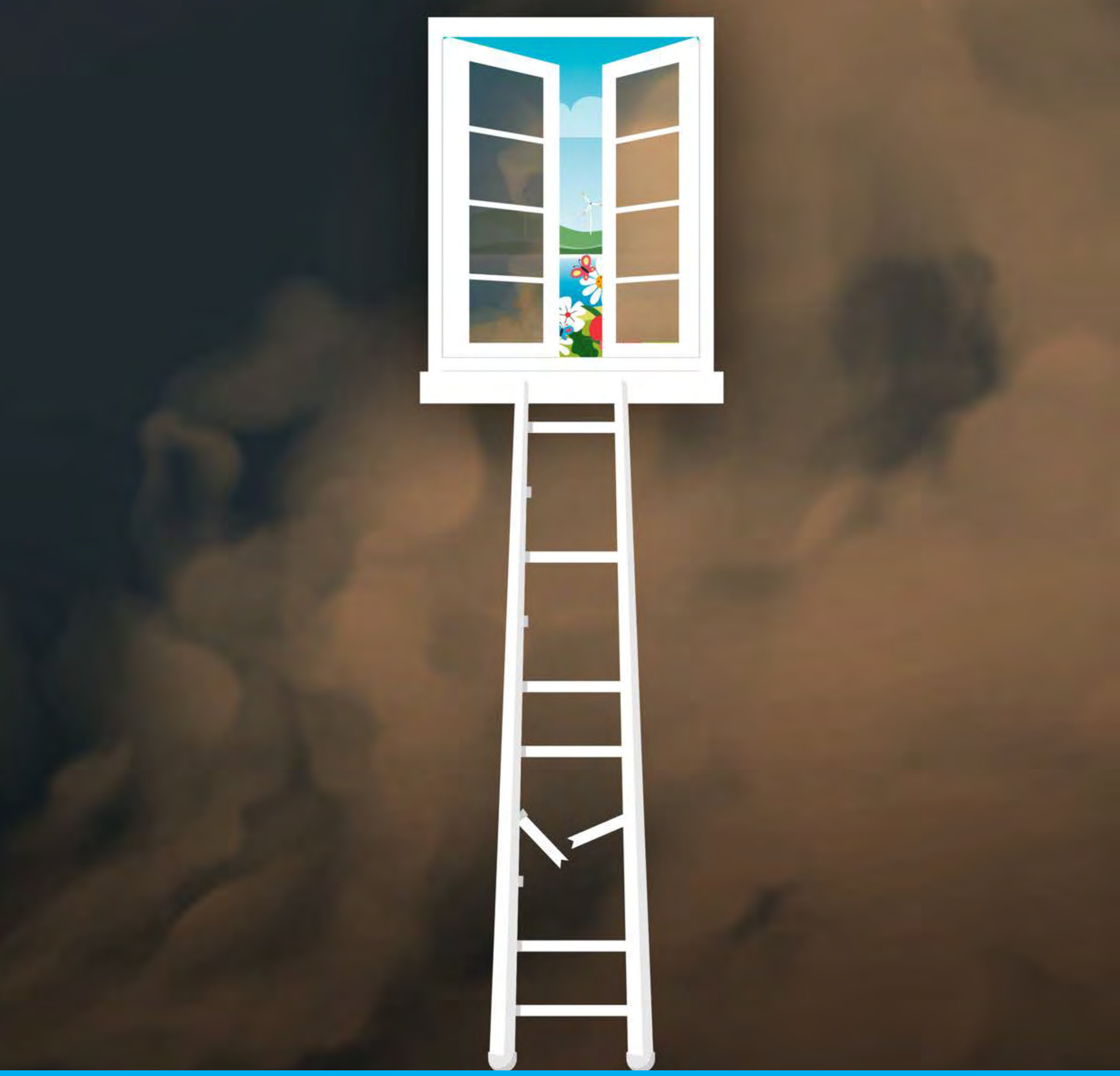
The Closing Window

Climate crisis calls for rapid transformation of societies



Emissions Gap Report 2022

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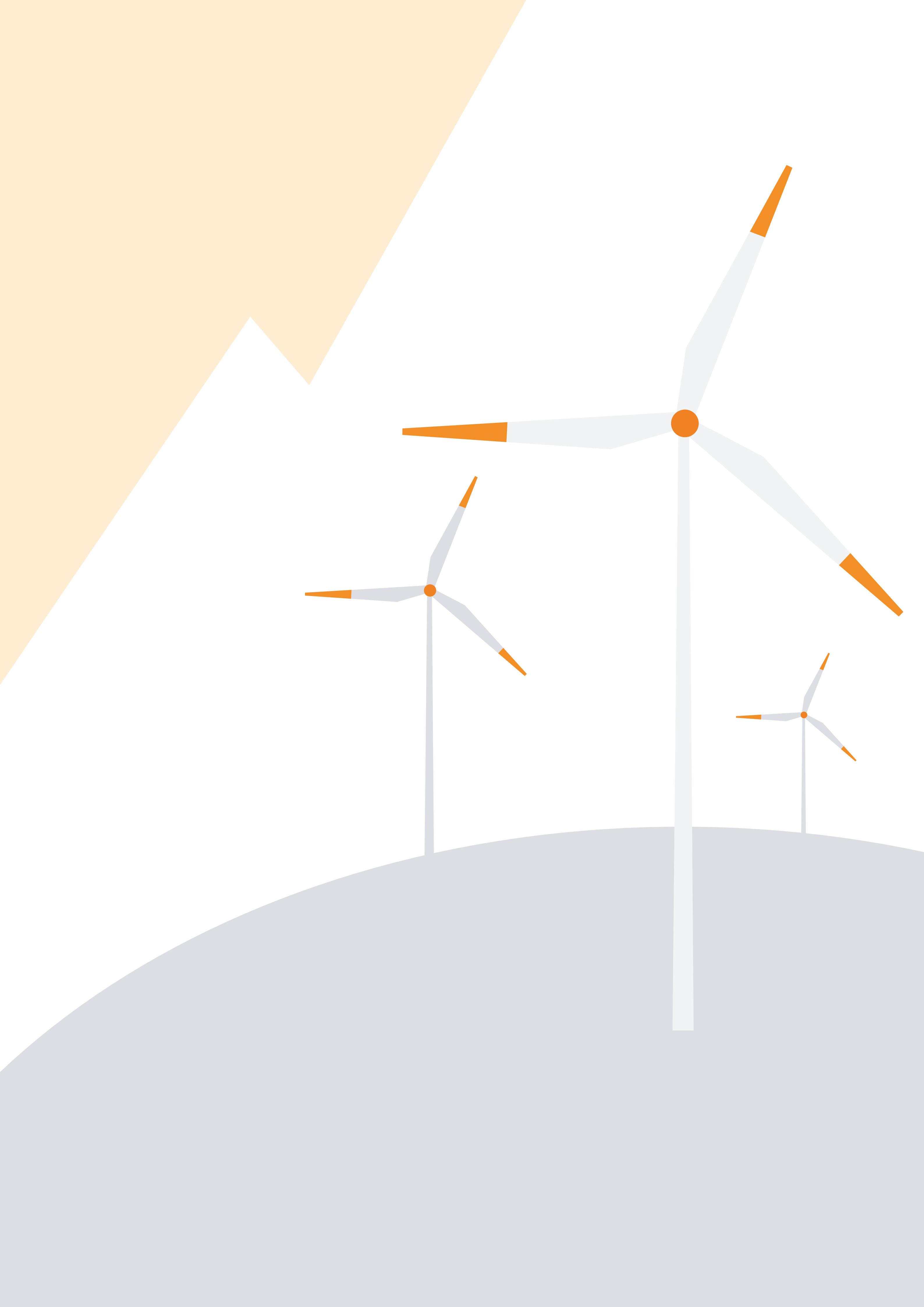

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Contents

Glossary

This glossary is compiled according to the lead authors of the report, drawing on glossaries and other resources available on the websites of the following organizations, networks and projects: the Intergovernmental Panel on Climate Change, United Nations Environment Programme, United Nations Framework Convention on Climate Change, and World Resources Institute.

Anthropogenic methane: Methane emissions derived from human activities. Anthropogenic emissions sources include coal mining, agricultural practices, wastewater treatment, certain industrial processes, and oil and gas systems, among others.

Baseline/reference: The state against which change is measured. In the context of climate change transformation pathways, the term 'baseline scenarios' refers to scenarios based on the assumption that no mitigation policies or measures will be implemented beyond those already in force and/or legislated or planned to be adopted. Baseline scenarios are not intended to be predictions of the future, but rather counterfactual constructions that can serve to highlight the level of emissions that would occur without further policy efforts. Typically, baseline scenarios are compared to mitigation scenarios that are constructed to meet different goals for greenhouse gas (GHG) emissions, atmospheric concentrations or temperature change. The term 'baseline scenario' is used interchangeably with 'reference scenario' and 'no-policy scenario'.

Carbon border adjustment mechanisms: Mechanisms that act to equalize the price of carbon between domestic products and imports, to eliminate financial incentives to relocate production outside regions with strong climate controls.

Carbon dioxide emission budget (or carbon budget): For a given temperature rise limit, for example a 1.5°C or 2°C long-term limit, the corresponding carbon budget reflects the total amount of carbon emissions that can be emitted for temperatures to stay below that limit. Stated differently, a carbon budget is the area under a carbon dioxide (CO_2) emission trajectory that satisfies assumptions about limits on cumulative emissions estimated to avoid a certain level of global mean surface temperature rise.

Carbon dioxide equivalent (CO_2e): A way to place emissions of various radiative forcing agents on a common footing by accounting for their effect on the climate. It describes, for a given mixture and amount GHGs, the amount of CO_2 that would have the same global warming ability, when measured over a specified time period. For the purpose of this report, GHG emissions (unless otherwise specified) are the sum of the basket of GHGs listed in Annex A to the Kyoto Protocol, expressed as CO_2e assuming a 100-year global warming potential.

Carbon markets: A term for a carbon trading system through which countries may buy or sell units of GHG emissions in an effort to meet their national limits on emissions, either under the Kyoto Protocol or under other agreements, such as that among member States of the European Union. The term comes from the fact that carbon dioxide is the predominant GHG, and other gases are measured in units called carbon dioxide equivalents.

Carbon neutrality: Is achieved when an actor's net contribution to global CO_2 emissions is zero. Any CO_2 emissions attributable to an actor's activities are fully compensated by CO_2 reductions or removals exclusively claimed by the actor, irrespective of the time period or the relative magnitude of emissions and removals involved.

Carbon offset: See Offset.

Carbon price: The price for a voided or released CO_2 or CO_2e emissions. This may refer to the rate of a carbon tax, or the price of emission permits. In many models used to assess the economic costs of mitigation, carbon prices are used as a proxy to represent the level of effort in mitigation policies.

Conditional nationally determined contribution: A conditional nationally determined contribution (NDC – see below) proposed by some countries that is contingent on a range of possible conditions, such as the ability of national legislatures to enact the necessary laws, ambitious action from other countries, realization of finance and technical support, or other factors.

Conference of the Parties (COP): The supreme body of the United Nations Framework Convention on Climate Change (UNFCCC). It currently meets once a year to review the UNFCCC's progress.

Double counting: Double counting involves two countries taking credit for the same emissions reductions, thereby giving the impression that the world has reduced emissions more than it actually has. For example, emissions reduction credits from a country might be sold to another country, while those reductions are still counted towards achievement of the NDC in the country where the credits originated.

Emission pathway: The trajectory of annual GHG emissions over time.

Emissions trading: A market-based instrument used to limit emissions. The environmental objective or sum of total allowed emissions is expressed as an emissions cap. The cap is divided in tradable emission permits that are allocated – either by auctioning or handing out for free – to entities within the jurisdiction of the trading scheme. Entities need to surrender emission permits equal to the amount of their emissions (e.g. tons of CO_2). An entity may sell excess permits. Trading schemes may occur at the intra-company, domestic or international level, and may apply to CO_2, other GHGs, or other substances. Emissions trading is also one of the mechanisms specified under the Kyoto Protocol.

Financial system: A financial system is a set of global, regional or firm-specific institutions and practices used to facilitate the exchange of funds. Financial systems can be organized using market principles, central planning, or a hybrid of both. Institutions within a financial system include everything from banks, to stock exchanges, to government treasuries.

Food security: A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Food systems: Food systems are the public policy decisions, the national and global systems (including production, farming, processing and global supply chains), and the individuals and groups (public and private), that influence the quantity and quality of food available for all.

Global warming potential: An index representing the combined effect of the differing times GHGs remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation.

Greenhouse gases (GHGs): The atmospheric gases responsible for causing global warming and climatic change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent, but very powerful, GHGs include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Greenhouse gas removal: Withdrawal of a GHG and/or a precursor from the atmosphere by a sink.

Industrial processes and products use (IPPU): The industrial processes and product use (IPPU) sector covers GHG emissions resulting from various industrial activities that produce emissions, that are not the direct result of energy consumed during the manufacturing process and the use of man-made GHGs in products.

Integrated assessment models: Models that seek to combine knowledge from multiple disciplines in the form of equations and/or algorithms, in order to explore complex environmental problems. As such, they describe the full chain of climate change, from production of GHGs to atmospheric responses. This necessarily includes relevant links and feedbacks between socioeconomic and biophysical processes.

Intended nationally determined contribution: Intended NDCs are submissions from countries describing the national actions that they intend to take to reach the Paris Agreement’s long-term temperature goal of limiting warming to well below 2°C. Once a country has ratified the Paris Agreement, its intended NDC is automatically converted to its NDC, unless it chooses to further update it.

Kyoto Protocol: An international agreement signed in 1997 and which came into force in 2005, standing on its own, and requiring separate ratification by governments, but linked to the UNFCCC. The Kyoto Protocol, among other things, sets binding targets for the reduction of GHG emissions by industrialized countries

Land use, land-use change and forestry (LULUCF): A GHG inventory sector that covers emissions and removals of GHGs resulting from direct human-induced land use, land-use change and forestry activities.

Least-cost pathway: Least-cost pathway scenarios identify the least expensive combination of mitigation options to fulfil a specific climate target. A least-cost scenario is based on the premise that, if an overarching climate objective is set, society wants to achieve this at the lowest possible cost over time. It also assumes that global actions start at the base year of model simulations (usually close to the current year) and are implemented following a cost-optimal (cost-efficient) sharing of the mitigation burden between current and future generations, depending on the social discount rate.

Likely chance: A likelihood greater than 66 per cent chance. Used in this assessment to convey the probabilities of meeting temperature limits.

Mitigation: In the context of climate change, mitigation relates to a human intervention to reduce the sources or enhance the sinks of GHGs. Examples include using fossil fuels more efficiently for industrial processes or electricity generation, switching to solar energy or wind power, improving the insulation of buildings, and expanding forests and other 'sinks' to remove greater amounts of CO_2 from the atmosphere.

Nationally determined contribution (NDC): Submissions by countries that have ratified the Paris Agreement which presents their national efforts to reach the Paris Agreement's long-term temperature goal of limiting warming to well below 2°C. New or updated NDCs are to be submitted in 2020 and every five years thereafter. NDCs thus represent a country's current ambition or target for reducing emissions nationally.

Offset: In climate policy, a unit of CO_2e emissions that is reduced, avoided or sequestered to compensate for emissions occurring elsewhere.

Purchasing power parity: A measurement that economists use to compare the spending power between two or more nations.

Scenario: A description of how the future may unfold based on 'if-then' propositions. Scenarios typically include an initial socioeconomic situation and a description of the key driving forces and future changes in emissions, temperatures, or other climate change-related variables.

S-curve: Adoption of new technologies often follows an S-curve trajectory. Under an S-curve, growth follows a non-linear pattern in which the curve initially increases slowly, before accelerating rapidly to a faster linear growth rate. As the variable approaches a new saturation point, the growth rate decelerates until a steady state is reached.

Source: Any process, activity or mechanism that releases a GHG, an aerosol or a precursor of a GHG or aerosol into the atmosphere.

Foreword

Every year, the negative impacts of climate change become more intense. Every year, they bring more misery and pain to hundreds of millions of people across the globe. Every year, they become more a problem of the here and now, as well as a warning of tougher consequences to come. We are in a climate emergency.

And still, as UNEP's Emissions Gap Report 2022 shows, nations procrastinate. Since COP26 in Glasgow in 2021, new and updated nationally determined contributions (NDCs) have barely impacted the temperatures we can expect to see at the end of this century.

This year's report tells us that unconditional NDCs point to a 2.6°C increase in temperatures by 2100, far beyond the goals of the Paris Agreement. Existing policies point to a 2.8°C increase, highlighting a gap between national commitments and the efforts to enact those commitments. In the best-case scenario, full implementation of conditional NDCs, plus additional net zero commitments, point to a 1.8°C rise. However, this scenario is currently not credible.

To get on track to limiting global warming to 1.5°C, we would need to cut 45 per cent off current greenhouse gas emissions by 2030. For 2°C, we would need to cut 30 per cent. A stepwise approach is no longer an option. We need system-wide transformation. This report tells us how to go about such a transformation. It looks in-depth at the changes needed in electricity supply, industry, transport, buildings and food systems. It looks at how to reform financial systems so that these urgent transformations can be adequately financed.

Is it a tall order to transform our systems in just eight years? Yes. Can we reduce greenhouse gas emissions by so much in that timeframe? Perhaps not. But we must try. Every fraction of a degree matters: to vulnerable communities, to species and ecosystems, and to every one of us. Most importantly, we will still be setting up a carbon-neutral future: one that will allow us to bring down temperature overshoots and deliver other benefits, like clean air.

The world is facing other crises. We must deal with them. But let us remember that they also offer opportunities to reform our global economy. We have missed the opportunity to invest in a low-carbon recovery from the COVID-19 pandemic. Now, we are in danger of missing the opportunity to boost clean and efficient energy as a response to the energy crisis. Instead of missing such opportunities, we must capitalize on them with confidence.

I urge every nation and every community to pore over the solutions offered in this report, build them into their NDCs and implement them. I urge everyone in the private sector to start reworking their practices. I urge every investor to put their capital towards a net-zero world. The transformation begins now.

Inger Andersen

Executive Director
United Nations Environment Programme

Executive summary

1. Testimony to inadequate action on the climate crisis and the need for transformation

This thirteenth edition of the Emissions Gap Report is testimony to inadequate action on the global climate crisis, and is a call for the rapid transformation of societies. Since the twenty-sixth United Nations Climate Change Conference of the Parties (COP 26), there has been very limited progress in reducing the immense emissions gap for 2030, the gap between the emissions reductions promised and the emissions reductions needed to achieve the temperature goal of the Paris Agreement, illustrated in the following:

- Countries' new and updated nationally determined contributions (NDCs) submitted since COP 26 reduce projected global greenhouse gas (GHG) emissions in 2030 by only 0.5 gigatons of CO_2 equivalent ($GtCO_2e$), compared with emissions projections based on mitigation pledges at the time of COP 26.

- Countries are off track to achieve even the globally highly insufficient NDCs. Global GHG emissions in 2030 based on current policies are estimated at 58 $GtCO_2e$. The implementation gap in 2030 between this number and NDCs is about 3 $GtCO_2e$ for the unconditional NDCs, and 6 $GtCO_2e$ for the conditional NDCs.

- The emissions gap in 2030 is 15 $GtCO_2e$ annually for a 2°C pathway and 23 $GtCO_2e$ for a 1.5°C pathway. This assumes full implementation of the unconditional NDCs, and is for a 66 per cent chance of staying below the stated temperature limit. If, in addition, the conditional NDCs are fully implemented, each of these gaps is reduced by about 3 $GtCO_2e$.

- Policies currently in place with no additional action are projected to result in global warming of 2.8°C over the twenty-first century. Implementation of unconditional and conditional NDC scenarios reduce this to 2.6°C and 2.4°C respectively.

- To get on track for limiting global warming to 1.5°C, global annual GHG emissions must be reduced by 45 per cent compared with emissions projections under policies currently in place in just eight years, and they must continue to decline rapidly after 2030, to avoid exhausting the limited remaining atmospheric carbon budget.

As these headline findings illustrate, incremental change is no longer an option: broad-based economy-wide transformations are required to avoid closing the window of opportunity to limit global warming to well below 2°C, preferably 1.5°C. Every fraction of a degree matters.

At COP 26 last year, this dire situation was recognized, and countries were called upon to "revisit and strengthen" their 2030 targets by the end of 2022. Consequently, a key question for this edition of the Emissions Gap Report is, what progress has been made in ambition and action since COP 26, and how can the necessary transformations be initiated and accelerated?

The report considers transformations required in the sectors of electricity supply, industry, transport and buildings. It furthermore investigates cross-cutting systemic transformations of food systems and the financial system, illustrating that there is immense potential to reduce emissions beyond current mitigation pledges.

The climate crisis is part of the triple planetary crisis of climate change, pollution and biodiversity loss. This year, the world is witnessing compounding energy, food and cost of living crises, exacerbated by the war in Ukraine, all of which are causing immense human suffering.

Several methodological improvements and updates have been made this year to improve the estimates and ensure consistency across the chapters of this report. These changes, along with their implications for the interpretation of the report results, are described in detail in the report chapters and online appendices. However, it is important to note that these improvements imply that the estimates presented are not directly comparable to those of previous reports.

2. Global GHG emissions could set a new record in 2021

Estimates of land use, land-use change and forestry (LULUCF) are currently only available up to 2020, limiting our analysis of total global GHG emissions for 2021. However, global GHG emissions for 2021, **excluding** LULUCF, are preliminarily estimated at 52.8 $GtCO_2e$, a slight increase compared to 2019, suggesting that **total** global GHG emissions in 2021 will be similar to or even break the record 2019 levels (figure ES.1).

This confirms earlier findings that the global response to the COVID-19 pandemic led to an unprecedented but short-lived reduction in global emissions. Total global GHG emissions dropped 4.7 per cent from 2019 to 2020. This decline was driven by a sharp decline in CO_2 emissions from fossil fuels and industry of 5.6 per cent in 2020. However, CO_2 emissions rebounded to 2019 levels in 2021, with global coal emissions exceeding 2019 levels. Methane and nitrous oxide emissions remained steady from 2019 to 2021, and fluorinated gases continued to surge.

Global GHG emissions have continued to grow in the past 10 years, but the rate of growth has slowed compared to the previous decade. Between 2010 and 2019, average annual growth was 1.1 per cent per year, compared to 2.6 per cent per year between 2000 and 2009. Thirty-five countries accounting for about 10 per cent of global emissions have peaked in CO_2 and other GHG emissions, but their reductions have been outweighed by global emissions growth elsewhere.

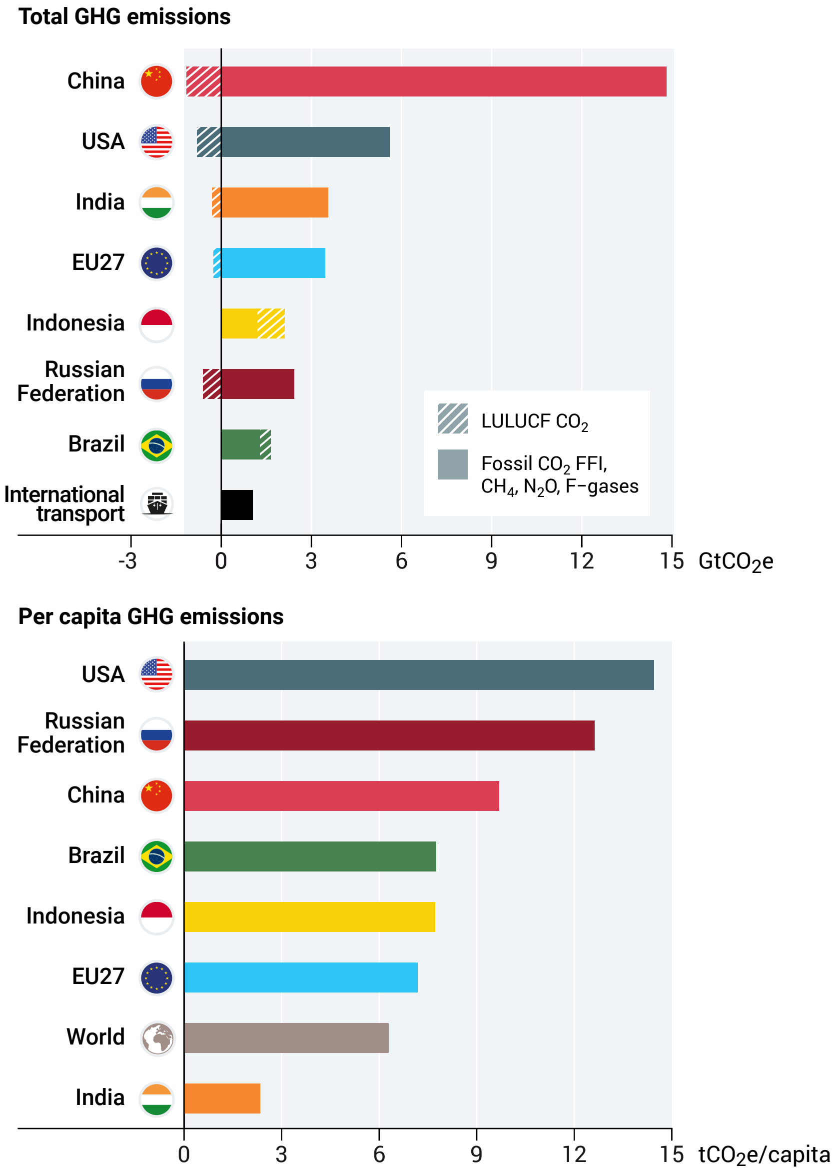
Estimates of LULUCF emissions and sinks are substantial, but also deeply uncertain. Based on national inventories, the LULUCF sector was a net sink in 17 of the G20 member States in 2020, including in China, the United States of America, India, the EU27 and the Russian Federation. GHG emissions excluding LULUCF in these countries are therefore higher, by as much as 33 per cent in the Russian Federation, 17 per cent in the United States of America, 9 per cent in India, and about 8 per cent in China and in the EU27. By contrast, the LULUCF sector is a net emitter in Indonesia and Brazil, accounting for 44 per cent and 22 per cent of their emissions respectively.

3. GHG emissions are highly uneven across regions, countries and households

The top seven emitters (China, the EU27, India, Indonesia, Brazil, the Russian Federation and the United States of America) plus international transport accounted for 55 per cent of global GHG emissions in 2020 (figure ES.1). Collectively, G20 members are responsible for 75 per cent of global GHG emissions.

Per capita emissions vary greatly across countries (figure ES.1). World average per capita GHG emissions (including LULUCF) were 6.3 tons of CO_2 equivalent (tCO_2e) in 2020. The United States of America remains far above this level at 14 tCO_2e, followed by 13 tCO_2e in the Russian Federation, 9.7 tCO_2e in China, about 7.5 tCO_2e in Brazil and Indonesia, and 7.2 tCO_2e in the European Union. India remains far below the world average at 2.4 tCO_2e. On average, least developed countries emit 2.3 tCO_2e per capita annually.

Figure ES.1 Total and per capita GHG emissions of major emitters in 2020, including inventory-based LULUCF



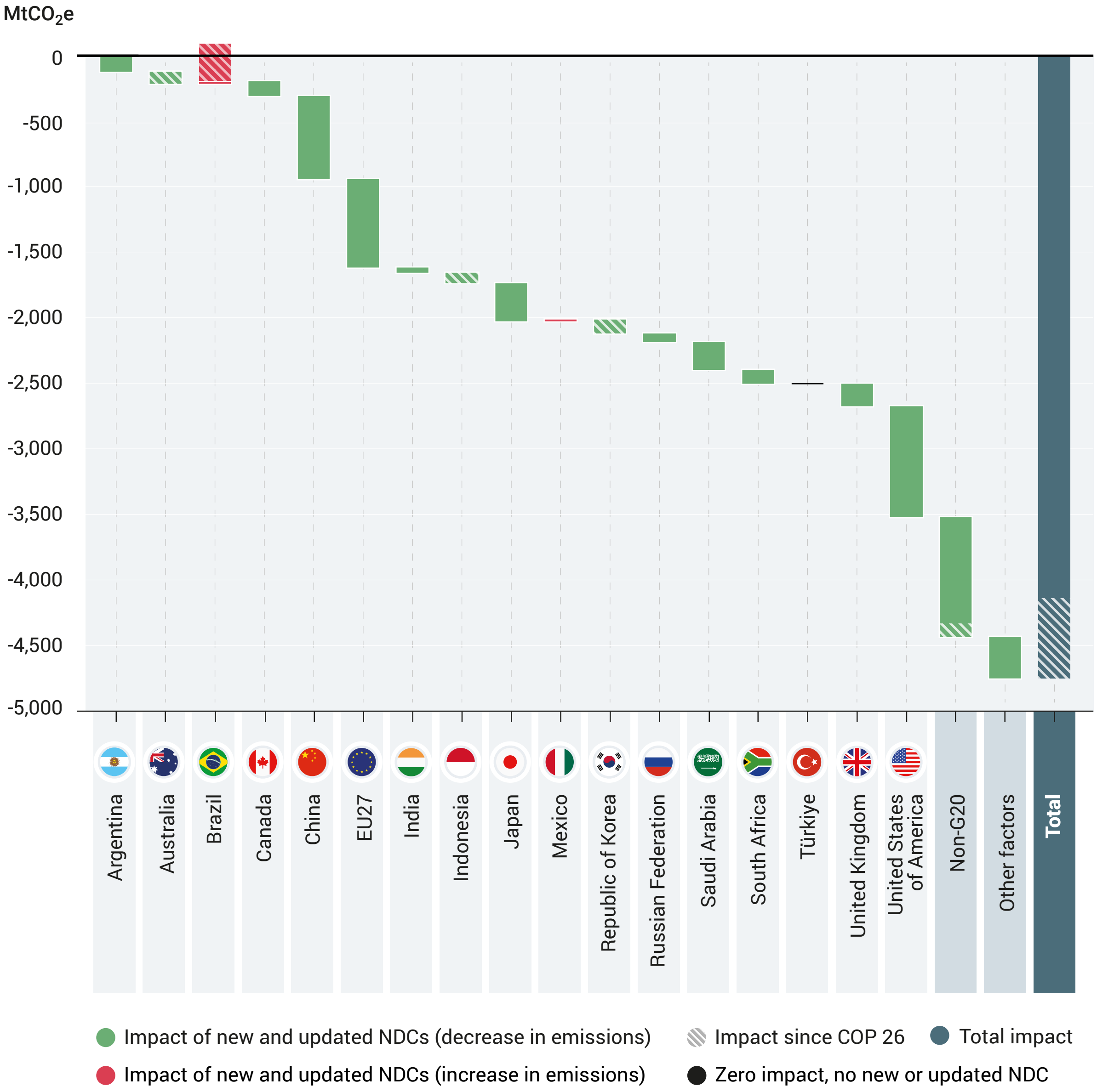
Consumption-based emissions are also highly unequal between and within countries. When emissions associated with both household consumption and public and private investments are allocated to households, and households are ranked by GHG emissions (excluding LULUCF), the bottom 50 per cent emit on average 1.6 tCO_2e/capita and contribute 12 per cent of the global total, whereas the top 1 per cent emit on average 110 tCO_2e/capita and contribute 17 per cent of the total. High-emitting households are present across all major economies, and large inequalities now exist both within and between countries.

4. Despite the call for countries to “revisit and strengthen” their 2030 targets, progress since COP 26 is highly inadequate

As part of the Paris Agreement’s five-year ambition-raising cycle, countries were requested to submit new or updated NDCs in time for COP 26. The Glasgow Climate Pact, adopted in 2021 at COP 26, further requested countries to revisit and strengthen their 2030 mitigation targets to align with the temperature goal of the Paris Agreement. Between 1 January 2020 and 23 September 2022 (the cut-off date used for this report), 166 parties representing around 91 per cent of global GHG emissions had submitted new or updated NDCs, up from 152 parties as of COP 26. As the European Union and its 27 member States submit a single NDC, 139 new or updated NDCs have been submitted. Relative to initial NDCs, a larger share includes GHG emission targets, coverage of sectors and gases is generally greater, and more include unconditional elements.

In total and if fully implemented, the new or updated unconditional NDCs are estimated to result in an annual additional reduction of 4.8 $GtCO_2e$ by 2030 relative to the initial NDCs. Progress since COP 26 amounts to about 0.5 $GtCO_2e$, mainly resulting from new or updated NDCs from Australia, Brazil, Indonesia and the Republic of Korea (figure ES.2).

Figure ES.2 Impact on global GHG emissions in 2030 of new and updated unconditional NDCs relative to initial NDCs



5. G20 members are far behind in delivering on their mitigation commitments for 2030, causing an implementation gap

Most of the G20 members that have submitted stronger NDC targets since 2020 have just started the implementation of policies and actions to meet their new targets. Those that are currently projected to meet their NDC targets are countries that have either not updated their original NDCs, or did not strengthen or only moderately strengthened their target levels in their updated NDCs. All other G20 members will need additional policies to achieve their NDCs.

The central estimate of aggregate emissions projections for G20 members in 2030 under current policies decreased by 1.3 $GtCO_2e$ compared with the 2021 assessment, mainly due to the projected emission reductions from the Inflation Reduction Act in the United States of America (about 1 $GtCO_2e$).

Collectively, the G20 members are not on track to achieve their new or updated NDCs. Based on current policies scenario projections in independent studies, there is an implementation gap, defined as the difference between projected emissions under current policies and projected emissions under full implementation of the NDCs. This implementation gap is 1.8 $GtCO_2e$ annually by 2030 for the G20 members. For two G20 members, the Russian Federation and Türkiye, the projected emissions under their NDCs have consistently been significantly above current policies projections, thereby lowering the implementation gap compared to what can reasonably be expected. If NDC projections are substituted by current policies scenario projections for these two members, the G20 members would collectively fall short of achieving their NDCs by 2.6 $GtCO_2e$ annually by 2030.

Beyond G20 members, the global implementation gap for 2030 is estimated to be around 3 $GtCO_2e$ for the unconditional NDCs and 6 $GtCO_2e$ for the conditional NDCs.

6. Globally, the NDCs are highly insufficient, and the emissions gap remains high

The emissions gap for 2030 is defined as the difference between the estimated total global GHG emissions resulting from the full implementation of the NDCs, and the total global GHG emissions from least-cost scenarios that keep global warming to 2°C, 1.8°C or 1.5°C, with varying levels of likelihood.

Current commitments by countries as expressed in their unconditional and conditional NDCs for 2030 are estimated to reduce global emissions by 5 and 10 per cent respectively, compared with current policies and assuming that they are fully implemented. To get on track for limiting global warming to below 2.0°C and 1.5°C, global GHG emissions must be reduced by 30 and 45 per cent respectively, compared with current policy projections.

Full implementation of unconditional NDCs is estimated to result in a gap with the 1.5°C scenario of 23 $GtCO_2e$ (range: 19–25 $GtCO_2e$) (table ES.1, table ES.2 and figure ES.3). This estimate is about 5 $GtCO_2e$ smaller than in the 2021 edition of the Emissions Gap Report. However, this difference is almost entirely due to methodological updates and updates to the 1.5°C scenarios. The emissions in 2030 are higher under the updated 1.5°C scenarios, because they start their reductions from the most up-to-date historical emissions, which have increased over the past 5 years. This does not come without consequences, as on average these scenarios have a lower chance of effectively keeping warming to 1.5°C. If the conditional NDCs are also fully implemented, the 1.5°C emissions gap is reduced to 20 $GtCO_2e$ (range: 16–22 $GtCO_2e$).

The emissions gap between unconditional NDCs and below 2°C pathways is about 15 $GtCO_2e$ (range: 11–17 $GtCO_2e$), which is about 2 $GtCO_2e$ larger than that which was reported last year. The main reason for this increase is that this year's report corrects for discrepancies in historical emissions through harmonization. If the conditional NDCs are also fully implemented, the below 2°C emissions gap is reduced to 12 $GtCO_2e$ (range: 8–14 $GtCO_2e$).

Emissions under current policies are projected to reach 58 $GtCO_2e$ in 2030. This is 3 $GtCO_2e$ higher than the estimate of last year's report. About half of the increase is due to the harmonization, about one quarter to the change of global warming potentials (GWPs), and the remainder to the methodological choice of only selecting model studies that explicitly account for the most recent current polices and NDC estimates.

Figure ES.3 Global GHG emissions under different scenarios and the emissions gap in 2030 (median estimate and tenth to ninetieth percentile range)

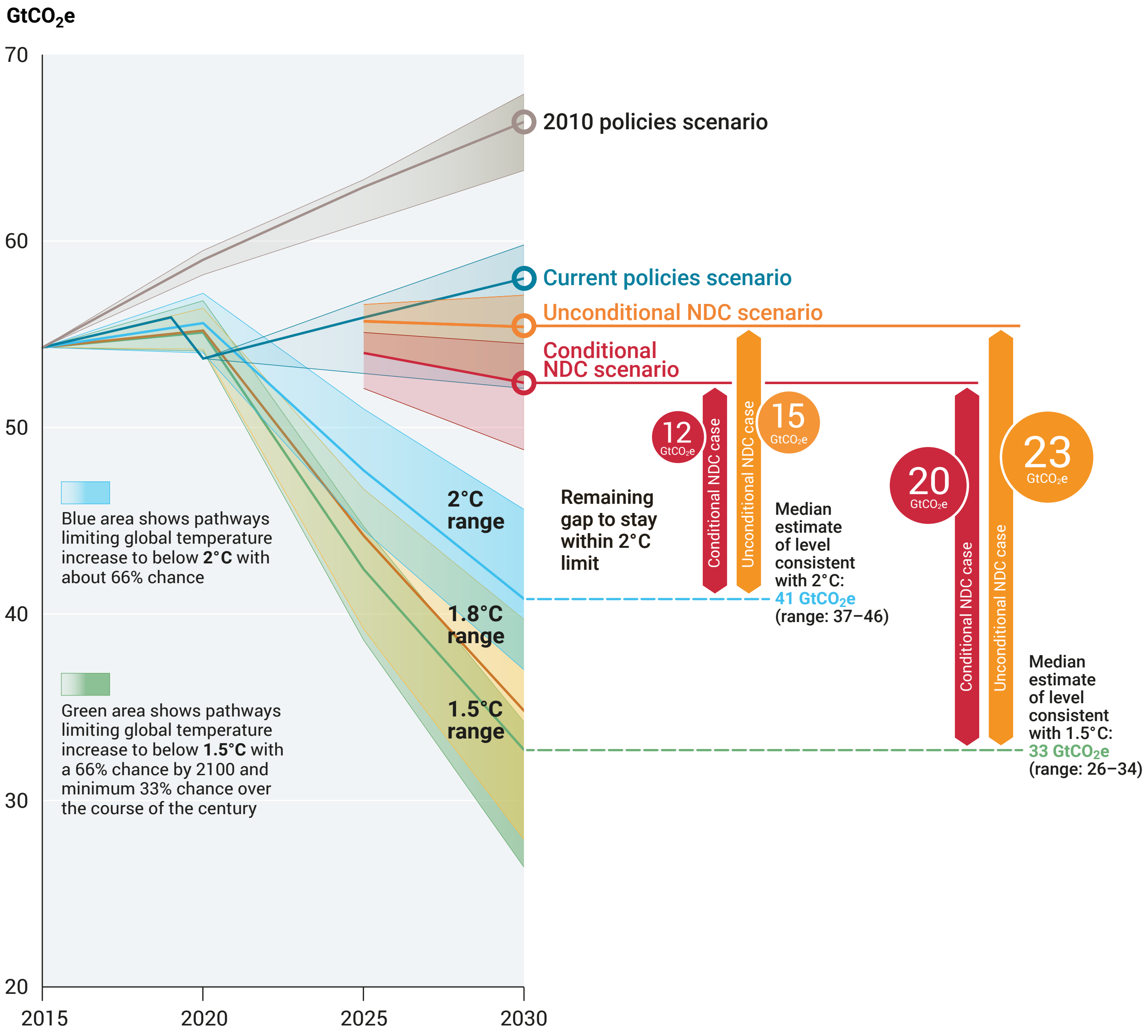


Table ES.1 Global total GHG emissions in 2030 and the estimated emissions gap under different scenarios

	GHG emissions in 2030 (GtCO₂e) Median and range	Estimated emissions gap in 2030 (GtCO₂e)		
		Below 2.0°C	Below 1.8°C	Below 1.5°C
Year 2010 policies	66 (64–68)	-	-	-
Current policies	58 (52–60)	17 (11–19)	23 (17–25)	25 (19–27)
Unconditional NDCs	55 (52–57)	15 (12–16)	21 (17–22)	23 (20–24)
Conditional NDCs	52 (49–54)	12 (8–14)	18 (14–20)	20 (16–22)

Note: The gap numbers and ranges are calculated based on the original numbers (without rounding), and these may differ from the rounded numbers in the table. Numbers are rounded to full GtCO₂e. GHG emissions have been aggregated with global warming potential over 100 years (GWP100) values of the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6).

Table ES.2 Global total GHG emissions in 2030 and global warming characteristics of different scenarios consistent with limiting global warming to specific temperature limits

Scenario	Number of scenarios	Global total GHG emissions ($GtCO_2e$)		Estimated temperature outcome			Closest approximate
		In 2030	In 2050	50% chance	66% chance	90% chance	IPCC AR6 Working Group (WG) III scenario class
Below 2.0°C (66% chance)*	195	41 (37–46)	20 (16–24)	Peak: 1.7–1.8°C In 2100: 1.4–1.7°C	Peak: 1.8–1.9°C In 2100: 1.6–1.9°C	Peak: 2.2–2.4°C In 2100: 2.0-2.4°C	C3a
Below 1.8°C (66% chance)*	139	35 (28–40)	12 (8–16)	Peak: 1.5–1.7°C In 2100: 1.3–1.6°C	Peak: 1.6–1.8°C In 2100: 1.4–1.7°C	Peak: 1.9–2.2°C In 2100: 1.8–2.2°C	N/A
Below 1.5°C (66% in 2100 with no or limited overshoot)*	50	33 (26–34)	8 (5–13)	Peak: 1.5–1.6°C In 2100: 1.1–1.3°C	Peak: 1.6–1.7°C In 2100: 1.2–1.5°C	Peak: 1.9–2.1°C In 2100: 1.6–1.9°C	C1a

* Values represent the median and tenth to ninetieth percentile range across scenarios. Percentage chance refers to peak warming at any time during the twenty-first century for the below 1.8°C and below 2.0°C scenarios. When achieving net-negative CO_2 emissions in the second half of the century, global warming can be further reduced from these peak warming characteristics, as illustrated by the "Estimated temperature outcome" columns. For the below 1.5°C scenario, the chance applies to the global warming in the year 2100, while the "no or limited overshoot" characteristic is captured by ensuring projections do not exceed 1.5°C with more than 67 per cent chance over the course of the twenty-first century or, in other words, that the lowest chance of warming being limited to 1.5°C throughout the entire twenty-first century is never less than 33 per cent. This definition is identical to the C1 category definition used by the IPCC AR6 WG III report. Compared to IPCC (2022), the Emissions Gap Report analysis also selects scenarios based on whether or not they assume immediate action.

Note: GHG emissions in this table have been aggregated with GWP100 values of IPCC AR6.

7. Without additional action, current policies lead to global warming of 2.8°C over this century. Implementation of unconditional and conditional NDC scenarios reduce this to 2.6°C and 2.4°C respectively

A continuation of the level of climate change mitigation effort implied by current unconditional NDCs is estimated to limit warming over the twenty-first century to about 2.6°C (range: 1.9–3.1°C) with a 66 per cent chance, and warming is expected to increase further after 2100 as CO_2 emissions are not yet projected to reach net-zero levels.

Continuing the efforts of conditional NDCs lowers these projections by around 0.2°C to 2.4°C (range: 1.8–3.0°C) with a 66 per cent chance. As current policies are insufficient to meet even the unconditional of NDCs, a continuation of current policies would result in about 0.2°C higher estimates of 2.8°C (range: 1.9–3.3°C) with a 66 per cent chance.

Global warming levels only get close to the Paris Agreement temperature goal if full implementation of the highly uncertain net-zero pledges is assumed. Achieving net-zero targets in addition to unconditional NDCs results in keeping projected global warming to 1.8°C (range: 1.8–2.1°C) with a 66 per cent chance. Assuming that conditional NDCs and pledges are achieved and followed by net-zero targets, global warming is similarly projected to be kept to 1.8°C (range: 1.7–1.9°C) with a 66 per cent chance. However, in most cases, neither current policies nor NDCs currently trace a credible path from 2030 towards the achievement of national net-zero targets.

8. The credibility and feasibility of the net-zero emission pledges remains very uncertain

Globally, 88 parties covering approximately 79 per cent of global GHG emissions have now adopted net-zero targets, either in law (21), in a policy document such as an NDC or a long-term strategy (47), or in an announcement by a high-level government official (20). This is up from 74 parties at COP 26. An additional eight parties covering an additional 2 per cent of global GHG emissions have another (non-net-zero) GHG mitigation target as part of their long-term strategies.

Focusing on the G20 members, 19 members have committed to achieving net-zero emissions, up from 17 at COP 26. These targets vary in a number of important respects, including their legal status; time frame; explicit consideration of fairness and equity; which sources, sectors and gases they cover; whether they will allow the use of international offsets to count towards their achievement; the level of detail they provide on the role of CO_2 removal; and the nature of planning, review of and reporting on target implementation.

Figure ES.4 visualizes the necessary direction for countries to move from their current emission levels to their NDC targets for 2030, and indicates the net-zero targets for each G20 member that has a net-zero target (noting that France, Germany and Italy are only assessed as part of the European Union). Those G20 members whose emissions have already peaked will need to further accelerate their emission declines to their net-zero target year, while members whose emissions will continue to increase through 2030 under the NDCs will require further policy shifts and investments – including adequate support to developing countries, where applicable – to achieve the emissions reductions implied by their national net-zero targets.

This illustration does not consider the relative merits in terms of equity or fairness of the choices countries make regarding their NDCs or their nationally determined pathways to net-zero. However, it brings to the fore the discrepancies between short-term policy implementation, midterm targets and long-term targets. It also serves as an important reminder that current evidence does not provide confidence that the nationally determined net-zero targets will be achieved.

9. Wide-ranging, large-scale, rapid and systemic transformation is now essential to achieve the temperature goal of the Paris Agreement

The task facing the world is immense: not just to set more ambitious targets, but also to deliver on all commitments made. This will require not just incremental sector-by-sector change, but wide-ranging, large-scale, rapid and systemic transformation. This will not be easy, given the many other pressures on policymakers at all levels. Climate action is imperative in all countries but must be achieved simultaneously with other United Nations Sustainable Development Goals.

The transformation towards zero GHG emissions in the sectors of electricity supply, industry, transportation and buildings is under way. However, increased and accelerated action is needed if these are to happen at the pace and scale required to limit global warming to well below 2°C, preferably 1.5°C.

Of these four sectors, electricity supply is the most advanced, as the costs of renewable electricity have reduced dramatically. Still, major obstacles continue to exist, including ensuring that transformations are just and deliver energy access for people who are currently not served. Furthermore, the impacts on communities and nations, and existing fossil energy companies and supply chains, must be handled, and grid integration of large shares of renewable energy must be prepared. For building operations and road transport, the most efficient technologies currently available need to be applied, while for industry, and shipping and aviation, zero-emissions technologies need to be further developed and deployed.

The following broad portfolio of key actions to initiate and advance the transformation must be undertaken, tailored to the specific context of each of the four sectors:

- avoiding lock-in of new fossil fuel intensive infrastructure
- enabling the transition by further advancing zero-carbon technologies, market structures and plans for a just transformation
- applying zero-emissions technologies and promoting behavioural change to sustain and deepen reductions to reach zero emissions

All actors have roles to play in initiating and accelerating the transformation, including in the removal of barriers that stand in the way of progress (table ES.3). While any individual actions may not amount to significant enough change, taken together they can spur more far-reaching, durable, systemic change.

Figure ES.4 Emissions trajectories implied by NDC and net-zero targets of G20 members. National emissions in $MtCO_2e$/year over time.

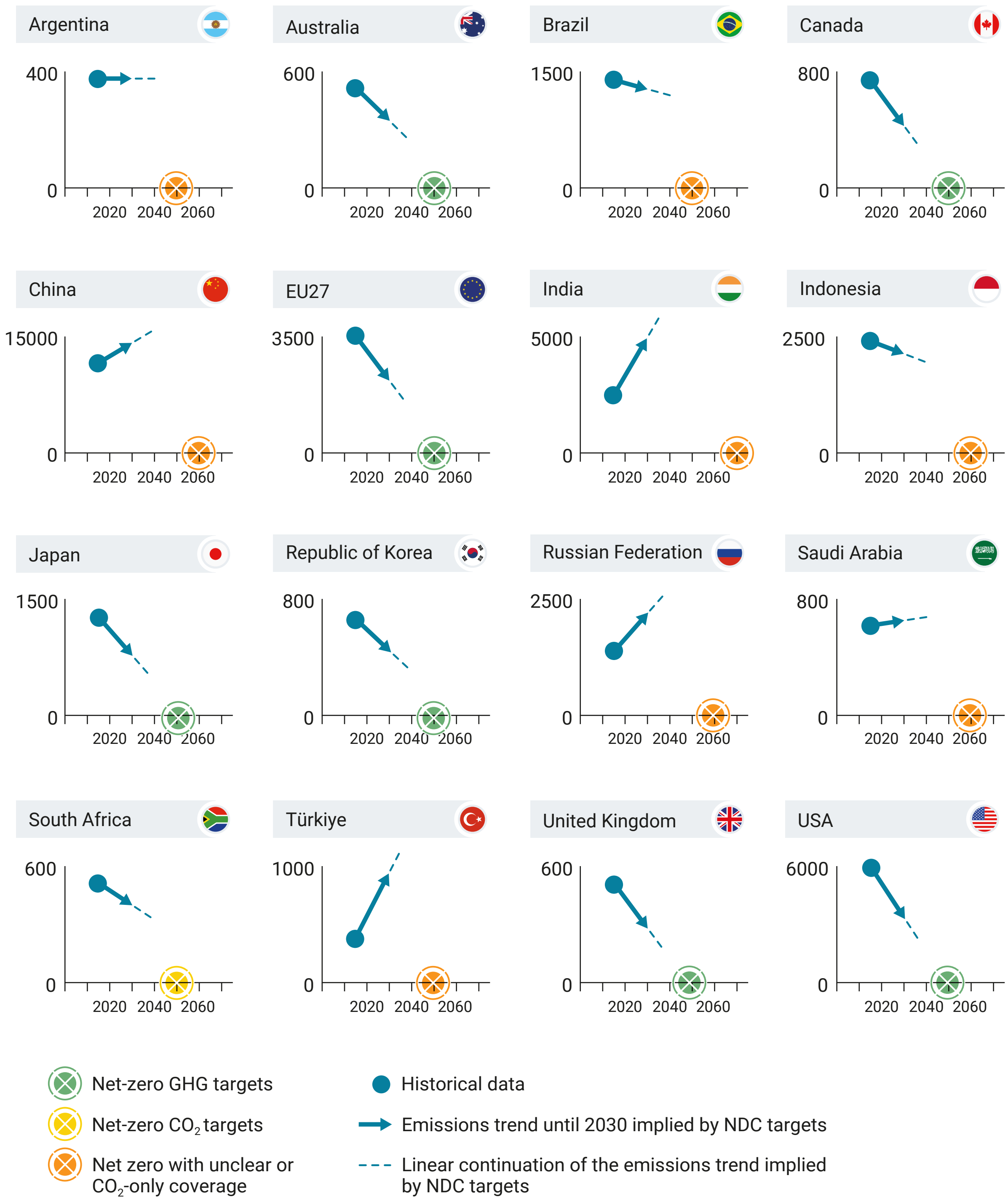


Table ES.3 Important actions to accelerate transformations in electricity supply, industry, transportation and buildings by different actors

	ELECTRICITY SUPPLY	INDUSTRY	TRANSPORTATION	BUILDINGS
National governments	› Remove fossil fuel subsidies in a socially acceptable manner › Remove barriers to expansion of renewables › Stop expansion of fossil fuel infrastructure › Plan for a just fossil fuel phase-out › Adapt market rules of electricity system for high shares of renewables	› Support zero-carbon industrial processes › Promote circular material flow › Promote electrification › Support alternative carbon pricing mechanisms › Support research and innovation › Promote low-carbon products › Plan for a just transformation	› Set mandates to switch to zero-emissions road vehicles by specific dates › Regulate and incentivize zero-carbon fuels for aviation › Adjust taxation/pricing schemes › Invest in zero-emissions transport infrastructure	› Regulate towards zero-carbon building stock › Incentivize zero-carbon building stock › Facilitate zero-carbon building stock
International cooperation	› Cooperate on a just coal phase-out › Support initiatives on emissions-free electricity, power system flexibility and interconnection solutions	› Cooperate on zero-carbon basic materials › Cooperate on hydrogen › Share best practice	› Cooperate on financing and policy development › Coordinate on target setting and standards	› Provide access and favourable conditions to finance › Support skills and knowledge growth
Subnational governments	› Set 100 per cent renewable targets › Plan for a just fossil fuel phase-out	› Engage in regional planning and regulations › Cooperate with various stakeholders	› Plan infrastructure and supporting policies that reduce travel demand › Adjust taxation/pricing schemes	› Implement zero-emissions building stock plans › Integrate low-emissions requirements in urban planning › Add requirements that go beyond the national level
Businesses	› Support a 100 per cent renewable electricity future	› Plan and implement zero-emissions transformation › Design long-lived products › Create circular supply chain	› Work towards zero-emissions transportation › Reduce travel in operations	› Construction and building material companies review business models › Achieve zero-carbon owned or rented building stock
Investors, private and development banks	› Engage with or divest from fossil fuel electricity utility companies › Do not invest in or insure new fossil fuel infrastructure	› Engage with or divest from emissions-intensive industry › Invest in low-carbon energy and process technologies › Drive awareness of climate risks	› Invest in zero-emissions transport infrastructure › Support zero-emissions vehicles, vessels and planes	› Adjust strategy and investment criteria for zero-carbon building stock › Support building renovation
Citizens	› Purchase 100 per cent renewable electricity	› Consume sustainably › Lobby	› Adopt active mobility practices › Use public transportation › Use zero-emissions vehicles › Avoid long-haul flights	› Retrofit for improved carbon footprint › Tenants challenge landlords › Adopt energy-saving behaviour

10. The food system accounts for one third of all emissions, and must make a large reduction

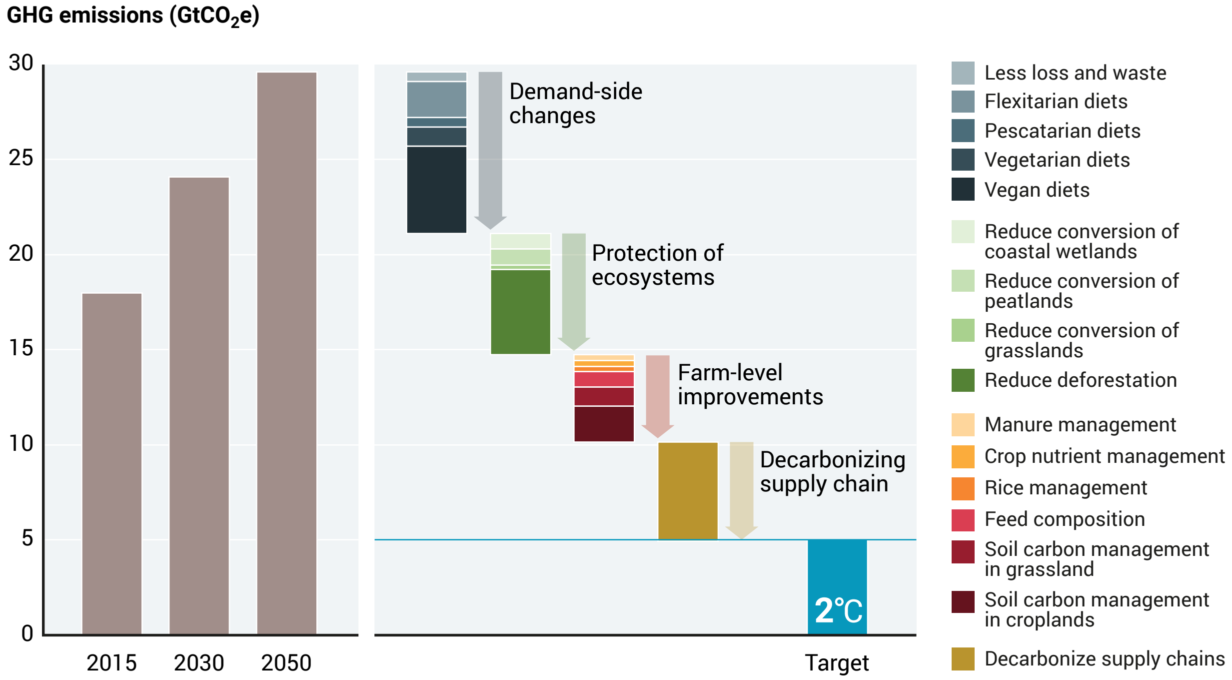
Food systems are major contributors not only to climate change, but also to land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems. Adopting a food systems lens implies a cross-sectoral approach that explicitly connects supply and demand sides, and all actors of the food supply chain. It facilitates identifying synergies and trade-offs across interconnected environmental, health and economic dimensions, but the inclusion of several sectors makes computation of emissions more difficult, and increases risks of double counting.

The food system is currently responsible for about a third of total GHG emissions, or 18 GtCO$_2$e/year (range: 14–22 GtCO$_2$e). The largest contribution stems from agricultural production (7.1 GtCO$_2$e, 39 per cent) including the production of inputs such as fertilizers, followed by changes in land use (5.7 GtCO$_2$e, 32 per cent), and supply chain activities (5.2 GtCO$_2$e, 29 per cent). The latter includes retail, transport, consumption, fuel production, waste management, industrial processes and packaging.

Projections indicate that food system emissions could reach ca 30 GtCO$_2$e/year by 2050. To get on an emissions pathway aligned with the Paris Agreement temperature goal, food systems will have to be rapidly transformed across multiple domains. Required transformations include shifting diets, protecting natural ecosystems, improving food production and decarbonizing the food value chain. Each transformation domain includes several mitigation measures. The potential to reduce GHG emissions is up to 24.7 GtCO$_2$e/year in 2050 (figure ES.5).

Transforming food systems is not only important for addressing climate change and environmental degradation, but also essential for ensuring healthy diets and food security for all. Actions by all major groups of actors is required to drive transformations forward and to overcome barriers.

Figure ES.5 Food systems emissions trajectory and mitigation potentials by transformation domain



11. Realignment of the financial system is a critical enabler of the transformations needed

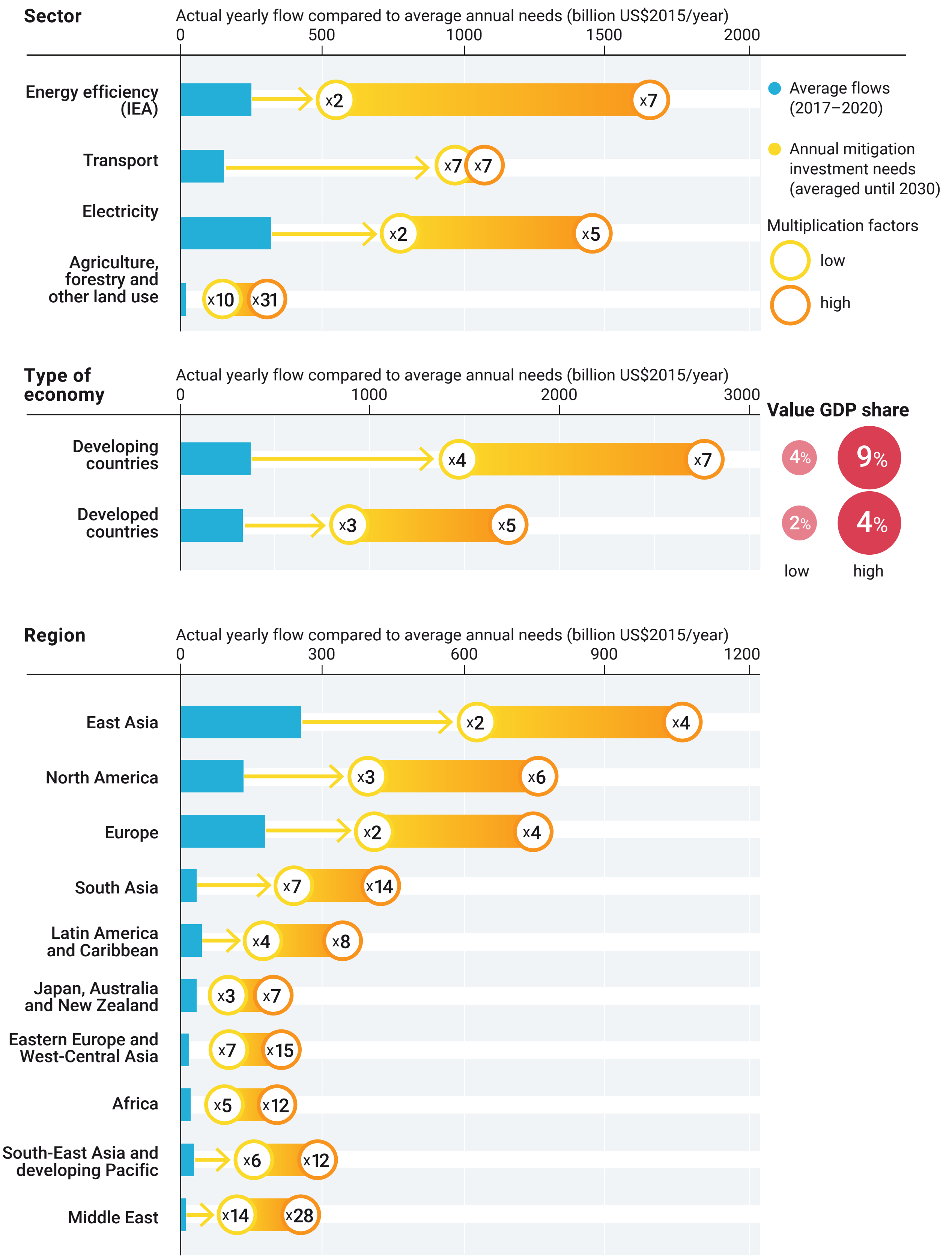
A realignment of the financial system is vitally important to enable the transformations needed are to be achieved. The financial system is a network of private and public institutions such as banks, institutional investors and public institutions that regulate the safety and soundness of the system, but also co-lend or finance directly. A global transformation from a heavily fossil fuel- and unsustainable land use-dependent economy to a low-carbon economy is expected to require investments of at least US$4–6 trillion a year, a relatively small (1.5–2 per cent) share of total financial assets managed, but significant (20–28 per cent) in terms of the additional annual resources to be allocated. The IPCC assesses that global mitigation investments need to increase by a factor of three to six, and even more for developing countries (figure ES.6). Financial systems change is required to enable such a global transformation.

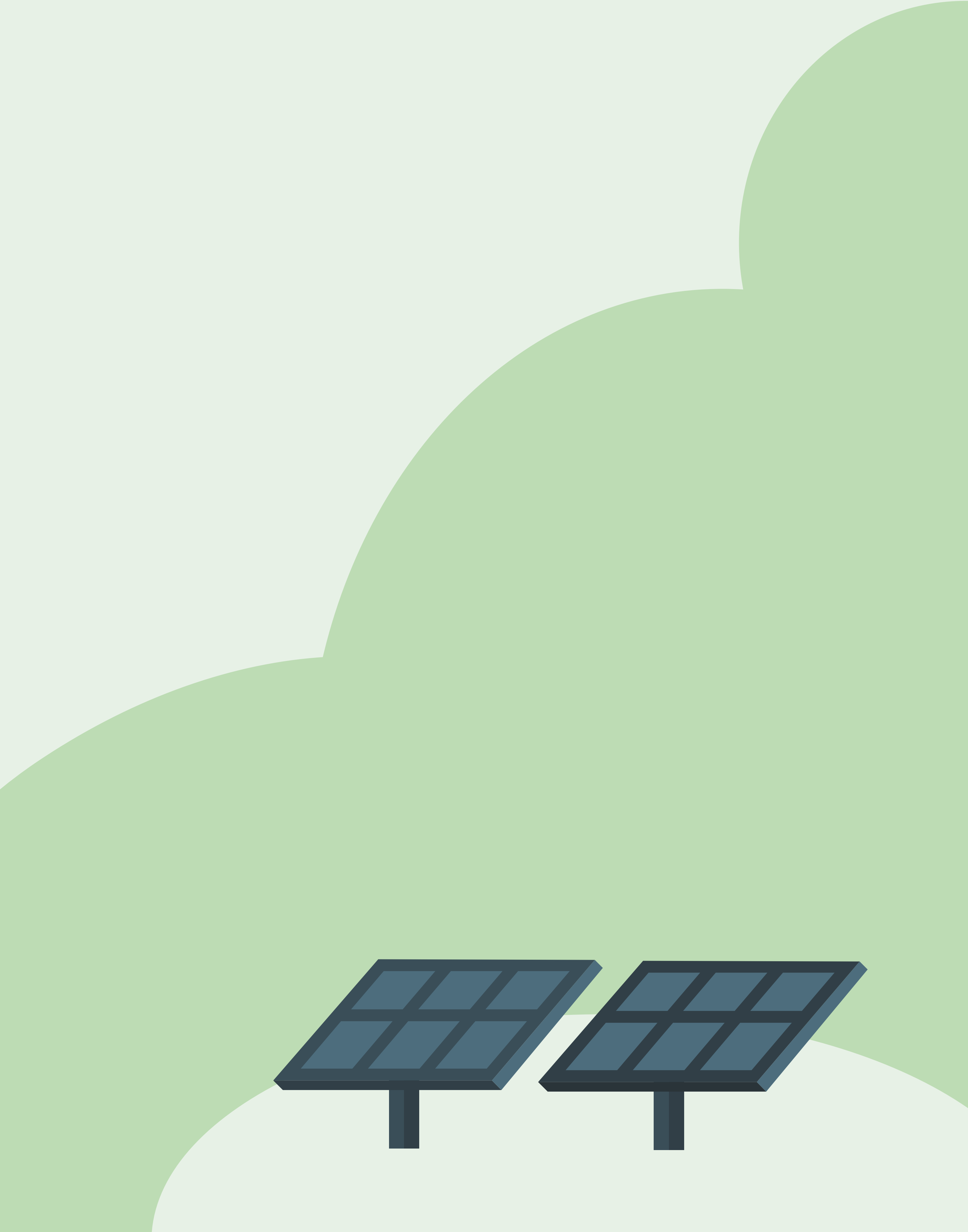
To date, most financial actors have shown limited action on climate change mitigation because of short-term interests and conflicting objectives, and because climate risks are not adequately recognized. Six approaches to bringing about a financial system that is capable of the shifting of finance flows needed for systemic transformation are identified:

- Increase the efficiency of financial markets. Key interventions include the provision of better information, including taxonomies and transparency, on climate risks. In developing country contexts, priorities will include capacity-building and strengthening institutions.
- Introduce carbon pricing. This can be done through policy instruments such as carbon taxes or cap-and-trade systems. Emissions-trading schemes and carbon taxes now cover 30 per cent of all global emissions, with a global average price of US$6 per ton of CO_2. Both the coverage and the price are insufficient for transforming the financial system: the International Monetary Fund has suggested a global average price of US$75 as required by 2030.
- Nudge financial behaviour. Climate finance markets are subject to deep information asymmetry, risk aversion and herd behaviour, all of which result in inefficient choices. Policy "nudges" can achieve better results, with strong public policy interventions, taxation, spending and regulations positively influencing behaviour.
- Create markets. Public policy action can remove existing market distortions and accelerate new product markets for low-carbon technology, pushing innovation through public finance, and replacing older, inefficient and fossil fuel-based technology. Development banks, including green banks, can play a more active role to stimulate financial markets as newer product markets are being accelerated. Multilateral development banks can support market creation through shifting financial flows, stimulating innovation and helping to set standards (e.g. for fossil fuel exclusion policies, GHG accounting and climate risk disclosure).
- Mobilize central banks. Central Banks are increasingly addressing the climate crisis. In December 2017, eight central banks and supervisors established the Network for Greening the Financial System, which has now grown to 116 members and 18 observers. Mandates of central banks in developing countries are often broader than those of central banks in developed countries; more concrete action towards this approach can therefore be observed. For example, the Reserve Bank of India requires that commercial banks allocate a certain proportion of lending to a list of "priority sectors", including renewable energy, and Bangladesh Bank has introduced a minimum credit quota of 5 per cent that financial institutions must allocate to green sectors.
- Set up climate clubs and cross-border finance initiatives. These can include just transition partnerships, and can alter policy norms and change the course of finance through credible financial commitment devices on cross-border financial flows, such as sovereign guarantees.

Evidence on the effectiveness of the six approaches above suggests that there is no single "silver bullet". Instead, nested and coordinated approaches are needed, tailored to contexts, and implemented across major groups of countries, with equity and "just transition" within and between countries. The success of such coordinated and cooperative action, depend, ultimately, on public support and pressures to avert the significant risks of inaction, and the willingness of key financial system actors to take on their roles.

Figure ES.6 Finance flows and mitigation investment needs per sector, type of economy and region (averaged until 2030)





1 Introduction

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1.1 Context and framing of the Emissions Gap Report 2022

Since 2010, the United Nations Environment Programme (UNEP) has provided annual science-based assessments of the gap between commitments made by governments to reduce greenhouse gas (GHG) emissions and those needed to achieve global temperature targets under the United Nations Framework Convention on Climate Change (UNFCCC).

This thirteenth edition of the Emissions Gap Report is a testimony to inaction on the global climate crisis. In just eight years, global GHG emissions must be reduced by 30 to 45 per cent compared to where they are headed under policies currently in place to get on track to limiting global warming to well below 2.0°C and 1.5°C respectively. Commitments by countries as expressed in their latest unconditional and conditional nationally determined contributions (NDCs) for 2030 will only reduce global emissions by 5 to 10 per cent, assuming that they are fully implemented.

Earlier this year, the Intergovernmental Panel on Climate Change (IPCC) published two reports as part of its Sixth Assessment cycle, on *Impacts, Adaptation and Vulnerability* (IPCC 2022a) and *Mitigation of Climate Change* (IPCC 2022b). The reports record the vast impacts of climate change that we are already experiencing, and how the climate risks of the future are of a much greater order of magnitude. Once again, these reports document that the scale and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, finding that projected adverse impacts and related losses and damages escalate with every increment of global warming. This year, as has repeatedly been the case in recent years, many countries have experienced an unprecedented number of climate events, with extreme weather leading to flooding, drought and wildfires, and causing food shortages, health problems, and major damage to ecosystems and human habitats, leading to internal displacement and migration around the world.

In line with the Emissions Gap Report, the IPCC reports send a reverberating message that the window of opportunity to limit global warming to well below 2°C, preferably 1.5°C, thereby avoiding some unmanageable climate risks, is closing rapidly. Every fraction of a degree matters.

Consistent with previous Emissions Gap Reports, the IPCC *Mitigation of Climate Change* report finds that "projected global emissions from NDCs announced prior to COP26 would make it likely that warming will exceed 1.5°C and also make it harder after 2030 to limit warming to below 2°C" (IPCC 2022b). Specifically, the report finds that GHG emissions levels by 2030 associated with the implementation of NDCs, imply that mitigation after 2030 can no longer establish a pathway that limits global warming to 1.5°C during the twenty-first century without significant overshoot, and that returning to below 1.5°C in 2100 is infeasible for some scenarios (IPCC 2022b).

Unprecedented scaling up of mitigation ambitions and implementation is a prerequisite to bridging the emissions gap, and is expected to be one of the focus areas of the twenty-seventh United Nations Climate Change Conference of the Parties (COP 27). Following up on the decisions made at COP 26, it was decided to establish a work programme for urgently scaling up mitigation ambition and implementation, the details of which are expected to be agreed upon at COP 27 (UNFCCC 2022a; UNFCCC 2022b). Recognizing the significant emissions gap, countries were furthermore encouraged to revisit and strengthen their 2030 mitigation pledges in 2022, and it was decided to establish annual high-level ministerial roundtables on pre-2030 ambition also starting in 2022. Consequently, a key question for COP 27 and for this year's Emissions Gap Report is, what progress has been made since COP 26, and how can the transformation necessary to bridge the emissions gap be initiated and accelerated?

The report looks at transformations required in electricity supply, industry, transport, buildings, food systems and the financial system. It is important to acknowledge that for transformations to be successful they need to be just and socially balanced. There is no universal model, and transformations will likely be very different between developed and developing countries.

In parallel with the climate crisis and other planetary crises, the world faces compounding energy, food and cost of living crises. These crises are exacerbated by the war in Ukraine, which is causing immense human suffering and undermines the recovery of the global economy following the COVID-19 pandemic. The crises are a wake-up call to the global community for more, rather than less, climate action. As previous editions of the Emissions Gap Report have documented, the unprecedentedly large fiscal rescue and recovery packages in response to the COVID-19 crisis were to a large extent missed as an opening to accelerate the green transition. While the current crises are fundamentally different, governments around the world face largely similar choices: (1) to use them as an opening to accelerate the transition away from fossil fuels and the expansion of renewable energy, while boosting energy conservation and energy efficiency, or (2) to allow them to divert attention from climate change action and continue investment in fossil fuels, causing lock-in and jeopardizing the Paris Agreement temperature goal. The global implications of these crises for climate action and GHG emissions are still unclear, and they are likely to differ in the short term and the long term, but they could be significant, depending on how governments respond to them.

1.2 Approach and structure of the report

The Emissions Gap Report is an assessment report. It provides an evaluation of credible scientific and technical knowledge on emissions trends, progress, gaps and opportunities, based on a synthesis of the latest scientific literature, models, and data analysis and interpretation, and models, including that published in the context of the Intergovernmental Panel on Climate Change (IPCC). As in previous years, this Emissions Gap Report has been prepared by an international team. This year, UNEP convened 77 leading scientists from 41 expert institutions across 23 countries. The assessment process has been overseen by a respected international steering committee and has been transparent and participatory, while also taking into account geographical diversity and gender concerns. All chapters have undergone external review, and the assessment methodology and preliminary findings were made available to the governments of the countries specifically mentioned in the report, to provide them with the opportunity to comment on the findings.

This year, several methodological updates were made to improve the estimates and ensure consistency across the chapters of the report. Two working groups were established to address recurrent issues in the Emissions Gap Reports, related to (1) land use, land-use change and forestry data sources, notably reconciliation of differences between global model estimates and national reporting of forest CO_2 sinks (also see chapter 2), and (2) harmonization of global emissions data based on historical emissions and global models (see chapters 3 and 4). Furthermore, the report scenarios have been updated based on IPCC's *Sixth Assessment Report*, and the most recent values of global warming potential over 100 years are used. It is important to note that these improvements also imply that the estimates presented are not directly comparable to those of previous reports. Full details can be found in chapters 2 to 4 and related appendices.

The report is organized into seven chapters, including this introduction. Chapter 2 assesses the trends in global GHG emissions, including the effects of COVID-19, and considers consumption-based emissions and their distribution between and within countries. Chapter 3 provides an updated global landscape of NDCs and long-term net-zero emissions pledges, and assesses the progress of G20 members towards achieving their NDCs and net-zero emissions pledges. Chapter 4 updates the assessment of the emissions gap by 2030 based on the latest NDCs, and considers the implications of the emissions gap on the feasibility of achieving the long-term temperature goal of the Paris Agreement. Chapter 5 provides the status of the transformation towards zero GHG emissions in the sectors of electricity supply, industry, transportation and buildings, and identifies actor-based actions that could accelerate the transformation. Chapter 6 provides an assessment of the food systems transformations needed, whether there are signs that they are happening, and how they could be accelerated. Finally, chapter 7 considers the transformations of the finance system needed to enable the achievement of the Paris Agreement.

2 Global emissions trends

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2.1 Introduction

This chapter assesses trends in greenhouse gas (GHG) emissions up to and including 2021. It analyses global emissions by gas, country, household and sector, providing the current and historical context for subsequent chapters on country pledges and mitigation pathways.

There are both short- and long-term influences on GHG emissions. In the short term, abrupt geopolitical and economic events such as the COVID-19 pandemic and the war in Ukraine can lead to significant but temporary changes in annual emissions. In the long term, structural shifts in technologies, production and investment decisions, as well as economic and climate policies, play an important role. One aim of this chapter is to provide both short- and long-term perspectives on trends in global GHG emissions.

Another focal area of the chapter is land use, land-use change and forestry emissions (LULUCF). The LULUCF sector is complex in terms of definitions, concepts and quantification, due to the scientific challenge of separating human from natural influences on GHG fluxes, and the fact that it is both a source and sink of CO_2. This year, the Emissions Gap Report has adopted a new approach for LULUCF emissions, as described in box 2.1.

Box 2.1 Methodological update to ensure consistency between global and national LULUCF emission estimates

Recent literature has highlighted significant differences in anthropogenic LULUCF estimates between the approach undertaken by countries in their reporting to the United Nations Framework Convention on Climate Change (UNFCCC) ('national inventory approach') and the global modelling approach ('bookkeeping approach') pioneered in the scientific community and used in the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (Grassi *et al.* 2021; Grassi, Schwingshackl *et al.* 2022). Both approaches are applicable in their specific contexts, but are not directly comparable as they use different system boundaries. The main conceptual difference is that bookkeeping models consider as anthropogenic only the fluxes that are due to direct human-induced effects, such as land-use change, shifting cultivation, harvest and regrowth. By contrast, national inventories generally consider as anthropogenic all the fluxes occurring on a larger area of managed forest than that used by models, and include most indirect human-induced effects on this area that models consider natural (i.e. the natural response to human-induced environmental changes such as increased CO_2 atmospheric concentration and nitrogen deposition, which enhance tree growth). Other reasons for the difference can arise from the limited representation of land management in global models and varying levels of accuracy and completeness of estimated LULUCF fluxes in national inventories. These differences hamper comparability between national inventories and bookkeeping models for the historical period, and between nationally determined contributions (NDCs) (based on the national inventory approach) and integrated assessment models (based on the bookkeeping approach) for projections.

To reflect and address this, the methodological approach to LULUCF emissions data is updated: when depicting country emissions trends, national inventory data is used. In this chapter this applies to historical emissions (based on Grassi, Conchedda *et al.* 2022 and gap-filled when necessary), and in chapter 3 it applies to country NDC emissions. When reporting global total GHG emissions, data from global models, i.e. the bookkeeping approach, is used. This chapter uses bookkeeping models that only cover LULUCF emissions (based on Friedlingstein *et al.* 2022), while chapter 4 uses integrated assessment models. This approach ensures that country estimates are consistent with those reported by countries themselves to the UNFCCC, and that global estimates are consistent with the carbon cycle, scenarios and climate science literature used in the IPCC Assessment Reports.

In addition, a harmonization procedure has been implemented in chapter 4 to ensure comparability between globally aggregated NDC estimates and integrated assessment model emission pathways consistent with different warming levels. The harmonization procedure adjusts global NDC scenarios to the outputs from integrated assessment models for the historical period.

For further details, please see appendix A, which is available online.

All GHG emission figures in this report are expressed using global warming potential over 100 years (GWP100) from the IPCC *Sixth Assessment Report* (Forster *et al.* 2021). In line with previous reports, non-LULUCF emissions in this chapter are based on a single consistent global source, the Emissions Database for Global Atmospheric Research (EDGAR), which is available up to 2021 (Crippa *et al.* 2022).[1] LULUCF emissions, based on both Grassi, Conchedda *et al.* (2022) and Friedlingstein *et al.* (2022), are currently only available up to 2020, limiting our analysis of total global GHG emissions to 2020. Nonetheless, an initial estimate of total global GHG emissions in 2021 excluding LULUCF is provided.

It should be noted that the emissions estimates presented differ from the Emissions Gap Report 2021 (United Nations Environment Programme [UNEP] 2021) due to the revision of the LULUCF data and the switch to GWP100 values from the *Sixth Assessment Report*. If total GHG estimates excluding LULUCF are recalculated based on the GWP100 from the IPCC Fourth Assessment Report, they show strong agreement with previous reports. Further information on the data used, estimations of growth rates and uncertainties is provided in appendix A, available online.

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[1] EDGAR includes all anthropogenic GHG emissions sources defined in the IPCC guidance and reflected in UNFCCC national inventories. Some additional sources with relevant warming impacts, such as chlorofluorocarbons, hydrochlorofluorocarbons and hydrogen gas are excluded (Minx *et al.* 2021; Dhakal *et al.* 2022).

2.2 Global emissions trends

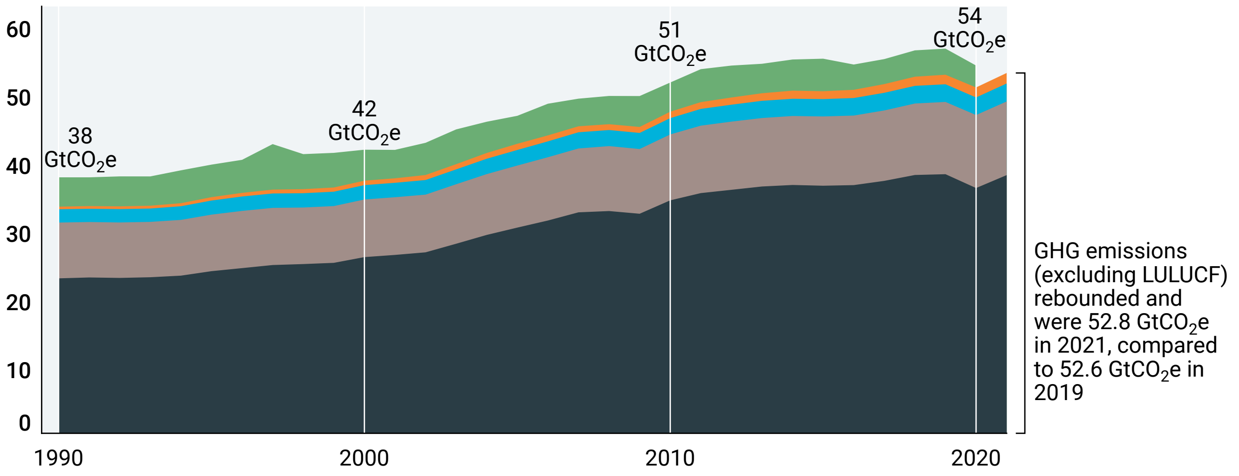
2.2.1 The rate of growth in GHG emissions has slowed in the past decade, but global GHG emissions could set a new record in 2021

While the rate of growth in GHG emissions (including LULUCF) in the past decade has slowed compared to the previous decade, average GHG emissions in the last decade were the highest on record (figure 2.1). Between 2010 and 2019, average annual growth was 1.1 per cent per year, compared to 2.6 per cent per year between 2000 and 2009. Reasons for this decadal slowdown include a global reduction in new coal capacity additions (particularly in China), the steady substitution of coal by gas in the power sectors of developed countries, the increasing pace of renewable energy deployments worldwide (Lamb, Wiedmann *et al.* 2021; Dhakal *et al.* 2022; Friedlingstein *et al.* 2022; Jackson *et al.* 2022;) and a reduction in LULUCF net emissions, although these are very uncertain (Friedlingstein *et al.* 2022). This raises the question of whether global GHG emissions are reaching a plateau, or whether slower levels of growth will continue in the coming years (see also section 2.2.3).

Total global GHG emissions averaged 54.4 gigatons of CO_2 equivalent ($GtCO_2e$) between 2010 and 2019, and reached a high in 2019 (figure 2.1, table 2.1). Estimates of LULUCF emissions for 2021 are not yet available, preventing conclusions regarding total global GHG emissions in 2021. However, the initial estimate of total global GHG emissions excluding LULUCF for 2021 exceeds comparable levels in 2019 by 0.26 $GtCO_2e$, or 0.2 per cent (table 2.1), suggesting that total global GHG emissions in 2021 will be similar to, or even surpassing, 2019 levels.

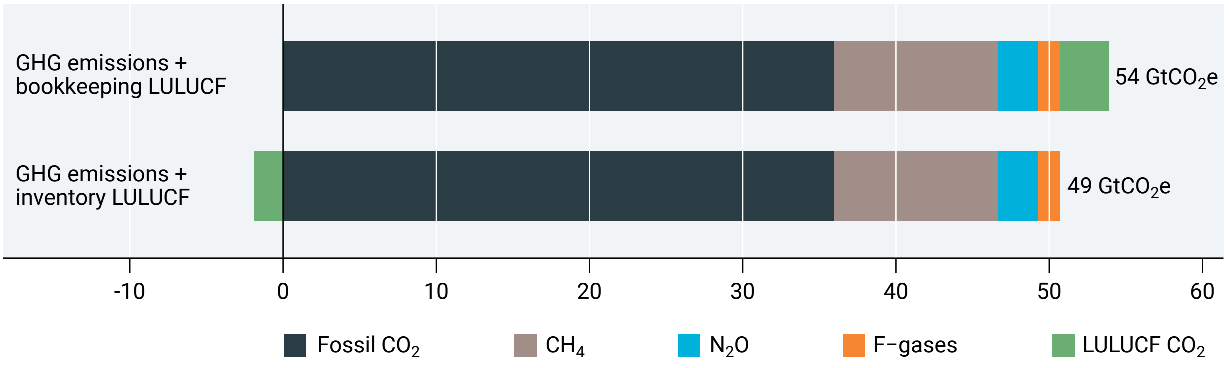
Figure 2.1 Total GHG emissions 1990–2021 and comparison of LULUCF estimates

Total GHG emissions 1990–2021 ($GtCO_2e$/year)



GHG emissions (excluding LULUCF) rebounded and were 52.8 $GtCO_2e$ in 2021, compared to 52.6 $GtCO_2e$ in 2019

Comparison of LULUCF estimates in 2020 ($GtCO_2e$)



Sources: Crippa *et al.* (2022); Friedlingstein *et al.* (2022); Grassi, Conchedda *et al.* (2022)

Note: Total emissions include CO_2 from fossil fuel and industry (fossil CO_2), CO_2 emissions from LULUCF, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases). LULUCF CO_2 emissions are depicted in the top panel up to 2020 as a net global source using the bookkeeping approach from the Global Carbon Budget (no data is available for 2021). A comparison of the bookkeeping to the national GHG inventory approach is provided in the lower panel for the year 2020.

This confirms that the global response to the COVID-19 pandemic had an unprecedented but short-lived effect on emissions (figure 2.1, table 2.1). Total global GHG emissions dropped 4.7 per cent from 2019 to 2020 – the largest single-year absolute drop in GHG emissions since 1970 when the data set starts (Dhakal *et al.* 2022). Nonetheless, daily emissions data suggests that CO_2 emissions from fossil fuel and industry (hereafter referred to as fossil CO_2 for brevity) had already rebounded by the end of 2020 (Le Quéré *et al.* 2020; Liu *et al.* 2020; Davis *et al.* 2022; Jackson *et al.* 2022).

Global atmospheric CO_2 concentrations continued to grow from 2019 to 2020, reaching an annual mean of 413 parts per million. This was slightly slower than during 2018 to 2019, but faster than the decadal average rate, despite COVID-19 restrictions (World Meteorological Organization 2022).

The long-term impacts of COVID-19 on global GHG emissions are not yet possible to discern (Kikstra *et al.* 2021; Shan *et al.* 2021). On the one hand, the global response to COVID-19 has disrupted supply chains and may have led to underlying shifts in energy supply and demand; on the other hand, economic stimulus packages appear to have favoured fossil fuels, missing an opportunity to support renewable energy and low-carbon investments (Hepburn *et al.* 2020; UNEP 2020; Bertram *et al.* 2021; Le Quéré *et al.* 2021; UNEP 2021). Emissions trends in 2022 and beyond will be further influenced by the war in Ukraine and subsequent disruptions to global energy supplies, which are driving a renewed policy focus on energy security. Early assessments project an increase in fossil fuel investments in 2022, as many countries have announced plans to expand natural gas infrastructures to shore up domestic supplies (Climate Action Tracker 2022; International Energy Agency 2022).

Table 2.1 Total emissions by source, 2019–2021

Year	$GtCO_2$	CH_4, N_2O, F-gases ($GtCO_2e$)	LULUCF ($GtCO_2$)	Total GHG emissions excluding LULUCF ($GtCO_2e$)	Total GHG emissions ($GtCO_2e$)
2021	37.9 (± 3)	15 (± 3.6)	N/A	52.8	N/A
2020	36 (±2.9)	14.8 (± 3.6)	3.2 (± 2.2)	50.8	54
2019	38 (±3)	14.6 (± 3.6)	3.8 (± 2.2)	52.6	56.4

2.2.2 COVID-19 responses mainly impacted CO_2 emissions from fossil fuels and industry, while methane and nitrous oxide remained steady, and F-gases continued to surge

Fossil CO_2 emissions declined by 5.6 per cent from 2019 to 2020, but rebounded to levels comparable to 2019 levels in 2021 (table 2.1). Methane, nitrous oxide and F-gas emissions continued to grow during and after the initial COVID-19 pandemic response. These non-CO_2 emissions sources are mainly linked to agricultural activities (methane and nitrous oxide), fossil fuel supply chains (methane), and cooling and industrial processes (F-gases). That they followed the longer-term trend of steady growth (for F-gas emissions, rapid growth) indicates that these sectors were less exposed to the energy demand reduction dynamics of the initial COVID-19 pandemic response.

At a source level, emissions from oil saw the steepest drop in 2020, followed by coal and gas (Friedlingstein *et al.* 2022). Oil is mainly used in land transport and aviation and shipping, which were most severely affected by the pandemic (Le Quéré *et al.* 2020; Liu *et al.* 2020). Emissions from oil have yet to rebound, and remained below 2019 levels in 2021 (Jackson *et al.* 2022). On the other hand, coal and gas rebounded strongly in 2021. In 2021, global coal emissions exceeded 2019 levels, mainly due to increased usage in China and India (Davis *et al.* 2022; Jackson *et al.* 2022). In some countries there has been a shift from coal to gas in recent decades; while this can reduce emissions in the short term, it has contributed the development of new gas infrastructures that have long lifetimes and cumulative emissions impacts, including via methane emissions from leakages (Alvarez *et al.* 2018).

2.2.3 LULUCF emissions remain substantial, but are deeply uncertain

Net LULUCF CO_2 emissions assessed using the bookkeeping approach (see box 2.1) experienced a small decline from 2019 to 2020, largely related to particularly large peat and tropical deforestation and degradation fires in 2019 (Friedlingstein *et al.* 2022). While the number of deforestation fires in the Amazon remained high in 2020, land-use related fire emissions in Indonesia decreased as the unusually dry conditions of 2019 ceased.

LULUCF emissions from bookkeeping models are highly uncertain in both magnitude and trend, and vary substantially by global regions (Pongratz *et al.* 2021). Average emissions between 2011 and 2020 were 4.1 ± 2.6 $GtCO_2$. The data indicates a decline in LULUCF emissions over this past decade (of 4 per cent/year). However, the literature reports a very low confidence in this trend, due to underlying data limitations (Dhakal *et al.* 2022, Friedlingstein *et al.* 2022). Whereas removals mainly take place in regions with a pretwentieth-century legacy of deforestation (i.e. Europe and North America), emissions are concentrated in tropical regions with a high present-day burden of deforestation (the Amazon basin, Southeast Asia and sub-Saharan Africa). Net emissions trends are primarily driven by deforestation, in places where the monitoring and quantification of land-use trends is challenging.

Net LULUCF emissions from national inventories remained stable between 2011 and 2020 at a decadal average of around -2 $GtCO_2$/year (appendix A, figure A.1), with temperate and boreal regions reporting net removals and tropical regions reporting close to net-zero emissions (Grassi, Conchedda *et al.* 2022). For 2011–2020, the difference in global net LULUCF CO_2 fluxes between national inventories and bookkeeping models is about 6.1 $GtCO_2$ (5.1 $GtCO_2$ for the year 2020; figure 2.1). This large difference is explained by a variety of factors, the most important being how areas of managed land and anthropogenic forest sinks are defined (Grassi *et al.* 2021; also see appendix A).

2.2.4 Sector emissions trends

Emissions can be divided among five global economic sectors: energy supply; industry; agriculture, forestry and other land-use change (AFOLU);[2] transport; and direct energy use in buildings. Since 1990, most growth in emissions has been from the energy supply, industry and transport sectors (Lamb, Wiedmann *et al.* 2021; Dhakal *et al.* 2022). In 2020, the energy supply sector contributed 20 $GtCO_2e$ (37 per cent of the total), industry was 14 $GtCO_2e$ (26 per cent), AFOLU was 9.5 $GtCO_2e$ (18 per cent), transport was 7.6 $GtCO_2e$ (14 per cent) and buildings was 3.1 $GtCO_2e$ (5.7 per cent). Reallocating the emissions associated with electricity and heat production (e.g. in the energy supply sector) to final consuming sectors increases the contribution of the industry and buildings sectors to 34 per cent and 16 per cent, respectively (Dhakal *et al.* 2022).

There are a number of particularly high-emitting subsectors that drive global emissions growth. These include electricity and heat production (14 $GtCO_2e$ in 2020, 25 per cent of the total), road transportation (5.6 $GtCO_2e$, 10 per cent), and the metals industry (3.2 $GtCO_2e$, 6 per cent). Methane emissions from enteric fermentation (i.e. livestock rearing), landfill sites, and fugitive methane emissions from oil, gas and coal supply chains, are also significant global sources with short-term warming impacts (Dhakal *et al.* 2022). As at 2021, emissions have rebounded relative to 2019 emissions across most sectors and subsectors, except for transportation, oil and gas fugitive emissions, and petroleum refining.

2.3 Emissions trends of major emitters

Eight major emitters – seven G20 members and international transport – contributed more than 55 per cent of total global GHG emissions in 2020: China, the United States of America, the European Union (27), India, Indonesia, Brazil, the Russian Federation, and international transport (figure 2.2). The G20 as a whole contributed 75 per cent of the total. Collectively, the emissions of the top eight fell from 32.8 $GtCO_2e$ in 2019 to 31.5 $GtCO_2e$ in 2020 (a change of -3.8 per cent).

In 2020, the LULUCF sector based on the national inventories (gap-filled when necessary) was a net sink in the emissions inventories of China, the European Union, India, the Russian Federation and the United States of America, and in 17 G20 members overall (figure 2.2). If LULUCF emissions and removals are excluded, total GHG emissions are higher by as much as 33 per cent in the Russian Federation, 17 per cent in the United States of America, 9 per cent in India, and about 8 per cent in China and the European Union. By contrast, the LULUCF sector is a net emitter in Indonesia and Brazil, accounting for 44 per cent and 22 per cent of their total emissions.

For most major emitters, including China, India, the Russian Federation, Brazil and Indonesia, GHG emissions (excluding LULUCF) rebounded in 2021, exceeding pre-pandemic 2019 levels (Crippa *et al.* 2022; Davis *et al.* 2022; Jackson *et al.* 2022). The highest increases between 2019 and 2021 were observed in Indonesia and China, at 6.8 per cent and 5.9 per cent respectively. International transport emissions in 2021 remain far below 2019 levels (-15.9 per cent) (figure 2.2).

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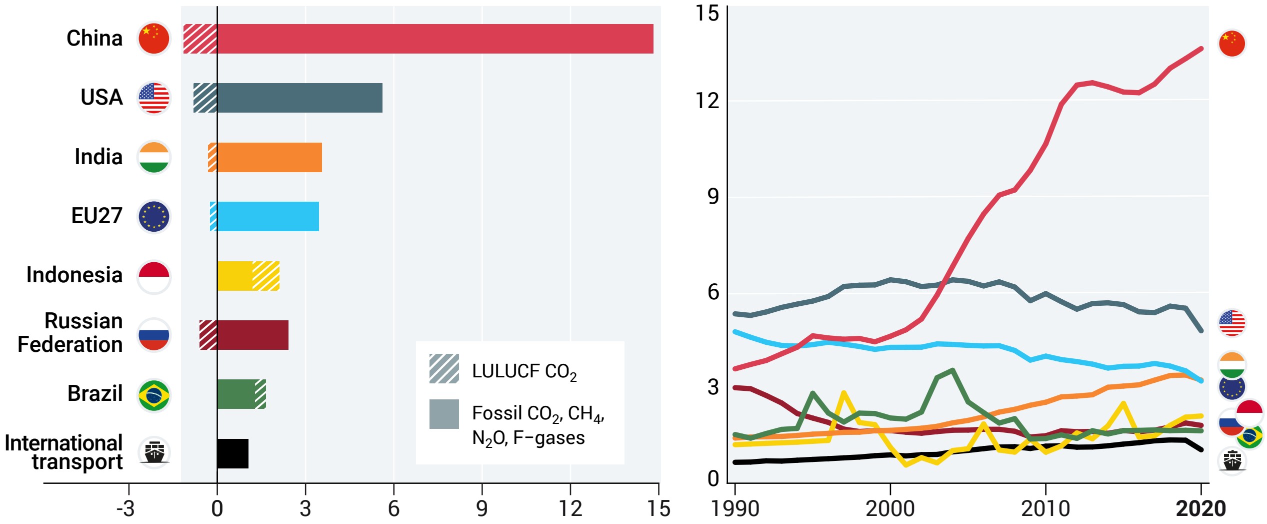
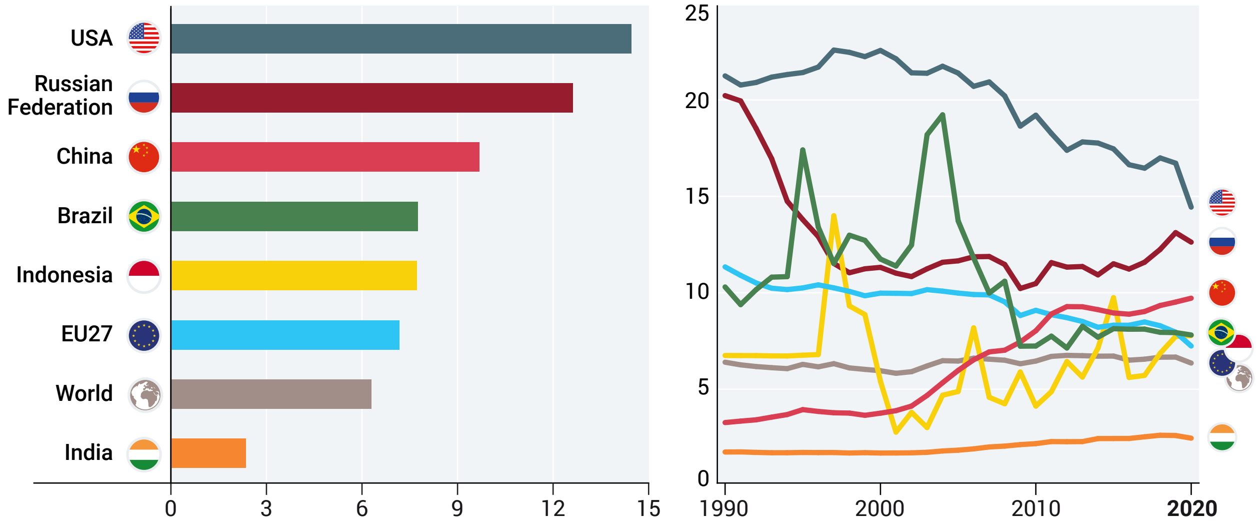
[2] AFOLU includes LULUCF CO_2 emissions, here accounted for using global bookkeeping model data, plus additional agricultural emissions from EDGAR, such as methane from livestock and rice cultivation and nitrous oxide from fertilizer application.

Figure 2.2 Total and per capita GHG emissions (including LULUCF) of major emitters in 2020 and since 1990, and estimated GHG emissions (excluding LULUCF) in 2021 compared to 2019

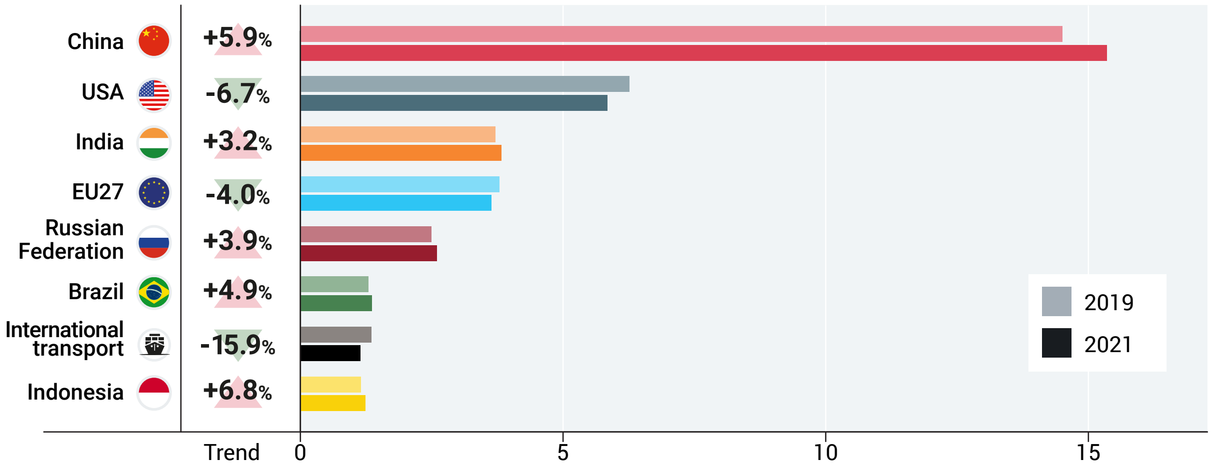
GHG emissions in 2020 and trend since 1990, including inventory-based LULUCF ($GtCO_2e$)



Per capita GHG emissions in 2020 and trend since 1990, including inventory-based LULUCF (tCO_2e/capita)



Estimate of GHG emissions in 2021 compared to 2019, excluding inventory-based LULUCF ($GtCO_2e$)



Sources: Crippa *et al.* (2022); Grassi, Conchedda *et al.* (2022)

Note: Where included, LULUCF emissions are based on the national inventory approach, gap-filled when necessary. Percentage values in the final panel refer to the relative emissions change between 2019 and 2021. In some countries, mainly due to deforestation, the LULUCF sector is a net source of emissions; in other countries it is a net sink of emissions, mainly due to forest regrowth and afforestation.

Per capita GHG emissions of the United States of America and the European Union have continued to decline over the past decade, while those of most other regions grew (figure 2.2). World average per capita GHG emissions (including LULUCF) were 6.3 tCO_2e in 2020. The United States of America remains far above this level at 14 tCO_2e, followed by 13 tCO_2e in the Russian Federation, 9.7 tCO_2e in China, about 7.5 tCO_2e in Brazil and Indonesia, and 7.2 tCO_2e in the European Union. India remains far below the world average at 2.4 tCO_2e. On average, least developed countries emit 2.3 tCO_2e per capita annually.

As with current per capita GHG emissions, contributions to historical cumulative CO_2 emissions (excluding LULUCF) vary greatly between countries and global regions (Gütschow *et al.* 2016; Matthews 2016). Whereas the United States of America and European Union contributed 25 per cent and 17 per cent respectively to total fossil CO_2 emissions from 1850 to 2019, China contributed 13 per cent, the Russian Federation 7 per cent, India 3 per cent, and Indonesia and Brazil 1 per cent each. Least developed countries contributed only 0.5 per cent to historical CO_2 fossil fuel and industry emissions between 1850 and 2019 (Dhakal *et al.* 2022).

2.3.2 Consumption-based emissions are highly unequal between and within countries

When national fossil CO_2 emissions are estimated on a consumption-basis (i.e. where the supply-chain emissions are allocated to consumers) rather than on the territorial-basis considered so far, emissions tend to be higher in high-income countries such as the United States of America and European Union (by 6 per cent and 14 per cent respectively; Friedlingstein *et al.* [2020]). Conversely, they are lower in countries such as India and China (by 9 per cent and 10 per cent respectively), which are net exporters of goods. International transfers of emissions embodied in traded products peaked in 2006 and have since stabilized to be about one quarter of global CO_2 emissions, or about 6.5 $GtCO_2e$ since 2014 according to the latest assessment (Wood *et al.* 2020; Hubacek *et al.* 2021; Dhakal *et al.* 2022).

Consumption-based accounting is also relevant for AFOLU emissions, as the production of highly traded agricultural commodities such as soybeans, palm oil, grains and meat products are known to drive deforestation and create methane and nitrous oxide emissions (Pendrill *et al.* 2022). Similar to fossil CO_2 transfers, high-income countries (United States of America, European Union and Japan) tend to be net importers of agricultural products and hence have higher consumption-based AFOLU emissions. Major net exporters of such commodities and their embodied AFOLU emissions include Brazil, Indonesia, Argentina and Australia. According to Hong *et al.* (2022), in the past decade China has become the largest net importer of embodied AFOLU emissions, superseding Europe and the United States of America. Approximately 22 per cent of agricultural land worldwide is used for traded products, resulting in annual consumption-based AFOLU emissions of 4.5–5.8 $GtCO_2e$ as at 2017, excluding sinks (Hong *et al.* 2022).

Consumption-based emissions also diverge starkly at a household level, in large part due to income and wealth disparities between and within countries (Capstick, Khosla and Wang 2020). When the emissions associated with both household consumption and public and private investments are allocated to households (see appendix A), and households are ranked by GHG emissions (excluding LULUCF), the bottom 50 per cent emit on average 1.6 tCO_2e/capita and contribute 12 per cent of the global total, whereas the top 1 per cent emit on average 110 tCO_2e/capita and contribute 17 per cent of the total (Chancel 2022; Chancel *et al.* 2022). Super-emitters in the top 0.1 per cent (average 467 tCO_2e/capita) and the top 0.01 per cent (2,531 tCO_2e/capita) have seen the fastest growth in personal carbon footprints since 1990. High-emitting households are present across all major economies, and large inequalities now exist both within and between countries (figure 2.3) (Chancel *et al.* 2022).

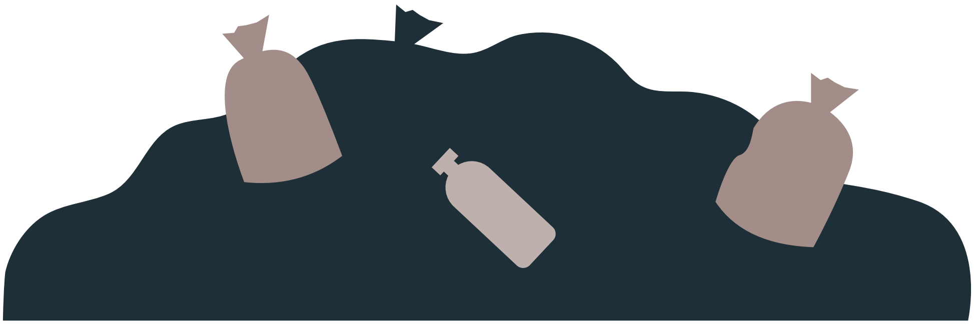
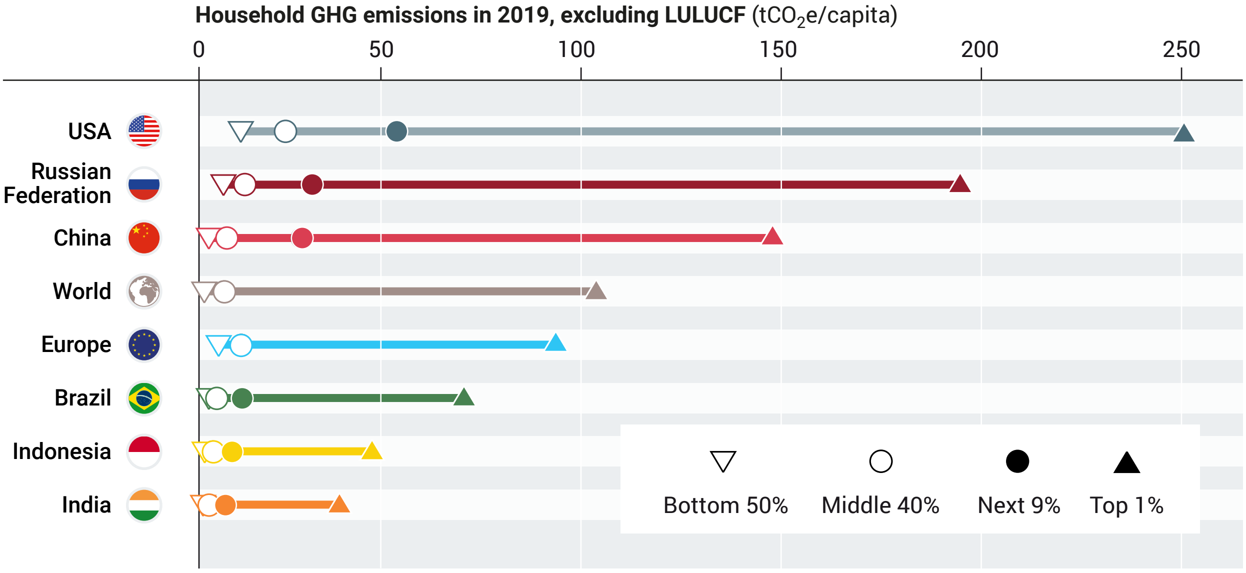


Figure 2.3 Household consumption-based emissions, excluding LULUCF, by emissions groups



Source: Chancel *et al.* (2022)

Note: Per capita emissions include emissions from domestic consumption, public and private investments, and imports and exports of carbon embedded in trade with the rest of the world. Households are ranked according to total emissions and divided accordingly into groups (e.g. the bottom 50 per cent refers to the 50 per cent of households with the lowest emissions in that country or region).

2.3.3 Some countries have peaked emissions, but their reductions have been outweighed by emissions growth elsewhere

By 2019, 35 countries accounting for about 10 per cent of global emissions had peaked and reduced net GHG emissions, including LULUCF, for at least 10 years. These countries, which are mainly in Europe and also include the United States of America, that have started from a high base of per capita and historical cumulative emissions (Lamb, Grubb *et al.* 2021; Le Quéré *et al.* 2019). Most of them have also achieved reductions on a consumption basis.

Countries with sustained emissions reductions have tended to reduce energy system emissions via switching from coal to gas, low or negative growth in energy demand, and/or scaling up renewable energy deployments. So far, they have had limited success in reducing transport or agricultural emissions (Lamb, Grubb *et al.* 2021; Lamb, Wiedmann *et al.* 2021). However, total reductions in the annual emissions of peaking countries to date have been modest – 3.2 $GtCO_2e$ from peak years to 2018, according to one estimate (Lamb, Grubb *et al.* 2021) – and have been outweighed by global emissions growth elsewhere. As at 2019, the majority of countries had increased emissions over the past decade (74 countries, 65 per cent of global emissions), or remained stable (39 countries, 25 per cent of global emissions).

3 Nationally determined contributions and long-term pledges: The global landscape and G20 member progress

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3.1 Introduction

This chapter provides an updated assessment of progress on nationally determined contributions (NDCs) and long-term pledges, focusing on three key questions:

1) What global progress has been made — overall and since the 2021 United Nations Climate Change Conference of the Parties COP 26 — by countries in their submissions of new or updated NDCs and long-term, net-zero emission pledges (section 3.2)?

2) What is the estimated impact on global greenhouse gas (GHG) emissions in 2030 of the latest NDCs, assuming they are fully achieved, and what progress is made by G20 members individually and collectively towards achieving their NDCs (section 3.3)?

3) What is the status of net-zero emission pledges by G20 members and are current policies and NDC targets aligned with the long-term pledges (section 3.4)?

Section 3.2 adopts a global perspective, whereas subsequent sections focus on G20 members. Currently, G20 members account for about 75 per cent of global GHG emissions (see chapter 2), and their success in implementing and potentially exceeding their NDC targets will carry a major impact on 2030 emissions and the possibility for bridging the emissions gap.

The cut-off date for the assessment is 23 September 2022. All GHG emission figures are expressed using the 100-year global warming potentials (GWPs) from the Intergovernmental Panel on Climate Change (IPCC) *Sixth Assessment Report* (AR6). The United Nations Framework Convention on Climate Change (UNFCCC) inventory reports for historical emissions are referred to when comparing them to individual G20 members' NDC targets. The methodology and preliminary findings of this chapter were made available to the governments of the G20 members specifically mentioned to provide them with the opportunity to comment on the findings.

Findings related to the progress of G20 members towards their NDC and net-zero targets should be read with two important caveats in mind. The Emissions Gap Report does not assess the level of ambition of NDCs. However, the level of ambition is one of the factors likely to influence whether countries are on track to achieving their NDC targets. In other words, a country currently on track to achieve its NDCs is not necessarily undertaking more mitigation action than a country not yet on track. Secondly, the Paris Agreement recognizes that each country faces unique national circumstances. Factors such as development stage and associated opportunities and barriers may affect both target ambition and target implementation.

3.2 Global developments in mitigation pledges for 2030 and beyond

3.2.1 NDCs

The ambition-raising cycle of the Paris Agreement builds on the submission by parties of increasingly ambitious NDCs every five years. Due to the COVID-19 pandemic, many parties submitted new or updated NDCs by COP 26 in 2021 instead of in 2020. As assessed by the Emissions Gap Report 2021, the new and updated NDCs showed some progress, but globally they remained highly insufficient to bridge the 2030 emissions gap. Reflecting this, the Glasgow Climate Pact, adopted at COP 26, requested that parties "revisit and strengthen" their 2030 targets by the end of 2022.

This section provides an update on the global landscape and the key characteristics of the new and updated NDCs (those that replaced an initial NDC between 1 January 2020 and 23 September 2022) as well as the initial NDCs (those in effect as of 31 December 2019).[1] Progress since COP 26 is highlighted.

As at 23 September 2022, 166 out of 194 Paris Agreement parties, representing around 91 per cent of 2019 global GHG emissions (Climate Watch 2022), have submitted new or updated NDCs, up from 152 parties as at COP 26. Since the European Union and its 27 member states submit a single NDC, this amounts to 139 new or updated NDCs having been submitted. These NDCs reflect emerging trends related to the ambition, form, coverage and conditionality of GHG mitigation pledges.

Effect on 2030 emissions: Of the 139 new or updated NDCs, just over half (74 NDCs from parties representing 77 per cent of global GHG emissions) would result in lower 2030 emissions relative to the initial NDCs (figure 3.1). This is up from 67 NDCs representing 69 per cent of global GHG emissions as at COP 26. Twenty-three NDCs, from parties representing 9 per cent of global GHG emissions, had communicated a new or updated NDC that would not reduce 2030 emissions relative to the previous NDCs. Forty-two NDCs from parties representing 5 per cent of global emissions could not be compared with the previous NDCs in terms of 2030 emissions, typically due to insufficient information in the previous NDCs, as transparency has improved in the current NDCs.

Pledge form: A total of 146 NDCs, from parties representing 91 per cent of global GHG emissions, now contain GHG targets. This is up from up from 128 initial NDCs (89 per cent of global emissions) and up from 143 NDCs as at COP 26 (90.5 per cent of global GHG emissions). These GHG targets comprise several different types, including base-year targets (commitments to reduce or control the increase in emissions by a specified amount relative to a base year, contained in 43 NDCs) and baseline scenario targets (commitments to reduce emissions by a specified amount relative to a projected emissions baseline scenario, contained in 83 NDCs), among other formulations (20 NDCs). Base-year targets typically result in emissions decreasing over time relative to historical levels, whereas baseline scenario targets are typically formulated to allow absolute emissions to continue to grow. A total of 43 NDCs, from parties representing 36 per cent of global GHG emissions, now contain a base-year target. This is up from 34 initial NDCs from parties representing 34 per cent of global GHG emissions. Of the 21 countries adopting a GHG target for the first time in their new or updated NDCs, 16 also adopted a baseline scenario target.

Sector coverage: GHG targets can be formulated to cover a country's entire economy or only a subset of it. Targets with economy-wide coverage include the energy, industrial process and product use, waste and land sectors. There are 95 current NDCs, from parties representing 55 per cent of global GHG emissions, that cover all sectors. This is up significantly from the 54 initial NDCs, from parties representing 46 per cent of global GHG emissions, that did so.

Gas coverage: Likewise, GHG targets can be formulated to cover all major GHGs — carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorochemicals (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) — or only a subset of them. GHG coverage of NDCs has remained relatively constant from the initial to the current NDCs, 24 of which, from parties representing 30 per cent of global emissions, cover all gases.

Conditionality: Some parties have submitted NDCs that are entirely or partially conditional on factors such as international support (e.g., finance or technology transfer), while others have submitted NDCs that are not conditional. NDCs now include more unconditional elements than previously. One hundred and twenty-six current NDCs, from parties representing 80 per cent of global emissions, now include at least some unconditional elements. This is up from 103 initial NDCs, from parties representing 76 per cent of global emissions.

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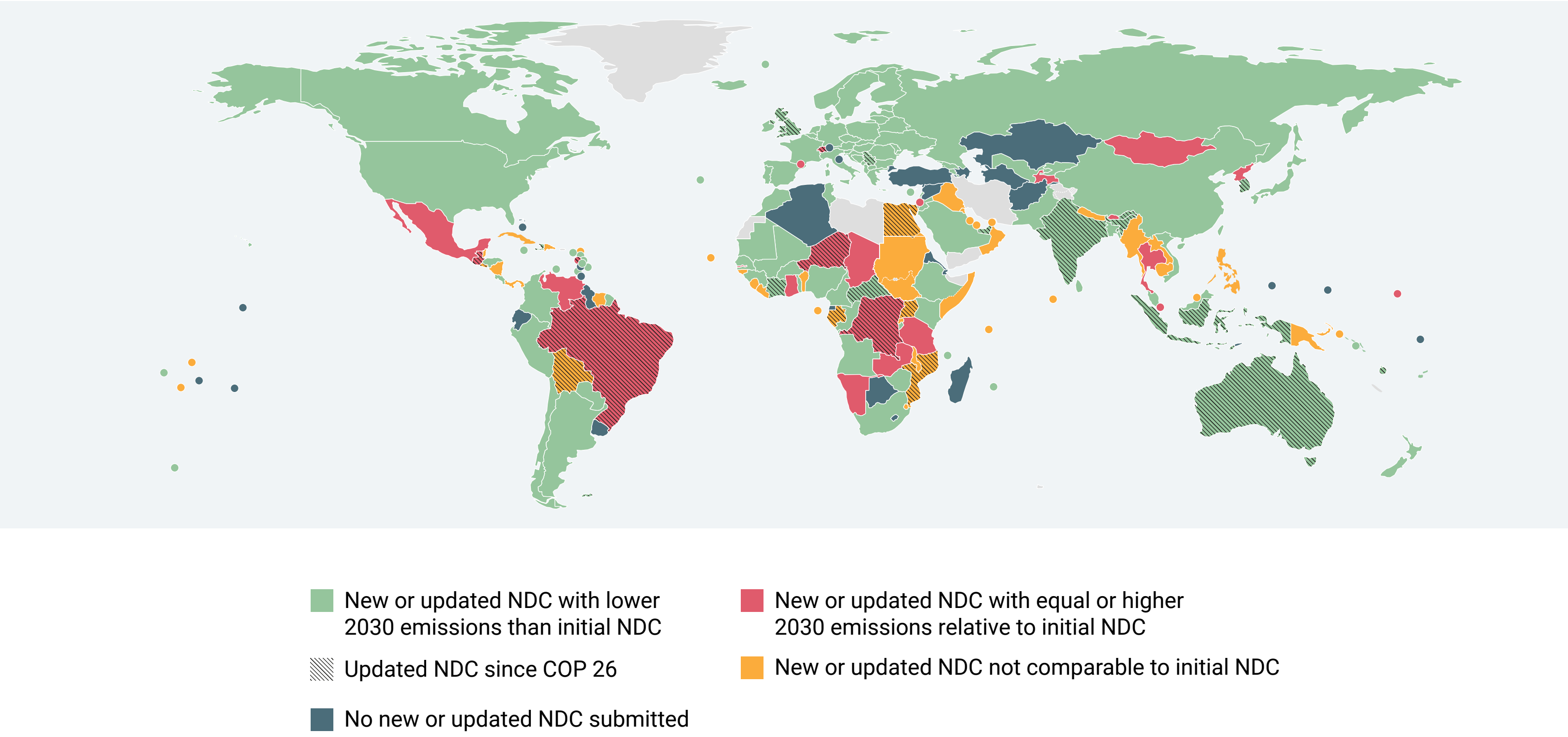
[1] Excluding updated first and second NDCs.

Figure 3.1 Effect of new or updated NDCs on 2030 GHG emissions relative to initial NDCs



3.2.2 Long-term and net-zero pledges

As at 23 September 2022, 88 parties covering approximately 79 per cent of global GHG emissions have adopted net-zero pledges either in law (21 parties), in a policy document such as an NDC or a long-term strategy (47 parties), or in an announcement by a high-level government official (20 parties). This is up from 74 parties as at COP 26. An additional eight parties covering an additional 2 per cent of global GHG emissions have another (non-net-zero) GHG mitigation target as part of their long-term strategy.

A total of 36 per cent of global GHG emissions are covered by net-zero targets for 2050 or earlier, while 43 per cent of global emissions are covered by net-zero pledges for years later than 2050. Currently, 21 per cent of global emissions are not covered by net-zero pledges.

A total of 53 net-zero targets cover all sectors, while 31 do not specify sectoral coverage. Moreover, 37 cover all gases, eight cover fewer than all gases and 40 do not specify. Two cover international shipping and aviation, one covers international aviation but not shipping, 12 cover neither and 71 do not specify. Five net-zero targets rule out the use of international offsets towards the net-zero targets, 19 anticipate the use of international offsets, and 61 do not specify.

3.3 Impacts of new and updated NDCs on global GHG emissions in 2030

This section estimates the impact on projected global 2030 emissions of new and updated NDCs as at 23 September 2022 (assuming they are fully implemented) compared to initial NDCs. The data come from three model groups that include updated NDCs with cut-off dates ranging from November 2021 to September 2022 (Keramidas *et al.* 2021; den Elzen *et al.* 2022; Meinshausen *et al.* 2022), and two open-source tools (Climate Action Tracker 2021; Climate Watch 2022).[2] To enable the inclusion of the updated NDCs of G20 members that were submitted after the cut-off dates of the five data sources (that is, Australia, Brazil, India, Indonesia, Republic of Korea and the United Kingdom), NDC emission estimates were recalculated based on the historical emissions data used in the respective studies.[3]

Full implementation of all new or updated unconditional NDCs is projected to lead to a total reduction in global GHG emissions for 2030 of about 4.8 gigatons (Gt) of CO_2e (range: 1.7–7.9 $GtCO_2e$) annually, compared with initial pledges (figure 3.2; see also appendix B and table B.2). New and updated NDCs submitted since the Emissions Gap Report 2021 account for about 0.7 $GtCO_2e$ of this total, mainly due to additional reductions from the updated

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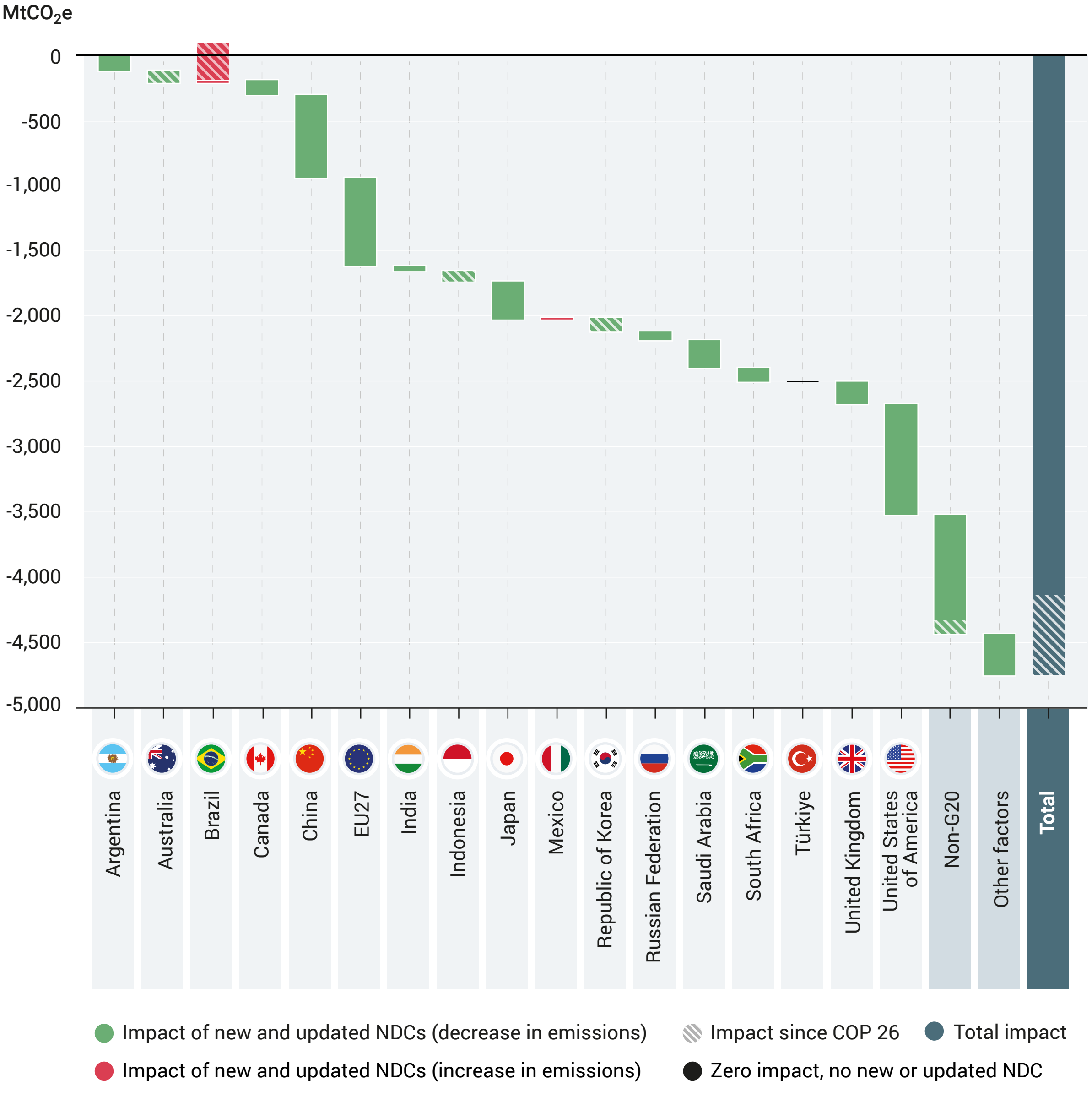
[2] This estimate includes reductions of around 0.3 $GtCO_2e$ resulting from other factors, including lower projections of international aviation and shipping emissions.

[3] The impact of the new and updated NDCs from non-G20 members since the cut-off date of the studies was not included.

NDCs of Australia (10 per cent of the 0.7 $GtCO_2e$), Brazil (35 per cent), Indonesia (10 per cent), Saudi Arabia (about 25 per cent),[4] Republic of Korea (5 per cent) and non-G20 members (15 per cent), while submissions since COP 26 account for 0.5 $GtCO_2e$ of the total (mainly from Australia, Brazil, Indonesia and Republic of Korea). For some G20 members, the impact on global GHG emissions in 2030 is estimated at zero. This applies to members that have not submitted an updated NDC (Türkiye), that have submitted NDCs with a similar target as in a previous update (United Kingdom) or where the updated target is estimated to result in higher emissions than emissions projected based on current policies for some studies (India and the Russian Federation). Brazil[5] and Mexico show an increase in the emissions targets compared to the previous targets, due to a change in the reference emissions.

Figure 3.2 Impact of new and updated unconditional NDCs on 2030 global emissions compared with initial NDCs



Notes: The additional reduction resulting from other factors, including lower projections of international aviation and shipping emissions, is included in the figure. The updated NDC of Brazil lowers the projected increase in emissions in 2030 compared with the previous NDC.

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[4] Brazil's 2022 NDC submission reduced emissions relative to their previous submission, which explains the contribution to the 0.7 $GtCO_2e$ reduction. However, the 2022 NDC submission still implies emissions that are higher than those of the initial NDC of Brazil.

[5] According to the IPCC guidelines for national inventories for Brazil.

3.4 Progress of G20 members towards their NDC targets

Ambitious targets are important but matter little unless they go hand in hand with ambitious policies and accelerated implementation. This section provides an updated assessment of the progress of G20 members towards their latest NDC targets as at 23 September 2022 based on a synthesis of recently published studies of emissions projections.[6] For each G20 member, GHG emissions projections were compiled and reviewed to assess the emission levels expected under existing policies i.e. the current policies scenario.[7] Expected emission levels in 2030 under current policies were then compared to projected emissions under the NDC target to assess whether the G20 members are likely to meet their respective emissions reduction targets for 2030. The assessment is based on 'point in time' emissions projections in the NDC target year. European Union member states are not assessed individually.

3.4.1 Methods and limitations

Current policies scenario projections are compared to the latest unconditional NDCs or to conditional NDCs for G20 members whose NDCs do not have unconditional elements. The assessment of conditionality of NDCs follows the World Resources Institute (Climate Watch 2022), which considers Indonesia and Mexico to have both unconditional and conditional NDCs, and India and South Africa to have only conditional NDCs (see appendix B, table B.2, available online).

To enable a robust comparison of projections published by independent research institutions, the methodology of den Elzen *et al.* (2019) is followed. Official assessments published by national governments are compared with independent assessments. All data sources are presented in appendix B (table B.1), available online. The assessment is based on emissions including land use, land-use change and forestry (LULUCF) (see appendix B for details on adjustments of emission projections excluding LULUCF). Historical emissions data for energy and industry sectors were taken from the latest inventory submissions to the UNFCCC, supplemented by the Potsdam Real-Time Integrated Model for probabilistic Assessment of emission Paths (PRIMAP) database for interval years and most recent years after the last inventory data year (Gütschow, Günther and Pflüger 2021). For historical LULUCF emissions, harmonized data from Grassi, Conchedda *et al.* (2022) and Grassi, Federici *et al.* (2022) are used. For the emission data from the literature expressed in GWPs other than the 100-year GWPs from the IPCC's AR6, conversion factors used in AR6 were applied (Lecocq *et al.* 2022).

The selection of studies projecting 2030 emissions is based on four main considerations: 1) whether the studies take into account the most recent societal, economic and policy developments—accordingly, only studies published in 2020 or later are included,[8] 2) that peer-reviewed studies are included to the extent possible, 3) inclusion of studies published by national experts and 4) that all GHGs and sectors are covered. Policy cut-off dates ranged from 2019 to mid-2022 across studies, meaning that recently adopted policies, including most of those presented later in section 3.4.3, are fully reflected in some of the scenario studies reviewed.

Many studies took limited account of the potential impact of the COVID-19 pandemic on future emissions. Chapter 2 shows that long-term impacts of the pandemic on emissions remain uncertain, that global emissions are expected to rebound fully in 2021 and that impacts show large variation across G20 members and sectors. Therefore, studies that do not explicitly take the impact of the pandemic into account are also considered. Furthermore, none of the emissions projections consider the potential implications of the war in Ukraine. Other limitations are similar to previous Emissions Gap Reports (see appendix B.3).

For the three G20 members that recently submitted more ambitious NDCs (Australia, Brazil and Republic of Korea), a few studies compared their current policies scenario projections to earlier NDC targets. Where required, NDC emission levels are recalculated based on the historical emissions data used in respective studies. No recalculations were done for the NDCs of India and Indonesia, both of which were updated towards the end of the drafting process.

3.4.2 Synthesis of recently published scenario studies

Table 3.1 shows the progress of G20 members towards their latest NDC targets, organized by the status and assessment of whether these targets will be met, based on current policies. Most G20 members that submitted stronger NDC targets in 2020 and 2021 have just begun their implementation efforts to meet their new targets. Those that are projected to meet their latest NDC target based on policies currently in place are G20 members that have not submitted a new or updated NDC, did not strengthen or only moderately strengthened their target levels in their updated NDCs (table 3.1). All other G20 members will need additional policies to achieve their NDCs.

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[6] The updated NDCs of India and Indonesia submitted after the cut-off date were not considered in this section because no study reviewed in this section quantified and or examined the target levels as the report went to press.

[7] Current policies scenario projections assume that no additional mitigation action is taken beyond current policies, even if it results in NDC targets not being achieved or being overachieved (United Nations Environment Programme [UNEP] 2015; den Elzen *et al.* 2019). Current policy projections reflect all adopted and implemented policies, which for the purpose of this report are defined as legislative decisions, executive orders or their equivalent. This implies that officially announced plans or strategies alone would not qualify, while individual executive orders to implement such plans or strategies would qualify.

[8] Exceptions were made in a few cases, where external reviewers suggested national studies published before 2020, that were assessed to provide relevant information.

Table 3.1 Assessment of progress towards achieving the current NDC targets, 2022 (unconditional, unless otherwise mentioned) for the G20 under current policies, based on independent studies mainly published in 2020 or later

		Projected progress towards the latest NDC target		
		Meet the target with existing policies (Indicated by +, if overachieved by more than 15)	*Miss the target with existing policies*	*Uncertain*
Status of new or updated NDC	Submitted stronger target	China (4/7), India (conditional: 4/7),[i] Saudi Arabia (2/2)	Argentina (0/3), Australia (0/4)[ii], Brazil (0/4, one within reach), Canada (0/4) EU27 (0/3),[ii,iii] Japan (0/3), Republic of Korea (0/3)[iv], South Africa (conditional: 0/3), UK (0/1), United States of America (0/4)	Indonesia (0/3, one within reach)
	No new target submitted	Türkiye (3/3)		
	Submitted equivalent or weaker target	Russian Federation^{+} (5/5)[ii]	Mexico (1/3)	

Notes: See appendix B.1 for the list of studies reviewed. The number of independent studies that project a country to meet its previous or the first NDC target are compared to the total number of studies and indicated in brackets. "Within reach" indicates that only the lower bound estimate of the current policies scenario projections is within the NDC target range.

[i] Submitted updated NDC after 1 August 2022, which has not been possible to consider in this assessment.

[ii] Current policies scenario projections from official publications were also examined. The official publications for three G20 members (Canada, the European Union and United Kingdom) show that they do not project to meet their 'point in time' NDC target under their current policies scenario. Australia's most recent official report reported its progress towards their earlier NDC (Australia, Department of Industry, Science, Energy and Resources 2021).

[iii] For the EU27, we refer to the European Union Reference scenario, which assumes full implementation of the National Energy and Climate Plans (NECPs) for the period 2021–2030 by European Union member states and sees European Union emissions reduce by around 43 per cent below 1990 levels by 2030 (European Commission 2021a). Including net removals from LULUCF, this increases to -45 per cent. This baseline scenario indicates that additional effort would be required to meet the European Union's current 2030 energy efficiency target while its current 2030 renewable energy target would be met. Additional member state measures will update to fully implement their NECPs for the period 2021–2030 by June 2023 (draft) and June 2024 (final plans) with additional measures, taking into account recent policy and geopolitical developments (European Commission 2020).

[iv] The Republic of Korea's Emissions Trading Scheme (K-ETS) is an instrument to fully achieve the country's NDC target and covers more than 70 per cent of its GHG emissions. The implementation phase 3 (2021–2025) has not been updated since the updated NDC was announced (International Carbon Action Partnership 2022).

Collectively, the G20 members are projected to fall short of their new or updated NDCs by 1.8 GtCO$_2$e (central estimate) annually by 2030. In other words, there is an implementation gap, defined as the difference between projected emissions in 2030 (assuming full implementation of NDC) and emissions based on current policies scenario projections. For two G20 members, the projected emissions under the NDC have consistently been assessed to significantly exceed current policies projections (the Russian Federation and Türkiye) since the Emissions Gap Report 2015 (UNEP 2015), thereby lowering the implementation gap compared to what can be reasonably expected. If NDC projections for these two members are substituted by current policies scenario projections, the G20 members would collectively fall short of achieving their NDCs in 2030 by an annual 2.6 GtCO$_2$e.

The 2030 GHG emission estimates of the G20 and its individual members under current policies scenario, unconditional NDCs and conditional NDCs (for four G20 members) are presented in figure 3.3 in comparison with historical emissions for 2015, the year in which countries adopted the Paris Agreement and submitted their intended NDCs. For most G20 members, central estimates of emissions projections under current policies for 2030 are lower than at the time of the Emission's Gap Report 2021. The central estimate of aggregate emissions projections for G20 members in 2030 under current policies decreased by 1.3 $GtCO_2e$ or about 4 per cent compared with the 2021 assessment, mainly due to the expected emission reductions from the Inflation Reduction Act (of about 1 $GtCO_2e$) that would bring the United States of America's emissions projections for 2030 closer to the NDC target. The G20 members with 10 per cent lower projections compared with the 2021 assessment are: Indonesia, Mexico, Saudi Arabia and the United States of America. It is worth noting that the lower bound estimate has decreased by about 2.4 $GtCO_2e$ (compared to 1.1 $GtCO_2e$ for the upper bound estimate), indicating a varied interpretation of NDC implementation policies and varied forecasts on the deployment of low-emission technologies across studies. Also note that for China and India, which are assessed to meet their NDCs with existing policies in table 3.1, the central estimates of the current policies scenario projections are higher than the central estimates of the NDC targets mainly due to the large variation of emissions projections across studies.

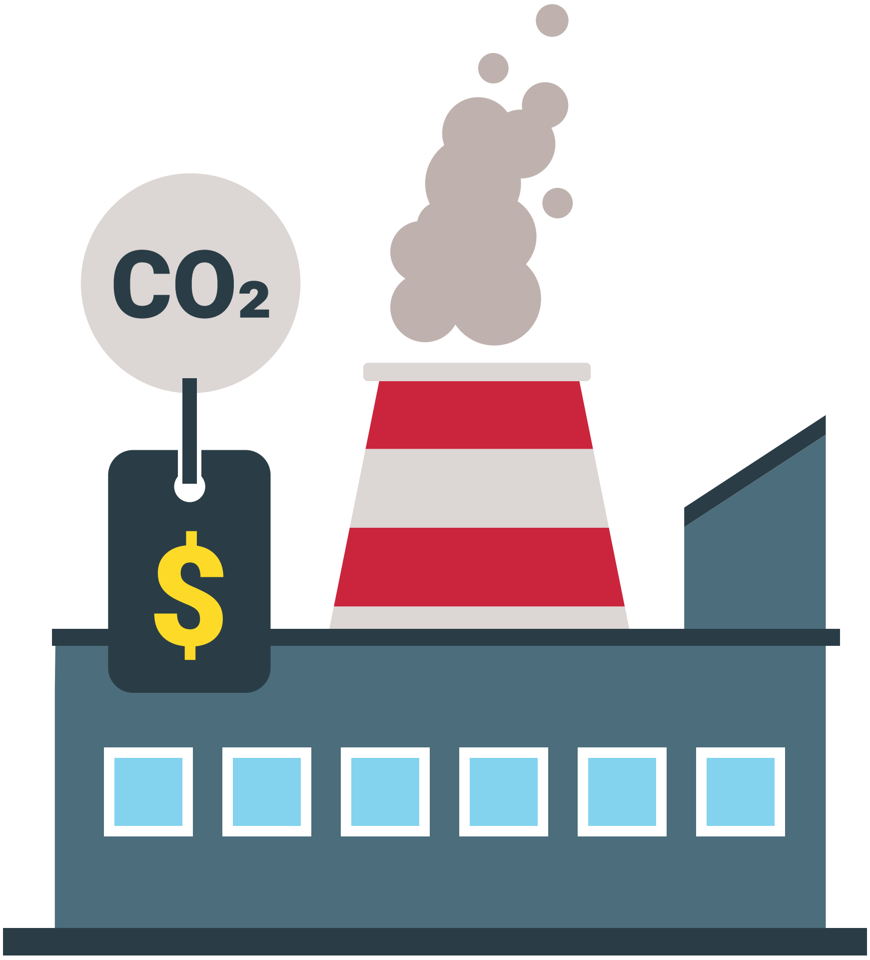
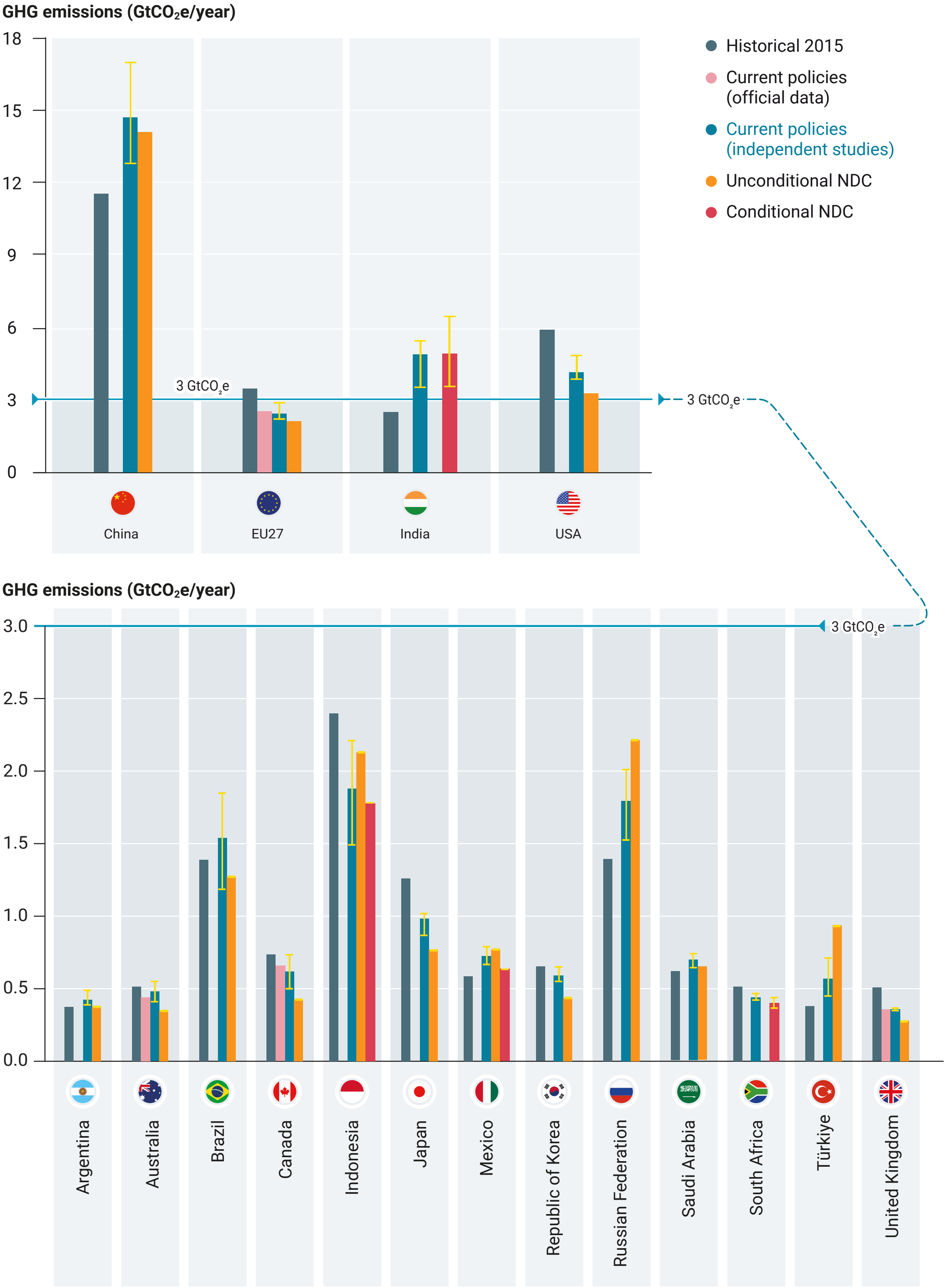


Figure 3.3 GHG (all gases and sectors, including LULUCF) of the G20 and its individual members by 2030 under current policies scenario, unconditional NDCs, and conditional NDCs (for four G20 members), compared with 2015 historical emissions



Notes: For current policies scenario projections, estimates based on independent studies are presented. Bars show the average values (median values in case of five or more studies) and error bars show the minimum and maximum values (tenth and ninetieth percentiles in case of five or more studies). For NDCs, official values (adjusted to AR6's GWPs) are presented where available. For reporting reasons, the emissions projections for China, the EU27, India and United States of America are shown in the top figure and the other G20 members are shown in the bottom figure, using two different vertical axes. See appendix B.1 for details on the underlying studies.

To supplement the findings presented above, table 3.2 presents per capita GHG emissions in 2015, which are projections for 2030 under the current NDC targets and current policies scenario, and the expected emission peaking year for the G20 members. The average per capita emissions in 2030 of G20 members under the latest NDCs are projected to be about 10 per cent lower (6.7 tCO_2e) than under the current policies scenario (7.4 tCO_2e). However, they are not lowered compared with 2010 levels and remain very far from the median estimates consistent with 2°C and 1.5°C scenarios by 2050, which are 1.9 tCO_2e (tenth and ninetieth percentile range: 1.2–2.3 tCO_2e) and 0.6 tCO_2e (0.3–1.1 tCO_2e), respectively.

Per capita emissions range widely across G20 members: emissions of India are about half of the G20 average, whereas Saudi Arabia reaches more than twice the G20 average. Australia, the European Union and South Africa are projected to reduce their per capita emissions by more than one third between 2010 and 2030 under current policies. The United Kingdom even reaches half. Mexico also reaches -10 per cent and -15 per cent of the projected development of per capita emissions under both current policies and NDC scenarios, respectively. Per capita emissions under current unconditional NDC targets are projected to increase between 2010 and 2030 for seven G20 economies.

On the peaking of emissions, all Annex I G20 members and some non-Annex I G20 members (Argentina, Brazil, Republic of Korea and South Africa) have peaked their emissions already while the NDCs of a few non-Annex I G20 members (China) are projected to peak their emissions by 2030. However, six of the non-Annex I G20 members do not project a peaking by 2030 under the current policies scenario.

Table 3.2 Overview of G20 member status and progress towards meeting NDC targets

Country	Unconditional NDC: per capita GHG emissions		Current policies scenario: per capita GHG emissions		Emission peaking	
	tCO_2e/cap in 2030	vs. 2015 levels	tCO_2e/cap in 2030	vs. 2015 levels	Peaking year unconditional NDC	Peaking year current policies
Argentina	7.7	-11%	8.7	0%	around 2005	Not clear
Australia	12.2	-44%	16.8	-22%	2007	2009
Brazil	6.2	-9%	6.7	-1%	around 2005	Not clear
Canada	10.2	-50%	14.9	-28%	2007	2007
China	9.8	18%	10.3	24%	Before 2030 (CO_2 only)	Not clear
EU27	4.8	-39%	5.4	-31%	1990 or earlier	1990 or earlier
India	3.1	62%	3.2	69%	No commitment to peak	Not expected to peak before 2030
Indonesia	7.0	-25%	6.2	-33%	No commitment to peak	Not clear
Japan	6.5	-35%	8.3	-17%	2013	2013
Mexico	5.7	16%	5.3	9%	No commitment to peak	Not expected to peak before 2030

Republic of Korea	8.5	-34%	11.5	-10%	By 2018	Possibly peaked by 2020
Russian Federation	15.2	58%	12.4	28%	1990 or earlier (former Soviet republic)	Peaked, but projected to be on an increasing trend by 2030
Saudi Arabia	16.7	-12%	16.7	-12%	No commitment to peak	Not expected to peak before 2030
South Africa	6.1	-34%	6.8	-26%	around 2015	around 2015
Türkiye	10.5	121%	6.4	34%	No commitment to peak	Not expected to peak before 2030
United Kingdom	4.0	-49%	5.1	-34%	1990 or earlier	1990 or earlier
United States of America	9.2	-49%	11.7	-36%	2007	2007
G20	6.9	-7%	7.3	-1%	Not assessed	Not assessed

Source: Adapted from den Elzen *et al.* (2022), basing the assessment of expected emission peak year on the method of Levin and Rich (2017)

Notes: The population projections are based on the medium fertility variant of the United Nations Population Prospects 2022 edition (United Nations Department of Economic and Social Affairs, Population Division 2022).

3.4.3 Overview of recently adopted policies

Table 3.3 presents selected energy and climate policy developments that may carry significant, direct impact on the implementation of NDC targets and long-term emission reduction goals adopted in late 2021 and 2022 for the top-seven emitting economies (Brazil, China, EU27, India, Indonesia, Russian Federation and the United States of America; for other G20 members' policies, see chapter 2 and appendix B.4). Policy responses to the energy crisis and the war in Ukraine are not included. Some of the policies highlighted by national policy experts were adopted after the publication of the scenario studies reviewed in section 3.4.1 Notable exceptions include the Inflation Reduction Act and the Infrastructure Investment and Jobs Act of the United States of America.

Table 3.3 Overview of recent policy measures adopted by the top seven GHG-emitting G20 members in 2021 and 2022 that are expected to affect the achievement of their NDC targets and long-term pledges

Brazil	• In its updated NDC, Brazil commits to reducing its GHG emissions by 37 per cent in 2025 and by 50 per cent in 2030 relative to 2005 levels. It has also committed to eliminating illegal deforestation by 2028 (Brazil 2022a). • In May 2022, Brazil adopted a federal decree establishing the procedures for setting up a national system for reducing GHG emissions as well as sectoral plans for climate change mitigation. The decree also establishes a single register of carbon and methane credits and classifies carbon credits as financial assets. The decree is expected to become a management mechanism and an operational instrument for the sectoral plans, which should establish gradual sectoral targets for emission reductions. These sectoral plans must be approved by the Interministerial Committee on Climate Change and Green Growth. Deadlines and specific rules are not yet specified under the decree (Brazil 2022b).
China	• The renewable energy development in China has continued its strong growth. By the end of 2021, the installed solar photovoltaics (PV) and wind capacity was more than 300 gigawatts (GW). Since 1996, the annual newly installed solar PV and wind capacity has accounted for about 55 per cent of new energy capacity (Statista 2022). • In April 2022, China announced that it would increase coal production by 300 million tons in 2022 through coal mining capacity increase, expanded and new production, and other measures. This comes despite China's pledge to strictly control coal-fired power generation projects, limit the increase in coal consumption over the 14th Five-Year Plan period (2021–2025) and phase down coal consumption during the 15th Five-Year Plan period (2026–2030). The transformation away from coal infrastructures is challenged by energy security concerns (China, National Development and Reform Commission [NDRC] 2022; China, National State Energy Administration 2022; Xinhua 2022). • To peak CO_2 emissions and achieve carbon neutrality, China has released an Action Plan for Carbon Dioxide Peaking before 2030 and a Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality. Specific objectives and implementing plans are published at the regional level and across all sectors covering energy, industry, urban-rural development, transportation, carbon sink, technology development, carbon market, climate and green finance, climate adaptation and social awareness (China, NDRC 2021a; China, NDRC 2021b).
European Union	• In December 2021, the European Commission proposed legislation to boost the renovation and decarbonization of buildings and reduce methane emissions in the energy sector by 80 per cent in 2030 (European Commission 2021b; European Commission 2021c). New requirements to promote sustainable products and construction were proposed in March 2022, which could lead to 132 million tons of oil equivalent (Mtoe) of primary energy savings (European Commission 2022a). • In May 2022, the European Commission presented its REPowerEU Plan in order to phase out Russian fossil fuels. Among others, the plan includes proposals to invest €210 billion mostly in clean energy and industry, speed up permitting procedures for renewable energy projects, and increase ambitions for renewable energy and energy efficiency. The plan would bring the EU's total renewable energy generation to 1236 GW by 2030 if adopted (European Commission 2022b; European Commission 2022c). • The EU's revision and update of legislation under the "Fit for 55" package to implement its 2030 climate target is in its final phase. The European Commission, European Parliament and member states have already supported a ban on the sale of new fossil fuel cars and vans by 2035, an EU Carbon Border Adjustment Mechanism (CBAM), and an expansion of emissions trading to new sectors (European Council 2022a; European Council 2022b; European Parliament 2022).

India	• In August 2022, the Cabinet approved an update of India's NDC. The updated NDC has led to major polices being pushed forward, including 1) electric vehicles (EVs), 2) co-firing of biomass pellets in thermal power plants by 7 per cent, 3) ethanol blending in petrol by 20 per cent, 4) inclusion of agroforestry and private forestry, 5) solarization of agricultural pumps, 6) clean cooking (by shifting to liquefied petroleum gas [LPG]), and 7) rooftop solar PV. The Government of India is considering coal gasification, conversion of coal into chemical projects, ammonia and hydrogen as future fuels. Energy storage is supported through a production linked scheme to promote renewable energy (India, Press Information Bureau 2022). • In recognition of the role of lifestyles, the movement Lifestyle for Environment has been proposed to foster a citizen-centric approach to combat climate change (Bhaskar 2022; India, Press Information Bureau 2022). • The Lok Sabha passed the Energy Conservation (Amendment) Bill on 9 August 2022, aiming to facilitate the establishment and development of domestic carbon markets. The markets' objective is to incentivize actions for emission reduction expected to result in increased investments in clean energy and energy efficiency areas, especially in the private sector (PRS Legislative Research 2022).
Indonesia	• In February 2022, the Ministry of Environment and Forestry released Ministerial Decree No. 168/2022 on Forestry and Other Land Use (FOLU) Net Sink 2030 along with its operational plan. This regulation is expected to remove GHG emissions while implementing the energy transition and decarbonization. The FOLU Net Sink commitment was introduced in the last Long-Term Strategy to Low-Carbon and Climate Resilience 2050 published in 2021 (Forest Hints 2022). • The Ministry of Energy and Mineral Resources has announced a net-zero emission road map for the energy sector, which indicates that Indonesia will no longer build new fossil fuel power plants, with the exception of the 35 GW power capacity addition plan, and begin to retire subcritical coal power plants from 2030 onwards. In the period of 2031–2060, 45 GW of coal power plants will be retired and shut down. In addition, the Indonesian State-owned electricity company Perusahaan Listrik Negara seeks to cancel some coal plants under construction. However, despite the verbal statement and political decision, no regulation to phase out coal has been issued yet (International Energy Agency [IEA] 2022; Indonesia, Ministry of Energy and Mineral Resources 2022; Organisation for Economic Co-operation and Development [OECD] Clean Energy Finance and Investment Mobilisation Programme 2021). • The Electricity Supply Business Plan 2021–2030, published in October 2021, aims to achieve renewable energy capacity to account for 51.6 per cent of total power addition until 2030. Hydropower dominates the upcoming renewable plan by around 25.6 per cent, followed by solar (11.5 per cent), geothermal and other renewables (Indonesia, Ministry of Energy and Mineral Resources 2021; OECD Clean Energy Finance and Investment Mobilisation Programme 2021).
Russian Federation	• In November 2021, the Russian Federation released the newest version of their Transport Strategy until 2030. The strategy outlines measures including energy-efficient or electric vehicles, low-carbon infrastructure and alternative fuels intended to reduce transport emissions by 1.2 per cent relative to total emissions in 2017 by 2030 (Russian Federation 2021a). • The Concept for the Development of Electric Vehicle Production was approved by the Russian Federation in August 2021, setting a target for EVs to make up at least 10 per cent of the Russian market by 2030. In addition to measures promoting EV production, the Government plans to stimulate demand by providing subsidies covering up to 25% of the price of domestically produced EVs (Russian Federation 2021b; Reuters 2021). • In August 2021, the Russian Government approved the concept for the Development of Hydrogen Energy. The plan presents strategic initiatives towards the development, use and export of low-carbon hydrogen energy (Russian Federation 2021a).

United States of America	• In August 2022, the United States of America enacted the Inflation Reduction Act, projected to reduce GHG emissions by 1 Gt. The law makes major investments in clean energy technologies including utility-scale and distributed solar, wind and other renewable resources, existing zero-emitting nuclear plants, carbon capture facilities in the power and industrial sectors, light, medium and heavy-duty clean vehicles as well as heat pumps and other energy-efficient upgrades for homes and businesses. The Act also provides tax credits for emerging clean technologies like clean hydrogen production, direct air capture facilities and clean fuel production (United States of America, Congress 2022a; United States of America, Department of Energy 2022; Jenkins *et al.* 2022; Larsen *et al.* 2022; Mahajan *et al.* 2022). • The United States of America also enacted the Infrastructure Investment and Jobs Act in November 2021, which makes US$27 billion in power grid and transmission investments, creates a new US$7.5 billion grant programme for EVs and alternative fuel infrastructure deployment, and provides US$3.5 billion and US$8 billion for direct air capture and clean hydrogen hubs, respectively, among other key investments (United States of America, Congress 2022b). • In 2021 and 2022, the Environmental Protection Agency and National Highway Traffic Safety Administration adopted standards for light-duty vehicles through model year 2026. The Environmental Protection Agency estimates that the standards will avoid more than 3 billion tons of GHG emissions through 2050 (United States of America, Department of Transportation undated; United States of America, Environmental Protection Agency 2021; United States of America, Environmental Protection Agency 2022).

3.5 Details on G20 members' net-zero pledges

A total of 19 G20 members have committed to achieving net-zero emissions, up from 17 as at COP 26. These targets vary in a number of important characteristics, including their legal status; timeline; explicit consideration of fairness and equity; which sources, sectors and gases they cover; whether they will allow the use of international offsets to count towards their achievement; the level of detail they provide on the role of carbon dioxide removal; and the nature of planning, review and reporting on target implementation (table 3.4).

Figure 3.4 visualizes the direction needed for countries to get from their current emission levels to their NDC targets for 2030 and indicates their net-zero targets for each G20 member that has a net zero target (noting that France, Germany and Italy are only assessed as part of the European Union). Those G20 members whose emissions have already peaked will need to further accelerate their emission declines to their net-zero target year, while those members whose emissions will continue to increase through 2030 under the NDCs will require further policy shifts and investments (including adequate support to developing countries, where applicable) to achieve the emission reductions implied by their national net-zero targets. This illustration does not consider the relative merit in terms of the equity or fairness of the choices countries make regarding their nationally determined pathways to net zero. However, it highlights the discrepancy between current emissions, near-term NDC targets and long-term net-zero targets. This serves as a clear reminder to all G20 members, or indeed any country, that aspirational targets such as NDCs or net-zero targets need to be backed up with effective policies. It also serves as an important reminder that current evidence does not provide confidence that the nationally determined net-zero targets will be achieved. This has clear repercussions for the anticipated global temperature projections (see chapter 4).

Table 3.4 Details on net-zero targets of G20 members

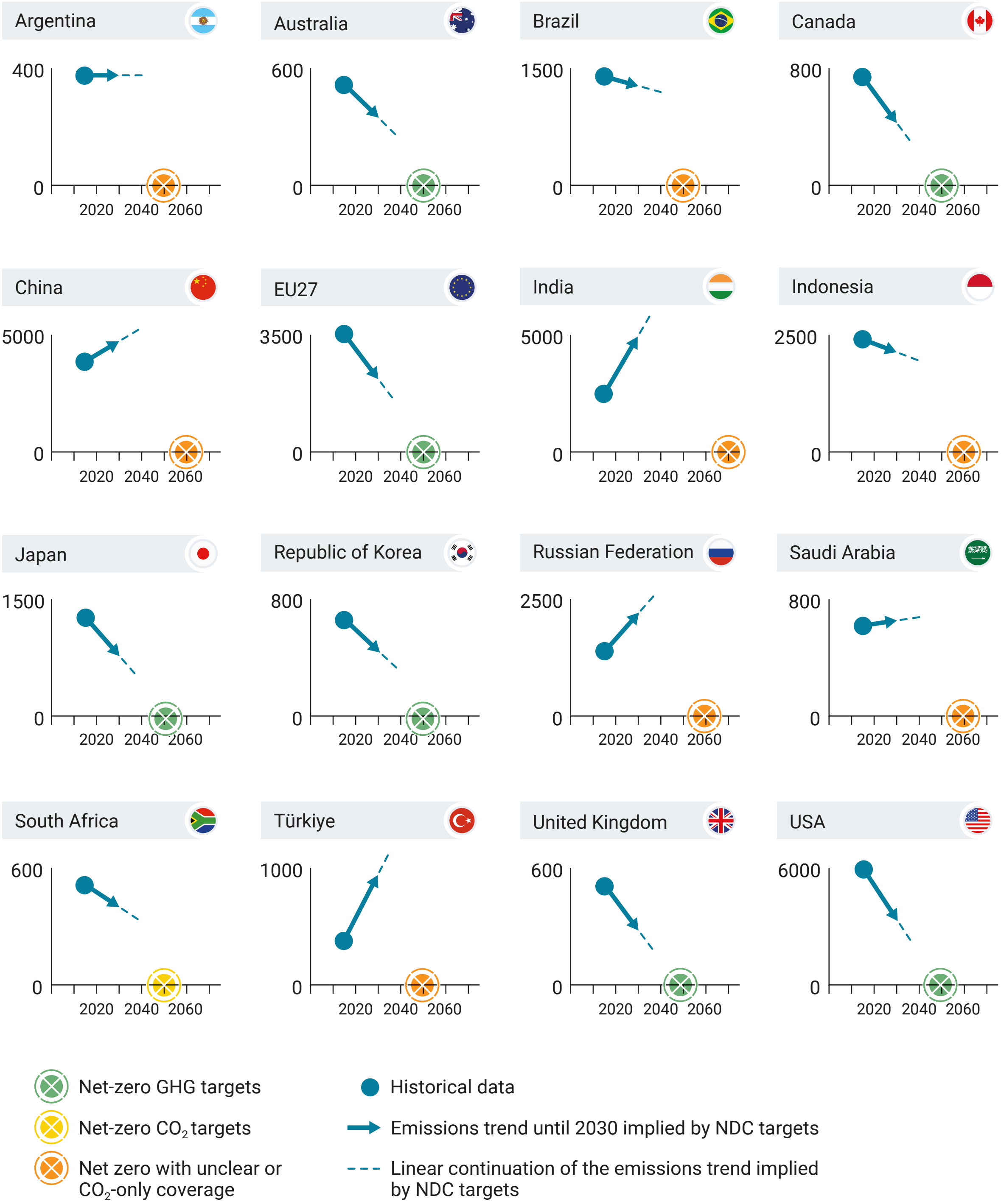
		Fundamentals			Scope and coverage				Carbon removal		Planning, review, reporting		
G20 member	**Annex**	Source	Target year	Reference to fairness	Covers all sectors	Covers all gases	Covers int'l shipping and aviation	Excludes int'l offsets	Separate removals targets	Removals transparency	Published plan	Review process	Annual reporting
Argentina	Non-Annex I	announcement	2050	✕	?	?	?	?	✕	✕	✕	?	✕
Australia	Annex I	law	2050	[inconclusive]	✓	✓	?	✕	✕	[inconclusive]	[inconclusive]	🟨✓	✓
Brazil	Non-Annex I	policy	2050	✕	✓	?	?	?	✕	✕	✕	?	✕
Canada	Annex I	law	2050	[inconclusive]	✓	✓	?	?	✕	[inconclusive]	✓	✓	✓
China	Non-Annex I	policy	2060	✓	?	✕	?	?	✕	[inconclusive]	✓	🟨✓	✕
European Union	Annex I	law	2050	✕	✓	✓	🟨✓	✓	✕	✓	✓	✓	✓
France	Annex I	law	2050	✓	✓	✓	✕	✓	✓	🟨✓	✓	✓	✓
Germany	Annex I	law	2045	✓	✓	✓	✕	✕	✕	[inconclusive]	[inconclusive]	✓	✓
India	Non-Annex I	policy	2070	✕	?	?	?	?	✕	✕	✕	?	✕
Indonesia	Non-Annex I	policy	2060	✕	✓	?	?	?	✕	[inconclusive]	[inconclusive]	?	✕
Italy	Annex I	policy	2050	✓	?	?	?	✕	✕	✓	✓	[no data]	✓
Japan	Annex I	law	2050	✕	✓	✓	?	?	✕	[inconclusive]	[inconclusive]	✓	✓
Mexico	Non-Annex I	[no net-zero target]											
Russian Federation	Annex I	law	2060	✕	?	?	?	✕	✕	[inconclusive]	[inconclusive]	🟨✓	✕
Saudi Arabia	Non-Annex I	announcement	2060	✕	?	?	?	?	✕	✕	[inconclusive]	🟨✓	✕
South Africa	Non-Annex I	policy	2050	[inconclusive]	✓	✕	?	?	✕	✕	✕	?	✕
Republic of Korea	Non-Annex I	law	2050	✕	✓	✓	?	?	✕	✕	[inconclusive]	?	✓
Türkiye	Annex I	announcement	2053	✕	?	✓	?	?	✕	✕	✕	?	✓
United Kingdom	Annex I	law	2050	✓	✓	✓	✓	✕	✕	✓	✓	✓	✓
United States of America	Annex I	policy	2050	✕	✓	✓	✕	🟨✓	✕	✓	✓	🟨✓	✓

🟥 Not fulfilled 🟨 Partially fulfilled 🟩 Fulfilled ⬜ No information

Sources: All indicators are based on a reconciliation of data from Climate Action Tracker (2022), Climate Watch (2022) and Net Zero Tracker (2022) with the following exceptions: "Covers all sectors" is based on Climate Watch (2022); "Review process" is based on Climate Action Tracker (2022); "Annual reporting" is based on Net Zero Tracker (2022); "Removals transparency" and "Reference to fairness" are based on Climate Action Tracker (2022) and Net Zero Tracker (2022).

Notes: Green checkmarks indicate the criterion is fulfilled; yellow checkmarks indicate the criterion is partially fulfilled or fulfilled to a lower level of robustness; red "X" indicates the criterion is not fulfilled; "?" indicates the member has not provided information on the criterion (where relevant); "[inconclusive]" indicates inconsistency across data sources consulted; "[no data]" indicates the data sources consulted do not track data on the member. See appendix B.5 and the respective trackers for further explanations of indicators and coding criteria.

Figure 3.4 Emissions trajectories implied by NDCs and net-zero targets of G20 members



Notes: The figure shows national net emissions in $MtCO_2e$/year over time. The timing of net-zero targets is approximate in this figure for G20 countries that have net-zero targets that only apply to CO_2. CO_2-only net-zero targets imply later (or no) achievement of net-zero GHG emissions (see table 3.4).

4 The emissions gap

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4.1 Introduction

The emissions gap is defined as the difference between the estimated total global greenhouse gas (GHG) emissions resulting from the full implementation of the nationally determined contributions (NDCs), and the total global GHG emissions from least-cost pathways consistent with the Paris Agreement long-term goal of limiting global average temperature increase to well below 2°C, and pursuing efforts to limit it to 1.5°C relative to pre-industrial levels. Or in other words, the gap between promised and needed emission reductions. The key questions assessed in this chapter are, what is the current best estimate of the emissions gap for 2030 considering the latest NDCs? What levels of global emissions are in line with the climate mitigation goals of the Paris Agreement? Where are we headed under current policies and various mitigation pledge scenarios in terms of global warming over the course of the century?

The assembled scenarios reflect the latest findings from the reports released by Intergovernmental Panel on Climate Change (IPCC) Working Groups I and III under the *Sixth Assessment Report* (AR6) (Canadell *et al.* 2021; IPCC 2021; Byers *et al.* 2022; IPCC 2022b; Lecocq *et al.* 2022; Riahi *et al.* 2022), ensuring consistency with the most recent climate science and mitigation trajectory assumptions. The achievement of net-zero GHG emissions, as aimed for under the Paris Agreement, was considered as part of the scenario classification. Current policies and NDC scenarios are also aligned with the assessment of the IPCC AR6 WGIII Report (Lecocq *et al.* 2022), taking into account the impact of COVID-19 and updated policies on future emission levels. Moving beyond the IPCC assessment, the NDC scenario uses updated emissions projections based on the same studies assessed in the AR6 WGIII Report, but including NDC updates up to a cut-off date of 23 September 2022.[1]

Improving on earlier emissions gap estimates, this chapter uses updated information on land use, land-use change and forestry emissions from national inventory data and the most recent IPCC AR6 values of global warming potential over 100 years (GWP100); it harmonizes the differences between global emissions data and scenarios. Resolving these issues results in changes in the global emissions projections for current policies, NDCs and temperature pathways, compared with previous Emissions Gap Reports, as well as with the estimates included in the United Nations Framework Convention on Climate Change (UNFCCC) Synthesis Report (UNFCCC 2021) and the AR6 WGIII Report (IPCC 2022). The updates mean that the estimates in this chapter cannot be directly compared with previous Emissions Gap Report estimates. However, differences in the estimates are explained in this chapter, and the report's central finding remains: current policies and NDCs are woefully insufficient to meet the temperature goal of the Paris Agreement.

The chapter first introduces the updated scenarios that underlie the quantification of the emissions gap (section 4.2). The emissions gap assessment for 2030 is presented in section 4.3, and the global temperature implications are discussed in section 4.4.

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[1] The IPCC AR6 assessed studies with cut-off dates varying between May 2021 and October 2021.

4.2 Scenarios considered for the 2030 emissions gap assessment

This section updates the three scenario categories considered for the 2030 emissions gap assessment. These categories comprise reference and current policies scenarios (section 4.2.1), new and updated NDC scenarios (4.2.2), and least-cost mitigation scenarios starting in 2020 consistent with specific temperature targets (4.2.3). All scenarios are summarized in table 4.1.

Table 4.1 Summary of assessed scenarios

Scenario	**Number of scenarios in set**	**Global total emissions in 2030 ($GtCO_2e$)**	**Estimated temperature outcomes**†
Reference and current policies scenarios	Reference or year 2010 policies	2010	This scenario only includes climate polices implemented up to 2010 and assumes no additional measures from 2010 onward.
	Current policies	2021	This scenario covers current policies and projects global GHG implications of climate mitigation policies adopted and implemented as of 2021. These scenarios account for the short-term and midterm socioeconomic impacts of COVID-19[2] (cut-off date: November 2021) and are adjusted for the impact of the Inflation Reduction Act in the United States of America.
NDC scenarios	Unconditional NDCs	2022	This scenario covers all the latest versions of the NDCs that have been indicated to be implemented without any explicit external support (cut-off date: 23 September 2022).
	Conditional NDCs	2022	In addition to the unconditional pledges, this scenario covers the latest versions of NDCs to be implemented conditional upon receiving international support (finance, technology transfer and/or capacity-building) (cut-off date: 23 September 2022).
Mitigation scenarios consistent with keeping warming below specific temperature limits	Below 2°C	N/A	Long-term least-cost pathway starting from 2020 and consistent with holding global warming below 2°C throughout the twenty-first century with at least 66% chance.
	Below 1.8°C	N/A	Long-term least-cost pathway starting from 2020 and consistent with holding global warming below 1.8°C throughout the twenty-first century with at least 66% chance.
	Below 1.5°C	N/A	Long-term least-cost pathway starting from 2020 and consistent with holding global warming below 1.5°C throughout the twenty-first century with limited or no overshoot.[3] This implies global warming in 2100 being held below 1.5°C with at least 66% chance, while throughout the twenty-first century it is kept below 1.5°C with at least 33% chance. In addition, consistent with the Paris Agreement, these scenarios achieve net-zero GHG emissions in the second half of the century.

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[2] The current policy scenario adjusts original modelling studies to account for different policy cut-off dates, which range from 2017 to 2020, and varying consideration of the impact of the COVID-19 pandemic on socioeconomic drivers.

[3] The below 1.5°C definition used in the 2022 Emissions Gap Report is consistent with the C1a category of the IPCC AR6 WGIII Summary for policymakers and selects scenarios based on both their temperature outcome and on whether they reach net-zero GHG emissions over the course of the century in line with the Paris Agreement article 4 (Schleussner *et al.* 2022).

4.2.1 Reference and current policies scenarios

Two scenarios are considered: the reference or year 2010 policies scenario and the updated current policies scenario.

The **year 2010 policies scenario** assumes that no additional climate mitigation policies are implemented after 2010. Global GHG emissions in this scenario are based on the scenarios assessed by the IPCC under AR6 WGIII category C8 (Byers *et al.* 2022; IPCC 2022a; Riahi *et al.* 2022). The estimated global emissions in 2030 under the year 2010 policies scenario is 66 $GtCO_2e$ (range: 64–68).

The **current policies scenario** projects global GHG emissions assuming all currently adopted and implemented policies (defined as legislative decisions, executive orders or equivalent) are realized and that no additional measures are undertaken. Typically, selected policies are based on literature research, input from the Climate Policy Database (NewClimate Institute 2020) and a country expert review of the policies identified, often following a modelling protocol for the implementation of policies in global models from Roelfsema *et al.* (2020; 2022). The data for this scenario are based on the same four modelling studies of the current policies assessment of the IPCC AR6 WGIII Report (Lecocq *et al.* 2022), but using more recent data from the same four modelling studies that provide updated estimates that apply the most recent AR6 GWP100 values and use a policy cut-off date of November 2021 (see table 4.1 and appendix C, available online, for further detail) (Climate Action Tracker 2021; Keramidas *et al.* 2021; Riahi *et al.* 2021; den Elzen *et al.* 2022; Roelfsema *et al.* 2022). The scenario considers the impact of COVID-19 on GHG emissions projections, and the projections are adjusted to include the expected emission reductions from the Inflation Reduction Act in the United States of America (amounting to about 1 $GtCO_2e$). The GHG emissions projections for the current policies scenarios were harmonized with 2015 emissions based on the IPCC AR6 historical emissions database (see box 4.1). The resulting median estimate of global GHG emissions in 2030 under current policies is 58 $GtCO_2e$ (range: 52–60). This is 3 $GtCO_2e$ higher than the estimate of the 2021 United Nations Environment Programme (UNEP) Emissions Gap Report (accounting for the impact of the United States of America). About half of the increase is due to the harmonization, about one quarter to the change in global warming potential (GWP), and the remaining increase is due to the methodological choice of only selecting model studies that explicitly account for the most recent current polices and NDC estimates (table 4.2).

4.2.2 NDC scenarios

The NDC scenarios cover the most recent versions of the NDCs submitted, with a cut-off date of 23 September 2022. The estimates are based on the studies used in the IPCC AR6 WGIII assessment (see table 4.2 of Lecocq *et al.* 2022); however, to reflect NDCs submitted since the IPCC publication, updated estimates have been provided. The data come from four model groups with cut-off dates ranging from November 2021 to February 2022 across studies (Climate Action Tracker 2021; Keramidas *et al.* 2021; den Elzen *et al.* 2022; Meinshausen *et al.* 2022). To include the implications of new or updated NDCs submitted by certain G20 members after these cut-off dates (i.e. Australia, Brazil, India, Indonesia, Republic of Korea and the United Kingdom), NDC emission estimates were recalculated based on the historical emissions data used in respective studies (following the same approach as in chapter 3).

The latest versions of the unconditional NDCs result in an annual emissions reduction of about 0.7 $GtCO_2e$ compared with last year's report (table 4.2, NDC updates column). As with the reference and current policies scenarios, the NDC scenarios were also harmonized with historical 2015 emissions (see box 4.1).

Table 4.2 The impact of the various updates on the GHG emissions projections (median estimates)

Scenario	Emissions Gap Report 2022	Emissions Gap Report 2021	Difference EGR 2022-2021	Factors explaining differences between EGR 2022 and EGR 2021 estimates				
				NDC updates	Methods	AR6 GWP	Harmonization	Scenario literature update
Year 2010 policies	66.4	64.4	+2.0			+0.9	+1.1	
Current policies	58.0	55.0	+3.0		+1.3	+0.8	+1.9	-1.0*
Unconditional NDCs	55.4	52.0	+3.4	-0.7	+0.8	+0.8	+2.5	
Conditional NDCs	52.4	49.7	+2.7	-0.7	+0.5	+0.7	+2.2	
Below 2.0°C	40.7	39.2	+1.5			+0.6		+0.9
Below 1.8°C	34.7	33.2	+1.6			+0.5		+1.1
Below 1.5°C	32.7	24.6	+8.2			+0.4		+7.8

* Impact of Inflation Reduction Act in the United States of America.

The unconditional and conditional NDC scenarios result in projected median global GHG emissions in 2030 of 55 $GtCO_2e$ (range: 52–57) and 52 $GtCO_2e$, (range: 49–54) respectively. These projections are 3.5 $GtCO_2e$ and 3 $GtCO_2e$ higher than the median estimates of the 2021 UNEP Emissions Gap Report, respectively, for reasons similar to those explaining the changes in the current policies scenario (see table 4.2). The harmonization of scenario projections and estimates of historical emissions are also the dominant factor here (see table 4.2), in addition to the impact due to the change in GWP and the change in methodological choice of only selecting model studies that account for the most recent NDCs. Note that this year's update also accounts for the impact of the updated NDCs made between the September cut-off date of the 2021 Emissions Gap Report and November 2021.

Box 4.1 Harmonization of emissions data

Historical emission inventories and emissions projections from global integrated assessment models differ and are associated with uncertainties (see chapter 2, Dhakal *et al.* 2022). To ensure comparability, data sources in this year's report were harmonized through the following three steps:

1. Discrepancies between the emissions of scenarios from the IPCC AR6 WGIII scenario database (Byers *et al*. 2022; Riahi *et al*. 2022) and updated historical global emissions estimates were harmonized as part of the IPCC AR6 scenario pipeline (Kikstra *et al*. 2022).

2. Emissions data from NDC estimates (based on a national inventory approach) and global integrated assessment modelling scenarios (consistent with a bookkeeping approach) were made conceptually more comparable in terms of the land use, land-use change and forestry emissions definition that they use, based on the harmonization presented in Grassi *et al.* (2021) (see chapter 2 and appendix A for further details).

3. The difference between historical emissions assumed in NDC studies and the historical emissions database of the IPCC AR6 was resolved by applying the modelled absolute change between the harmonization year and the 2030 projections of NDC studies to the historical emissions database of the IPCC AR6 for 2015.

These methodological updates improve the comparability of values across chapters, but it is important to note that they limit the comparability of this year's estimate with those of previous editions of the Emissions Gap Report.

4.2.3 Mitigation scenarios keeping warming below specified temperature limits

To assess the emissions and implementation gaps in 2030, current policies and NDC scenarios are compared with least-cost mitigation scenarios that are consistent with keeping warming below specific temperature limits. Least-cost mitigation scenarios are in line with the principle of the UNFCCC that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost" (UNFCCC 1992). However, least-cost mitigation scenarios generally do not account for the economic co-benefits and avoided damages of mitigation (see box 4.2). Emission pathways from the literature are categorized according to their projected peak global warming outcomes relative to pre-industrial levels over the course of this century. Three scenarios are defined to reflect the three different levels of warming relevant for the temperature goal of the Paris Agreement: 2°C, 1.8°C and 1.5°C (see tables 4.1 and 4.3).

As outlined in the introduction to this chapter, this year the mitigation scenarios have been updated based on the latest set of scenarios collected as part of the IPCC AR6 WGIII Report (Byers *et al.* 2022; Riahi *et al.* 2022), with temperature projections based on the physical science assessment by Working Group I under the IPCC AR6 (Forster *et al.* 2021).

Table 4.3 Global total GHG emissions in 2030 and global warming characteristics of different scenarios consistent with limiting global warming to specific temperature limits

Scenario	Number of scenarios	Global total GHG emissions ($GtCO_2e$)		Estimated temperature outcome			Closest approximate
		In 2030	In 2050	50% chance	66% chance	90% chance	IPCC AR6 WGIII scenario class
Below 2.0°C (66% chance)*	195	41 (37–46)	20 (16–24)	Peak: 1.7–1.8°C In 2100: 1.4-1.7°C	Peak: 1.8–1.9°C In 2100: 1.6–1.9°C	Peak: 2.2–2.4°C In 2100: 2.0–2.4°C	C3a
Below 1.8°C (66% chance)*	139	35 (28–40)	12 (8–16)	Peak: 1.5–1.7°C In 2100: 1.3-1.6°C	Peak: 1.6–1.8°C In 2100: 1.4–1.7°C	Peak: 1.9–2.2°C In 2100: 1.8–2.2°C	N/A
Below 1.5°C (66% in 2100 with no or limited overshoot)*	50	33 (26–34)	8 (5–13)	Peak: 1.5–1.6°C In 2100: 1.1–1.3°C	Peak: 1.6–1.7°C In 2100: 1.2–1.5°C	Peak: 1.9–2.1°C In 2100: 1.6–1.9°C	C1a

* Values represent the median and tenth to ninetieth percentile range across scenarios. Percentage chance refers to peak warming at any time during the twenty-first century for the below 1.8°C and below 2.0°C scenarios. When achieving net-negative CO_2 emissions in the second half of the century, global warming can be further reduced from these peak warming characteristics, as illustrated by the "Estimated temperature outcome" columns. For the below 1.5°C scenario, the chance applies to the global warming in the year 2100, while the "no or limited overshoot" characteristic is captured by ensuring projections do not exceed 1.5°C with more than 67 per cent chance over the course of the twenty-first century or, in other words, that the lowest chance of warming being limited to 1.5°C throughout the entire twenty-first century is never less than 33 per cent. This definition is identical to the C1 category definition used by the IPCC AR6 WG III report. Compared to IPCC (2022), the Emissions Gap Report analysis also selects scenarios based on whether or not they assume immediate action.

Notes: GHG emissions in this table have been aggregated with GWP100 values of IPCC AR6.

Source: Based on underlying data from Byers *et al.* (2022) and Riahi *et al.* (2022)

The 2030 emission benchmark values of the least-cost mitigation pathways in this year's report are higher than those in previous reports, especially for the below 1.5°C scenario. There are two main reasons for this (table 4.2). The most important is the update of the scenario literature evidence base collected in support of the IPCC AR6 (Byers *et al.* 2022; Riahi *et al.* 2022). The rate of emissions decline after 2020 in the below 1.5°C scenario[4] is similar to that of the IPCC Special Report on global warming of 1.5°C and the IPCC AR6. However, the AR6 scenarios show higher GHG emissions in 2030 because the emission reductions generally start from higher levels in 2020, as reflected in the most recent historical emissions inventories (IPCC 2022a; IPCC 2022b). More scenarios in the IPCC AR6 scenario database also end up closer to the temperature limit in the below 1.5°C scenario category (see table 4.3), which again results in higher 2030 emission values.[5] A second, more minor contributing factor, which affects all scenario categories, is the update to the most recent IPCC AR6 values of GWP100.

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[4] These scenarios are all within the IPCC AR6 WGIII category C1.

[5] A detailed discussion of this change between the IPCC Special Report on global warming of 1.5°C and the AR6 WGIII Report is provided in appendix III to the IPCC AR6 WGIII Report (IPCC 2022a), section 3.2.1.

Box 4.2 Putting cost estimates from least-cost emissions scenarios in context

Least-cost scenarios are constructed to achieve global emission reductions at the lowest cost possible. However, estimates of mitigation costs vary extensively and depend critically on the reference and mitigation scenario assumptions and data parameterization chosen (Köberle *et al.* 2021; Riahi *et al.* 2022). If a reference scenario in which global and local economies are at their efficiency frontier is assumed, climate policies will inevitably entail macroeconomic costs. However, the literature, including the latest IPCC assessment, illustrates that this is a stylized and unrealistic assumption (Riahi *et al.* 2022). An economy at its efficiency frontier implies no fossil fuel subsidies, no taxation that distorts the allocation of labour, no "misallocation or under-utilization of production factors such as involuntary unemployment", and no "imperfect information or non-rational behaviours" (Riahi *et al.* 2022). Each of these economic imperfections are common across real-world economies at all levels of development. However, the models that produce least-cost pathways rarely represent all these aspects and hence disregard them in their model estimates of mitigation costs. This results in mitigation cost estimates that are biased high (Köberle *et al.* 2021; Riahi *et al.* 2022). Studies that model a reference economy below the efficiency frontier find that a low-carbon transformation can result in economic stimulus and increase economic growth, conditional on green investments not replacing investment in other parts of the economy (Pollitt and Mercure 2018; Mercure *et al.* 2019; Riahi *et al.* 2022). Because of regional differences in governance, development and societal and technological context, mitigation cost estimates differ between countries. For example, under the idealized assumption that emission reductions are achieved through a globally uniform carbon price, countries with carbon-intensive economies or fossil fuel exporting countries would have relatively higher macroeconomic costs as their economies require a deeper transformation (Stern, Pezzey and Lambie 2012; Tavoni *et al.* 2015; Böhringer *et al.* 2021). For a detailed discussion see Riahi *et al.* (2022).

In addition, mitigation cost estimates of least-cost pathways disregard the economic benefits that accrue through avoided damages and societal co-benefits of a low-carbon transition, such as improved public health because of improved air quality (Köberle *et al.* 2021; Riahi *et al.* 2022). Even when considering least-cost mitigation scenarios where costs are biased high, these benefits likely outstrip the modelled costs (see figure 4.1) (Riahi *et al.* 2022). For example, one study found that health co-benefits outweigh the policy cost of achieving fair national contributions to limit warming to 1.5°C in China and India, with the modelled costs compensated by health co-benefits (Markandya *et al.* 2018).

In conclusion, typically an ideal, perfectly working economy is assumed when mitigation costs are quantified, while the economic co-benefits and avoided damages are unaccounted for. As a result, modelled mitigation cost estimates typically only provide limited real-world insights about the net burden to economies or society. In all cases, these modelled costs occur in a world of continued economic development and growth.

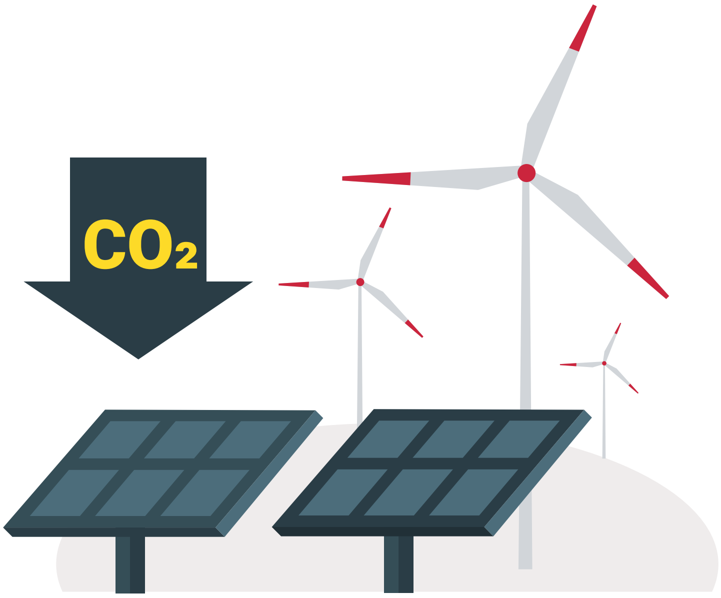
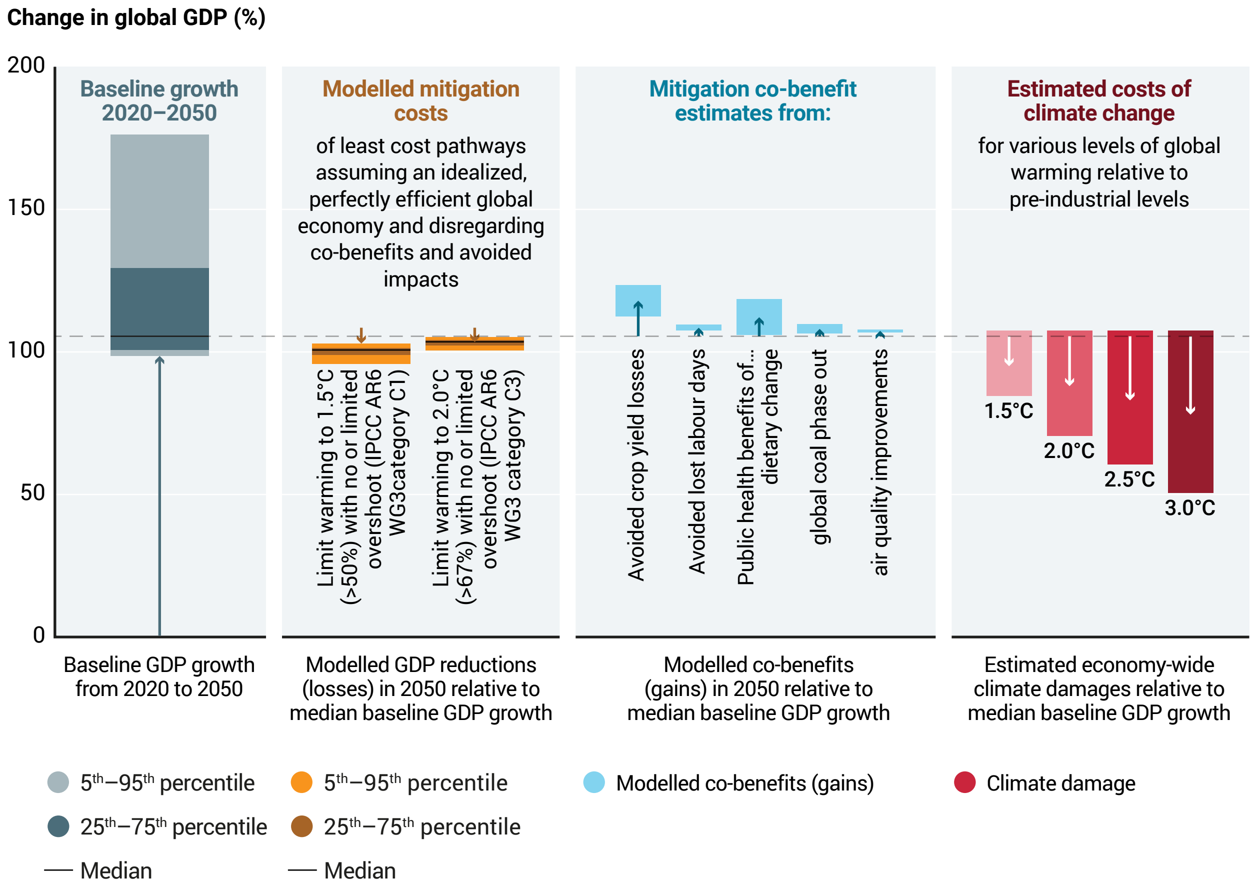


Figure 4.1 Estimated implications for global GDP of mitigation measures, co-benefits and climate damages



Sources: Global baseline GDP growth projections and modelled mitigation costs are from the IPCC AR6 WGIII scenario database (Byers *et al.* 2022; Riahi *et al.* 2022). Modelled GDP co-benefits: crop yields based on Vandyck *et al.* (2018); avoided lost labour days derived from Vandyck *et al.* (2018); public health benefits of a healthier diet from Springmann *et al.* (2016); public health benefits of a global coal exit based on Rauner *et al.* (2020); and an additional estimate of co-benefits from air-quality improvements from stringent mitigation following from Markandya *et al.* (2018). Estimated GDP reductions from economy-wide climate damages are based on the IPCC AR6 WGII Cross-Working Group Box on Economics (O'Neill *et al.* 2022). The latter are quantified for when a specific level of global warming is reached for the first time, irrespective of when exactly this takes place. Note that under current policies, global warming by 2050 can range up to about 2.0–2.5°C. Global warming of 3.0°C would only be achieved later in the century.

Notes: Dark lines in global baseline GDP growth projections and modelled mitigation costs are median estimates, with dark and light ranges representing 25–75 per cent and 5–95 per cent confidence intervals respectively. Mitigation co-benefit estimates cannot be aggregated across sources.

4.3 The emissions gap

The emissions gap for 2030 is defined as the difference between estimated global GHG emissions resulting from full implementation of NDCs, and global total GHG emissions under least-cost scenarios that keep global warming to below 2°C, 1.8°C or 1.5°C with varying levels of chance (see table 4.4). This section updates the gap based on the scenarios described in section 4.2.

Figure 4.2 shows the emissions gap for 2030, with table 4.4 indicating the details. While the latest NDCs narrow the gap slightly compared with previous NDCs, they are highly insufficient to bridge the gap. Altogether, they reduce expected emissions in 2030 under current policies by only 5 per cent. Meeting all conditions and implementing the conditional NDCs would take this reduction to 10 per cent, whereas 30 or 45 per cent is needed for 2.0°C or 1.5°C, respectively.

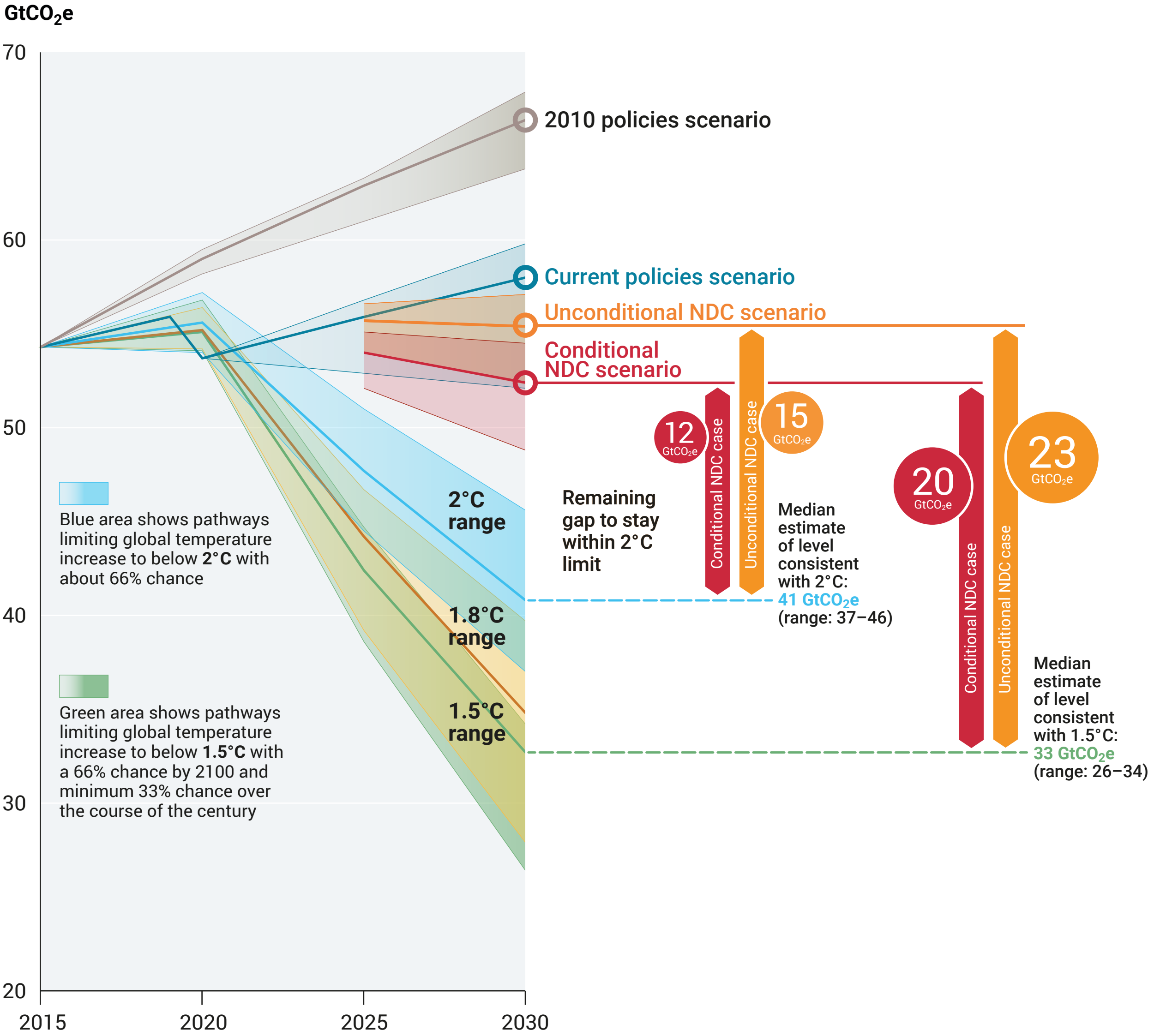
Full implementation of unconditional NDCs is estimated to result in a gap to the 1.5°C scenario of 23 $GtCO_2e$ (range: 20–24). This is about 5 $GtCO_2e$ smaller than estimated in the 2021 report (UNEP 2021) – a difference that is almost entirely due to updates to the 1.5°C scenarios (see table 4.2). As outlined in section 4.2.3, these show higher emissions in 2030 because they start their reductions from higher 2020 emission levels, reflecting a global delay in ambitious climate action. This delay is not without consequences: on average the below 1.5°C scenarios now have a lower chance of effectively keeping warming to 1.5°C . If the conditional NDCs are also fully implemented, the emissions gap to the 1.5°C scenario is reduced by about 3 $GtCO_2e$.

The emissions gap between unconditional NDCs and below 2°C pathways is about 15 $GtCO_2e$ (range: 12–16 $GtCO_2e$), which is about 2 $GtCO_2e$ larger than last year. The main reason for this increase in the assessed gap for 2°C is that this year's report corrects for discrepancies in historical emissions through harmonization (see table 4.2 and box 4.1). Again, the additional full implementation of the conditional NDCs, lowers the emissions gap to the 2°C scenario by about 3 $GtCO_2e$.

In conclusion, the central message remains: NDCs are highly insufficient to put the world on a path to meeting the temperature goal of the Paris Agreement.

Furthermore, countries are not yet on track to achieve these globally insufficient NDCs. The implementation gap, which is the difference between emissions expected under the current policies scenario and those needed to achieve the NDCs, is estimated to be about 3 $GtCO_2e$ and 6 $GtCO_2e$ for the unconditional and conditional NDC scenarios respectively (table 4.4). These gap estimates are 1 $GtCO_2e$ and 3 $GtCO_2e$ larger than last year, mainly because NDCs have been updated while policies have not yet followed suit.

Figure 4.2 GHG emissions under different scenarios and the emissions gap in 2030 (median estimate and tenth to ninetieth percentile range)



With eight years left to bridge the emissions gap, the urgency of rapid emission reductions is clear. The urgency is equally evident when considering the remaining carbon budget. The carbon budget refers to the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given chance, taking into account the effect of other anthropogenic climate forcers. The IPCC estimates that the remaining carbon budget from the beginning of 2020 for limiting warming to a maximum of 1.5°C is approximately 400 $GtCO_2$ and 1,150 $GtCO_2$ for 2°C (both with a 67 per cent chance) (IPCC 2021). When comparing with the current levels of annual global emissions provided in chapter 2, it is evident that the remaining carbon budget for 1.5°C will be exhausted around the end of this decade, unless significant emission reductions are rapidly achieved. In this context, there is growing attention to the potential contributions from reducing emissions from short-lived climate pollutants, particularly methane emissions (see box 4.3).

Table 4.4 Global total GHG emissions in 2030 and the estimated emissions gap under different scenarios

Scenario	GHG emissions in 2030 ($GtCO_2e$)	Estimated emissions gap in 2030 ($GtCO_2e$)		
	Median and range	Below 2.0°C	Below 1.8°C	Below 1.5°C
Year 2010 policies	66 (64–68)	--	--	--
Current policies	58 (52–60)	17 (11–19)	23 (17–25)	25 (19–27)
Unconditional NDCs	55 (52–57)	15 (12–16)	21 (17–22)	23 (20–24)
Conditional NDCs	52 (49–54)	12 (8–14)	18 (14–20)	20 (16–22)

Notes: The gap numbers and ranges are calculated based on the original numbers (without rounding), and these may differ from the rounded numbers in the table. Numbers are rounded to full $GtCO_2e$. GHG emissions have been aggregated with the IPCC AR6 values of GWP100.

Box 4.3 The role of rapid methane emission reductions

In conjunction with CO_2 emission reductions, rapid reductions in emissions from methane and other short-lived climate pollutants are critical to lower peak warming, reduce the likelihood of overshoot and decrease the reliance on CO_2 removal methods to limit warming later in this century (IPCC 2021; IPCC 2022). Global average methane concentrations in the atmosphere have increased by 162 per cent compared with pre-industrial levels (WMO 2021). This increase is largely driven by anthropogenic sources, mainly enteric fermentation of livestock and manure, rice cultivation, waste, and fossil fuel exploration (Jackson *et al.* 2020). Methane has a significantly higher global warming potential than CO_2 (80 and 83 times higher over 20 years for biogenic and fossil methane, respectively), but a much shorter atmospheric lifetime (about 12 years) (Forster *et al.* 2021). Reducing methane emissions therefore affects warming rates in the near term, resulting in benefits for ecosystems and people, and enabling humans to adapt to climate change (UNEP 2021).

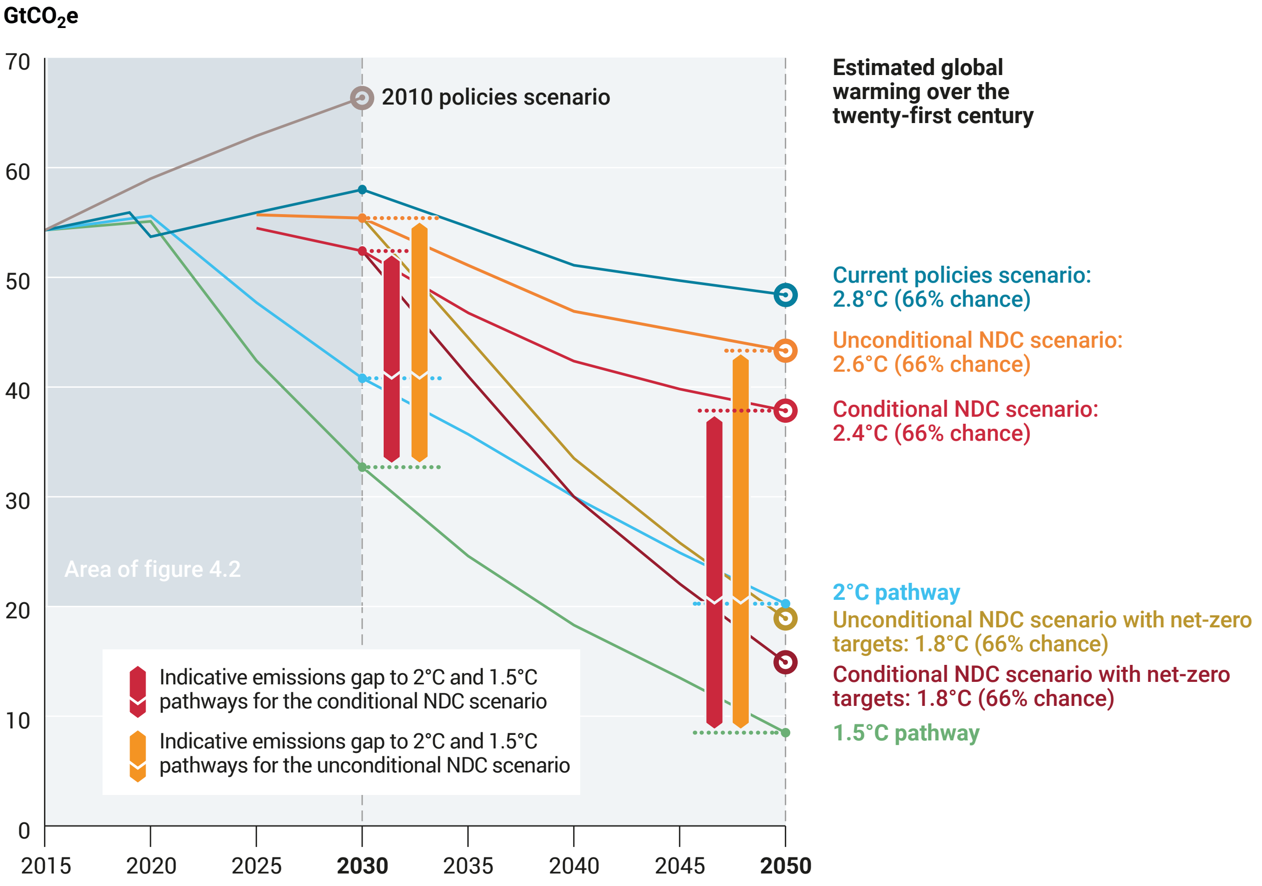
Estimates of the remaining global carbon budget for 1.5°C assume that methane is strongly reduced by at least 30 per cent, 40 per cent and 50 per cent relative to 2020 levels in 2030, 2040 and 2050 respectively (IPCC 2018). Every ca 100 Mt shortfall in methane reductions compared with these benchmarks diminishes the already very small cumulative remaining carbon budget by around 450 $GtCO_2$ (UNEP 2021). Reducing emissions from methane is therefore an essential part of Paris-compatible mitigation strategies.

The 2021 Emissions Gap Report (UNEP 2021) found that global anthropogenic methane emissions can be reduced by around 30 per cent by 2030 through implementation of readily available methane-targeted measures. Implementation of both readily available mitigation measures and broader structural and behavioural measures could reduce methane emissions by nearly 50 per cent by 2030 (UNEP 2021). The largest methane emission reduction potential is available in the fossil fuel sector, followed by the waste sector and the agriculture sector. Roughly one third of all technical mitigation options pay for themselves, with the largest fraction in the oil and gas subsector (UNEP and Climate and Clean Air Coalition 2021).

To realize this opportunity, a Global Methane Pledge was announced at United Nations Climate Change Conference of the Parties (COP) 26, with the aim to reduce global anthropogenic methane emissions by at least 30 per cent by 2030 from 2020 levels. So far, 122 countries have joined the pledge, covering half of global methane emissions and nearly two thirds of the global economy. Large methane emitters such as Australia, China, India, Iran, and the Russian Federation have yet to join the pledge, and efforts to track its implementation are still in the process of being established.

Looking beyond 2030, figure 4.3 projects global GHG emissions out to 2050 under different scenarios and indicates the associated global warming implications over this century (see section 4.3). The figure illustrates the substantial increase in the emissions gap for 2050 if climate efforts implied by current policies and NDC scenarios are continued without further strengthening. Implementation of net-zero targets by around mid-century would significantly reduce these gaps, but even then, gaps with the 1.5°C scenarios would remain.

Figure 4.3 Projections of GHG emissions under different scenarios to 2050 and indications of emissions gap and global warming implications over this century (medians only)



4.4 Temperature implications of the emissions gap

Neither current policies nor NDCs put emissions on track to limit global warming to the temperature goal of the Paris Agreement. The extent of the shortfall in ambition and implementation can also be expressed in terms of the estimated resulting global warming. The same method is applied as in last year's report (see box 4.1 in UNEP 2021) to project the emissions implications of current policies and NDCs from 2030 out to 2100. The global warming implications of these emissions are subsequently assessed with a climate model that captures the latest climate science assessment and uncertainties of the IPCC AR6 (Smith *et al.* 2018; Forster *et al.* 2021). This approach allows accounting for the uncertainties in current policies and NDCs, the degree to which climate action continues beyond 2030, and the uncertainties of how the climate responds to these emissions.

As table 4.5 and figure 4.3 show, a continuation of the level of climate change mitigation efforts implied by current unconditional NDCs is estimated to limit warming over the twenty-first century to about 2.6°C (range: 1.9–3.1°C) with a 66 per cent chance, and warming is expected to increase further after 2100 as CO_2 emissions are not yet projected to reach net-zero levels. Continuing the efforts of conditional NDCs lowers these projections by around 0.2°C to 2.4°C (range: 1.8–3.0°C) for a 66 per cent chance. Because current policies are insufficient to meet even the unconditional NDCs, a continuation of current policies would result in about 0.2°C higher estimates of 2.8°C (range: 1.9–3.3°C) for a 66 per cent chance.

Table 4.5 Estimated global warming implications over the course of the twenty-first century under different scenarios and likelihoods

Scenario	Estimated global warming over the twenty-first century with various chances (median and range)		
	66%	50%	90%
Current policies	2.8°C (range: 1.9–3.3°C)	2.6°C (range: 1.7–3.0°C)	3.3°C (range: 2.3–3.9°C)
Unconditional NDCs	2.6°C (range: 1.9–3.1°C)	2.4°C (range: 1.7–2.9°C)	3.1°C (range: 2.3–3.7°C)
Conditional NDCs	2.4°C (range: 1.8–3.0°C)	2.2°C (range: 1.7–2.7°C)	2.8 (range: 2.2–3.5°C)
Unconditional NDCs and long-term net-zero targets	1.8°C (range: 1.8–2.1°C)	1.7°C (range: 1.7–1.9°C)	2.1 (range: 2.0–2.5°C)
Conditional NDCs and long-term net-zero targets	1.8°C (range: 1.7–1.9°C)	1.7°C (range: 1.6–1.8°C)	2.0°C (range: 2.0–2.3°C)

Net-zero targets provide further information about how emissions might evolve after 2030, assuming these targets are achieved. This year's report considers net-zero targets and announcements of the G20 members and nine other countries with at least 100 $MtCO_2e$/year emissions in the year 2018 (see appendix C, table C.3).[6] This is an expansion of the analysis compared with last year, where only targets of G20 members were considered. Achieving net-zero targets in addition to unconditional NDCs results in projected global warming being held to 1.8°C (range: 1.8–2.1°C) with a 66 per cent chance. Assuming that conditional NDCs and pledges are achieved and followed by net-zero targets, global warming is similarly projected to be kept to 1.8°C (range: 1.7–1.9°C) with a 66 per cent chance. However, in most cases neither current policies nor NDCs currently trace a credible path from 2030 towards the achievement of national net-zero targets (see chapter 3).

These temperature projections are slightly lower than those reported in the 2021 Emissions Gap Report, because the latest NDCs, if fully implemented, lower 2030 emissions estimates by about 0.7 $GtCO_2e$ (see table 4.3) and because the inclusion of more countries in the net-zero analysis further lowers emissions projections over the course of the century. The effect of the methodological updates for the gap estimations is much lower, as similar methodological steps were already used in the temperature projections in earlier reports.

As illustrated above, global warming levels only get close to the Paris Agreement temperature goal when full implementation of the highly uncertain net-zero targets is assumed in addition to the NDC scenarios. In addition, there is still significant uncertainty about how much warming we will experience over the course of this century. Figure 4.4 shows the range of global warming outcomes under three scenarios (current policies, unconditional NDCs and unconditional NDCs combined with net-zero targets announced by countries). The figure illustrates that the risk of levels of warming clearly beyond 2°C remains, even under the optimistic assumption of current climate promises expressed in NDCs and net-zero targets. Current policy projections globally lead to about a 20 per cent chance of global warming exceeding 3°C. If measures are put in place that ensure current NDC and net-zero targets will be achieved, the risk of exceeding 3°C is strongly reduced. Taking more ambitious climate actions by 2030 is urgently needed and is of utmost importance for getting the world on track to meeting the Paris Agreement.

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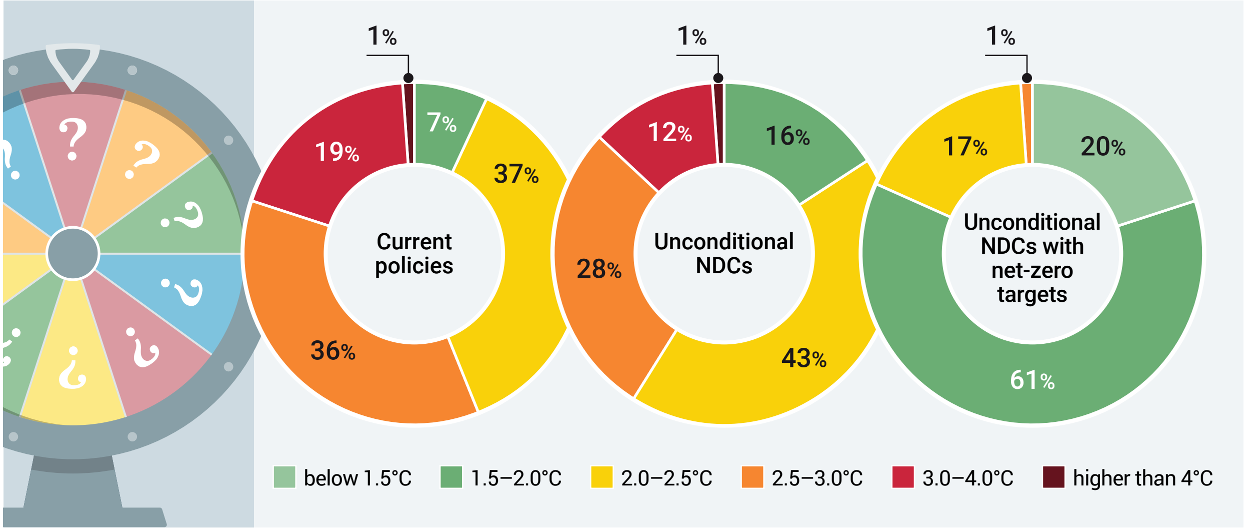
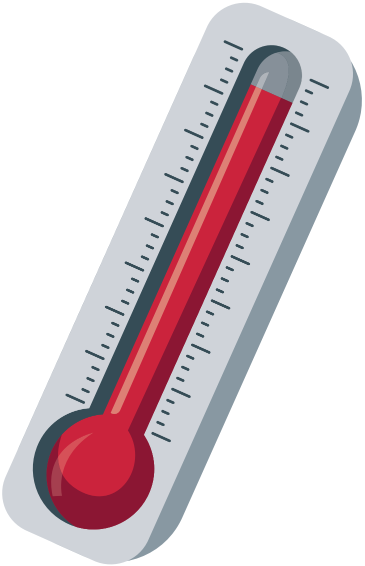
[6] This estimate assumes countries' emissions remain constant once their net-zero target is achieved.

Figure 4.4 Range of global warming projections for three key scenarios

Range of global warming outcomes projected if current policies (left), unconditional NDCs (middle), and unconditional NDCs combined with net-zero targets announced by countries (right) are achieved.





5

Transformations needed to achieve the Paris Agreement in electricity supply, industry, buildings and transportation

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5.1 Introduction

In light of the magnitude of the emissions gap, wide-ranging, large-scale, rapid and systemic transformation is now necessary to achieve the temperature goal of the Paris Agreement. To inform action, the emissions gap can be translated into sectoral transformations that bend the emissions trajectory by 2030 and lead to zero emissions in the longer term. The challenge is that multiple major transformations must be initiated in this decade, simultaneously across all systems. Transformations of the way we power our homes and businesses; transport people, goods and services; grow and consume food; build our cities; and manage our lands, are among the required shifts, which need to take place while simultaneously improving the livelihoods of the poorest including women and minorities, and achieving the Sustainable Development Goals. Shifts are needed from phasing out fossil fuels, to electrifying transport, to stopping deforestation, to retrofitting buildings (Intergovernmental Panel on Climate Change [IPCC] 2021).

The energy, food security and cost of living crises fuelled by the war in Ukraine, with resulting energy supply shortages and price spikes, has added an additional imperative to act. The conflict highlights the vulnerability of the current global energy system, given its dependence on fossil fuels produced from a very small number of countries. In the short term, many governments seek to secure alternatives to Russian oil and gas; in some cases, coal use is on the rise. They also aim to reduce demand for fossil fuels through behavioural measures, energy efficiency and faster investments in renewable energy. The net effect on the climate agenda and transition to renewables is still unknown (Climate Action Tracker [CAT] 2022b).

This chapter focuses on the key transformations required in electricity supply, industry, buildings and transportation, while chapter 6 focuses on the transformation of food systems, and chapter 7 on transforming the financial system. For the purposes of this report, transformation is defined as "the reconfiguration of a system, including its component parts and the interactions between these elements, such that it leads to the formation of a new system that produces a qualitatively different outcome" (Boehm *et al.* 2021).

For each sector, the shifts required to limit warming to well below 2°C, preferably 1.5°C, including benchmarks for 2030 and 2050, are assessed and pressure points to accelerate action are identified. Sets of actions that are most critical to advance, as well as sets of actions that should be avoided given the barriers they create to accelerating change, are offered, while highlighting what various actors can do to accelerate action.

The chapter presents a global agenda. While the list of priority actions is relevant for most countries, the chapter does not offer recommendations at the national or regional level. Each nation varies in its resources, capacity and emissions composition, and accordingly, mitigation priorities and opportunities will vary.

5.2 Initiating, accelerating and accomplishing the transformation towards zero emissions

A significant challenge is that the required transformations have to happen in all sectors and all countries in parallel. The sequencing of actions can vary slightly by country, but as the remaining carbon budget is so limited that the transition needs to be initiated at an accelerated pace immediately, everywhere.

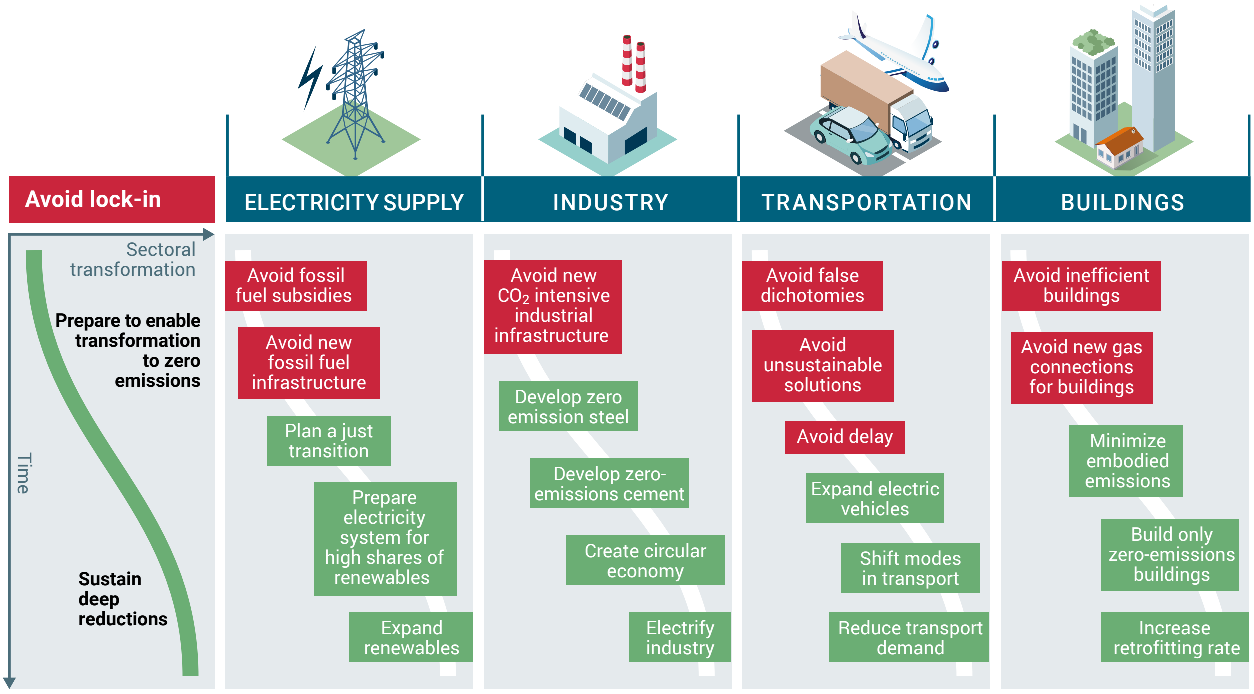
Sectoral transformation based on technological change can follow an S-curve path, with limited change initially, followed by sudden exponential growth and then by saturation (figure 5.1, also see the glossary). With the clear goal of transformation towards zero emissions, there are three broad areas of actions that need to be undertaken in all emitting sectors:

- **Avoid lock-in:** Decisions made today can define emissions trajectories for decades to come. For example, a building lasts 80 years on average; a coal-fired power plant 45 years; a cement plant 40 years (Erickson, Lazarus and Tempest 2015). Pipelines and gas connections create decade-long dependencies. Interventions can also lock in behaviour and policies that reinforce incumbent systems (Seto *et al.* 2016). Actions today that lock in a high-energy and high-carbon future for decades must be avoided, including avoiding new fossil fuel infrastructure for electricity and industry, car-centred city or regional planning, and inefficient new buildings. These actions do not always result in immediate emission reductions, but are fundamental for the long-term transition.

- **Initiate zero-carbon technological advancements:** Zero-carbon technologies, market structures and planning for a just transformation typically need to be advanced in the beginning of a transition and are fundamental for the long-term transition. For many transformations, it will also be necessary to phase out incumbent fossil fuel-intensive industries at the same time as zero-carbon alternatives are scaled up. Focusing only on the latter is risky, as zero-carbon alternatives may not entirely replace new demand or existing infrastructure.

- **Sustain deep reductions:** For sectors and technologies that are advanced on the transformation curve, deep reductions need to be sustained, for example through further expansion of renewables, electrification of industry, electric vehicles and increasing the retrofit rate of buildings.

Figure 5.1 Selected important transformation interventions (green) and things to avoid (red) grouped by “avoiding lock-in” and different stages of the transformation S-curve



Notes: See sections 5.5–5.8 for more details.

The ability to achieve the transformations necessary depends on how a series of interrelated barriers and drivers of progress are approached. These include the following (Boehm *et al.* 2021, based on Olsson *et al.* 2004; Geels and Schot 2007; Chapin *et al.* 2010; Folke *et al.* 2010; Westley *et al.* 2011; Levin *et al.* 2012; O’Brien and Sygna 2013; Moore *et al.* 2014; Few *et al.* 2017; Patterson *et al.* 2017; Sterl *et al.* 2017; Hölscher *et al.* 2018; Reyers *et al.* 2018; Victor, Geels and Sharpe 2019; Initiative for Climate Action Transparency 2020; Levin *et al.* 2020; Otto *et al.* 2020; Sharpe and Lenton 2021):

- **Institutions:** Institutions guide decision-making, and their design can stymie or accelerate progress.

- **Policies and incentives:** Strong regulations such as mandates and standards, and incentives such as tax breaks, can either steer towards low-carbon alternatives or perpetuate an uneven playing field for new entrants.

- **Norms, culture and behaviour:** Once norms and culture that favour low-carbon alternatives are engrained in behaviour, change can take off more rapidly and is harder to reverse.

- **Actors:** Actors in their individual capacity (e.g. leaders, citizens, consumers, voters), professional capacity (e.g. town planners, builders, teachers, investors) or collective capacity (e.g. the youth climate movement) can catalyse and sustain change. At the same time, entrenched interests present significant barriers to advancing systems change. Involving diverse sets of champions can help shape durable outcomes.

- **Innovation:** Advances in technology, practice and approaches can help leapfrog current ones and hasten rates of decarbonization (Boehm *et al.* 2021). The enabling environment for innovation, e.g. spending on research and development and intellectual property rights, can be designed in a way that either advances an innovation agenda or stymies progress.

- **Exogenous shocks/change:** Conflicts, recessions, elections, etc., create openings for advancing change, or close doors to making progress. Preparing for these openings can help ensure that transformational change is catalysed rather than stalled.

5.3 Electricity supply

Achieving the temperature goal of the Paris Agreement requires rapid global transformation of the power system, which is the single largest source of energy-related CO_2 emissions globally, covering 42 per cent of total energy-related emissions (International Energy Agency [IEA] 2021c). At least four shifts need to occur to decarbonize power: (1) steeply accelerating the share of zero-carbon power, (2) phasing out unabated coal and gas generation, (3) adapting grid/storage and demand management, and (4) ensuring reliable energy access for all (Boehm *et al.* 2022).

(1) Steeply accelerate the share of zero-carbon power in electricity generation: The share of zero-carbon power in electricity generation should be between 65 and 92 per cent by 2030, and between 98 and 100 per cent by 2050 (Monteith and Menon 2020; IEA 2021e; International Renewable Energy Agency [IRENA] 2021; Boehm *et al.* 2022).

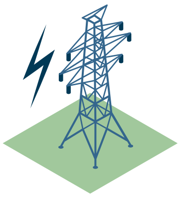
(2) Phase out unabated coal and gas generation: The share of generation from unabated coal needs to fall to zero or near zero in 2030, requiring the pace of change to accelerate by about six times in the next eight years (IEA 2021e; IRENA 2021; Boehm *et al.* 2022). To be aligned with 1.5°C, the share of generation from unabated natural gas needs to fall to 17 per cent in 2030 before being phased out by 2040–2050, requiring a turnaround from its current upward trend (IEA 2021b; IRENA 2021; Boehm *et al.* 2022).

(3) Adapt grid/storage and demand management: A decarbonized power system relying primarily on renewables will require different grid systems than exist today. Flexibility will be key in decentralized supply, storage and demand, given the characteristics of wind and solar.

(4) Ensure reliable energy access for all: Currently, 10 per cent of the world's population has no access to electricity and over 40 per cent has unreliable access (Ayaburi *et al.* 2020; World Bank 2022). Ensuring universal energy access must be part of the shift to a global clean energy system.

A generic set of immediate actions that are necessary to initiate and accelerate the global transformation of the electricity sector (table 5.1) and related actions by different groups of actors (table 5.2) are summarized below.

Table 5.1 Actions that accelerate or hinder the transformation of the electricity sector



ELECTRICITY SECTOR TRANSFORMATION	
MOST IMPORTANT ACTIONS	ACTIONS TO AVOID
EXPAND RENEWABLES: Renewable energy needs to be expanded as fast as possible. Removing barriers is most important, as costs are no longer the issue in many geographies. This can be achieved through policies, incentives, purchases of green electricity, removal of administrative barriers, and direct investments (Falk, Gaffney *et al.* 2020; IEA 2021e; Clarke *et al.* 2022).	**AVOID NEW FOSSIL FUEL INFRASTRUCTURE:** Building new fossil fuel infrastructure needs to be avoided, as it locks in fossil fuel dependency and greenhouse gas emissions for decades, in particular for coal and gas (Falk, Gaffney *et al.* 2020; Clarke et al. 2022).
PLAN A JUST TRANSFORMATION: The transformation needs to be planned carefully in regions that are currently dependent on fossil fuel extraction for jobs and public revenue. Anticipating the change and planning for it seems essential (Falk, Gaffney *et al.* 2020; IEA 2021e).	**AVOID FOSSIL FUEL SUBSIDIES:** Fossil fuel subsidies are still widely applied and stand in the way of the transformation. It is important to eliminate these subsidies in a socially acceptable manner and not to introduce new ones (Falk, Gaffney *et al.* 2020; Clarke *et al.* 2022).
PREPARE ELECTRICITY SYSTEM FOR HIGH SHARES OF RENEWABLES: This includes providing flexible electricity supply, short- and long-term storage, adapting the distribution grids, considering variable electricity demand, and adapting the electricity market to incentivize this (Falk, Gaffney *et al.* 2020; IEA 2021e; Clarke *et al.* 2022).	

Table 5.2 Immediate actions to accelerate the transformation of the electricity sector by actor groups

ELECTRICITY SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP

NATIONAL GOVERNMENTS

- **Remove fossil fuel subsidies in a socially acceptable manner:** While all G20 members have pledged to remove fossil fuel subsidies, all G20 members still apply some fossil fuel subsidies. Due to the energy crisis, many have decreased taxes on fossil fuels, which is a form of new fossil fuel subsidies (Falk, Gaffney *et al.* 2020; CAT 2022b; Clarke *et al.* 2022).
- **Remove barriers to the expansion of renewables:** Allow production for own use, accelerate planning and provision of sites, remove bureaucratic hurdles, regulate grid access and connection, and educate workers (Falk, Gaffney *et al.* 2020).
- **Stop expansion of fossil fuel infrastructure:** This is necessary to avoid lock-in of continued high emissions or expanding stranded assets (IEA 2021e). Many coal power plants are still planned globally (Global Energy Monitor *et al.* 2022), and the current energy crisis has led to a gold rush for new fossil gas infrastructure (CAT 2022b).
- **Plan for a just fossil fuel phase-out:** All governments need to plan for fossil fuel phase-out well ahead and in a socially just manner (Falk, Gaffney *et al.* 2020). Governments should quantify any international support they need.
- **Adapt market rules of electricity system for high shares of renewables:** Adapt the electricity market to cope with the fundamentally different situation of large shares of electricity only being available under certain weather conditions (Falk, Gaffney *et al.* 2020).

INTERNATIONAL COOPERATION

- **Cooperate on and support a just fossil fuel phase-out:** National governments need to cooperate on just fossil fuel phase-out plans (IEA 2021e). Donor governments and multilateral development banks can target support for jobs, skills and investments (IEA *et al.* 2022). South Africa is an example, where a set of donors provide US$8.5 billion for a just transition away from coal (Mason, Shalal and Rumney 2021). Donor governments should also facilitate expert exchanges, capacity-building and support for policy reforms, and leverage both public and private finance (IEA *et al.* 2022).
- **Support international initiatives on emissions-free electricity and power system flexibility and interconnection solutions:** Governments should initiate, sign and implement international initiatives on coal phase-out, the end of fossil fuel production and the end of financing fossil fuel infrastructure, and on scaling renewable electricity, including energy storage, smart grids and interconnection efforts (IEA *et al.* 2022).
- **Agree to higher energy performance standards:** In consultation with industry, governments can cooperate on higher minimum energy performance standards for high energy-consuming appliances, coupled with support for implementation of such standards. This can cut costs and growth in demand (IEA *et al.* 2022).

SUBNATIONAL GOVERNMENTS

- **Set 100 per cent renewable targets:** Subnational governments can create demand for renewable electricity by setting 100 per cent renewable targets (Falk, Gaffney *et al.* 2020).
- **Plan for a just fossil fuel phase-out:** Subnational governments need to plan for fossil fuel phase-out well ahead and in a socially just manner (Falk, Gaffney *et al.* 2020).

BUSINESSES

- **Support a 100 per cent renewable electricity future:** Businesses should purchase 100 per cent renewable power with high quality power purchase agreements or with own production (not through renewable energy credits), electrify their energy end-use, and provide demand flexibility, on-site storage, training and skills (Falk, Gaffney *et al.* 2020; Day *et al.* 2022).

INVESTORS, PRIVATE AND DEVELOPMENT BANKS

- **Engage with or divest from fossil fuel electricity utilities:** Investors need to take responsibility for their shares and engage with fossil fuel electricity utilities to incentivize change, or divest from these assets.
- **Do not invest in or insure new fossil fuel infrastructure:** Investors, banks and insurers should refrain from investing in, supporting or insuring new fossil fuel infrastructure (Falk, Gaffney *et al.* 2020).

CITIZENS

- **Purchase 100 per cent renewable electricity:** Citizens with the economic power to do so should create demand for renewable energy by purchasing 100 per cent renewable power from high quality providers (Falk, Gaffney *et al.* 2020).

5.4 Industry

The industry sector is the largest contributor to global emissions when direct and indirect emissions are included, and the second-largest contributor when only direct emissions are considered (IPCC 2022). To date, efforts to decrease emissions have mainly focused on improved energy efficiency and application of best available technologies. As many industrial processes have already reached maximum theoretically attainable energy efficiency, the key transformations needed to bring the industry sector to a Paris-compatible pathway include (1) electrifying industry and transform production processes, using (2) new fuels, and (3) specific solutions for hard-to-abate sectors; (4) accelerating material efficiency and scaling up energy efficiency everywhere, and (5) promote circular material flow.

(1) Electrify industry: To get on track for the Paris Agreement, the share of electricity in industry's final energy demand must increase to 35 per cent in 2030 and 50–55 per cent in 2050 (CAT 2020). The share of electricity reached 28.5 per cent in 2019, but decreased slightly to 28.4 per cent in 2020 (IEA 2021b).

(2) Reduce demand for and decrease carbon intensity of global cement and steel production: Demand reduction, substitution and carbon management are crucial for decarbonizing the industrial sector. The carbon intensity of global cement production needs to be reduced by 40 per cent from 2015 levels by 2030, and at least 85–91 per cent by 2050 (CAT 2020). The carbon intensity of global steel production needs to be reduced by 25–30 per cent from 2015 levels by 2030, and 93–100 per cent by 2050 (CAT 2020).

(3) Grow and integrate green hydrogen production capacity: There is vast potential for green hydrogen to help decarbonize several sectors, especially the hard-to-abate energy-intensive industry sectors that cannot use electricity. Green hydrogen production capacity needs to grow to 0.23–3.5 Mt (25 GW cumulative electrolyser capacity) by 2026 (in order to achieve costs below US$2/kg) and then massively scale up to 500–800 Mt (2,630–20,000 GW cumulative electrolyser capacity) by 2050 (United Nations Framework Convention on Climate Change 2021), up from almost 0 tons today (IEA 2021d).

(4) Accelerate and scale up material and energy efficiency: Demand for materials has grown 2.5–3.5 times over the past 25 years (Bashmakov *et al.* 2022). Material processing and rising demand are the main drivers of industrial emissions. Basic materials production leads to increases in both direct and indirect emissions. Supply side interventions include changing the material intensity of the product used.

(5) Promote circular material flow: Recycling of waste materials helps to reduce emissions, but the growing complexity of product design and functionality increases the demand for materials. There are still huge gaps and regional variations in recycling. The rates of recycling across various metals varies from 20 to 85 per cent, and the recycling rate of end-of-life waste from industrial material is very low at ca 10 per cent (IPCC 2022; Teske and Pregger 2022).

A generic set of immediate actions necessary to initiate and accelerate the global transformation of the industry sector are summarized in table 5.3, and related actions by different groups of actors are summarized in table 5.4.

Table 5.3 Actions that accelerate or hinder the transformation of the industry sector

INDUSTRY TRANSFORMATION	
MOST IMPORTANT ACTIONS	ACTIONS TO AVOID
FULL DECARBONIZATION OF INDUSTRIAL PRODUCTION: Full decarbonization needs to be initiated today by use of electricity, green hydrogen and carbon management for heat sources and feedstock; for cement, iron and steel; and chemicals and plastics (Rissman *et al.* 2020; Roy *et al.* 2021; Bashmakov *et al.* 2022).	**AVOID NEW CO_2-INTENSIVE INFRASTRUCTURE:** The pipeline of long-lived, carbon-intensive new industrial infrastructure (e.g. steel, cement, chemicals) needs to be avoided by incentivizing new low-carbon processes (Falk, Gaffney *et al.* 2020; Bashmakov *et al.* 2022).
REDUCE MATERIAL WASTE AND RECIRCULATE MATERIALS: Costs and emissions can be lowered by using fewer materials and by increasing the usable lifetime through appropriate infrastructure, industrial parks and networks, policies and expertise (Falk, Gaffney *et al.* 2020; Rissman *et al.* 2020; Bashmakov *et al.* 2022).	**AVOID FOCUS ON NARROWLY DEFINED POLICIES:** Policies that support linear production processes which generate more waste need to be avoided and to be replaced by sequential, cross-sectoral policies which have a wide impact on societal and environmental domains (Rissman *et al.* 2020; IPCC 2022)
REDUCE DEMAND AND ENHANCE ACCESS TO ENERGY-EFFICIENT, MATERIAL-EFFICIENT AND CO_2-NEUTRAL MATERIALS: Access to material-efficient design, light-weight products, and products with longer lifetime reduces total product demand and materials needed. Promotion of sharing economy reduces the demand for automobiles and buildings, and can be facilitated by increased digitalization with strategic policies to avoid rebound in demand (Rissman *et al.* 2020; Bashmakov *et al.* 2022; Creutzig, Roy *et al.* 2022). Material use can also be reduced through process change and technology choice.	

Table 5.4 Immediate actions to accelerate the transformation of the industry sector by actor groups

INDUSTRY SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP

NATIONAL GOVERNMENTS

- **Support zero-carbon industrial processes:** Implement strategic, well-designed policy and incentives to accelerate innovation, technology deployment of clean energy and low-carbon input materials, e.g. development of new, CO_2-free processes or carbon capture (Rissman *et al.* 2020).
- **Promote circular material flow:** Incentivize the use of recycled materials, reduce demand through material efficiency (e.g. foster shift to paper which uses less pulp), substitute low-carbon for high-carbon materials, and introduce circular economy measures such as improving product longevity, reusability and recyclability (Millward-Hopkins *et al.* 2018; Rissman *et al.* 2020).
- **Promote electrification:** Introduce policies to incentivize electrification of the industrial processes that currently use fossil fuels (Rissman *et al.* 2020).
- **Support alternative carbon pricing mechanisms:** Implement carbon pricing policies to incentivize industry leadership in low-carbon action, improve productivity and drive innovation (Rissman *et al.* 2020; World Bank 2021).
- **Support research and innovation:** Remove barriers to and invest in research, development, deployment and innovation, and support energy efficiency and/or emissions standards (Falk, Gaffney *et al.* 2020; Rissman *et al.* 2020; Bashmakov *et al.* 2022).
- **Promote low-carbon products:** Ensure labelling and government procurement of low-carbon products, information dissemination, promoting repair work, data collection and implementation of disclosure requirements, and incentives for recycling (Rissman *et al.* 2020; Bashmakov *et al.* 2022).
- **Plan a just transformation:** Prepare national-level plans for social protection to stay gender sensitive, meet development needs of low- and middle-income countries, and enhance social acceptance of new production systems with the aim to ensure a just transformation for displaced workers and affected communities (Rissman *et al.* 2020).

INTERNATIONAL COOPERATION

- **Cooperate on zero-carbon basic materials:** International cooperation and coordination may be particularly important in enabling change in emissions-intensive and highly traded basic materials industries (IPCC 2022). This can include procurement commitments, strategic dialogues, shared learning on pilot projects, and standard adoption (IEA *et al.* 2022). Additionally, funding will need to be significantly increased to support the industrial transition (IEA *et al.* 2022).
- **Share best practice:** There needs to be support for low- and middle-income countries while making the International Organization for Standardization more progressive, helping in the development of standards and regulations, sharing technology, and accounting to reduce waste in the global supply chain. Global decarbonization efforts need to acknowledge various starting points and stages of human and economic development (Rissman *et al.* 2020; Bashmakov et al. 2022).
- **Cooperate on hydrogen:** International cooperation and coordination is important to develop a market for hydrogen from renewable sources, with coordinated targets, standards, and bilateral and multilateral cooperation agreements and blended finance (IEA *et al.* 2022).

SUBNATIONAL GOVERNMENTS

- **Regional planning and regulation:** Reconsider regional spatial planning and regulations, reform procurement guidelines, explore carbon pricing instruments, engage in labelling, align regulations to facilitate implementation, and ensure accountability for emissions (Bashmakov *et al.* 2022).
- **Cooperate with various stakeholders:** Mitigation actions are implemented at subnational levels, so subnational governments must cooperate with national governments, industry and citizens in implementing mitigation actions (IPCC 2022).

BUSINESSES

- **Plan and implement zero-emission transformation:** Companies, including those operating in hard-to-abate sectors, need to plan their operations to become zero carbon and to implement these plans (Falk, Bergmark *et al.* 2020; Roy *et al.* 2021).
- **Design long-lived products:** Industrial service providers should lead in design of long-lived repairable products and help in the digitization of the processes (Rissman *et al.* 2020; Bashmakov *et al.* 2022; Creutzig, Roy *et al.* 2022).
- **Create circular supply chains:** Create circular and value-free supply chains through collaboration with suppliers and customers (Falk, Gaffney *et al.* 2020).

INDUSTRY SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP

INVESTORS, PRIVATE AND DEVELOPMENT BANKS

+ **Engage with or divest from emissions-intensive industry:** Investors can actively engage with the companies they own shares of to move them towards zero emissions. If this is not successful, they should divest (Creutzig, Roy *et al.* 2022).

+ **Invest in low-carbon energy and process technologies:** Investors and banks should enable investment in low-carbon energy and process technologies and novel chemistries. Investments to significantly reduce costs of new technologies and innovations will be essential for uptake by developing countries (Rissman *et al.* 2020).

+ **Drive awareness of climate risk:** Despite various regulatory and voluntary initiatives, climate-related financial risks remain grossly underestimated. Banks and financial institutions can drive awareness and actions (Roy 2021).

CITIZENS

+ **Consume sustainably:** Users can practice sustainable consumption by intensive use of longer-lived repairable products and avoiding short lifespan products (Creutzig, Roy *et al.* 2022).

+ **Lobby:** Citizens can join various lobby groups to advocate new narratives to influence social norms, corporate advertisements and public policy. Professionals can engage in monitoring, develop and communicate embodied emissions (Creutzig, Roy *et al.* 2022).

5.5 Transportation

Transportation is the second-largest source of energy-related CO_2 emissions globally, contributing 25 per cent of total energy-related CO_2 emissions (IEA 2021c). Transformation of the transportation system requires a number of shifts: (1) a shift to low-emitting modes of transport, (2) an acceleration of the move to zero-carbon cars and trucks, and (3) preparation for the move to zero-carbon aviation and shipping. In addition, car and plane use by frequent travellers should be abated. These shifts should be promoted simultaneously, and many actions can address more than one shift.

(1) Shift to low-emitting modes of transport: A significant shift to lower emitting modes, including public transport, walking and cycling, is required alongside the electrification of transport modes to align with a well-below 2°C and 1.5°C pathway (Institute for Transportation and Development Policy [ITDP] and University of California Davis 2021). Currently, private light-duty vehicles make up 53.2 per cent of all trips (as at 2015, International Transport Forum 2021). The number of trips made by private light-duty vehicles needs to decrease by 4–14 per cent below business-as-usual levels by 2030. The number of kilometres of public transit per 1,000 inhabitants must be doubled by 2030, while the number of kilometres of high-quality bicycle lanes per 1,000 inhabitants should be increased fivefold (Transformative Urban Mobility Initiative 2021; Boehm *et al.* 2022).

(2) Accelerate the move to zero-carbon cars and trucks: Light-duty electric vehicle sales reached 8.3 per cent of total sales in 2021 (Irle 2021). This must increase to between 35 per cent and 95 per cent by 2030, and reach 100 per cent by 2035, requiring an increase in the rate of change by 1.8 to 6 times in the next eight years (Bloomberg New Energy Finance [BloombergNEF] 2018; ICCT 2021; IEA 2021e; IRENA 2021; McKerracher *et al.* 2022; Boehm *et al.* 2022; Cheung and O'Donovan 2022). Heavier vehicles, including buses and medium- and heavy-duty vehicles (MHDVs), should also be decarbonized. Buses have proven to be a success story for vehicle electrification, reaching a high of 43 per cent of bus sales in 2017, driven largely by demand in China (BloombergNEF 2021). However, sales have slowed since then, falling to 39 per cent in 2020, whereas the share needs to increase to 60–100 per cent in 2030 and 100 per cent in 2050 (ICCT 2021; IEA 2021e; IRENA 2021; Boehm *et al.* 2022; Sen and Miller 2022). Zero-carbon options for MHDVs have only just begun to hit the market, reaching 0.2 per cent of sales in 2020 (BloombergNEF 2021). Electric and fuel cell MHDVs are required to reach between 5 and 45 per cent of sales in 2030, and 100 per cent between 2040 and 2050 (IEA 2021e; IRENA 2021; Boehm *et al.* 2022; Sen and Miller 2022; Xie, Dallmann and Muncrief 2022).

(3) Transformation to zero-carbon aviation and shipping: Sustainable aviation fuels are required to meet 13–18 per cent of aviation fuel needs in 2030 and 78–100 per cent in 2050, requiring a significant increase in uptake (IEA 2021e; University Maritime Advisory Services 2021; Boehm *et al.* 2022; Graver *et al.* 2022). Maritime shipping faces similar problems, with a dearth of options for decarbonization outside zero-emissions fuels. Vessels have not yet begun to use zero-emissions shipping fuels, but zero-emissions fuels will need to meet 5–17 per cent of maritime shipping needs in 2030 and 84–93 per cent by 2050 (IEA 2021e; Boehm *et al.* 2022).

A generic set of immediate actions that are necessary to initiate and accelerate the global transformation of the transport sector (table 5.5) and related actions by different groups of actors (table 5.6) are summarized below.

Table 5.5 Actions that accelerate or hinder the transformation of the transport sector

TRANSPORT SECTOR TRANSFORMATION

MOST IMPORTANT ACTIONS	ACTIONS TO AVOID
AVOID: Adopt integrated land-use planning to avoid transport need by prioritizing moving people and improving transport access over private cars.	**AVOID UNSUSTAINABLE SOLUTIONS:** Avoid supporting technologies that are incompatible with deep decarbonization, such as natural gas in road transport and biofuels that lead to deforestation and/or compete with food production (Searchinger *et al.* 2019).
SHIFT: Make investments in, establish pricing for and shift towards low-carbon modes of transport (trains, public transport, cycling).	**AVOID DELAY:** It is important not to delay transport electrification until the electricity grids are cleaner (Sen *et al.* 2021).
IMPROVE: Complete transformation to zero-emissions vehicle technologies for cars, vans, buses and trucks, and for ships and planes in combination with zero-emissions fuels.	**AVOID FALSE DICHOTOMIES:** A 1.5°C pathway requires both electrification of transportation and investment in more compact cities (public transit, walking, biking).

Table 5.6 Immediate actions to accelerate the transformation of the transport sector by actor groups

TRANSPORT SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP

NATIONAL GOVERNMENTS

- **Set mandates to switch to zero-emissions road vehicles by specific dates:** Governments, regions and cities can set regulations to shift towards 100 per cent zero-emissions vehicle sales for new buses by 2030, cars and vans by 2035, and trucks by 2040 (Hall *et al.* 2021; Sen and Miller 2022). These can be complemented with demand-side action to accelerate uptake. Setting CO_2 standards for manufacturers will also help accelerate the transition.
- **Regulate and incentivize zero-carbon fuels for aviation:** Develop regulations and support fiscal policies to transition to 100 per cent low-carbon fuels for aviation and marine sectors by 2050, including advanced biofuels, green hydrogen, renewable electricity, and e-fuels generated with additional renewable electricity (Graver *et al.* 2022; Pavlenko and O'Malley 2022).
- **Adjust taxation/pricing schemes:** Align pricing, taxes and fees on vehicle sales (Wappelhorst 2022), ownership, fuels and transportation activity to support environmental objectives (technology changes, mode shift, avoided travel) (Jaramillo *et al.* 2022).
- **Invest in zero-emissions transport infrastructure:** Align transportation infrastructure funding to invest in high quality zero-emissions public transport, rail, walking/bicycling facilities, ships, aeroplanes and vehicle-charging infrastructure (Minjares *et al.* 2021; Jaramillo *et al.* 2022; Ragon *et al.* 2022).

TRANSPORT SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP

INTERNATIONAL COOPERATION

- **Cooperate on financing and policy development:** Enhance the offer of international financial and technical assistance to support more ambitious transformations and policy development in emerging markets and developing economies (Khan *et al*. 2022). In addition, governments should exchange best practice and improve rules governing trade of vehicles (IEA *et al*. 2022).
- **Coordination on target setting and standards:** Governments and vehicle manufacturers can agree on targets for achieving net-zero vehicle sales, harmonized standards, and scaling up related infrastructure (IEA *et al.* 2022).

SUBNATIONAL GOVERNMENTS

- **Plan infrastructure and supporting policies to reduce travel demand:** Initiate or intensify systemic planning and infrastructure changes that reduce transport demand (ITDP and University of California Davis 2021; Creutzig, Niamir *et al.* 2022; Creutzig, Roy *et al.* 2022; Jaramillo *et al.* 2022). This can include the development of low- and zero-emission zones to accelerate shifts to zero-emissions vehicles in cities (Cui, Gode and Wappelhorst 2021).
- **Plan infrastructure and supporting policies for zero-emissions vehicles:** Invest in smart-charging infrastructure and support regulation for the acceleration of rapid deployment.
- **Adjust taxation/pricing schemes:** Regional and local government should align on local pricing (Basma *et al.* 2022), taxes and fees on car ownership, parking and car access to cities, and public transport to support transformation (technology changes, mode shift, avoided travel) (Jaramillo *et al*. 2022).

BUSINESSES

- **Work towards zero-emissions transport:** Business fleet owners and operators, and shared mobility platforms, can work towards 100 per cent zero-emissions cars (Climate Group 2022), vans, trucks, buses, vessels (Martin 2021) and aeroplane fleets (see action E in Austria *et al.* 2022).
- **Reduce travel in operations:** This especially applies to long-haul flights, and can include the promotion of telecommuting, and provision of workplace charging of electric vehicles.

INVESTORS, PRIVATE AND DEVELOPMENT BANKS

- **Invest in zero-emissions transport infrastructure:** Invest in transit and active transport infrastructure (Jaramillo *et al.* 2022).
- **Support zero-emissions vehicles, vessels and planes:** Support an accelerated transition to zero-emissions vehicles by proactive engagement with investees, encouraging all their holdings to decarbonize their fleets, by making capital and financial products available for consumers, businesses and charging infrastructure manufacturers (see actions F and G in Austria *et al.* 2022).

CITIZENS

- **Adopt active mobility practices:** Opt for walking and cycling where ability and distance allows, and use teleworking or telecommuting in other cases (Creutzig, Roy *et al.* 2022).
- **Use public transit:** Opt for public transit such as (ideally zero-emissions) buses and trains for commuting where available, and when active modes of transport are not practical.
- **Use zero-emissions vehicles:** Choose zero-emissions vehicles when purchasing, leasing or renting (where possible).
- **Avoid long-haul flights:** Avoid the use of private jets and limit long flights whenever alternatives exist, such as trains or electric vehicles (Creutzig, Roy *et al.* 2022).

5.6 Buildings

Direct emissions through building operations are relatively small compared to other sectors and are estimated at 5 per cent of global greenhouse gas emissions, but this number increases to 17 per cent when accounting for indirect emissions from electricity and heat consumption (IPCC 2022). While direct emissions have remained relatively stable at 3 gigatons of CO_2 per year, indirect emissions have almost doubled since 1990 (IEA 2020). To decrease emissions in the building sector, four major shifts are necessary: (1) excess floor area must be minimized, (2) energy intensity must be reduced, (3) the emissions intensity of energy use must decline, and (4) embodied emissions from construction must be reduced (Boehm *et al.* 2022).

(1) Reduce excess floor area: Energy use and emissions from space and water heating and cooling are directly linked to the total amount of floor area that undergoes active thermal control. Furthermore, the greater the extent of new floor area that is constructed, the more materials are required, and the higher are the embodied emissions. The amount of floor area used per person vastly differs across countries, but also within countries. Minimizing the amount of floor area which is well above the area necessary to meet basic needs, can have a large effect on emissions in the sector.

(2) Reduce energy intensity of buildings: The energy that is used for heating, cooling and appliances per square metre of floor area, needs to decrease globally by 10–30 per cent in commercial buildings and 20–30 per cent in residential buildings, relative to 2015 levels, by 2030 (CAT 2020). Global average energy intensity in buildings reduced by 19 per cent between 2000 and 2015, but the reduction has slowed in recent years, with only an additional 2 per cent between 2015 and 2019 (Boehm *et al.* 2022).

(3) Reduce emissions intensity of energy use in buildings: Emissions intensity, or the amount of CO_2 emitted per floor area, is related to energy intensity, but adds the decarbonization factor, meaning that a switch from fossil fuels to electric power (sourced from renewable energy) is needed. In buildings, this entails installing and replacing cooking and heating devices with cleaner technologies, such as heat pumps instead of oil or gas heating, or district heating in dense urban areas (CAT 2020). Emissions intensity in buildings needs be reduced by 45–65 per cent for residential buildings and 65–75 per cent for commercial buildings compared to 2015 levels by 2030, and 95–100 per cent by 2050 (CAT 2020). Although emissions intensity has decreased steadily, the pace needs to be accelerated to meet these targets (Boehm *et al.* 2022).

(4) Reduce emissions from construction: The production of materials such as steel, cement and concrete to construct buildings is a highly energy- and emissions-intensive process. While measures to reduce the emissions intensity of these materials should be pursued (see section on industry above), further reductions can be achieved by more efficient use of these materials. This can include reconstructing existing buildings (rather than demolition and new construction), minimizing the volume of materials required and substituting alternative construction materials (Energy Transitions Commission 2019). Integrated planning and design can be used to minimize energy demand throughout the building construction phase, including transport and on-site energy use. Furnishing the interior of buildings can also be energy intensive, with circular economy principles providing opportunities for lifecycle emission reductions.

A generic set of immediate actions that are necessary to initiate and accelerate the global transformation of the buildings sector (table 5.7) and related actions by different groups of actors (table 5.8) are summarized below.

Table 5.7 Actions that accelerate or hinder the transformation of the buildings sector

BUILDINGS SECTOR TRANSFORMATION

MOST IMPORTANT ACTIONS

EFFICIENT BUILDING SHELL: Optimize building shells to minimize the need for active heating and cooling.

SCALE UP ZERO-EMISSIONS HEATING AND COOLING TECHNOLOGY: Highly efficient air conditioners and heat pumps without hydrofluorocarbons can be powered by renewables, either on-site or supplied off-site through electricity.

ALL NEW BUILDINGS SHOULD BE ZERO CARBON IN OPERATION: New buildings should be designed and constructed so that they are zero carbon in operation, with a minimal energy demand that is met through zero-carbon sources (IEA 2021e).

MINIMIZE EMBODIED EMISSIONS: Emissions from construction materials should be minimized by reducing the emissions intensity of steel and cement production and substituting lower carbon materials, including recycled materials, where possible.

INCREASE RETROFITTING RATE: 2.5–3.5 per cent of buildings need to be retrofitted every year, but recent rates are below 1 per cent per year (IEA 2021a).

ACTIONS TO AVOID

AVOID INEFFICIENT BUILDINGS: Due to the long lifetime of buildings, the lock-in effect of inefficient new buildings is significant and currently potentially incentivized by low ambition or no building codes (Cabeza *et al.* 2022).

AVOID NEW FOSSIL GAS CONNECTIONS: New gas connections should be avoided to not create a lock-in, which would last decades. Improved insulation and electric heating and cooling can reduce fossil gas demand.

PHASE OUT FOSSIL FUEL SUBSIDIES: Several countries subsidize fossil fuel use in buildings, directly or indirectly.

Table 5.8 Recommendations from immediate actions to accelerate the transformation of the buildings sector by actor groups

BUILDINGS SECTOR TRANSFORMATION – RECOMMENDATIONS BY ACTOR GROUP

NATIONAL GOVERNMENTS

- **Regulate towards zero-carbon building stock:** Require all new buildings to be zero carbon in operation and introduce minimum energy performance standards for existing buildings to increase retrofit rates, both accompanied by a comprehensive enforcement strategy (CAT 2022a). Buildings codes can be used to accelerate the transition to using low-carbon building materials for construction, and in limiting emissions during the end-of-life phase of a building. Setting requirements to calculate and monitor these embodied emissions is an important first step (Jordan *et al.* 2020).
- **Incentivize zero-carbon building stock:** Modify cost structures in favour of zero-carbon options through taxes and subsidies, provide incentives for 'best in class' technologies and practices, improve access to finance, and address the landlord-tenant dilemma (CAT 2022a).
- **Facilitate zero-carbon building stock:** Ensure an appropriately skilled workforce and increase institutional capacity for enforcement and awareness-raising (CAT 2022a).

INTERNATIONAL COOPERATION

- **Provide access and favourable conditions to finance:** Support, de-risk or guarantee the upfront investments required to achieve a zero-carbon building stock (GlobalABC and UNEP 2022).
- **Support skills and knowledge growth:** Expand the massively needed skills training and knowledge exchange (GlobalABC and UNEP 2022).

SUBNATIONAL GOVERNMENTS

- **Implement zero-emissions building stock plans:** Subnational governments in particular cities should plan and implement how to arrive at an 100 per cent zero-emissions building stock (Burrows *et al.* 2021). Particularly important is that the design of any new construction is fossil fuel free, and the presence of a vision to rapidly reduce embodied emissions.
- **Integrate low emissions requirements in urban planning:** This includes zoning and parks (Jordan *et al.* 2020).
- **Add requirements on top of national requirements:** Stronger requirements at subnational level can accelerate the transformation (Falk, Gaffney *et al.* 2020). Several examples exist where, for example, cities add renewable obligations or low/no interest loans for low-income households that are not required at the national level (CAT 2022a).

BUSINESSES

- **Construction and building material companies review business models:** Make and implement zero-emissions plans with zero-carbon building materials if the business model relies on carbon intensive raw materials and high energy buildings (Falk, Gaffney *et al.* 2020).
- **Achieve zero-carbon owned or rented building stock:** Building owners should make their building stock zero carbon without overburdening tenants. Companies that own or rent buildings for their operation, such as offices, shops, warehouses and factories, should do the same (Falk, Gaffney *et al.* 2020; World Economic Forum 2021).

INVESTORS, PRIVATE AND DEVELOPMENT BANKS

- **Adjust strategy and investment criteria for zero-carbon building stock:** Review strategies and align investment criteria with a zero-carbon building stock. This includes the high need for long-term, low-interest loans for zero-carbon buildings with their higher upfront investment and lower operating costs.
- **Support building retrofits:** Financial institutions, in particular banks, should actively support building retrofits with favourable conditions.

CITIZENS

- **Retrofit:** Private homeowners should retrofit their buildings to become zero carbon, where relevant.
- **Tenants challenge landlords:** Tenants should actively approach their landlords and ask for zero-carbon buildings and necessary retrofits.
- **Adopt energy-saving behaviour:** Citizens should save energy by choosing desired inside temperatures that do not greatly differ from outside temperatures, switching off unnecessary lights and being mindful when using appliances (Creutzig, Roy *et al.* 2022).

6 Transforming food systems

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6.1 Introduction

Food systems are major contributors to climate change and other environmental problems, such as land-use change and biodiversity loss, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems through nitrogen and phosphorus run-off from fertilizer and manure application (Cordell and White 2014; Crippa *et al.* 2021; Diaz and Rosenberg 2008; Foley *et al.* 2005; Newbold *et al.* 2015; Robertson and Vitousek 2009; Shiklomanov and Rodda 2004; Intergovernmental Panel on Climate Change [IPCC] 2019; Wada *et al.* 2010; Willett *et al.* 2019).

If current trends continue, the environmental pressures on food systems are likely to intensify (Jalava *et al.* 2014; Tilman and Clark 2014; Davis *et al.* 2016; Springmann *et al.* 2016; Springmann, Clark *et al.* 2018). Key targets of several Sustainable Development Goals (SDGs) are projected to be at risk (Springmann, Clark *et al.* 2018; Springmann *et al.* 2020), and the greenhouse gas (GHG) emissions from food systems could, on their own, preclude achieving the Paris Agreement goal of limiting global warming to below 2°C, aiming for 1.5°C (Clark *et al.* 2020). Transforming food systems is therefore imperative for avoiding dangerous levels of climate change and other environmental problems.

Moreover, transforming food systems is not only important for addressing climate change and environmental degradation, but also essential for ensuring healthy diets and food security for all. Currently, imbalanced diets that are low in fruits, vegetables, nuts and whole grains and high in red and processed meat are a leading health burden in most regions and are responsible for more than one in five premature deaths globally (GBD 2017 Diet Collaborators 2019; Springmann, Mozaffarian *et al.* 2021). In addition, about 2 billion people are overweight and obese, and 2 billion have nutritional deficiencies, while about 800 million are still suffering from hunger due to poverty and poorly developed food systems (Food and Agriculture Organization of the United Nations [FAO] *et al.* 2020). As the dietary transition towards more processed and high-value products continues in many regions of the world, these dietary health risks are expected to worsen (Springmann *et al.* 2016; Springmann, Wiebe *et al.* 2018).

At the same time, many of the world's poor cannot afford to pay for healthy and sustainable diets (FAO *et al.* 2020; Springmann, Clark *et al.* 2021), and the ongoing crises caused by COVID-19, the war in Ukraine, and widespread extreme climate events are further exacerbating this situation by disrupting food systems and increasing the costs of foods (Guénette, Kose and Sugawara 2022; Organisation for Economic Co-operation and Development [OECD] 2020; Ogundeji and Okolie 2022) (see box 6.1).

Adopting a food systems lens can help in identifying the synergies and trade-offs across the various interconnected environmental, health and economic impacts. Compared to the traditional categorization of agriculture, forestry and other land use (AFOLU), food systems include pre- and post-production processes, which are related to the transportation, industrial activities, storage and consumption of food (IPCC 2019; Rosenzweig *et al.* 2020). The inclusion of several sectors makes the computation of food system emissions more difficult and increases the risk of double counting when summed with and compared to individual sectors (figure 6.1). However, having a food systems approach that explicitly connects the supply and demand sides and all the actors of the food supply chain has many advantages. It ensures that climate change mitigation strategies are compatible with food security, and facilitates the design of integrated adaptation and mitigation policies, including their trade-offs and synergies (Rosenzweig *et al.* 2020). This is particularly important in the current context in which multiple crises impact the supply and demand of food.

This chapter presents the needs, current state and options for accelerating a food system transformation. It focuses on GHG emissions and climate change, but also discusses important synergies and trade-offs with the environmental, health, and economic/equity dimensions throughout the chapter. The chapter will present and discuss transformative solutions that can decrease emissions in the supply and demand side of food systems along with examples of initiatives already in place in various parts of the world. It will also discuss how further actions can be accelerated to ensure that food systems contribute their share to fulfilling the goals of the Paris Agreement.

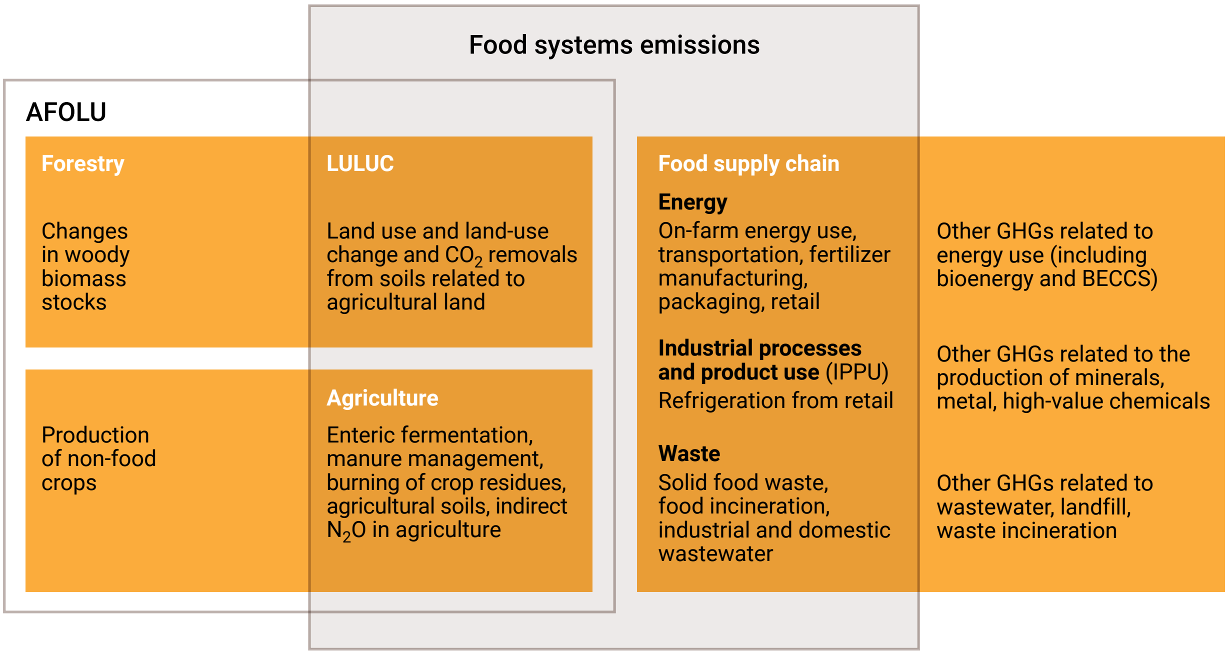
Box 6.1 Equity and justice as vital components to accelerate transformations of food systems

Although any climate stabilization pathway requires a substantial reduction in emissions from food systems, such mitigation efforts must not come at the expense of the health and livelihoods of low-income populations. At a per-person level, the richest 10 per cent of the world's population produces the highest emissions, while the poorest produce the least emissions and suffer the highest consequences of climate change due to their socioeconomic status and reduced adaptive capacities. In 2021, approximately 828 million people were affected by hunger globally, and this figure is estimated to continue increasing with the instability caused by COVID-19 and the war in Ukraine. The current rise in inflation and energy prices adds further pressure to the world's food supply chain. These adverse impacts concern everyone, but they are especially felt by the poorest and the most vulnerable in society, the majority of whom are women.

Better distribution of food and more efficient use of resource is essential to fight food insecurity and malnutrition within the decade (FAO *et al.* 2022). Reducing the use of much of the world's grain production to feed animals and producing more food for direct human consumption can significantly contribute to this objective (IPCC 2022a). In most high and middle-income countries, healthier and more sustainable diets can be cheaper than current diets, but in many low-income countries, they are higher in cost than the prevalent starch-based diets (FAO *et al.* 2020; Springmann, Clark *et al.* 2021). Making healthy and sustainable diets affordable for all is possible, but will require dedicated food system interventions in low-income settings (Springmann, Clark *et al.* 2021).

Poverty alleviation remains a prime goal of low-income countries, and agricultural development will remain a key part of their development strategies, with climate actions more focused on adaptation than mitigation. Climate-resilient development in Africa's rural areas, if it is to tackle entrenched chronic poverty, will need to be transformational, with elements of farm consolidation, irrigation development, improved fertilizer usage, increased market access and enhanced social safety nets, among other elements (Orr *et al.* 2013; Beegle, Coudouel and Monsalve 2018; Lefore *et al.* 2019; Giller 2022). Some of the expected changes can produce mitigation co-benefits, but in other cases food system emissions are likely to rise (Springmann, Wiebe *et al.* 2018). An important objective is therefore to ensure that rural transformation is placed on a low emissions trajectory.

Figure 6.1 Classification of food systems emissions and the difference to standard emissions categories of the IPCC



Notes: The IPCC categories included in food systems are shown within the faded grey square. This figure shows the main differences and overlaps with the more traditional IPCC category of AFOLU (Crippa *et al.* 2021; IPCC 2019). For all official IPCC categories, only parts are included in food systems. Although some agricultural production is dedicated to non-food uses, non-food crops only represent 2 per cent of the emissions, so most of agricultural production is included in food systems. From the category land use, land-use change and forestry (LULUCF), we only include emissions from land use and land-use change within food systems. Thus, emissions and/or sequestration in remaining forest land are excluded from food systems. We followed FAO's definition for the categories energy, industrial processes and product use (IPPU), and waste (Tubiello *et al.* 2021).

6.2 Transformation needs and potential

The food system is currently responsible for about a third of total GHG emissions or 18 (range: 14–22) gigatons of CO_2 equivalent ($GtCO_2e$) per year (IPCC 2019; Crippa *et al.* 2021). The largest contribution stems from agricultural production (7.1 $GtCO_2e$, 39 per cent) including the production of inputs such as fertilizers, followed by changes in land use (5.7 $GtCO_2e$, 32 per cent), and supply chain activities (5.2 $GtCO_2e$, 29 per cent). The latter includes retail, transport, consumption, fuel production, waste management, industrial processes and packaging. Developing countries currently contribute about three quarters (73 per cent) of emissions from food systems, but given their large populations, per capita emission footprints are up to four times lower than those in industrialized countries (Crippa *et al.* 2021). Food system emissions are projected to increase by up to 60–90 per cent between 2010 and 2050 without dedicated measures and if current trends continue with respect to population growth and dietary changes towards more animal source foods, especially in low and middle-income countries (Riahi *et al.* 2017; Springmann, Clark *et al.* 2018; Mbow *et al.* 2020).

Both the current and the projected levels of food system emissions are at odds with the scale of rapid emissions reductions needed across all sectors to achieve the Paris Agreement goals (Clark *et al.* 2020; IPCC 2022b). Even if fossil fuel emissions were quickly reduced, food system emissions could prevent achieving the well below 2°C, preferably 1.5°C goal by the end of the century (Clark *et al.* 2020). For having a 66 per cent chance of limiting global warming to below 2°C, estimates from integrated assessment models have suggested a limit of agricultural emissions (i.e. methane and nitrous oxide) of about 5 $GtCO_2e$ in 2050, in addition to decarbonizing the energy system and limiting emissions from land-use changes (Costa *et al.* 2022; Willett *et al.* 2019).

A range of transformation domains with several mitigation measures have been identified where food systems can contribute to bridge the emissions gap (Springmann, Clark, *et al.* 2018; Roe *et al.* 2019; Clark *et al.* 2020; IPCC 2022b). They include:

1) **demand-side changes**, including dietary changes towards sustainable and nutritionally balanced diets, and reductions in food loss and waste,

2) **protection of natural ecosystems**, including reductions in deforestation for agriculture and degradation of agricultural land,

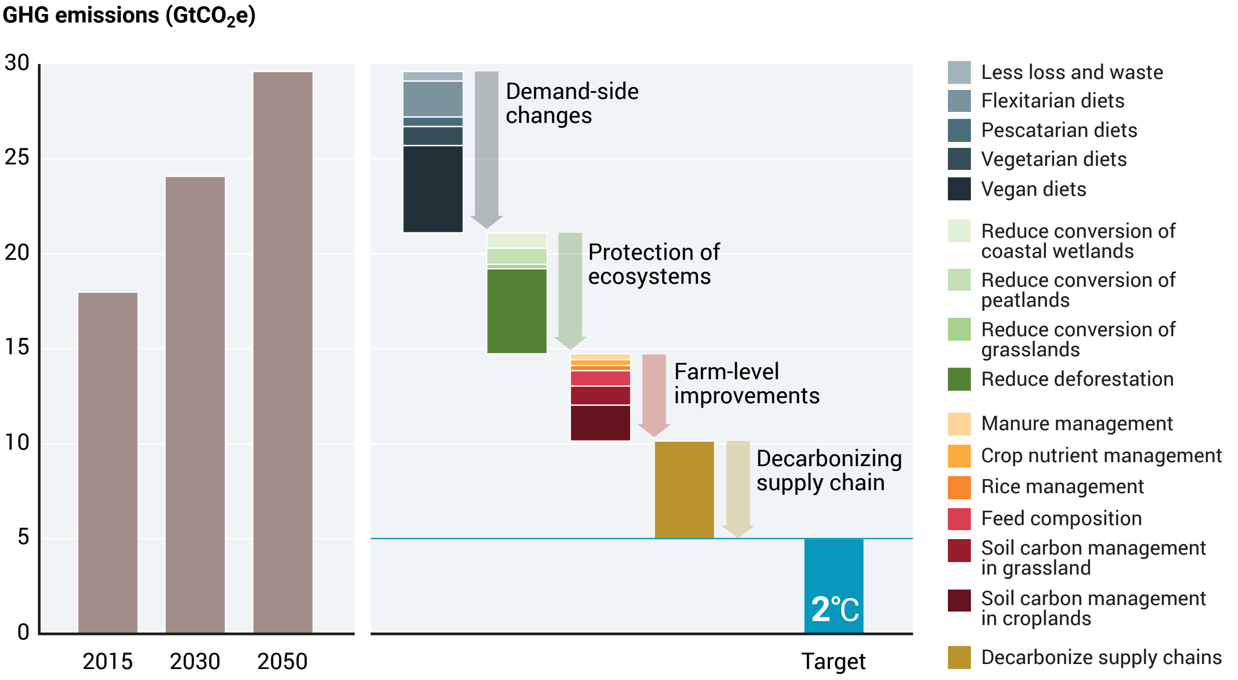
3) **improvements in food production at the farm level**, including changes in the composition of animal feeds, better rice management, better manure management, and improvements in crop nutrient management, and

4) **decarbonizing the food supply chain**, including in retail, transport, fuel use, industrial processes, waste management and packaging.

Figure 6.2 provides an overview of the mitigation potentials of the different measures. We focus on the technical mitigation potentials in the figure, but note that economic potentials (i.e. those achievable below a cost of carbon of US\$100/tCO_2e) are much lower and often just half of the technically achievable potential (IPCC 2022b). To avoid double counting in these estimates, the chapter isolates the demand-side impacts from land use and technical improvements at the farm level. However, any one domain will generally be affected by changes in any other domain. For example, dietary changes towards more plant-based diets will reduce the demand for cropland that then eases measures to reduce deforestation. In addition, each estimate is subject to considerable uncertainty. This is especially evident for technologies or management practices that have not yet been proven to work at scale, including bioenergy with carbon capture and storage (Low and Schäfer 2020) and a range of soil-related activities often classified as regenerative agriculture (Willett *et al.* 2019; Giller 2022). What is clear however is that there is no simple solution, and a combination of measures will be needed to transform food systems in line with targets and pathways for reducing emissions.

When combining mitigation measures, care will have to be taken to avoid trade-offs with other issues of concern, including food security and health, and instead generate synergies. Especially when it comes to food and diets, important synergies exist across the public health concerns for the provision of healthy diets and the elimination of malnutrition and the climate change concern for reducing emissions (Springmann, Wiebe *et al.* 2018; Willett *et al.* 2019).

Figure 6.2 Food systems emissions trajectory and mitigation potentials by transformation domain



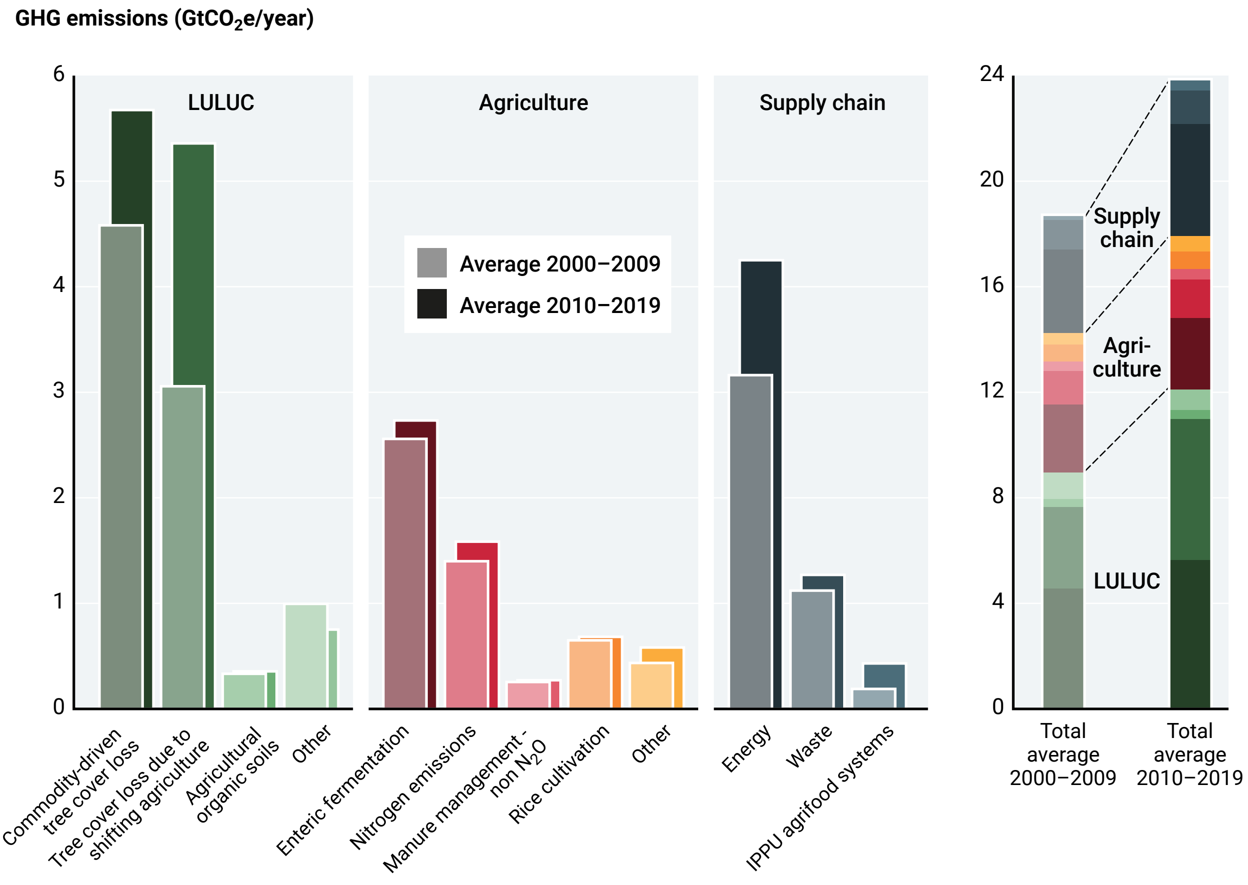
Notes: Current food systems emissions were adapted from Crippa *et al.* (2021), future projections from Costa *et al.* (2022) and the target value for limiting global warming to below 2°C from Willett *et al.* (2019). The projections of future emissions are based on life cycle assessments that include all GHG emissions and land-use effects but hold technologies constant at current levels. The mitigation potentials denote technical potentials and, except for diet changes and supply chains, were adopted from the IPCC *Sixth Assessment Report* (AR6) (2022b). The potentials for dietary changes were updated based on Springmann *et al.* (2018), which are controlled for double counting and include all GHG emissions except those for land-use changes. The estimate of current supply chain emissions from Crippa *et al.* (2021) was used as an illustrative value for mitigation potential for decarbonizing supply chains.

6.3 Signs of progress and options for further action

The evolution of global GHG emissions per transformation domain highlights signs of progress and options for further action. It also shows some encouraging examples across the world. Global food system emissions have increased during the last two decades (figure 6.3). Emissions from agriculture have only slightly increased, while emissions from the food supply chain have dramatically increased (FAO 2021a; Ritchie 2019).

The following examines key subcategories within each transformation domain to get a more detailed understanding of their relative importance and discuss concrete mitigation options. The selected subcategories are meat consumption for demand-side changes, deforestation for the protection of natural ecosystems, nitrous oxide emissions from agricultural soils for improvements in food production at farm level, and energy use in food systems for decarbonizing the food supply chain. Figure 6.3 shows the evolution of emissions by subcategories. These subcategories together account for more than half of total emissions from food systems.

Figure 6.3 Average global annual emissions from food systems between 2000–2009 and 2010–2019



Source: The GHG emissions from food systems supply chain, agriculture, and land use and land-use change (LULUC) excluding forest cover change are taken from FAOSTAT Emissions shares and Emissions Totals (Tubiello *et al.* 2021). Emissions from tree cover loss are taken from Global Forest Watch (Curtis *et al.* 2018). This selection leads to higher total emissions from food systems than Crippa *et al.* (2021), Tubiello *et al.* (2022), and Costa *et al.* (2022).

6.3.1 Sustainable and nutritionally balanced diets

The production of meat was responsible for approximately 54 per cent of GHG emissions from agriculture between 2018 and 2020 (OECD and FAO 2021). Life cycle analyses indicate that meat production—from inputs in its production to retail—has a median value of CO_2e per 100g of protein that is significantly higher than alternative plant-based sources of protein (Poore and Nemecek 2018). For example, beef has a median GHG intensity that is more than 5–10 times higher than pork and poultry, and 50–100 times higher than plant-based protein sources such as beans and lentils. In addition to the climate benefits, eating less red meat, only moderate amounts of poultry, seafood and lean fish as well as increasing the intake of plant-based foods is associated with a lower risk of major chronic diseases (Springmann, Wiebe *et al.* 2018; FAO and WHO 2019; Willett *et al.* 2019).

The production of meat has more than quadrupled since the 1960s (Ritchie 2019). However, developments in how much meat individuals consume per country have been uneven. We see a high correlation between meat consumption and income level. The average daily meat consumption per capita varies from around 25g in low- and lower-middle-income countries which as a total is within the range of recommended intake, but red meat consumption alone is above the recommended levels. In upper-middle-income countries and high-income countries, average meat consumption is far above recommended levels with 105g/cap/d in upper-middle-income countries and 154g/cap/d in high-income countries. In many industrialized countries where the per capita red meat consumption has started to decrease it is partly compensated by an increase in poultry consumption.

These trends show that progress on changing diets has been very limited. This is also reflected in a review of the nationally determined contributions (NDCs) that shows the inaction towards reducing meat consumption both in high-income and higher-middle-income countries (box 6.2). Meat production is projected to increase more than 60 per cent between 2010 and 2050, primarily being driven by population and economic growth, especially in low- and middle-income countries. However, if everybody on the planet consumed within levels recommended for health and the environment (14 g/d or less of red meat, 29 g/d or less of poultry, and 28 g/d or less of fish), meat production would not need to increase beyond current levels (Springmann, Clark *et al.* 2018).

Table 6.1 Examples of positive shifts in meat consumption

Area	Positive shifts
Slovenia, Uruguay and Ecuador*	Average per capita meat consumption between 2010 and 2019 has decreased despite economic growth (Ritchie 2019). More research is needed to highlight the determinants of this change.
Europe and North America*	Vegetarian diets are increasing in popularity. Non-meat consumers represent between 5 and 10 per cent of the total population (Kansas State University 2022; Lusk and Norwood 2016).
Global	Total consumption of meat substitutes has increased by more than three times, and total consumption of milk substitutes has almost doubled between 2013 and 2020 (Friedlingstein *et al.* 2022).

*In these areas, meat consumption currently far exceeds recommended levels.

Box 6.2 Coverage of food system in revised NDCs

Currently, all NDCs include food systems. However, demand-side measures and actions to reduce emissions from food processing, storage and transportation of the food systems are frequently overlooked (Food and Land Use Coalition [FOLU] and Food, Environment, Land and Development Action Tracker 2021; Global Alliance for the Future of Food 2022; Hamilton *et al.* 2021). None of the revised NDCs submitted ahead of the 2021 United Nations Climate Change Conference of the Parties (COP 26) mention the need to reduce the consumption of animal protein. Food loss and waste are only covered in a few NDCs including the ones for the United Kingdom, the European Union, France and South Africa (Global Alliance for the Future of Food, 2022). On the production side, the agriculture and land use sectors feature prominently in the NDCs of developing countries with 86 per cent prioritizing mitigation in these sectors (Crumpler *et al.* 2021), but sustainable livestock production could be better covered, especially by large meat producing countries (Global Alliance for the Future of Food, 2022). Agroecology and regenerative approaches are common, but a clear operational definition of regenerative agriculture is needed. Except for Colombia, food systems actors tended to be overlooked in domestic consultation processes which has likely led to gaps in food systems coverage in the NDCs.

With new data available in FAOSTAT Emissions shares and the Emissions Database for Global Atmosphere Research's global food emission (EDGAR-FOOD) databases (Crippa *et al.* 2022) released in 2021, quantifying and discerning food systems-related emissions and acquiring data on emission patterns has improved. This should facilitate the coverage of food systems in future NDCs (Crippa *et al.* 2021).

6.3.1 Protection of remaining natural ecosystems

For this transformation domain, the selected subcategory is deforestation, the main source of emissions from LULUC (figure 6.3). Deforestation also reduces the future removals of atmospheric carbon in natural forests, further exacerbating climate change (Maxwell *et al.* 2019). At the global level, food systems can be directly related to almost half of tree cover loss through commodity-driven deforestation and shifting agriculture, and the contribution could be higher if linked to wildfires (Curtis *et al.* 2018; Pendrill *et al.* 2022). Halting deforestation therefore is key for both environment protection and climate change mitigation. The SDGs include a target of halting deforestation by 2020 (target 15.1), and the objective has been restated in several declarations e.g. during COP 26 with the Glasgow Leaders' Declaration on Forests and Land Use.

Despite all these commitments, deforestation related to food systems has continued to increase from 8 million hectares (Mha) per year in 2001–2010 to 11.5 Mha/year in 2011–2020 according to statistics from the Global Forest Watch (GFW) on tree cover loss driven by commodities and shifting agriculture (GFW 2022). It is estimated that 29–39 per cent of emissions were driven by international trade (Pendrill *et al.* 2019).

Global GHG emissions estimates for deforestation in 2001–2020 vary between 3.4 and 9.5 $GtCO_2$ per year on average (FAO 2021a; Grassi *et al.* 2022; Friedlingstein *et al.* 2022; GFW 2022). Differences can be partly explained due to differences in definitions of forests and deforestation. Uncertainty in carbon stocks in forests is another source of variation across estimates, especially at fine scales.

Without new forest conservation policies, 289 million hectares of tropical forest could be cleared by 2050 (Busch and Engelmann 2017) and have dramatic impacts on climate change, traditional livelihoods, human health, biodiversity loss and ecosystem services.

With less than eight years to close the emissions gap there is a need for effective, unified and public systems of monitoring, reporting and verification (MRV) of deforestation to make governments and companies accountable for their deforestation commitments (Nabuurs *et al.* 2022). Local communities and traditionally marginalized groups such as indigenous communities inhabiting and or living close to forested areas are deeply vulnerable to the impacts of deforestation and therefore should be closely involved (FAO 2022). Their contributions and knowledge are invaluable and can help to address important sources of risk.

Table 6.2 Examples of positive shifts in addressing deforestation

Area	Positive shifts
Brazil	There was an impressive slowdown in deforestation in the Brazilian Amazon between 2005 and 2011. The combination of real-time monitoring (Real Time Deforestation Detection System), public release of annual deforestation data (Basin Restoration Program), strong law enforcement, expansion of protected territory and adoption of a conditional rural credit policy has been key to curbing deforestation during that period (Assunção, Gandour and Rocha 2015). Unfortunately, political changes mean that deforestation has increased again since then, even if it remains below its peak in 2005 (zu Ermgassen *et al.* 2020).
Indonesia	Deforestation in Indonesia has been reduced for the fourth year in a row (GFW 2022; Gaveau *et al.* 2022). The moratorium on new licences for primary forests and peatlands introduced in 2011 has played an important role to reduce conversion of natural forests and peatland drainage to install timber or oil palm plantations. More than 80 per cent of the oil palm refining capacities and the pulp and paper industry in Indonesia have also committed to 'No Deforestation, No Peat and No Exploitation'.
European Union	In September 2022, the European Parliament voted to enable a law that conditions farmers to document that products being sold to the European Union are neither involved with human rights abuse nor deforestation. Being responsible for approximately 16 per cent of deforestation in the tropics (Pacheco *et al.* 2021), the European Union can address its consumption of products associated with ecosystem degradation to have real impacts.

6.3.2 Reduction of emissions from agricultural production

Enteric fermentation of ruminant livestock is the major source of emissions from agricultural production. beyond changes in diets, the reduction of methane emissions from ruminants can be achieved through changes in feed level and feed composition, which can also increase animal productivity (Frank *et al.* 2018; Arndt *et al.* 2022).

Growing rice is another important source of emissions from agriculture, especially for low- and middle-income countries. Paddy farming relies on flooded cultivation fields that emit large quantities of methane into the atmosphere via anaerobic decomposition (Gupta *et al.* 2021). Changes in water management can significantly reduce methane emissions from rice (Islam 2021).

Another prominent GHG is nitrous oxide, which is mainly emitted from agricultural activities. This includes emissions from the application of synthetic fertilizers on agricultural land and from livestock manure that is either used as organic fertilizers for crops or left on pastures. In 2019, nitrous oxide emissions from soils represented 25 per cent of total agricultural emissions (FAO 2021a), making it the second largest source of emissions from agriculture after methane emissions. Production of synthetic fertilizers is also a large source of emissions from the supply chain. reducing on-farm synthetic fertilizer would therefore lead to a reduction in this source of emissions too. Tackling excessive on-farm nitrogen use carries important co-benefits for air pollution through reduced ammonia emissions that would otherwise contribute to particular matter concentrations, and for water quality, as excessive nitrogen use leads to the excessive growth of aquatic plants and algae that can reduce the diversity of animals and plants and compromise the possible uses of the affected water (de Vries 2021; Maúre *et al.* 2021).

Global nitrogen emissions from synthetic fertilizers and livestock manure have continued to grow after 2010, and the average annual emissions in 2010–2019 were 14 per cent higher than in 2000–2009 (FAO 2022). While average annual emissions have been nearly stable in high-income countries and only increased by 7 per cent in upper-middle-income countries, they have strongly increased in lower-middle-income and low-income countries (by 25 and 69 per cent, respectively). Reducing nitrogen use without impacting yield is not straightforward due to the fact that different crops have different needs independent of factors such as topography and slope (which can vary during the growing cycle), crop type and weather conditions (Sharma and Bali 2018).

From equity and food security perspectives, unequal access to fertilizers is an important area of concern. For example, judicious use of fertilizers and organic nutrients are essential to increasing crop productivity in large areas of inherently poor and highly weathered soils in Africa (Zingore and Njoroge 2022). For context, to achieve self-sufficiency in maize in nine countries in sub-Saharan Africa, maize yields would have to increase from about 20 per cent of water-limited yield potential currently to approximately 50–75 per cent of the potential, with nitrogen input rising disproportionately more (by 9–15 times) (Rurinda *et al.* 2020).

Table 6.3 Examples of positive shifts in emissions from agricultural production

Area	Positive shifts
China	Nitrogen emissions from synthetic fertilizers and livestock manure have reduced over the last three years because of a long focus on reducing fertilizer use. Since 2005, a policy on zero increase in chemical fertilizer use has been introduced (Wang *et al.* 2022) and a programme has been running to test soils and use fertilizers based on exact needs, with US$1.2 billion of government investment. The scheme has been applied on 100 Mha of land, which has increased the efficiency of fertilizer use by 5 per cent while increasing grain harvests by 6–10 per cent. In 2017, the Government of China started a five-pronged push to develop green agriculture. This included replacing chemical fertilizers with organic compost made from fruits, vegetables and tea (Kun and Genxing 2021).
Europe	Nitrous oxide emissions declined from 1990 levels (IPCC 2022b) and the nitrogen surplus applied to agricultural land was reduced by 18 per cent between 2000 and 2009, (Cook 2018), mainly thanks to public regulation. The European Union Nitrates Directive (91/676/EEC) was established in 1991 to balance fertilization requirements and prohibited nitrogen application during some periods (European Environment Agency 2020). This has been strengthened by other directives on improving the quality of water and setting emission reduction commitments by country, and policy instruments within the Common Agricultural Policy.
Denmark	From the 1980s, a wide range of policy instruments were introduced that led to a cut in nitrogen use by almost two between 1990 and 2011 without reduction of agricultural production (Petersen *et al.* 2021). A key factor of success was the definition of several action plans with clear targets that have been progressively adjusted according to the monitored progress. Introduction of farm-level nitrogen quotas has also proved to be costly but effective.

India	Legumes such as beans, peas and lentils increase the release of ammonium nitrogen into the soil. The greater availability of nitrogen in the soil can reduce the needs for nitrogen fertilizers for other crops when legumes are used in rotations or as cover crops or intercrops. India has observed a consistent increase in the production of legumes in the last five years. In 2020, some states decided to include pulses in the Public Distribution Package that previously only included wheat and rice to further encourage production.
North America	Precision farming techniques have increasingly been adopted. These include a management approach that focuses on (near real-time) observation, measurement and responses to variability in crops, fields and animals. However, it has not yet translated into lower nitrogen emissions. It is not so clear if even the most promising technologies for reduced nutrient use (Sharma and Bali 2018) can significantly reduce nitrogen input use and increase economic benefits (Späti, Huber and Finger 2021).
Viet Nam	The national strategy for achieving emission reductions in rice includes controlled water management, reduction of straw burning and conversion of inefficient rice land for other uses. Low-emission practices have already been successfully implemented in An Giang, a major rice-producing province in the Mekong Delta, contributing to a reduction of over 2 megatons (Mt) of CO_2e/year and improving smallholder famers' net income per hectare by 7–25 per cent through the use of alternate wetting and drying (Tran *et al.* 2019). In the Mekong, alternate wetting and drying could be practised on an additional 900,000 hectares, resulting in emission reductions of 10.97 $MtCO_2e$.
Global	The area under organic farming is increasing in all continents with close to 75 million ha globally in 2020 (1.6 per cent of global farmland) compared to 11 Mha in 1999 (Willer *et al.* 2021). The contribution of organic farming to the overall reduction in GHG emissions is debated because of indirect land-use effects due to lower yields and the increased manure-related emissions compared to synthetic fertilizers (Smith *et al.* 2019).

6.3.3 Decarbonizing the food supply chain

Energy use along the whole food supply chain is the source of emissions in the food systems that has grown the fastest during the last two decades. This covers emissions from on-farm fuel use for machinery and irrigation, food transportation, energy use for cooking, cooling and freezing in the food processing industry and for packaging, energy use within retail and supermarkets, and household food-related energy consumption. Household food-related energy consumption includes energy use related to travel to purchase foods, food storage in freezers/refrigerators, meal preparation and clean-up (Pelletier *et al.* 2011). Households represent 30 per cent of total food systems' energy emissions, while the retail and supermarket sector come second with 20 per cent of food systems' energy emissions (Tubiello *et al.* 2021), a number only expected to increase as supermarkets continue expanding in developing countries (Reardon, Timmer and Minten 2012). Despite a high average distance travelled for many food products (Pelletier *et al.* 2011), transport represents only between 5 and 11 per cent of total emissions from energy in the global food system (Poore and Nemecek, 2018; Tubiello *et al.* 2022).

The rapid growth in fluorinated gases (F-gases) emissions from cooling equipment used in the food chain, particularly in emerging economies, is worrying as F-gases greatly contribute to climate change due to their significantly higher warming potential than CO_2.

The food and beverage industry is a critical area of activity characterized by: a large geographical spread unlike many other industries, large multinational corporations alongside numerous small and medium enterprises, a broad heterogeneity of products that cut across very different processes, and stringent requirements related to rapid post-production shelf life and health considerations (Sovacool *et al.* 2021). This leads to specific mitigation options and potentials compared with other industries. The main options include improved management and technologies to increase energy use efficiency and better waste recovery and use of by-products (Sovacool *et al.* 2021). More generally, the food sector has great potential for adopting renewable sources of electricity or heat, especially biomass waste or biogas from anaerobic digestion. It is projected that renewable energy could cover 60 per cent of existing heat demands of the sector (International Renewable Energy Agency [IRENA] 2015). Simple things like putting doors on refrigerators in supermarkets could also help cut energy use, but this is often perceived as a sales barrier (Jesse, Perotti and Roos 2022).

Table 6.4 Examples of positive shifts in decarbonizing supply chains

Area	Positive shifts
Kenya	A major dairy processor has partnered with an off-grid solar technology provider to provide solar-powered irrigation to support fodder crops and water access for cattle, thus boosting milk production (IRENA and FAO 2021; Lukhanyu 2021).
Europe	A leading European dairy producer is working closely with almost 8,000 farms in seven countries to promote circular farming practices. As a result, the carbon footprint of milk production for the company is less than half the global average per kilogram (Jesse, Perotti and Roos 2022).

6.4 How can transformation be accelerated?

Although a food systems transformation is essential for limiting global warming and would have a number of other environmental, health, food security and equity benefits, little progress has been made in the last two decades (UNEP and UNDP 2021). In this final section, the role of different actors in accelerating transformations is discussed. Main actors include national governments, cities and local governments, the private sector, civil society and the scientific community.

6.4.1 National governments

At the national level, structures for food system governance that integrate relevant sectors and food system components are essential to drive transformative action (Springmann *et al.* 2020; Steiner *et al.* 2020). One of the first challenges to scaling transformations is the fragmentized state of data, information, knowledge and awareness across sectors, population groups and public and private agencies (OECD and FAO 2022). Multicomponent approaches that combine e.g. information campaigns with economic incentives and fiscal measures are more likely to lead to meaningful changes than the narrow focus on the provision of information that many governments have traditionally followed (Mozaffarian *et al.* 2012; Mozaffarian 2016).

Reforming national dietary guidelines can be a good start and help guide citizens make healthier and more sustainable food choices (e.g. Seychelles, Ministry of Health 2020), but this needs to be disseminated both through educational programmes and government-sponsored campaigns (Springmann *et al.* 2020), and combined with other measures such as mandatory labelling and the provision of additional information e.g. carbon footprint data. The practice of public institutions making their data sets available to the wider public ('open government data') allows citizens, civil society organizations and businesses to creatively use and combine these data, which may in turn lead to innovative ways of delivering public services (Deconinck *et al.* 2021) and increased trust for upcoming policy reforms.

Fiscal policies, including taxation and the provision of directed subsidies, is another measure that can contribute to food system transformation. A global analysis with country-level data has shown that taxing foods in accordance with their GHG emissions could improve diets and reduce emissions by about 1 $GtCO_2e$ for a modest carbon price of about US\$50/tCO_2e (Springmann *et al.* 2017). When examining subsidies, currently approximately 87 per cent of support to agricultural producers is either distorting prices or supporting approaches that are harmful to nature and health (UNEP and UNDP 2021). Reforms are necessary to direct subsidies to the production of healthy and more sustainable foods to increase their availability, reduce their prices and increase their consumption, which carries knock-on effects in the form of reduced GHG emissions (FOLU 2019; Springmann and Freund 2022).

Lastly, targeted investments and regulation can also play a role. Reducing on-farm emissions will require increased investment in public infrastructure such as storage or waste management. Moreover to support farmers, the food industry and retailers can invest in renewable energy and equipment via subsidized loans (UNEP and UNDP 2021).

6.4.2 Cities and local governments

Cities will be home to two thirds of the world's population by 2050 and already approximately 70 per cent of all food produced worldwide is consumed inside cities (United Nations Department of Economic and Social Affairs 2019). City management can therefore play a key role in food systems transformation. Since 2015, city-to-city cooperation and best practices exchanges have been fostered by the Milan Urban Food Policy Pact, which includes 225 cities worldwide. In many cities, this has translated into revised public procurement policies (e.g. for public schools, canteens, hospitals, care centres and so on) to align them with healthy diet recommendations (FAO *et al.* 2020), to increase the share of organic products and/or from local suppliers and to reduce waste through directives, resolutions or orders, for example.

Moreover, integrating food production, access and distribution across urban planning must be considered as cities expand (FAO *et al.* 2020). Policies related to food systems inside cities also positively impact the creation of jobs related to producing, distributing, delivering, redistributing and recycling food.

Lastly, cities and local governments can serve as testing grounds for policies that could be scaled nationally and for innovative solutions, including those from start-ups.

6.4.3 Private sector

Business opportunities in implementing the SDGs related to food have been estimated to be around US$4.5 trillion out of the total food sector turnover of US$10 trillion per year by 2030, representing a huge opportunity for current businesses and for entrepreneurship in the sector (FOLU 2019). Given the investment opportunities in the food system, companies and their investors could pursue new opportunities, disruptive innovations and technology transfer in line with social and environmental goals.

New protein sources are a disruptive technology. In 2021, plant-based meat substitutes generated US$5 billion in sales, and forecasts suggest up to US$85 billion in 2030 (Thornton, Gurney-Smith and Wollenberg, forthcoming). Processing plant-based protein sources such as legumes into meat substitutes generate five times higher emissions than unprocessed plant-based sources, but remains 5–8 times lower than those from beef (Clune, Crossin and Verghese 2017; Rubio, Xiang and Kaplan 2020; Smetana *et al.* 2015). In contrast, lab-grown meat (sometimes referred to as cellular meat) currently has footprints that can be as high as those of beef (Smetana *et al.* 2015; World Economic Forum 2019).

Another important area to drive food system transformation, from a private sector perspective, includes sector- and company-wide targets to reduce emissions and eventually reach carbon neutrality (Burns *et al.* 2022). The Science-Based Targets initiative (SBTi) and other entities offer companies with target-setting methodologies based on the best scientific evidence and guidelines to track GHG emissions within the companies' operations. This initiative already comprises over 1,200 companies worldwide. A key aspect is enhanced transparency through systematic reporting and verification of company operations.

An example that openly accessible information can help drive action is the Big Climate Database developed in Denmark using life cycle assessments, which has already been used by several supermarket chains and the food service industry. Public disclosure of data used to measure progress and independent audits and initiatives, such as those of the World Benchmarking Alliance which ranks companies on their performance, will be important in assessing progress and increasing accountability.

6.4.4 Civil society (citizens and non-governmental organizations)

Citizens can drive food systems transformation through their consumption choices, their electoral choices and their mobilization in favour or against certain policy reforms related to food systems e.g. through boycott, public demonstration, disruption of traffic, etc. Social media has also played an important role in raising awareness on the need to shift diets and how to shift diets to reduce our carbon footprint. But this may only reach a certain audience e.g. with a higher education level (Eker *et al.* 2021).

An important voice for civil society initiatives are non-governmental organizations (NGOs). They often work closely with citizens and can represent a multitude of voices at local, national and international levels of governance. For example, the United Nations World Food Programme (WFP) works with over 1,000 NGOs worldwide to support 'close to citizen' activities and efforts.

Table 6.5 Potential solutions and barriers to food systems transformation by actor group

	MAJOR TRANSFORMATION GAPS	POTENTIAL SOLUTIONS	BARRIERS
National governments	– Absence of national strategy and clear measurable targets – Lack of data and capacity – Lack of key performance indicators to monitor progress – Weak evaluation of externalities and incorporation into national accounting	› Science-based national food systems transformation strategy and corresponding national coordination and accountability mechanism › Open government data › Integrate low carbon into national food and dietary guidelines › Strengthen national land monitoring system for carbon reduction	! Unbalanced power across ministries (and objectives) ! Lack of multisectoral coordination ! Acceptability of measures versus success at next elections
Cities and local governments	– Carbon reduction is not part of the local and city government mandate – Lack of awareness of carbon footprint of food systems	› Strengthen coordination between national and city governments/local plans and policies › Strengthen coordination between urban and rural areas › Align public procurement with healthy and sustainable diets	! Local economic development versus carbon reduction ! National versus local/city interests
Private sector	– Lack of commitments – Lack of capacity – Lobby against taxes and environmental regulations	› Monitor and disclose progress towards environmental commitments › Remove 'best before' label from fresh fruits and vegetables	! Economic profitability versus social and environmental objectives
Civil society	– Lack of knowledge and incentives – Small number of platforms which enable involvement in decision-making – Lack of resources (NGOs)	› Social campaigns and social movements › Mainstream low carbon into teaching curriculums › NGOs develop score cards for companies	! Budget constraints ! Well-being, cultural norms and preferences versus social and environmental goals
Academia	– Science not fully aligned with societal needs – Interdisciplinary approaches required but difficult to implement	› Build strong science-policy interface between governments and academia › Independent monitoring of progress towards targets related to food policy	! Disciplinary funding structures and research traditions ! Independence/separation of academia from policy processes

6.4.4 International cooperation

International cooperation is essential amid a strong interconnectedness of countries' food systems, large inequalities such as the impacts of climate change on food production and the complexity of climate change. While developments in food trade over the past decades have increased food availability and diversity, it has also increased the vulnerability of some countries' food systems to climate and political shocks (Wang and Dai 2021) and accelerated the destruction of natural ecosystems such as tropical forests (zu Ermgassen *et al.* 2020).

With strong interconnectedness, even well-intentioned national policies to reduce GHG emissions from food systems can be offset by spillovers to the rest of the world and/or could raise food prices but could also spur positive change in other countries. The negative impacts of climate change on agricultural production are also especially strong in developing countries. International cooperation to ensure that no one will be left behind is crucial. Channelling emergency food aid when there are crises, avoiding trade disruptions even when there is a war, or reducing food overconsumption can all contribute to reducing inequalities within global food systems.

Many technologies exist that are capable of increasing crop and livestock productivity, enhancing nutrition of food crops and reducing GHG emissions (Pathak and Aggarwal 2012;

Fan 2021; Islam 2021; Huang *et al.* 2022) but much needs to be done to scale up, adapt to local contexts and also ensure the equitable distribution of costs and benefits. International cooperations, including South-South cooperation, have a critical role in low-emission technology transfer and scaling.

As highlighted in this chapter, positive examples of reducing GHG emissions from food systems exist but they are scarce. International networks such as the Milan Urban Food Policy Pact for cities, the World Business Council for Sustainable Development for private companies, and the Food, Agriculture, Biodiversity, Land and Energy Consortium for scientists can help in sharing positive experience and peer learning across countries, fostering innovation. In the same vein, a global data and knowledge platform would be desirable to guide food systems transformation using science based recommendations (Singh *et al.* 2021). During COP 26 in Glasgow, various international key food systems-related activities were announced (box 6.3). These and similar initiatives carry the potential to unite actors internationally, (e.g. countries, international organizations, think tanks, development banks and more) to mobilize resources and capacity and pursue common goals.

Box 6.3 COP 26 initiatives that bear strong mitigative potential with regards to land and food systems emissions and the protection of natural ecosystems

The **Glasgow Leaders' Declaration on Forests and Land Use** reaffirms the critical role of forests "in enabling the world to meet its sustainable development goals" and the need to "reduce, halt, and reverse forest loss and land degradation by 2030". The Declaration has 141 signatory governments that together represent around 91 per cent of forested areas.

The **Forest, Agriculture and Commodity Trade Roadmap** aims to halt forest loss associated with agricultural commodity production and trade, joined by 28 countries and 12 companies so far that hold a considerable market share in forest commodities (that is, in soy, palm oil, cocoa and cattle).

The **High Ambition Coalition for Nature and People** includes nearly 100 countries that push for the ratification of ambitious post-2020 biodiversity targets at the upcoming Convention on Biological Diversity, such as placing 30 per cent of the territory under protection by 2030.

The **Global Methane Pledge**, currently signed by 122 countries, aims to reduce methane emissions by 30 per cent below 2020 levels.

7 Transforming the finance system to enable the achievement of the Paris Agreement

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7.1 Introduction: The need for a transformation of the financial system

A realignment of the financial system is a critical enabler of the sectoral transitions required to address the current climate crises. Article 2.1(c) of the Paris Agreement calls for this and establishes a new objective for all countries to make finance flows consistent with low-carbon and climate-resilient development pathways (United Nations Framework on Climate Change Convention [UNFCCC] 2015). In contrast to the mobilization of climate finance for developing countries under the UNFCCC (article 9), another key goal, the climate consistency of finance flows represents a new purpose that relies on support and action to transform the global financial system (Zamarioli *et al.* 2021). This chapter therefore focuses on a transformation of the financial system that engages all relevant actors, including governments, central banks, commercial banks and institutional investors. The success of the transformation can ultimately be measured based on two indicators: a rapid increase in investments in low-carbon assets worldwide and a rapid decrease in investments in greenhouse gas (GHG)-intensive assets. Although this has significance for all sectors, examples in this chapter focus on the energy sector, where literature on finance and transformation is emerging (Steffen and Schmidt 2021).

Investments in low-carbon assets need to rapidly increase. Tracked climate-related investments in mitigation rose significantly to about US$571 billion per year in 2019–2020 (Buchner *et al.* 2021).[1] However, the Intergovernmental Panel on Climate Change (IPCC) estimates that global mitigation investments need to increase by the factor of 3 to 6. In developing countries, this gap is even larger (see figure 7.1) (Kreibiehl *et al.* 2022). Access to capital in developing countries is more difficult and financing costs much higher, reflecting perceived cross-border investment risks and international capital market inefficiencies (see box 7.1).

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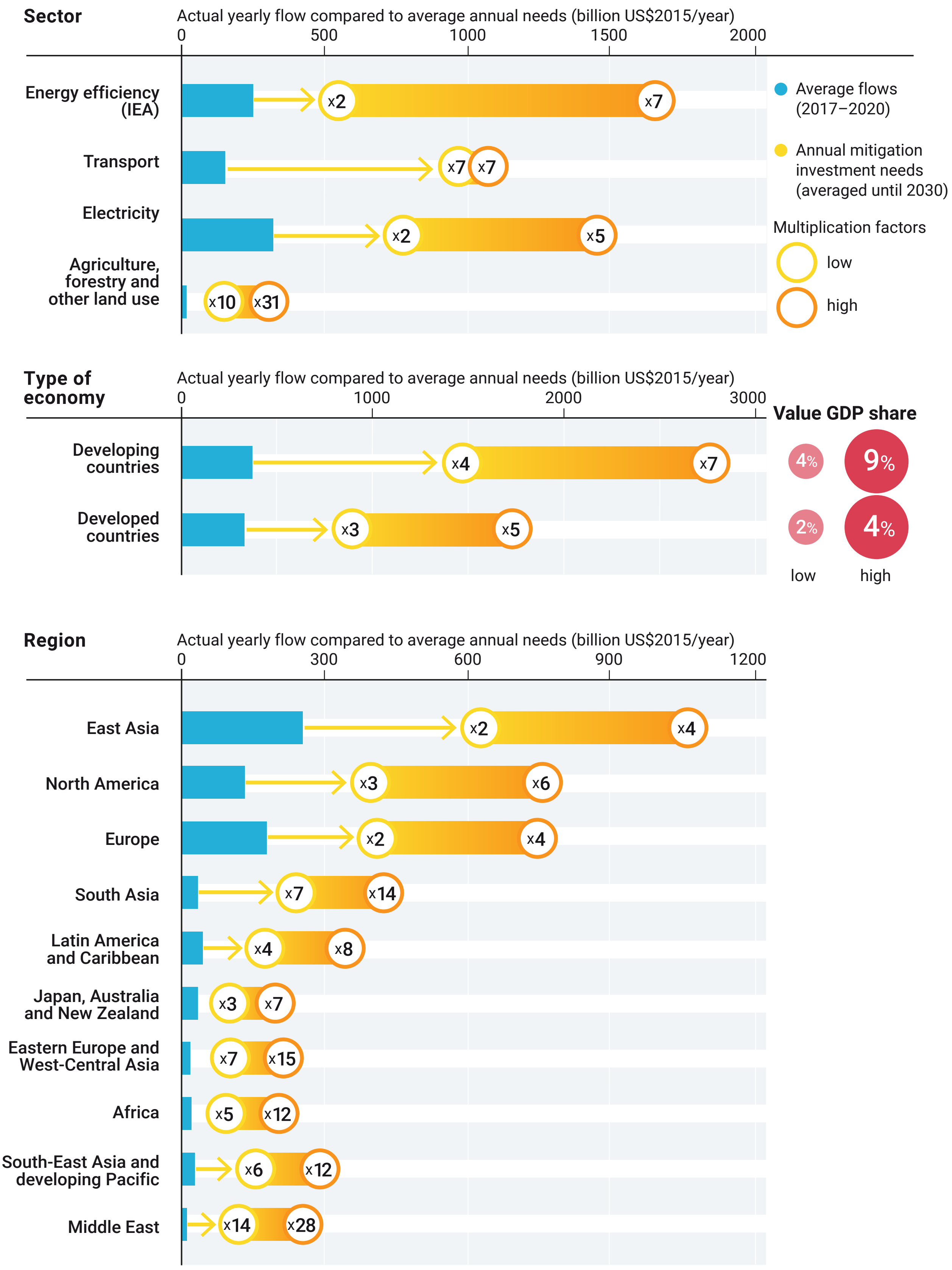
[1] Methodological issues and data limitations persist. Limited data availability prevents a full accounting of domestic government expenditures on climate finance and of private sector investments in energy efficiency, transport and land use (Buchner *et al.* 2021).

Figure 7.1 Finance flows and mitigation investment needs by sector, type of economy and region



Source: Adapted and modified from Figure TS.25 from Pathak, M., Slade, R., Shukla, P.R., Skea, J., Pichs-Madruga, R., Ürge-Vorsatz, D. *et al.* (2022). Technical summary. In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change. Geneva. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_TS.pdf.

Box 7.1 Financing the low-carbon transformation in developing countries

Developing economies account for 83 per cent of global population, one half of global GDP (in purchasing power parity terms), and 36 per cent of global GDP (at market-based exchange rates) (World Bank 2020). Given their development needs and low per capita consumption of energy, virtually the entire future increase in global primary energy demand is expected to occur in these economies (International Energy Agency 2021). An 'efficient' global financial market would mobilize flows from capital abundant high-income economies for investment in faster-growing and capital-scarce developing economies in theory (see section 7.3), but this mobilization is missing in practice (Agenor 2001; Gourinchas and Jeanne 2006; Obstfeld 2021).

There are at least three 'frictions' that prevent capital markets from investing more in developing countries. First, the perceived high risks of investing (Koepke 2018), sometimes attributed to weaker policy settings and compounded by credit rating agency risk assessment and their observed bias or tendency to assign higher credit ratings to firms and enterprises located in financial centres (Ioannou, Wójcik and Pažitka 2021). Exchange rate risks can be an additional deterrent in contexts where local capital markets are not well developed and the risks cannot be hedged because of limited risk markets. In marked contrast, investments in fossil fuel sectors in many developing countries are considered less risky because such investments, as globally traded primary energy sources, have greater asset backing and liquidity. For example, the single biggest private investment in sub-Saharan Africa in 2020 was in fossil fuel (liquefied natural gas [LNG]) export investment (Pekic 2022).

Second, persistent 'home-bias' of investors in high-income markets to invest within their own borders, contravening efficient capital markets functioning (Hau and Rey 2008) (Ardalan 2019).

Finally, observed procyclical volatility of capital flows (larger inflows in 'good times' and faster outflows in 'bad times') can exacerbate the problem and lead to periodic economic crises, debt defaults and exchange rate volatility (Dadush, Dasgupta and Ratha 2000).

These three frictions can potentially worsen with increasing climate vulnerability and unsustainable debt burdens (Volz *et al.* 2020) or lead to a "climate investment trap", especially for least developed countries, as in sub-Saharan Africa (Ameli *et al.* 2021).

Multilateral development banks (MDBs) and regional development banks can play a larger and countercyclical role, but their overall role in global capital markets is relatively small and decreasing (see section 2). Strategic international positioning and growing financial resources have led to alternative South-South financing in recent years (Chen, Dollar and Tang 2016). Some developing countries have also benefited from new market instruments, such as green bonds (see section 2), but this has not provided a solution to the financing difficulties.

Investments in fossil fuel assets need to decline rapidly, because they work against the clean energy transition now and lock in GHG emissions for decades to come, leading to stranded assets in the future (Campiglio *et al.* 2018; Mercure *et al.* 2018; Kreibiehl *et al.* 2022). The financial sector has historically funded and is highly exposed to GHG-intensive assets (see section 7.2), including fossil fuel extraction and GHG-intensive industrial sectors (e.g. steel and cement). For example, of the equity holdings portfolios of the European Union's 50 biggest banks, 4–13 per cent is directly in the fossil fuel sector and 36–48 per cent is in climate-relevant sectors such as fossil fuels, utilities and energy-intensive industries (Battiston *et al.* 2017).

Across all portfolios in the energy sector, renewable power generated higher returns than fossil fuel investments (Fomicov *et al.* 2020). Additionally, current returns in fossil fuel investments are only possible because of the continued absence of clear government policies to counteract rising climate risk (Griffin *et al.* 2015) and because of continued public fossil fuel subsidies. Explicit fossil fuel-related subsidies (US$340 billion annually)[2] are estimated to be much greater than for renewable energy (US$170 billion) (IPCC 2022).

It is also in the long-term interest of the financial system to reduce investments in fossil fuel assets, because a considerable share of fossil fuel assets is likely to become stranded (Campiglio *et al.* 2018; Mercure *et al.* 2018; Kreibiehl *et al.* 2022). Based on ongoing low-carbon technology trends, global estimates of potential stranded fossil fuel assets amount to at least US$1 trillion. When more stringent policies to limit global warming to well below 2°C are adopted, these can increase to US$4 trillion (Mercure *et al.* 2018). Together with societal and litigation risks, these technological and policy risks cause a "transition risk" that

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[2] Parry, Black and Vernon (2021) estimate that implicit fossil fuel subsidies (undercharged environmental costs, including climate change, and foregone consumption taxes) amount around US$5.9 trillion per year.

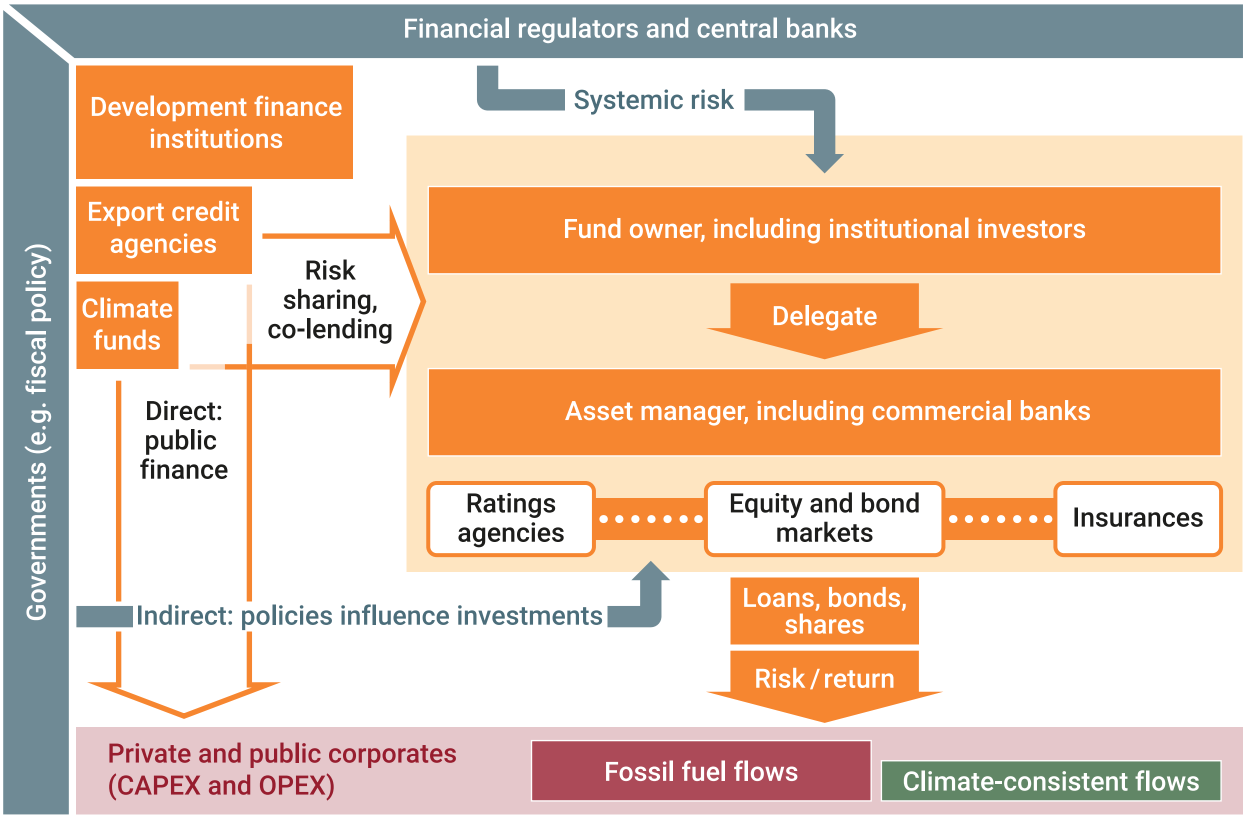
should be managed to avoid financial instability (Campiglio *et al.* 2018). The bursting of a carbon bubble cannot be ruled out (Griffin *et al.* 2015).

7.2 Aligning financial system actors with climate change

The core function of the large and complex global financial system is "to facilitate the allocation and deployment of resources, spatially and across time, in an uncertain environment" (Merton 1990). The financial system is a network of private and public institutions such as banks, institutional investors and public institutions that regulate the safety and soundness of the system but also co-lend or finance directly. Financial systems are regulated as they influence the economic system, and their capabilities facilitate the growth and productivity of real assets (see figure 7.2 for more insight into key roles and relations of actors in the financial system).

The size of assets held by a myriad of financial actors in global capital markets is very large: recent estimates indicate US$128 trillion in global bond markets (International Capital Market Association 2020), US$83 trillion in banking credit (Bank for International Settlements 2021), and US$124 trillion in equity markets (Securities Industry and Financial Markets Association 2021), totalling some US$225 trillion in credit to the non-financial sector (Bank for International Settlements 2021) and growing by about 7 per cent (US$15 trillion) annually. Given rapidly changing economic opportunities, risks and returns, decisions by actors in capital markets to change their allocation of assets even modestly, or not, have an enormous bearing on economic transitions (see box 7.2).

Figure 7.2 The financial system, its actors and their roles and relations



Source: Authors' illustration, based on Climate Finance Leadership Initiative (2019)

Box 7.2 Complexity of financial system, policy and climate finance progress

Climate-related investments have increased considerably over recent years and so has the interest in climate action of various actors in the financial system. Nevertheless, progress on the alignment of financial flows towards the goals of the Paris Agreement remains slow (Kreibiehl *et al.* 2022). This box therefore puts the climate-related finance flows in a broader macrofinancial economic perspective.

Tracked climate-related finance flows fall consistently short of the levels needed. Their share in total credit to the non-financial sector (core debt) during 2012–2021 remained very low (rising from 0.23 per cent in 2012 to 0.32 per cent in 2021) (IPCC 2022; Bank for International Settlements 2022). In equity markets (reported from public data), the market capitalization of the top-ten listed renewable energy companies globally was a small 0.2 per cent (US$215 billion) of global equity markets in 2021. To put this in perspective, market capitalization of major technology stocks was bigger and rose faster (US$600 billion in 2012 to over US$9 trillion by 2021). Even highly speculative cryptocurrency stocks (with energy-intensive 'mining' operations) reached higher peak valuations (US$2 trillion in 2022), before sliding recently. In the wake of the 2008 financial crisis, the re-emergence of the real estate and housing sector as a reinvigorated global asset class, after its earlier market collapse, has been remarkable (Fields 2017; Ghent, Torous and Valkanov 2019; Christophers 2021).

Between 2012 and 2021, a period that saw a surge in debt and equity markets, there was no significant increase in the relative scale of climate finance, despite large technology gains as seen in renewable energy. In contrast, other sectors, many highly speculative, saw extremely rapid growth, attracting bigger investment and financing support. The share of 'zombie' firms, for example, defined as firms unable to even cover debt servicing costs from current profits, rose from 4 per cent in late 1980s to 15 per cent by 2017. Such misallocation in financial markets can be attributed to low nominal interest rates and quantitative easing policies as well as a rise in central bank balance sheet assets, which hit creditworthy firms (Acharya *et al.* 2019). A consensus on cutting wealth taxes emerged in public finances (Lierse 2022) while fossil fuel financing remained unabated (Kirsch *et al.* 2022). Whether such broader macroeconomic policy and finance directions carried significant negative effects on the slow, observed progress of climate finance is a complex question (van 't Klooster and Fontan 2020), but the relative magnitudes confirm that climate finance has not been significant in the financial system nor in the overall macrofinancial setting globally.

A global transformation from a heavily fossil fuel energy-dependent economy to a low-carbon economy is expected to require investments of at least US$4–6 trillion a year, a relatively small (1.5–2 per cent) share of total financial assets managed, but significant (20–28 per cent) in terms of the additional annual resources to be allocated. While the size of the global financial system is clearly sufficient to close funding gaps, there is a qualitative mismatch between available and required types of capital (Polzin and Sanders 2020; IPCC 2022).

Table 7.1 Actors in the financial system relevant to climate change

Actor	Role in financial system
Governments	Set out policies and regulations, especially to manage public goods externalities, such as climate. In addition, governments influence investments through fiscal policy levers (including green procurement), public finance (including grants, loans and sovereign guarantees) and information instruments (Whitley *et al.* 2018). Furthermore, governments own and operate financial institutions such as development finance institutions (DFIs), 'green' banks, climate funds, export credit and aid agencies (see below).
Central banks and financial regulators	Primary mandate to ensure price stability and financial stability in the economy. Institutional settings vary between countries, but many central banks also have a mandate to support government policies. Dikau and Volz (2021) found that 114 central banks consider curbing climate change as part of their existing mandate. Besides, climate change poses risks to financial stability and has implications for prudential regulation.

DFIs (bilateral and multilateral)	Provide financial and technical support to developing countries public and private sectors, thereby filling gaps where governments and other financial actors cannot deploy needed investments in critical sectors of the economy. Backed by their shareholders, DFIs have recognized the need to play an essential role through initiatives (e.g. green bond programmes by the International Finance Corporation, African Development Bank and European Investment Bank; mainstreaming climate in financial institutions' initiatives) in addressing global development challenges such as climate change.
International climate funds	Channel international public finance to mitigation and adaptation projects in developing countries. The funds vary in size, geographic coverage, aims and governance.
Export credit agencies (ECAs)	Official or quasi-official government agencies that provide government-backed support for the international operations of corporations from their home country. Such support can either take the form of credits (financial support) or credit insurance and guarantees (pure cover) or both, depending on the ECA's mandate. This way, ECAs can crowd in billions of dollars of private investment.
Insurance industry	Provides insurance as a risk management instrument to hedge against the risk of contingent or uncertain (financial) loss. Insurance payouts for catastrophes have increased significantly over the last 10 years, and this trend is expected to continue (Kreibiehl *et al.* 2022).
Commercial banks	Commercial banks are financial institutions that accept deposits from the public and give loans for the purposes of consumption and investment to make profit. Loans from commercial banks are the most important source of external finance for firms.
Institutional investors	Institutional investors, such as mutual funds, pension funds and insurance companies invest money on behalf of others. They have large assets under management (US$84 trillion) in Organisation for Economic Co-operation and Development (OECD) countries in 2017 (OECD 2018) and long timescales of their liabilities, which can potentially match the timescales of climate change (Ameli *et al.* 2020).
Equity markets	Compared to other financial instruments (e.g. debt instruments, guarantees and grants), equity investments require enhanced assessment and governance (OECD 2021) because of increased investors' ownership of a company or asset class.
Credit rating agencies	Credit rating agencies (CRAs) are crucial actors for access to finance on international and domestic capital markets. CRAs rate the creditworthiness of debt and equity securities based on quantitative and qualitative analyses (Mathiesen 2018).

Notes: See also figure 7.2.

The actors within the financial system can play key roles in shaping its transformation (see Hölscher, Wittmayer and Loorbach 2018). Some of the actors in the financial system have an explicit mandate or aim to enable action on climate change (table 7.1). However, it is not the primary objective of any of them, except for the climate funds, to address climate change. Furthermore, successful integration of climate risks into financial decision-making requires a time-horizon of multiple decades, but most actors in the climate finance system typically have time-horizons of 1–5 years (Chenet 2019). Aligning the actors of the financial system with the goals of the Paris Agreement is therefore challenging.

Public sector actors

Public sector authorities are most strongly linked to climate change, in particular governments, central banks and regulators, DFIs and climate funds. Governments, as signatories to the Paris Agreement, have a responsibility to implement its article 2.1(c), but they are also important to give climate policy signals to address macroeconomic uncertainty and to help guide investment decisions (Kreibiehl *et al.* 2022).

Central banks and financial regulators recognize that climate change can impact the macroeconomic aggregates that they are required to stabilize, such as inflation and employment (Robins, Dikau and Volz 2021). Furthermore, climate impacts and the transition to net zero will affect financial markets (key for the monetary transmission), financial institutions (often supervised by central banks) and the broader financial system, for which central banks have a macroprudential mandate (Chenet, Ryan-Collins and van Lerven 2021; Svartzman *et al.* 2021).

Central banks must choose how to react to climate change: by trying to maintain the status quo by focusing purely on climate risk assessment, which is more easily framed within their primary mandate of financial stability, or proactively by addressing climate change and transition risks by including climate risk criteria, e.g. in their asset purchase programmes, adjusting collateral frameworks and capital requirements (see Bolton *et al.* 2020). The former will pose a barrier to the transformation of the financial system because risk disclosure alone does not ensure the expected shift in financial decision-making (Ameli *et al.* 2021).

Bilateral and multilateral DFIs have recognized their role in addressing climate change. For example, some European DFIs have committed to ending lending to fossil fuel projects by 2030 as well as immediately ceasing the financing of new oil and coal projects (e.g. European Investment Bank, Investment Fund for Developing Countries [IFU], and Swedfund, which has invested in renewables only since 2014). Using instruments such as loans, guarantees and equity acquisitions, many DFIs leverage their financial resources to mobilize and scale up finance to address climate change in developing countries (Lemma 2015; Attridge, te Velde and Andreasen 2019). However, despite their potential significance in climate finance, the eight largest international DFIs only mobilized US$50 billion in mitigation finance in 2020 (African Development Bank *et al.* 2020). This may reflect their preference for direct project finance operations (Hourcade, Dasgupta and Ghersi 2020) over de-risking and crowding in private capital (African Development Bank *et al.* 2015) as well as limits on their capital exposure (single-country exposure limits).

Climate funds have a stronger focus on climate change than DFIs but they are relatively small: together, they held US$34.8 billion in deposits from donors and committed US$28.4 billion in approved projects by January 2022 (Climate Funds Update 2022). Some funds function exclusively through grants, as in the case of the Adaptation Fund, while others, such as the Green Climate Fund (GCF), use a variety of financial instruments to engage public and private actors to implement and co-finance projects. Since 2020, the GCF also intends to support mainstreaming of climate considerations in developing countries' national financial systems, by developing climate investment capacities of national institutions or by formulating supportive policy/regulatory frameworks (GCF 2020).

Finally, export credit agencies: between 2016 and 2018, ECAs from OECD members reported US$5.7 billion of climate finance through export credits (OECD 2021). In the same period, the ECAs of the G20 provided at least US$120.3 billion in support for fossil fuel projects (excluding the Export-Import Bank of the United States) (Tucker and DeAngelis 2020). ECAs thus currently tend to work against the implementation of article 2.1(c) and the low-carbon transformation (see Shishlov, Censkowsky and Darouich 2021).

If the public sector-backed financial system actors would work in an aligned way towards shifting financial flows away from high-GHG investments to low-GHG ones, they could multiply each other's impact and increase the viability of low-GHG projects.

Private sector actors

Private actors in the financial system include commercial banks, insurance companies, institutional investors and private equity (equity markets).

Commercial banks are simultaneously an important source of debt financing for low-carbon investments (Polzin, Sanders and Täube 2017) and a source of fossil fuel financing. As an illustration, the world's 60 largest banks alone provided US$4.6 trillion in fossil fuel financing in the six years since the adoption of the Paris Agreement, with no sign of decline (see Kirsch *et al.* 2022). Macroprudential regulation, such as Basel III,[3] promotes short-termism and hence negatively affects the already problematic access to finance of low-emission sectors (Campiglio 2016).

For the insurance industry, climate change is a threat because losses limit the affordability (through increased premiums) and availability of coverage (when insurers withdraw from particular perils and geographical areas) (Collier, Elliott and Lehtonen 2021). Financial instruments are being developed by private insurers and other financial services entities to price in climate risks, but a majority of the companies does not integrate climate change into their risk management practices (e.g. Thistletwaite and Wood 2018). Furthermore, internal conflicts may arise when an insurer's underwriters advise against issuing insurance in areas with increasing climate risk, while doing so would decrease the value of the insurer's real estate investments in that same area (Riedl 2022).

Institutional investors (including insurers) accounted for just 0.2 per cent of total climate-related finance flows in 2016 (Ameli *et al.* 2020). The very broad current permissive classifications of environmental, social and governance (ESG) investments obscures rather than promotes scaled-up climate finances (Berg, Kölbel and Rigobon 2019). More significant action has also been limited by the priorities of institutional investors on short-term returns, lack of climate expertise and their lingering scepticism about climate risk exposure.

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[3] The Basel accords provide recommendations on banking regulations issued by the Basel Committee on Banking Supervision. Basel III introduces stricter standards for banks on both the liquidity of their assets and the robustness of their capital.

In equity markets, private equity expansion (e.g. corporate financing or early-stage investors into a portfolio of start-ups) is essential for riskier tranches of low-carbon investments (Hourcade *et al.* 2021), but private equity energy investments continue to be dominated by GHG-intensive activities. The higher cost of equity capital for GHG-intensive production activities provides still a relatively weak market disincentive mechanism (Trinks *et al.* 2022).

While still predominantly a barrier to addressing climate change, private actors in the financial system demonstrate a willingness to act on climate change. For example, the United Nations-convened Net-Zero Banking Alliance brings together a global group of 117 banks, currently representing about 39 per cent of global banking assets (UNEP Finance Initiative 2022). Insurance companies and institutional investors are increasingly aware of the risk climate change is posing as well as increasing ESG pressures from shareholders and stakeholders. However, effects have been limited so far.

This is where CRAs may contribute. Climate and ESG risks are increasingly integrated into CRAs' rating methodologies (Mathiesen 2018; Angelova *et al.* 2021) and climate risks have started to negatively affect credit ratings (Cevik and Jalles 2020). Especially in developing countries, higher-risk premiums have already raised costs of public (sovereign) capital (Beirne, Renzhi and Volz 2021; Kling *et al.* 2021). However, climate risks tend to materialize with high uncertainties and on longer time-horizons (Network for Greening the Financial System [NGFS] 2020; Coelho and Restoy 2022), while ratings issued by CRAs are relatively short-term-oriented. The limited response by CRAs to the growing scientific and economic evidence of climate-related risks may cause markets and investors to struggle to correctly identify, price and manage their investments (Agarwala *et al.* 2021).

In summary, most actors in the financial system only align their activities with the aims of the Paris Agreement to a limited extent compared to the total scale of their activities. For actors to do more and move faster to address the climate crisis, both individually and as a system, external forces of climate policy-setting by governments as well as financial regulators and supervisors are necessary.

Box 7.3 Gender responsive transformation of the financial system

A growing number of recent studies (e.g. Bosone, Bogliardi and Giudici 2022; Clancy *et al.* 2020; Robino and Jackson 2022) have consolidated the importance of a gender lens and gender responsiveness in investments and financial policies for low-carbon transitions, both in terms of equity and increased impact. A gendered approach should ensure that women will gain equally in the emerging opportunities from a green economy, while also improving effectiveness to decarbonize through, for example, girls' education. Women are inordinately affected by climate change, creating strong links between gender and adaptation. Yet evidence has shown the relevance of gender and gender-smart investments also for most mitigation-related areas, from renewable energy to agriculture and forestry, infrastructure and waste. The practice is developing to boost women's financial inclusion in climate finance/investment, with the example of climate funds (Kreibiehl *et al.* 2022). Overall, however, practice and literature remain deficient, particularly in advancing the business case to mainstreaming gender in the broader context of shifting finance flows.

7.3 Transforming the financial system: Six approaches to public policy

Inspired by the innovation system literature (Bergek *et al.* 2008; Geels 2002), the financial system can be viewed as a complex constellation of actors, interactions and institutions with a specific internal dynamic, as well as a relation to the real economy of projects, assets and policy instruments. When a system is influenced by external pressures or by social, technological or institutional innovations within the system, it can change rapidly. This has been extensively documented for technological innovation systems (Blanco *et al.* 2022) and recently scholars started applying the concept to finance (Hafner *et al.* 2020; Naidoo 2020; Steffen and Schmidt 2021). Processes to shape transitions are necessarily about interactions between technology, policy/power/politics, economics/business/markets, and culture/discourse/public opinion (Geels 2011).

There are multiple approaches to reach inflection points that lead to a financial system capable of supporting actions to limit warming to 1.5°C:

- **Increase the efficiency of financial markets.** In well-developed financial markets, markets function efficiently, but in their 'weak' form, markets are inefficient, especially in the context of uncertainty. However, agents can correct this with time and better information (Krueger *et al.* 2020). Financial innovations through 'engineering' of new financial products to address special needs are a mark of such relatively efficient markets. The main policy prescription is better information, including taxonomies for sustainable economic activities and transparency through disclosure of climate risks (Carney 2015; Dietz *et al.* 2016; Zenghelis and Stern 2016; Campiglio *et al.* 2018). In developing country contexts (Bond, Tybout and Utar 2015; Hamid *et al.* 2017), priorities will include capacity-building and strengthening institutions (Banga 2019). Relying solely on the efficient markets and information disclosure can hide imperfections that are inherent to financial markets' structure and practices (Ameli, Kothari and Grubb 2021; Bolton and Kacpercyzk 2021) and depend on the uncertain (behavioural) responses of boards, stockholders and markets to such disclosures.

Examples of increasing the efficiency of financial markets can be found in both developed and developing countries. For example:

- through voluntary disclosures (e.g. recommendations from the Task Force on Climate-Related Financial Risk Disclosures) and mandatory rules (e.g. European Union Corporate Sustainability Reporting Directive) on enterprises' observed emissions and projected risks from climate change

- the definition of low-carbon consistent or transition activities via taxonomies and classification systems (e.g. Chinese Green Bond Catalogue and Green Industry Guiding Catalogue; Bangladeshi Green Taxonomy; European Union Taxonomy for sustainable activities)

- the protection of consumers of ESG-related services against 'greenwashing' (e.g. by the United States of America Securities and Exchange Commission or the German Federal Financial Supervisory Authority)

► **Introduce carbon pricing.** In the presence of strong externalities and missing or incomplete futures markets, this approach suggests that the most important response is to price carbon explicitly and high enough for it to provide signals for investors to alter decisions (Aghion *et al.* 2016). This can be done through carbon taxes or through cap-and-trade systems (Haites 2018). Carbon taxes have practical appeal because they provide more certainty over future emissions prices, helping encourage low-carbon investments and lower energy use. Emissions trading schemes, on the other hand, provide certainty over future emission levels. They can be designed to mimic some of the advantages of taxes, including through carbon price floors (Newbery, Reiner and Ritz 2019).

An increasing number of countries are putting carbon pricing in place. Emission trading schemes and carbon taxes now cover 30 per cent of all global emissions, with a global average price of US$6 per ton of CO_2 (Black, Parry and Zhunussova 2022). Both the coverage and the price are insufficient to transform the financial system: the International Monetary Fund (IMF) (Black, Parry and Zhunussova 2022) suggested a global average price of US$75 as required by 2030. Similarly, the High-Level Commission on Carbon Prices (2017) concluded that an explicit carbon price level should be at least US$50–100/tons of CO_2 (tCO_2) by 2030 to limit global warming to between 1.5°C and 2°C warming above pre-industrial levels, provided a supportive policy environment is in place. The report proposed that this goal can also be achieved with lower near-term carbon prices, but that this would require stronger action through other policies and instruments and/or higher carbon prices later (Stern and Stiglitz 2017). Currently, there are proposals for higher near-term international carbon price floors (Chateau, Jaumotte and Schwerhoff 2022), differentiated between high-, medium- and low-income countries (US$75, US$50 and US$25, respectively).

In jurisdictions without explicit carbon pricing, shadow pricing is a tool for firms, development banks and governments to internalize a carbon price in investments and take more informed decisions. Rising (minimum) carbon price floors can strengthen such future investment decision-making (Stern and Stiglitz 2017).

► **Nudge financial behaviour.** Climate finance markets are subject to deep information asymmetry, risk-aversion and herd behaviour (contagion and bandwagon), all of which result in inefficient choices, status quo and deter actions. In addition, the financial system is characterized by the existence of strong and complex networks, nodes and inter-linkages among financial institutions (Battiston *et al.* 2016), (Hüser 2015). While this might create hard-to-change behaviour and inertia, they can be addressed through credible public signals directed at such financial networks and nodes. Routines are strongly determined by networks and are relatively easily adaptable: imitation of other actors' new routines can result in herding effects towards transformation (Steffen and Schmidt 2021).

On the demand side, solutions to reduce consumption of GHG-intensive uses can be significant, reducing 40–70 per cent of the gap in low-carbon transition (Creutzig *et al.* 2016; Creutzig *et al.* 2022; IPCC

2022) and can enhance household welfare. Current demand-side policy strategies, however, still rely heavily on individual self-responsibility. Governments need to steer more actively, through taxes, subsidies, regulations, standards, labelling and public infrastructure, especially in sectors such as mobility, food, housing and urban transitions (Moberg *et al.* 2019). In the case of electric vehicles, for example, in addition to subsidies and tax rebates, charging density, fuel prices and road priority incentives are increasingly important across countries (Ingeborgrud and Ryghaug 2019; Wang *et al.* 2019). Green finance institutions additionally play a critical role (Polzin and Sanders 2020; Song, Xie and Shen 2021) in nudging investor and financial behaviour (Zhang, Li and Ji 2020; Koutsandreas *et al.* 2022).

Institutions and local governments pledging to divest from carbon-intense assets, for example coal and oil companies, can help. Building on climate awareness and its associated moral claims, shareholders and activists create uncertainty among institutional investors about the future stability of the fossil fuel industry and its reliability as a continuing source of profitable investment (Ayling and Gunningham 2017). The effectiveness of divestment has been criticized, for example because entities that are divesting do not account for a large share of investors, the effects might only be temporary (Ansar, Caldecott and Tilbury 2013), or because investment funds are not mandated to operate based on ethics but on rules that protect them from the forces of politics (Mercure 2019). However, the stigmatization and reputational damages impact the fossil fuel companies (Ayling and Gunningham 2017). Based on a divestment campaign by 350.org, about 1500 institutions in 71 countries representing US$40 trillion in assets are divesting (Lipman 2021). Divestment also takes place outside of this movement. For example, Europe's biggest pension fund, ABP of the Netherlands, pledged to divest US$17.4 billion worth of fossil fuel assets by 2023 (Marsh 2021) and stated that it reduced the CO_2 footprint of its portfolio by 40 per cent in 2022 compared with 2015 (ABP 2022).

- **Create markets.** Public policy can accelerate new product markets for low-carbon technology, replacing the older, inefficient (fossil fuel-based) technology. Public policy actions include: (a) financial and product market regulations (such as fuel or energy-efficiency standards), (b) altering the risk-reward profiles of investment classes through public policies, taxes and subsidies and (c) directly engaging in public financing through public financial institutions, green banks and innovation funds, public financial guarantees to private investments, and by public contracting and guaranteed purchase agreements. All actions lower the risks of new technology and can lead the financial system to follow and shift financial flows accordingly. The most important recent example of swift public actions to rapidly develop a product market using a blend of indirect and direct instruments was the development of COVID-19 vaccines. In the case of low-carbon product markets, an example is the rapid uptake of LEDs in India's lighting market from negligible to a dominant share in five years (annual sales grew 130 times between 2014 and 2018) (Kamat *et al.* 2020), attributable to a programme aimed at lowering prices through at-scale public agency procurement.

  Industrialized countries can support the creation of markets in developing countries. Development banks, including green banks, can play a more active role to stimulate financial markets as newer product markets are being accelerated. These banks are at the nexus of the public and private sectors and the developed and developing worlds, and with their ability to provide concessional public financing, alongside technical and policy expertise, and working with domestic financial institutions, they can lower risks in new low-carbon asset markets (e.g. accelerated solar rooftop power in India). MDBs can support market creation through shifting financial flows, stimulating innovation and helping to set standards (e.g. for fossil fuel exclusion policies, GHG accounting and climate risk disclosure).

  Consistency of public policy is, however, essential: signals must go in one direction. Alignment of public policies towards creating new markets in low-carbon energy transition also requires exiting from subsidies and other support to fossil fuel sectors, such as guarantees from ECAs. Steering in other directions prolongs the status quo, and is expensive and ineffective. It also prevents norms and practices from changing, because signals towards the actors in the financial system are unclear.

- **Mobilize central banks.** Central banks are increasingly addressing the climate crisis, and have different tools at their disposal (see section 7.2). In December 2017, eight central banks and supervisors established the NGFS, which has now grown to 116 members and 18 observers. Mandates of central banks in developing countries are often broader than those of central banks in developed countries; More concrete action towards this approach can therefore be observed. For example, the Reserve Bank of India requires that commercial banks allocate a certain proportion of lending to a list of 'priority sectors', including renewable energy, and Bangladesh Bank has introduced a minimum credit quota of 5 per cent that financial institutions must allocate to green sectors (Campiglio *et al.* 2018).

Furthermore, prudential regulations are increasingly starting to include climate change. Prudential regulation aims at ensuring that banks and other financial institutions (the micro level) and the whole of the financial system (the macro level) are robust against market risks. Apart from stress testing, central banks could also consider green quantitative easing and making transition plans, or transition pathways, mandatory for commercial banks, for example through science-based net-zero targets with interim emissions reduction targets every five years, sectoral decarbonization trajectories for the entire portfolio, and minimizing the use of offsets (Pinko and Pastor 2022). The European Central Bank, for example, announced the incorporation of climate criteria in their asset purchase programmes in 2022. The prioritization of which bonds to purchase, or to keep in their portfolio, is crucial. By choosing to release high-emitting assets first, central banks send a strong signal to the market for firms and financial institutions. The same is true for changing capital requirements and collateral frameworks.

Another important recent development is that the IMF has set up a special Resilience and Sustainability Trust Fund (special drawing rights [SDR] 33 billion, equivalent to US$45 billion) as part of the recent SDR issuance of US$650 billion in August 2021. Aim is to help low-income and vulnerable middle-income countries access long-term funding (up to 20 years) for climate change and other structural challenges, at low interest rates, using a part of new SDR reserves (IMF 2022).

- **Set up climate clubs and cross-border finance initiatives.** This approach draws from game theory literature, and suggests a strong advantage of smaller 'clubs' of cooperating countries (Nordhaus 2015), to move faster on commitments to shifting financial flows (since global climate agreements have greater difficulties in coordinated actions). Because of the smaller size and leverage of participating countries, such clubs could alter policy norms and change the course of finance through credible financial commitment devices, such as sovereign guarantees on cross-border financial flows.

For example, at COP 26 in Glasgow, a group of 34 countries signed an agreement to end new direct public support for the international unabated fossil fuel energy sector by the end of 2022, except in limited and clearly defined circumstances that are consistent with a 1.5°C warming limit and the goals of the Paris Agreement (United Nations Climate Change Conference of the Parties 2021). This agreement directly targets ECAs. For the transition of the financial system, it is crucial that this agreement is fully implemented and that additional countries join the agreement, as Japan did in the context of the G7 meeting in 2022. The International Just Energy Transition Partnership initiative was also announced at COP 26, and could be enlarged and operationalized. Climate clubs are more effective and could do more; they currently primarily act as information-sharing and voluntary arrangements among small groups of influential cooperating countries (such as at the G20) (Unger and Thielges 2021).

Another example is fossil fuel subsidy reform, an emerging norm (Skovgaard and van Asselt 2019) that is advocated by climate clubs. For example, after earlier commitments by the G20 and the Asia-Pacific Economic Cooperation to reform fossil fuel subsidies, this was also mentioned in the UNFCCC Glasgow Climate Pact. A demonstration effect caused by deepening these initiatives domestically would have an important impact.

Evidence on the effectiveness of the six approaches above suggests that there is no single 'silver bullet' that will transform the financial system, and that multiple instruments, institutions and actors under different approaches need to be mobilized (see table 7.2). For example, while institutional investors are making markets more efficient by applying exclusionary screens (or not), they have done so solely on the basis of scope 1 emissions intensity, and only for the industries with the highest CO_2 emissions (oil and gas, utilities, and motor industries) (Bolton and Kacperczyk 2021). It will take time and more reliable data to overcome such shortcomings. Similarly, when governments postpone ambitious climate policy, the transition risks are downplayed, which makes the short-term effects for financial stability less problematic, thus limiting action by central banks with the mandates they have (even if long-term risks are aggravated). Instead, nested and coordinated approaches are likely to work better in transforming climate finance (Schmidt and Sewerin 2019; Bhandary, Gallagher and Zhang 2020): the ensure that action is implemented in the same direction, tailored to contexts and pursued across major groups of countries, with equity and a just transition within and between countries. The institutional challenges to achieving such coordinated and cooperative actions, however, ultimately depend on public support and pressures to avert the significant risks of inaction.

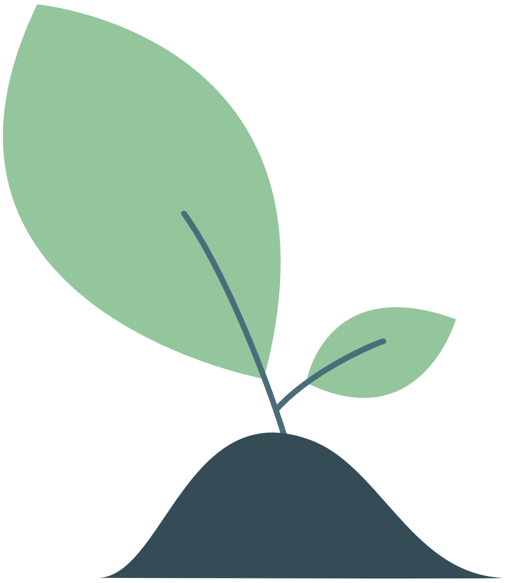
Adopting multiple approaches in the same direction ultimately helps address a variety of different binding constraints to accelerate the pace of change. Low-carbon transitions are undertaken by a wide range of actors with differing interests, resources, capabilities and beliefs about their preferred solutions (Geels, Berkhout and van Vuuren 2016; Edomah *et al.* 2020). The other reason is that a multiplicity of approaches may signal a stronger 'whole of society' commitment. For example, combinations of carbon taxes, use of pooled green bond markets and supportive state fiscal policies have worked in some contexts (Hoff 2017; Nassiry 2018; Andersen 2020; Hans *et al.* 2022). These, in turn, help drive faster movement up the typical S-curves observed in the uptake of large system/technological/finance transitions where such transitions are typically non-linear (Dasgupta 2015; Grubb, Drummond and Hughes 2020).

Table 7.2 Accelerating climate finance flows for emissions gap reduction and low-carbon transition: Multiple approaches, instruments and actors

	Instruments	Institutions and actors
Increase the efficiency of financial markets	• Financial transparency rules and protection of investors and consumers • Climate-related financial risk disclosure (voluntary and mandatory) • Taxonomies and classification systems • Financial engineering (structured finance, asset-backed non-recourse debt, venture capital, private equity etc.) • Definitions and disclosure/recognition of risk of stranded assets • Green bonds and bond market classifications and standards, including ESG standards • Capacity-building	• Financial regulatory institutions • Central banks • Credit rating and related agencies • Banks and institutional investors • Bond market regulators
Introduce carbon pricing	• Carbon taxes • Emissions trading schemes • Fossil fuel subsidy reduction • Carbon credit instruments	• Ministries of finance and treasuries • Financial regulatory agencies • Ministries of power/ environment • International agreements (e.g. UNFCCC)
Nudge financial behaviour	• Nudges to address herd behaviour and behavioural and system inertias, and to provide benefits from switching to low-carbon alternatives • Divestment movements • Tax benefits to accelerate low-carbon investments • Product taxes, subsidies, regulations, standards, labelling and public infrastructure • Carbon taxes and regulations on GHG-intensive activities	• Ministries of finance and treasuries • Ministries of environment • Large corporates, supply chains • MDBs, DFIs, ECAs
Create markets	• Public bonds and guarantee issuances for domestic, early-stage research and development investment and direct investment support, green banks • Innovation intermediaries and investment • Public-private partnerships • Enabling policy support (feed-in tariffs, reverse auctions etc.) • Product market regulations and standards • Public procurement contracts and purchase guarantees • Taxes and subsidies	• Ministries of finance and treasuries • National and regional development banks and green banks • Cities and regions • Private equity investors

Mobilize central banks	• Priority sector lending and credit quotas • Prudential lending standards and bank supervision, collateral requirements • Stress testing and financial stability prudential requirements • Enhanced liquidity support to financial system • Creating new asset classes for climate in banking/investment regulation • Quantitative easing and central bank balance sheet activities • Low-carbon climate remediation assets • IMF SDR issuance funding for climate investment support in low-income contexts	• Central banks • Financial regulators • IMF • Banks and institutional investors
Set up climate clubs and international cross-border financial initiatives	Instruments depends on type of initiative, but include: • Voluntary standards and agreements on fossil fuel subsidy reductions • Agreement on ECA norms • Just transition initiatives and financial support structures • Multilateral and bilateral climate funds • Multi-sovereign and other guarantee support to de-risk and leverage private investment	• Climate funds • MDBs, ECAs • Multi-sovereign guarantee mechanisms • CRAs • G7/G20 agreements • Larger private institutional actors

Notes: There are significant overlaps between categories, and only a limited exercise has been conducted to net out these overlaps.



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Chapter 6

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