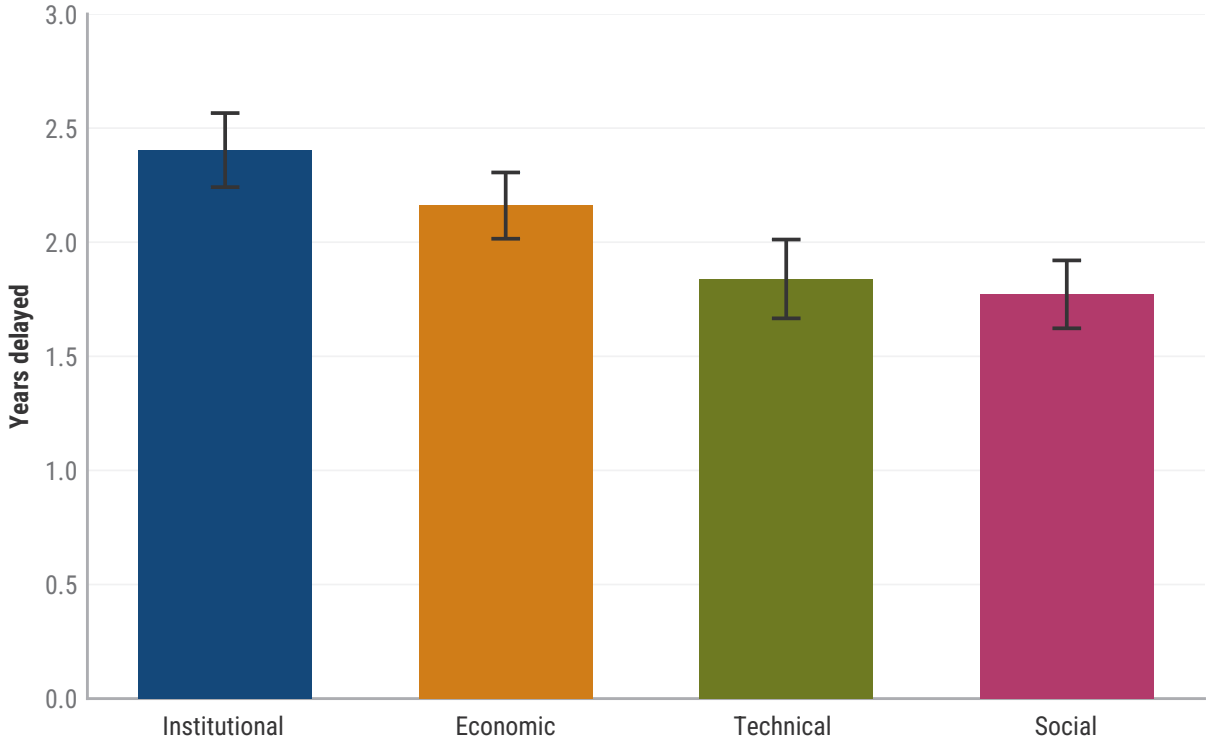
Categories	Challenges
Technical	• The lack of access to cleaner technology/fuels • The lack of technologies/infrastructure enabling the implementation of a cleaner solution
Economic	• The costs of cleaner technology/fuels • Policies (i.e. subsidies) that lower cost of resource-intensive options
Social	• The limited acceptance or awareness of benefits of the cleaner alternatives • The lack of stakeholder engagement mechanisms for selecting cleaner options
Institutional	• The lack of interagency coordination/capacity • Design flaws in policies

This Assessment estimates that implementation of the solutions could be delayed by approximately 7.5–8 years on average globally, summing the delays attributable to each barrier. Institutional barriers prove most critical to achieving the full benefits of the integrated action scenario, followed by economic, technical, and social ones. Left unaddressed, institutional barriers alone could slow transitions by approximately 2.4 years over a notional 15-year period (Figure 2.15).

Institutional issues are prominent because institutions are inherently crosscutting, shaping social, technical and financial enablers alike. Institutional coordination and administrative capacities, for instance, directly influence implementation effort and shape government and stakeholder willingness to invest in supporting technologies, public finance, and resources for awareness-raising programmes. Overcoming these institutional barriers such as siloed decision-making and limited enforcement capacity is particularly important, since these barriers affect not only the

25 solutions directly but also other enablers, such as public-finance allocation and investment climates. This finding aligns with a recent World Bank report (World Bank 2025) and a growing emphasis on enablers from the IPCC, both of which underline the need to strengthen institutions and governance to accelerate implementation.

Figure 2.15: The relative importance of different barriers, years delayed.

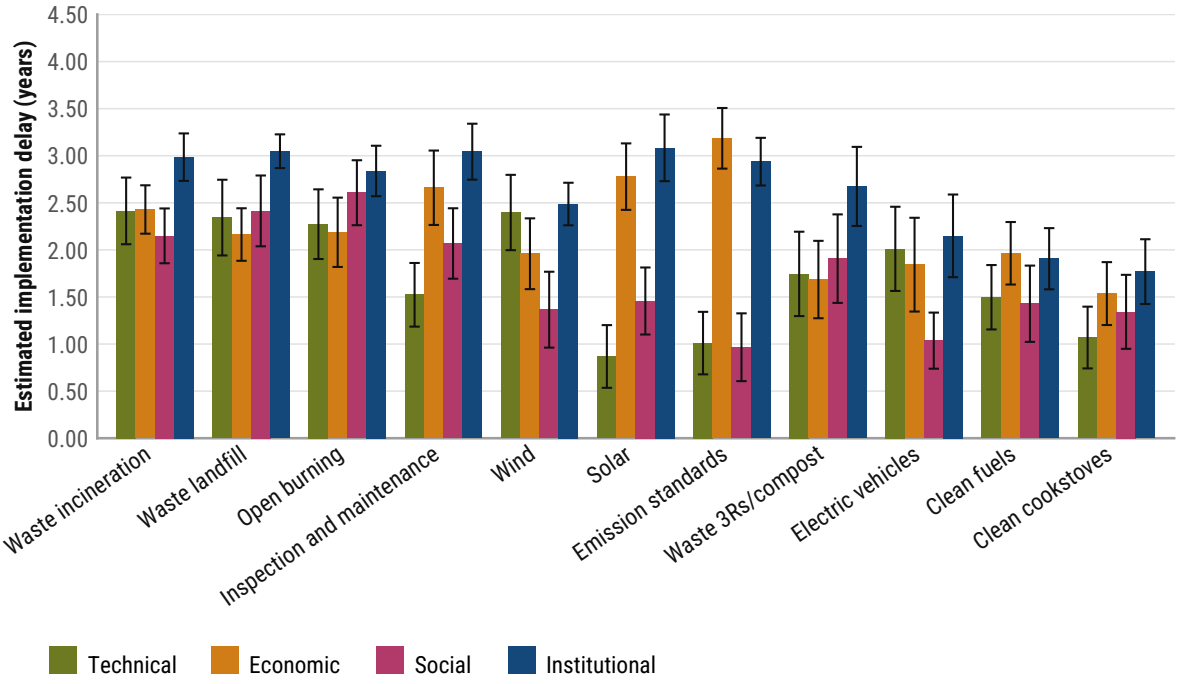


Note: The error bars reflect upper and lower ranges of 95 per cent confidence intervals for all solutions for each type of barrier for the 4 countries, China, India, Mexico and Nigeria.

Results show how much enabling reforms matter across different contexts. Applying this Assessment to Delhi, India, for example, shows that slower achievement of national air quality standards, delayed by the same 7–8 years estimated globally, significantly increases the population's cumulative $PM_{2.5}$ exposure. Starting in 2026 with no delay, the cumulative exposure burden falls by 20 per cent by 2040; with an 8-year delay, it falls by only 10 per cent. This translates into substantially greater health impacts over the period (Box A1.1 in Annex 1.5).

This approach can also assess how different enablers affect different solutions. In Mexico, strengthening institutional and economic factors offers significant scope to improve implementation of emissions standards (Figure 2.16). Addressing the open burning of agricultural waste, by contrast, requires a more holistic approach spanning a broader range of enablers.

Figure 2.16: The effects of different implementation barriers on key solutions in Mexico.

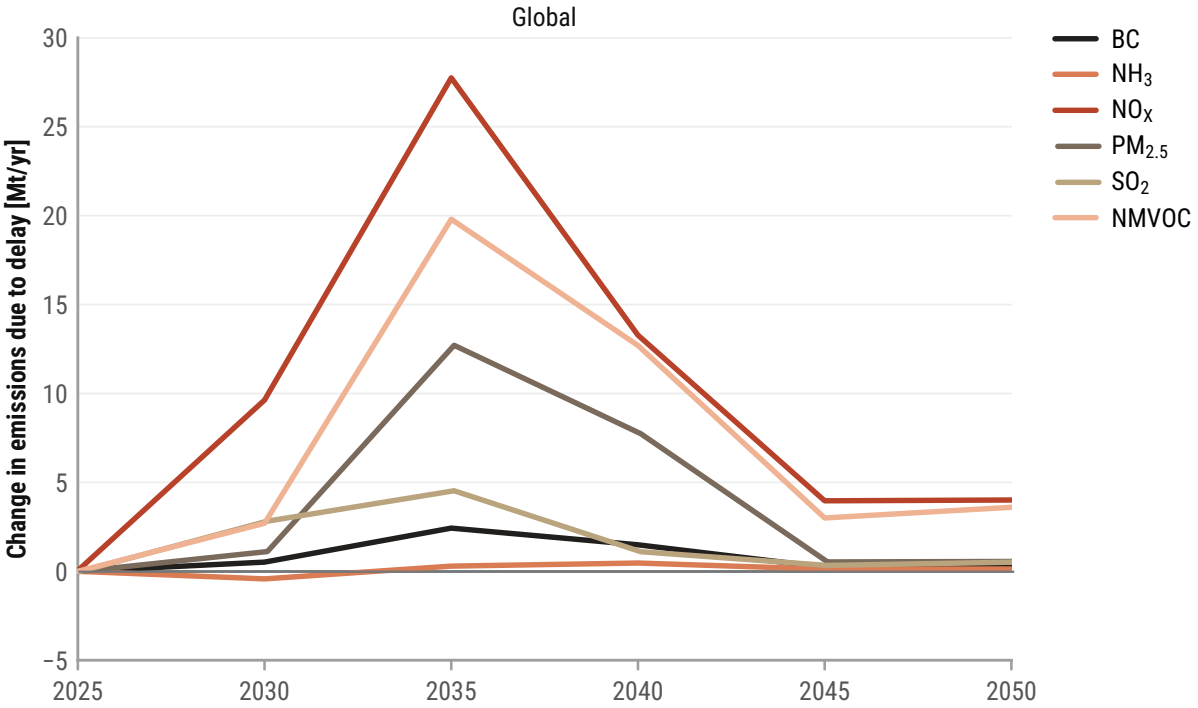


Note: The error bars reflect upper and lower ranges of 95 per cent confidence intervals based on survey data.

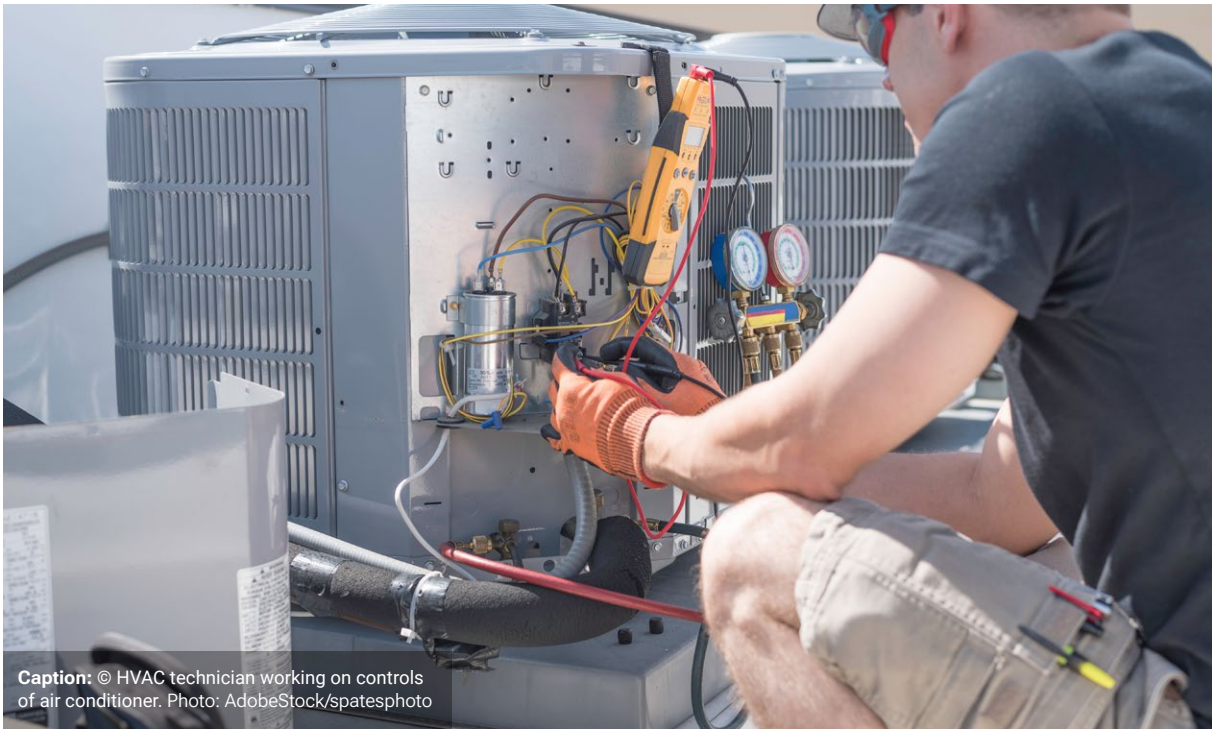
Extrapolating the survey data and literature review from the four featured countries to countries with similar enabling environments makes it possible to estimate the effects of these scenarios across much of the world. This Assessment compares scenarios with 5, 7.5, and 10-year implementation delays against a technically maximal feasible scenario, for countries grouped by similarity of enabling environment (Box A3.1 and Annex 3).

Weak enabling environments increase emissions globally, with the degree of increase varying by pollutant and by how strongly enablers affect implementation speed across regions (Figure 2.17). The late 2020s to early 2030s represent a critical window for maximizing the benefits of integrated climate and air pollution solutions. Timely implementation of solutions targeting methane, black carbon, and tropospheric ozone precursors during this period drives rapid reductions in near-term warming and $PM_{2.5}$ exposure. Slower action, by contrast, prolongs harmful emissions, causing avoidable health impacts, additional warming, and agricultural losses. These effects are especially pronounced for black carbon and $PM_{2.5}$, for which early reductions yield immediate health benefits, and for methane, for which delay weakens the effectiveness of near-term climate mitigation.

Figure 2.17: The effects of implementation barriers on global emissions of key precursors of fine particulate matter and tropospheric ozone globally, 2025–2050, million tonnes per year.

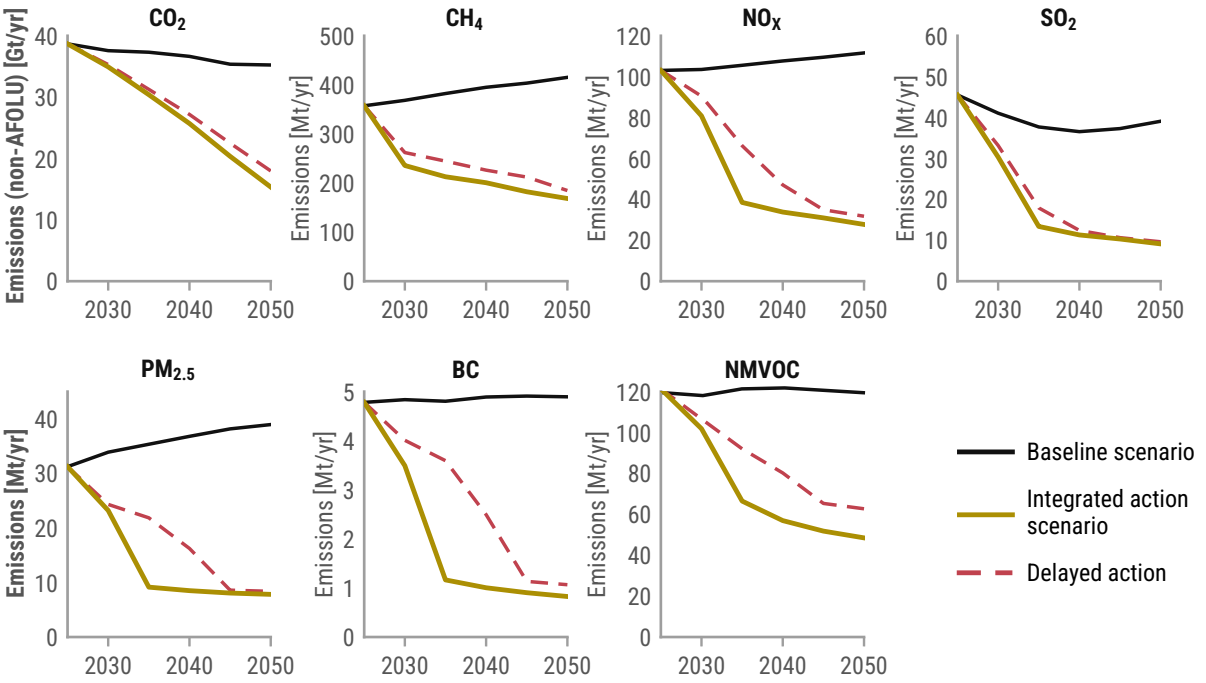


Delayed implementation significantly affects the trajectory of all emissions for 2025 – 2050, with slower action risking irreversible climate and health impacts. Figure 2.18 shows that total anthropogenic emissions of greenhouse gases, $PM_{2.5}$ and ozone precursors in the period 2025 – 2050 remain higher under delayed implementation. By 2035, for example, when the difference is the largest if implementation is delayed, only half, or even less for black carbon, of the mitigation potential is achieved compared to the integrated action scenario under which timely and effective implementation is considered.



Caption: © HVAC technician working on controls of air conditioner. Photo: AdobeStock/spatesphoto

Figure 2.18: The impact of delayed action on global anthropogenic emissions of precursors of fine particulate matter and tropospheric ozone, compared to the effective and timely implementation of solutions, 2025–2050, carbon dioxide billion tonnes per year, others million tonnes per year.



The damage caused by higher emissions in earlier decades is irreversible. Additional warming, excess premature deaths from air pollution, and crop yield losses accumulated under slower implementation cannot simply be offset by stronger action later, underlining that timing matters as much as long-term ambition. Policies that slow implementation, whether due to institutional, financial, technological, or social constraints, risk undermining near-term health and development gains. Integrating air pollution into NDCs, long-term low-emission development strategies (LT-LEDS), air-quality management plans, and sectoral policies is therefore essential, with a strong focus on rapid deployment in the 2020s and early 2030s. Understanding how enablers and barriers affect health impacts (Chapter 3), together with a more systematic approach to building an enabling environment (Chapter 4), are equally critical to capturing the full benefits of accelerated implementation.



Box 2.4: Methods for estimating implementation delays

This study estimates how different barriers can slow implementation of key climate and air pollution solutions through a five-step process.

First, approximately 30 experts from China, India, Mexico and Nigeria assessed the effects of four barrier types on implementing a representative subset of solutions from the energy, transport, waste and agricultural sectors. These four countries, which together represent about 40 per cent of the world's population, were selected for their differing levels of development, governance arrangements, and experience with the solutions. The solutions assessed were limited to keep the survey concise and ensure that the experts had the requisite knowledge to respond.

The survey covered four types of barriers: economic, technical, social, and institutional. Experts rated each barrier's effect on implementation speed as none, small, moderate, or significant; these ratings were then converted into numerical values for comparison and averaging (Annex 3). To complement the survey, the authors also reviewed published studies on the same solutions, assessing how strongly each barrier was described in the literature. Barriers mentioned frequently and characterised as major issues received a significant rating, while those mentioned only briefly or indirectly received a lower score.

Survey results and literature review findings were then combined into an overall score for each barrier type, with greater weight given to the survey results, since these reflected more recent practitioner and policymaker views, while the literature was generally older and covered broader topics.

The authors then translated these barrier scores into delay estimates, assuming that solutions could be implemented over a 15-year period under ideal conditions. Greater barriers produce longer delays; for example, a 20 per cent reduction in adoption pace translates into a delay of approximately three years over the 15-year period.

After calculating delays for each solution in the four countries, the researchers extrapolated similar delays to other countries by comparing four indicators reflecting the conditions needed to support climate and clean-air action: government effectiveness, innovation capacity, income levels, and social capital. Countries with similar conditions were assigned similar delays. Finally, these delay estimates were incorporated into an emissions and health model to assess how slower implementation would affect air pollution greenhouse gas emissions and public health outcomes.

03 Benefits and costs



Caption: © Household bins for waste sorting in the kitchen. Photo: AdobeStock/Fevziie

Key messages

This Assessment applies state-of-the-art tools and methods to quantify the health impacts of current and future pollution levels and climate burdens, as well as the health and economic benefits of the 25 integrated solutions presented in Chapter 2. Together, the solutions target clean air and near-term climate change to deliver rapid climate benefits, substantial improvements in air quality, and support for long-term decarbonization pathways. Implementing all 25 integrated solutions creates opportunities for greater efficiency, confirms the economic rationale for immediate action, and unlocks benefits that separate climate and air pollution policies cannot achieve.

- Implementing all 25 integrated solutions generates a benefit-cost ratio of 15 (15:1), at a total cost that remains under 0.6 per cent of global gross domestic product (GDP) throughout the century. Total avoided damage, combining market and non-market benefits, reach the equivalent of 4.5 per cent of global GDP by 2050 (US$ 13 trillion in constant 2025) and 11.4 per cent by 2100 (US$ 48 trillion). The economic case for action is not marginal: the internal rate of return on integrated action is 60 per cent, placing it on par with the highest-impact public investments anywhere in the global economy.

- In 2025, ambient fine particulate matter ($PM_{2.5}$) and ground level ozone caused 6.4 million premature deaths worldwide (IQR 5.2–7.3 million here and throughout), corresponding to approximately 91 million life years lost. Indoor air pollution from solid fuel cooking added an estimated 2 (1.8–2.2) million deaths, including nearly 300,000 (260,000–330,000) children. Beyond mortality, $PM_{2.5}$ exposure alone is associated annually with 5.5 (4.7–6.2) million new cases of childhood asthma, 22 per cent of all cases; 4.2 (3.3–4.9) million heart attacks, 20 per cent of all cases; 2.5 (2.0–2.9) million strokes, 20 per cent of all cases; 2.0 (1.6–2.3) million cases of dementia, 19 per cent of all cases; and 0.5 (0.4–0.58) million cases of lung cancer, 19 per cent of all cases, all in people who did not previously have these conditions. Without further action, the share of the global population exposed to the most dangerous

$PM_{2.5}$ concentrations will rise from 27 per cent in 2025 to 34 per cent by 2050. Full implementation of the 25 integrated solutions would almost eliminate these highest exposure ranges and avoid 60 – 70 per cent of the total air pollution health burden annually.

- The current level of global warming is estimated to cause 360,000 premature deaths per year. Premature death rates from cardiovascular problems, diseases and weakened immune systems are expected to rise as temperatures increase, particularly in the hottest regions of the world. Full implementation of the 25 integrated solutions is projected to avoid 200 million premature deaths due to air pollution and climate change by 2050.

- Market benefits from reduced healthcare costs and higher productivity alone exceed the total costs of implementing the 25 integrated solutions by 2035. Adding non-market benefits, reflecting the value people place on quality of life, brings the total benefit-cost ratio to 7 – 8 by 2035. These returns are not deferred: air pollution benefits begin to accrue immediately once solutions are implemented, meaning that the economic case for action strengthens with every year that action is brought forward. Each year of delay forgoes more than 0.5 per cent of global GDP in benefits, equivalent to more than US$ 1.5 trillion in combined market and non-market value, around a decade later.

- The 25 integrated solutions avoid approximately 0.34 ºC (95% CI 0.1–0.6) of warming by 2050 and 1.4 °C by 2100, reducing sea-level rise from an estimate of about 1 metre (m) to 0.8 metres by 2100 and saving around 130,000 lives per year by 2050, many due to avoided heat stress, rising to approximately 600,000 per year by 2100 from avoided warming alone. Importantly, the pollution reductions produced by only the four long-term climate solutions generate economic benefits that exceed their climate benefits up to 2070, meaning that even before long-term climate damage is avoided, the air quality benefits alone make the investment worthwhile.

- The economic returns from integrated action are highest in the world's most vulnerable regions. Benefit-cost ratios range from 3 in high-income regions to 26 in Southern Africa, reflecting the prevalence of health and climate risks in lower-income countries. Approximately 95 per cent of premature deaths attributable to air pollution occur in low- and middle-income countries, and regions in South Asia, Sub-Saharan Africa and the Middle East face combined pollution and climate risks equivalent to more than 5 per cent of regional GDP by 2100.

- The analysis identifies significant gender differences in the disease burden of air pollutants, with dementia disproportionately affecting women and lung cancer and childhood asthma more prevalent in men. Other differences have been identified that lead to heightened risk for women and girls. They tend to spend more time in the home which can lead to heightened exposure to air pollution. They are also relied on disproportionately for collecting biomass fuels, reducing opportunity for education and paid employment. Collecting firewood has also been associated with increased risk of sexual violence. These factors demonstrate the breadth of the wider impacts associated with activities and with the 25 solutions considered here in order to optimise policy design.

- The 25 integrated solutions generate additional economic benefits beyond those quantified in this Assessment, making the Assessment estimates conservative. These include further human health, food production, ecosystem and water quality benefits and, improvements in the urban environment, such as to reduced congestion, as well as socio-economic and gender equity benefits. Evidence indicates that trade-offs tend to be small relative to the benefits of action.

3.1 Methods for quantifying air quality and climate benefits

The chapter examines the current status of air pollution and climate change, baseline trends, and how the 25 integrated solutions affect population exposure to air pollution and public health. The analysis quantifies health impacts, including deaths, associated loss of life expectancy; and cases of long-term health conditions such as asthma in children, as well as the economic consequences of these impacts. The chapter then examines three areas:

- how emissions in the baseline and integrated action scenarios affect air pollution concentrations and climate indicators globally and regionally throughout this century and the resulting impacts on sea-level rise, coastal storm surges, trade and capital losses, human health, agricultural productivity and market-related risks to GDP;
- the economic benefits of implementing the solutions contained in the integrated action scenario, relative to the baseline, for individual outcomes, as well as the overall impact on the global economy;
- how the costs of implementing the solutions compare with their economic benefits over this century. The analysis distinguishes benefits from avoided climate change and air pollution damage, market and non-market benefits, and the effects of long-term climate action and clean air and near-term climate solutions.

The methods used to quantify climate and air quality benefits are summarised in Box 3.1 below, with further information in Annex 2 (e.g. the overview of impacts covered in the Assessment in Table A2.1). Section 3.6 describes further impacts of the solutions on crops, ecosystems, and other outcomes not modelled in detail (see also Annex 2.7).



Box 3.1: Methods

Building on the emissions under different scenarios and from Chapter 2, this chapter uses the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model (Amann et al. 2011, 2020) and Policy Analysis of the Greenhouse Effect (PAGE) model (Rising 2026, Annex 2.3) to quantify the health and economic benefits of policy actions. The baseline GDP and population levels follow SSP2 projections and feed into the Model for Energy Supply Strategy Alternatives and their general Environmental Impact (MESSAGE) (Huppmann et al. 2019) model which also computes policy costs for Long-term Climate Action while the GAINS model calculates the costs for the clean air and near-term climate actions. From the emissions of $PM_{2.5}$, SO_2, NO_x, NH_3, and NMVOC, GAINS calculates ambient concentrations of $PM_{2.5}$, while ozone changes, in response to each emission scenario, are calculated separately using the EMEP and GISS models, with results provided to GAINS for the evaluation of health impacts. The GAINS model then estimates mortality and morbidity impacts by health outcome using recently published response functions for Europe (WHO 2025), linking population weighted pollutant concentrations to health effects. The uncertainty in the exposure and relative risk are considered and the distribution of the attributable fraction modelled using Monte Carlo simulations (Annex 2.1). Adjustments, drawing on Burnett et al. (2022), modified the dose response functions used to enable quantification in regions where pollutant concentrations are significantly higher than the prescribed applicable range (Annex 2.1). The GAINS model computes productivity, health care, and disutility costs for each health outcome for 15 world regions, using results aggregated for 103 countries and regions in the GAINS model. Section 3.2 details the assumptions used to calculate economic gains from averted health impacts. For climate modelling, the Finite Amplitude Impulse Response (FaIR) model (Leach et al. 2021) uses greenhouse gases from MESSAGE and GAINS to estimate global temperature changes. Parameterised results from five Earth System Models are then used to downscale these changes to 183 regions. PAGE projects aggregate market and non-market, and sea-level rise impacts driven by temperature change, as well as auxiliary sector-specific impacts (Annex 2.3). The PAGE model uses statistical emulators of the GAINS health impacts. Regional statistical relationships estimate total $PM_{2.5}$ levels and translate those levels into morbidity and mortality outcomes (Annex 2.3.3). PAGE uses pollution policy costs and health benefits from GAINS to determine total economic consequences for the baseline and integrated action scenarios. Market impacts from climate and pollution affect the level of capital growth in PAGE, resulting in additional feedback effects. PAGE and GAINS both aggregate results into 15 world regions.

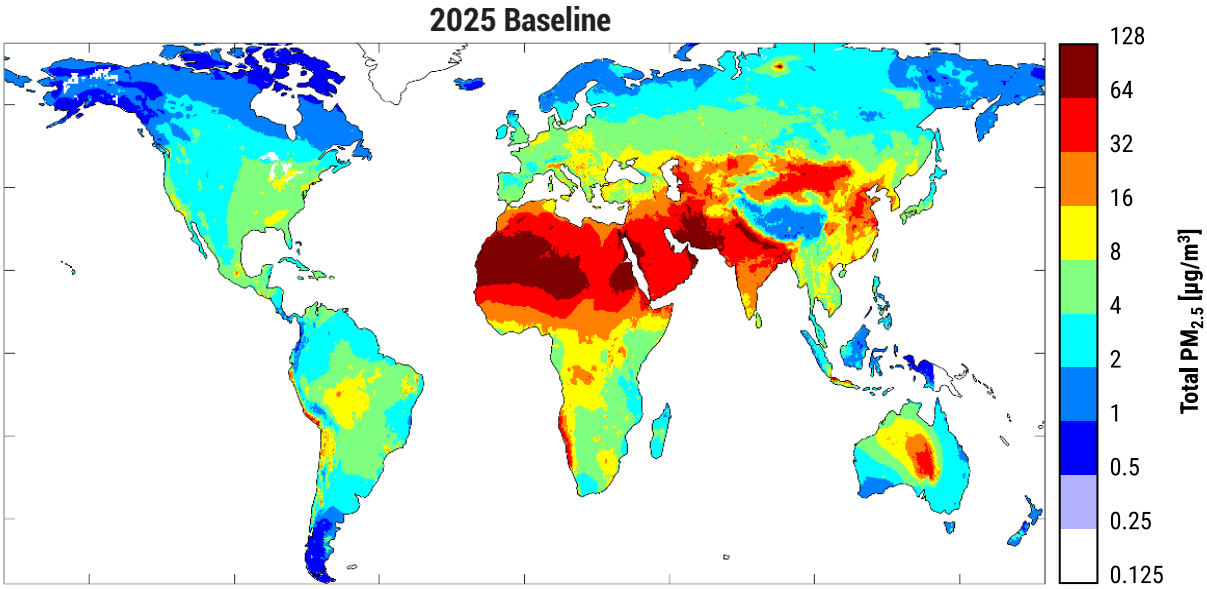
The assessment reports market and non-market damage (Annex 2.2) both as real 2025 US dollars, or their monetary equivalent for non-market impacts, or as a per cent of contemporaneous GDP, in purchasing-power parity (PPP) terms.

3.1.1 Exposure of people to air pollution under the baseline and integrated action scenarios

The World Health Organization (WHO) reported in 2019 that 99 per cent of the global population breathes air that exceeds its recommended air quality guidelines (WHO 2024a). This Assessment focuses on two key pollutants that cause the bulk of health impacts from air pollution globally, $PM_{2.5}$ and ozone, though noting that NO_2 is also important especially in urban settings (see section 3.6). The assessment gives more attention to $PM_{2.5}$ because associated health impacts are an order of magnitude larger than those of ozone.

Total $PM_{2.5}$ concentrations currently exceed the WHO 2021 Air Quality Guideline level of 5 micrograms per cubic metre ($\mu g/m^3$) as an annual average across most regions of the world (Figure 3.1). In many areas, however, natural sources dominate total concentrations, with particularly large contributions from desert dust in the Sahara and the Middle East. Although human activity influences emissions from natural sources, this Assessment does not consider direct control of these sources because the potential is limited.

Figure 3.1: GAINS model estimates of annual mean total concentrations of fine particulate matter, 2025, micrograms per cubic metre, logarithmic scale.



Note: sea regions are intentionally left blank.

Removing the natural dust component reveals the man-made, or anthropogenic, fraction of $PM_{2.5}$. All 25 integrated solutions analysed in this Assessment, apart from phasing-down hydrofluorocarbons (HFCs), can reduce this anthropogenic fraction. Anthropogenic $PM_{2.5}$ concentrations show clear hotspots in Europe and in South and East Asia (Figure 3.2). Elevated $PM_{2.5}$ levels are, however, widespread across much of the urbanised world, although Figure 3.2 does not fully show many cases due to the limited resolution of the map.

Figure 3.2: GAINS model estimates of anthropogenic fine particulate matter concentrations, 2025, micrograms per cubic metre, logarithmic scale.

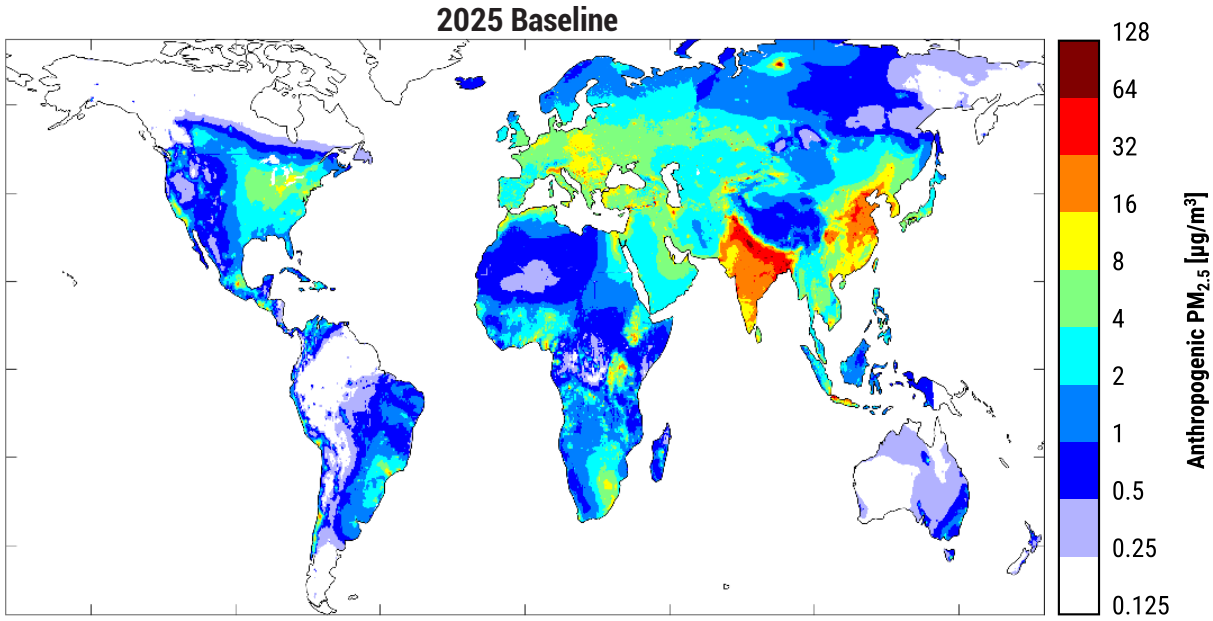
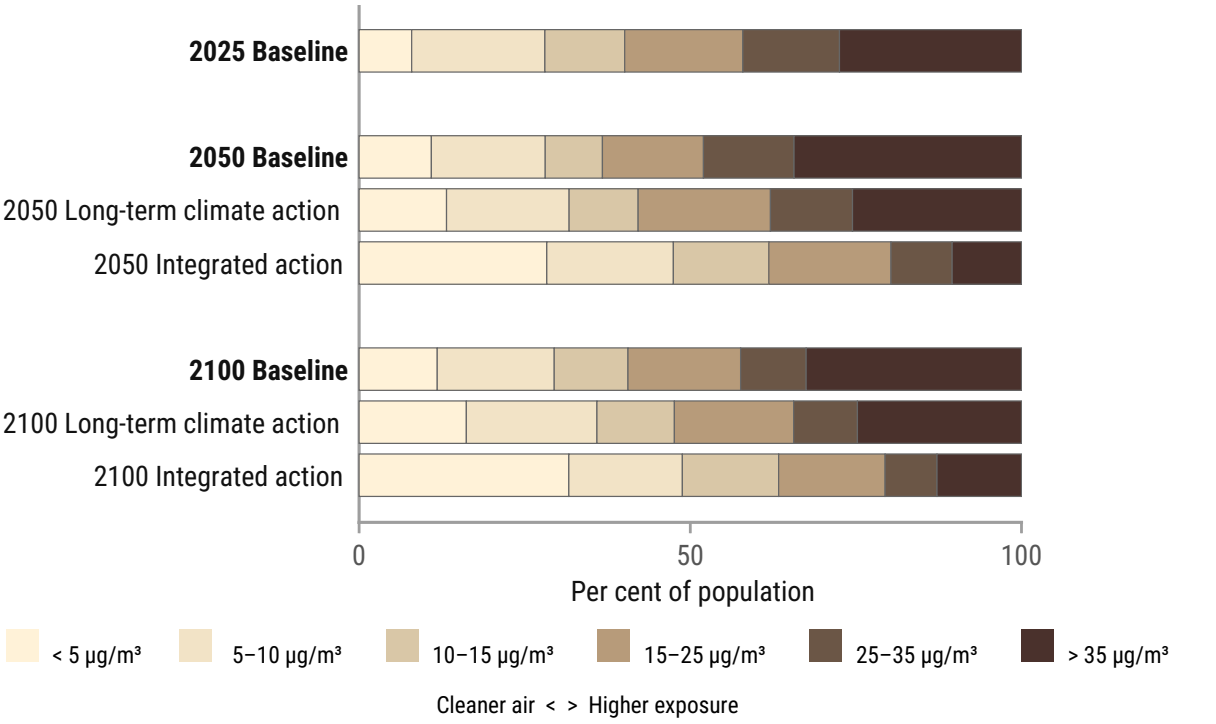


Figure 3.3 shows the proportion of the population exposed to $PM_{2.5}$ concentrations exceeding the WHO Air Quality Guideline of 5 $\mu g/m^3$ and the associated Interim target levels. In the 2025 baseline scenario, only 8 per cent of the global population breathes air that meets the WHO Guideline level, while concentrations above its Interim Target 1 of 35 $\mu g/m^3$ affect 27 per cent of the population. Interim Target 1 applies to regions with the highest pollutant levels. In the absence of action, this proportion will rise to 34 per cent in 2050.

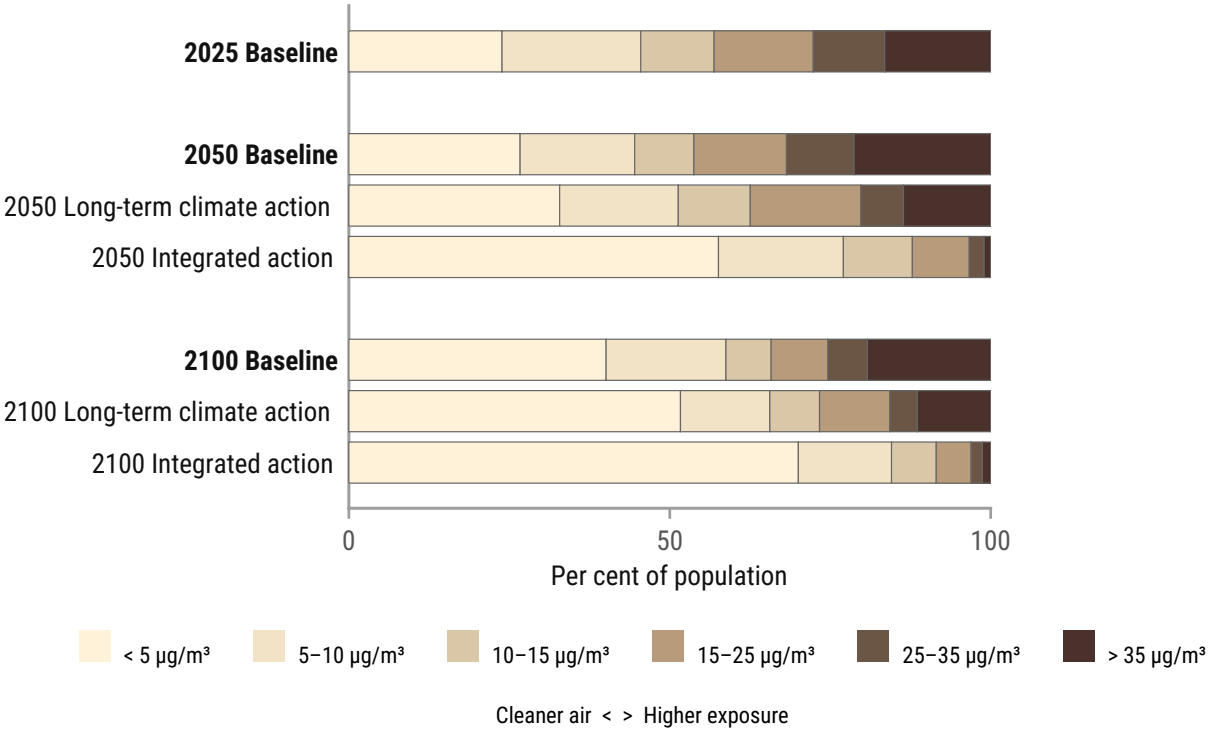
Figure 3.3: Global exposure to fine particulate matter from natural and anthropogenic sources, 2025, 2050, 2100, per cent of the global population exposed within concentration bands corresponding to the World Health Organization Air Quality Guideline of 5 micrograms per cubic metre and its Interim Targets.



Note: only the lowest band (<5 µg/m³) meets the Guideline value, whilst the highest band (>35 µg/m³) exceeds the Guideline and all the Interim targets.

Some regions of the world experience very high natural concentrations of $PM_{2.5}$ from deserts and other sources that are largely beyond human control. Evidence indicates possible health effects from natural dust, but this Assessment focuses on anthropogenic $PM_{2.5}$ as shown in Figure 3.2. After excluding all contributions from natural sources, less than a quarter of the global population currently breathes air with an annual average $PM_{2.5}$ concentration of less than 5 $\mu g/m^3$ (Figure 3.4).

Figure 3.4: Global exposure distribution to anthropogenic fine particulate matter, 2025, 2050 and 2100, per cent of the global population exposed within concentration bands corresponding to the World Health Organization Air Quality Guideline of 5 micrograms per cubic metre and its interim targets.

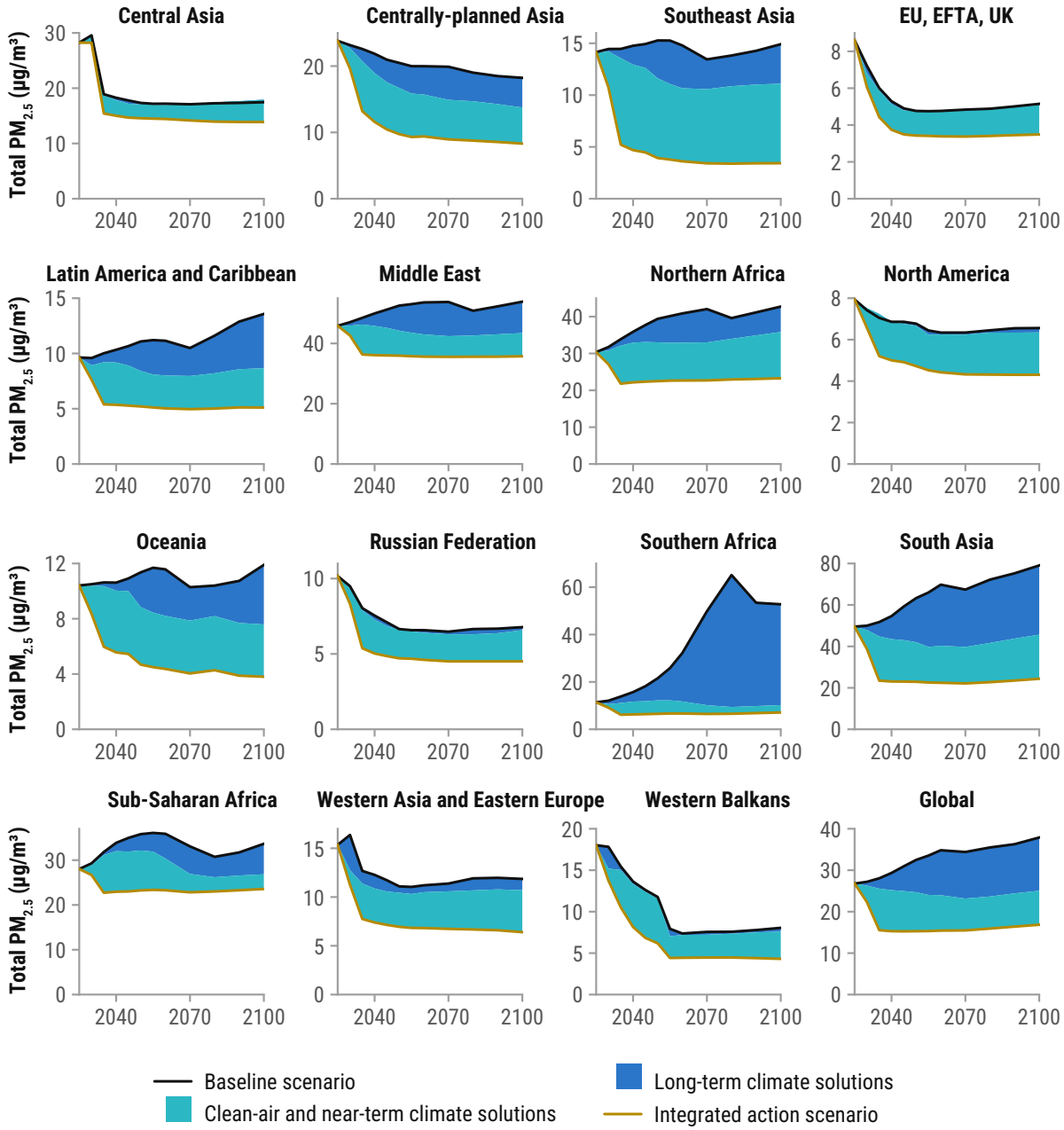


Note: only the lowest band (< 5 µg/m³) meets the Guideline value, whilst the highest band (> 35 µ/m³) exceeds the Guideline and all the interim targets.

Figures 3.3 and 3.4 show that the baseline scenario projects population growth in both the cleanest and most polluted exposure ranges. These trends reflect contrasting dynamics in different world regions relating to industry, environmental protections, population growth and other factors. While the four long-term climate solutions reduce the population exposed to concentrations above 35 $\mu g/m^3$ by a third, full application of the 25 integrated solutions would almost eliminate the highest exposure ranges (the last bar in Figure 3.4).

Without additional climate and air pollution policies, the Baseline scenario projects an increase in global average $PM_{2.5}$ concentration (Figure 3.5), consistent with the emission trends discussed in Chapter 2. Regional trends, however, differ substantially. Model projections indicate declining $PM_{2.5}$ concentrations under existing legislation in Central Asia, Centrally-planned Asia, Europe and North America. In contrast, projections indicate increasing concentrations throughout Africa, and in Latin America and the Caribbean, and Southeast Asia. In these projections, activity trends primarily drive concentration changes beyond 2050, while the projections hold emissions control legislation constant after 2050.

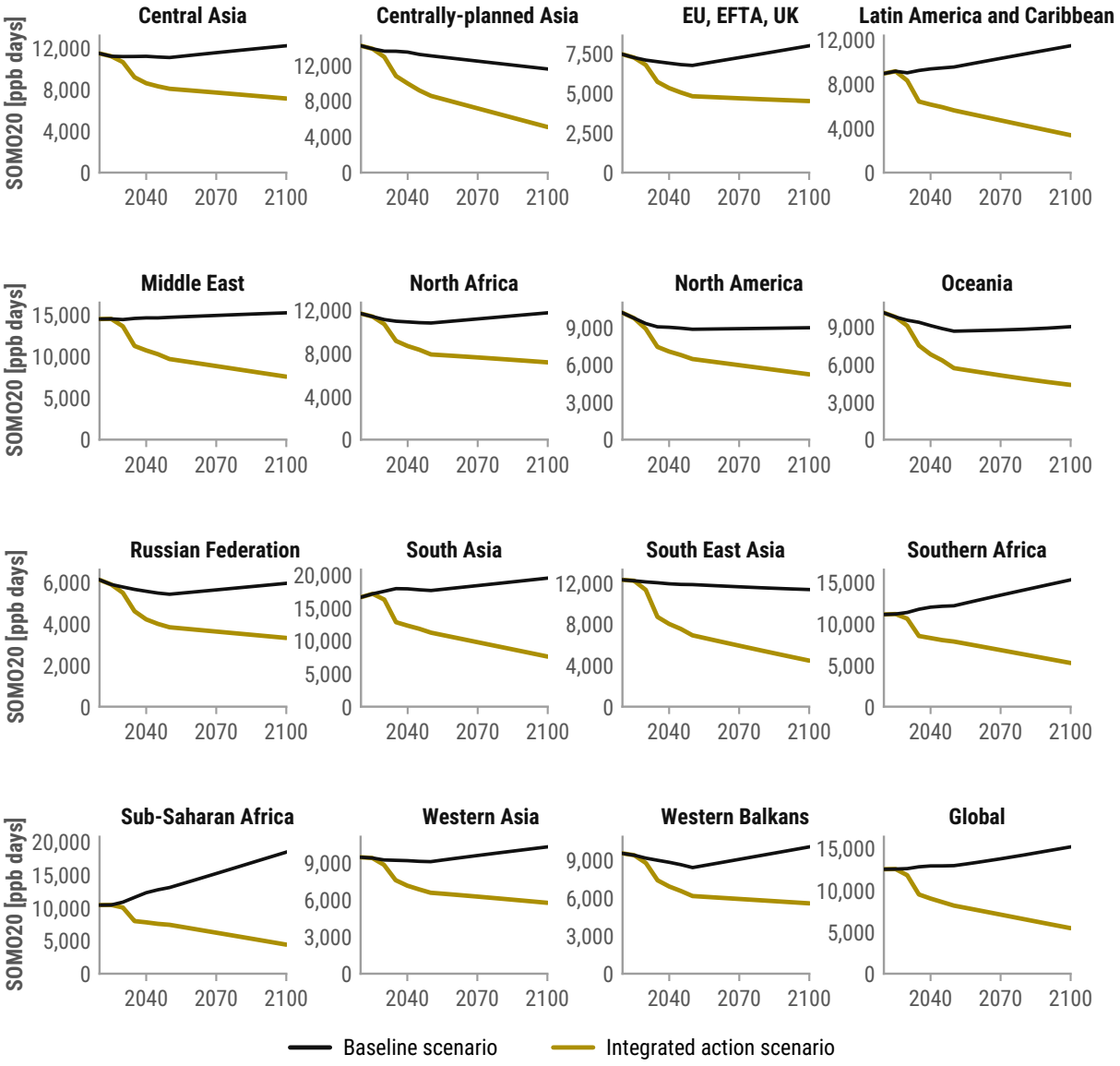
Figure 3.5: **Trends in total population-weighted mean fine particulate matter concentrations in selected world regions, as well as the global average, under the main scenarios, separated into long-term climate action, and clean air and near-term climate solutions, 2025–2100, micrograms per cubic metre.**



The 25 integrated solutions lead to dramatic global decreases in the world's population exposure to $PM_{2.5}$ pollution. This trend is the result of further decreases in regions in which emissions are already in decline, and substantial decreases in regions in which exposure would increase without further action - South and Southeast Asia, the Middle East, Latin America and Africa.

Without further action the baseline scenario projects increasing ozone concentrations in many parts of the globe (Figure 3.6). This Assessment uses the SOMO20 indicator as a measure for peak ozone concentrations for estimating health impacts. Long-range transport of pollution and global emission trends influence ozone much more strongly than $PM_{2.5}$ (van Caspel et al. 2024). Consequently, the trends differ from those for $PM_{2.5}$. The baseline scenario projects increasing peak ozone concentrations in some regions even with declining emissions under strong legislation, including the European Union. Trends shown in Figure 3.6 are likely too optimistic because the effect of increasing temperatures is not considered. Therefore, achieving substantial reductions in ozone everywhere requires global action. In the integrated action scenario, substantial reductions in ozone precursor emissions, including methane, cut peak ozone levels by 48 per cent on average globally in 2050, and by 78 per cent in 2100.

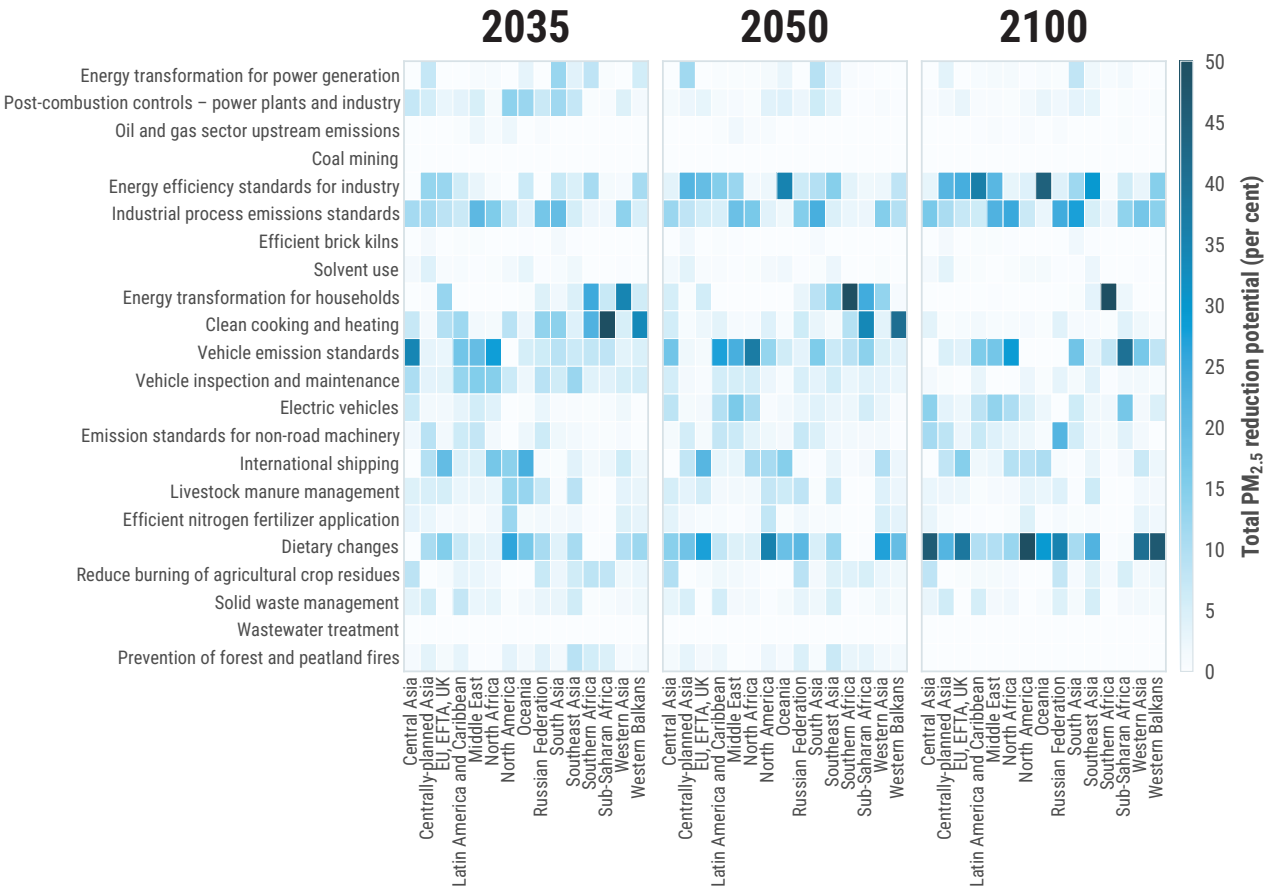
Figure 3.6: Trends in global peak ozone concentrations, expressed through the SOMO20 indicator, in the baseline and integrated action scenarios, global and selected regions, 2020-2100, ppt days.



Household air pollution remains a problem in the baseline scenario. In 2025, 24 per cent of the global population relied on solid fuels for cooking, leading to elevated indoor air pollution levels and increased health risks. Large differences exist between regions, with the least developed regions having the highest shares of the population without access to clean cooking fuels. In Africa, for instance, only 20 per cent of the population had access to clean cooking fuels in 2020. With increased economic development, the baseline scenario projects a slow decrease in the global share of the population using solid fuels for cooking, to 18 per cent in 2050 and 5 per cent in 2100. One single measure, one of the 25 integrated solutions, would address household air pollution rapidly: providing access to clean cooking. The integrated action scenario assumes that efficiently providing global access to clean cooking eliminates traditional use of solid fuel for cooking by 2035.

The potential of individual solutions to reduce ambient $PM_{2.5}$ exposure varies across regions and over time (Figure 3.7). In some regions, a single measure dominates the mitigation potential, whereas in others multiple solutions contribute equally. No single measure fully addresses the $PM_{2.5}$ burden in any region. Any one measure achieves at most 50 per cent of the total reduction potential in any region or year.

Figure 3.7: Relative importance of different solutions for reducing total fine particulate matter exposure in each region in 2035, 2050, and 2100, per cent.

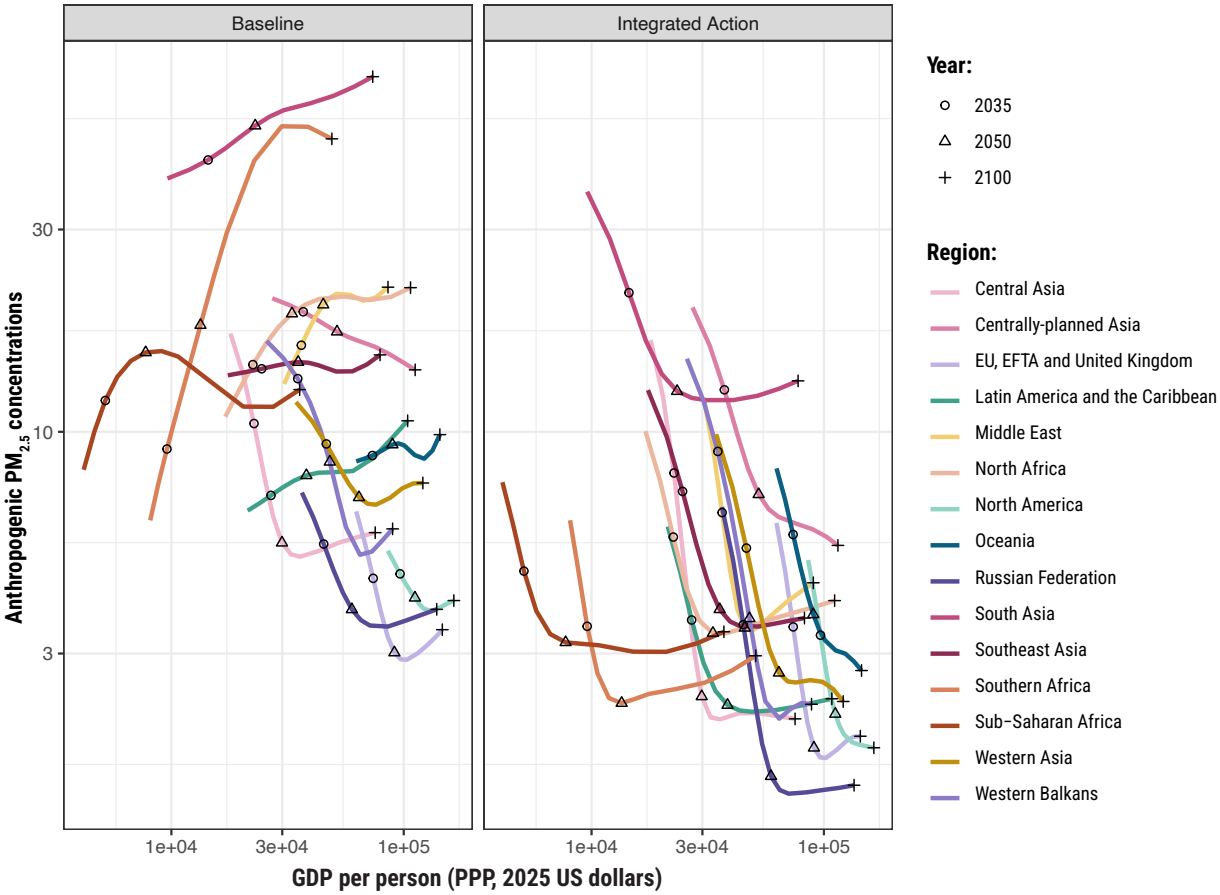


Note: percentages sum to 100 per cent for each region and year. The figure does not show the absolute reduction in 3 micrograms per cubic metre.

Certain solutions have global relevance, particularly those targeting improvements in industrial process efficiency. By contrast, many regions have already largely exploited the potential for additional end-of-pipe controls on large point sources. Solutions targeting the residential sector, such as fuel switching, improved energy efficiency and better insulation of homes, as well as the adoption of cleaner stoves, account for a large share of the mitigation potential in Africa, Europe and Western Asia. Road transport also offers substantial opportunities for reducing $PM_{2.5}$ exposure through tighter emission standards, mandatory inspection and maintenance programmes, and electrification. Dietary shifts to less meat-heavy diets have large potential in Europe, North America, and other high-income regions because of reductions of ammonia emissions from less meat production, which in turn leads to decreased formation of secondary inorganic aerosols. This is particularly relevant in the longer term when strong controls already cover most combustion sources. Solutions related to fossil fuel extraction and refining show limited impact on secondary aerosol formation in this analysis because they primarily target methane emissions, an ozone precursor, rather than $PM_{2.5}$ directly.

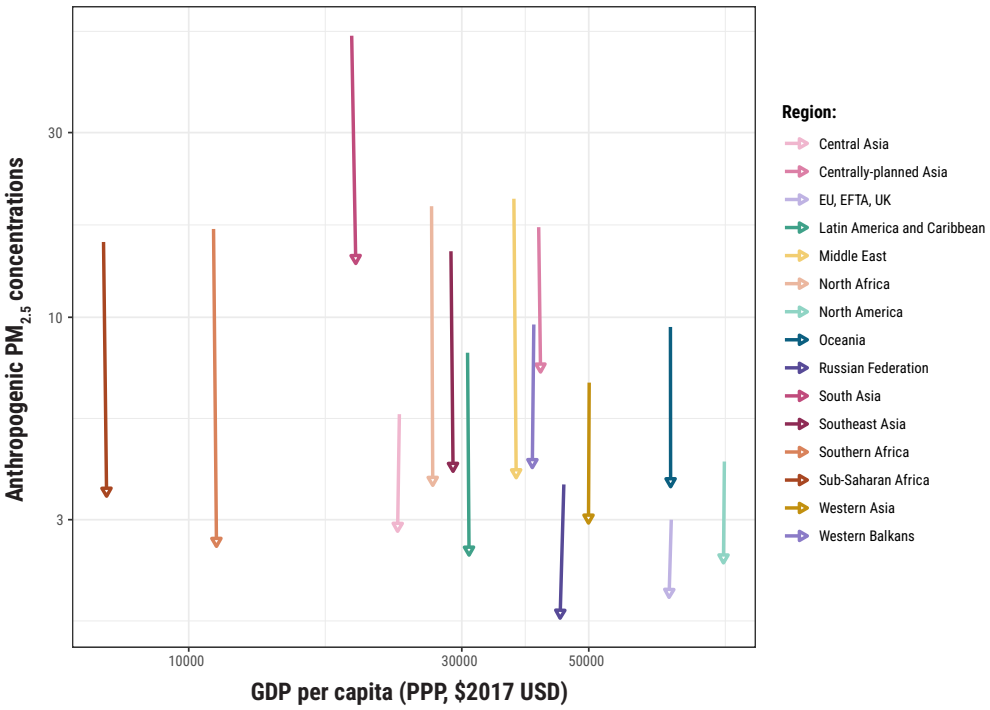
Economic growth and strong pollution controls work together to form a consistent development strategy. Figure 3.8 shows the evolution of incomes (along the horizontal axis) and $PM_{2.5}$ concentrations (on the vertical axis) over the century. Under the baseline scenario, pollution worsens with income growth in many regions. The integrated action scenario allows every region to break this trend. This Assessment demonstrates that pollution controls directly support economic growth as well.

Figure 3.8: The evolution of population-weighted anthropogenic fine particulate matter exposure, as regions become wealthier, 2035, 2050 and 2100, micrograms per cubic metre and 2025 United States dollars.



Under the integrated action scenario, clean air becomes less dependent on income, and clean air is distributed more equitably (Figure 3.9). Income and $PM_{2.5}$ concentrations currently show a strong relationship, with richer countries experiencing lower pollution. A shift from the baseline to the integrated action scenario reduces $PM_{2.5}$ across the globe, flattens this relationship and advances environmental justice.

Figure 3.9: The shift in exposure to population-weighted anthropogenic fine particulate matter concentrations from the baseline to the integrated action scenario, by region, across levels of income, 2050, micrograms per cubic metre and 2017 United States dollars.



Note: each arrow starts at the baseline values of $PM_{2.5}$ and income in 2050 and ends at the integrated action scenario values.

3.1.2 Health impacts of air pollution under the baseline and integrated action scenarios

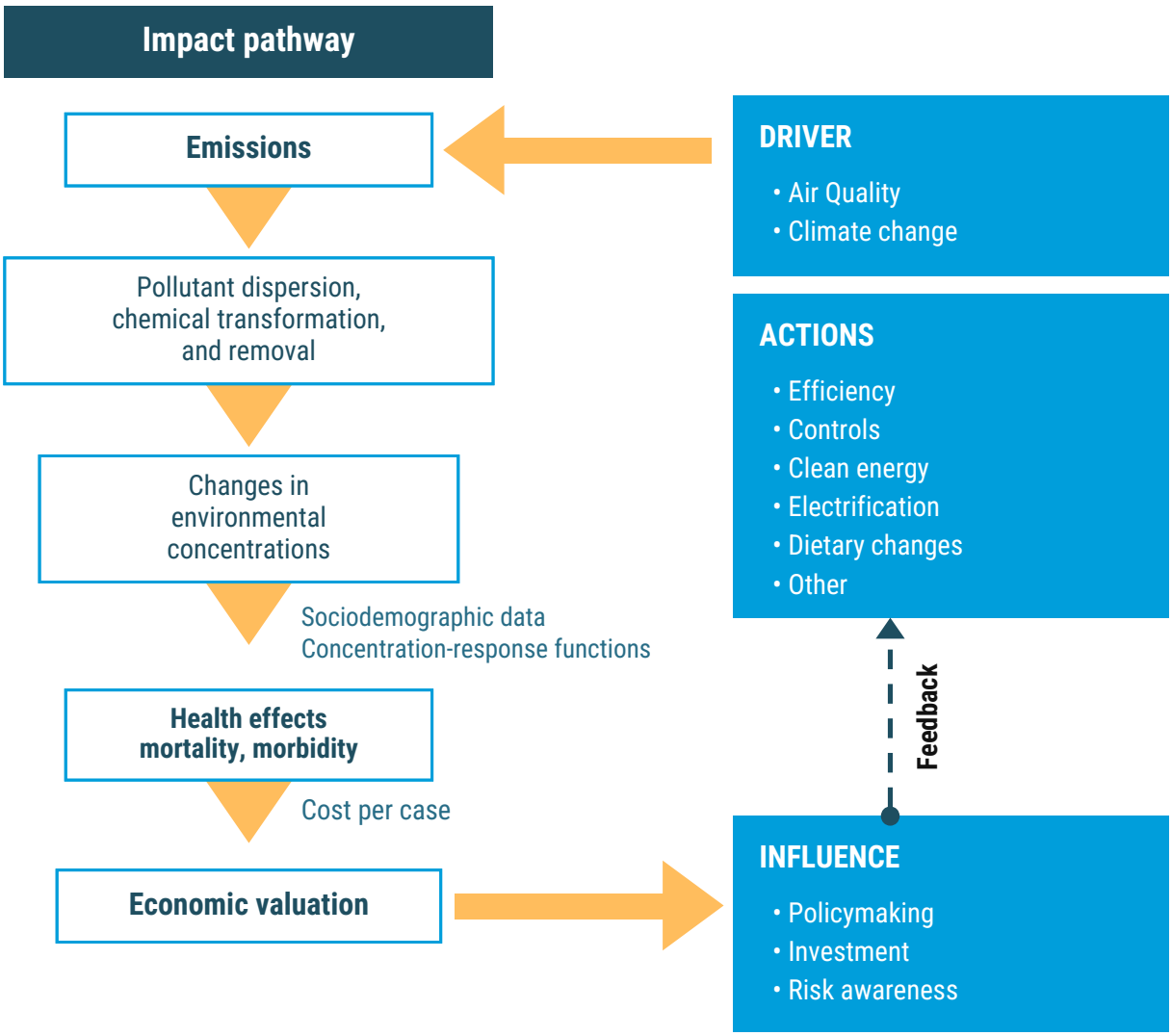
Approach

The health impacts of air pollution include increases in mortality and in levels of cardiovascular, respiratory, neurological and metabolic disease. Whilst many of these effects are most common in the adult population, some also harm infants and children and impair development. United States Environmental Protection Agency (USEPA) and others have conducted a series of causality assessments that considered the plausibility of various impact and pollutant combinations (US EPA 2016; 2019; 2020; 2022). A substantial number of epidemiological studies investigating population responses to air pollution have since provided further scientific evidence (Forastiere *et al.* 2024; WHO 2025). Studies across many countries identify $PM_{2.5}$, ozone and nitrogen dioxide as the pollutants with the clearest links to adverse health impacts.

This epidemiological research provides concentration-response functions (CRFs) that link pollutant exposure to a broad range of health outcomes. This Assessment applies CRFs from Forastiere *et al*. (2024) to quantify global morbidity linked to $PM_{2.5}$ and the benefits of mitigation. The Assessment uses the FUSION risk model to estimate mortality from long-term $PM_{2.5}$ exposure associated with non-communicable diseases and lower respiratory infections (Burnett *et al*. 2022), while risk functions from the WHO Health risk of air pollution in Europe (HRAPIE)-2 assessment quantify mortality from short-term ozone exposure (WHO 2025). The Burnett *et al*. (2022) function applies across the entire global range of exposures and is more robust at high exposures than HRAPIE-2. At low concentrations, the FUSION model replicates HRAPIE-2. Furthermore, this Assessment covers exposure to indoor $PM_{2.5}$, as use of solid fuels and traditional stoves for cooking significantly increases population exposure in some regions. The indoor impact analysis is carried out applying the cause-specific mortality integrated exposure response functions from the Global Burden of Disease (GBD) (Murray *et al*. 2020). Overall, the assessment uses the latest knowledge to provide a more comprehensive analysis of mortality and morbidity impacts of air pollution across scenarios than previous analysis, especially in relation to chronic illnesses and disease.

The analysis of health impacts follows the impact pathway approach (Figure 3.10). The approach combines evidence and methods from atmospheric physics and chemistry, epidemiology, toxicology and economic valuation.

Figure 3.10: Stages in the Impact Pathway approach for health-economic risk analysis showing a logical and sequential progression from emission to effect and influence.



Because $PM_{2.5}$ and nitrogen dioxide share some common sources - traffic, domestic combustion, etc.- CRFs derived from epidemiological observation for each pollutant separately are likely to overlap. This Assessment therefore takes a conservative approach and excludes nitrogen dioxide from the analysis. This exclusion could bias estimates of impacts and the benefits of further action downward. Further, the approach taken, in this Assessment, to modelling mortality impacts of household exposure avoids any potential double counting of ambient and indoor $PM_{2.5}$ effects. Accordingly, ambient and indoor mortality estimates are additive. Excluding morbidity impacts of both indoor $PM_{2.5}$ and ambient ozone creates further downward bias because agreed response functions remain unavailable for these effects in this situation.

This Assessment estimates the share of each health burden that reductions in exposure relative to the baseline could avoid. The Assessment then monetises these health benefits using standard methods from the field of environmental economics.

Beyond health impacts, air pollution also affects agricultural productivity, forests, ecosystems, natural and built environments, but the quantitative modelling in this Assessment does not cover these impacts, apart from the combined risks from air pollution and warming to agriculture quantified in Section 3.2.3. Excluded effects include damage to cultural heritage sites, loss of physical integrity of man-made structures, soiling of buildings, and drops in tourism and retail shopping activity (drop in footfall). Air pollution also degrades water and soil quality and drives biodiversity loss. Data limitations prevent global quantification of these effects, which biases overall benefit estimates

downward. Section 3.6 further describes these and other effects omitted from the core analysis and discusses attempts to monetise the impacts.

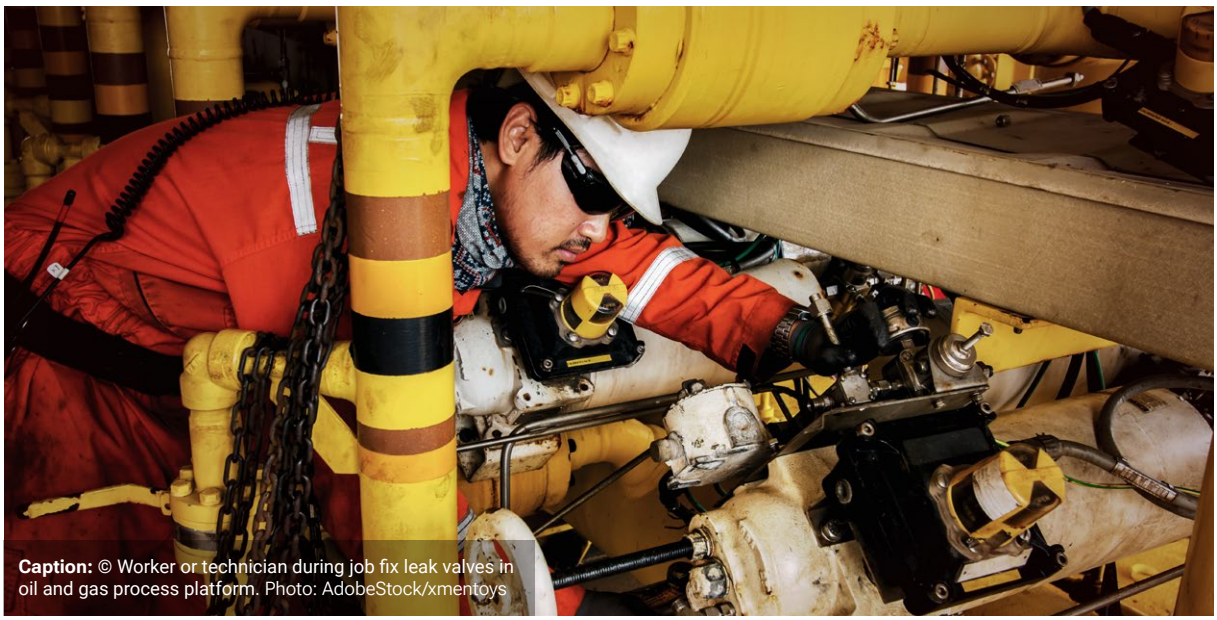
Health benefits of air pollution mitigation

Throughout this section, figures in brackets denote interquartile ranges (see Annex 2.1). In 2025, the Assessment estimates that ambient $PM_{2.5}$ and ozone caused 6.4 (5.2–7.3) million premature deaths, corresponding to approximately 91 million life years lost. Indoor $PM_{2.5}$ exposure in households using solid fuels for cooking adds approximately 2 (1.8–2.2) million premature deaths, including nearly 300,000 (260,000–330,000) among children (Annex 2.1, Table A2.2a). Despite some methodological differences, these numbers are comparable to other recent estimates, such as estimates from WHO (2024b) and the GBD initiative (GBD 2023 Disease and Injury and Risk Factor Collaborators 2025).

The Assessment attributes the following new cases of morbidity in 2025 to ambient $PM_{2.5}$ exposure alone: 5.5 (4.7–6.2) million cases of childhood asthma, 4.2 (3.3–4.9) million cases of acute myocardial infarctions (heart attacks), 3.8 (3.2–4.3) million cases of chronic obstructive pulmonary disease (COPD), 3.3 (2.6–3.9) million cases of type-2 diabetes, 2.5 (2.0–2.9) million cases of stroke, 2.0 (1.6–2.3) million cases of dementia, and 0.5 (0.4–0.58) million cases of lung cancer (Annex 2.1, Table A2.2a). The new cases represent a significant proportion of disease incidence, including 22 per cent of all cases of childhood asthma, 20 per cent of cases of acute myocardial infarctions, 21 per cent of cases of COPD, 15 per cent of cases of diabetes, 20 per cent of cases of stroke, 19 per cent of cases of dementia and 19 per cent of cases of lung cancer.

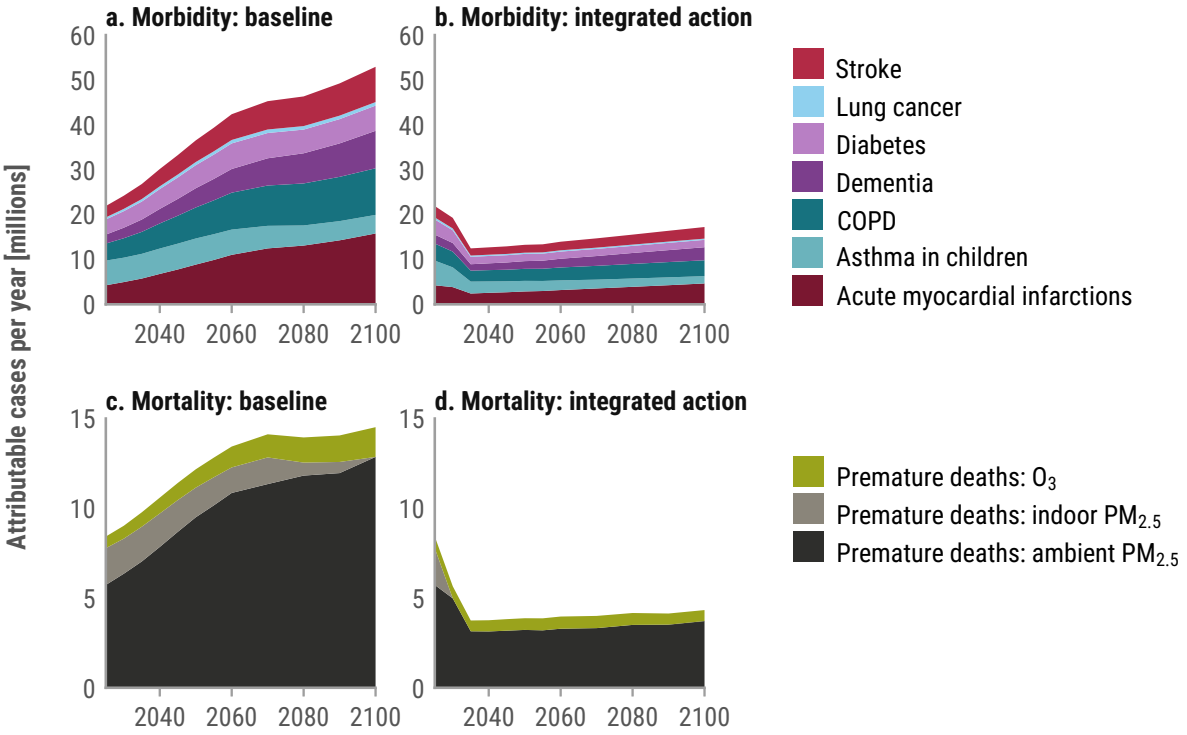
Figure 3.11 presents the global health burden attributable to ambient $PM_{2.5}$ covering annual morbidity incidence and premature deaths. Morbidity and mortality associated with exposure to $PM_{2.5}$ pollution both increase over this century, due to changes in exposure and a growing and ageing population. Disease-specific trends differ: cardiovascular disease and dementia increase with population ageing, while childhood asthma declines. Globally, the preventable burden reaches 60 per cent in 2035 and maintains at 60–70 per cent, depending on health outcome, throughout the century.

Cumulatively, by 2050, the 25 integrated solutions would avoid hundreds of millions of cases of chronic diseases and an estimated 144 million premature deaths from ambient and household PM2.5 exposure plus ozone exposure. This is made up of an estimated 62 (37–77) million cases of childhood asthma, 87 (65–103) million acute myocardial infarctions (heart attacks), 63 (50–73) million cases of COPD, 56 (39–68) million cases of diabetes, 45 (37–51) million cases of stroke, 36 (29–42) million cases of dementia, 7 (5.4–8.2) million cases of lung cancer, 96 (80–109) million premature deaths attributable to ambient $PM_{2.5}$, 43 (38–48) million premature deaths from household $PM_{2.5}$ exposure, and 5 (4.0–5.8) million premature deaths from exposure to ozone.



Caption: © Worker or technician during job fix leak valves in oil and gas process platform. Photo: AdobeStock/xmentoys

Figure 3.11: Morbidity and mortality burden from fine particulate matter: new cases of different diseases, and premature deaths, attributable to fine particulate matter globally every year under the baseline and integrated action scenarios, 2025–2100, millions. Premature deaths due to ozone also shown.



The health benefits from implementing the 25 solutions vary by region, with the largest benefits seen in the more polluted locations in Africa and Asia, and the least in those regions that have already successfully reduced air pollution and decoupled it from economic growth - Europe and North America (Figure 3.12).

Figure 3.12: Morbidity avoided by the full implementation of all 25 solutions, 2035, 2050 and 2100 (avoided new cases per 100,000 people).



The full implementation of 25 solutions would prevent 7.9 million premature deaths in 2050 from avoided exposure to ambient and indoor $PM_{2.5}$, and 370,000 from avoided exposure to ozone. The global health benefits of individual solutions have been calculated and are disaggregated in Table 3.1 for 2050. The ozone benefits in the table are an underestimate, as solutions also reduce other major ozone precursors, nitrogen oxides, non-methane volatile organic compounds and carbon monoxide, whose ozone-related impacts have not been calculated here (Section 3.6).

Table 3.1: Benefits of individual solutions in terms of annual premature deaths averted, 2050, thousands.

Premature deaths (1000s) averted by reductions in:		
	$PM_{2.5}$	O_3 from methane only (unless otherwise stated)
Energy transformation for power generation	454	6
Post-combustion controls - power plants and industry	244	0
Oil and gas sector upstream emissions	9	15
Oil and gas sector downstream emissions	0	4
Coal mining	0	0
Energy efficiency standards for industry	815	1
Industrial process emissions standards	900	0
Efficient brick kilns	63	0
Solvent use	92	0
Energy transformation for households	508	1
Clean cooking and heating*	1932	0
Vehicle emission standards	749	1
Vehicle inspection and maintenance	202	0
Electric vehicles	241	0
Emission standards for non-road machinery	272	0
International shipping	231	0
Livestock manure management	129	1
Efficient nitrogen fertiliser application	61	0
Dietary changes	599	12
Rice paddies	0	1
Reduce burning of agricultural crop residues	106	1
Solid waste management	184	8
Wastewater treatment	0	4
Prevention of forest and peatland fires	138	
HFC phase-down	0	0
All 25 integrated solutions**	7,927	370

Note: ozone benefits for individual measures only account for reductions in methane, whereas the total sum includes all precursors (see text).

*$PM_{2.5}$ related averted premature deaths for this measure include 1.65 million cases from indoor $PM_{2.5}$ and 280 thousand from outdoor $PM_{2.5}$. All other measures only influence outdoor $PM_{2.5}$.

**The total averted deaths from O_3 include all precursors, while the measure-specific breakdown includes only CH_4 related O_3 (totalling 55 thousand cases).

These results only cover the two air pollutants with the largest and best-evidenced health impacts, $PM_{2.5}$ and ozone. Other pollutants, including carbon monoxide, nitrogen dioxide, non-methane volatile organic compounds, polycyclic aromatic hydrocarbons and sulphur dioxide can carry significant risks (see Section 3.6). Air pollution also affects the quantity and quality of food crops, the structure and function of ecosystems, and the built environment. The magnitude and economic valuation of these various effects are discussed in Section 3.6.

3.1.3 Estimating the degree of climate change to 2100 under the baseline and integrated action scenarios

Approach

Without strong mitigation action to reduce greenhouse gases, temperatures will continue to rise throughout this century, with consequences for natural and agricultural systems, economic productivity, and human health. This Assessment uses a model of global temperature change (Leach *et al*. 2021), downscaled to the national level using five Earth system models, and models the evolution of sea-level rise using global temperature to drive melt processes.

Climate benefits

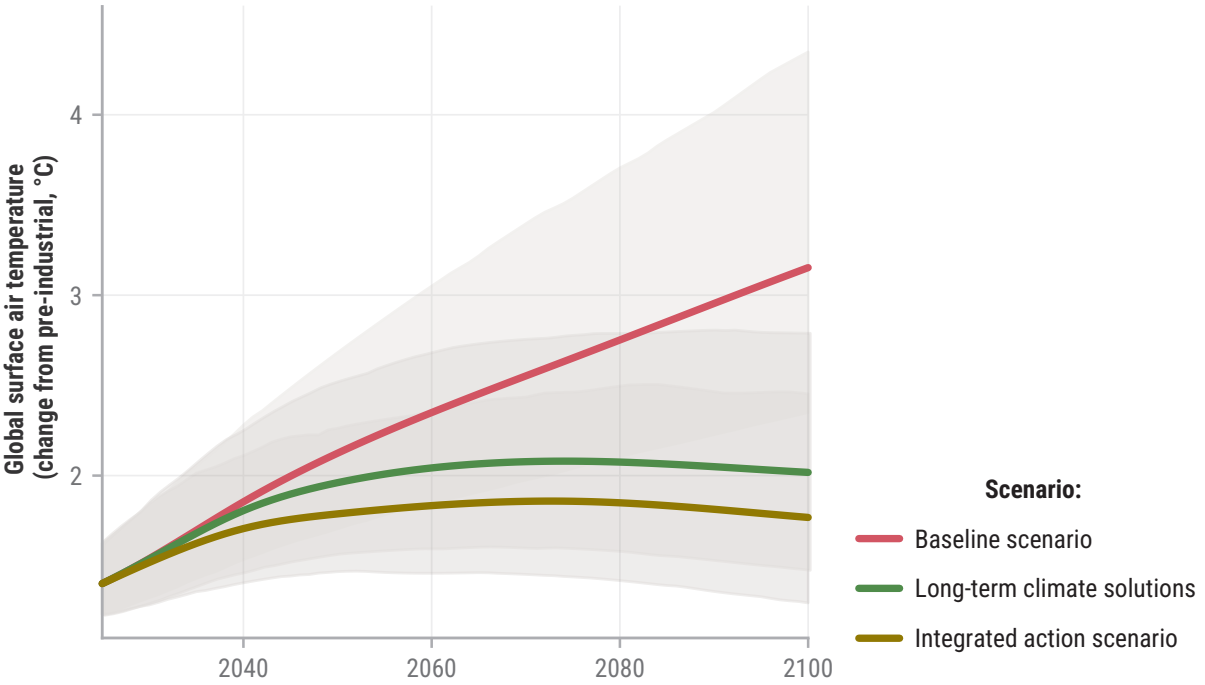
The full implementation of the 25 solutions reduces warming by approximately 0.34 °C (95 per cent confidence interval 0.1–0.6 °C) by mid-century compared with the baseline, producing a temperature increase of approximately 1.8 °C in 2050. The four long-term climate solutions alone, for example, through the shift to a renewable energy system, reduce the 2050 temperature increase from about 2.1 °C to 2.0 °C, partly through methane reductions.

The Assessment modelling estimates that transitioning to a renewable energy system through the four long-term climate solutions can drastically cut the rate of warming. The greatest potential to avoid warming is realised in 2100, when the four long-term climate solutions avoid around 1.38 °C (0.9 - 2.1) of warming, from a global warming level of more than 3.15 °C estimated for the baseline scenario to approximately 1.77 °C (Figure 3.13a).

Sea level rise is reduced from almost 1 metre to 0.8 metres (Figure 3.13b).The 21 clean air and near-term climate solutions produce temperature reductions immediately, growing to an additional 0.2 °C reduction by mid-century relative to the baseline scenario and remaining constant thereafter. This is the additional benefit of the 21 clean air and near-term climate solutions beyond the SLCP reductions delivered with the four long-term climate solutions.

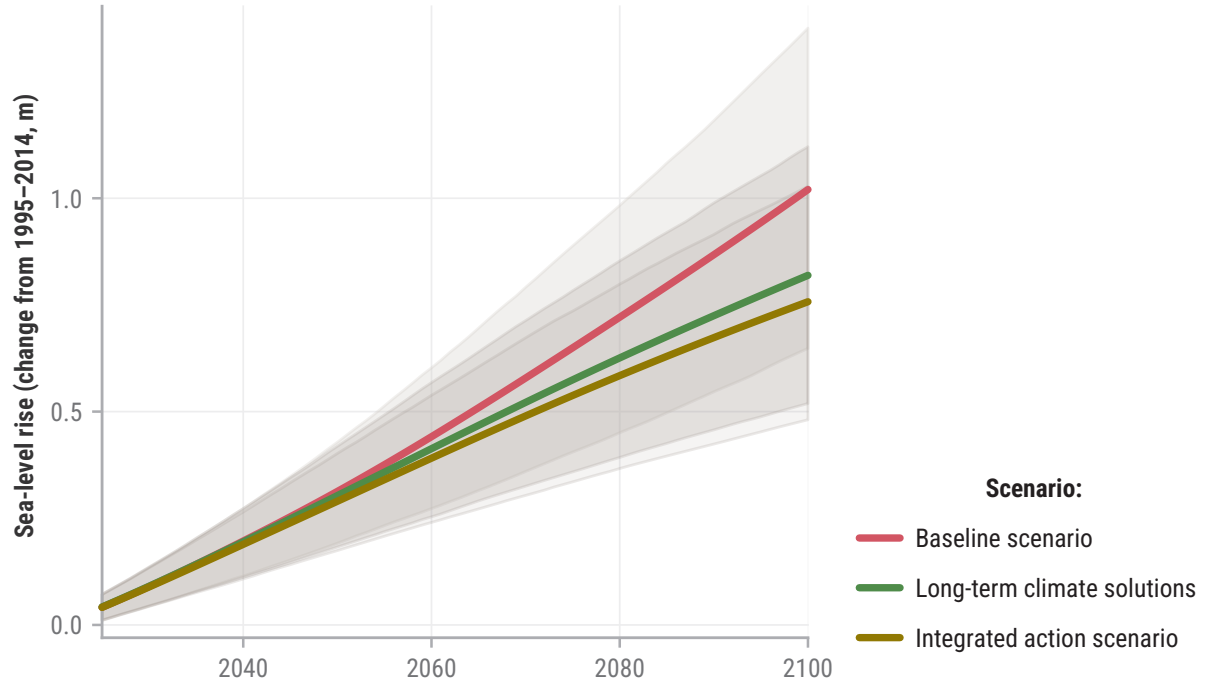

© AdobeStock/Anatoliy Gleb

Figure 3.13a: Changes in global temperature, for the baseline scenario, the four long-term climate solutions and the full 25 integrated solutions (integrated action scenario) relative to pre-industrial levels, 2020–2100, degrees Celsius.



Note: bands show the 95 per cent confidence interval.

Figure 3.13b: Changes in sea level, for the baseline scenario, the four long-term climate solutions and the full 25 integrated solutions (integrated action scenario) relative to 1995–2014 averages, 2020–2100, metres.



Note: bands show the 67 per cent confidence interval.

Sea level adjusts more slowly to temperature change, so differences between the scenarios do not emerge until after 2050 (Figure 3.13b). The PAGE model captures the wide range of possible sea-level changes, accounting for scientific uncertainty surrounding the Greenland and West Antarctic ice sheets (Annex 2.3). Higher sea-level rise within each scenario reflects the potential for tipping points and accelerated melting. By 2100, sea levels are projected to be 1 metre above the 1995–2014 average under the baseline scenario. The 25 integrated solutions reduce this change to approximately 0.75 metres. Much of the sea-level rise projected for the next 75 years is already committed because of the warming that has already occurred.

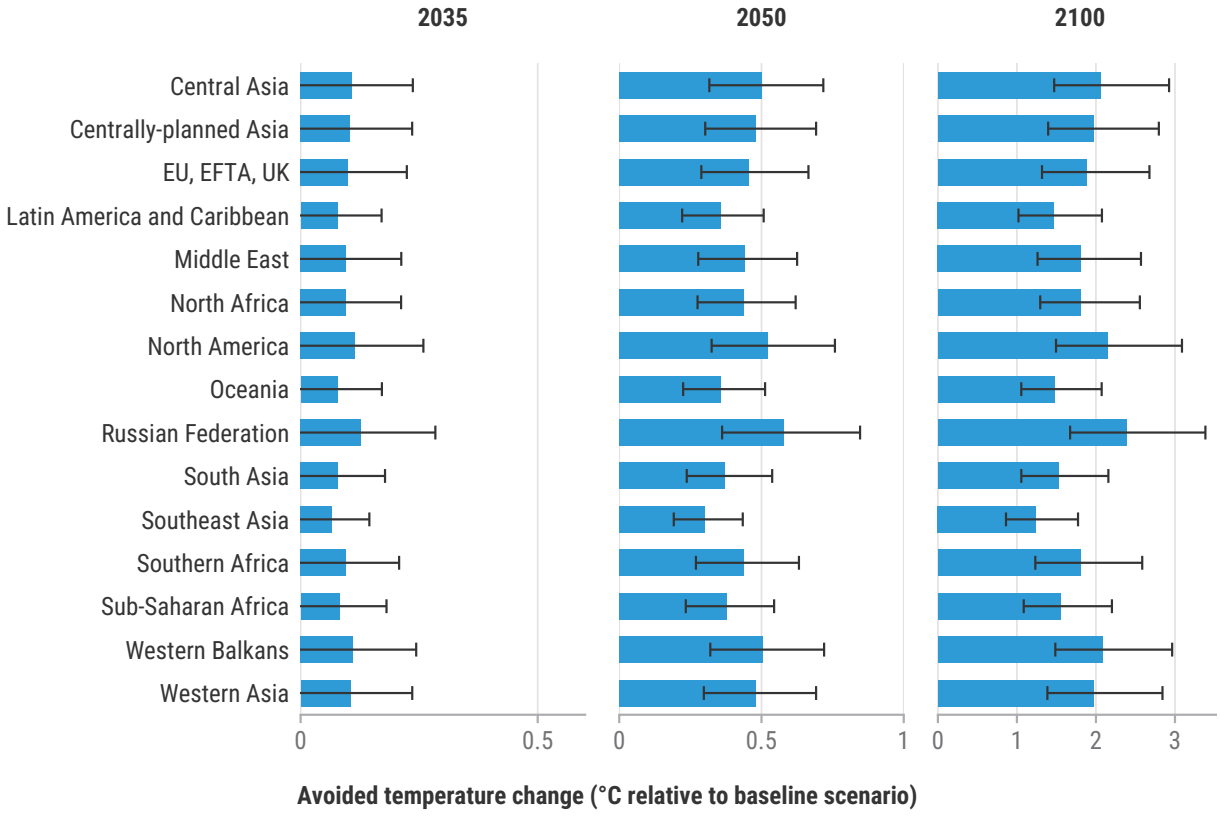
The central values and uncertainty ranges of the temperature and sea-level rise projections are compared with commonly used Coupled Model Intercomparison Project (CMIP) 6 scenarios in Annex 2.4.

Since temperatures over land rise faster than the global average, the benefits of the 25 integrated solutions are larger at the regional level than global figures suggest, with avoided warming of approximately 0.1 °C in 2035, 0.5 °C in 2050 and 1.5 – 2 °C in 2100 in most regions (Figure 3.14). These differences carry large consequences for the scale of social and economic impacts.



Caption: © Gas leak in gas cylinder, at home.
Photo: AdobeStock/Fabián Montaño

Figure 3.14: Changes in local temperature in the integrated action scenario, relative to the baseline scenario, 2035, 2050 and 2100, degrees Celsius.



Note: bars show the mean difference. Error bars show the 90 per cent confidence intervals at the regional level.

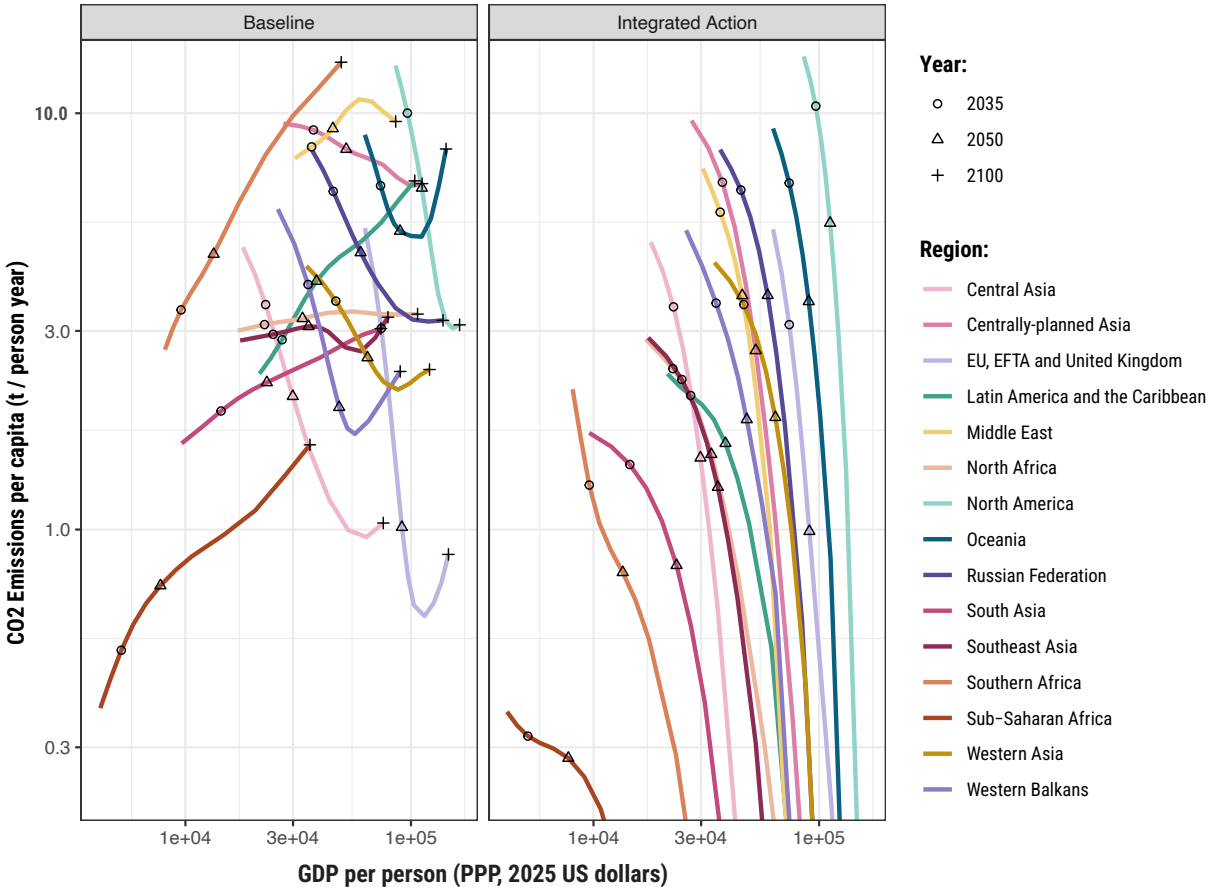
Reducing pollution has the potential to increase temperatures in some regions, as lower levels of aerosols reduce a current cooling benefit. Despite this concern, all regions are expected to experience lower temperatures under the full implementation of all 25 solutions. The increase in temperatures that results from a reduction in aerosols is more than offset by a decrease in temperatures from lower greenhouse gas emissions, already by 2035.

As with pollution control, economic growth and a green-energy transition work together to form a consistent development strategy, as Figure 3.15 illustrates, tracking per person carbon dioxide emissions against income over the century. Under the baseline scenario, per person carbon dioxide emissions rise as income grows in many regions. The integrated action scenario breaks this trend in every region. All regions reach net zero under the integrated action scenario between 2050 and 2100.



Caption: © Thermal camera used to find leaks. Photo: AdobeStock/Andrey Popov

Figure 3.15: The evolution of carbon dioxide emissions as countries become wealthier over the century, tonnes per person per year, gross domestic product, 2025 United States dollars.

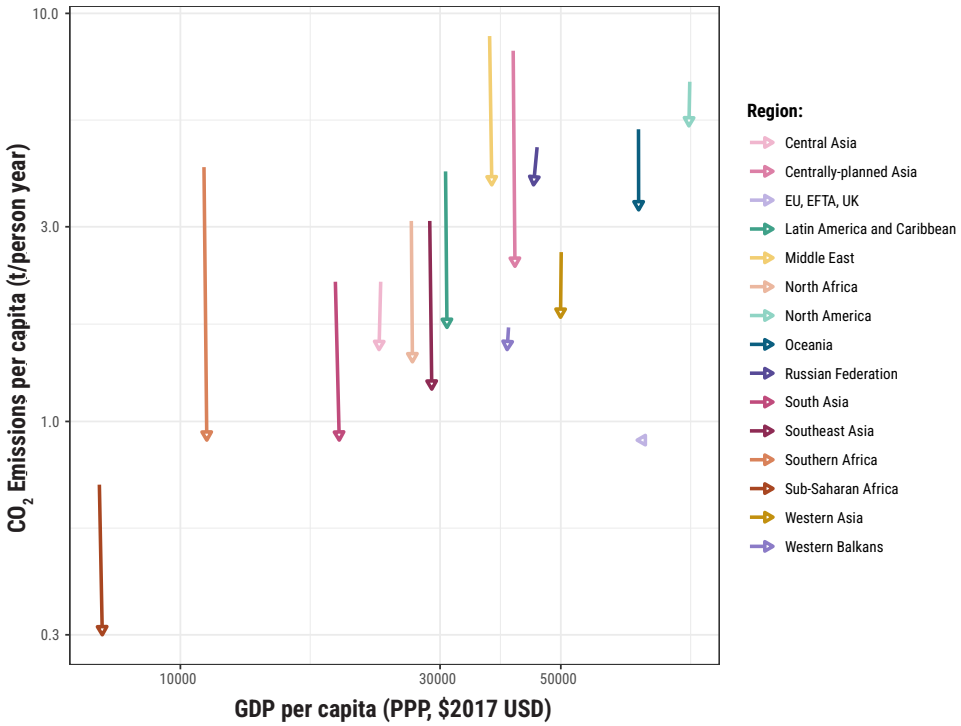


Under the integrated action scenario, the historical relationship between income and emissions is broken. Today, the richest regions generally still generate the highest emissions, but with the shift to renewable energy, high energy use no longer entails high greenhouse gas emissions. While some high-income countries continue to register elevated carbon dioxide emissions through 2050, emissions fall rapidly across the globe. Section 3.4 shows that long-term climate action also directly supports economic growth.



Caption: © Freight train on electrified railway. Photo: AdobeStock/Bence

Figure 3.16: The shift in carbon dioxide emissions from the baseline to the integrated action scenario, by region, across levels of income, in 2050, with income measured in 2017 United States dollars.



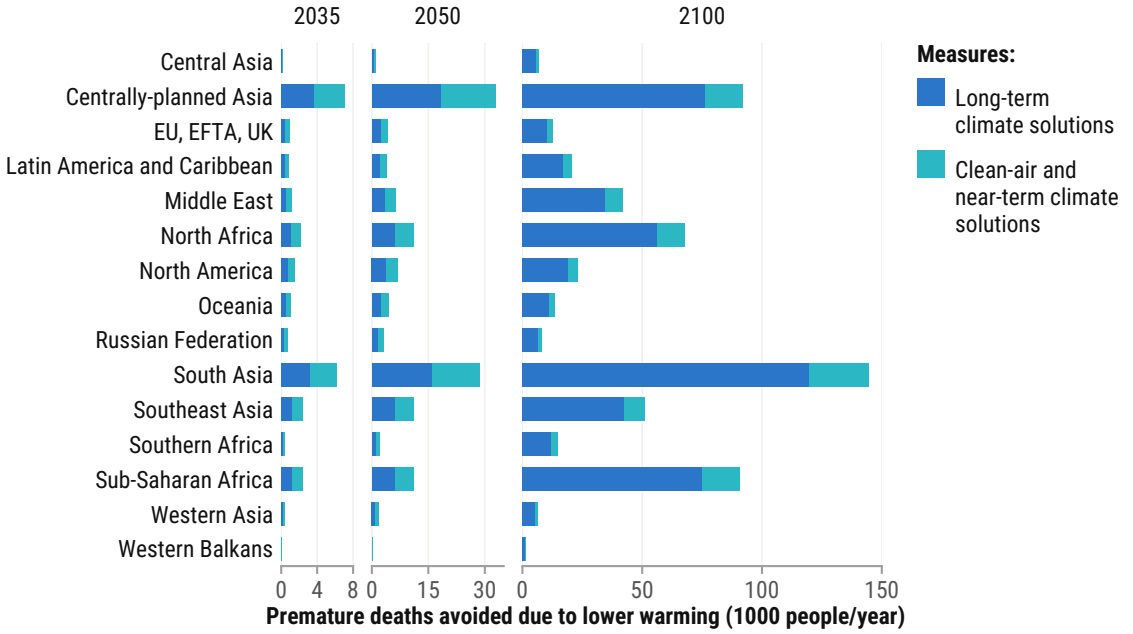
Note: each arrow starts at the baseline values of CO_2 emissions and income in 2050 and ends at the integrated action scenario values.

3.1.4 Effects of climate change on human health and labour productivity under the baseline and integrated action scenarios

Avoided warming, through the 25 integrated solutions, reduces premature mortality through multiple channels, including improved cardiovascular health, avoided accidents and developing stronger immune systems. Across all causes of mortality attributable to climate change, the 25 integrated solutions avoid premature mortality of an estimated 130,000 people per year by 2050 and 600,000 people per year by 2100. These benefits are broken down by region in Figure 3.17.

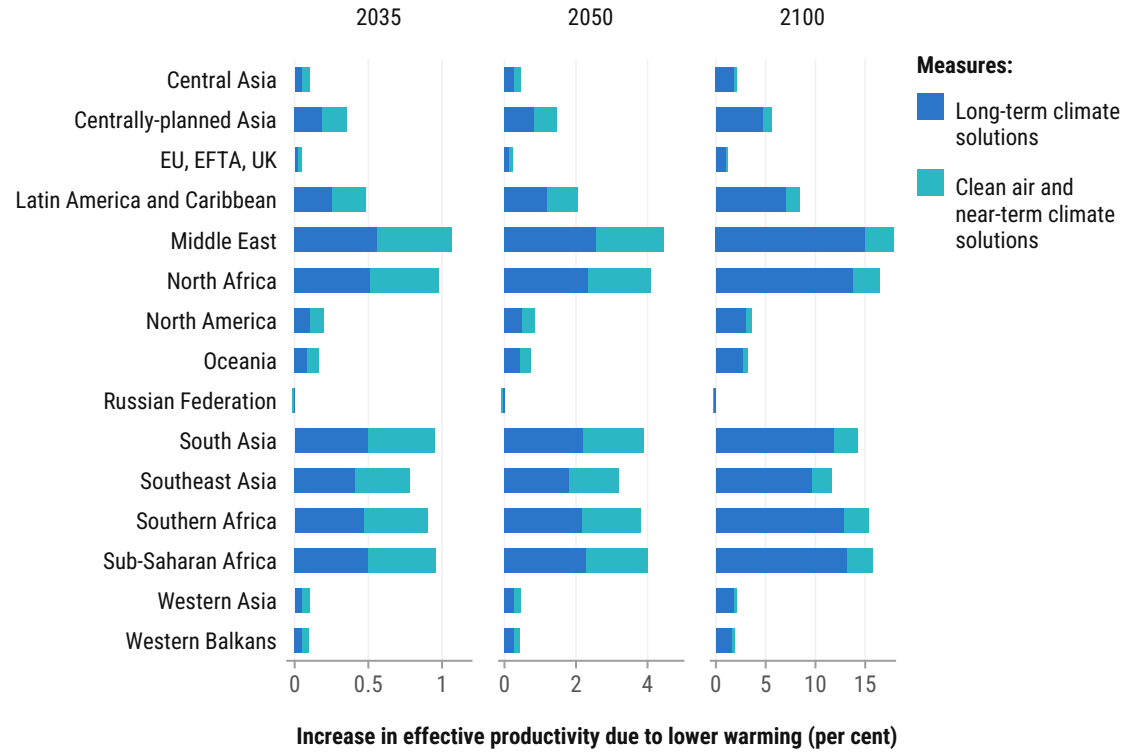


Figure 3.17: Avoided mortality due to lower warming under the full implementation of all solutions, by year (total deaths in thousands).



Warming also imposes a wide range of other risks, such as reduced agricultural productivity (Hultgren *et al*. 2025) and reduced labour productivity (Dasgupta *et al*. 2021), loss of assets from inland and coastal flooding (Dottori *et al*. 2018; Diaz 2016), and impacts on ecosystems and their services (Scholes 2016). Figure 3.18 shows the labour productivity gains from the 25 integrated solutions. Agriculture and coastal impacts are discussed as economically valued losses later in this chapter.

Figure 3.18: Increase in effective labour productivity, labour supply and direct productivity effects due to lower warming under the implementation of the four long-term climate solutions and 21 clean air and near-term climate solutions, by region, per cent of total productivity.



Several risk categories remain outside this analysis, introducing a systematic bias towards underestimation of damage and benefits. These include impacts not well-represented in the historically but likely to be significant in the future, such as wildfires and shifts in vector-borne diseases; impacts arising from climate tipping points and systemic risks from interactions in the biosphere and economy; risks that arise from cascading or sequential chains of impacts, or from interactions that cross national or system boundaries; and plausible risks not widely included in the literature on damage, such as non-market risks, even though these tail risks may be important for decision-making (Rising *et al*. 2022).

3.2 Economic valuation of the air pollution and climate change impacts and benefits of further action

Approach

The PAGE model applies two approaches to quantify climate impacts. The first is sector-specific, linking climate-driven changes to mortality, labour productivity and agricultural productivity. Mortality draws on a global meta-analysis of cold and heat excess death rates, from Cromar *et al*. (2022). Labour productivity draws on Dasgupta *et al*. (2021), representing total effective labour loss including changes in both direct productivity and labour supply. Agricultural productivity follows the methodology of the Global Methane Assessment (UNEP and CCAC 2021).

The second is a top-down approach capturing total economic impacts across both market and non-market related risks. Market risks combine an empirical relationship between warming and GDP from Burke, Hsiang and Miguel (2015) with models of losses from sea-level rise, coastal storm surges, and trade and capital effects. Non-market damage draws on a meta-analysis of damage functions from Howard and Sterner (2017), which relies heavily on expert elicitation given the limited availability of economically valued non-market evidence. Welfare loss estimates typically use revealed or stated preferences, such as surveys in which respondents express willingness to pay to reduce their risk of premature death or morbidity (de Vries *et al*. 2025; Kanya *et al*. 2019; Breidert *et al*. 2006).

Health impacts impose several types of economic cost, both market costs linked to healthcare utilization and productivity losses, and non-market costs linked to losses of utility, also referred to as loss of quality of life. These utility losses translate the negative impacts on individuals or society, encompassing pain, anxiety, inconvenience, restriction on choice and time cost into economic terms.

Unit costs for air pollutant impacts are calculated separately for each quantified health effect, covering healthcare, productivity and non-market utility costs. Healthcare costs and productivity losses are quantified using the results of cost-of-illness studies. Total economic impacts are calculated by summing across all quantified morbidity outcomes and mortality.

For mortality, two valuation options are available, the value of a statistical life (VSL), representing the collective willingness of society to pay to prevent an anonymous death, and the value of a statistical life year (VSLY), representing willingness to pay for extending life expectancy by one year. The two are not additive, so for any burden, only one of the options is used. In the economic analysis, the VSL applies to the number of deaths, whereas the VSLY applies to changes in life expectancy - life years lost. The number of life years lost due to early death is estimated using a life table analysis (Miller and Hurley 2003). The VSLY metric was used to value mortality changes. The country-specific VSLY draws on European VSLY, calculated using the Organisation for Economic Co-operation and Development (OECD) and Narain and Sall (2016) and is scaled for income differences between locations using GDP per person at PPP prices. At the time of the analysis, the reanalysis of VSL by the OECD (2025) was not yet published, and accounting for this revision would increase the non-market cost component by roughly 40 per cent. For morbidity, the cost of reduced quality of life is estimated from the duration and disability weight of the condition, and the cost per quality-adjusted life year (QALY), assumed here to be equal to the VSLY.

Economic consequences are reported as a percentage of current and future gross domestic product (GDP), providing a common unit for comparing both market and non-market impacts. Non-market impacts do not directly reduce measured GDP; rather, the welfare loss is expressed as the reduction in consumption that would produce an equivalent loss in well-being. Expressing both market and non-market damage as a share of GDP avoids the difficulty of interpreting

absolute losses in a future economy that may be much larger than today's. For example, a 10 per cent loss of GDP in 2025 represents US$ 20.5 trillion in purchasing power parity terms, but US$ 89.3 trillion in 2100 under the baseline scenario.

Benefit-cost analysis of emission controls establishes whether the present value of future benefits exceeds the present value of control costs over an appropriate investment time horizon (O'Mahony 2021). The benefit-to-cost ratio (BCR) then identifies the actions that deliver the highest benefit per unit of expenditure.

The BCRs estimated in this Assessment are influenced by the omission of some impacts from the analysis. For air pollution this includes:

- impacts linked to ozone generated from emissions of precursors other than methane, including carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds
- the lack of quantification of various recognised impacts including the health effects of nitrogen dioxide the morbidity effects linked to ozone, and ozone impacts on pasture quality (Section 3.1.2).

And, for climate burdens:

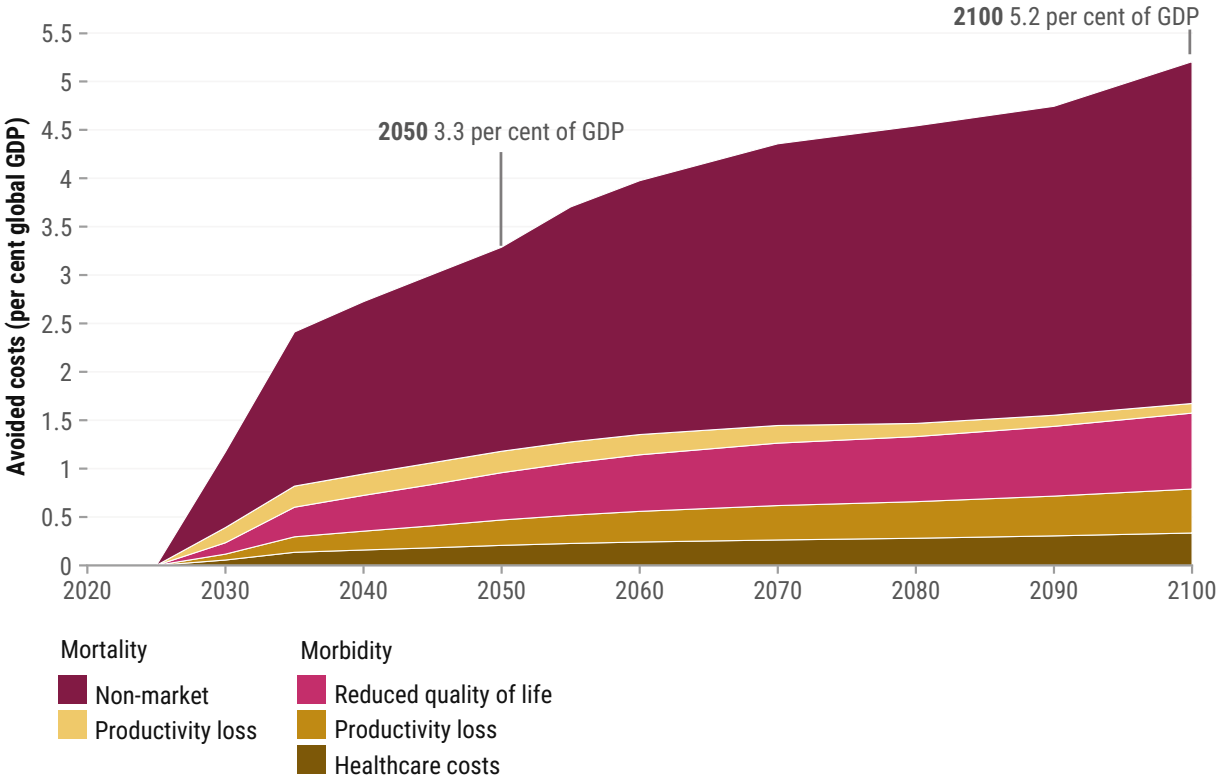
- consequences of extreme events, such as hurricanes and flooding;
- impacts that are not well-represented historically, but are likely to play a significant role in the future, such as wildfires and shifts in vector-borne diseases;
- impacts that result from climate tipping points and other systemic risks arising from interactions in the biosphere and economy;
- risks that emerge from cascading interactions, such as a drought leading to crop failure, sequential interactions, for example, a drought followed by a flood, or cross-boundary interactions, for instance, a drought in one area causing a loss of hydropower downriver;
- naturally, inclusion of these effects would further increase the BCRs, strengthening the case for intervention.

Including the benefits of reducing these impacts, and those discussed in Section 3.6, could lead to the BCRs being higher than those presented in Section 3.4. This potential underestimation must be balanced against the potential for overestimation through omissions on the mitigation costs side, although these missing costs are not estimated to be large enough to change the direction of the result (Section 2.5).

3.2.1 Economic benefits from reduction in air pollution under the integrated action scenario

The 25 integrated solutions generate substantial market and non-market economic benefits from air pollution reductions alone, building rapidly from the first year of implementation. As shown in Figure 3.19, air pollution-related benefits covering mortality and morbidity from ambient and indoor $PM_{2.5}$, and ozone increase rapidly. In 2035, avoided healthcare costs equal 0.1 per cent of global GDP (rising to 0.2 per cent in 2050), while avoided productivity losses from morbidity and mortality equal 0.2 per cent. Together, these avoided healthcare and productivity losses constitute a total market benefit equal to 0.3 per cent of global GDP in 2035, rising to 0.7 per cent in 2050 and total avoided productivity losses to 0.5 per cent of global GDP. By 2100, avoidable market costs from air pollution reach 0.9 per cent of global GDP. The non-market value of avoided quality-of-life losses from morbidity alone is equivalent to 0.3 per cent of global GDP in 2035, 0.5 per cent in 2050, and 0.8 per cent in 2100. The non-market value of avoided premature mortality is substantially larger, estimated at 2.1 per cent of global GDP in 2050. Unlike market costs, non-market costs do not directly reduce GDP, instead they represent welfare losses of equivalent magnitude.

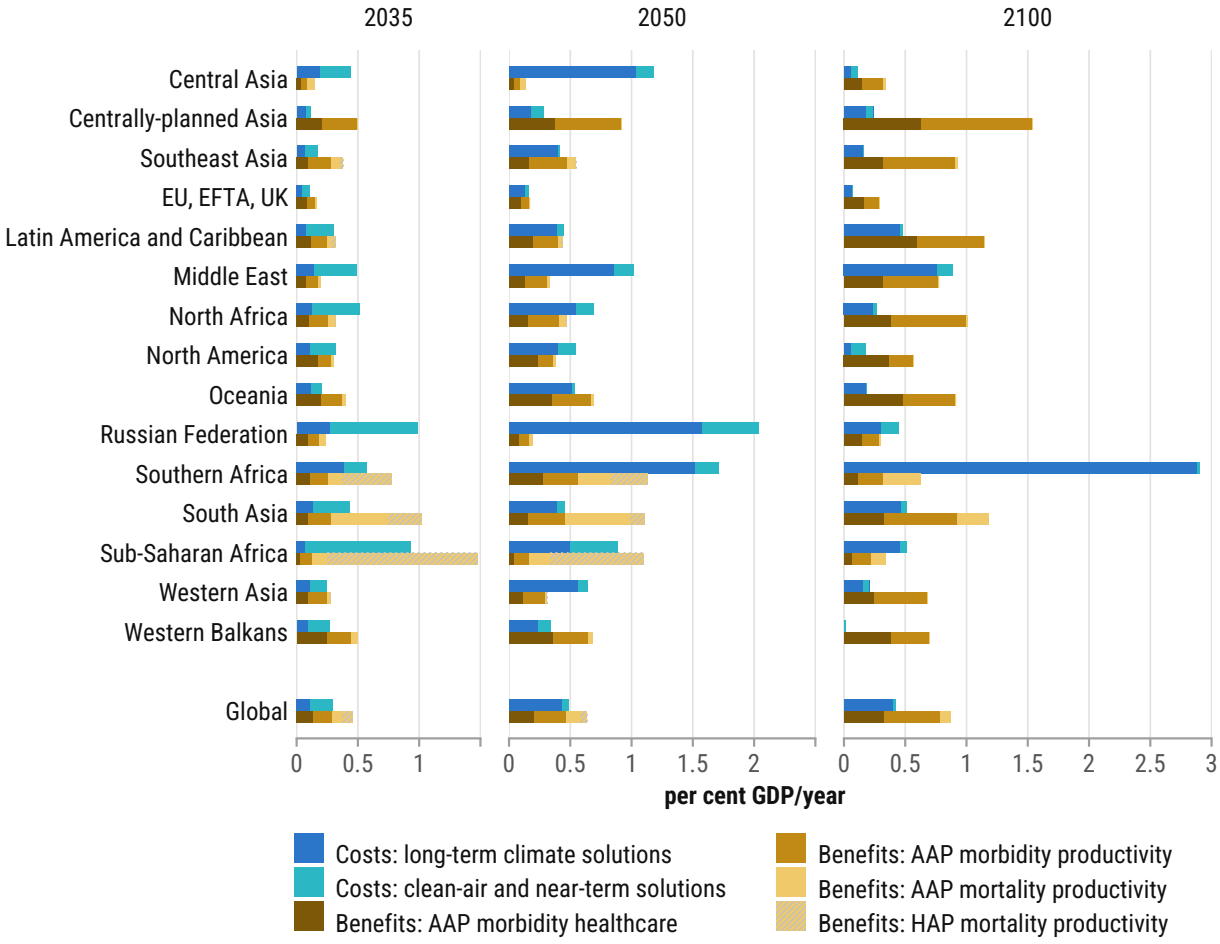
Figure 3.19: Annual morbidity and mortality air-pollution-related costs avoided by implementing all 25 integrated solutions (these results include benefits from outdoor, indoor $PM_{2.5}$ and ozone), 2025–2100, per cent of global gross domestic product.



Globally, market benefits of reduced health impacts of air pollution alone exceed the total costs of implementing the 25 integrated solutions in both 2035 and 2050. Adding non-market benefits, total air pollution benefits exceed the costs by approximately 7–8 times in 2035 and 6 times in 2050. For context, implementation costs of the 25 integrated solutions are estimated at 0.3 per cent of global GDP in 2035 and 0.5 per cent in both 2050 and 2100.

In most world regions, the avoided market cost of illness alone, covering healthcare costs and productivity losses from morbidity and premature death, exceeds or is comparable to the cost of implementing the 25 integrated solutions (Figure 3.20). There are a few notable exceptions in Africa, Central Asia and the Middle East and especially Southern Africa and Russian Federation, where decarbonization measures may be taking place in areas where $PM_{2.5}$ benefits are low, as they are away from the population, or where there is heavy fossil fuel industry and mitigation reduces methane emissions rather than $PM_{2.5}$ and its precursors. Furthermore, the affluence level versus costs of implementation (which are similar across the world assuming a world market for technology) play a role. For example, in Africa, lower GDP per person makes solution costs comparably higher (costs follow international market prices), while the monetised benefits of avoided morbidity and mortality-related income losses are lower. Implementation costs in Figure 3.20 are shown as differences relative to the baseline scenario. Regions that have already made substantial investments in air-pollution control, such as the European Union, North America, and Oceania, retain less remaining mitigation potential from air pollution control solutions than other regions. Their high GDP levels also mean that the costs of further solutions are relatively small as a share of GDP. System transformation costs are included in Figures 3.20 and 3.21. These costs rise over the longer term as electrification of transport and other deep decarbonization solutions take hold.

Figure 3.20: Air pollution market benefits (lower bars) relative to total implementation costs of solutions (upper bars) by region and global, 2035, 2050 and 2100, per cent of gross domestic product per year.

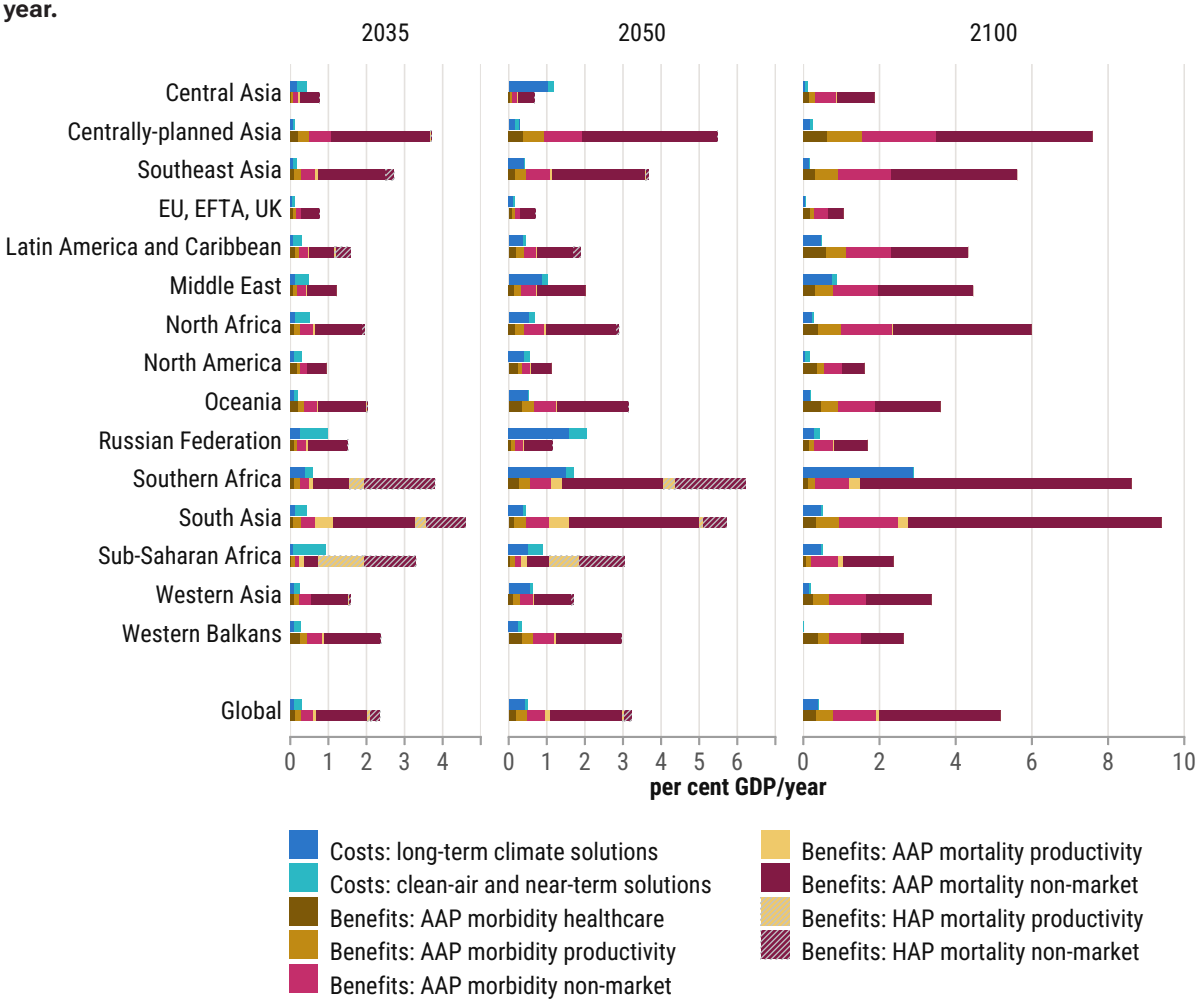


Note: implementation costs reflect differences compared to the baseline scenario. Costs for long-term climate objectives include all system transformation costs for decarbonization. Benefits only include market costs of morbidity and mortality from ambient (AAP) and household (HAP) fine particulate matter ($PM_{2.5}$).

Including the non-market value of avoided quality-of-life losses and premature mortality, total benefits substantially exceed implementation costs in all regions and years considered (Figure 3.21).



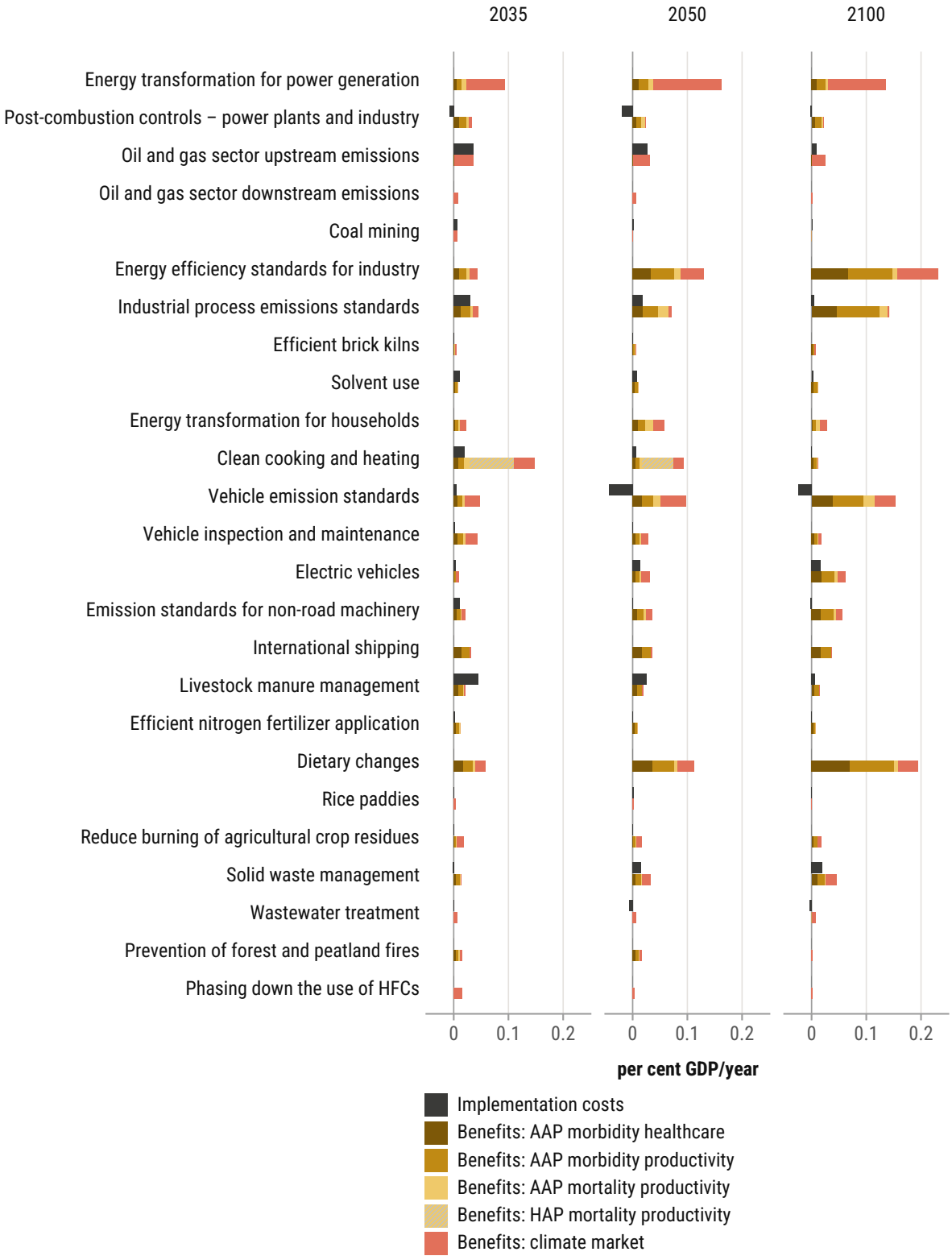
Figure 3.21: Air pollution market and non-market benefits (lower bars) relative to implementation costs of solutions (upper bars) by region and global, 2035, 2050 and 2100, per cent of gross domestic product per year.



Note: benefits include market and non-market costs of morbidity and mortality from ambient and household fine particulate matter. Implementation costs reflect differences compared to the baseline scenario. Costs for long-term climate objectives include all system transformation costs for decarbonization.

For many solutions, market benefits from reductions in air pollution alone already exceed implementation costs in 2035 and do so by an increasing margin in later years. Figure 3.22 compares global total costs and benefits over time for individual solutions. In this comparison benefits include only market costs, healthcare expenditure and productivity losses associated with reductions in $PM_{2.5}$-related morbidity and mortality. Costs are not estimated for the long-term transformation solutions individually, nor for market benefits which do not exceed implementation costs for all solutions or in all regions – some solutions targeting only methane emissions have little influence on air pollution beyond ozone formation but generate larger direct climate benefits, which are not shown in this comparison. Notably, some the implementation costs for some solutions (relative to Baseline) become negative when the underlying activity is removed through other solutions: with the shift towards electrification and other carbon-neutral fuels in industry and transport, the need for end-of-pipe controls decreases.

Figure 3.22: Global costs (top bars) and benefits (bottom bars) of different solutions, 2035, 2050 and 2100, per cent of gross domestic product per year.



Note: benefits show market costs of morbidity and mortality from ambient and household fine particulate matter only in the respective year, and market costs of climate change (cumulative effect). Costs for long-term climate action solutions in power, industry and households estimated cumulatively (Figure 3.19, Figure 3.20) and not for individual solutions. Costs for dietary change, forest fire prevention, and HFC phase-down are not estimated.

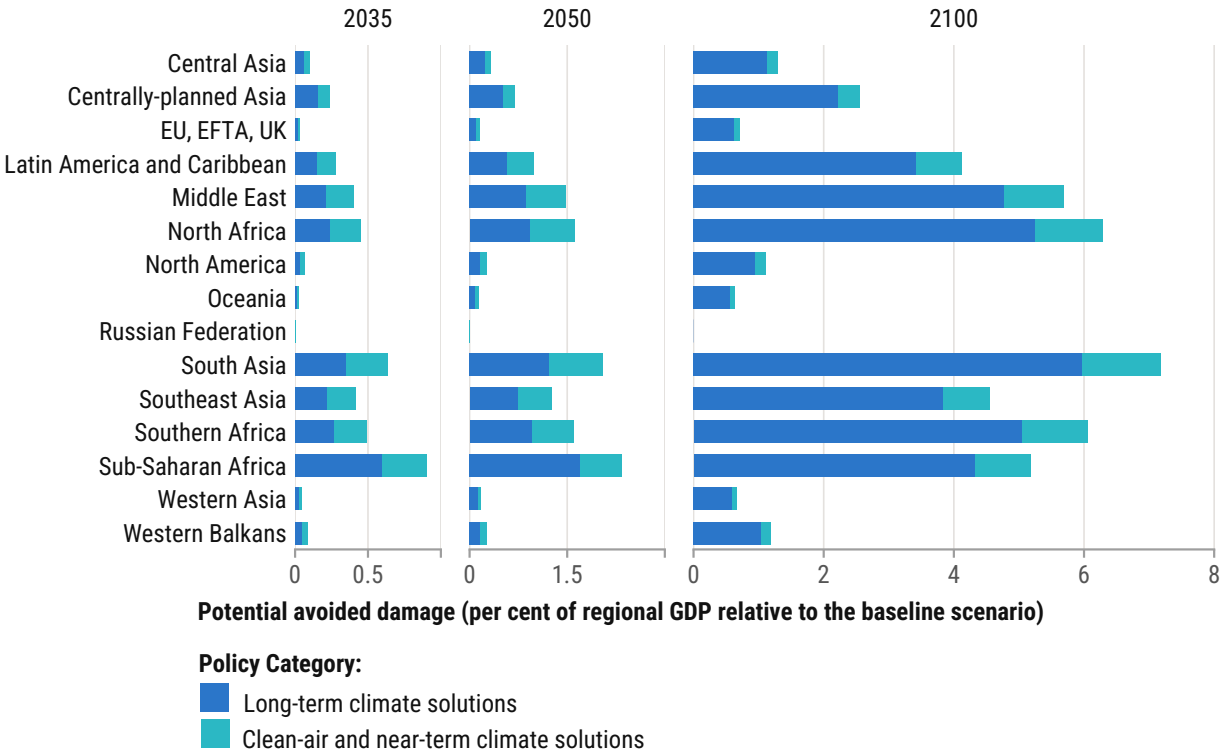
3.2.2 Economic benefits from avoided warming under the integrated action scenario

This section reports the benefits of the 25 integrated solutions through reductions in warming, distinguishing between those that accrue from the four long-term climate solutions and those from the 21 clean air and near-term climate solutions.

Rising temperatures reduce labour productivity, particularly among outdoor workers who must expend additional time and effort to manage heat exposure. At extreme temperatures, workers may experience heat stress or heat stroke which require immediate medical attention and can severely limit work capacity. These estimates draw on empirical evidence of labour supply and productivity responses to temperature changes (Dasgupta *et al*. 2021).

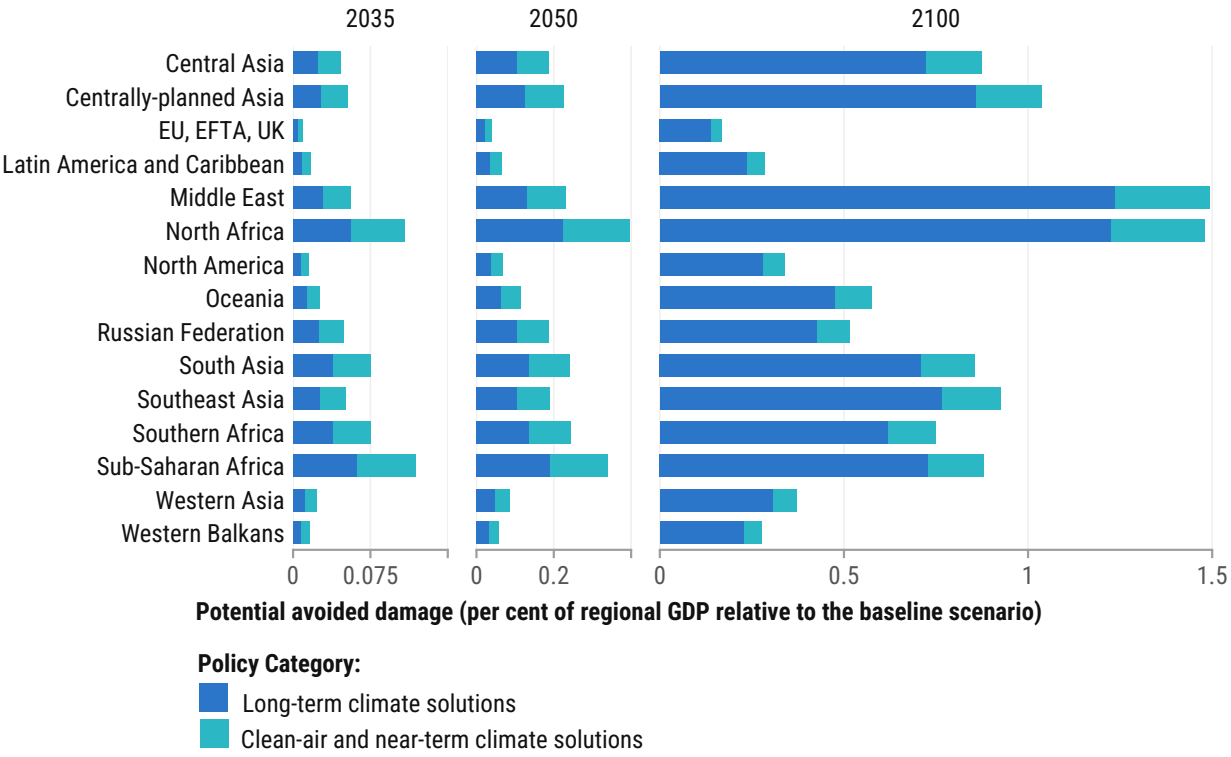
In 2050, market gains from reduced warming through avoided labour productivity losses are equivalent to approximately 2 per cent of GDP in Sub-Saharan Africa and South Asia (Figure 3.23). By 2100, welfare losses from labour impacts exceed the equivalent of 5 per cent of GDP in all regions of Africa, the Middle East and South Asia. Russian Federation is the only region to show small positive effects, the result of less extreme winters.

Figure 3.23: Avoided total economic losses from reducing impacts on labour productivity due to lower warming that results from the implementation of the 25 integrated action solutions, by region, in 2035, 2050 and 2100, per cent of regional gross domestic product relative to the baseline scenario.



High temperatures also cause excess mortality. By 2100, Centrally-planned Asia, the Middle East, North Africa and, South Asia, show the largest benefits from reduced warming through this pathway, with avoided damage exceeding 1 per cent of regional GDP (Figure 3.24). The value of statistical life is used to estimate the economic implications of this avoided mortality. Regions facing the highest mortality risks are those experiencing both high exposure to extreme temperatures and elevated vulnerability from underlying socio-economic and health conditions. These regions also stand to gain most from emissions reductions.

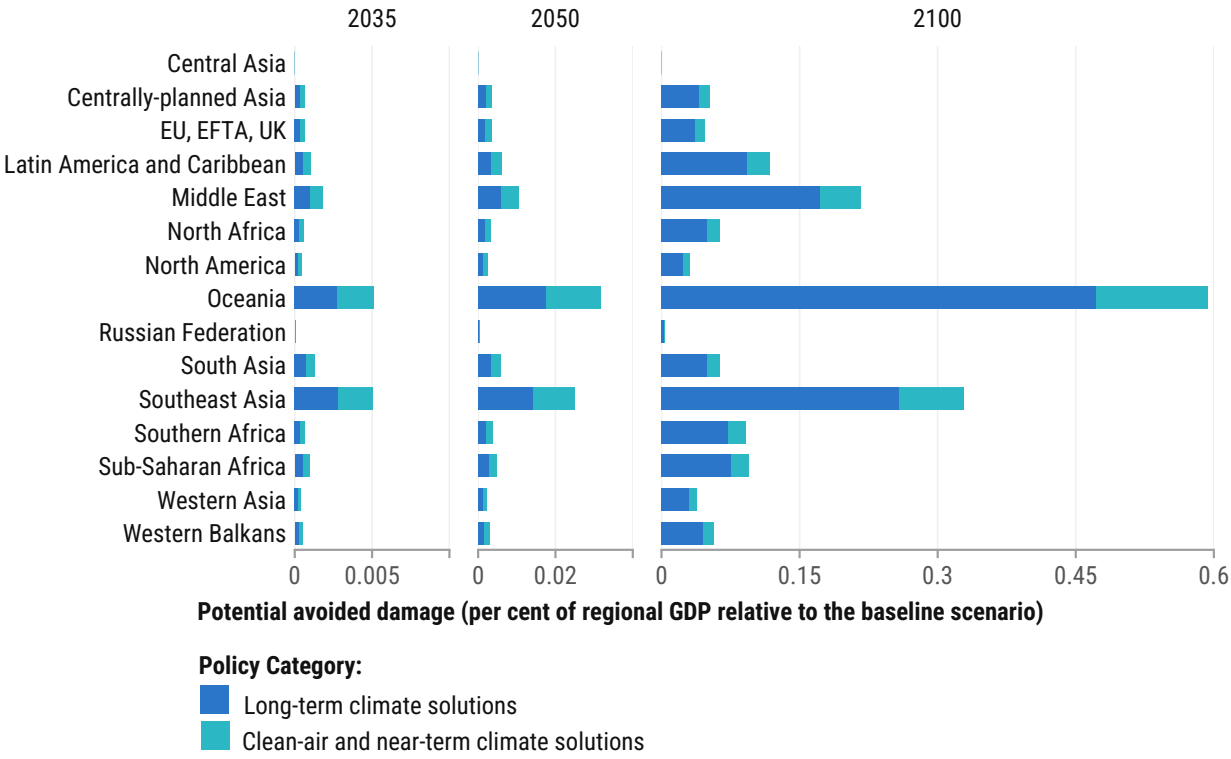
Figure 3.24: Avoided damage from lower warming through avoided excess all-cause mortality, by region, in 2035, 2050 and 2100, per cent of regional gross domestic product relative to the baseline scenario.



Sea-level rise and storm surge represent important risk categories for many countries, particularly small island states (Figure 3.25). Coastal damage draws on the Python Coastal Impacts and Adaptation Model (pyCIAM) (Depsky *et al*. 2023) and covers the loss of land and immobile capital to permanent inundation, the costs of retreat, relocating people and movable assets, and the costs of protection, building and maintaining levees and the land they occupy. The model also captures expected annual damage from extreme sea-level events to capital through depth–damage relationships. Non-market damage calculated in pyCIAM is excluded to avoid double-counting.

The potential for avoiding this coastal damage is greater in 2100 than in 2050. This reflects the long timescales governing the processes that drive sea-level rise. By the end of the century, full implementation of the 25 integrated solutions could avoid coastal damage equivalent to more than 0.2 per cent of GDP for the Middle East, Oceania, and Southeast Asia. Regions with long but sparsely populated coastlines, such as Russian Federation, face minor damage given low population and capital densities. Across the globe, both the risks and the benefits of action can be substantially larger at the local level than regional or global averages suggest.

Figure 3.25: Avoided damage from reduced sea-level rise and coastal damage, by region, in 2035, 2050 and 2100, per cent of regional gross domestic product relative to the baseline scenario.



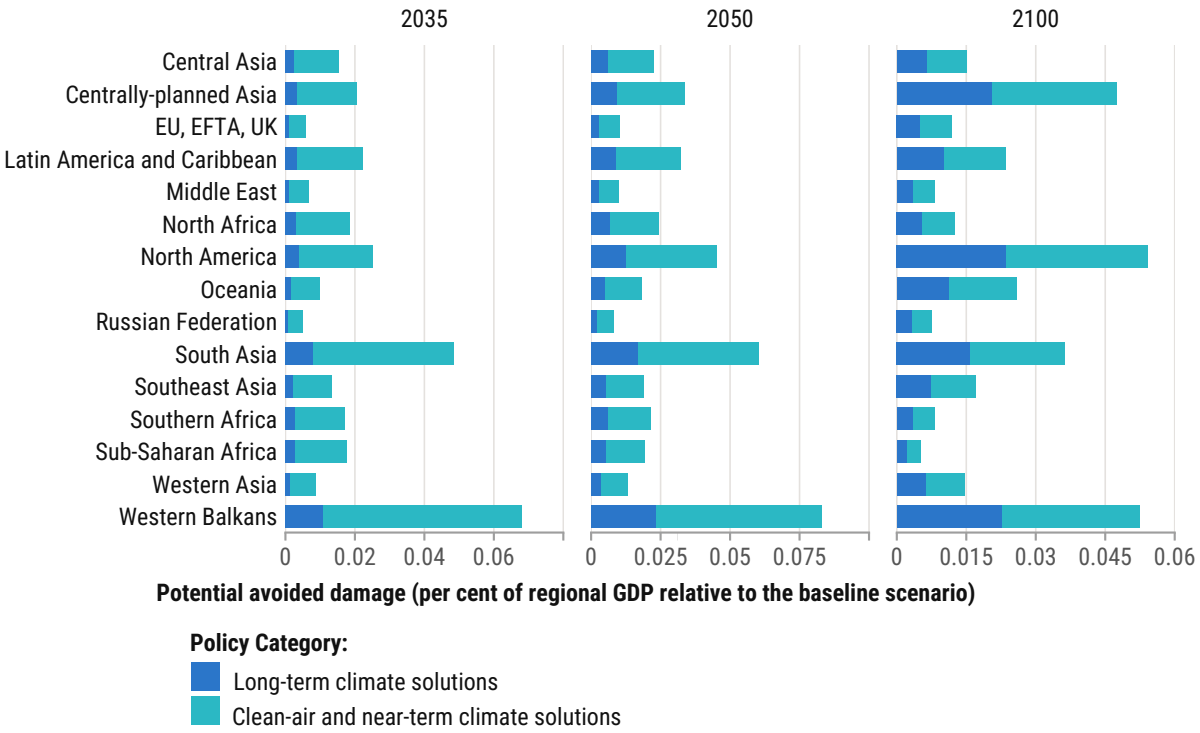
Many other climate risks could yield major economic benefits from mitigation but are not quantified here. Climate mitigation would reduce the incidence of extreme events in many regions, including flooding, drought, and wildfires, and could potentially avoid destabilizing tipping points, such as the shutdown of the Atlantic Meridional Overturning Circulation (AMOC).

3.2.3 Combined risks from air pollution and warming on agriculture

Agriculture is among the sectors most exposed to climate risks and is also significantly affected by tropospheric ozone, an air pollutant. Total avoided damage from climate change and ozone exposure are similar in magnitude in 2100 but remain below 0.1 per cent of GDP in all regions (Figure 3.26). This Assessment applies the approach from the Global Methane Assessment to evaluate these impacts at a regional level (UNEP and CCAC 2021). The analysis considers several key factors affecting crop yields. The empirical crop model evaluates relationships between temperature, precipitation, carbon dioxide concentrations, and ozone levels, rather than conducting plant-level simulations. Within this modelling framework, however, the effects of temperature and ozone dominate the response, with minimal projected impact from changes in precipitation or carbon dioxide, consistent with prior analyses (Shindell *et al*. 2019).

The modest impact of agricultural losses on GDP partly reflects the relatively small contribution of agriculture to GDP in higher-income countries within each region. The total impact on crop yields is likely underestimated, since the modelling only considers the effect of ozone on four staple crops (maize, rice, soy and wheat) and excludes other crops sensitive to ozone (Section 3.6). It also neglects the effects of reductions in ozone precursors other than methane on ozone levels. Furthermore, the modelling does not consider the potential effect of ozone on the forage quality of pasture, which may also affect livestock productivity (Hayes *et al*. 2016). More recent evidence suggests that this approach may underestimate substantial losses in food productivity due to climate change (Hultgren *et al*. 2025).

Figure 3.26: Avoided damage to agricultural productivity due to reduced climate change and surface-level ozone, by region, in 2035, 2050 and 2100, per cent of regional gross domestic product relative to the baseline scenario.



3.3 Economy-wide impacts of air pollution and climate change

The combined losses from climate and air pollution undermine economic growth, social welfare, and the prospects for sustainable development. In this section, health benefits of reducing air pollution are combined with the aggregate benefits of climate mitigation.

Market benefits from the 25 integrated solutions reach approximately US$ 1.2 trillion per year by 2035, US$ 2.4 trillion per year by 2050 and US$ 7.3 trillion by 2100, equivalent to between 0.5 and 0.9 per cent of global GDP annually over the century (Annex 2.5; Table A2.6). Total economic benefits, including both market and non-market benefits, reach approximately US$ 7 trillion per year by 2035, US$ 13 trillion by 2050 and US$ 48 trillion by 2100, equivalent to 2.6 and 5.7 per cent of global GDP annually (Annex 2.5; Table A2.6).

The higher monetary values later in the century reflect both greater benefits of reducing climate change and anticipated growth in the global economy. Air pollution health benefits are estimated using the GAINS model and climate-related health benefits using the PAGE model (Figures 3.27 and 3.28). Most of the economic benefits come from reduced air pollution: in 2100 reduced climate-related health damage accounts for 15 per cent of the total economic market and non-market benefits for that year (Annex 2.5, Table A2.8).

These results represent the net impact of the cost of climate and air pollution policies and the market benefits those policies produce through a more productive economy, reduced health-care costs, fewer extreme events, and so on. Market climate damage includes GDP loss, coastal assets, adaptation, and market feedbacks – those are additional losses to the economy that result from the occurrence of both climate and air pollution damage, beyond the damage attributable to either climate or air pollution individually. Market air pollution damage equals morbidity productivity loss and healthcare costs. Nevertheless, even with policy action, climate and air-pollution related damage continue to increase through the end of the century.

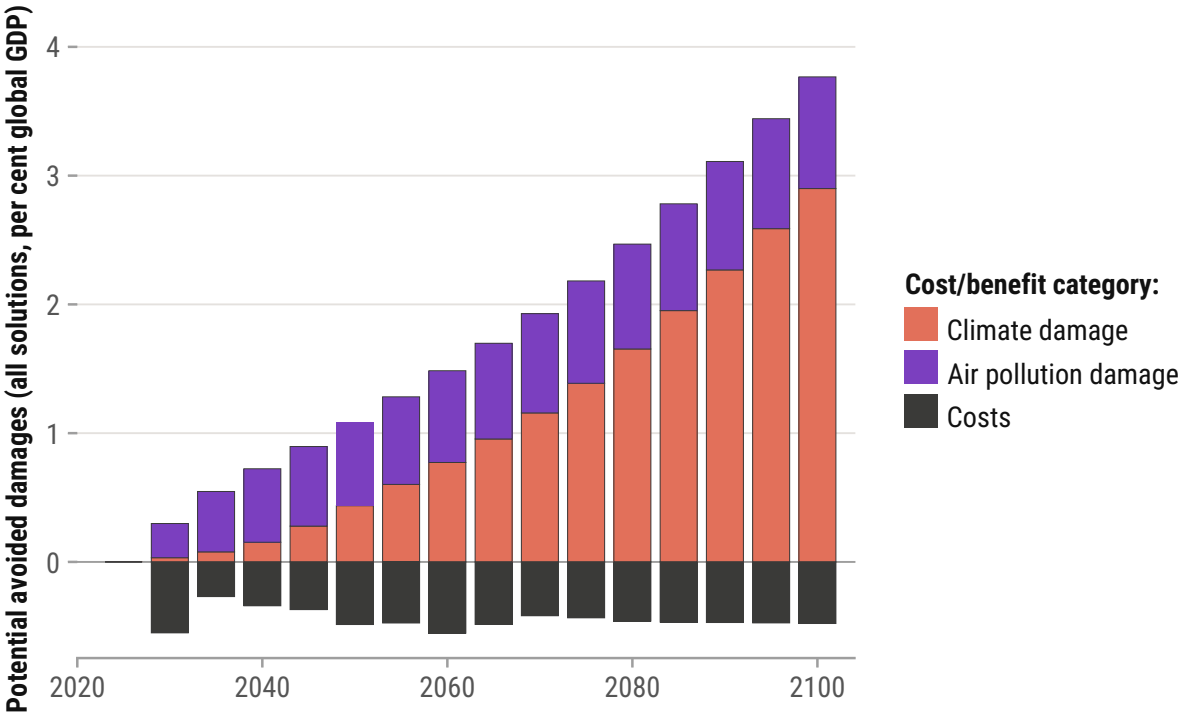
Comparing the market and non-market economic benefits of implementing the 25 integrated action solutions with costs of implementing them

By 2100, total avoided market damage reaches 3.7 per cent of global GDP (Figure 3.26), and non-market damage rises to a welfare loss equivalent to 7.7 per cent of global GDP (Figure 3.27). Total avoided market and non-market losses due to air pollution and climate change (Figure 3.27) are equivalent to 4.5 per cent of global GDP in 2050, rising to approximately 11.4 per cent by 2100.

Despite being lower than the non-market losses, the value of the market benefits exceeds implementation costs in every year beyond 2030, including when restricted to the market benefits of reduced air pollution alone.

Market benefits from avoided air pollution arise immediately once mitigation occurs and initially exceed market climate benefits. After 2060, avoided climate market benefits exceed those from air pollution, as the climate impacts being avoided grow steadily larger in the future.

Figure 3.27: Total avoided market damage from the implementation of the 25 integrated solutions compared to policy costs, 2025–2100, per cent of global gross domestic product.

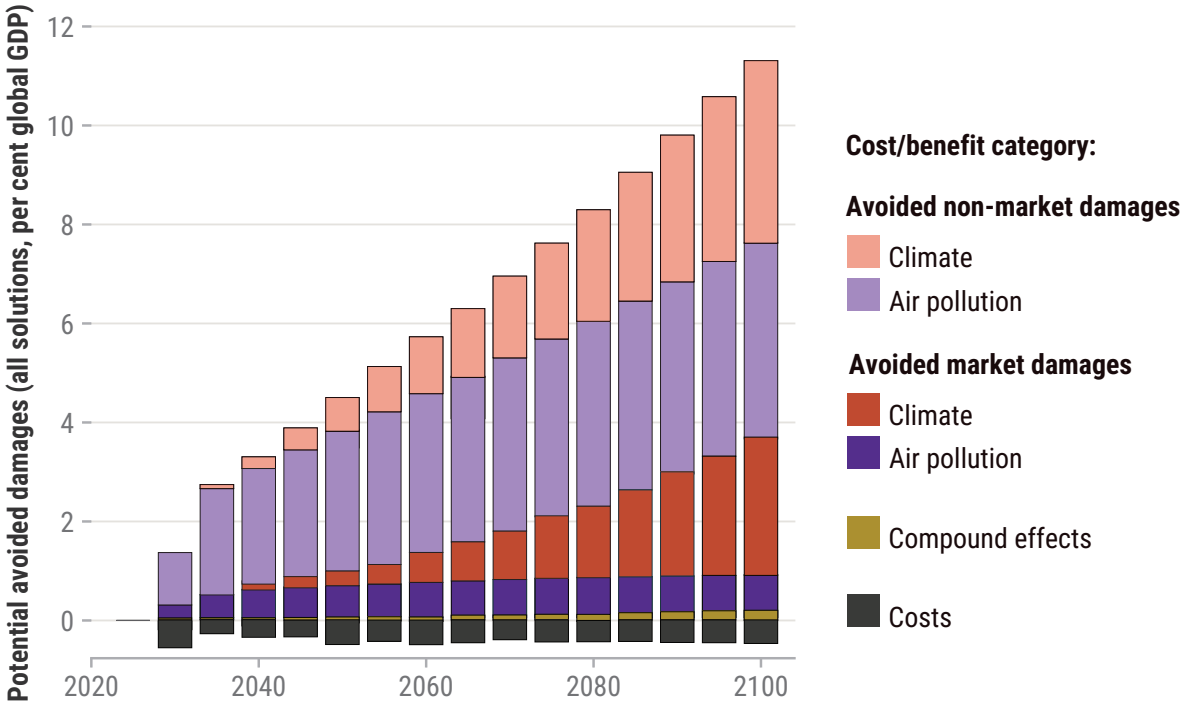


Both climate and air pollution benefits underlie these large avoided losses. The 21 clean air and near-term climate solutions reduce both climate and air pollution damage and therefore long-term climate solutions do as well, but more slowly than the former.

Market losses are less than half of total market and non-market losses (Figure 3.28), and accounting for non-market benefits strengthens the economic case further. Pursuing climate and air quality action together rather than separately generates approximately 0.2 per cent of GDP in additional economic benefits. These gains arise because many benefit channels – avoided climate damage, reduced healthcare expenditure, higher labour productivity and quality-of-life improvements linked to reduced morbidity and mortality – only materialise fully when the climate and clean air agendas are pursued together. These benefits are captured in the graph as compound effects (Figure 3.28).

The economic value of avoided air pollution damage exceeds that of avoided climate damage in early years and remains nearly half of the total economic benefit in 2100 (Figure 3.28). Considering only climate therefore misses the bulk of the near-term and almost half of the long-term economic benefits of action, underlining the importance of the integrated approach.

Figure 3.28: Total avoided market and non-market damage from the implementation of the 25 integrated solutions compared to policy costs, 2025–2100, per cent of global gross domestic product.

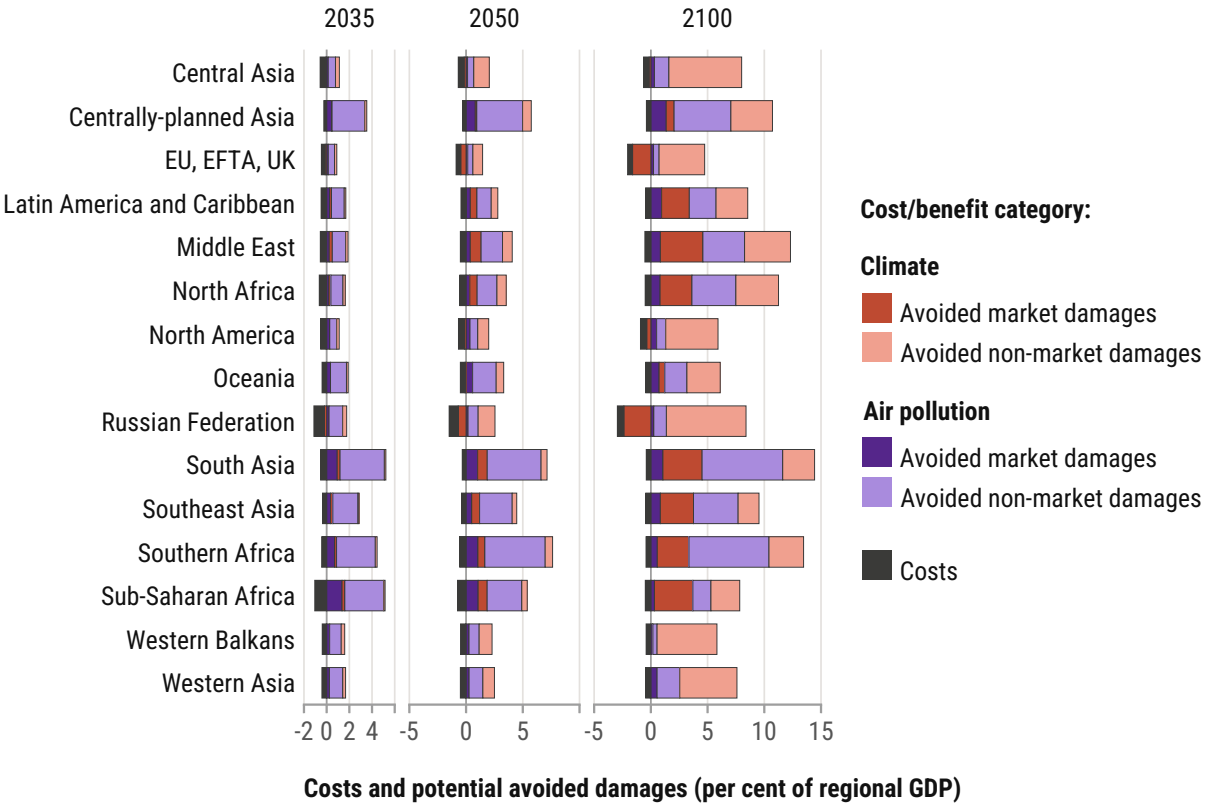


Note: "Compound effects" refers to additional foregone benefits, or synergies, which are not specifically attributable to climate or pollution, that emerge when action is taken on both. Benefits are expressed as their equivalent change in global GDP, placing both market and non-market impacts into common units.



Combined market and non-market benefits far exceed costs in every region as Figure 3.29 shows.

Figure 3.29: Total potential avoided market and non-market damage from the implementation of the 25 integrated solutions compared to policy costs by region, 2025–2100, per cent of regional gross domestic product.

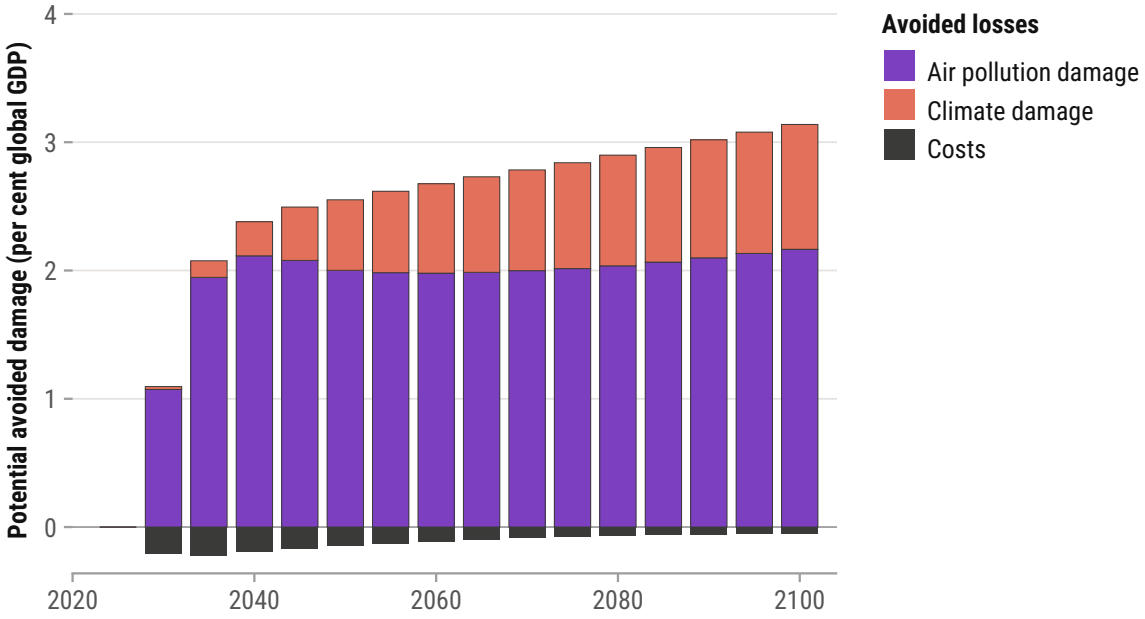


Comparing the market and non-market economic benefits of implementing the 21 clean air and near-term climate solutions with costs of implementing them

The costs of implementing the 21 clean air and near-term climate solutions are largest in the near-term, reflecting the need to address current air pollution urgently, but the solutions produce rapid benefits that greatly exceed implementation costs by in 2030 and by an increasing margin over time (Figure 3.30).

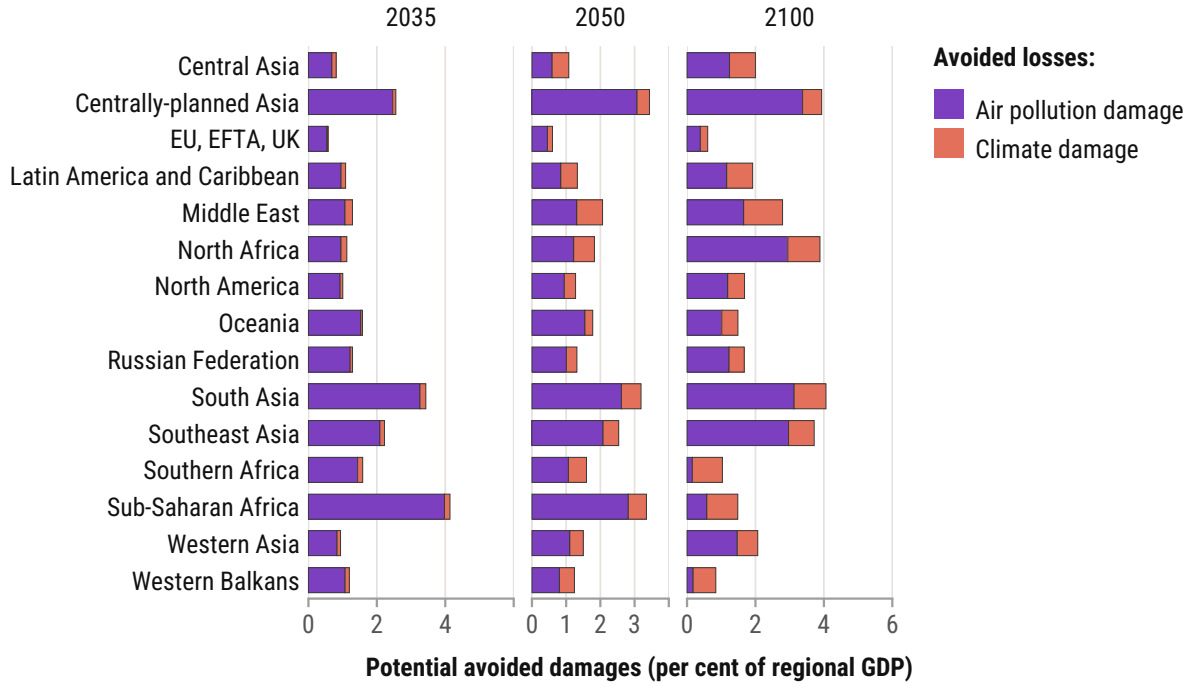
Total climate and pollution benefits from the 21 clean-air and near-term climate solutions reach the equivalent of 2.5 per cent of global GDP in 2050 and 3.1 per cent in 2100. Even at the end of the century, avoided pollution damage accounts for more than half of the economic benefit. Until 2030, benefits come from reduction in air pollution, covering health gains from higher productivity, lower healthcare costs and reduced disutility from mortality risk. Climate co-benefits emerge after 2030, reflecting the near-term warming benefits of reduced SLCP emissions. As 3.29 shows, benefits from these solutions accrue rapidly, while the relative benefits of decarbonization emerge mainly after 2050.

Figure 3.30: Avoided market and non-market climate and air pollution damage that result from implementing the 21 clean air and near-term climate solutions, only, 2025–2100, per cent of global gross domestic product.



In 2035, regional benefits from implementing the 21 clean air and near-term climate solutions exceed 3 per cent of regional GDP in South Asia and Sub-Saharan Africa (Figure 3.31). These regions currently have some of the highest pollution levels, and most of the benefits come from reduced air pollution. By 2100, most regions show air-pollution and climate -related benefits equivalent to 1 – 2 per cent of regional GDP, with four regions exceeding 3 per cent. Avoided warming from the 21 clean-air and near-term climate solutions delivers a relatively uniform benefit across the globe in 2100.

Figure 3.31: Regional breakdown of the avoided market and non-market climate and air pollution damage from implementing the 21 clean-air and near-term climate solutions, 2035, 2050, and 2100, per cent of regional gross domestic product.

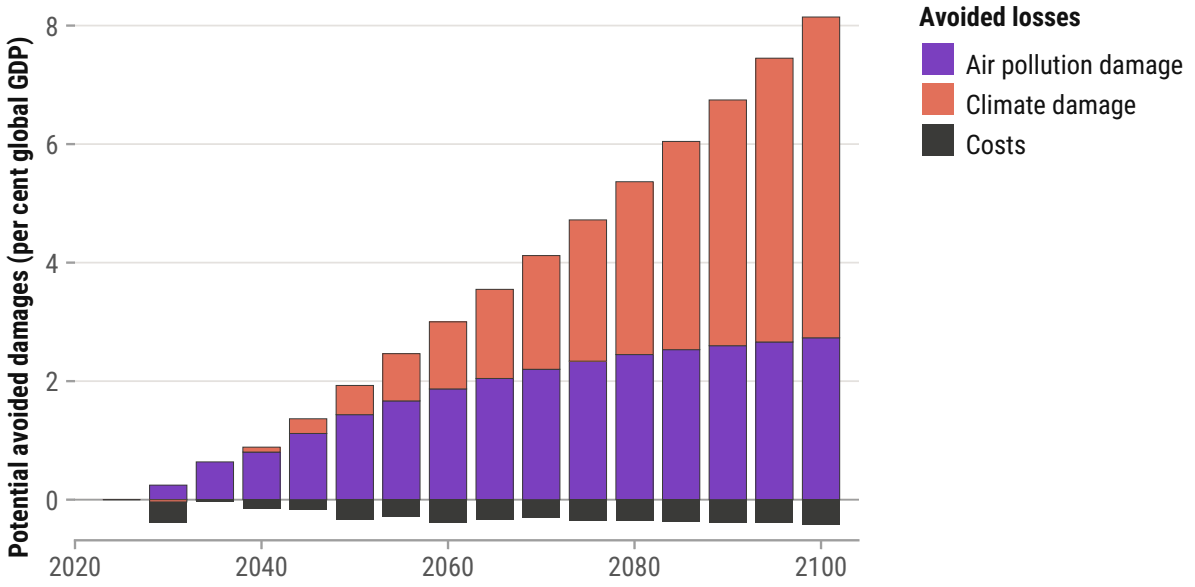


Comparing the market and non-market economic benefits with implementation costs of the four long-term climate solutions

Total costs of the four long-term climate solutions are much higher than those of the 21 clean air and near-term climate solutions but generate larger benefits later in the century. Over half of the economic value of avoided damage in 2100 comes from climate damage, but reductions in air pollution are significant and their benefits exceed climate benefits until after 2070. Figure 3.32 shows the benefits of implementing the four long-term climate solutions through both climate change and air-pollution impact reductions.

Climate-mitigation costs to society, covering both direct investment costs and indirect market losses, are below 0.25 per cent of GDP. Most of the benefits do not accrue until after 2050. In 2050, avoided damage from climate change and pollution are equivalent to about 2.0 per cent of global GDP, rising to 8.2 per cent by 2100.

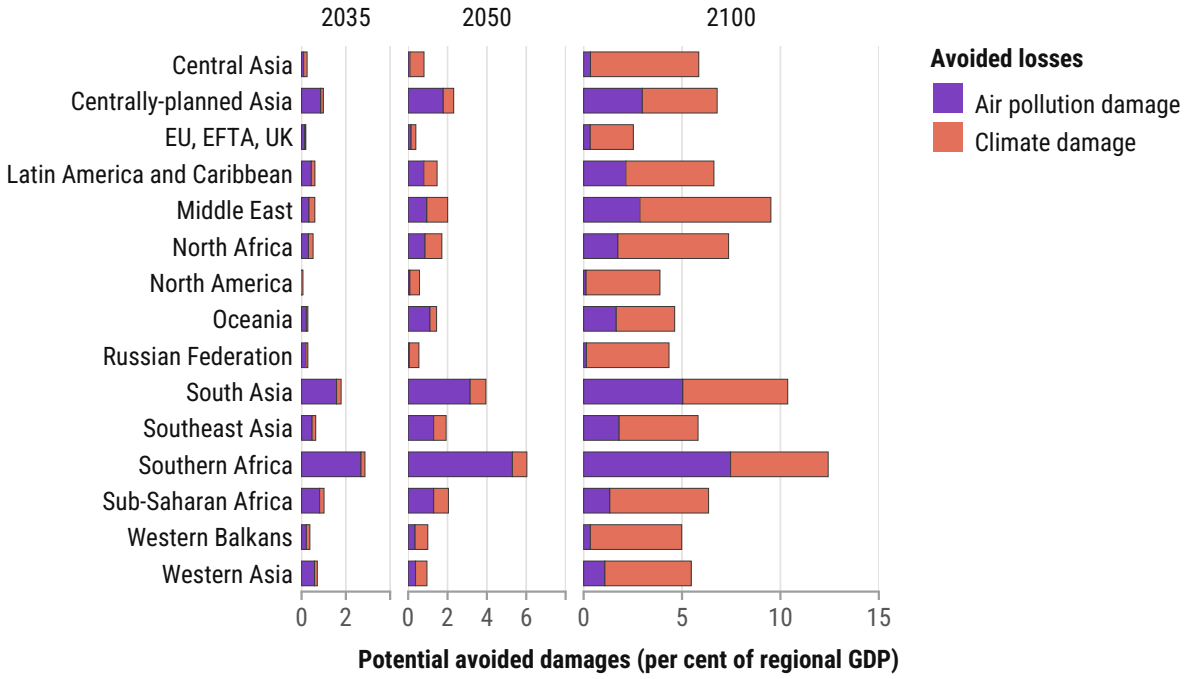
Figure 3.32: Avoided market and non-market damage from implementing the four long-term climate action solutions, 2025–2100, per cent of regional gross domestic product



Across regions, total avoided damage by 2100 exceeds 5 per cent in most regions (Figure 3.33). Europe, North America, Oceania and Russian Federation show somewhat lower percentages, while South Asia and Southern Africa exceed 10 per cent.



Figure 3.33: Regional breakdown of the avoided losses from implementing the four long-term climate solutions, 2035, 2050 and 2100, per cent of regional gross domestic product.



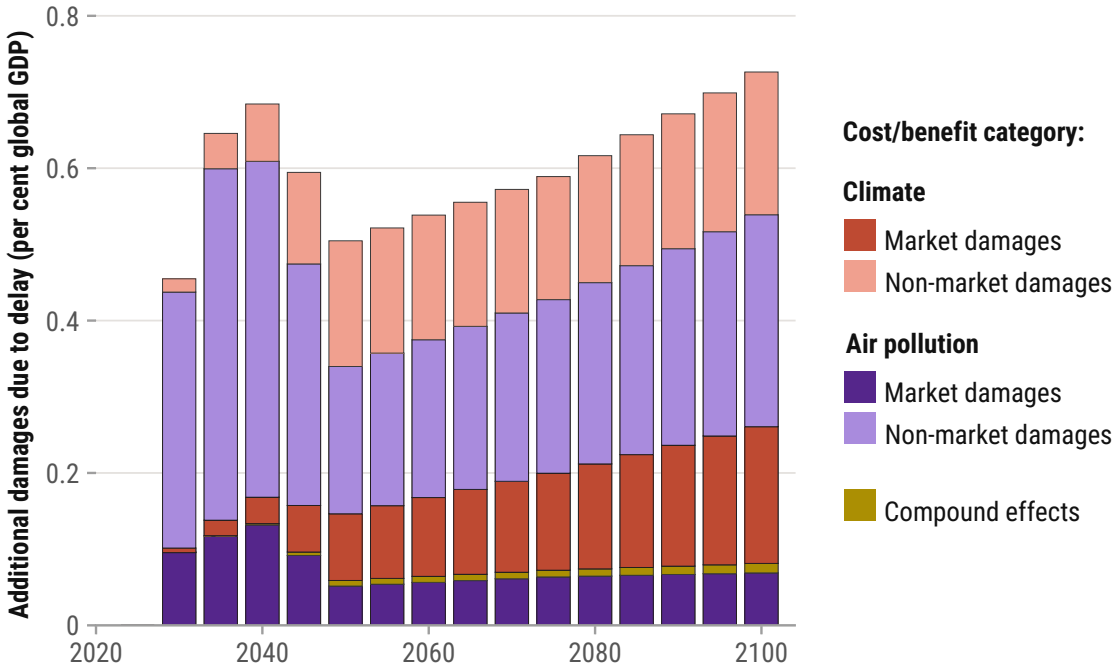
Effects of delayed implementation

Delaying implementation carries a large economic cost, with foregone benefits equivalent to more than 0.5 per cent of global GDP in most years (Figure 3.34). In early years these foregone benefits are dominated by pollution, in later years, followed by a nearly even split between pollution and climate benefits. In 2035 alone, delays forego approximately US$ 500 billion in market benefits and more than US$ 1.5 trillion in total economic benefits, in 2025 US dollars. In Figure 3.34, foregone air pollution benefits are higher up to 2045, the period when the returns on earlier action are greatest. Climate benefits emerge later but become substantial after 2050, where they match the foregone air pollution benefits in scale. Near-term delays in climate action increase damage throughout the century and beyond.

The economic benefits of enabling implementation are substantial but realizing them depends on effective and timely action. Maximizing the air quality, health and economic benefits identified in this Assessment requires a well-designed enabling environment. This entails addressing technical, social, economic and institutional factors that influence the pace and scale of implementation. Key elements include ensuring that implementing agencies have sufficient staffing, capacity and financial resources, and designing policies that incentivise affected industries to invest in cleaner technology and practices.

Investment in enabling environments that strengthen implementation can deliver significant domestic public-health benefits. Globally, these investments could prevent substantial new cases of illness, such as up to 17 million children from developing asthma over the course of this century.

Figure 3.34: Foregone economic benefits if implementation of the 25 integrated solutions is delayed, 2025–2100, per cent of global gross domestic product.

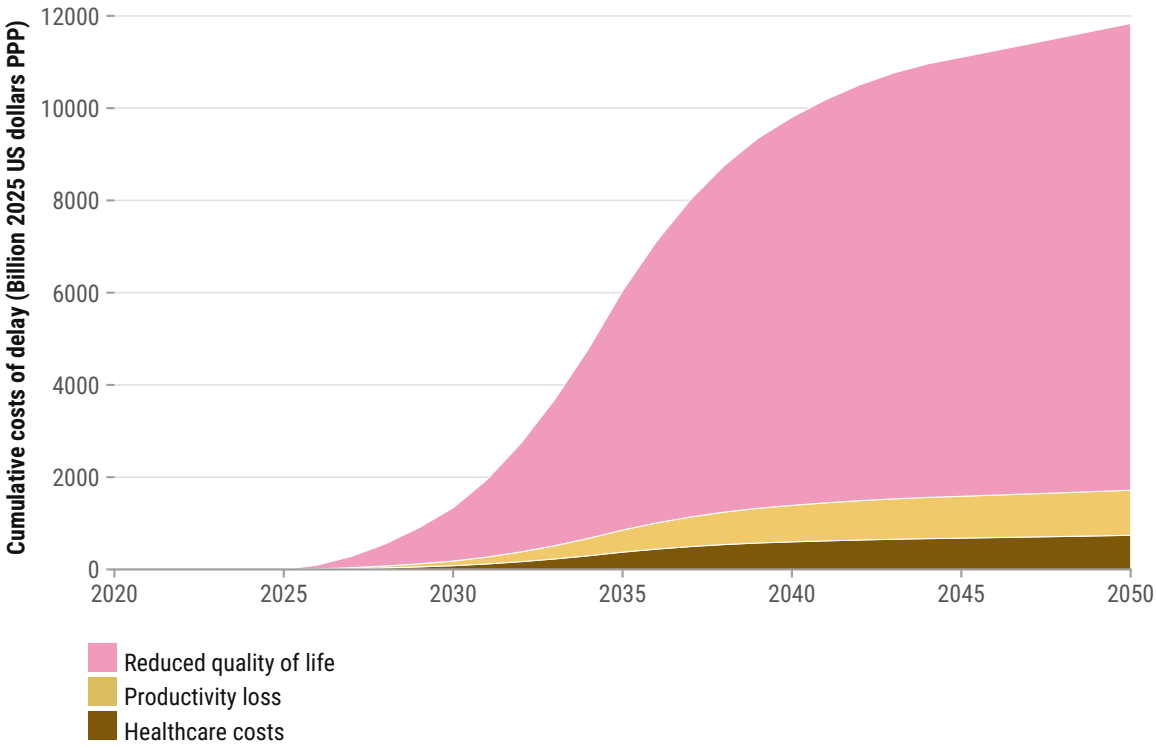


Note: "Compound effects" refers to additional foregone benefits, or synergies, which are not specifically attributable to climate or pollution, that emerge when action is taken on both. Benefits are expressed as their equivalent change in global GDP, placing both market and non-market impacts into common units.

In the near-term enabling actions could generate combined market and non-market benefits of up to US$ 10 trillion by 2040 (ppp adjusted prices), reflecting morbidity and mortality benefits, providing a strong economic justification for targeted investment (Figure 3.35). These estimates are conservative: the modelling assumes no long-term technological or behavioural lock-in and that implementation barriers are eventually overcome even in the absence of specific enabling actions.



Figure 3.35: Cumulative costs of delay accounting for air pollution only (morbidity and mortality) because of barriers to implementation, 2025–2050, billion 2025 United States dollars, purchasing power parity.



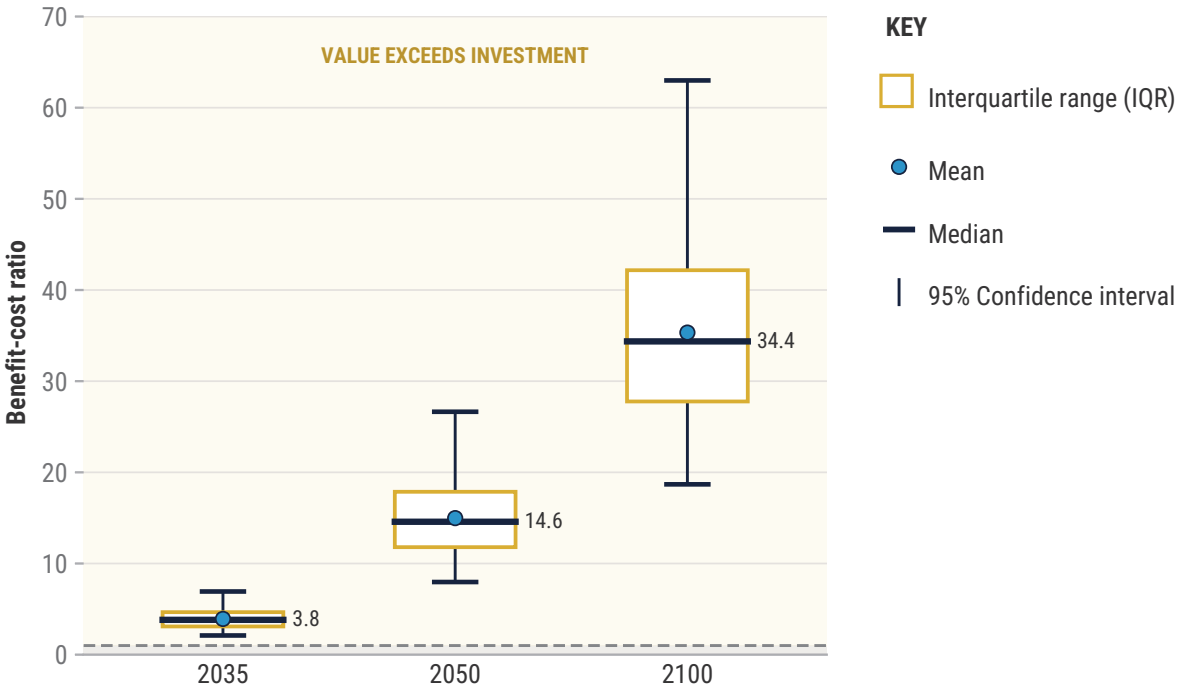
Note: for this cumulative result, future costs are discounted to 2025 at 3 per cent per year.

3.4 Benefit-cost analysis of the 25 integrated solutions

This section reports two BCR metrics. First, annual BCRs measure benefits and costs within individual years, incorporating climate benefits in the form of the social cost of greenhouse gases emissions in that year, since climate benefits only accrue in future years. Second, forward-looking BCRs describe the discounted flow of benefits and costs at the macroeconomic level from now to 2100. The uncertainty for both costs and market-related benefits is assessed in Figure 3.35. The 25 integrated solutions deliver economic benefits that far exceed their costs, with BCR increasing substantially over the century. Shown in Figure 3.36, annual BCR exceeds 1 throughout the period, rising from a mean of 3.9 (IQR: 3.1 – 4.7) in 2035 to 35 (28 – 42) in 2100. Including non-market benefits would substantially increase these BCRs further.

The economic benefits of the 21 clean air and near-term climate solutions exceed their implementation costs across all time periods. For the four long-term climate solutions, implementation costs exceed benefits in the first two decades, though these costs are partially offset by near-term air pollution benefits. Reductions in greenhouse gases produce near-permanent reductions in warming, with the largest benefits emerging after 2050. Taken together, the two groups of solutions are complementary: the 21 clean air and near-term climate solutions deliver returns quickly, while the four long-term climate solutions lock in much larger benefits that accumulate over the long-term.

Figure 3.36: Uncertainty in global estimates of the benefit-cost ratio in 2035, 2050 and 2100, accounting for costs and market only benefits.



Note: market benefits include healthcare costs and loss of productivity associated with morbidity from ambient air pollution, loss of productivity from premature mortality due to both household and ambient air pollution, and the market share cost from the social cost of carbon. (See Annex 2.5.1)

Box 3.2: Caveats to the benefit-cost ratio

Benefit-cost ratios rely on simplifications worth noting. They aggregate costs and benefits over time: installing scrubbers at an industrial facility, for example, requires a large upfront investment, while the resulting air pollution reductions deliver benefits for decades. This timing mismatch is even more pronounced for climate mitigation, for which emissions reductions today lower damages over many decades or longer. To make costs and benefits comparable, BCRs use net present values, which convert future costs and benefits into today's monetary terms using a discount rate. These reflect how valuable future benefits are relative to costs borne today. At the 3 per cent discount rate applied here, benefits 25 years from now are worth approximately half of their future nominal value, i.e., discount factor $=1/(1+r)^t$, where r is the discount rate and t= time, $1/(1+3 \text{ per cent})^{25} = 48$ per cent in present value terms.

All values in this report are in real terms, and discount rates are unrelated to inflation rates. Future costs and benefits in nominal terms will be larger due to inflation, but effect is removed by separately reporting all values in constant 2025 US dollars.

The BCRs reported here do not capture how costs and benefits are distributed across actors. Pollution controls may impose costs on firms while generating benefits for surrounding populations. In addition, this Assessment includes non-market values, which represent real welfare gains to individuals but are not captured in market, i.e., GDP transactions. Ensuring that private investments are made to achieve these BCRs requires aligning the incentives of firms with the public good. For transparency, BCRs presented below are both based on market costs only and on combined market and non-market costs.

At a 3 per cent discount rate, the forward-looking benefit-cost ratio for the 25 integrated solutions is approximately 15 (interquartile range. This places the 25 integrated solutions among the highest return public investments available. It is comparable, for example, to childhood immunization, which returns approximately US$ 16 for every dollar invested when measured against the cost of illness averted, and up to US$ 44 when the broader value of longer, healthier lives is included (Ozawa *et al*. 2016), and to investment in nutrition and agricultural research, assessed at a benefit-cost ratio of 16 with an internal rate of return of 61 per cent (Hoddinott *et al*. 2012).

Benefits include reductions in market and non-market impacts from both avoided damages related to warming and to air pollution. When restricted to market costs and benefits only, the net present value of benefits is 4.0 times greater than costs, reflecting both climate and air pollution benefits and the relatively rapid and low-cost nature of many solutions. Stoerk *et al*. (2025) developed a comparable estimate for the costs and benefits of the Global Methane Pledge (GMP), finding BCRs of at least 3 excluding health co-benefits, or 6 when co-benefits are included, consistent with the findings here.

Benefits and costs vary substantially across regions, nonetheless in every region benefits exceed costs under the full economic assessment (Table 3.2). The 25 integrated solutions consistently yield BCRs larger than 1 because benefits accrue more quickly than costs. Across regions, BCRs range from 3 in the European Union, EFTA and the United Kingdom of Great Britain and Northern Ireland to 26 in Southern Africa. These patterns reflect the extent of climate benefits, which are smallest for regions at higher latitudes, as well as the energy mix, with higher BCRs in more polluted regions, and age structure, with higher BCRs in more vulnerable populations. When non-market benefits are excluded, benefits still exceed costs in 8 of 15 regions, with higher BCRs in more vulnerable populations, demonstrating that the economic case does not rest solely on non-market valuation.

Table 3.2: Benefit-cost ratios for integrated action scenario. Under "Full economic benefits", both market and non-market benefits are included while "Market-only benefits" includes only market benefits. In both cases, the benefits include both those of avoided warming and benefits from reduction in air pollution.

Region	Full economic benefits	Market-only benefits
Central Asia	7	< 1
Centrally-planned Asia	18	3
EU, EFTA, UK	3	< 1
Latin America and Caribbean	9	3
Middle East	11	4
North Africa	11	3
North America	5	< 1
Oceania	8	1
Russian Federation	4	< 1
South Asia	21	6
Southeast Asia	13	4
Southern Africa	26	5
Sub-Saharan Africa	11	5
West Balkan	8	1
Western Asia	8	1
Global	15	4

The internal rate of return (IRR) is another useful metric for comparing benefits and costs. The IRR is the discount rate at which the net present value of an investment is zero. A high IRR means that even under aggressive discounting, benefits exceed costs, confirming the robustness of the economic case for action. The internal rate of return for all measures is 60 (49 – 69) per cent, implying very high returns to investment. Restricted to market benefits only, the IRR is 16 (12 – 18) per cent for the 21 clean air and near-term climate solutions and 10 (7 – 11) per cent for the four long-term climate solutions. Both figures comfortably exceed typical public investment thresholds.

3.5 Regional priorities: which solutions deliver the greatest benefits and when

The 25 solutions are designed to be implemented as a package. The full economic and health benefits identified in this Assessment, including the synergistic gains from addressing climate change and air pollution together, are only realised when all 25 integrated solutions are pursued simultaneously. Within that package, however, the solutions delivering the largest benefits in any given region and time period differ substantially, reflecting differences in current pollution levels, energy systems, demographics and the extent of existing policies. Figures 3.37 and 3.38 identify the seven solutions delivering the greatest market benefits in each of the 15 regions in 2030 and 2050 respectively, expressed as a percentage of regional GDP and accounting for both air pollution and climate benefits.

In this analysis, the air pollution benefit for a given measure reflects impacts in a single year, while the climate benefit is cumulative, capturing the social cost of all relevant greenhouse gas and SLCP emissions integrated over the remainder of the century at a 3 per cent discount rate. This differs from the full PAGE model methodology used in the BCR analysis in Section 3.4. and the two sets of figures should not be directly compared.

Regional groupings in 2035

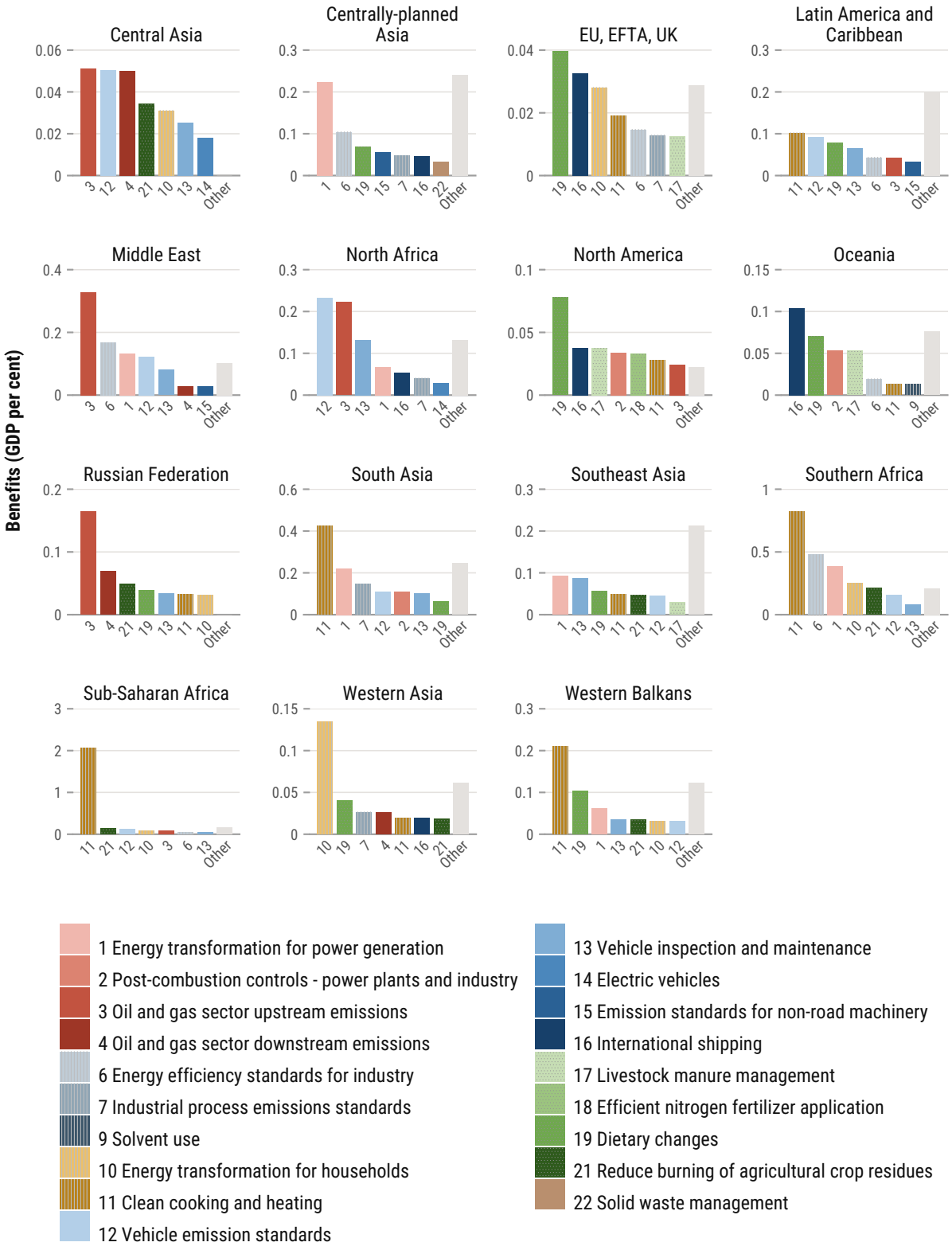
In high-income regions with mature pollution control frameworks, including the European Union, EFTA and United Kingdom of Great Britain and Northern Ireland, North America and Oceania, the lower-cost technical mitigation options have already largely been implemented under existing policies. The remaining high-benefit solutions involve more difficult transformational or behavioural changes: dietary change and reductions in international shipping emissions rank among the top measures in all three regions, reflecting the dominance of agriculture and trade-related emissions once industrial and energy sources are controlled.

In developing regions in which clean cooking and heating with solid fuels are prominent, including Latin America and the Caribbean, South Asia, Sub-Saharan Africa and the Western Balkans, high exposure to indoor air pollution from solid fuel combustion generates large and immediately quantifiable health benefits from switching to cleaner technologies. As Chapter 2 shows, the implementation costs of clean-cooking solutions are among the most favourable of any measure in the package, and the benefits are concentrated among the populations bearing the greatest burden.

In regions where oil and gas upstream emissions dominate, the Middle East, North Africa and Russian Federation, methane leakage, and venting and flaring from fossil fuel production generate both significant climate impacts and local air-quality harms. Solutions targeting these emissions are among the most cost-effective available globally, delivering large benefits relative to implementation costs and rapid results.

The remaining groupings cover parts of Asia where energy transformation is the dominant priority. In Centrally-planned Asia and Southeast Asia the priority is clean power generation, reflecting the continued dominance of coal-fired electricity. In Western Asia, household energy transformation ranks more highly, reflecting a different residential energy profile.

Figure 3.37: Priority solutions by region in 2035 considering air pollution and climate policies, ranked by total market benefit, per cent of regional gross domestic product.



Note: the figure shows the seven solutions delivering the greatest market benefits in each of the 15 regions in 2035, expressed as a percentage of regional GDP and accounting for both air-pollution and climate benefits. The grey bar shows 'other' - the combined effect of the rest of the 25 measures.

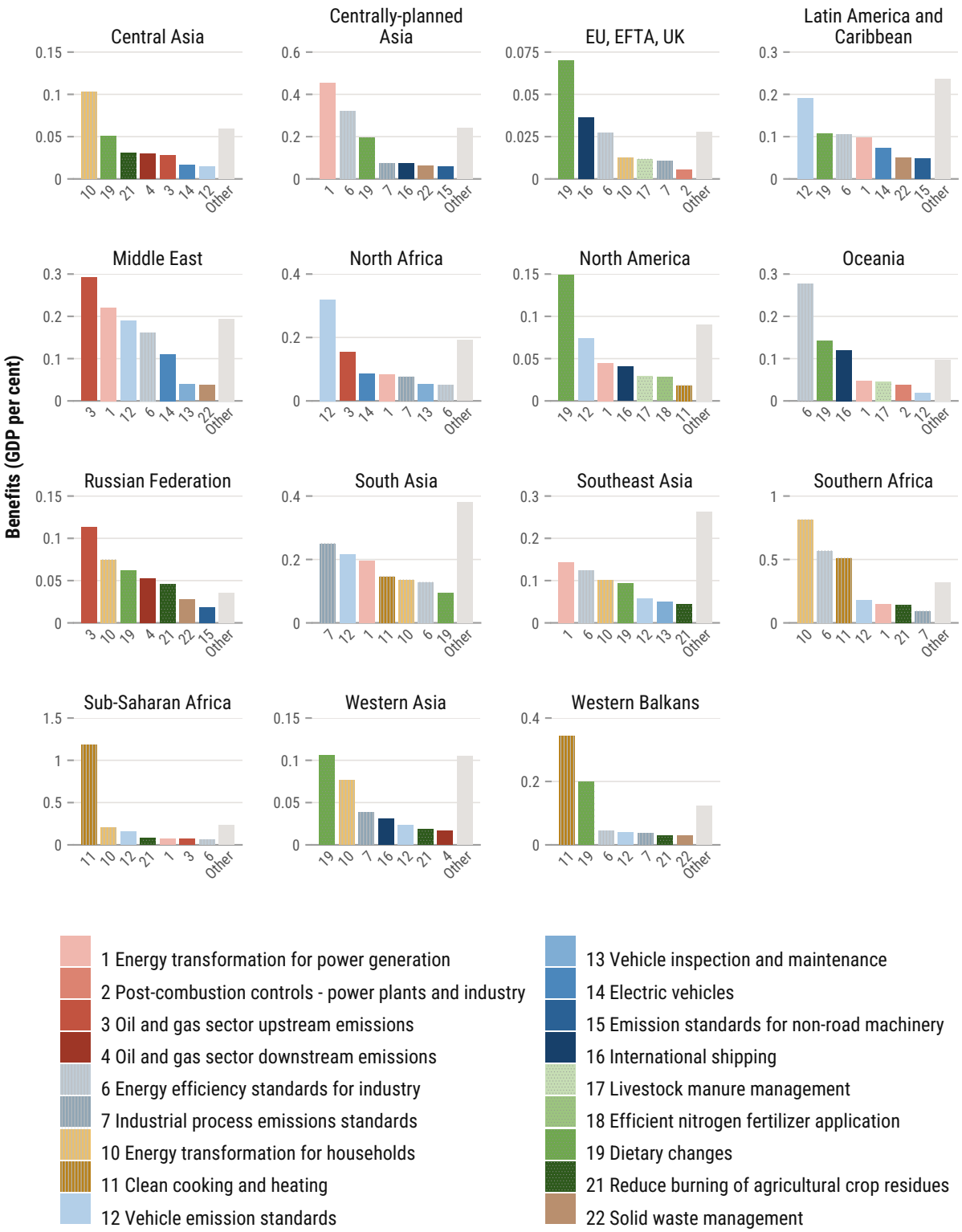
How priorities shift between 2035 and 2050

The regional groupings of priority measures remain broadly stable in 2050, but important shifts occur as the baseline scenario evolves and the cumulative climate benefits of earlier action become more significant. In high-income regions, the four long-term climate solutions gain relative importance as near-term air pollution benefits are progressively captured. In developing regions, clean cooking and heating remain highly significant, but energy transformation solutions become more prominent as economic development increases energy demand. In the oil and gas producing regions, upstream methane controls remain a high priority throughout, but the balance shifts towards such transformative solutions focused on longer-term climate benefits. By the end of the century, dietary change and/or energy efficiency standards for industry dominate the benefits in many regions, whereas it is transformation for power generation in the Middle East, vehicle emissions standards and industrial process emission standards in North Africa and South Asia, energy transformation for households in Southern Africa, and vehicle emission standards and energy transformation for power generation in Sub-Saharan Africa replacing clean cooking and heating (Figure A2.12, Annex 2.6).



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Figure 3.38: Priority solutions by region in 2050 considering air pollution and climate policies, ranked by total market benefit, per cent of regional gross domestic product.



Note: The figure shows the seven solutions delivering the greatest market benefits in each of the 15 regions in 2050, expressed as a percentage of regional GDP and accounting for both air pollution and climate benefits. The grey bar shows 'other' - the combined effect of the rest of the 25 measures.

Implications for implementation

The solutions that fall outside the top seven in any given region are not unimportant. They continue to contribute to the full package of benefits and are essential for the synergistic gains that only emerge when all 25 solutions are implemented together. The regional variation in priority solutions is itself an agreement for the integrated approach. The fact that clean cooking leads in South Asia with dietary change leading in North America reflects different starting points, not different frameworks. Both regions need the same package of 25 solutions, applied with sensitivity to local context and costs. The solutions that are not a top priority today may become so as circumstances change, as the shift from 2035 to 2050 already illustrates, and the institutional infrastructure built to deliver the highest-priority measures will in many cases be the infrastructure needed to deliver the rest.

3.6 Further benefits and trade-offs

The 25 integrated solutions generate additional effects beyond those quantified in the preceding sections, both beneficial and adverse. Understanding these co-benefits and trade-offs is important for policy design, since capturing the full range of benefits while avoiding unintended negative consequences can substantially strengthen the case for action and improve implementation outcomes.

Potential benefits and trade-offs were mapped to the solutions through a combination of literature review and expert discussion. These effects are diverse, spanning human health, food production and ecosystems, the built environment, water quality, and broader societal dimensions including socio-economic and gender equity. Where trade-offs exist, the evidence strongly indicates they are small relative to the benefits of action. Further details and references are in Annex 2.7.

Several categories of health impacts are not fully captured in the main analysis. These include the effects of ozone generated from non-methane precursors such as carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds, additional health effects of $PM_{2.5}$ not included in the core assessment, health benefits from improved diets and effects linked to other air pollutants including carbon monoxide, nitrogen dioxide and polycyclic aromatic hydrocarbons, as well as persistent substances such as fluorocarbons. Each of these omissions is likely to result in underestimation of total benefits.

Air pollution and climate change also impose significant costs on agriculture, forestry and ecosystems that are only partially reflected in the analysis (Annex 2.7, Table A2.12). Ozone damages crop yields and reduces forest carbon sequestration capacity, and while ozone impacts on four staple crops are partially accounted for in Section 3.2.3, damage to other sensitive crops and to forage quality for livestock is not (Hayes *et al*. 2016). Acid deposition affects soils and forests in some regions, though its global aggregate impact appears modest. Evidence indicates that the fertilization benefits of nitrogen deposition are small compared to the harm from ozone exposure. More broadly, air pollution and climate change degrade biodiversity and ecosystem services, including carbon sequestration, water purification, soil fertility, flood regulation and food provision, with implications that current models do not fully capture (see Annex 2.7). Water quality is also affected through nitrogen deposition and agricultural run-off, as well as emissions from extractive industries such as coal mining and oil and gas production.

Chapter 2 included discussion of deadweight losses linked to price increases within the economy arising from introduction of the 25 solutions, showing that they may be important. They will be countered to some degree by macroeconomic consequences linked to better health from reduced air pollution beyond the productivity benefits that have been quantified and reduced climate impacts. There is also the possibility that green investment makes the economy more efficient, through increased public investment.

The 25 integrated solutions also generate significant equity benefits. Air pollution impacts fall most heavily on poorer populations, who face higher health risks under the baseline scenario, reduced access to health services and greater exposure to pollution. Climate impacts similarly disproportionately affect the poor, who live in more vulnerable locations and have fewer resources to adapt to or recover from climate risks. Efficiency solutions reduce the costs of energy and other goods, benefits that are felt most keenly by lower-income households. These distributional advantages mean that ambitious action on air pollution and climate change is also an investment in equity, with the largest

gains likely to accrue to those who need them most (Annex 2.7.6).

Gender differences in health outcomes further shape how the benefits of the 25 integrated solutions are distributed. Women bear a disproportionate burden of dementia and are more likely to become carers for those with the condition, while men face higher rates of lung cancer and childhood asthma attributable to air pollution. These and other differential impacts of the 25 solutions on gender are examined in Box 3.3 and Annex 2.7.7.

Finally, additional co-benefits and trade-offs arise from solutions not examined in this report. Active travel schemes, for example, can reduce both air pollution and greenhouse gas emissions while also improving public health through increased physical activity and reducing congestion (Annex 2.7.9). Box 3.4 illustrates this with a case study from Austin, Texas.

Box 3.3: How gender interacts with the 25 solutions (see also Annex 2.7.7)

Gender shapes the costs and benefits of the 25 integrated solutions in three important ways: differences in the type, incidence and severity of disease; differences in exposure to air pollutants at home and at work; and the disproportionate burden on women and girls of collecting biomass fuel. The Annex 2.7.7 shows higher impacts of dementia in women (Bourzac 2025) and of lung cancer in men, and the experience of these diseases also differs by gender.

The types, incidence and severity of health conditions

The experience of disease is also variable. Healthy women have better memory than men even into very old age, but experience more rapid cognitive decline and lose independence earlier once dementia sets in (Alzheimer Society of Canada 2024). Women are also more likely to become carers for those with dementia. Stroke outcomes are worse for women across functional recovery, quality of life, depression, anxiety and cognitive impairment (Kim *et al*. 2010). Men may develop type 2 diabetes at a lower age and body mass index than women. Women with the condition, however, have a higher risk of some complications such as blindness and heart disease (Ramírez-Morros *et al*. 2024). Evidence is also emerging of significant impacts on women during pregnancy (Nazarpour 2024).

Exposure to pollutants at home and at work

Disease incidence and severity are compounded when women are exposed to higher pollution concentrations than men. Cooking on traditional stoves with polluting fuels generates particularly high exposures (Okello *et al*. 2018; Abeldaño Zuñiga and de Lima 2024). Women also face higher exposure in informal employment where worker protections are limited (WRI 2025).

Time spent collecting wood and other biomass

Worldwide, 2 billion people still rely on traditional stoves, and the task of collecting fuel falls disproportionately on women and girls. They can spend up to four hours a day gathering fuel and cooking, reducing time for school and paid work and eroding future autonomy and choice (IEA 2025). Time spent collecting firewood is also associated with a heightened risk of sexual assault (UNEP 2016).

Box 3.4: Benefits of integrated action on transport and mobility (see also Annex 2.7.9)

Beyond the solutions considered in this report, significant additional opportunities exist to reduce air pollution and greenhouse gas emissions. Urban transport systems offer one important example, illustrated here through city-level action in Austin, Texas. Pfeil *et al*. (2026) assessed 'realistic' and 'ambitious' transport scenarios aligned with Austin's Climate Equity Plan (City of Austin 2020), reflecting ongoing investments in pedestrian infrastructure, cycle lanes, and trail networks, alongside progress in vehicle electrification, modal shifts to public transport and active travel between 2025 and 2040 (Ramkissoon 2025).

Under the ambitious scenario, transport-related emissions decline by 72 per cent by 2040 and 41 per cent under the realistic scenario, with comparable reductions in carbon monoxide, nitrogen oxides and $PM_{2.5}$. Increased physical activity is estimated to avert approximately 230 to 460 deaths over this period, comparable to all 424 traffic fatalities recorded in the city between 2019 and 2022 (City of Austin 2025). At a VSL of US$ 7.5 million and a 3 per cent discount rate, cumulative benefits reach US$ 1.7 – 3.1 billion (2025 US dollars) by 2040, and this estimate excludes additional gains from reduced congestion.



04 Breaking down barriers and building enabling environments for climate change and clean air solutions



Caption: © Students actively participating in sustainable urban transport, using shared electric bikes under solar panels. Photo: AdobeStock/KoldoStudio

Key messages

- A well-designed enabling environment is critical to increasing the pace, scale and effectiveness of efforts to implement the 25 recommended solutions. Previous chapters used novel methods to quantify the health and economic benefits from the kinds of institutional coordination, stakeholder engagement, supportive technologies, initial finance and other reforms that would help construct such an enabling environment.

- Policymakers need a systematic framework for identifying which enabling reforms can strengthen implementation in diverse contexts. Such a framework can help policymakers think strategically about how to motivate different stakeholders to translate policy on paper into action on the ground.

- The assessment framework developed in this chapter is consistent with relevant literature and distilled from real-world experiences in China, India, Mexico and Nigeria. Together, these four countries are home to more than 40 per cent of the world's population, are often regarded as regional leaders and have rich experience with key solutions. This experience can contribute to an empirically grounded understanding of how more targeted and broader cross-cutting enablers can overcome economic, institutional, technical and social barriers to implementation.

Table 4.1: 16 implementation enablers

Targeted enablers (*illustrative examples*)	Cross-cutting enablers (*illustrative examples*)
Mechanisms for selecting appropriate technologies *(Mexico's national cookstove projects)*	Air-quality monitoring networks and emissions inventories *(India's expansion of its air-quality monitoring network)*
Supportive technologies/infrastructures *(China's support for electric vehicle charging stations)*	Leadership backing for integrated planning and principles *(China's decision to pursue co-control or synergistic pathways)*
Consensus-building and awareness-raising programmes *(Nigeria's open burning awareness-raising workshops)*	Science-policy interface *(Mexico's work on Climate and Clean Air Coalition (CCAC) National Planning Activities)*
Programmes addressing distributional impacts and equity *(India's Pradhan Mantri Ujjwala Yojana (PMUY) cookstove programme)*	Horizontal coordination mechanisms *(Mexico's Intersecretarial Committee on Climate Change)*
Programmes allocating public finance for initial investment costs *(Nigeria's funding for clean energy projects)*	Vertical coordination mechanisms *(Nigeria's integration of short-lived climate pollutants (SLCPs) in its* Nationally Determined Contribution (*NDC))*
Regulations attracting private financial flows *(Mexico's national strategy for electric mobility)*	Integration of air pollution/climate in planning and budgeting processes (5-year plans) *(China's mainstreaming of synergies into local environmental plans/action)*
Sector-specific promotional programmes and missions *(India's solar mission)*	Sustained capacity-building programmes *(China's commitment to building regulatory capacity over the past decade)*
Combinations of government-led and market-based enablers and incentives *(China's clean energy transition)*	Local governments empowered to serve as hubs of innovation *(Mexico City's designation as transport leader)*

- Policymakers will often need to embed the above eight targeted sector-specific enablers into eight broader cross-cutting institutional ones. Fitting the targeted enablers into broader cross-cutting enabling conditions can generate incentives for implementing not just an isolated but an integrated suite of solutions. A good fit between different enablers can generate a virtuous cycle of reforms, bringing many countries to the results in the integrated action scenario (Chapters 2 and 3).

- A more systematic approach to breaking down barriers and building enabling environments in regional capacity-building programmes and experience-sharing platforms could sharpen the focus of international air-pollution/climate initiatives on implementation. This systematic approach can be operationalised by decision-making tools that help policymakers identify what kinds and combinations of enabling reforms work in different contexts.

4.1 Introduction

Previous chapters suggest that significant economic and health benefits can be achieved from adopting 25 solutions to air pollution and climate change.

Capturing these benefits is, however, not guaranteed; that depends on how well they are implemented. Robust economic assessments of the benefits of key solutions can help strengthen implementation, persuading policymakers that the gains of implementing solutions outweigh the costs (Chapters 2 and 3).

While estimating economic benefits is arguably necessary for delivering clean-air and climate benefits, it is not sufficient. Achieving the full benefits of key solutions also requires a robust assessment of the institutional, social, technical and economic reforms enabling their implementation. A clearer understanding of the benefits of enabling reforms can also help countries make progess down implementation pathways.

Chapters 2 and 3 drew on a novel quantitative assessment of the benefits of investment in strengthening capacities, enhancing institutional coordination, facilitating stakeholder engagement, providing supportive technologies, allocating initial finance and other undervalued enabling reforms. An important contribution of this study is therefore quantifying the value of investing in these kinds of enabling reforms to accelerate implementation (Chapters 2 and 3). Yet estimating the gains from enabling implementation will only take policymakers part of the way to achieving the full benefits of integrated clean-air and climate solutions.

A more systematic approach to qualitatively assessing what enables implementation under varying conditions is also needed. Such a systematic framework can help policymakers think carefully about how to motivate different stakeholders to translate policy on paper into action on the ground. The main purpose of Chapter 4 is to offer a systematic framework to assess what elements of an enabling environment can strengthen implementation of key solutions for the transport, energy, waste and agricultural sectors in diverse contexts.

The framework is consistent with recent trends in climate policy and related literature. That research has employed increasingly robust methods to identify and overcome barriers to effective implementation of different policies and solutions. For example, the Intergovernmental Panel on Climate Change's (IPCC) Special Report on 1.5 ºC underlines the five dimensions of feasibility – economic, environmental, institutional, social and technical – that can influence the potential of mitigation and adaptation options (IPCC 2018). The IPCC Sixth Assessment Report (AR6) Working Group III (WG3) takes this approach a step further, focusing on factors hindering the rapid implementation of key sectoral solutions (IPCC 2022). Other studies have used frameworks for a systematic comparison of scenarios using different dimensions of feasibility (Brutschin et al. 2021) or incorporated multiple dimensions of feasibility into sector-specific modelling (Akahoshi *et al*. 2024; Zusman *et al*. 2025). Work analysing the barriers and enablers to implementing air pollution and other sectoral solutions can be found in studies on wastewater management, recycling and the circular economy, climate action, air pollution and health at the national and subnational levels (Kuehne *et al*. 2017; Gómez-Sanabria *et al*. 2020; Kleimann *et al*. 2022; AlJaber 2023; Goudsblom and Clarke 2025; Pilogallo *et al*. 2025).

Understanding what enables implementation is viewed as increasingly critical to achieving the benefits of climate and related policies. Following trends in the IPCC and elsewhere, as well as the quantitative assessments of Chapters 2 and 3, this chapter focuses on barriers and enablers that could affect some of the 25 featured solutions' implementation prospects. Those barriers, also consistent with Chapters 2 and 3, are broken up into the following four admittedly narrowly defined categories. Economic barriers refer to the high initial costs and the financial incentives for relying on outdated pollution-intensive technologies; technical barriers refer to the lack of access to appropriate technologies, the limits on capacity of using technologies and outdated infrastructure that stalls the adoption of sustainable alternatives; social barriers refer to the lack of acceptance or low levels of awareness of benefits of key options or a lack of stakeholder-engagement mechanisms to address distributional issues; and institutional barriers refer to the limits on administrative capacity and insufficient coordination between agencies at the same or different levels of decision-making (Akahoshi *et al*. 2024; UNEP 2025; Zusman *et al*. 2025).

The above scheme for classifying barriers is neither exhaustive nor definitive in its coverage. For instance, limits on trade and strains on environmental resources – an environmental barrier – can slow the adoption and implementation of clean energy and other solutions.

In addition, psychological barriers – loss aversion or perceived reduction in political support – and political economy barriers, such as vested interests, can also impact the implementation of solutions (Hallsworth *et al*. 2018; Clean Air Fund 2025).

Further, the four types of barriers are not perfectly distinct categories; many are related, overlap and can generate lock-ins when they intersect (Unruh 2000 and 2002; Foxon 2002; Loorbach 2007). Even when these barriers interact, however, rarely do they block progress permanently. In fact, countries have often succeeded in removing not just one but multiple constraints in addressing environmental crises. Further, this is often because countries combine different enablers to overcome barriers and drive implementation (Olczak *et al*. 2023). Finally, as will be argued elsewhere in this chapter, embedding narrower enablers into wider mostly institutional ones will often be needed to create momentum for implementing a suite of solutions, as opposed to just one, consistent with the assumptions underlying the integrated action scenario in Chapter 2 and 3.

The chapter begins by assessing progress enabling the implementation of a representative subset of nine solutions in the transport, renewable/residential energy, waste, and agricultural (open burning) sectors (Table 4.2 for a listing of specific solutions). Because the analysis applies to a representative subset of the 25 solutions, it is indicative and illustrative of potential for the full collection of solutions. While the findings provide useful insights, they may not fully capture all the barriers, costs and impacts associated with all solutions featured elsewhere in the report. It was nonetheless determined that a subset of solutions was needed to keep the case studies manageable and align the assessment with the surveys for the barriers outlined in Chapters 2 and 3.

Table 4.2: Solutions featured in this chapter's case studies.

Sector	Description of solutions
Energy	Clean cooking and heating (e.g., natural gas/electricity and efficient stoves)
	Energy transformation for power generation (solar and wind)
Transport	Emission standards for road vehicles
	Emission standards for non-road vehicles
	Vehicle inspection and maintenance (I&M)
	Increase number of electric vehicles
Agriculture	Prevention of crop-residue burning
Waste	Solid-waste management

The analysis of barriers and how they are overcome is based on four countries – China, India, Mexico, and Nigeria were selected, in part, because they have had varying degrees of success with enabling the implementation of key solutions. These diverse track records demonstrate that several opportunities exist for strengthening implementation in varied contexts. In fact, as will be shown in the case studies, those differences often begin with how countries frame discussions of integrating air pollution and climate change in broader policies and institutions. They then carry over to more sector-specific targeted/sector-specific barriers. Importantly, though the four countries vary in their approaches, they have all accrued useful experience as they encounter and overcome obstacles.

The four countries' experience leads to two further justifications for the case study selection: their size and regional leadership. In terms of size, the four selected countries account for 3.2 billion people, nearly 40 per cent of the world's population. In terms of leadership, the four countries' experience can influence others within their region countries. Large emerging economies, including China and India and to a lesser extent Nigeria and Mexico, play important roles in shaping the trajectory of environmental policy across regions. While China and India are widely recognised as influencing climate policy beyond their borders (Qi and Dauvergne 2022; Sinha 2026), Nigeria and Mexico contribute through their respective roles as major economies influencing

regional dynamics and early adopters of environmental policy reforms (Adetula 2014; Averchenkova and Guzman 2018). This is important because, though the countries are different, they also have some shared experience that can be distilled and tailored to other contexts, generating insights that can enhance learning on implementation and enablers elsewhere.

The chapter is not only organised around presenting empirically rich case studies but developing a more systematic framework that can support learning across countries. To that end, each case begins with a context-setting discussion of the challenges and progress that helps shed light on the broader, cross-cutting enablers for the integration between climate and clean air in key national institutions and policies. This is then followed by a review of challenges to and progress on key sector-specific transport, energy (renewables/residential), waste and agricultural (open burning) solutions, together with suggestions on how to overcome hurdles in the four case studies. Following the four-country case studies, the chapter pulls back to an empirical framework with enablers and more quantitative evidence of their positive effects.

4.2 China

4.2.1 Setting the context: integrating air pollution and climate change in China

China's interest in controlling air pollution while mitigating climate change can be traced back approximately two decades. At that juncture, the national government demonstrated an interest in win-win options that addressed greenhouse gases (GHGs) in parallel with criteria pollutants that formed the basis for a co-control approach (*xietong kongzhi*). This co-control framing highlighted the potential for government-led policies and programmes to address climate while tackling air pollution (Cai et al. 2023). The co-control concept would also help strengthen horizontal integration between agencies working on these issues.

Since this initial interest in co-control, China has placed synergistic pollution reduction and carbon mitigation at the core of efforts to transition to a more sustainable development model. The commitment to that concept is reflected in the 2015 revision of the Air Pollution Prevention and Control Law, the first law to incorporate the principle of synergistic pollutants and greenhouse gas control in China. In 2018, institutional reforms that integrated climate responsibilities into the work of the Ministry of Ecology and Environment (MEE) helped build additional support for working on synergies in China. Based on the concept that "*lucid waters and lush mountains are invaluable assets*", China then adopted an Implementation Plan for Synergy Between Reducing Pollution and Bringing Down Carbon Dioxide Emissions in 2022. This established a framework for promoting supportive integrated policies through 2030 (Lei 2024) and reaffirmed the central role of synergies in promoting green development. In 2023, China released its Methane Emission Control Action Plan, yet another policy demonstrating a desire to "*strengthen the synergistic control of pollutants and methane*" as one of its main objectives. The report to the 20th National Congress of the Communist Party of China took this commitment a step further, explicitly calling on policymakers to *"promote concerted efforts to cut carbon emissions, reduce pollution, expand green development, and pursue economic growth"*. Building on this, the fourth plenary session of the 20th Central Committee of the Communist Party of China further identified this integrated approach as a critical pathway to accelerate transformations and building a Beautiful China (Kumar *et al*. 2025).

A series of measures since then have translated those principles and high-level decisions into concrete action. Examples include, *inter alia*, issuing integrated emission inventory guidelines, incorporating greenhouse gas assessment into the environmental impact evaluation system, defining synergistic tasks in key sectors and advancing co-control in areas such as wastewater treatment and control of methane emissions. Pilot programmes in cities and industrial parks, along with the dissemination of exemplary cases, have also served to further strengthen practical implementation capacity (MEE 2024a and 2025). To illustrate these practical implications, China designated 21 cities and 43 industrial parks as pilot areas that demonstrate tangible examples of operationalizing climate-air pollution synergies to help implement environmental plans.

Due in part to these sustained efforts and sustained efforts to build relevant regulatory capacities at multiple levels over the past decade, China has seen significant reductions in pollution and carbon intensity. For example, the average fine particulate matter ($PM_{2.5}$) concentration in Chinese cities dropped from

46 micrograms per cubic metre (µg/m³) in 2015 to 29.3 µg/m³ in 2024 (Chen *et al*. 2025), while carbon intensity decreased by more than 35 per cent between 2012 and 2023 (China Central Television 2024), even as gross domestic product (GDP) grew at an average annual rate of 6.1 per cent (Qiu 2025).

4.2.2 Transport

Transport is one of the key sectors in which the concept of synergies has been reflected in both policy and action. To illustrate, the 14th Five-Year Plan for Green Transport explicitly identified *"synergic pollution reduction and carbon mitigation"* as a guiding principle and a primary indicator for green transport development, illustrating efforts to assess progress with potentially complementary air-pollution and climate targets. Some of the additional efforts to achieve those targets have focused on progressively tightening standards. China has, for instance, moved from China VIa standards to China VIb for diesel-powered vehicles over a relatively short time frame (2019 to 2023). Other signs of progress included regional programmes aimed at phasing out diesel vehicles that are at or below China III standards in Beijing, Jingji and Hebei as well as the Fenwei Plain. In addition to regulating newer vehicles, China has also strengthened solutions intended to improve performance of in-use vehicles through the spread of Demonstration Stations of Vehicle Emission Performance Maintenance (Repair). To illustrate, in the Beijing-Tianjin-Hebei region, surrounding areas and the Fenwei Plain, the phase-out of operating diesel trucks meeting China III and lower emission standards has been fully completed, with more than 1.1 million vehicles eliminated by the end of 2021 (MEE 2024b)

Beyond conventional vehicles, China has provided a strong push for transitioning to new energy vehicles (NEVs). This transition is driven by a policy framework that combines financial support, tax incentives, production mandates and long-term industrial planning, stimulating both innovation and market demand. Beyond direct support, synchronised advancements in battery technology, charging infrastructure and a complete domestic supply chain have created a powerful ecosystem for change. In addition, several local governments have complemented these efforts by supporting purchasing and production incentives with their own subsidies (Ezell 2024). Local governments have also supported the provision of charging stations and battery-placement facilities or license-plate schemes and discounts on parking for NEVs (Oxford Institute for Energy Studies 2022). The above mix of incentives and enablers have led to the rapid expansion of the NEV industry.

Though China has made significant progress curbing transport-related emissions, there may be opportunities to increase the speed and scale of the impacts of these efforts even further. It may be feasible, for instance, to even more closely align transport policies with broader air-pollution and climate strategies under the heading of synergies.

4.2.3 Renewable and residential energy

China has also prioritised the development of non-fossil energy as a key measure for its energy transition, spurring the rapid expansion of renewable capacity. The share of non-fossil energy in total consumption increased from 16.0 per cent in 2020 to 19.8 per cent in 2024. Large-scale wind and solar power bases have been developed in many parts of the country. Notable examples of these efforts have capitalised on high levels of available sunlight in the Gobi Desert as well as other arid regions (Box 4.1), alongside the promotion of rooftop solar in urban and rural areas, and distributed wind power in rural communities. As of August 2025, installed wind and solar capacity exceeded 1.69 billion kilowatts (kW), more than triple the 2020 level (China, State Council Information Office 2025).

Box 4.1: Photovoltaic desert control-climate, environmental and economic co-benefits in Ordos, China

In the Kubuqi Desert, China's seventh-largest desert, Ordos has advanced photovoltaic (PV) desert control by integrating sand prevention with wind and solar power generation. The 2-gigwatt (GW) Kubuqi PV Desert Control Project in western Inner Mongolia has been successfully connected to the grid. It generates approximately 4.1 billion kilowatt-hours (kWh) of green electricity annually.

The project pioneers the large-scale use of flexible bracket materials in desert areas. Double-glass modules enable bifacial power generation, increasing output by 5–10 per cent. Under the panels, extensive planting of forage grasses and medicinal herbs prevents desert movement. Between the panels, a *"livestock-forage coupling"* approach – first raising chickens, then sheep – is applied, along with using animal manure to improve soil quality. This integrated model delivers multiple *"PV+"* benefits: power generation above, planting below, breeding between panels, desert control and rural revitalization. The initial phase involved 5,000 chickens, linking new energy generation with desert restoration and modern agriculture. During construction, the project employed more than 1,000 local farmers and herders. Through a *"company + farmers + cooperative"* partnership, it is expected to provide stable employment for 500 people annually (China, Ordos Municipal Bureau of Ecology and Environment 2025b). To date, Ordos has built 10.02 GW of PV projects in the Kubuqi Desert, rehabilitating about 40,000 hectares of desertified land and increasing incomes for more than 50,000 residents (China, Ordos Municipal Bureau of Ecology and Environment 2025a).

Some of this progress was attributable to the strategic use of a mixture of solutions that have brought more support and resources to renewables. This can be traced to China's 2006 Renewable Energy that created the legal basis for government-led mechanisms, including feed-in-tariffs that lowered the prices of renewables and generated an additional push for manufacturers to innovate. China has more recently used reference prices to communicate the maximum price at which renewable energy plants can sell electricity and build certainty in investments. Those shifts in the emphasis have increasingly moved away from government-backed support to a reliance on the market to determine the scale and location of investment in renewables.

China has also enjoyed success with residential energy and cookstove programmes. China's policymakers have been promoting clean cooking options since the 1980s. Over the past two decades, the Ministry of Agriculture has invested in research, standard setting, pilot demonstrations and industrial development in this area. That programme marked an effort to bring cleaner stoves to more than 100 million households and it benefited from consistent leadership from the Ministry of Agriculture (IEA 2023). Interestingly, China has also linked some of these efforts to a broader push for cleaner air as illustrated by a focus on clean cooking in rural areas in the Three-year Action Plan to Fight Air Pollution.

In addition to cooking, substantial progress has been made in promoting clean heating in colder regions. In northern China, for instance, cumulative installations of clean heating systems exceeded 40 million households in rural northern areas. At the end of 2024, the clean-heating rate in northern China reached 83 per cent, an increase of nearly 20 percentage points since 2020 (China, State Council Information Office 2025). This has also helped reduce winter $PM_{2.5}$ concentrations by 8.2 μg/m³ in Beijing and surrounding areas (He *et al*. 2025), preventing an estimated 23,000 premature deaths from reduced exposure to air pollution (University of Birmingham 2023).

4.2.4 Waste and agriculture

Waste management has also improved in China. Much of that progress is related to China's efforts to develop a circular economy and improve resource-use efficiency. To illustrate, China enacted a Circular Economy law nearly two decades ago and since then included targets aimed at boosting resource efficiencies and recycling rates in the 14th Five-

Year Plan (2021-2025) (Chen 2023). China has also adopted the *"Implementation Plan for Addressing Weaknesses and Deficiencies in Municipal Solid Waste Classification and Treatment Facilities"*. This plan has promoted zero landfilling of raw domestic waste and further guides the reduction of waste landfilling through the Zero-Waste Cities initiative. There have also been efforts to highlight leading provinces and cities, including Anhui (Guan and Jin 2024), Beijing (Zhang 2025) and Jiangxi (Xiong and Zhang 2025), that have moved quickly to achieve zero landfilling of raw domestic waste. In 2019, the proportion of sanitary landfill treatment in China was surpassed by waste-to-energy for the first time. By the end of 2023, the share of sanitary landfill treatment in urban and county domestic waste had fallen to 13 per cent from approximately 90 per cent in 2006 (Liu *et al*. 2024; Zhang *et al*. 2025).

There have also been policies intended to bring similar circular principles to agricultural waste. In this area, China has adopted policies that demonstrate not only an awareness of the issue but a willingness to work across ministries. This is evident, for instance, in a 2013 notice on strengthening the utilization of straw from the National Development and Reform Commission (NDRC), the Ministry of Environmental Protection (the predecessor of the current MEE) and Ministry of Agriculture. Provincial governments then followed this lead as illustrated by Hubei Province's 2015 decision on *"Prohibiting open burning and promoting comprehensive use of crop straw"*. Adding strength to both these national and provincial-level decisions was their inclusion into the 2015 Atmospheric Pollution Prevention Law.

4.2.5 Enabling implementation and overcoming barriers in China

China has incorporated synergistic pollution reduction and carbon-emission control into its national institutions and policies. Through revised laws, institutional reforms and action plans, an integrated policy framework has been established. Synergies have also been mainstreamed into key sectors such as transport and energy. Over the past decade, China's carbon intensity has dropped by more than 35 per cent, accompanied by substantial improvements in $PM_{2.5}$ concentrations.

Looking ahead, China and many other developing countries face significant systemic external challenges, primarily related to two key points. On one hand, decarbonization efforts are constrained by a substantial funding gap and high financing costs. According to an Organisation for Economic Co-operation and Development (OECD) assessment, the climate finance provided by developed countries in 2021 still fell short of annual US$ 100 billion commitment, with more than two-thirds of this finance delivered as loans. This creates a gap of several orders of magnitude compared to the actual annual needs of developing countries, which are estimated to reach US$ 1 – 2.4 trillion starting from 2025 (OECD 2023). Furthermore, the International Energy Agency (IEA) notes that the capital cost for deploying clean-energy and energy-efficiency projects in developing countries is typically two to three times higher, or even more, than in developed nations (IEA 2021). These elevated financing costs hinder investment in and adoption of technologies that integrate pollution reduction and carbon mitigation. On the other hand, the United Nations Conference on Trade and Development (UNCTAD) highlights significant tariff barriers in the global trade in renewable energy (UNCTAD 2025). The average tariffs faced by developing countries for acquiring key components can be higher than those in developed markets. These non-neutral unilateral trade measures transmit additional costs through global supply chains, directly or indirectly increasing the transition expenses for Chinese companies in areas such as technology acquisition, equipment procurement, and industrial chain collaboration (UNCTAD 2025).

4.3 India

4.3.1 Setting the context: integrating air pollution and climate change in India

India, as China, has established institutions and adopted policies that strengthen integrated approaches to climate change and air pollution. In terms of institutions, the Ministry of Environment, Forests and Climate Change (MoEFCC) serves as the nodal coordinator of work cutting across 15 ministries, including power, transport, renewables and urban affairs. Many of these efforts are also guided by high-level committees – national level apex, steering, monitoring and implementation councils and committees – that are intended to ensure directives

are followed by relevant ministries and subnational bodies. Although inter-ministerial coordination efforts have faced some issues, such as ministries prioritizing their own mandates, for example, energy production or economic growth, India has also enacted ambitious policies aimed at integrating climate and air pollution.

Evidence of the above policies include the National Action Plan on Climate Change (NAPCC). Released by the Prime Minister's Office, the NAPCC advocates for a co-benefits approach, wherein greenhouse gas emission reductions contribute to lowering $PM_{2.5}$ concentrations (India, Prime Minister's Council on Climate Change 2008). India's National Action Plan on Climate Change and Human Health (2018), released by the Ministry of Health and Family Welfare (MoHFW), highlights the links between air pollution, climate change and health – noting that climate change contributes to a range of direct and indirect impacts, including respiratory and cardiovascular diseases (India, Ministry of Health and Family Welfare).

In addition, India's National Clean Air Programme (NCAP) is guided by the principle that solutions addressing air pollution and climate change can generate co-benefits (India, Ministry of Environment, Forest and Climate Change 2019). In this connection, it acknowledges that the greatest co-benefits, particularly in the energy and industrial sectors, can be achieved by reducing the carbon intensity of energy use while meeting rising demand across residential, industrial and transport sectors (Change to India, Press Information Bureau 2026). Further, India's NDC reflects its commitment to a low-carbon development pathway while ensuring inclusive growth and aligns with NCAP objectives to reduce particulate matter pollution by 40 per cent in 131 cities that were not attaining air quality standards. These objectives have been aided by a growing commitment to expanding India's air-pollution monitoring network: the last decade has seen a marked 16-fold increase in the number of continuous ambient air quality monitoring sites (CAAQMS) (Vohra *et al*. 2025).

Some of these efforts also extend to the subnational level. Subnational governments often integrate local climate and air-quality concerns by concentrating on co-benefits in high-impact sectors such as road transport, waste and clean cooking. The NCAP, for example, has been effective in driving climate action by mandating the involvement of non-environmental ministries and leveraging existing development schemes, such as the Smart Cities Mission or the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), to fund projects addressing urban air pollution including road sweeping, greening and public transport upgrades. These projects also aim to reduce precursor emissions linked to climate change. In addition, the states of Punjab and Haryana have launched SLCP specific reports and integrated SLCPs in their State Action Plan on Climate Change (SAPCC) and State Emissions Profile (SEP), while in total nine Indian states are working on SLCP inventories (Singh *et al*. 2025a and 2025b).

At the same time, challenges also exist at the subnational level. Although states are, for example, primarily responsible for sectors critical to climate action, including natural resources, infrastructure and industries, and for preparing SAPCCs, the perception that these plans were imposed by the central government can weaken ownership at both state and local levels (Oxford Policy Management 2017). Financial and capacity constraints can also slow progress since, according to some estimates, more than half of all positions sanctioned in State Pollution Control Boards (SPCBs) remain vacant (Basu 2024). Consequently, capacity constraints, particularly in staff and technical expertise, can prevent SPCBs from executing regular inspections, enforcing compliance among polluting industries and holding polluters accountable for harms from emissions. Municipalities, which oversee various pollution mitigation activities such as waste management and dust suppression, may also lack funds and capacity, with revenues and expenditure in India hovering around 1 per cent of GDP (Kapoor and Chakma 2024).

Implementation challenges can be even greater for urban local bodies (ULBs), which interact most directly with the public. Because climate and clean-air measures often impose visible costs on citizens, they can become politically sensitive, encouraging efforts to shift responsibility to other actors, a dynamic often observed during frequent air-pollution crises in Delhi (Guttikunda 2025). This challenge is frequently compounded by a lack of coherence between national and state authorities on air pollution and climate change (Prasad *et al*. 2025).

4.3.2 Transport

India has made modest progress in integrating climate and clean air objectives in the transport sector. This progress is partly attributable to the adoption of Bharat Stage VI (BS VI) vehicular emission standards under the Graded Response Action Plan (GRAP), which places restrictions on pre-BS IV vehicles in the National Capital Region: presently, approximately 25 per cent of vehicles comply with these norms (Mohan *et al*. 2025). To accelerate clean-energy transitions in the transport sector, India has set a target of 30 per cent penetration for electric vehicles by 2030 and placed electric mobility at the centre of the NCAP and NAPCC (NITI Aayog 2025). In parallel, many Indian states have introduced demand-side upfront incentives, developed charging infrastructure and prioritised electric mobility in urban action plans to reduce emissions, particularly from passenger and light commercial vehicles for last-mile freight (Ministry of Power 2023). These efforts are complemented by the NAPCC's support for Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) schemes, which provide purchase incentives and seek to expand charging infrastructure to accelerate electric mobility deployment (India, Ministry of Heavy Industries 2025).

At the same time, it is worth noting that FAME-I (2015 – 2019) has faced some critiques for slow implementation and unspent funds. Concerns have also been raised that FAME-II (2019–2024) offers insufficient incentives for the establishment of charging infrastructure (Kohli 2024). Other issues relate to trucks and freight, which account for only 3 per cent of the fleet but are the largest emitters of $PM_{2.5}$ in road transport, with slow electric vehicle (EV) penetration in the subsector (CEEW and Climate Group 2025). A related difficulty is the absence of effective vehicle scrappages and emission inspection regimes, which allows older polluting vehicles to remain on the roads (Guttikunda 2024).

4.3.3 Renewable and residential energy

In terms of renewable energy, India's National Solar Mission has established ambitious targets to reduce reliance on fossil fuels, which has led to decreased emissions from power generation. These targets and related programmes, including the National Green Hydrogen Mission; the National Bio Energy Programme; and the Green Energy Corridor, have been supported by the Ministry of New and Renewable Energy's (MNRE) to provide a range of incentives for renewable energy development (India Science, Technology and Innovation Portal 2024). These efforts have been largely successful: India has already met the capacity target of 50 per cent of its current installed power capacity coming from non-fossil fuel sources, with its clean energy transition outpacing many other countries (Ministry of Power 2025; Bond and Sinha 2026). Some of these gains are, however, tempered by India's continued dependence on coal, with coal-fired power plants accounting for approximately 75 per cent of electricity generation in fiscal year 2023–24 (NITI Aayog 2025). According to the Central Electricity Authority (CEA), coal is expected to remain a major source of power generation, reflecting ongoing challenges related to renewable energy variability, storage capacity, transmission infrastructure and coal's continued economic role (India, Central Electricity Authority 2023). India also faces policy gaps that limit progress on objectives for air pollution and climate change in the energy sector. Approximately 75 per cent of coal-fired power generation, for example, is exempt from flue-gas desulphurization requirements (Srikanth, Krishnan and James 2024).

India has made multi-sectoral progress in addressing



Caption: © Farmer's fields after harvest.
Photo: AdobeStock/Nemeziya

Box 4.2: India's solar mission

India announced that it had achieved 50 per cent non-fossil fuel electricity capacity five years early, fulfilling its 2030 Paris Agreement target and signalling an accelerating clean-energy transition, with solar power contributing the largest share to this growth. The implementation of India's Solar Mission was achieved primarily through a clear institutional and financial strategy. The Mission provided a crucial long-term policy roadmap, which gave private investors the institutional certainty they needed to commit capital and rapidly scale capacity. Financially, the Mission de-risked projects using the innovative gap-funding mechanism – a one-time capital grant that bridged the gap between developer costs and achievable low tariffs. This was complemented by standardised, aggregated procurement through the MNRE and other agencies, coupled with necessary grid infrastructure upgrades, which ensured that the newly developed, cost-competitive solar power could be reliably integrated and utilised by the national power system. India continues its ambition with a revised target of achieving 500 GW of installed electricity capacity from non-fossil fuel sources by 2030.

air-quality and climate challenges from the residential sector. Much of the recent progress in reducing these emissions is attributable to the *Pradhan Mantri Ujjwala Yojana* (PMUY); this programme has expanded access to liquefied petroleum gas (LPG) connections and facilitated the spread of cleaner cooking fuels (Jha 2025). This is particularly notable because the programme took a gender-responsive approach, funding deposit-free connection under women's names (India, Press Information Bureau 2023). It nonetheless merits noting that sustained adoption may require some modifications in the programme to cover issues such as the high cost of cylinder refills and inconsistent supply in remote areas (Kar *et al*. 2019).

4.3.4 Waste and agriculture

In the waste sector, the *Swachh Bharat Abhiyan* (Clean India Mission) has driven national demand for solutions, creating success stories in cities including Indore and Pune. In fact, the *Swachh Bharat Abhiyan* generated a surge in demand for waste management solutions and led to the sharing of good practice examples across cities (India, Department of Drinking Water and Sanitation 2025; NITI Aayog 2025). Programmes under the *Swachh Bharat Abhiyan* (Phase II), such as Galvanizing Organic Bio-Argo Resources Dhan (GOBARdhan Initiative), have also led to some success managing biodegradable waste, primarily in rural areas. It is worth noting, however, that poor waste segregation, unscientific landfilling and the practice of open burning have slowed progress in some cases. While the recently updated solid waste management (SWM) rules may strengthen implementation of source segregation and decentralised waste processing, compliance remains limited because many municipalities lack adequate waste processing centres and disposal facilities. Authorities have also set up waste-to-energy (W2E) plants in 10 states/Union Territories (UTs) and bio-methanation facilities in 22 (United States, International Trade Administration 2023). Municipalities allocate only about 5 per cent of their SWM budgets to waste processing and scientific disposal (United States, International Trade Administration 2023), contributing to landfill overflows and associated air-pollutant emissions.

Both national and state governments have also introduced programmes to curb the open burning of agricultural residues. These range from subsidies for specialised machinery, such as happy seeders and balers, to support *in-situ* residue management, to programmes that create markets for agricultural biomass, including selling unwanted residue to waste-to-energy applications (India, Ministry of Environment, Forest and Climate Change 2025). The effectiveness of these efforts has, however, been constrained by coordination challenges across agencies, including MoEFCC and the Central Pollution Control Board (CPCB), and the transboundary nature of agricultural burning. Barriers extend beyond funding to include narrow planting windows, limited awareness and socioeconomic incentives that continue to favour burning.

4.3.5 Enabling implementation and overcoming barriers in India

India has integrated co-benefits into key national policies and increasingly recognises the links between air pollution, health and climate change at the subnational level. It has also seen some success with the strengthening of regulations in sectors such as transport and provided targeted support for urban and clean-energy transitions. One of the most visible drivers of success has been well-defined missions that have sent strong signals to national and local policymakers, as well as the private sector, of the government's commitment. Indeed, India's National Solar Mission stands out as an example of how credible policy signals can accelerate investment and the adoption of new technologies induce such changes.

At the same time, opportunities remain to strengthen integration across different administrative levels and sectors through both horizontal and vertical governance reforms. Horizontally, enhancing the MoEFCC's ability to coordinate across policy areas and promote multi-benefit approaches could improve policy coherence. Vertically, strengthening pollution control boards, through greater funding, technical capacity and autonomy could improve implementation and enforcement. Such reforms could also support expanded EV charging infrastructure, improved waste segregation and increased investment in composting.

4.4 Mexico

4.4.1 Setting the context: integrating clean-air and climate planning

Mexico has demonstrated a commitment to aligning clean-air and climate planning. That commitment is evident in Mexico's amended 2011 General Law of Ecological Balance and Environmental Protection (LGEEPA) and provisions therein aimed at integrating climate and air quality objectives. Similarly, Mexico's 2012 General Law on Climate Change (LGCC) holistically frames climate action as contributing to a healthy environment and includes emissions reduction for black carbon – a 51 per cent reduction by 2030. Mexico was one of the first countries that helped to form the CCAC. The passage of these laws and the decision to join the CCAC set the stage for Mexico to become the first developing country to include black carbon in its Intended NDC – a 25 per cent reduction by 2030.

Some of the institutional arrangements supporting these commitments are outlined in Mexico's National Climate Change Strategy (ENACC). Jointly crafted by the Ministry of Environment and Natural Resources (SEMARNAT), the National Institute of Ecology and Climate Change (INECC) and the Climate Change Council (CCC), this strategy is based on the General Law on Climate Change (LGCC) and is designed to guide implementation across different levels of government and society. The LGCC also provides a statutory basis for a National Climate Change System (SINACC) to facilitate the above coordination and generate synergies across climate mitigation and adaptation actions. The SINACC is made up of the Inter-Ministerial Commission on Climate Change (CICC), INECC, the CCC, the states, associations of municipal authorities and the Congress of the Union. In addition, the CICC brings together heads of secretariats to support coordination and implementation of climate policies, for instance, making links to sector- and issue-specific programmes such as the National Air Quality Strategy (ENCA).

Beyond outlining the institutional arrangements, the LGCC also created a foundation for crafting other plans and supporting policy instruments. These include two versions of the Special Climate Change Programme, running from 2014–2018 and then from 2021–2024; the recently updated National Climate Change Strategy (ENACC) and three increasingly ambitious Nationally Determined Contributions (NDCs) – in 2015, 2020 and 2022. Mexico's NDC is notable in that it makes explicit references to SLCPs, considering the findings reported in CCAC-supported Mexican National Planning Activities. Above and beyond the support for policy at the national level, the LGCC has also motivated 32 states to publish subnational climate programmes. Relevant examples include Jalisco and Querétaro that both align national policies with subnational needs in areas that have benefits for climate and clean air, such as sustainable transport and mobility.

4.4.2 Transport

Mexico has also adopted a variety of transport policies with the potential for climate and clean-air benefits. Many policies have focused on targeting

mobile-source emissions in Mexico City, home to approximately 33 per cent of the national population and a region that has been vulnerable to air pollution due to its unique geography and fast-growing vehicle fleet (Mexico, Secretaría del Medio Ambiente de la Ciudad de México 2023). Successful efforts in Mexico City set the stage for addressing emissions from new and in-use mobile sources and fuel quality standards as well as vehicle testing procedures across the entire country. In recent years, Mexico has relied on a growing variety of instruments to rein in mobile-source emissions. These range from implementing mandatory vehicle verification programmes and relying more on natural gas in public transport systems. They also entailed a push from the Transport Ministry to strengthen emission standards and mandate manufacturers to innovate and install low-emission engines. These interventions have been joined more recently by programmes aimed at promoting a transition to sustainable mobility and EVs, such as the declaration *"driving change together"* and the creation of trolleybus lines as zero-emission corridors. More recently, Mexico has put forward the ambitious goal that all new cars sold from 2040 will have zero emissions.

Although Mexico has made progress in achieving transport-related co-benefits, scope exists for further improvements. Some of these will require reducing preferences for purchasing older vehicles and/or circumventing restrictions on vehicle circulation. In some instances, these restrictions have led motorists to opt for older pollution-intensive vehicles rather than using public transport, increasing kilometres travelled and emissions (Davis 2008). Further alignment between national efforts to integrate air-quality and climate objectives in NDCs and subnational sustainable mobility interventions would also help in this regard. This may involve ensuring that the National Electric Mobility Strategy (ENME) focuses on electrifying public transport and developing equitable charging infrastructure while demonstrating the reliability of electromobility to the public. There is also a need to think carefully about equity since low-income populations may encounter problems affording high-tech vehicle repairs. Strengthening collaboration on climate and clean air across states and cities would also create opportunities for peer learning and leveraging help, replicating successful approaches developed in Mexico City across surrounding regions.

Mexico can continue its efforts to make transport more sustainable by curbing incentives for vehicle ownership. This can be achieved with progressive taxation on second vehicles, parking fees, rapid-route fees and the redirection of collected revenues to public transport and EV infrastructure. These reforms would also gain momentum from concerted efforts to invest in integrated, affordable and reliable mass-transit systems. Finally, it would be helpful to implement a national vehicle-scrappage programme with incentives for retiring older, high-emission vehicles and replacing them with cleaner alternatives.

4.4.3 Renewable and residential energy

Mexico's energy transition has gained momentum over the past two decades, supported by reforms aimed at diversifying the electricity mix and reducing reliance on fossil fuels. The 2008 Law for the Use of Renewable Energies and the Financing of the Energy Transition (LAERFTE), and the 2014 Energy Reform both opened the sector to private participation and introduced long-term sustainability targets. These policy shifts have enabled rapid renewable expansion: between 2013 and 2023, solar capacity increased from 33 megawatts (MW) to 7,211 MW and wind capacity from 1,959 MW to 7,462 MW. Mexico now stands among the world's leading renewable-energy producers, with vast untapped solar, wind, and geothermal potential that could anchor a broader clean-energy transition.

Building on this potential, Mexico's 2024 National Strategy for the Electricity Sector targets 45 per cent renewable-electricity generation by 2030, with the Federal Electricity Commission (CFE) maintaining a 54 per cent share of this and the remainder being mobilised through market finance. This approach seeks to balance state leadership with private investment, linking energy independence with decarbonization and sustainable-development objectives. Realizing these ambitions will, however, require addressing grid bottlenecks, regulatory uncertainty and zoning issues. Overcoming such obstacles can serve as a catalyst for a structural transformation of the Mexican economy, stimulating domestic supply chains and regional industrial development in the manufacturing, installation and maintenance of clean-energy technologies.

While solutions in this sector have yielded moderate success in reducing emissions and improving public

health, additional progress will arguably depend on systemic reforms in the electricity sector, such as enhancing grid efficiency, diversifying the energy mix and strengthening institutional coordination.

At the household level, the Mexican government has achieved moderate success. Emission reductions in this sector directly improve public health, as 15.4 per cent of households rely on firewood (Mexico, Instituto Nacional de Estadística y Geografía 2021). In the rural residential sector, mitigation has focused on introducing efficient stoves and reducing energy consumption from electricity, LPG and natural gas. Household energy use, firewood reliance and health outcome data collectively indicate that these solutions have yielded measurable improvements, supporting the assessment of the initiative as moderately successful.

Part of the above progress is attributable to Mexico's national programme for efficient wood-burning stoves, led by the Secretariat of Energy (SENER). The Secretariat was launched in 2025 to reduce indoor air pollution in rural and marginalised communities through the promotion of clean, locally appropriate technologies. This programme builds on earlier national efforts implemented primarily between 2007 and 2012 by the Secretariat of Social Development (SEDESOL) and other agencies, which distributed hundreds of thousands of stoves to address energy poverty, reduce deforestation and improve public health (Secretariat of Energy 2025; Accenture Development Partnerships 2012). The 2025 initiative expands upon these earlier efforts with a more integrated and results-based approach, emphasizing cultural adaptation, community ownership and inter-agency coordination.

Despite growing institutional support, the widespread adoption of clean cookstoves in Mexico has not been perfect. Previous studies estimated that more than 6 million households relied on firewood for cooking, with nearly 5 million living in dispersed, remote areas – many of them Indigenous communities – posing logistical and outreach challenges (Accenture Development Partnerships 2012). Moreover, more than 3.36 million households nationwide continue to rely on open-air stoves, exposing residents to harmful household air pollution and its associated health risks. The national program aims to replace these technologies with 1 million efficient stoves, beginning with an initial phase targeting 16,500 homes in Michoacán state, where 72 per cent of investment will circulate locally through the purchase of supplies and services (Jiménez 2025).

Ensuring the long-term success of stove programmes arguably requires stronger coordination across sectors, culturally sensitive implementation and sustained public investment to reach vulnerable and traditionally underserved populations. This will necessitate moving away from an earlier reliance on subsidies and towards enhanced user training, better maintenance systems and an emphasis on locally appropriate designs (Accenture Development Partnerships 2012). It should be noted that adoption and sustained use are enhanced when programmes incorporate modest user copayments, stove designs tailored to regional cooking practices and community-based monitoring (Accenture Development Partnerships 2012). The 2025 initiative reflects these insights to deliver more durable and context-sensitive outcomes (SENER 2025).

Additional efforts could involve women in cookstove design, distribution, and monitoring as part of a broader effort to promote a just transition. In other cases, it would be beneficial to prioritise off-grid renewable solutions, such as solar microgrids, in remote regions and subsidise clean fuels like LPG for vulnerable populations. Both efforts would gain support with stronger links to rural-development programmes and provisions concentrated on reforestation, renewable energy and education to address the root causes of energy poverty.

4.4.4 Waste and agriculture

Mexico has achieved moderate success in aligning its waste management strategies with broader climate and air quality objectives. Federal initiatives have increasingly promoted circular economy models and shared responsibility across value chains, signalling a more integrated approach to these issues. Key action includes the commitment to build 10 new recycling facilities and updates to legal and regulatory instruments, such as the 2023 amendment of the General Law for the Prevention and Integrated Management of Waste (LGPGIR). This has been complemented by technical standards for site selection, design, construction, operation, monitoring and decommissioning as well as

complementary work on a final disposal site for urban solid waste. These efforts are particularly timely given that, according to recent emissions inventories, urban solid waste generation continues to rise (SEMARNAT 2022).

At the subnational level, states and municipalities are required to formulate municipal urban solid waste management programmes (PMPGIRSU). These efforts are reinforced by national policies aligned with the Sustainable Development Goals (SDGs) including efforts to promote waste separation, targets on reducing landfill use and support for sustainable urban systems.

Implementation, however, remains uneven as population growth and consumption continue to drive increases in urban solid waste generation, while many final disposal sites operate without emissions-mitigation infrastructure or adequate enforcement of current regulations. Source separation also remains limited, undermining material recovery efforts and reinforcing a reliance on final disposal that damages air quality. Challenges include inadequate waste separation, over-reliance on landfilling, limited alternative-treatment infrastructure and long transportation distances, particularly in northern regions (Albalate-Ramírez *et al*. 2024). Research suggesting a proliferation of unauthorised waste disposal sites, linked to irregular settlements and economic constraints, underlines that there are often spatial variations and a rural-urban divide in waste service provision (De la Rosa-Belmonte *et al*. 2025).

There are several levers that could be used to enhance implementation. Some of the options could focus on national behavioural-change campaigns that would promote waste separation, composting and reuse in communities and schools. Additional efforts could target waste-to-energy and recycling. These could be enabled by the construction of recycling facilities with technical and financial oversight to ensure environmental standards. Finally, efforts could be made to bring the private sector into the circular economy by implementing extended producer responsibility (EPR) programmes that mandate manufacturers to finance and manage the recycling of packaging.

While Mexico has made progress in its waste management, addressing the barriers will require a more integrated and systematic approach. Strengthening local-level implementation in the waste sector will involve building capacity in municipal authorities, improving access to technical resources, and adapting programmes to urban and rural communities. Enhancing institutional coordination across government agencies, civil society and research institutions would align objectives, enable the sharing of data and support waste management initiatives. Incentivizing private-sector engagement in material recovery and innovation could also complement active participation by community groups, non-governmental organisations (NGOs) and other stakeholders to foster co-ownership and ensure that interventions are equitable and sustainable.

There has been progress with some policies and practices on the open burning of crop residue in Mexico. The key to understanding that progress is noting that close to 90 per cent of the burning involves corn, 43 per cent; sorghum, 26 per cent; and sugarcane, 18 per cent. Much of this burning occurs in the states of Sinaloa and Jalisco – for instance, more than 20 per cent of the burning of corn stover is in those two states (Becerra-Pérez *et al*. 2025). Some of the progress in controlling burning has come through efforts to enforce Mexico's Official Standard known as NOM-015-Semarnat/Sagarpa-2007. This 2007 standard includes restrictions on burning but also incentives for alternative approaches to residue management, such as composting, using biochar and no-till farming, and educational programmes for farmers. The standard also includes provisions for controlled burning and enhanced air-quality monitoring. Beyond the 2007 standard, there have also been efforts at the subnational levels. Sinaloa, for example, has a regulation that prohibits the practice while Mexico City has worked with surrounding regions to curb the spread of fires by creating buffer zones between agricultural and forested areas (Mexico, Congreso Estado de Sinaloa 2018; CCAC 2018).

Though Mexico has adopted policies to curb open burning, implementation barriers exist. It has, for example, proven difficult to persuade farmers to invest in zero-burning practices when alternatives cost more (Prateep Na Talang and Sirivithayapakorn 2022). This is particularly the case for small-scale farmers with lower profit margins and limited capital to invest in control technologies. In a similar vein, farmers can

also be reluctant to modify burning practices; it can be difficult to enforce national standards and subnational regulations. There is also a notable lack of a coherent national strategy covering the lifecycle of agricultural waste with measurable performance indicators to shift to more sustainable food systems (Mundo-Rosas *et al*. 2024). Efforts focus on educating farmers about the negative impacts of open burning and promoting eco-friendly alternatives to improve agricultural practice and yields.

4.4.5 Opportunities to accelerate implementation in Mexico

Mexico has a significant opportunity to build upon the progress in national and subnational institutions and policies and sectoral solutions. To some extent, this will require strengthening horizontal integration by standardizing tools, such as the common tabular format (CTF) complemented by digital platforms for real-time data sharing, to deepen mutual understanding on co-benefits. Likewise, sectoral programmes – energy, transport and forestry – and national policies, such as the National Climate Change Policy (PNCC) and the National Air Quality Strategy (ENCA), could be made compulsory to assess climate and air-quality co-benefits, supported by investment in federal modelling, monitoring and enforcement capacity. It would also be helpful to enhance vertical integration by, for example, tailoring the above efforts to the needs of subnational governments with capacity building programmes and the tools needed to assess potential.

Mexico also has a chance to attract more finance for implementing solutions with multiple benefits. One of the opportunities in this regard would involve establishing dedicated climate-air funds at the national and local levels. In addition to public finance, the proposed fund could draw revenue from carbon markets or environmental taxes that could be directed to projects and programmes with co-benefits, based on the previously mentioned assessments.

4.5 Nigeria

4.5.1 Setting the context: integrating air pollution and climate planning in Nigeria

In Nigeria, work at the intersection of climate change and air pollution can be traced back for more than a decade. Many of these early-stage efforts are related to Nigeria's 2012 decision to join the CCAC. That raised awareness of the benefits of controlling SLCPs as well as action capable of achieving those benefits. One of the reasons for Nigeria's awareness is that it has worked through a process of assessing SLCP mitigation opportunities. Much of the process was organised as part of the development of Nigeria's National Action Plan to Reduce SLCPs. That plan identifies major sources of SLCPs, including methane from the oil and gas sector, waste and agriculture – livestock and open burning, while outlining mitigation pathways that would lead to their reduction (Nigeria, Federal Ministry of Environment 2018). The SLCP National Action Plan has also informed other policies and plans. In addition, these efforts have also contributed to the integration of air-pollution and climate change considerations into other key policy frameworks, including Nigeria's NDC and Long-Term Low-Emission Development Strategy (LT-LEDS).

Some of the additional relevant policies in which there are links include the National Environmental (Air Quality Control) Regulation (2014) made under the National Environmental Standards and Regulation Enforcement Agency Act. These regulations feature air-quality standards for particulate matter (PM) with the potential effects on black carbon. Other relevant policies include Nigeria's NDC, which includes provisions to reduce not only methane but black carbon emissions by implementing key sectoral interventions on improved cookstoves and clean transport, discussed later (Nigeria, Federal Ministry of Environment 2025).

At the same time, Nigeria may also need institutional reforms that raise the profile of work on SLCPs in the National Council on Climate Change (NCCC) to break down silos between key line agencies. Other similarly motivated reforms could concentrate on aligning mandates and demarcating responsibilities between the Department of Climate Change (DCC) and the Department of Pollution Control (DPC) under the Federal Ministry of Environment. Further, while national-level policies and institutions have made progress, implementation within 36 states and 774 local government areas (LGAs) has been difficult. Nigeria's states often lack the technical capacity and budget for the implementation of SLCP-related policies. This results in uneven adoption of mitigation solutions and difficulties sharing data between local and national institutions.

4.5.2 Transport

Nigeria has made progress with regulations that could limit the transport sector's emissions. Notable milestones include a relatively recent set of vehicle emission standards that aim to comply with the Euro IV/4 standard for imported vehicles by 2021. This was a part of a larger effort to improve air quality in West Africa across the 15 member states of the Economic Community of West African States (ECOWAS). Other milestones involve a set of mobile-source regulations from the National Environmental Standards and Regulations Enforcement Agency (NESREA) and efforts to improve fuel efficiency. The latter efficiency improvements would come from efforts to promote EVs among newly imported vehicles. Arguably and most importantly, given significant contributions to black carbon from older vehicles, are 10-year age limits for imported used vehicles, with a complementary proposed five-year limit for light-duty vehicles (UNEP 2020).

These regulatory advances need to overcome some hurdles to realise their full potential. Such reforms consist of a concerted effort to improve fuel quality; Nigeria's traditional reliance on high-sulphur fuels could undermine stronger emissions standards. Other reforms concentrating on I&M of older vehicles, especially given a reliance on older imported vehicles, might also be helpful. A significant way to control the quality of fuel concerns locally owned refineries the output from which should be controlled to ensure that the standard expected in the country, Euro IV, is met. Alternatively, at the point of import, there may be a need for enforcement of standards by national agencies.

4.5.3 Renewable and residential energy

Nigeria has adopted a series of larger national plans and programmes to harvest ample supplies of renewable energy. Many of the key targets are outlined in Nigeria's Energy Transition Plan (ETP), which anticipates a shift to clean cooking fuels, electrification and methane mitigation as part of a larger effort to achieve net-zero targets by 2060 (Nigeria, Energy Transition Office 2023). In recent years, those targets have been pursued through policy frameworks like the Renewable Energy Master Plan (REMP) and the National Renewable Energy and Energy Efficiency Policy that set a 23 per cent renewable goal for the energy mix by 2025. The Nigerian government has also invested in renewables, particularly for household applications in rural areas. In fact, there has been a sharp uptick in the introduction of solar PV systems as policymakers recognise grid-connected and off-grid solar PV systems can lower energy costs and boost energy security. There has been growing investor confidence in the wake of these reforms (Nkalo 2025). Nonetheless, some analyses suggest that scope may exist for doing more on renewables particularly if some of the difficulties in administrative processes and supportive infrastructure can be addressed (Nkalo 2025).

Yet another area with potential for progress is through specific projects in Nigeria such as the introduction of clean cookstoves. Those projects include efforts that are being managed by the Lagos state government in partnership with a private company called GreenPlinth Africa in what is billed as Africa's largest clean cookstoves project, designed to distribute 80 million clean cookstoves across Nigeria. The project also aims to lower the costs of those stoves with carbon finance from the newly created Article 6.4 mechanism. These initiatives could build on existing efforts to promote clean cooking at BURN's 3,700 m^2 factory in Kano – a factory that currently produces 35,000 cookstoves per month but with the capacity to produce 100,000 units per month (Gupte 2025).

While the above projects and programmes marked a step forward, they may be hampered by a lack of social acceptance in shifting to new stoves or cleaner forms of energy. There may also be difficulties encountered in expanding the scale of projects from Lagos to other states with lower capacity and resources. These difficulties could be managed by not simply targeting capacity-building and enhanced funding efforts but also by underlining the tangible development benefits such as job creation. On this point specifically, studies have shown that those gains are significant: decentralised renewable energy (DRE) could create more than double the new jobs in that sector and surpass employment figures in oil and gas (Power For All 2022).

4.5.4 Waste and agriculture

Nigeria has adopted policies to support sustainable waste management. Notable milestones include the 2005 Nigerian National Environmental Sanitation Policy for general waste as well as more targeted policies such as 2021 National Policy on Plastic Waste

Management (NPPWM). Both the above policies aim to reduce waste through source minimization – reduce, reuse and recycle (3Rs); improved infrastructure, promoting a circular economy and emphasizing public education. Like other solutions in this section, implementation is supported by laws like the NESREA (National Environmental Standards and Regulations Enforcement Agency) Act 2007, which clarifies that local governments play a crucial role in implementation.

While there have been efforts to sustainably manage waste and move to more circular economy models, some have noted that efforts in the sector have encountered challenges. To illustrate, one set of concerns has focused on the rather piecemeal and uncoordinated nature of policies and institutions (Chukwuemeka *et al*. 2012). Other concerns have focused on the need for a greater role of legal and judicial systems in enforcing sanitation related policies. A linked set of suggestions has come from those who call for greater efforts to build the capacities of communities to manage waste and transition to more inclusive circular economy approaches (Pat-Mbano and Ezirim 2015). Another set of points has suggested a need for raising public awareness of the benefits of sanitation, and a need for strengthening enforcement and judicial processes to enhance compliance (Ofulue and Gasiokwu 2025).

Another set of sectoral interventions that are locally relevant are regulations on open burning. In this connection, Nigeria has adopted a 2011 regulation that is explicitly aimed at controlling land fires and open burning. It places a heavy emphasis on limiting burning by entrusting the NESREA to oversee a permitting process that effectively tracks and monitors burning (Nigeria, Federal Ministry of Environment 2011).

In more recent years, there have also been additional efforts to understand the extent of burning and develop solutions beyond the 2011 regulation. These efforts include, for instance, workshops with representation from 12 countries in Africa and other stakeholders, which were intended to outline a set of milestones and action for the next 15 years (CCAC 2025). Similarly motivated efforts under the Agroecology and Circular Economy for Ecosystem Services in Sub-Saharan Africa (ACE4ES) project have also sought to align the interests of different stakeholders around controlling burning (ACE4ES 2024).

Though existing regulations and more recent efforts to control burning demonstrate progress, there may also be scope to consider alternative methods of limiting the practice beyond acquiring permits and awareness raising. These include incentives to use crop residues for other productive purposes besides burning as well as financing to support those transitions. Outreach efforts targeting those farming communities that most likely burn to clear land could also add to the enabling environment.

4.5.5 Enabling implementation in Nigeria

As noted at the beginning of this subsection, Nigeria has made some progress integrating air pollution and climate change. Additional efforts within NESREA aim at strengthening capacity to enforce existing regulations while ensuring transparency and fairness. Other similarly motivated reforms could concentrate on enshrining action plans in law. A related step could involve bringing co-benefits more explicitly into the work of the NCCC to support more integrated planning. Finally, ensuring that national policies support local action with the transfer of financial and human resources is needed. These efforts could build on technical assistance that has focused chiefly at the national level on methane under the Nigeria's Federal Ministry of Environment and Department of Petroleum but would foreseeably have a greater impact with resources transferred to the subnational level (CCAC 2022).

It is similarly possible to extend enabling reforms by expanding community and stakeholder engagement for key social segments. Some of these efforts could target farmers who might be reluctant to alter conventional practices while others could concentrate on women's groups and young people who could be empowered to contribute to community-based waste management initiatives. There might also be opportunities to appeal to owners of older vehicles with programmes aimed at incentivizing participation in I&M programmes. Finally, interventions could concentrate on raising general-public awareness of the links between climate change and air pollution with some of the information already integrated into school curriculum.

As for economic challenges, additional progress could involve financing by introducing subsidies and rebates that reduce initial costs for key control technologies

such as clean cookstoves and EVs; this would be a logical extension of efforts through which Nigeria offers import duty and value added tax (VAT) exemptions for renewable energy. It would similarly be beneficial for Nigeria to enable public-private partnerships (PPPs) to attract investment and expertise for areas such as large-scale waste management systems and expanding the clean cookstove industry. Additional enabling reform could focus on building capacity to boost local innovation and entrepreneurship: This would involve training local entrepreneurs in control technologies following examples related to leak detection and repair equipment for methane in the oil and gas. Further, it may be possible to secure grants and concessional loans through the Green Climate Fund, CCAC and the World Bank (Oxfam 2024).

As for technical barriers, some efforts could focus on training engineers, farmers, waste managers and technicians locally, such as for the manufacture of cookstoves and methane recovery techniques. Additional efforts could concentrate on channelling resources to universities and research institutes, funding projects such as waste-to-wealth initiatives to reduce methane and other SLCPs. These efforts could be paired with attempts to initiate demonstration projects such as community-based biogas plants and an improved cookstove factory. They could similarly be complemented by the creation of innovation centres encouraging PPPs and supporting startups in the development and testing of technologies.

4.6 Towards a systemic framework for building an enabling environment

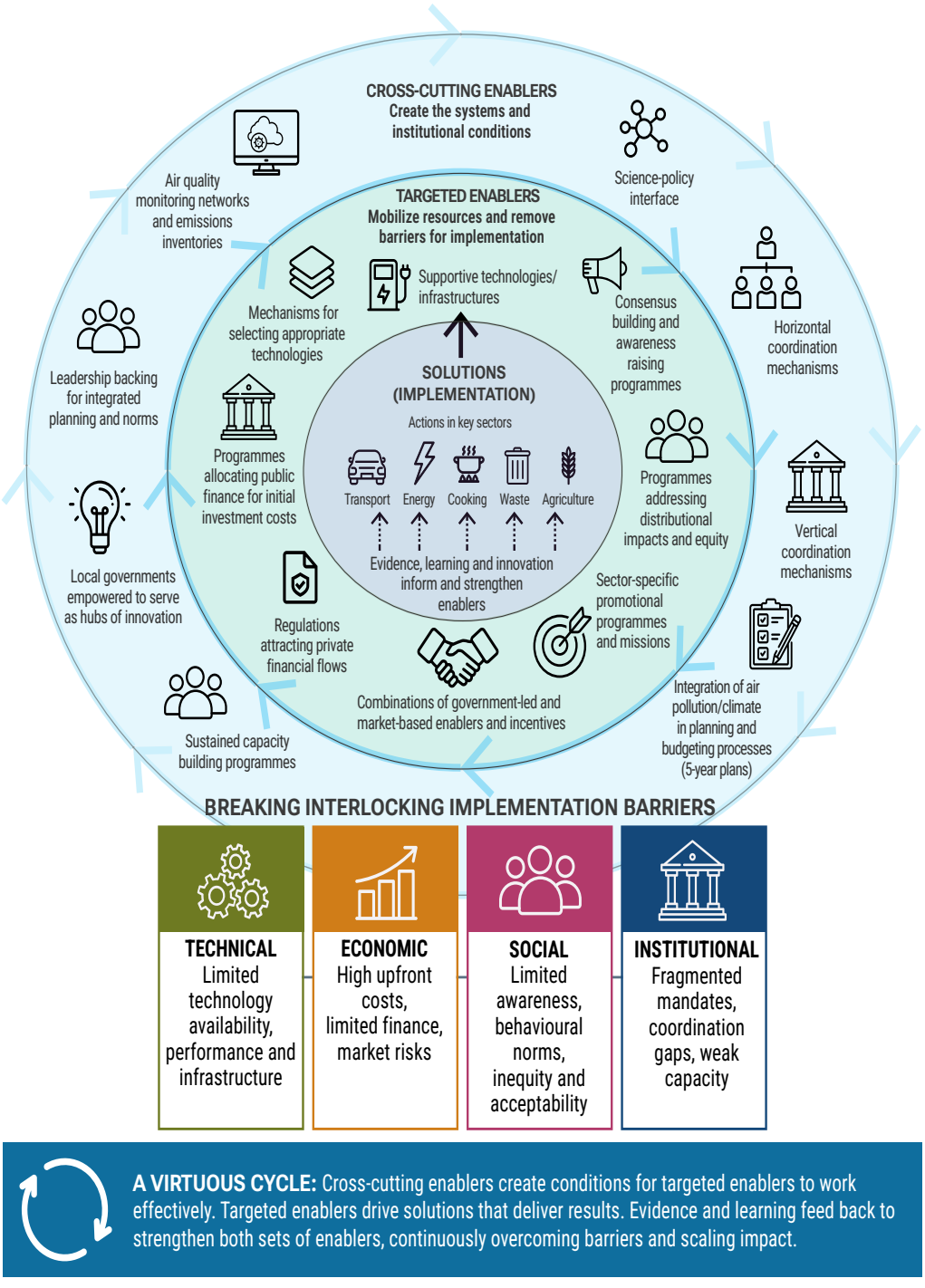
The case studies reveal the surveyed countries have had varying degrees of success enabling the implementation of integrated solutions. They further point to key reasons for that progress ranging from expanding monitoring networks and institutional coordination mechanisms to targeted, barrier specific enabling reforms.

The case studies also demonstrate it is possible to work towards a more systematic framework for building an enabling environment to accelerate implementation of key solutions. Some of the significant elements focus on overcoming narrower technical, economic, social and policy/institutional barriers. Others involve broader cross-cutting, mostly institutional, reforms. The proposed enabling reforms, as illustrated in Table 4.2, are not only evident in the case studies but have generated measurable impacts on emissions or other indicators of success.



Caption: © Black soldier fly (BSF) technology has become an innovative and sustainable solution for managing organic waste while producing valuable by-products. Photo: AdobeStock/Irin

Figure 4.1: 16 enablers that break the 4 implementation barriers to accelerate action.



Another point involves the relationship between the two kinds of narrow barrier-specific and broader cross-cutting enablers. As illustrated in Figure 4.1, embedding the narrow enablers within the broader cross-cutting ones can help strengthen connections between policymakers working on air pollution and climate change as well as policymakers focused on more targeted sectoral concerns. In this way, the broader, mostly institutional, issues serve as enablers of enablers.

Getting the right fit between these sets of enabling reforms can induce virtuous cycles of change across sectors and decision-making levels. Further, as presented in Tables 4.3 and 4.4, both the targeted and cross-cutting enablers are not simply conceptual; they are related to specific examples from the country case studies, detailed with more specific descriptions of how they are operationalised and have led to demonstrated reductions in emissions.

Table 4.3: Targeted enablers

Enabler	Evidence from case studies	Illustrative evidence of effects
Mechanisms for selecting appropriate technologies *Matching technologies to user needs and local contexts*	Mexico's national cookstove projects	Mexico: Cardoso *et al*. (2022) found that improved cookstoves reduced firewood consumption by 39–48 per cent and GHG emissions by approximately 46 per cent.
Supportive technologies/ infrastructure *Investing in enabling infrastructure for cleaner technologies*	China's support for EV charging stations	China: Ma *et al*. (2026) found that increased EV charging activity was associated with lower NO_2 and $PM_{2.5}$ concentrations.
Consensus building and awareness raising programmes *Increasing awareness and acceptance of cleaner practices*	Nigeria's open-burning awareness workshops	Nigeria: CCAC (2024) reported that training programmes increased the share of farmers viewing no-burn agriculture as feasible to 82 per cent.
Programmes addressing distributional impacts and equity *Ensuring vulnerable groups benefit from transitions*	India's PMUY clean-cooking programme	India: Mani *et al*. (2020) found that PMUY expanded LPG access to approximately 80 million low-income households.
Programmes allocating public finance for initial investment costs *Using public funds to support early deployment*	Nigeria's Rural Women Energy Security (RUWES) clean-cooking initiative	Nigeria: CCAC (n.d.) reported adoption rates of up to 93 per cent in publicly funded clean-cooking pilots.
Regulations attracting private financial flows *Creating conditions for private investment*	Mexico's electric mobility strategy	Mexico: Salgado-Conrado *et al*. (2025) found EV charging infrastructure expanded from approximately 100 stations in 2015 to more than 3,300 by 2023.
Sector-specific promotional programmes and missions *Setting clear sectoral goals and implementation pathways*	India's National Solar Mission	India: Shrimali *et al*. (2020) found solar capacity increased from 11 MW in 2010 to more than 22 GW by 2018.
Combinations of government-led and market-based enablers and incentives *Sequencing public and private incentives*	China's clean energy transition	China: Zeng *et al*. (2025) found that a mix of 121 financial instruments helped mobilise private investment in renewable energy.

For the narrower, targeted enablers, some of the most effective options focus on programmes that promote the selection and spread of appropriate technologies (García Martí *et al*. 2025). This is evident in countries such as Mexico with its national cookstove programme. Strengthening these efforts can include extending user co-payments to encourage higher-quality uptake, piloting tailored stove designs to complement local cooking practices and supporting community-based monitoring to sustain adoption.

Other technical enablers focus on building the supporting infrastructure needed to accelerate the spread of cleaner technologies or facilitate transitions within key sectors (Xie *et al*. 2026). China's large-scale investment in EV charging stations has, for example, supported a shift driven in part by local governments to encourage investment in supporting infrastructure.

Another set of narrower enablers involves awareness-raising and consensus-building mechanisms (Alagbe and Danjuma 2025). These have been demonstrated in Nigeria and other parts of Africa through stakeholder workshops on open burning and sustainable alternatives – along with incentives that encourage farmers to use residues for more productive purposes.

Other social enablers involve creating mechanisms that focus on limiting uneven distributional impacts and bringing in marginalised stakeholders (Aggarwal and Kumar 2025). This approach is reflected in India's PMUY cookstove programme, which builds gender considerations into its design and prioritises outreach to women and low-income households to optimise to cleaner fuels. Insights from behavioural public policy further highlight that awareness-raising accounts for cognitive biases together with better structured communication and engagement processes (Hallsworth *et al.* 2018).

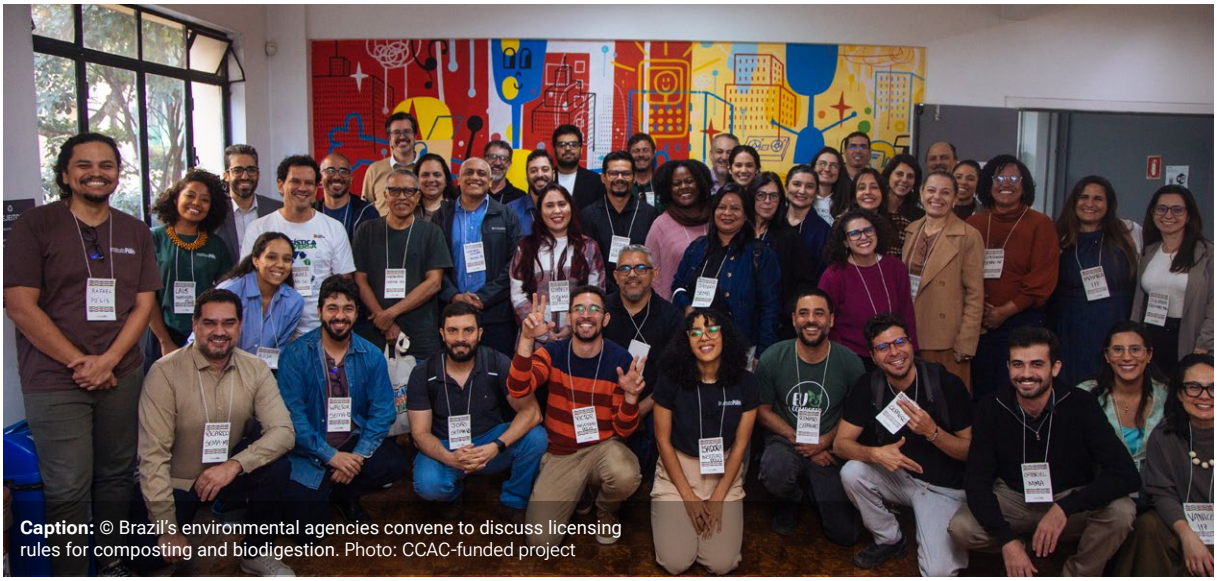
As for economic enablers, several examples highlight how public finance can help overcome upfront cost barriers (Olaoye, Akintoye and Ogbebor 2025). In Nigeria, for instance, government funding has supported early investment in solar energy, with public budgets earmarked for pilot projects capable of demonstrating viability at scale.

Many countries have relied on regulatory measures to provide predictability for investors and mobilise private capital (Smith 2025). Mexico's national strategy for electric mobility illustrates this approach, in which participation has been strengthened through market guarantees that encourage private operators to enter and expand within the sector.

Another set of more targeted supportive enablers centre on policy, regulatory and institutional measures designed to strategically combine incentives for smoother transitions, a phenomenon that is also evident in the broader literature on policy mixes (Stechemesser *et al.* 2024). China provides a useful example, in which a coordinated mix of policies helped foster a robust clean-energy sector, moving steadily from government-backed feed-in tariffs to more market-based mechanisms. This sequencing and mix of incentives helped guide a progressive shift from public funding toward more sustained private sector investment.

Finally, several countries have introduced sector-specific programmes with firm targets that accelerate progress in priority areas (Kumar and Pal 2025). India's solar mission exemplifies this approach, setting clear, time-bound targets for expanding renewable-energy generation and strengthening the foundation for continued growth in the sector.

An additional set of enablers comprises broader institutional, cross-cutting enablers within a broader framework that can support the integration across agencies and planning processes or encourage multilevel integration. As noted previously, these enablers provide a broader framework for the more targeted reforms described above and function as 'enablers of enablers'.



Caption: © Brazil's environmental agencies convene to discuss licensing rules for composting and biodigestion. Photo: CCAC-funded project

Table 4.4: Cross-cutting institutional enablers

Enabler	Country case	Illustrative evidence
Horizontal coordination mechanisms *Coordinating action across ministries and sectors*	Mexico's Intersecretarial Commission on Climate Change	Mexico: SEMARNAT (2019) reported that the Commission coordinated 14 federal ministries.
Vertical coordination mechanisms *Aligning national and subnational implementation*	China's local environmental planning reforms	China: Wang *et al.* (2021) found industrial carbon reductions generated measurable air-pollution co-benefits across provinces and cities.
Leadership backing for integrated planning and principles *Providing political support for integrated action*	China's co-control strategy	China: Geng *et al.* (2024) found integrated planning contributed to substantial reductions in $PM_{2.5}$ concentrations between 2013 and 2020.
Science-policy interface *Linking scientific evidence with decision-making*	Mexico's CCAC planning activities	Mexico: CCAC (2021) documented the development of integrated SLCP and air-pollution inventories across agencies.
Integration of air pollution/ climate in planning and budgeting processes *Embedding co-benefits into development planning*	Nigeria's integration of SLCPs into its NDC	Nigeria: Federal Ministry of Environment (2018) found that full implementation of SLCP measures could reduce black carbon emissions by 83 per cent and methane emissions by 61 per cent by 2030.
Sustained capacity-building programmes *Building long-term technical and institutional capacity*	China's regulatory capacity-building efforts	China: Zhang *et al*. (2019) reported expansion of the national monitoring network from 74 to 338 cities between 2013 and 2017.
Local governments empowered to serve as hubs of innovation *Enabling local experimentation and implementation*	Mexico City's Metrobus programme	Mexico: Bel and Holst (2018) found Metrobus reduced CO concentrations by 5.5 – 7.2 per cent and also lowered NO_x and PM_{10} near bus rapid transit (BRT) corridors.
Air quality monitoring networks and emissions inventories *Generating data to support policy and implementation*	India's air-quality monitoring expansion	India: Nobell *et al.* (2023) found low-cost sensors identified $PM_{2.5}$ exceedances with 91 per cent accuracy.

Arguably the most notable of these enablers are institutional mechanisms that strengthen horizontal coordination (Averchenkova *et al.* 2025). This function, central to effective implementation in many countries, has been partially addressed in Mexico through the Intersecretarial Commission on Climate Change (CICC), which has helped align the work across climate, energy, health and urban development ministries. More generally, this alignment can be facilitated by the establishment of integrated policy frameworks and joint monitoring systems; legally mandated coordination mechanisms – inter-ministerial working groups; shared data platforms/integrated emissions inventories; strong political commitment; and sustained engagement with the health sector.

A complementary set of institutional enablers involves vertical multi-level integration between national and local authorities (Chen and Ye 2025). China demonstrates this through its efforts to embed combined air-pollution and climate objectives in subnational environmental plans, forging synergistically across policy and planning frameworks.

Other cross-cutting enablers involve strong leadership backing for principles that encourage more integrated

planning and policy development (Igbini *et al.* 2026). China demonstrates this through its support for co-control approaches and broader climate-air quality synergies, coupled with efforts to improve coordination between state and city authorities responsible for air-quality management and climate action.

A related set of enablers reinforces this normative support with evidence by strengthening science-policy interfaces (Schiller *et al.* 2026). Mexico's work on SLCPs – including its engagement with CCAC National Planning Activities – illustrates how dedicated mechanisms can enhance data sharing, strengthen monitoring links, and improve the integration of greenhouse gas and air-pollutant emissions inventories to guide more coherent policy decisions.

A related cross-cutting enabler involves embedding air-pollution and climate considerations in high-level planning processes (Igbini *et al*. 2026). Nigeria's decision to integrate SLCP mitigation into its NDC illustrates this approach, accompanied by strengthened provisions that directly target pollutants such as methane and black carbon.

Similar enablers centre on leveraging locally driven innovation and recognizing cities as hubs as innovation (Sosa *et al.* 2025). Mexico's efforts to spotlight Mexico City's leadership in transport, for example, show how urban initiatives can inform national strategies and strengthen integration across urban planning, public transport and regional air-quality management.

Another institutional enabler is sustained capacity building (Yang 2020). China has supported this objective through long-term investment in the technical, regulatory and institutional capacities of agencies responsible for air-quality and climate governance.

A further cross-cutting enabler is a robust air-quality monitoring system, including through the integration of low-cost sensors (Smith *et al.* 2025). India, for instance, has demonstrated that low-cost sensors can substantially expand monitoring coverage while providing sufficiently accurate data for air-quality management and emissions-inventory development.

The selection of the appropriate mix of enablers will vary across different combinations of solutions and different countries. The need for a context-specific approach is particularly important when it comes to the cross-cutting enablers given varying governance arrangements. Some countries, for example, feature centralised target-setting and implementation, with policies enforced primarily through top-down administrative lines. Others operate in context in which there is a clearer division of power among central and state governments and there is more reliance on legislative and judiciary systems for accountability (Wang *et al.* 2023). In addition, there may be other types of enablers that are not fully captured in this framework that could be relevant and require additional attention, such as accountability mechanisms or institutional arrangements that insulate decision makers from changing political cycles.

The above descriptions can also guide policymakers in breaking down barriers and building their own enabling environments. More concretely, these categories of enablers can serve as a framework for assessing and improving efforts to implement integrated climate and air-pollution beyond the solutions themselves in diverse contexts. This can include informal exercises that convene decision makers from different agencies to reflect on both sector-specific and broader cross-cutting challenges as part of capacity-building programmes.

Those discussions can also be supported by a simple learning tool that helps structure dialogue around the types of enablers relevant to different contexts. Such a tool could present concrete options linked to specific challenges and opportunities. For policymakers aiming to strengthen vertical integration, for instance, it might outline options such as establishing staff-rotation schemes between national and local agencies; designating focal points within national ministries to monitor local developments; using fiscal transfers to incentivise more integrated air-pollution and climate responses; and linking subnational performance metrics to climate and air-quality indicators.

Illustrating this potential with another example, for policymakers seeking to bolster programmes addressing distributional socioeconomic impacts and gender equity, the tool might include deliberate efforts to bring women, low-income and informal segments into planning processes that affect livelihoods; investment in transparent reporting of science, data and impacts; building and extending networks with concerned civil-society groups;

strengthening connections between clean air and climate, and just transitions; and compensation mechanisms for losses of income. Using a tool of this kind can facilitate more constructive exchanges among policymakers, helping them translate and operationalise practical combinations of enablers that suit their specific governance arrangements. It can also help break down silos and add momentum to the virtuous reform cycles described earlier.

Many of the recommendations in this chapter may also be supported by reforms at the international and regional level. The Convention on Long-Range Transboundary Air Pollution (CLRTAP) and current negotiations on revisions to the Gothenburg Protocol, which incorporates SLCPs such as black carbon, are likely to consider the possibility of further action on black carbon and explore the integration of methane mitigation measures. These advances could open the door for more work on enabling implementation.

In addition, as suggested, the nationally determined nature of mitigation under the Paris Agreement allows countries to voluntarily highlight the co-benefits of climate measures for air quality that could focus further on enabling implementation.

Several international organisations and transnational networks, including the World Health Organization (WHO), UNEP, and the CCAC, could play a significant role in enabling integrated solutions to climate change and air pollution. This could involve, for instance, integrating learning tools focused on implementation to support more technical cost-benefit analyses. They might also focus on building sustainable capacity within existing institutions by embedding staff with knowledge of climate change and air pollution in government agencies. Finally, they could leverage existing or create new platforms to spotlight the reasons behind implementation success and share those lessons within and across regions.



Caption: © Farmers in Offinso, Ghana, gain practical agroecology skills to boost productivity and climate resilience. Photo: CCAC-funded project

05 Conclusion and the way forward



Caption: © Implementing agroecology and circular economy technologies to reduce SLCPs from maize and rice production. Photo: CCAC-funded project

This Assessment shows that integrated action on climate change and air pollution is not only environmentally necessary but economically beneficial, reducing avoidable health expenditure, limiting productivity losses, lowering long-term damage costs and improving the return on public and private investment. This concluding chapter draws out the implications of the three core innovations behind these findings. It first shows how integrating climate and clean-air mitigation allows for a single set of interventions to reduce multiple forms of damage. It then sets out how the latest morbidity evidence reveals health benefits that arrive early and outweigh costs within a decade. Finally, it turns to the enabling conditions that determine whether these benefits are actually captured, and to the wider measurement, equity, governance and innovation challenges that shape the way forward.

5.1 Integrated action reduces multiple forms of damage through the 25 solutions

Climate change and air pollution often arise from the same economic activities, particularly fossil-fuel combustion, so many solutions address both problems at once. This makes integrated policy especially attractive from an economic and fiscal perspective, as one set of interventions can reduce multiple forms of damage, improve policy coherence and increase the return on investment.

Although climate change and air pollution operate on different spatial and temporal scales, both harm human health, ecosystems and economies, and their adverse impacts further reinforce one another. The actions to reduce greenhouse gas emissions have direct implications for pollution and generate benefits for human health and natural ecosystems that begin to accrue immediately. Conversely, rapid action on critical air pollutants, particularly methane, as a precursor of tropospheric ozone, and black carbon, reduces radiative forcing and lowers near-term warming. This is a compelling argument for immediate action on air pollution. These conclusions are in line with other studies, including Organisation of Economic Co-operation and Development (OECD) modelling that found welfare gains of around US$ 290 billion by 2050 at no overall cost to GDP, while reducing the black carbon that accelerates warming (OECD 2021).

Global energy use is increasing, albeit with a growing share of renewables, leading to carbon dioxide

emissions plateauing at a high level (Chapter 2). By contrast, emissions of nitrous oxide, a long-lived greenhouse gas, the short-lived climate pollutant (SLCP) methane, and air pollutants such as nitrogen oxides, ammonia and fine particulate matter ($PM_{2.5}$), are still rising strongly driven by economic growth, expanding agricultural activity and limited control policies. Emissions of some air pollutants, for example, volatile organic compounds and SLCPs such as black carbon are declining as reliance on solid fuels for cooking and heating falls in several regions.

Sectoral and regional trends diverge. Developments in power generation, industry, transport and residential energy use drive the evolution of energy-related pollutants – carbon dioxide, nitrogen oxides, sulphur dioxide, black carbon and $PM_{2.5}$ – while agricultural activities dominate biogeochemical pollutants – methane, nitrous oxide and ammonia). These sectoral trends prevent any one set of mitigation policies from reducing all pollutants effectively. Emissions are declining in regions with mature control regimes, such as the European Union (EU), while rising in rapidly growing economies across South Asia and Africa, where strong economic and demographic trends are outpacing the expansion of emissions controls.

The modelling shows that the near-term benefits of prompt implementation generate increasingly important, well-quantified economic and health gains, reinforcing the case for early and ambitious action, and reduce the healthcare costs that would otherwise arise from the projected pollution-related rise in morbidity under the baseline.

Mitigation costs decline over time as a share of GDP. Under the baseline scenario, the costs of implementing current policies fall from 4.5 per cent of global GDP in 2030 to 1.5 per cent in 2100. The additional costs of the 25 integrated solutions are approximately 0.7 per cent of global GDP in the next decade, declining to approximately 0.5 per cent by 2100. Nearly two thirds of the early investment is associated with the four long-term climate solutions. The costs of air-pollution measures alone decline after rising initially in the first one or two decades, as investments in renewables and electrification reduce air pollution control costs over time.

The regional distribution of these global costs is uneven. Black carbon mitigation, for example, requires regionally specific strategies, while methane mitigation is globally consistent, enabling greater international cooperation. Partly as a result, developing regions such as Africa, Latin America and South Asia will bear a higher relative share of costs in the integrated action scenario over time, though in some developing regions the costs decline gradually towards 2100 after rising through 2050. This rising share reflects growth rather than burden: costs increase where populations, energy demand and industrial capacity are expanding fastest, and where emission controls and waste management systems have yet to be built. Crucially, these are also the regions where returns are highest. Benefit-cost ratios reach 26 to 1 in Southern Africa, 21 to 1 in South Asia and 11 to 1 in Sub-Saharan Africa, compared with 3 to 1 in the European Union, EFTA and the United Kingdom of Great Britain and Northern Ireland (Chapter 3). Developing regions therefore invest more over time because they gain more, not because the burden is unfairly distributed. International cooperation on finance and technology can further lower the cost of that investment, and integrated approaches promote a more balanced regional distribution of contributions over time, improving long-term feasibility, equity and cooperation.

5.2 Health benefits arrive early and outweigh costs within a decade

This Assessment draws on an expanded evidence base to quantify, for the first time in comparable economic terms, the health and associated economic damage caused by climate change and air pollution, and the benefits of implementing integrated mitigation measures. This approach allows the total market and non-market economic benefits of policy interventions to be compared directly with their costs, across regions and over time.

Globally, the avoided market costs associated with chronic disease are comparable to the total costs of mitigation, though there are significant regional differences. Counting only measurable market benefits, the net present value of benefits is approximately four times greater than costs. When non-market benefits are included, the overall benefits of action far exceed the costs in all regions and years considered, with a benefit-cost ratio of approximately 15 to 1 and an internal rate of return of 60 per cent. The value of the health benefits is so substantial that it exceeds the full cost of implementing the 25 integrated solutions

by the end of the first decade. These benefits continue to accumulate significantly over time, further strengthening the economic case for action with every year of delay avoided. Similarly, early methane mitigation delivers rapid reductions in the burden of climate-related health impacts. These findings make a compelling case for prompt and consistent action.

A wide range of chronic health outcomes are associated with air-pollution exposure. This Assessment finds that ambient $PM_{2.5}$ and ozone together currently cause 6.4 million premature deaths annually worldwide, with an additional estimated 2 million premature deaths, including nearly 300,000 among children, attributable to elevated indoor $PM_{2.5}$ concentrations in households using solid fuels for cooking. Ambient $PM_{2.5}$ exposure alone is associated with millions of new cases annually of childhood asthma, acute myocardial infarctions (heart attacks), chronic obstructive pulmonary disease (COPD), diabetes, stroke, dementia and lung cancer. In the absence of additional policy action, population growth and ageing is expected to increase this burden over the coming decades.

Adverse health effects carry a range of socio-economic costs, including increased health-care expenditure, temporary or permanent loss of income due to disability, and broader impacts on society through reduced productivity and economic output (GDP). Beyond these market costs, air pollution also imposes non-market costs related to premature mortality and reduced quality of life or well-being at both individual and societal levels. Although seemingly less tangible than the market effects, these non-market effects strongly influence health planning and intervention decisions.

The majority of damage represents non-market loss of welfare, for both climate and pollution. Out of the total avoided damage equivalent to 11.4 per cent of global GDP in 2100 (Chapter 3), 3.7 per cent represents market damage and 7.7 per cent represents non-market damages. The benefits from the 21 clean air and near-term climate solutions accrue rapidly, including health benefits from productivity, lower healthcare costs and reduced disutility from mortality risk. The four long-term climate solutions also generate meaningful near-term public health benefits, even though the majority of their economic benefits emerge after 2050 and are indispensable for addressing long-term climate stabilization and generating the much larger economic benefits that accumulate over the long-term.

Equity considerations are relevant across all measures. Climate impacts disproportionately affect poorer populations, who are more likely to live in vulnerable locations and have fewer resources to adapt to environmental change or to recover from extreme events such as crop failure and flooding. The health impacts of air pollution are similarly more severe for socio-economically disadvantaged groups, so measures that reduce air pollutants can reduce inequalities by disproportionately benefiting these groups. The same holds for solutions that mitigate climate change, though these benefits manifest more gradually.

Health-related impacts are expected to be positive for all population groups, contributing to improved equity outcomes, but the impact of cost-related effects may be uneven. Energy efficiency measures, for example, generally reduce energy expenditure and improve affordability, but some measures may increase the costs of energy or other goods, which could disproportionally affect more deprived populations. If the costs of implementing the mitigation measures are passed on to consumers, this can affect low-income consumers disproportionately. The magnitude and direction of these second-order effects should therefore be taken into account at the programme design stage.

5.3 Enabling conditions determine whether and when the benefits are realised

The Assessment identifies 25 proven solutions that combine long-term climate action with solutions targeting air-pollution and near-term climate impacts. Together, these solutions generate economic benefits equivalent to about 4.5 per cent of global gross domestic product (GDP) by 2050 and around 11.4 per cent by 2100.

Many benefits begin quickly. Reduced exposure to air pollution improves health, lowers income losses from illness and raises labour productivity within a few years. Effectively introduced, these gains can outweigh implementation costs within the first decade. This timing matters. It means that well-designed,

integrated action on air pollution and climate change can produce near-term economic returns while also supporting the longer-term structural transformation of energy systems, land use and industrial processes that decarbonization requires.

Capturing these gains, however, depends on governments' ability to implement measures fully and quickly. Delays extend the period of harmful emissions, increase cumulative damage, and reduce the value of investments already made. Delayed action locks in higher future expenditure on healthcare, disaster response, lost productivity and adaptation, while weakening the economic returns from mitigation spending.

Chapter 4 shows that countries can improve implementation by addressing economic, social, technical and institutional barriers. This is a core economic issue. Governments should treat the assessment and removal of barriers to implementation as part of integrated policy design. Investment in enabling environments can generate returns that have rarely been fully evaluated in research.

Economic barriers include high upfront costs, weak access to affordable finance and competition with other budget priorities in the context of constrained resources. These considerations affect both public and private actors. Yet the Assessment shows that avoided damage and lower health-related costs can justify early expenditure. Governments and investors can maximise health and welfare and minimise trade-offs by screening new project proposals against their combined climate and air quality costs and benefits before funding decisions are made. When governments reduce implementation delays, the balance between the outlays and avoided costs of illness and productivity losses can become positive within a decade.

Social barriers also have budget implications. Limited public understanding of the costs of inaction can slow adoption and weaken support for reform, increasing political and implementation risks. Public communication that highlights visible near-term gains, including especially cleaner air, better health and lower household burdens, can help build support for measures whose full climate benefits accrue over longer periods, particularly among poorer or more disadvantaged groups who are disproportionately affected by the impacts of air pollution.

Technical constraints often reflect underinvestment in supportive technology infrastructure and limited access to affordable, appropriate technologies. International cooperation can help reduce these barriers by improving access to technology, lowering capital costs and supporting deployment. Domestic policy reform also matters, since governments can remove incentives that favour outdated, polluting technologies and redirect support to cleaner, more productive alternatives.

Institutional barriers remain a major source of inefficiency. Weak administrative capacity, fragmented regulatory mandates, and poor coordination across ministries and levels of government often slow implementation and raise costs. Stronger coordination can improve policy coherence, reduce duplication and support better sequencing of expenditure and reform, which is especially important when air quality, energy, transport, health and agricultural policies interact.

The case studies in Chapter 4 show that targeted and cross-cutting enablers can significantly improve implementation outcomes. Countries that align sectoral measures with broader reforms in governance, planning, budgeting and capacity building are better able to capture the benefits of integrated action, which also improves the effectiveness of public expenditure more generally.

The Assessment proposes a framework linking targeted enablers, aimed at overcoming the specific barriers in each of the four areas – economic, technical, social and institutional – with broader cross-cutting enablers that strengthen horizontal and vertical coordination, build up the science-policy interface and increase capacity, and integrate air-pollution and climate action into planning and budgeting cycles (Figure 4.1). The approach depends on sustained, publicly demonstrated political support for integrated planning and policy development, and on a stronger evidence base to guide policy design.

5.4 Aligning the findings with global commitments and targets

The economic case set out in this Assessment does not stand apart from the political commitments that governments have already made. The action, impacts and benefits quantified here map directly on to two of the most consequential commitments and targets

in the climate and clean air agenda. Read against these benchmarks, the Assessment shows that the 25 integrated solutions deliver on existing commitments, as a net economic gain.

Delivering the World Health Organization 2040 air pollution mortality reduction target

In May 2025, the Seventy-eighth World Health Assembly adopted the World Health Organization (WHO) roadmap for an enhanced global response to the adverse health effects of air pollution, through a voluntary target of reducing the population-attributable fraction of mortality from anthropogenic sources of air pollution by 50 per cent by 2040, relative to a 2015 baseline (WHO 2025). Achieving this target requires an average annual reduction of approximately 3.3 per cent in attributable mortality between 2025 and 2040. The reductions in air pollution projected from global implementation of the 25 integrated measures deliver an average annual reduction of approximately 4 per cent in attributable mortalities over the same period. Full implementation of the integrated package would therefore exceed the pace of progress required to meet the target.

This Assessment establishes that the economic value of the health and climate benefits of action greatly exceeds the costs of implementing control measures. The WHO roadmap calls for cost-benefit analysis of sectoral interventions; comparison of the health, climate and economic benefits of policy options; and estimation of the costs of inaction in order to build the economic case for clean air. The Assessment responds directly to that need, offering a concrete, economically grounded pathway to a health outcome to which WHO Member States have committed through the World Health Assembly.

Consistency with 1.5 °C scenarios and overshoot

Exceeding 1.5 °C is now widely assessed as unavoidable (UNEP 2026). This does not diminish the relevance of the 1.5 °C goal, but it changes the nature of the task: the central challenge is now to limit peak warming as much as possible, reduce the duration of exceedance, and minimise irreversible losses and damages, while continuing to pursue efforts to return warming to 1.5 °C. In an era of overshoot, speed matters as much as scale. Each additional five years of sustained high emissions adds approximately 0.1 °C to peak warming (UNEP 2026), and every fraction of a degree above the 1.5 °C threshold increases the risks of further ecosystem collapse, food insecurity, economic disruption and displacement. Higher peak temperatures also degrade the performance of the low-carbon energy systems and carbon removal capacity on which later-century strategies depend, meaning that delayed action both raises the peak and weakens the tools available to bring temperatures back down (UNEP 2026). Minimizing the magnitude and duration of overshoot requires immediate and deep emissions reductions across all sectors. The means of achieving these reductions are well known and available; the persistent challenge has been consistent, timely implementation. Alleviating the barriers to implementation, examined in Chapter 4, needs to be given primacy.

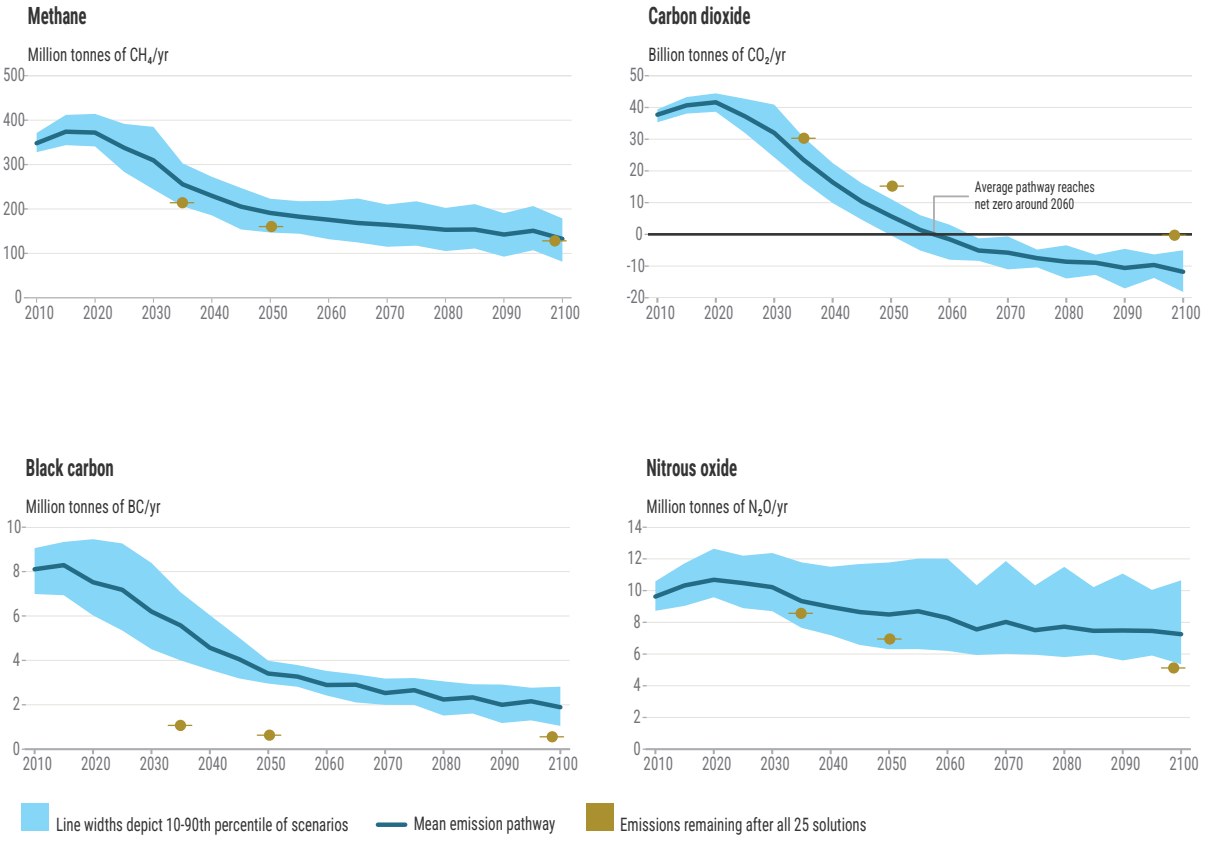
Intergovernmental Panel on Climate Change (IPCC) overshoot, peak and decline pathways that limit warming to 1.5 °C by the end of the century require reaching net zero-carbon dioxide before 2060 and sustained net-negative carbon dioxide emissions for the remainder of the century (Byers et al. 2022). Parallel, significant and sustained reductions in super pollutant emissions, particularly methane, are critical for reducing the near-term rate of warming, limiting the peak, and returning temperatures to 1.5 °C.

This Assessment finds that global implementation of the 25 integrated solutions can reduce emissions of key pollutants to levels consistent with, or well below, IPCC 1.5 °C overshoot pathways, and the solutions map directly onto the three phases of overshoot response identified by UNEP (2026). The 21 clean air and near-term climate solutions deliver the rapid reductions in warming that the emergency response and containment phases require, while the four long-term climate solutions drive the sustained decarbonization that halts warming at its peak. The net-negative carbon dioxide emissions the solutions achieve after 2080, together with sustained methane reductions, particularly in the agriculture and waste sectors, contribute directly to the long-term resilience phase, in which warming begins to decline.

Figure 5.1 illustrates the IPCC 1.5 °C overshoot emissions pathways for key pollutants (carbon dioxide, methane, nitrous oxide and black carbon) and estimated emissions reductions from the 25 solutions in the near-term, mid-term and long-term. For methane and nitrous oxide, the 25 solutions reduce emissions below the average levels of the IPCC 1.5 °C overshoot

scenarios in the critical next few decades and maintain reductions throughout the century. For black carbon and other relevant air pollutants, the 25 integrated solutions achieve reductions far exceeding those in the IPCC 1.5 °C scenarios. For carbon dioxide, the 25 integrated solutions can meaningfully contribute to reductions of anthropogenic emissions in a way that is complementary to the direction of current climate policy, reaching net-zero emissions by approximately 2080. Three criteria informed our selection of measures for the integrated package: (i) broadly applicable to most world regions and where there is information about efficiency and costs; (ii) cut multiple pollutants at once (CO_2, non-CO_2 GHGs, air pollutants); (iii) deliver large near-term health and climate benefits, while also supporting long-term climate mitigation. This excludes some measures that can nonetheless still be important in meeting climate goals. Closing the CO_2 emissions gap to the net-zero by 2060 required can thus be bridged with additional, climate-focused measures, such as carbon capture and storage, and some further land-use change measures.

Figure 5.1: Net anthropogenic methane, carbon dioxide, black carbon and nitrous oxide emissions in the Intergovernmental Panel on Climate Change Sixth Assessment Report pathways limiting global warming to 1.5 °C with high overshoot (C2). The middle line shows the average emissions for all pathways, and shaded area shows 10–90 per cent ranges of these pathways. The gold dots show emissions reductions and residual emissions from implementation of the 25 measures in 2035, 2050 and 2100.



5.5 Remaining challenges and the way forward

Integrated action is an economic strategy, not only an environmental one

The Assessment shows that integrated action on climate change and air pollution can reduce substantial and growing economic losses. Over time, these benefits can strengthen growth, ease pressure on public budgets and support the broader transition to low-emission, more resilient economies.

By combining near-term air-quality gains with long-term decarbonization, governments make integrated climate and air-pollution policy a practical economic strategy rather than just an environmental one. It allows trade-offs to be managed more effectively, capturing multiple benefits from the same interventions, and building support for sustained reform. The case for action rests not only on avoiding environmental damage, but on improving economic performance and reducing fiscal risk.

The scale of avoidable losses remains very large. While the benefits of clean air and near-term climate solutions are considerable (Section 5.3), capturing the benefits identified in this Assessment requires continued investment in enabling conditions, stronger implementation and better integration of economic, social and environmental objectives.

The full benefits are larger than current models can capture

The current analysis captures the impacts of key pollutants, integrating the latest evidence with innovative methodologies, along with the latest evidence on the costs of mitigation. Several important sources of economic damage (Section 3.6) and costs (Section 2.5), however, remain only partially quantified. Taking costs and benefits together, this Assessment likely underestimates the full costs of inaction and the full benefits of mitigation.

Additional pollutants, such as nitrogen dioxide, carbon monoxide, and polycyclic aromatic hydrocarbons (PAHs), can impose independent health risks. Excluding them avoids double counting the health burdens, since the epidemiological evidence for pollutants such as nitrogen dioxide and $PM_{2.5}$ is not fully independent and attributing harm to each separately would risk overstating total damages. This conservative approach, however, means the analysis captures a narrower set of health benefits. Other pollutants, including heavy metals and persistent organic compounds, affect human health through food systems and environmental pathways that current models do not fully capture (e.g. Spadaro and Rabl 2004).

Air pollution also generates significant economic losses beyond human health. Ground-level ozone reduces crop yields and lowers agricultural productivity, with estimated losses of tens of billions of dollars annually. These estimates, however, are based on a small number of staple crops and do not reflect the full scale of damage to all sensitive crop varieties. Ozone also reduces forest growth and carbon sequestration. As well as air quality, nitrogen pollution degrades water quality, increases treatment costs, and contributes to ecosystem damage and biodiversity loss, while nitrous oxide depletes the stratospheric ozone layer (UNEP and FAO 2024).

These impacts carry direct fiscal implications through reduced economic output, higher public expenditure, higher commodity prices and increased pressure on natural resource systems. They remain, however, only partially reflected in integrated assessment models. This limitation is consistent with other studies, such as OECD modelling cited above, which quantified the agricultural co-benefits of cleaner air but confined its estimates to market impacts, leaving wider ecosystem effects unvalued (OECD 2021).

In addition, several policy-relevant measures, such as active mobility, congestion reduction, vehicle scrappage and livestock health interventions, offer potentially large benefits but lack robust quantification at scale. Expanding the evidence base for these measures would improve policy design and help governments identify low-cost high-reward opportunities.

Strengthening modelling capacity in these areas would allow future assessments to provide a more complete estimate of economic risks and returns, supporting better-informed fiscal and investment decisions.

Protecting human and natural capital, not just gross domestic product

One of the major shortcomings of GDP as a measure of economic progress is that it does not capture the consequences of growth that may undermine the assets that underpin it – human capital, natural capital

and physical capital (UN 2026). This report follows the established approach of translating morbidity and mortality impacts into tangible, measurable costs expressed as equivalent changes in GDP, using GDP as a numeraire across different kinds of costs. What is innovative is the breadth and recency of the evidence drawn upon. This Assessment incorporates a substantially expanded set of health outcomes, including conditions such as dementia, diabetes and childhood asthma, that prior economic assessments have not fully valued. This draws welcome attention to the economic damage caused by air pollution. The approach allows a partial approximation of negative changes in the quality of human capital caused by air pollution and climate change, and of the improvements that can be generated by policy solutions that chart a path to sustainability while avoiding that damage. This ensures that future GDP growth, strengthened through the 25 integrated solutions, is not achieved at the expense of damaging human capital, as has been the case in the past.

An additional challenge looking forward is to expand the policy focus to include measures that address the triple planetary crisis, adding biodiversity loss to the integrated consideration of climate change and environmental pollution. Strengthening the analysis of ecosystem and biodiversity degradation, and other forms of environmental degradation would allow a similar quantitative assessment of the accumulating damage and potential gains from policy, advancing natural capital, another of the major assets essential to humanity's future. Even if the empirical analysis of the impact of biodiversity loss is not fully understood, there is good reason to integrate policies aimed at slowing biodiversity loss and reconstituting natural ecosystems into solutions that deliberately work to preserve and enhance the quality of the three types of capital – economic, natural and social – and contribute to a more sustainable future.

As policymakers integrate these considerations into the design of policy, the limitations long evident in GDP as an instrument for measuring current progress and guiding the future will become less binding. Expanding the analysis, modelling capabilities and the evidence base beyond the limits of the present Assessment will contribute to this process.

Cleaner air narrows health inequalities

The incidence of several health conditions linked to air pollution and climate change differs between males and females, and therefore the benefits from implementing the solutions will accrue differentially to the two genders. Evidence points, for example, to higher rates of dementia for females, contrasting with considerably more cases of lung cancer among men, and some excess incidence of childhood asthma among males. Spending more time indoors cooking on traditional stoves exposes many women and children in developing countries to extremely high levels of indoor air pollution, and thus substantially higher incidences of the associated chronic diseases. Stove improvement programmes and the use of cleaner fuels can reduce this impact, while also generating significant additional co-benefits for females through reduced time spent collecting firewood, providing more opportunity for education with subsequent benefits for autonomy and choice, and reducing the risk of sexual violence outside the home. Deepening the evidence base in some areas, such as the gender differentiation of response functions, would enable more precise modelling of the differentiated impacts and the integration of appropriate supporting measures.

The measures discussed in this Assessment have a positive effect on equity in several ways. Air-pollution impacts are greater in deprived populations facing higher baseline health risks, poorer general health and reduced access to and affordability of health services. Similarly, climate impacts disproportionately affect the poor who live in vulnerable locations with fewer resources to adapt to or recover from climate risks. While the health impact of the solutions would be positive for all population groups, the health benefits will be proportionately greater for more disadvantaged groups. Efficiency measures have reduced costs of energy and other goods, which will be felt most keenly by poorer people. Some measures, however, could increase costs, further disadvantaging poorer groups, unless they are accompanied by compensating measures. Poorer people will also be less able to afford to upgrade their cooking, heating, electricity and transport options without additional support measures. Targeted subsidies from governments to low-income households could, for example, help defray higher electricity costs. Equity considerations should be explicitly built into policy design to take full advantage of co-benefits and properly address trade-offs that could compromise prompt and consistent implementation.

Coordinated governance is decisive for delivery

The case studies presenting the experience of four countries in developing integrated policy frameworks and strengthening their implementation indicate that weak or absent coordination mechanisms between agencies with different policy responsibilities, or at different levels of government, are among the institutional barriers that delay effective and timely policy implementation (Chapter 4). Strengthening governance is one of the institutional enablers identified in this Assessment.

Greater coordination among relevant agencies not only helps implement policies but also identify possible co-benefits and trade-offs and build these into an integrated policy framework. This would facilitate budgetary planning and programme-design processes that enable a realistic and comprehensive assessment of the initial costs of the 25 integrated solutions and help secure the necessary flow of resources to ensure consistent implementation of the policies over time.

Strengthened governance for air-pollution and climate policy implementation would also improve cross-agency coordination in other policy areas, raising the overall efficiency of government planning and implementation more broadly.

Sustained innovation is needed to lock in and extend the gains

Sustaining and expanding the gains identified in this Assessment will require continuous innovation across technologies, metrics for assessing impacts, policy design, financing mechanisms, institutional arrangements and public outreach. While many proven solutions are available, emerging challenges, evolving economic landscapes and remaining gaps in mitigation potential demand new approaches that can deliver faster, more cost-effective, and more scalable outcomes. Strategic investment in innovation can reduce future abatement costs, unlock additional benefits, strengthen competitiveness and safeguard the future, while also improving the precision and effectiveness of policy for enabling environments. Positioning innovation as a core component of integrated action is imperative to accelerate progress, manage uncertainty and maximise long-term economic prosperity.

Areas for innovation identified in this Assessment include developing approaches to protect the human and natural resource base underpinning sustainable and equitable growth; developing methodologies to more effectively include dimensions of gender and equity in climate, clean-air and economic analyses; and finding innovative ways to make meaningful investment in the enabling environment.

5.6 What can governments and partners do now?

The findings of this Assessment suggest several areas in which governments, international partners and the research community can strengthen action to capture the full range of identified benefits.

- **Strengthen national and regional action to capture near-term benefits.** Governments should accelerate implementation of integrated climate and clean-air solutions. Many of the associated health, productivity and economic gains are largely within national or regional control and can materialise in the near-term, providing a strong foundation for sustained policy efforts.
- **Enhance international cooperation to secure long-term climate stability**. Governments should strengthen international cooperation, through finance, technology exchange and aligned mitigation efforts to ensure that collective action delivers necessary long-term climate outcomes.
- **Invest in enabling conditions as a core component of policy.** Governments should strengthen institutional capacity, regulatory frameworks, enforcement mechanisms and coordination across sectors and levels of government to ensure effective horizontal and vertical integration of institutions and action.
- **Expand the evidence base to support integrated decision-making.** Researchers and policymakers should work together to extend integrated economic analyses across the full range of environmental challenges. By incorporating climate change, air pollution, ecosystem degradation and biodiversity loss into quantitative analytical frameworks, and translating their impacts into comparable economic terms, future assessments can provide an even stronger foundation for decision-making.

- **Reprioritise public and private investment to integrate air-quality and climate priorities, directing capital toward higher-return opportunities and accelerating implementation at scale.** Governments can start by requiring co-benefit assessment in public investment appraisal, so that avoided health costs and productivity gains are counted alongside emissions reductions when projects compete for funding. Development finance institutions can weigh concessional capital toward the regions where returns are highest, which are also those with the least access to affordable finance.



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