Brot für die Welt Briefing Paper

Key results of the

IPCC 6th Assessment Report, Part 3:

Climate Change 2022: Mitigation of Climate Change

Mitglied der actalliance

Brot für die Welt

Contents

List of figures

Abbreviations

AFOLU	Agriculture, Forestry and Land-use Change
AR6	6th Assessment Report of the IPCC (2021-2022)
BECCS	Bioenergy with Carbon Capture and Storage
BRICS	Brazil, Russia, India, China, South Africa
CCS	Carbon Capture and Storage
CDR	Carbon Dioxide Removal
CO2	Carbon Dioxide
CO2_eq	Carbon Dioxide Equivalents
EJ	Exajoule (10^{18} Joule)
GDP	Gross Domestic Product
GHG	Greenhouse Gases
LDCs	Least Developed Countries
LULUCF	CO2 emissions from land-use, land-use change & forestry
MDBs	Multilateral Development Banks
NDC	Nationally Determined Contribution
PPP	Public Private Partnership
SIDS	Small Island Developing States
SSC	South-South Cooperation
TPES	Total Primary Energy Supply
UNFCCC	UN Framework Convention on Climate Change
WFEN	Water-Food-Energy-Nexus

Glossary

Climate resilient development: development that deliberately adopts mitigation and adaptation measures to secure a safe climate, meet basic needs, eliminate poverty and enable equitable, just and sustainable development. It halts practices that contribute to dangerous levels of global warming and maladaptation. Climate resilient development may necessitate deep societal transformation to ensure wellbeing for all.

Emission pathways: term used for modelled trajectories of global anthropogenic emissions over the 21st century.

Scenario: term used for an internally consistent, plausible and integrated description of a possible future of the human-environment system.

Stranded assets: assets that have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities.

Introduction

The IPCC 6th Assessment Report (AR) 'Climate Change 2022: Mitigation of Climate Change' was published eight years after its predecessor and seven years after the adoption of the Paris Agreement. Many things have changed since then. This makes it a 'must' to deal with the new report. In this briefing, we therefore summarise key messages.

As a development organisation and an evangelical relief agency committed to climate justice, we are setting appropriate accents here. These are those which show the possible synergies and co-benefits, but also trade-offs between climate mitigation required to achieve the goals of the Paris Agreement and the Sustainable Development Goals (SDGs).

The briefing paper documents the IPCC's findings without evaluating. Likewise, no political or programmatic conclusions are drawn for the future practice of Bread for the World and other actors in the fields of mitigation of climate change. This necessary next step must nevertheless be taken, because the IPCC's findings can only lead to the conclusion that considerable additional efforts are needed to close the alarmingly growing emission gap. In particular, according to a key finding of the IPCC, far more needs to be done in the coming years to move from incremental and sectoral to systemic and cross-sectoral transformations; to quickly switch from a business-as-usual development pathway to a truly new paradigm of sustainable development, with equity and justice as two key elements of it; to mobilise capacity-building, technical, financial and, last but not least, societal support for a deep transformation; and to deal with the fact that the transformation will be disruptive, requires trade-offs, and needs to balance between competing interests, always bearing the risk that uncomfortable decisions will be postponed into the future in favour of short-term interests. But climate change no longer offers this leeway.

Without massive measures today, we are burdening future generations with incalculable risks and high costs, which fundamentally contradicts the principle of climate justice between generations.

The selection of the takeaways summarised is highly selective. It is limited to 10 chapters of the IPCC Report that are of particular interest from Bread for the World's point of view. Key passages have been taken from these chapters and summarised in a condensed form. Formal citation has been dispensed with, because otherwise the text would have become unreadable. With the exception of this introductory chapter, no own comments are made at all.

The selection and compilation of key statements from the IPCC report is necessarily subjective. The authors are solely responsible for any contextualisation or citation error that may have occurred due to the great time pressure during the preparation of this briefing.

The Briefing Paper starts with 15 summarised key messages from the IPCC AR6 on Mitigation of Climate Change, selected from a climate justice perspective. In a second step, the following chapters are briefly summarised, again with a focus on aspects that are particularly relevant from a climate justice and sustainable development perspective, and with a clear focus on developing countries and international cooperation with them:

- Framing
- Emission trends and drivers
- Mitigation pathways compatible with long-term goals
- Mitigation and development pathways in the near to mid term
- Energy systems
- International cooperation
- Investment and finance
- Accelerating the transformation in the context of sustainable development.

Key Messages of the IPCC AR6th on Mitigation of Climate Change from a Climate Justice Perspective

1. **Current greenhouse gas (GHG) emission trends at global level are incompatible with the goals agreed in the Paris Agreement, which highlights the need for urgent and accelerated mitigation action at all scales**.

2. **Globally effective climate mitigation needs to be implemented to achieve global sustainable development and to eradicate poverty as enshrined in 17 SDGs, recognising there are synergies and/or trade-offs. Equity and justice are important issues to address to get national and international support for deep decarbonisation.**

3. **The economic benefits of mitigating climate change outweigh costs in most regions**. **Delayed participation in global mitigation efforts raises participation costs, especially in developing economies.**

4. **Emissions taxation has important distributive effects on some sectors, particularly in developed countries**. **Revenues from emissions taxation can be used to lessen their regressive distributional impacts or turned into a progressive policy reducing inequality and/or leading to gains for lower-income households**.

5. **Prices have dropped rapidly over the last five years for several key energy system mitigation options, notably solar PV, wind power, and batteries.** From 2015 to 2020, the prices of electricity from PV and wind dropped 56% and 45%, respectively, and battery prices dropped by 64%. Electricity from PV and wind is now cheaper than electricity from fossil sources in many regions, electric vehicles are increasingly competitive with internal combustion engines, and large-scale battery storage on electricity grids is increasingly viable.

6. **Global wind and solar PV capacity and generation have increased rapidly.** Solar PV grew by 170% (to 680 TWh); wind grew by 70% (to 1420 TWh) from 2015 to 2019. Policy, societal pressure to limit fossil generation, low interest rates, and cost reductions have all driven wind and solar PV deployment. Solar PV and wind together accounted for 21% of total low-carbon electricity generation and 8% of total electricity generation in 2019. Nuclear generation grew 9% between 2015 and 2019 and accounted for 10% of total generation in 2019 (2790 TWh); hydroelectric power grew by 10% and accounted for 16% (4290 TWh) of total generation. In total, low- and zero-carbon electricity generation technologies produced 37% of global electricity in 2019. **The viable speed and scope of energy system change will depend on how well such change can support broader societal objectives. If investments in coal and other fossil infrastructure continue, energy systems will be locked-in to higher emissions, making it harder to limit warming to well below 2°C.** Many aspects of the energy system – physical infrastructure; institutions, laws, and regulations; and behaviour – are resistant to change or take many years to change. New investments in coal-fired electricity without CCS are inconsistent with limiting warming to well below 2°C.

7. **Finance to reduce GHG emissions and enhance resilience to climate impacts represents a critical enabling factor for the transition. Fundamental inequities in access to finance as well as its terms and conditions, and countries' exposure to physical impacts of climate change overall result in a worsening outlook for a global just transition.** This challenge is exacerbated by economic vulnerability and indebtedness of many countries. The rising public fiscal costs of mitigation and of adaptation is affecting many countries and is worsening public indebtedness and country credit ratings at a time when there were already significant stresses. The COVID-19 pandemic has made these stresses worse and tightened public finances still further

8. **Progress on the alignment of financial flows with low GHG emissions pathways remains slow. There is a climate financing gap which reflects a persistent misallocation of global capital.**

Persistently high levels of both public and private fossil-fuel related financing continue to be of major concern despite promising recent commitments.

9. **To meet the needs for rapid deployment of mitigation options, global mitigation investments are expected to need to increase by the factor 3 – 6. The finance gap represents a major challenge for developing countries,** especially Least developed Countries, where flows have to increase by a factor 4-8.

10. **Feasibility of the transition also relates to social justice as an important element, which could be essential to enhance the political and public acceptability of low-carbon transition.** Three elements are key: i) protecting vulnerable people from climate change impacts, ii) protecting people from disruption of transformation, iii) enhancing the process of envisioning and implementing an equitable post-carbon society.

11. **Accelerating mitigation will require integration of assessment frameworks and tools that combine multiple perspectives**. **Ethical frameworks are essential to choose policies to avoid negative distributional impacts across income groups, countries and generations.**

12. **A rapid transition to sustainable development pathways is as desirable as it is difficult. Climate change stems from decades of unsustainable energy production, land use, production and consumption, as well as governance practices**. **Changing these patterns requires a fundamental reframing of development.** Sustainable development, by emphasising sectoral integration and social inclusion, offers such a reframing. A sustainable transition must be socially equitable and just. This equity principle also applies across countries. Developing countries often craft climate responses in decision-making environments with limited resources, deep social divisions and few advanced technologies.

13. **Policy attention on eight key areas may have important catalytic benefits**: (1) stepped-up technical support and partnership in low-income and vulnerable countries in sub-Saharan Africa, which currently receives less than 5% of global climate financing flows; (2) continued strong role of MDBs, but also national development banks; (3) de-risking cross-border investments in low-carbon infrastructure, development of local bond markets, and transparency in fossil-fuel investments; (4) lowering transaction costs and risks through green banks, funds and risk-sharing mechanisms for under-served small urban municipalities, smallholder agriculture, small and medium-sized enterprises (SMEs), and grid connectivity of small renewables; (5) accelerated finance for nature-based solutions, forestry and climate responsive social protection; (6) improved financing instruments for loss and damage events, including blended finance for risk pooling; (7) political economy options for phasing in carbon pricing options which address equity and access; and (8) gender responsive and women-empowered programmes.

14. **Mitigation policies may affect the poorest through effects on energy and food prices. Negative impacts of climate change mitigation policy can be mitigated and possibly prevented when distributive and procedural justice are taken into consideration in all stages of policy making**.

15. **The AFOLU sector has significant mitigation potential, with many scenarios showing net negative CO_2 emissions early in this century.** The largest share of GHG emissions reductions from AFOLU from 1.5°C and 2°C scenarios is from forest-related measures such as reforestation, resulting in substantial negative CO_2 emissions. **Significant differences exist in pathways with overshoot and pathways without; pathways without overshoot have significant reductions in CH_4 and N_2O through reductions in agricultural production, with implications for water use and risk of hunger**.

16. **Early shifting in mitigation action results in substantial land use change reducing the amount of land required for afforestation and BECCS as CDR measures. Earlier action could also reduce climate impacts on agriculture and land-based mitigation options**.

Framing

Summary of the conclusions from Chapter 1 of the report

Current greenhouse gas (GHG) emission trends at global level are incompatible with the goals agreed in the Paris Agreement, which highlights the need for urgent and accelerated mitigation actions at all scales. Meeting Paris Agreement goals requires global CO2 emissions to peak before 2025, and decline to net zero generally within the third quarter of the century. This implies urgent and ambitious action combining national initiatives with regional and global cooperation.

Globally effective climate mitigation needs to be implemented to achieve sustainable development and to eradicate poverty as enshrined in 17 SDGs, recognising there are synergies and/or trade-offs. There has been a strong relationship between development and GHG emissions, as historically emissions have risen with industrialisation. Countries have different priorities in achieving the SDGs, in view of their national conditions. Given the differences in historical and current responsibilities and impacts, as well as capacities within and between nations, **equity and justice are important issues to address to get national and international support for deep decarbonisation**. International cooperation can enhance efforts to achieve ambitious global climate mitigation in the context of sustainable development.

Advances in technologies and policies, including transformative changes in some regions and sectors, have opened up new and large-scale opportunities for deep decarbonisation, and for alternative development pathways, which could deliver multiple social and developmental goals. The development and deployment of innovative technologies and systems at scale are important for achieving deep decarbonisation. In recent years, several clean energy technologies have expanded rapidly and declined in cost, and significant numbers of countries have sustained emission reductions. However, competing priorities combined with institutional and political inertia could pose challenges. The transition to low-carbon development depends on a wide range of additional drivers and enabling conditions. These include: the means by which services are being provided and for whom, the emissions intensity of traded products, finance and investment, political economy forces, equity and fairness, social innovation and behaviour change, legal framework and institutions, and the quality of international cooperation.

Accelerating mitigation will require integration of assessment frameworks and tools that combine multiple perspectives. Analysing a challenge on the scale of fully decarbonising our economies requires integration of multiple analytic frameworks, including approaches to risk assessment. Economic frameworks indicate increasing convergence of cost-benefit assessment with cost-effective delivery of the Paris goals. **Ethical frameworks are essential to choose policies to avoid negative distributional impacts across income groups, countries and generations.** Transition frameworks explain the dynamics of transitions to low-carbon systems. Psychological, behavioural and political frameworks underline the constraints and opportunities arising from psychology and the power of incumbent interests. A comprehensive understanding must combine these frameworks. Together they explain potential synergies and trade-offs, imply a need for a wide portfolio of policies, and underpin **'just transition'** strategies.

The speed, direction and depth of transition will be determined by choices. Transitions are not smooth and gradual. They can be sudden and disruptive. The pace of transition can be impeded by 'lock-in' from existing capital, institutions and social norms. The interaction between power, politics and economy is central in explaining why commitment does not always translate into urgent action. Supporting policies in the realms of finance, regulation, institutions and social norms are essential to accelerate low-carbon transitions, whilst **addressing distributional concerns**.

Achieving global transition to a low-carbon, climate-resilient and sustainable world requires coordinated planning and decisions at many scales of governance including municipal, subnational, national and global levels. It also involves a range of non-nation state actors such as cities, businesses and civil society organisations. The governance has to navigate power, political, economic and social dynamics at all levels of decision making. Institutions, ideas and experimentation are key factors in shifting perceptions, engaging stakeholders and building momentum for effective climate action at all scales of governance.

Emission Trends and Drivers

Summary of the conclusions from Chapter 2 of the report

Global net anthropogenic Greenhouse Gas emissions during the last decade (2010-2019) were higher than at any previous time in human history. Since 2010, GHG emissions have continued to grow reaching 59±6.6 $GtCO_2eq$ in 20191, but the average annual growth in the last decade (1.3%, 2010-2019) was lower than in the previous decade (2.1%, 2000-2009. Average annual GHG emissions were 56 $GtCO_2eqyr^{-1}$ for the decade 2010-2019 growing by about 9.1 $GtCO_2eqyr^{-1}$ from the previous decade (2000-2009) – the highest decadal average on record.

Emission growth has been varied, but persistent across different gases. In 2019, CO_2 emissions were 45±5.5 $GtCO_2$, CH_4 11±3.2 $GtCO_2eq$, N_2O 2.7±1.6 $GtCO_2eq$ and fluorinated gases (F-gases: HFCs, PFCs, SF_6, NF_3) 1.4±0.41 $GtCO_2eq$. Compared to 1990, the magnitude and speed of these increases differed across gases: CO_2 from fossil fuel and industry (FFI) grew by $GtCO_2eqyr^{-1}$ 14 (67%), CH_4 by 2.4 $GtCO_2eqyr^{-1}$ (29%), F-gases by 0.97 $GtCO_2eqyr^{-1}$ (250%), N_2O by 0.65 $GtCO_2eqyr^{-1}$ 15 (33%). CO_2 emissions from net land use, land-use change and forestry (LULUCF) have shown little long-term change, with large uncertainties preventing the detection of statistically significant trends.

Cumulative net CO_2 emissions of the last decade (2010-2019) are about the same size as the remaining carbon budget for keeping warming to 1.5°C. Cumulative net CO_2 emissions since 1850 are increasing at an accelerating rate. 62% of total cumulative CO_2 emissions from 1850 to 2019 occurred since 1970 (1500±140 $GtCO_2$), about 43% since 1990 (1000±90 $GtCO_2$), and about 17% since 2010 (410±30 $GtCO_2$). For comparison, the remaining carbon budget for keeping warming to 1.5°C with a 67% (50%) probability is about 400(500)±220 $GtCO_2$.

A growing number of countries have achieved GHG emission reductions longer than 10 years – 39 a few at rates that are broadly consistent with climate change mitigation scenarios that limit warming to well below 2°C.

Consumption-based CO_2 emissions in developed countries and the Asia and Developing Pacific region are higher than in other regions (high confidence). In developed countries, consumption-based CO_2 emissions peaked at 15 $GtCO_2$ in 2007, declining to about 13 $GtCO_2$ in 2018. The Asia and Developing Pacific region, with 52% of current global population, has become a major contributor to consumption-based CO_2 emission growth since 2000 (5.5% yr^{-1} for 2000-2018); it exceeded the developed countries region, which accounts for 16% of current global population, as the largest emitter of consumption-based CO_2.

Many (43 out of 166) countries have decoupled CO_2 emissions from economic growth in recent years (2010-2015). A group of developed countries, i.e. some EU countries and the US, and some developing countries, have achieved absolute decoupling of consumption-based CO_2 emissions and GDP growth. The decoupling has been achieved at various levels of per capita income and per capita emissions.

Carbon intensity improvements in the production of traded products have led to a net reduction 18 in CO_2 emissions embodied in international trade. A decrease in the carbon intensity of traded products has offset increased trade volumes between 2006 and 2016. Emissions embodied in internationally traded products depend on the composition of the global supply chain across sectors and countries and the respective carbon intensity of production processes.

There is a net CO_2 emission transfer from developing to developed countries via global supply chains. This net emission transfer increased from 6.1% in 1995 and peaked in 2006 at 7.3%. Developed countries tend to be net CO_2 emission importers, whereas developing countries tend to be net emission exporters. This is caused by the international division of labour in the production of consumer goods, where emission-intensive processes are increasingly carried out in developing countries. Most recently, emission transfers between developing countries have been sharply increasing with the centre of trade activities shifting from Europe to Asia.

Emissions from developing countries have continued to grow, starting from a low base of per 30 capita emissions and with a lower contribution to cumulative emissions than developed countries. Average 2019 per capita CO2-FFI emissions in three developing regions - Africa (1.2 tCO2/cap), Asia and developing Pacific (4.4 tCO2/cap), and Latin America and Caribbean (2.7 tCO2/cap) - remained less than half that of developed countries (9.5 tCO2/cap) in 2019. CO2-FFI emissions in the three developing regions together grew by 26% between 2010 and 2019, compared to 260% between 1990 and 2010, while in Developed Countries emissions contracted by 9.9% between 2010-2019 and by 9.6% between 1990-2010. Historically, the three developing regions together contributed 28% to cumulative CO2-FFI emissions between 1850 and 2019, whereas Developed Countries contributed 57% and least developed countries contributed 0.4%.

GHG emissions continued to rise across all sectors; most rapidly in industry, energy and transport. In 2019, 34% (20 GtCO2eq) of global GHG emissions came from the energy sector, 24% (14 GtCO2eq) from industry, 22% (13 GtCO2eq) from AFOLU, 15% (8.7 43 GtCO2eq) from transport and 5.6% (3.3 GtCO2eq) from buildings.

Average annual growth in GHG emissions from energy supply decreased from 2.3% for 2000– 2009 to 1.0% for 2010–2019. This slowing of growth is attributable to further improvements in energy efficiency (annually, 1.9% less energy per unit of GDP was used globally between 2010 and 2019). Reductions in global carbon intensity by -0.2% yr-1 contributed further - reversing the trend during 2000-2009 (+0.2% yr-1).

GHG emissions of the buildings sector are mainly driven by a growing demand for building stock, floor space per capita and building energy services as countries develop and urbanise. Since 2010, GHG emissions in the buildings sector have declined in North America and Europe. In contrast, GHG emissions have risen sharply in East Asia where they have reached the highest level of all regions due to urbanisation.

Road transport for passengers and freight represent by far the largest component of transport sector emissions (73%), which

have continued to grow at a rate of about 2% per year over the last three decades. The high proportion of fossil fuels in transport (92%), insufficient improvements in transport energy efficiency and a global increase in passenger and freight travel activity levels mean that transport emissions kept increasing in all world regions. The adoption of electric vehicles is rapidly increasing in several regions departing from very low levels. While accounting for a small share of total GHG emissions, aviation emissions are growing faster than road transport emissions.

GHG emissions from AFOLU increased by 1% per year on average between 2010 and 2018. CO_2 emissions from land-use change and CH_4 emissions from enteric fermentation together account for almost 70% of the sector's emissions. CO_2 emissions from land-use change grew substantially only in Africa. CH_4 emissions from enteric fermentation were highest and strongly growing in Latin America, South Asia and Africa, reflecting rising consumption of animal-based diets in low- and middle-income countries.

Eradicating extreme poverty and providing universal access to modern energy services to poor populations across the globe has negligible implications for emissions growth.

Low-carbon technologies have shown rapid progress in cost, performance and adoption, enhancing the feasibility of rapid energy transitions. The rapid historic cost decreases of technologies like solar, wind and batteries have occurred much faster than expected. Small-scale technologies tend to improve faster than largescale technologies. **Incentives for investment in innovation are central to accelerating low-carbon technological change**.

The top 10% emitters (the global wealthiest 10% on a per capita basis) contribute about 36-45% of global GHG emissions. Within countries, inequalities have increased for both income and GHG emissions. The top global 10% emitters live on all continents, with two-thirds in rich OECD regions and one-third in emerging economies.

Estimates of future CO_2 emissions from existing fossil fuel infrastructures already exceed remaining cumulative net CO_2 emissions in pathways limiting warming to 1.5°C with no or limited overshoot. Assuming variations in historic patterns of use and decommissioning, estimated future CO_2 emissions from existing fossil fuel infrastructure alone are 660 $GtCO_2$ and from existing and currently planned infrastructure 850 $GtCO_2$. This compares to overall cumulative net CO_2 emissions until reaching net zero CO_2 of 510 Gt in pathways that limit warming to 1.5°C with no or limited overshoot, and 880 Gt in pathways that limit warming to 2°C.

Decommissioning and reduced utilization of existing fossil fuel installations in the power sector as well as cancellation of new installations are required to align future CO_2 emissions from the power sector with projections in these pathways (high confidence).

Climate policies play an increasing role in emissions reductions taking place as a result of carbon pricing associated with carbon taxes or emissions trading.

Mitigation Pathways Compatible with Long-term Goals

Summary of the conclusions from Chapter 3 of the report

Pathways consistent with the implementation and extrapolation of countries' current policies see GHG emissions reaching 52-60 $GtCO_2$-eq yr^{-1} by 2030 and to 46-67 $GtCO_2$-eq yr^{-1} by 2050, leading to a median global warming of 2.4°C to 3.5°C by 2100. Main emissions drivers include population growth, reaching between 8.5-9.7 billion people by 2050, and the increase in the global GDP of 2.7-4.1% per year between 2015 and 2050.

Cost-effective mitigation pathways assuming immediate actions to likely limit warming to 2°C are associated with net global GHG emissions of 30-49 $GtCO_2$-eq yr^{-1} by 2030 and 13-27 $GtCO_2$-eq yr^{-1} by 2050. This corresponds to reductions of 12-46% by 2030 and 52-77% by 2050 relative to 2019 levels. **Pathways that limit global warming to below 1.5°C with no or limited overshoot require net GHG emissions around 21-36 $GtCO_2$-eq yr^{-1} by 2030 and 1-15 $GtCO_2$-eq yr^{-1} by 2050**; thus, reductions of 38–63% by 2030 and 75-98% by 2050 relative to 2019 levels.

Pathways following current NDCs until 2030 reach annual emissions of 47-57 $GtCO_2$-eq by 2030, making it impossible to limit warming to 1.5°C with no or limited overshoot and strongly increasing the challenge to likely limit warming to 2°C.

Pathways accelerating actions compared to current NDCs that reduce annual GHG emissions to 47 (38-51) $GtCO_2$-eq by 2030, or 3-9 $GtCO_2$-eq below projected emissions from fully implementing current NDCs reduce the mitigation challenge for likely limiting warming to 2°C after 2030.

Mitigation pathways limiting warming to 1.5°C with no or limited overshoot reach 50% reductions of CO_2 in the 2030s, relative to 2019, then reduce emissions further to reach net zero CO_2

emissions in the 2050s. Pathways likely limiting warming to 2°C reach 50% reductions in the 2040s and net zero CO2 by 2070s.

Rapid reductions in non-CO2 GHGs, particularly methane, would lower the level of peak warming. Residual non-CO2 emissions at the time of reaching net zero CO2 range between 4-11 GtCO2-eq yr-1 in pathways likely limiting warming to 2°C or below. Methane emission reductions in pathways limiting warming to 1.5°C are substantially higher by 33% (19-57%) by 2030, but only by 50% (33-69%) by 2050 relative to 2019. N2O emissions are reduced too, but similar to CH4, emission reductions saturate for more stringent climate goals. With reduced use of fossil fuels, the mitigation pathways see less emissions of cooling aerosols.

Pathways likely limiting warming to 2°C and below exhibit substantial reductions in emissions from all sectors. Projected CO2 emissions reductions between 2019 and 2050 in 1.5°C pathways are around 77% (31-96%) for energy demand, 115% for energy supply (90 to 167%), and 148% for AFOLU (94 to 387%). In pathways likely limiting warming to 2°C, projected CO2 emissions are reduced between 2019 and 2050 by around 49% for energy demand, 97% for energy supply, and 136% for AFOLU.

Delaying or sacrificing emissions reductions in one sector or region involves compensating reductions in other sectors or regions if warming is to be limited. Mitigation pathways show differences in the timing of decarbonization and when net zero CO2 emissions are achieved across sectors and regions. In cost-effective mitigation pathways, the energy supply sector reaches net zero CO2 before the economy as a whole.

Pathways likely limiting warming to 2°C and below involve substantial reductions in fossil fuel consumption and a near elimination of the use of coal without CCS.

Stringent emissions reductions at the level required for 2°C and below are achieved through increased direct electrification of

buildings, transport, and industry, resulting in increased electricity generation in all pathways.

The measures required to likely limit warming to 2°C or below can result in large scale transformation of the land surface. These pathways are projected to reach net zero CO_2 emissions in the AFOLU sector between 2020 and 2070 – with an increase of forest cover of about 322 million ha in 2050 in pathways limiting warming to 1.5°C. Cropland area to supply biomass for bioenergy (including BECCS) is around 199 million ha in 2100 in pathways limiting warming to 1.5°C.

Pathways that likely limiting warming to 2°C or below involve some amount of CDR to compensate for residual GHG emissions remaining after substantial direct emissions reductions in all sectors and regions. CDR can be used to accelerate the pace of emissions reductions, to offset residual emissions, and to create the option for net negative CO_2 emissions. CDR options in the pathways are mostly limited to BECCS and afforestation.

Limiting warming requires shifting energy investments away from fossil-fuels and towards low-carbon technologies. The bulk of investments are needed in medium- and low-income regions. Investment needs in the electricity sector average 2.3 trillion USD2015 yr^{-1} over 2023-2052 for pathways limiting temperature to 1.5°C, and 1.7 trillion USD2015 yr^{-1} for pathways likely limiting warming to 2°C.

Pathways likely avoiding overshoot of 2°C warming require more rapid near-term transformations and are associated with higher up-front transition costs, but meanwhile bring long-term gains for the economy as well as earlier benefits in avoided climate change impacts. The modelled cost-optimal balance of mitigation action over time depends on the discount rate: lower discount rates favor earlier mitigation, reducing reliance on CDR and temperature overshoot.

Mitigation pathways likely limiting warming to 2°C entail losses in global GDP with respect to reference scenarios of between

1.3% and 2.7% in 2050; and in pathways limiting warming to 1.5°C with no or limited overshoot, losses are between 2.6% and 4.2%. Yet, these estimates do not account for the economic benefits of avoided climate change impacts. In mitigation pathways likely limiting warming to 2°C, marginal abatement costs of carbon are about 90 USD2015/tCO2 in 2030 and about 210 USD 2015/tCO2 in 2050; in pathways that limit warming to 1.5°C, they are about 220 USD2015/tCO2 in 2030 and about 630 USD2015/tCO2 in 2050.

The global benefits of pathways likely limiting warming to 2°C outweigh global mitigation costs over the 21st century, if aggregated economic impacts of climate change are at the moderate to high end of the assessed range, and a weight consistent with economic theory is given to economic impacts over the long-term. This holds true even without accounting for benefits in other sustainable development dimensions or non-market damages from climate change. Avoided impacts for poorer households and poorer countries represent a smaller economic share, whereas their well-being and welfare effects are comparatively larger.

Differences between aggregate employment in mitigation pathways compared to reference scenarios are relatively small, although there may be substantial reallocations across sectors, with job creation in some sectors and job losses in others. Mitigation has implications for employment through multiple channels, each of which impacts geographies, sectors, and skill categories differently.

The economic repercussions of mitigation vary widely across regions and households, depending on policy design and level of international cooperation. Delayed global cooperation increases policy costs across regions.

The timing of mitigation actions and their effectiveness have significant consequences for sustainable development outcomes in the longer term. Ambitious mitigation can be considered a precondition for achieving SDGs, especially for vulnerable

populations and ecosystems with little capacity to adapt to climate impacts.

Many of the potential trade-offs of mitigation measures with sustainable development depend on the policy design and can be compensated or avoided with additional complementary policies and investments or through policies that integrate mitigation with other SDGs.

Decent living standards, which encompass many SDG dimensions, are achievable at lower energy use than previously thought. Mitigation strategies focusing on low-energy have overall lower trade-offs and negative consequences on sustainable development than pathways involving high emissions, and those involving high consumption and emissions compensated by large quantities of BECCS.

Different mitigation pathways are associated with different feasibility challenges, though enabling conditions can reduce these challenges. These challenges are multi-dimensional, context-dependent, and malleable to policy, technological, and societal trends.

Institutional and economic feasibility challenges are particularly relevant, and possibly more important than technological and geophysical ones. Institutional capacity is a key limiting factor for a successful transition. As a result of this, and of the size of the low-carbon transition, emerging economies appear to have higher feasibility challenges than industrialised countries in the short to medium term.

Key takeaways on the timing of net-zero emissions

- The global average warming limit of 1.5C implies carbon neutrality around 2035-2070 – if an overshoot of over 0.2C is avoided. Keeping temperatures under 2C implies carbon neutrality between 2060 and 2100. In scenarios limiting temperatures to 1.5C or under 2C, methane and nitrous oxide emissions need to be reduced – methane emissions reducing by almost 50% by 2050
- The timing of net zero by sector depends on the cost of abatement in that sector, the availability of CDR options, and the scenario design. In scenarios limiting warming to 1.5C with no or limited overshoot, the energy system reaches net zero CO2 emissions from 2060 onwards. Sectors such as long-distance transport, air transport, and process heat are anticipated to face greater challenges to decarbonisation than the electricity sector.

Table 3.2 GHG, CO_2 emissions and warming characteristics of different mitigation pathways submitted to the AR6 scenarios database and as categorized in the climate assessment.

p50 (p5-p95) [0] Global Mean Surface Air Temperature change			GHG emissions Gt CO_2-eq/yr			GHG emissions reductions from 2019 % [5]			Emissions milestones [6,7]				Cumulative CO_2 emissions Gt CO_2 [9]		Cumulative net-negative CO_2 emissions Gt CO_2	Temperature change 50% probability [10] °C		Likelihood of staying below (%) [11]			Time when specific temeprature levels are reached (with a 50% probability)		
Category [1,2,3,4] [# pathways]	Category description	WG1 SSP & IPs alignment	2030	2040	2050	2030	2040	2050	Peak CO_2 emissions	Peak GHG emissions	net-zero CO_2 [% net-zero pathways]	net-zero GHGs [8] [% net-zero pathways]	2020 to netzero CO_2	2020-2100	year of net-zero CO_2 to 2100	at peak warming	2100	<1.5°C	<2.0°C	<3.0°C	1.5°C	2.0°C	3.0°C
C1 [97]	Below 1.5°C with no or limited overshoot	SP, LD Ren, SSP1-1.9	31 (21-36)	17 (6-23)	9 (1-15)	43 (34-60)	69 (58-90)	84 (73-98)	2020-2025 [100%] (2020-2025)	2020-2025 [100%] (2020-2025)	2050-2055 [100%] (2020-2025)	2095-2100 [52%] (2050-...)	510 (330-710)	320 (-210-570)	-200 (-560-0)	1.6 (1.5-1.6)	1.3 (0.8-1.5)	38 (33-73)	90 (86-98)	100 (99-100)	2030-2035 [90%] (2030-...)	...-... [0%] (...-...)	...-... [0%] (...-...)
C2 [133]	Below 1.5°C with high overshoot	Neg	42 (31-55)	25 (16-34)	14 (5-21)	23 (0-44)	55 (40-71)	75 (62-91)	2020-2025 [100%] (2020-2030)	2020-2025 [100%] (2020-2030)	2055-2060 [100%] (2045-2070)	2070-2075 [87%] (2055-...)	720 (540-930)	400 (-90-620)	-330 (-620--30)	1.7 (1.4-1.8)	1.4 (0.8-1.5)	24 (15-58)	82 (71-95)	100 (99-100)	2030-2035 [100%] (2030-2035)	...-... [0%] (...-...)	...-... [0%] (...-...)
C3 [311]	Likely below 2°C	SSP2-2.6	44 (32-55)	29 (20-36)	20 (13-26)	21 (1-42)	46 (34-63)	64 (53-77)	2020-2025 [100%] (2020-2030)	2020-2025 [100%] (2020-2030)	2070-2075 [91%] (2060-...)	...-... [30%] (2075-...)	890 (640-1160)	800 (500-1140)	-40 (-280-0)	1.7 (1.4-1.8)	1.6 (1.1-1.8)	20 (13-66)	76 (68-97)	99 (98-100)	2030-2035 [100%] (2030-2040)	...-... [0%] (...-...)	...-... [0%] (...-...)
C3a [204]	Immediate action		41 (30-49)	29 (21-36)	20 (13-27)	26 (12-46)	47 (35-63)	63 (52-77)	2020-2025 [100%] (2020-2025)	2020-2025 [100%] (2020-2025)	2070-2075 [88%] (2060-...)	...-... [24%] (2080-...)	880 (640-1180)	790 (480-1160)	-20 (-280-0)	1.7 (1.4-1.8)	1.6 (1.1-1.8)	22 (14-71)	78 (69-97)	100 (98-100)	2030-2035 [100%] (2030-2040)	...-... [0%] (...-...)	...-... [0%] (...-...)
C3b [97]	NDCs	GS	52 (47-55)	29 (20-36)	18 (10-25)	5 (0-14)	46 (34-63)	68 (56-82)	2020-2025 [100%] (2020-2030)	2020-2025 [100%] (2020-2030)	2065-2070 [96%] (2060-2100)	...-... [42%] (2075-...)	910 (720-1150)	800 (560-1050)	-70 (-300-0)	1.8 (1.4-1.8)	1.6 (1.1-1.7)	17 (12-61)	73 (67-96)	99 (98-99)	2030-2035 [100%] (2030-2035)	...-... [0%] (...-...)	...-... [0%] (...-...)
C4 [159]	Below 2°C		50 (41-56)	38 (28-43)	28 (19-35)	10 (0-27)	31 (20-50)	49 (35-65)	2020-2025 [100%] (2020-2030)	2020-2025 [100%] (2020-2030)	2075-2080 [86%] (2065-...)	...-... [31%] (2075-...)	1210 (970-1500)	1160 (700-1490)	-30 (-390-0)	1.9 (1.5-2.0)	1.8 (1.2-2.0)	11 (7-50)	59 (50-93)	98 (95-99)	2030-2035 [100%] (2030-2035)	...-... [0%] (...-...)	...-... [0%] (...-...)
C5 [212]	Below 2.5°C		52 (46-56)	45 (36-52)	39 (30-49)	6 (-1-18)	18 (4-33)	29 (11-48)	2020-2025 [100%] (2020-2035)	2020-2025 [100%] (2020-2035)	...-... [40%] (2075-...)	...-... [11%] (2090-...)	1780 (1400-2360)	1780 (1260-2360)	0 (-140-0)	2.2 (1.6-2.5)	2.1 (1.5-2.5)	4 (0-28)	37 (18-84)	91 (83-99)	2030-2035 [100%] (2030-2035)	2060-2065 [99%] (2055-2095)	...-... [0%] (...-...)
C6 [97]	Below 3°C	SSP2-4.5 Mod-Act	54 (50-62)	53 (48-61)	52 (45-57)	2 (-10-11)	3 (-14-14)	5 (-2-18)	2030-2035 [100%] (2020-2085)	2030-2035 [100%] (2020-2085)	...-... [0%] (...-...)	...-... [0%] (...-...)	2790 (2440-3520)	2790 (2440-3520)	0 (0-0)	2.7 (2.0-2.9)	2.7 (2.0-2.9)	0 (0-2)	8 (2-45)	71 (53-96)	2030-2035 [100%] (2030-2035)	2050-2055 [100%] (2045-2060)	...-... [0%] (...-...)
C7 [164]	Below 4°C	SSP3-7.0 Cur-Pol	62 (53-69)	67 (56-76)	70 (58-83)	-11 (-18-3)	-19 (-31-0)	-24 (-41--2)	2090-2095 [100%] (2035-2100)	2090-2095 [100%] (2035-2100)	...-... [0%] (...-...)	...-... [0%] (...-...)	4220 (3160-5000)	4220 (3160-5000)	0 (0-0)	3.5 (2.5-3.9)	3.5 (2.5-3.9)	0 (0-0)	0 (0-5)	22 (7-80)	2030-2035 [100%] (2030-2035)	2045-2050 [100%] (2045-2055)	2080-2085 [100%] (2070-2100)
C8 [29]	Above 4°C	SSP5-8.5	71 (68-80)	79 (77-96)	87 (82-112)	-20 (-34--17)	-35 (-66--29)	-46 (-92--36)	2080-2085 [100%] (2060-2100)	2080-2085 [100%] (2060-2100)	...-... [0%] (...-...)	...-... [0%] (...-...)	5600 (4910-7450)	5600 (4910-7450)	0 (0-0)	4.2 (3.3-5.0)	4.2 (3.3-5.0)	0 (0-0)	0 (0-0)	4 (0-27)	2030-2035 [100%] (2025-2035)	2040-2045 [100%] (2040-2050)	2065-2070 [100%] (2060-2075)

Figure 1: GHG, CO2 emissions and warming characteristics of different mitigation pathways. Source: IPCC 2022b,[1] chapter 3

Key takeaways on mitigation strategies and sectors therein

- 100% renewable energy system can be achieved by 2050. Scenarios have in common unabated coal use completely phased out by 2050; gas and oil use

[1] IPCC 2022b, Climate Change 2022: Mitigation of Climate Change

significantly reduced, and oil phased out in the second half of the century (most scenarios); and nuclear power playing a role as a mitigation strategy.

- The majority of scenarios reaching low GHG targets apply a considerable amount of CCS and scenarios consistent with the Paris Agreement targets rely on significant improvement of energy efficiency, rapid decarbonisation of supply and many of them CDR.
- In 2010, about 40% of emissions originated from developed countries, while 60% came from developing countries and Eastern Europe and west-central Asia regions. Projections show an increase to about 70% of developing countries' emissions by 2050.
- To change the dynamics of the buildings sector, mitigation scenarios rely on fuel switching and technology, efficiency improvement in building envelopes and behavioural changes are found to be essential.
- In transportation, reductions in CO_2 emissions are achieved by combining demand-side reduction, energy efficiency improvements, fuel switching, and decarbonisation of fuels.
- In the industrial sector, emission reduction is achieved through a combination of energy savings, structural change, fuel switching, and decarbonisation of fuels. There is a large mitigation potential in the industrial sector by 2050, including the potential for net zero CO_2 emissions for steel, plastics, ammonia and cement.
- The largest share of emissions reductions from AFOLU is from forest area-related measures such as afforestation/reforestation and avoided deforestation; limiting warming to likely 2C or below can result in large scale transformation of the land surface in terms of forest cover and increased energy cropland areas.
- If mitigation action is not properly managed, it can decrease food security through changes in land and food prices and leading to higher risk of hunger for an additional 80 to 280 million people. Food security support is needed to protect impoverished and vulnerable people from the risk of hunger. Introducing more biofuels and careful selection of bioenergy feedstocks could also reduce negative impacts. Reconciling bioenergy demands with food and biodiversity, as well as competition for land and water, will require changes in food systems – agricultural intensification, open trade, less consumption of animal-products and reduced food losses – and advanced biotechnologies.
- **Early shifting in mitigation action reduces the pressure on crop yields, increases food security, and positively influences nutrition and mortality. The yield reduction of global food**

production will increase food insecurity and influence nutrition and mortality.

Key takeaways on carbon lock-in and stranded assets

- There already exists a substantial and growing carbon lock-in today, as measured by committed emissions with existing long-lived infrastructure.
- The later climate policies are implemented, the stronger the carbon lock-in by 2030, and the higher the socioeconomic and political strain on rapid emission reduction rates after 2030.
- Literature on carbon lock-in showed that coal power plants are the most exposed to risk of becoming stranded, delayed mitigation action increases stranded assets and sectoral distribution and amount of stranded assets differ between countries.
- Coal power plants are the most exposed to the risk of becoming stranded, with only 42% of operating and planned plants being compatible with the 2C pathway – China and India being the most exposed.
- Stranded power sector assets might reach a value of USD 1.8 trillion by 2050 in scenarios consistent with a 2C target.
- The risk of stranded assets has implications for workers depending on them, asset owners, financial institutions, and the stability of the financial system.

Key takeaways on mitigation costs and benefits

- The **economic benefits of mitigating climate change outweigh costs in most regions**. Fostering technological change and finance, climate cooperation can generate economic benefits for both large developing economies and industrialised countries. **Delayed participation in global mitigation efforts raises participation costs, especially in developing economies**.
- Equitable burden sharing can be achieved with partly differentiated regional carbon prices.
- It is apparent that the bulk of investment requirements of many medium- and low-income countries needs to replace existing fossil generation capacity shifting away towards electricity generation while meeting the same growing demands.

- Emissions taxation has important distributive effects, both between and within income groups, which are more significant in some sectors and depend on country-specific consumption structures. **Revenues from emissions taxation can be used to lessen their regressive distributional impacts or be turned into a progressive policy reducing inequality and/or leading to gains for lower-income households**.
- **Mitigation policies may affect the poorest through effects on energy and food prices. Negative co-impacts of climate change mitigation policy can be mitigated** (and possibly prevented) when distributive and procedural justice are taken into consideration in all stages of policy making and focusing on carbon intensity of lifestyles, sufficiency and equity, wellbeing, and decent living standards for all.

Key takeaways on the feasibility and enablers of transitions

- Most studies have focused on expanding low-carbon system, yet political constraints might arise, mostly from phasing out fossil fuel-based ones.
- Other factors to be included are electoral market orientation of politicians, the status quo orientation of senior public officials, path dependencies, or the benefits of deliberate inconsistencies between talk, decision and actions in climate policy.
- **Feasibility also relates to social justice as an important element, which could be essential to enhance the political and public acceptability of low-carbon transition. Three elements are key: i) protecting vulnerable people from climate change impacts, ii) protecting people from disruption of transformation, iii) enhancing the process of envisioning and implementing an equitable post-carbon society**.
- Climate policy institutional framework and technological progress have a profound impact on the attainability of low carbon pathways. Delaying international cooperation reduces the available carbon budget and locks into carbon intensive infrastructure, exacerbating implementation challenges.

Mitigation and Development Pathways in the Near to Mid term

Summary of the conclusions from Chapter 4 of the report

An emissions gap persists, exacerbated by an implementation gap, despite mitigation efforts including those in near-universal nationally determined contributions. Current policies lead to median global GHG emissions of 63 GtCO2-eq with a full range of 57-70 by 2030, and unconditional and conditional nationally determined contributions (NDCs) to 59 and 56 GtCO2-eq, respectively. This leaves a median estimated **emissions gap** of 14-23 GtCO2eq for limiting warming to 2°C and 25-34 GtCO2eq for limiting warming to 1.5°C. **The magnitude of this emission gap calls into question whether current development pathways and efforts to accelerate mitigation are to achieve the Paris mitigation objectives.** In addition, an **implementation gap** exists between the projected emissions of 'current policies' and the projected emissions resulting from the implementation of unconditional and conditional NDCs, and is estimated to be around 4 and 7 GtCO2eq in 2030, with many countries requiring additional policies and associated climate action to meet their mitigation targets as specified under the NDCs.

Given the gaps, there is a need to explore accelerated mitigation. There is increasing understanding of the technical content of accelerated mitigation pathways, differentiated by national circumstances. Transformative technological and institutional changes for the near term include demand reductions through efficiency and reduced activity, rapid decarbonisation of the electricity sector and low-carbon electrification of buildings, industry and transport. A focus on energy use and supply is essential, but not sufficient on its own – the land sector and food systems deserve attention.

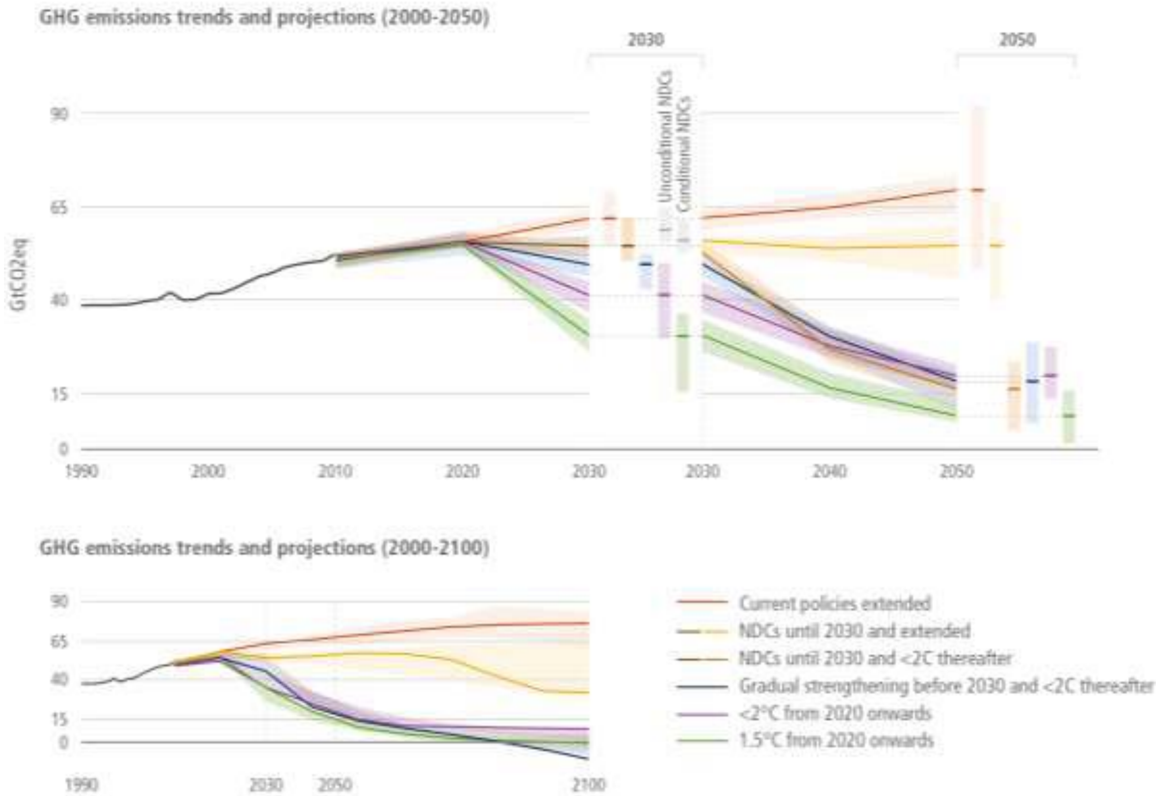


Figure 2: GHG emission trends and projections (2000-2050). Source: IPCC 2022b, cross-chapter box 3

Accelerated mitigation alone may run into obstacles. Various actors have developed an increasing number of mitigation strategies up to 2050 (mid term). A growing number of such strategies aim at net zero / carbon neutrality, but it is not yet possible to draw global implications due to the limited size of sample. Non-state actors are also engaging in a wide range of mitigation initiatives. When adding up emission reduction potentials, sub-national and non-state international cooperative initiatives could reduce up to about 20 Gt of CO2eq in 2030. **Yet perceived or real conflicts between mitigation and other SDGs can impede such action.** If undertaken without precaution, accelerated mitigation is found to have significant implications for development objectives and macroeconomic costs at country level. For example, most country-level mitigation modelling studies in which GDP is an endogenous variable report negative impacts of mitigation on GDP in 2030 and 2050, relative to the reference. In all reviewed studies, however, GDP continues to grow even with mitigation. **Employment effect of mitigation policies tends to be limited on aggregate, but can be significant at sectoral level and that the detailed design of mitigation policies is critical for distributional impacts**.

Shifting development pathways towards sustainability offers a way to (i) broaden the range of levers and enablers that a society can use to provide enabling conditions and accelerate mitigation; and (ii) increases the chances of advancing at the same time towards mitigation and towards other development goals. The way countries develop determines their capacity to accelerate mitigation and achieve other sustainable development objectives simultaneously. Yet **meeting ambitious mitigation and development goals cannot be achieved through incremental change, hence the focus on shifting development pathways**. **Though development pathways result from the actions of a wide range of actors, it is possible to shift development pathways through policies and enhancing enabling conditions**.

The literature identifies a broad set of enabling conditions that can foster shifting development pathways and accelerated mitigation along five categories. Policy integration is a necessary component of shifting development pathways addressing multiple objectives. To this aim, mobilising a range of policies is preferable to single policy instruments. Governance for climate mitigation and shifting development pathways is enhanced when tailored to national and local contexts. Improved institutions and governance enable ambitious climate action and help bridge implementation gaps. Accelerated mitigation and shifting development pathways necessitate both re-directing existing financial flows from high- to low-emissions technologies and systems and to provide additional resources. At the national level, it is also essential to create fiscal space for actions promoting the SDG agenda and thereby broadening the scope of mitigation. Changes in behaviour and lifestyles are important to move beyond mitigation as incremental change, and when supporting shifts to more sustainable development pathways will broaden the scope of mitigation. The direction of innovation matters.

Equity can be an important enabler of deeper ambition for accelerated mitigation, dealing with the distribution of costs and benefits and how these are shared as per social contracts, national policy and international agreements. Transition pathways have distributional consequences such as large changes in employment and economic structure. To that regard, the **just transition concept has become an international focal point tying together social movements, trade unions and other key stakeholders to ensure equity is better accounted for in low-carbon transitions** (see figure). Effectiveness of cooperative action and the perception of fairness of such arrangements are closely related, in that pathways that prioritise equity and allow broad stakeholder participation can enable broader consensus for the transformational change implied by deeper mitigation efforts. **Hence, equity is an ethical imperative, but it is also instrumentally important.**

The immediate tasks are to broaden and deepen mitigation in **the near term if the global community is to deliver emission reductions at the scale required to keep temperature well below 2°C and pursue efforts at 1.5°C. Deepening mitigation means more rapid decarbonisation. Shifting development pathways to increased sustainability (SDPS) broadens the scope of mitigation. Putting enabling conditions in place supports both**.

Measures for accelerating mitigation: 1) Decarbonising electricity supply to produce net zero CO_2, including through renewable energy; 2) Radically more efficient use of energy; 3) Electrification of end-uses; 4) Dramatically lower use of fossil fuels; 5) Converting other uses to low- or zero-carbon fuels (e.g., hydrogen, bioenergy, ammonia) in hard-to-decarbonise sectors; 6) Setting ambitious targets to reduce methane and short-lived climate forcers; 7) Setting targets for net zero may provide a vision, which policy measures help achieve.

Broadening opportunities by focusing on development pathways and considering how to shift them: Given inertia, putting in place the conditions to shifting development pathways to increased sustainability rapidly is essential. Though there is increasing experience with pricing carbon directly or indirectly, decision makers might consider a broader toolbox of enablers and levers that is available in domains that have not traditionally been climate policy. **In a nutshell, think about climate whenever you make choices about development, and vice versa**.

Figure 3: Just transition commissions, task forces and dialogues. Source: IPCC 2022b, chapter 4

Energy Systems

Summary of the conclusions from Chapter 6 of the report

Warming cannot be limited to well below 2°C without rapid and deep reductions in energy system CO2 and GHG emissions. In scenarios limiting likely warming to 1.5°C with limited overshoot (likely below 2°C), net energy system CO2 emissions fall by 87% to 97%% in 2050.

Prices have dropped rapidly over the last five years for several key energy system mitigation options, notably solar PV, wind power, and batteries. From 2015 to 2020, the prices of electricity from PV and wind dropped 56% and 45%, respectively, and battery prices dropped by 64%. Electricity from PV and wind is now cheaper than electricity from fossil sources in many regions, electric vehicles are increasingly competitive with internal combustion engines, and large-scale battery storage on electricity grids is increasingly viable.

Global wind and solar PV capacity and generation have increased rapidly. Solar PV grew by 170% (to 680 TWh); wind grew by 70% (to 1420 TWh) from 2015 to 2019. Policy, societal pressure to limit fossil generation, low interest rates, and cost reductions have all driven wind and solar PV deployment. Solar PV and wind together accounted for 21% of total low-carbon electricity generation and 8% of total electricity generation in 2019. Nuclear generation grew 9% between 2015 and 2019 and accounted for 10% of total generation in 2019 (2790 TWh); hydroelectric power grew by 10% and accounted for 16% (4290 TWh) of total generation. In total, low- and zero-carbon electricity generation technologies produced 37% of global electricity in 2019.

Some mitigation options can provide more immediate and cost-effective emissions reductions than others, but a comprehensive approach will be required over the next ten years to limit warming to well below 2°C. There are substantial, cost-effective opportunities to reduce emissions rapidly in several sectors, including electricity generation and light-duty transportation. But near-term reductions in these sectors will not be sufficient to limit warming to well below 2°C.

The viable speed and scope of energy system change will depend on how well such change can support broader societal objectives. If investments in coal and other fossil infrastructure continue, energy systems will be locked-in to higher emissions, making it harder to limit warming to well below 2°C. Many aspects of the energy system – physical infrastructure; institutions, laws, and regulations; and behaviour – are resistant to change or take many years to change. New investments in coal-fired electricity without CCS are inconsistent with limiting warming to well below 2°C.

The economic outcomes of low-carbon transitions in some sectors and regions may be on par with, or superior to those of an emissions-intensive future. Cost reductions in key technologies, particularly in electricity, have increased the economic attractiveness of near-term low-carbon transitions. Long-term mitigation costs are not well understood and depend on policy design and implementation, and the future costs and availability of technologies. Advances in low carbon energy resources and carriers such as next-generation biofuels, hydrogen produced from electrolysis, synthetic fuels, and carbon-neutral ammonia would substantially improve the economics of net zero energy systems.

Key takeaways on developments in the energy system

- **Current energy sector emissions trends**, if continued, will not limit global temperature change to 'well below 2°C'. Over the last decade, there has been a significant increase in the total primary energy supply (TPES). Energy demands and emissions have continued to rise. Fossil fuel CO_2 emissions from the global energy system grew at an average annual rate of 1.26% between 2010 and 2019, reaching a historic high of 38 $GtCO_2\ yr^{-1}$, despite declining energy intensity in almost all regions.
- **Coal** is faring differently across regions. Coal use is decreasing in the US, the European Union, and many other OECD countries. Major coal consuming countries are still far from phasing out coal. China, the US, Australia and South Africa continue to extract and use substantial amounts of coal. In most developing countries with abundant coal reserves, coal use has been increasing to support energy security.

Key takeaways on main mitigation options

- **Solar energy:** Solar PV is increasingly competitive with other forms of electricity generation and is the low-cost option in many applications. Costs have declined by 62% since 2015 and are anticipated by an additional 16% by 2030.
- **Wind energy:** Wind power is increasingly competitive with other forms of electricity generation and is the low-cost option in many applications. Costs have declined by 18% and 40% on land and offshore since 2015, and further reductions can be expected by 2030.
- **Hydroelectric power:** Hydropower is a mature technology that is well proven worldwide with local adapted solutions. The efficiency of hydroelectric plants is greater than 85%.
- **Bioenergy:** It can support many different parts of the energy system and is particularly valuable for hard-to-decarbonise sectors with limited alternatives to fossil fuels.
- **Geothermal energy:** The geophysical potential of geothermal resources is 1.3 to 13 times the global 42 electricity demand in 2019 (medium confidence). Geothermal energy can be used directly for various thermal applications, including space heating and industrial heat input, or converted to electricity.
- Marine energy and waste-to-energy are further options with potential.

Key takeaways on cross-sector coupling and energy storage

- **In electricity**, sector coupling can significantly increase system flexibility, driven by the interaction between sectors and the application of advanced technologies. System balancing services can be provided by electricity storage and electric vehicles based on vehicle-to-grid concepts – through smart control of EV batteries without compromising customers' requirement for transport.
- **Strategic energy system planning** will minimise long-term mitigation costs. With the whole-system perspective, integrated planning can be optimised.
- **Energy storage** technologies will make low-carbon energy systems more cost-effective. Energy storage enhances security of supply. Energy storage extends beyond electricity storage and includes technologies which can store energy as heat, cold, and both liquid and gaseous fuels.

Key takeaways on demand side mitigation

- **People are more likely to engage in mitigation behaviour** when they believe such behaviour has more individual benefits than costs, including financial benefits, convenience, comfort, autonomy, and independence in energy supply.
- Mitigation actions, including saving energy and hot water, limited meat consumption, and investments in energy efficiency, resource efficiency in buildings, and renewable energy generation are **more likely when people more strongly care** about others and the environment.

Key takeaways on regional integration of energy systems

- **Electricity system integration.** Given the significant variations in the location of low carbon electricity resources and the temporal variability of some renewable electricity sources, notably solar and wind power, regional electricity grids could reduce costs of net zero energy systems. Electricity transmission interconnections could reduce local energy balancing costs and investment in peaking plants needed to meet security of supply, and it could increase system resilience, especially in the case of extreme events such as heat waves or cold spells. Important challenges to regional electricity integration include geopolitical concerns from cross-border trade and challenges associated with building new transmission lines.
- **Hydrogen integration.** If hydrogen plays a significant role in future net-zero energy systems, there may be a need to transport hydrogen across long distances. In net-zero systems with substantial wind and solar power generation, hydrogen can be generated through electrolysis and then shipped to other locations.
- **Trade in biomass.** Large-scale bioenergy requirements in net-zero energy systems are likely to trigger major global trade of biomass, potentially on a scale similar to fossil fuel trade today. In a net-zero context, trade in bioenergy is projected to be greater than current trade in coal or natural gas. Latin America and Africa are projected to be the main exporting regions, with EU, the USA and East Asia being key importers.

International Cooperation

Summary of the conclusions from Chapter 14 of the report

New forms of international cooperation have emerged since AR5 in line with an evolving understanding of effective mitigation policies, processes and institutions, and together with pre-existing forms these are vital for achieving climate mitigation goals in the context of sustainable development. International cooperation is now believed to be effective at helping countries achieve long-term mitigation targets when it directly supports countries' development and diffusion of low-carbon technologies, often at the level of individual sectors, which can simultaneously lead to significant benefits in the areas of sustainable development and equity.

International cooperation under the UN climate regime has taken an important new direction with the conclusion and entry into force of the 2015 Paris Agreement, which strengthened the objective of the UN climate regime, including its long-term temperature goal, but adopted a different architecture to that of the Kyoto Protocol to achieve it. The core national commitments under the Kyoto Protocol have been legally binding quantified emission targets for developed countries based on common metrics and tied to well-defined mechanisms for monitoring and enforcement. By contrast the commitments under the Paris Agreement are procedural, extend to all parties, and are designed to trigger domestic policies and measures, enhance transparency, and stimulate climate investments, particularly in developing countries, and to lead iteratively to rising levels of ambition across all countries. Issues of equity remain of central importance in the UN climate regime.

There are conflicting views on whether the Paris Agreement's commitments and mechanisms will lead to the attainment of its stated goals. The strongest critique of the Paris Agreement is that it lacks a mechanism to review the adequacy of individual Parties' Nationally Determined Contributions (NDCs), and that collectively current NDCs are inconsistent in their level of ambition with achieving the Paris Agreement's temperature goal. Arguments in support of the Paris Agreement are that the processes it initiates and supports will lead in multiple ways to rising levels of ambition over time.

International cooperation outside the UNFCCC processes and agreements provides critical support for mitigation in particular regions, sectors and industries, for particular types of emissions, and at the sub- and trans-national levels. Social science modelling suggests that sub-global and regional cooperation, often described as **climate clubs**, can play an important role in accelerating mitigation, including the potential for reducing mitigation costs through linking national carbon markets, although actual examples of these remain limited. Cooperation is occurring at multiple governance levels, including **cities, with trans-national partnerships and alliances involving non-state and subnational actors playing a growing role in stimulating technology diffusion and emissions reductions**.

International cooperation is proving effective, yet would need to be strengthened in several key respects in order to support mitigation action consistent with limiting temperature rise to well below 2°C in the context of sustainable development and equity. Collectively, countries' NDCs are inadequate for achieving the temperature goal of the Paris Agreement. A large number of developing countries' NDCs are contingent on receiving assistance with respect to finance, technology transfer and capacity building, to an extent greater than what has been provided to date. Sectoral cooperation is providing critical support, and yet there is room for further progress.

Key takeaways on climate clubs

- A recent development has been increased attention to the potential for **climate clubs** – sub-global coalitions of states and non-state actors committed to advancing global mitigation objectives. Results based on an agent-based model suggest that climate clubs result in major emission reductions if there is a sufficiently high provision of the club good and if initial membership by several states with sufficient emissions weight materializes. Such configurations allow the club to grow over time to enable effective global action.

Key takeaways on the Paris Agreement

- In relation to the **criterion of environmental effectiveness**, the Paris Agreement potentially exceeds the Kyoto Protocol in terms of coverage of GHGs and participation of states in mitigation actions. In relation to the **criterion of transformative potential**, there is, as yet, limited empirical data or theoretical analysis on which to assess the Paris Agreement's transformative potential. The linking of the UNFCCC financial apparatus, including the GCF, to the Paris Agreement, and the provisions on technology support and capacity building, provide potential avenues for promoting increased investment flows into low-carbon technologies and development pathways. In relation to **the criterion of institutional strength**, the performance of the Paris Agreement is mixed. The Paris Agreement's institutional strength in terms of its signalling and guidance function is, however, arguably high. In conclusion, it remains to be seen whether the Paris Agreement will deliver the collective ambition necessary to meet the temperature goal. While the Paris Agreement does not contain strong and stringent obligations of result for major emitters, backed by a demanding compliance system, it establishes binding procedural obligations, lays out a range of normative expectations, and creates mechanisms for regular review, stock taking, and revision of NDCs. In combination with complementary approaches to climate governance, engagement of a wide range of non-state and subnational actors, and domestic enforcement mechanisms, these have the potential to deliver the necessary collective ambition.

Key takeaways on the role and effectiveness of finance

- Both the Paris Agreement and the SDGs reinforce the need to forge strong linkages between climate and development by addressing the twin challenges of development and climate change. This has highlighted the need for greater attention to the relationship between development assistance and finance, and climate change. Multilateral Development Banks (MDBs) play a key role in international cooperation at the global, regional and sub-regional levels. There is a growing recognition of the importance of mobilising private sector financing including for climate action.

Key takeaways on the role of trade agreements

- Trade rules may impede mitigation action by limiting countries' discretion in adopting trade-related climate policies, but they also have the potential to stimulate the international adoption and diffusion of mitigation technologies and policies. In their NDCs, parties mention various trade-related measures, including import bans, standards and labelling schemes, border carbon adjustments, renewable energy support measures, fossil fuel subsidy reform, and the use of international market mechanisms. Options can also be pursued at the plurilateral and regional level. Studies suggest that climate clubs could employ trade measures, such as lower tariffs for climate-related goods and services, or boarder carbon adjustments.

Key takeaways on South-South cooperation

- South-South Cooperation (SSC) is an innovative, and rapidly developing means of strengthening cooperation. Through SSC, countries are able to map their capacity needs and knowledge gaps and find sustainable, cost-effective, long-lasting and economically viable solutions. Emphasis is given to experience sharing, co-financing, and co-development of new knowledge, especially in developing and newly industrialised countries.

Key takeaways on energy sector cooperation

- International cooperation on energy supply and security has a long and complicated history. There exists a plethora of institutions, organisations, and agreements concerned with managing the sector. Global energy governance has encompassed five broad goals – security of energy supply and demand, economic development, international security, environmental sustainability, and domestic good governance – and as only one of these provides an entry point for climate mitigation, effort in this direction has often been lost. Recently, new institutions have emerged, and existing institutions have realigned their missions, in order to promote capacity building and global investment in low-carbon energy technologies.

Key takeaways on transnational business and PPP

- Transnational business partnerships are a growing feature of the landscape of multi-level, multi-actor governance of climate change. A leading example is the World Business Council on Sustainable Development, a global organisation of over 200 leading businesses working together to accelerate the transition to a sustainable world. Another potentially influential type of transnational business partnership is investor coalitions formed to push investee companies to adopt stronger measures for stranded asset management and climate change mitigation.

Key takeaways on cooperation on subnational level

- A great deal of policy making has occurred at the level of city governments in particular. Many of them have started to take their own initiative in enacting and developing mitigation policies. Second, sub-national governments can fill the void in policy leadership in cases where national governments are ineffectual. Several international networks, such as C40, ICLEI, and the Covenant of Mayors have played an important role in defining and developing climate-policy initiatives at the city level. Furthermore, an increasing number of large corporations have committed to decarbonising their industrial processes and supply chains. And, an ever-increasing number of non-state actors are adopting goals and initiating mitigation actions.

Investment and finance

Summary of the conclusions from Chapter 15 of the report

Finance to reduce net greenhouse gas (GHG) emissions and enhance resilience to climate impacts represents a critical enabling factor for the low carbon transition. Fundamental inequities in access to finance as well as its terms and conditions, and countries exposure to physical impacts of climate change overall result in a worsening outlook for a global just transition. Decarbonising the economy requires global action to address fundamental economic inequities and overcome the climate investment trap that exists for many developing countries. For these countries the costs and risks of financing often represent a significant challenge for stakeholders at all levels. This challenge is exacerbated by these countries' general economic vulnerability and indebtedness. The rising public fiscal costs of mitigation, and of adapting to climate shocks, is affecting many countries and worsening public indebtedness and country credit ratings at a time when there were already significant stresses on public finances. The COVID-19 pandemic has made these stresses worse and tightened public finances still further. Other major challenges for commercial climate finance include: the mismatch between capital and investment needs, home bias considerations, differences in risk perceptions for regions, as well as limited institutional capacity to ensure safeguards represent.

Investors, central banks, and financial regulators are driving increased awareness of climate risk. 17 This increased awareness can support climate policy development and implementation . Climate-related financial risks arise from physical impacts of climate change and from a disorderly transition to a low carbon economy. Financial regulators and institutions have responded with multiple regulatory and voluntary initiatives by to assess and address these risks. Yet despite these initiatives, climate-related financial risks remain greatly underestimated by financial institutions and markets limiting the capital reallocation needed for the low-carbon transition. National and international equity are yet to be reflected in decisions by the financial community. Stronger steering by regulators and policy makers has the potential to close this gap.

Significant financing gaps exist across all sectors and regions which reflects a persistent misallocation of global capital. Persistently high levels of both public and private fossil-fuel related financing reflect policy misalignment, the current perceived risk-return profile of fossil-fuel investments, and political economy constraints. With rising damage costs of climate change and increasing awareness of the economic effects on financial stability, there is a need for rapid deployment of mitigation options. The need for global mitigation investments expected to increase by the factor of 3 to 6, especially for Least Developed Countries, where flows have to increase by the factor of 4 to 8.

The relatively slow implementation of commitments by countries and stakeholders in the financial system to scale up climate finance reflects neither the urgent need for ambitious climate action, nor the economic rationale for ambitious climate action. Delayed climate investments and financing and, consequently, limited alignment of investment activity with the Paris Agreement, will result in significant carbon lock-ins and stranded assets, particularly in energy, transport and urban infrastructure.

Ambitious global policy coordination and stepped-up (public) climate financing over the next decade (2020–2030) can help address macroeconomic uncertainty and alleviate developing countries' debt burden post-COVID-19. It can also help redirect capital markets and overcome challenges to the need for parallel investments in mitigation and the up-front risks that deter economically sound low carbon projects.. Political leadership and intervention remain central, addressing uncertainty and the lack of credible public commitments as well as existing policy misalignments, particularly in fossil fuel subsidies.

The mutual benefits of coordinated support for climate mitigation and adaptation in the next decade for both developed and developing regions could potentially be very high in the post-Covid era. Climate compatible stimulus packages could significantly reduce the macro-financial uncertainty generated by the pandemic and increase the sustainability of the world economic recovery.

Political leadership and intervention remain central to addressing uncertainty as a fundamental barrier for a redirection of financial flows. Existing policy misalignments – for example in fossil fuel subsidies – undermine the credibility of public commitments, reduce perceived transition risks and limit financial sector action

Innovative financing instruments could help reduce the systemic under-pricing of climate risk and foster demand of Paris-aligned investment opportunities. Approaches include de-risking instruments, robust 'green' labelling and disclosure schemes, and regulatory focus on transparency and reforming international monetary system financial sector regulations could help shift inertia. Green bond markets and markets for sustainable finance products have increased significantly, underpinning investor preference for scalable investment opportunities. Challenges remain in the green bond market, including the potential for 'greenwashing', and creditworthiness constraints in developing countries. New business models can facilitate the aggregation of small-scale financing needs and provide investment opportunities with more attractive risk-return profiles. Support and guidance for enhancing transparency can promote capital markets' climate financing by providing quality information to price climate risks and opportunities. The outcome of these market-correcting approaches on capital flows cannot be taken for granted without appropriate fiscal, monetary and financial policies. Mitigation policies will be required to enhance the risk-weighted return of low emission and climate resilient options, and to accelerate the emergence and support for financial products based on real projects, such as green bonds, and phase out fossil fuel subsidies. Greater public private cooperation can encourage the private sector to create a track record in new segments/regions.

Policy attention on eight key areas may have important catalytic benefits: (1) stepped-up both the quantum and composition of financial, technical support and partnership in low-income and vulnerable countries in sub-Saharan Africa, which currently receives less than 5% of global climate financing flows; (2) continued strong role of international and national financial institutions including MDBs and national development banks; (3) de-risking cross-border investments in low-carbon infrastructure, development of local bond markets, and the alignment of climate and non-climate policies; (4) lowering transaction costs and risks through green banks, funds and risk-sharing mechanisms for under-served small urban municipalities, smallholder agriculture, SMEs, and climate responsive social protection; (5) accelerated finance for nature-based solutions, forestry, and climate responsive social protection; (6) improved financing instruments for loss and damage events, including blended finance for risk pooling; (7) phasing-in carbon pricing and phasing out fossil fuel subsidies in a way that address equity and access; and (8) gender responsive and women empowered programmes.

Key takeaways on macroeconomic context

- Tangible policy responses to reduce greenhouse gas emissions have been grossly insufficient to date and four key aspects of the current global macroeconomy pointed towards a deteriorating environment for climate financing over the next decade:
    - More unstable and slowing GDP growth due to worsening climate change impact events.
    - Rising public fiscal costs of mitigation and adapting to rising climate shocks in countries already affected by public indebtedness and negative credit ratings.
    - Rising financial and insurance sector risks arising and stresses from the impacts of climate change, systematically affecting both national and international financial institutions and raising their credit risk.
    - Entering 2020 there was a sharply slowing global macroeconomic growth and rising financial risk which were negatively impacting climate financing possibilities.

Key takeaways on climate finance towards a Just Transition

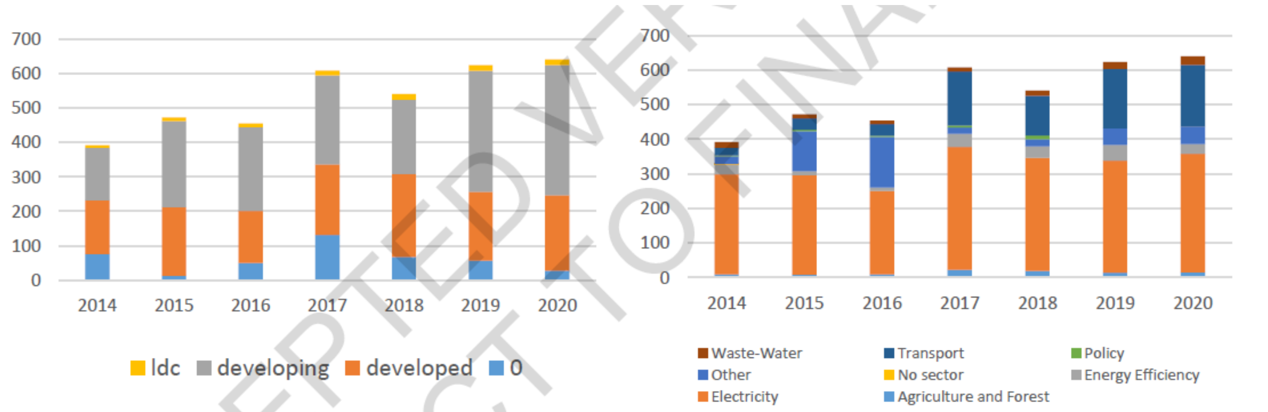
- The shift to a new social compact for a Just Transition is necessary with greater financing support from developed to developing regions in recognition of ‘common but differentiated responsibilities and respective capabilities’ and a greater ethical sense of climate justice.
- While Just Transition issues apply within developed countries as well, these are of relatively less urgency given the scale of financing and existing social safety nets in developed countries and their absence in poorer countries.
- The implications for a Just Transition in climate finance are clear: expanding equitable and greater access to climate finance for vulnerable countries, communities and sectors, not just for the most profitable private

investment opportunities, and a larger role for public finance in fulfilling existing finance commitments.

- It is evident that very few resources are available to countries, investors, civil society, and international development institutions seeking to achieve a Just Transition.

Key takeaways on estimated financial flows

- Flows of annual global climate finance are growing with a high-bound estimate of USD 681 billion in 2016. Current climate finance flows remain small compared to the gross fixed capital formation and with perspective to remaining fossil fuel financing.
- Climate finance in developing countries remains heavily concentrated in a few large economies with Brazil, Russia, India, China, and South Africa accounting for 25-43% depending on the year, a share similar to that represented by developed countries. LDCs continue to represent less than 5% year-on-year.



Type of Economy	Sector

Figure 15.3 Available estimates of global climate finance between 2014 and 2020

Note: Numbers in billion USD. Type of Economy figure (left): Regional breakdown based on official UN country classification. "0" no regional mapping information available. Sectorial figure (right): *Policy*, incl. "Disaster Risk Management"; "Policy and national budget support & capacity building". *Transport*, incl. "Sustainable/Low Carbon Transport". Energy Efficiency, incl. "Industry, Extractive Industries, Manufacturing & Trade", "Low-carbon technologies", "Information and Communications Technology", "Buildings & Infrastructure". *Electricity*, incl. "Renewable energy generation", "Infrastructure, energy and other built environment", "Transmission and distribution systems", and "Energy Systems". *No sector*: no sector information available, or neglegting flows. *Other*, incl. Non-energy GHG reductions, Coastal protection. Source: Own calculations, based on (Naran et al. 2021).

Figure 4: Estimates of climate finance flows. Source: IPCC 2022b, chapter 15

- Mitigation continues to take the largest share of global climate finance (between 90% and 95% between in 2017-2018), particularly renewable energy followed by energy efficiency and transport.

Key takeaways on fossil fuel-related transition finance

- Scenarios compatible with a below 2°C warming state clearly that the share of fossil fuels in energy supply has to decrease or be phased out. Fossil fuel-related investments reached an estimated USD 120 billion a year on average between 2019-2020. In 2019, an estimated USD 650 billion was invested in oil supply and USD 100 billion in coal supply.
- New fossil fuel-related assets lock in future GHG emissions. That is due largely to insufficient level of ambition and coherence of public policies. As a result, the demand for fossil fuels remains high and the risk-return profile of fossil fuel-related investments is still positive in many instances. A gradual phasing out of fossil fuel subsidies could reduce the risks of stranded assets and of negative distributive effects of a low carbon transition.

Key takeaways on the impact of sustainable finance products

- Scaled-up finance across sectors, regions and stakeholders should be ensured through domestic and international public interventions. But location of financing and vicinity to capital matter due to home bias, transaction costs, and risk considerations.
- ESG integration amounted to over USD 37 trillion. Shareholder activism/corporate engagement continued to grow to nearly USD 10 trillion.
- The depth of capital markets is greater in developed countries, increasing the challenges to mobilise substantial volumes of additional funding for many developing countries.
- Indirect impacts of divestment frame the narrative around sustainable finance decisions.
- Sustainable investment could have a broader positive impact by creating an enabling environment and strengthening the trend for CSR activities and investments and sustainable and green investment opportunities (15, innovative financial products.
- Research indicates a positive relation between ESG criteria and disclosure, and economic sustainability of a firm. However, there is a research gap in

assessing the direct impact of ESG and sustainable investments on climate change indicators. Moreover, research indicates that ESG strategies by themselves, do not yield meaningful social or environmental outcomes and there is ambiguity when it comes to the tangible impact of the financial sector on addressing climate change and sustainable development.

Key takeaways on finance needs for energy transition

- Low- and medium-income countries have a growing energy demand presenting an opportunity to build-up sustainable energy infrastructures and a risk of additional carbon lock-in investments. Redirecting and increasing investments to ensure a climate-safe future would require reaching an average USD 1 trillion a year by 2030 for electricity generation as well as grids and storage, increasing to an average of above USD 2 trillion a year until 2030 in the 1.5C scenario. In the 1.5S scenario the total annual investment needs, excluding fossils and nuclear, decrease from USD 5 trillion a year until 2030 to USD 3.8 trillion for 2030-2050.
- Over 100 countries included adaptation components in their intended NDCs. It is estimated that adaptation finance needs amount to USD 140-300 billion a year by 2030 and USD 280-500 billion a year by 2050.

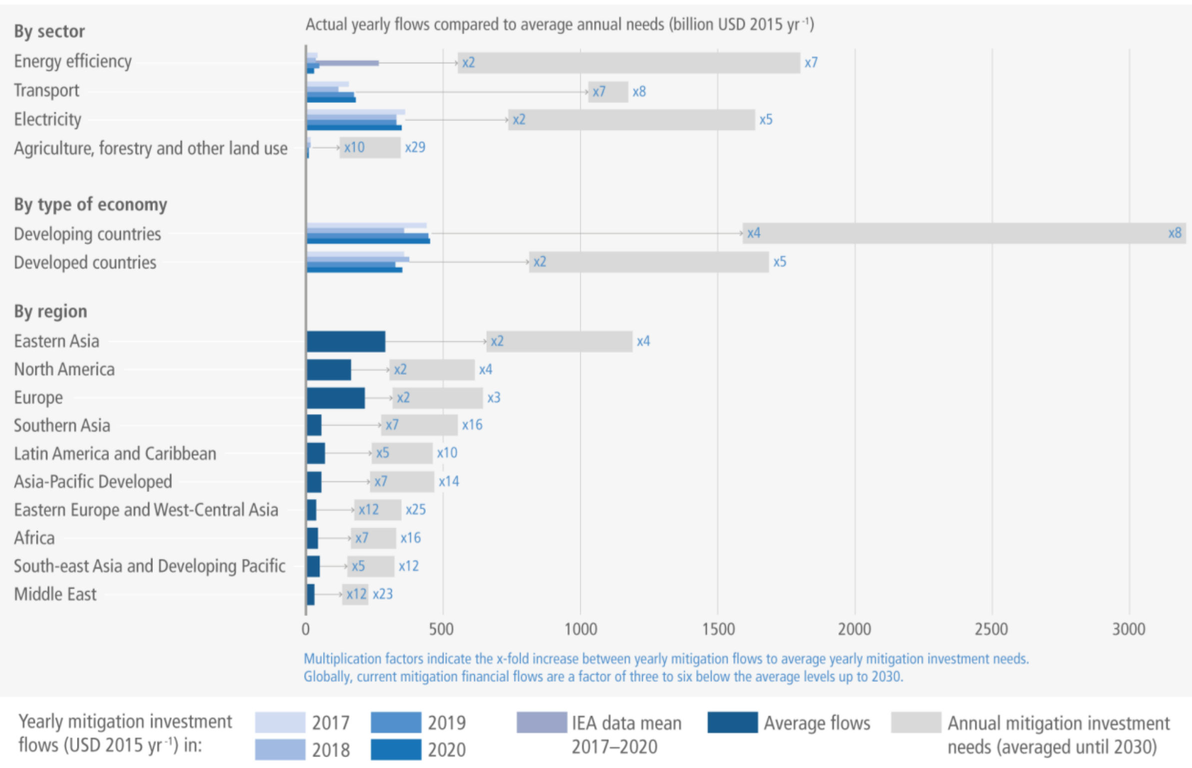


Figure 5: Breakdown of average investment flows and needs until 2030. Source: IPCC 2022b, chapter 17

Key takeaways on addressing financing gaps

- **The role of the government is crucial** for creating an enabling environment for climate, and governments are critical in the launching and maintenance of a self-reinforcing circle of trust between project initiators, industry, institutional investors, the banking system and governments by lowering the political, regulatory, macroeconomic and business risks. The government can reduce the financing risks by establishing green bonds and credit guarantee schemes in both domestic and international level, to enhance the attractiveness of clean energy investments.
- **Central banks are likely to play a critical role** in supporting the financing of fiscal operations particularly in a post-COVID world.
- **Financial markets** are moving investment portfolios away from fossil-fuels and towards rising portfolios of low-carbon investments. In developing countries, the financial markets have it worse due to weaker financial institutions, heightened credit-rationing behaviour and high-risk aversion, as most markets are rated as junk, or below/barely investment grade.
- In combination with subsidies, public R&D on resource-saving technologies, carbon taxes can facilitate the shift towards low-carbon, resource-efficient investments. Feed-in-tariffs had positive impacts on technology diffusion.
- State Investment Banks (SIBs) can assist with overcoming financial barriers, to signal and direct investments towards green projects, and to attract the private investors by taking up a de-risking role.

Accelerating the transformation in the context of sustainable development

Summary of the conclusions from Chapter 17 of the report

Accelerating climate actions and progress towards a just transition is essential to reducing climate risks and addressing sustainable development priorities, including water, food and human security. Acceleration is not merely about moving faster. The broader and deeper this support, the more likely the transition is to be sustainable.

A rapid transition to sustainable development pathways is as desirable as it is difficult. Climate change stems from decades of unsustainable energy production, land use, production and consumption, as well as governance practices. Changing these patterns requires a fundamental reframing of development. Sustainable development, by emphasising sectoral integration and social inclusion, offers such a reframing. A sustainable transition must also be socially equitable and just. This equity principle also applies across countries. Developing countries often craft climate responses in decision-making environments with limited resources, deep social divisions and few advanced technologies.

This reframing must be backed by concrete actions and sincere efforts. Strengthening the 'response capacities' of different actors to mitigate and adapt to a changing climate will be necessary. Response capacities will increase with efforts to align multiple stakeholder interests across levels of decision making. This alignment will also help achieve synergies and manage trade-offs between climate and other sectoral policies, thus breaking out of sectoral silos and adopting policy-coherent integrated approaches to overcome the challenges.

Sustainable development and mitigation policies are closely linked in the agricultural, food and land use sectors. Agriculture, Forestry, and Other Land Uses (AFOLU) sector offers many low-cost mitigation options, but they can also create trade-offs

between land use to produce bioenergy, food and biodiversity. Some options can help to mitigate such trade-offs, for example, integrated land management and efficiency improvements. Lifestyle changes, including dietary changes and reduced food waste, have several synergies regarding climate change mitigation and the SDGs.

The water, energy and food nexus involves tight and complex interlinking. Within it, the implementation of options related to water management and water conservation and the added coherence of policies within the water, energy and food sectors will be critical in achieving the SDG targets.

Industrial transformation is a core component of faster progressing towards sustainable development. Across all industrial sectors, the development and deployment of innovative technologies, business models and policy at scale will be essential.

There are several examples of mitigation options which have synergies between mitigation and adaptation, including energy efficiency options, renewable energy, the circular economy, sustainable city planning, and efficiencies in industry and buildings. In general, many of the mitigation options are assessed as having synergies, with or without trade-offs, with SDGs, but some sectors are also reporting trade-offs.

The contributions of digital technology could contribute to efficiency improvements, cross-sectoral coordination, including new IT services, and decreasing resource use, potentially implying several synergies with SDGs, as well as trade-offs, for example, in relation to reduced employment.

The landscape of transitions to sustainable development is changing rapidly, and we are witnessing multiple transitions. This creates the room to manage these transitions in ways that

will prioritise the need for workers in vulnerable sectors to secure their jobs and to maintain secure and healthy lifestyles.

Sustainable development and deep decarbonisation will involve people and communities being connected locally through various means, including globally via the internet, in ways that form social fields that allow sustainability to happen and prompt other shifts in thinking and behaviour.

Accelerating the transition to sustainability will be enabled by explicit consideration being given to the principles of justice, equality and fairness. Interventions to promote sustainability transitions that integrate local spaces into the whole development process are necessary but not sufficient in creating a Just Transition process.

Key takeaways on transition processes

- Transitions require essential elements: consideration of shocks and stresses; working horizontally across all sectors; working on gradual vertical scales across social dimensions; drastic measures to reduce carbon emissions; inspiration from successes related to climate change/action; think future-oriented; focus on climate disadvantage and reduce inequalities; focus on processes and pathways; and transformative change for resilience.
- **Another key element of the transition process is the aspect of equity and justice at all levels**. Both distribution and procedure matter, as does inter-generational and intra-generational equity in transition planning. Looking at climate change from a justice perspective means placing the emphasis on a) the protection of vulnerable populations from the impacts of climate change, b) mitigating the effects of the transformations themselves, and c) envisaging an equitable decarbonised world. **Renewable energy transitions in rural, impoverished locations can simultaneously reinforce and disrupt local power structures and inequities. Policy interventions to help the most impoverished individuals in a community gain access to the new energy infrastructure are**

critical in ensuring that existing inequalities are not reinforced. Individuals who are empowered by energy development projects can influence the onward extension of sustainable energy to other communities.

Key takeaways on economic transition theories

- A key issue in studies based on economic models is their assumptions about market adjustment instruments and innovation policies. Despite the shortcomings of conventional economic thoughts and models, some views are beginning to demonstrate a potential for addressing climate and other sustainable development concerns in improved models. One perspective is that innovation can imply increases in efficiency and that the substitution of energy, material and labour can lead to the accumulation of capital and productivity gains. This appears to be occurring with innovation in end-use energy applications generating emissions reductions and delivering on other sustainable development benefits. Nonetheless, there are still very important limits on the degree to which economic models can integrate ethics, equity and several other factors that will determine wellbeing or happiness.

Key takeaways on coal transitions

- The role of coal in the global energy system is changing fast. The coal transition will impose challenges not only in the power sector, but even more importantly on coal mining industries. A less diversified local economy, low labour mobility and heavy dependence on coal revenues will make closing down coal production particularly challenging from a political economy perspective. Policy is needed to support and invest in impacted areas to smooth the transition. Earlier involvement with local stakeholders in a structured approach is crucial and will make the transition policy more targeted and better administered. Most importantly, ex-ante policy implementation is far better than ex-post compensation. Even without the climate imperative, historical evidence shows that coal closures can happen surprisingly fast.
- Coal has hitherto been the dominant energy source in China and has accounted for more than 70% of its total energy consumption for the past 20 years, falling to 64% in 2015. The main driving forces of the coal transition in China are increasing domestic environmental concerns and the pressure to reduce greenhouse gas emissions. Coal combustion contributes about 90% of total SO2 emissions, 70% of NOx emissions

and 54% to primary PM2.5 emissions in China. The phasing out of coal also delivers a co-benefit in terms of air pollutant reductions consistent with China's goal to improve air quality, as well as the reduction of methane and black carbon. The coal transition in China will change the future value of coal-related assets, and both coal power generators in China and coal producers outside China need to identify appropriate responses to avoid and manage the stranding of fossil fuel assets.

Key takeaways on AFOLU

- Agriculture, Forestry and Other Land Uses (AFOLU) are expected to play a vital dual role in the portfolio of mitigation options across all sectors. The IPCC Special Report on Climate Change and Land emphasises the need for governance in order to avoid conflict between sustainable development and land use management. AR6 emphasises that diets high in plant protein and low in meat, in particular red meat, are associated with lower GHG emissions. Emerging food-chain technologies such as microbial, plant, or insect-based protein promise substantial reductions in direct GHG emissions from food production. Achieving zero-food waste could reduce the demands for land (SDG 15), water use (SDG 6) and chemical fertilisers (SDG 9), leading to GHG emissions reductions (SDG 13) by encouraging sustainable consumption and production practices (SDG 12).

Key takeaways on the water-energy-food-nexus

- The continually increasing pressures on natural resources, such as land and water, due to the rising demands from increases in populations and living standards, which also require more energy, emphasises the need to integrate sustainable planning and exploitation. **The water-energy-food nexus is the epicentre of these challenges, which are of global relevance and are the focus of policies and planning at all levels and sectors of global society**. The water, energy and food nexus (WEFN) is closely linked in a complex manner and needs careful attention. The WEFN touches upon the majority of the SDGs, such as 2, 6-7 and 11-15, and deals with basic commodities, thus guaranteeing the basic livelihoods of the global population. The task of gaining an improved understanding of WEFN processes across disciplines such as the natural sciences, economics, the social sciences and politics has been further exacerbated by climate change, population growth and resource depletion.

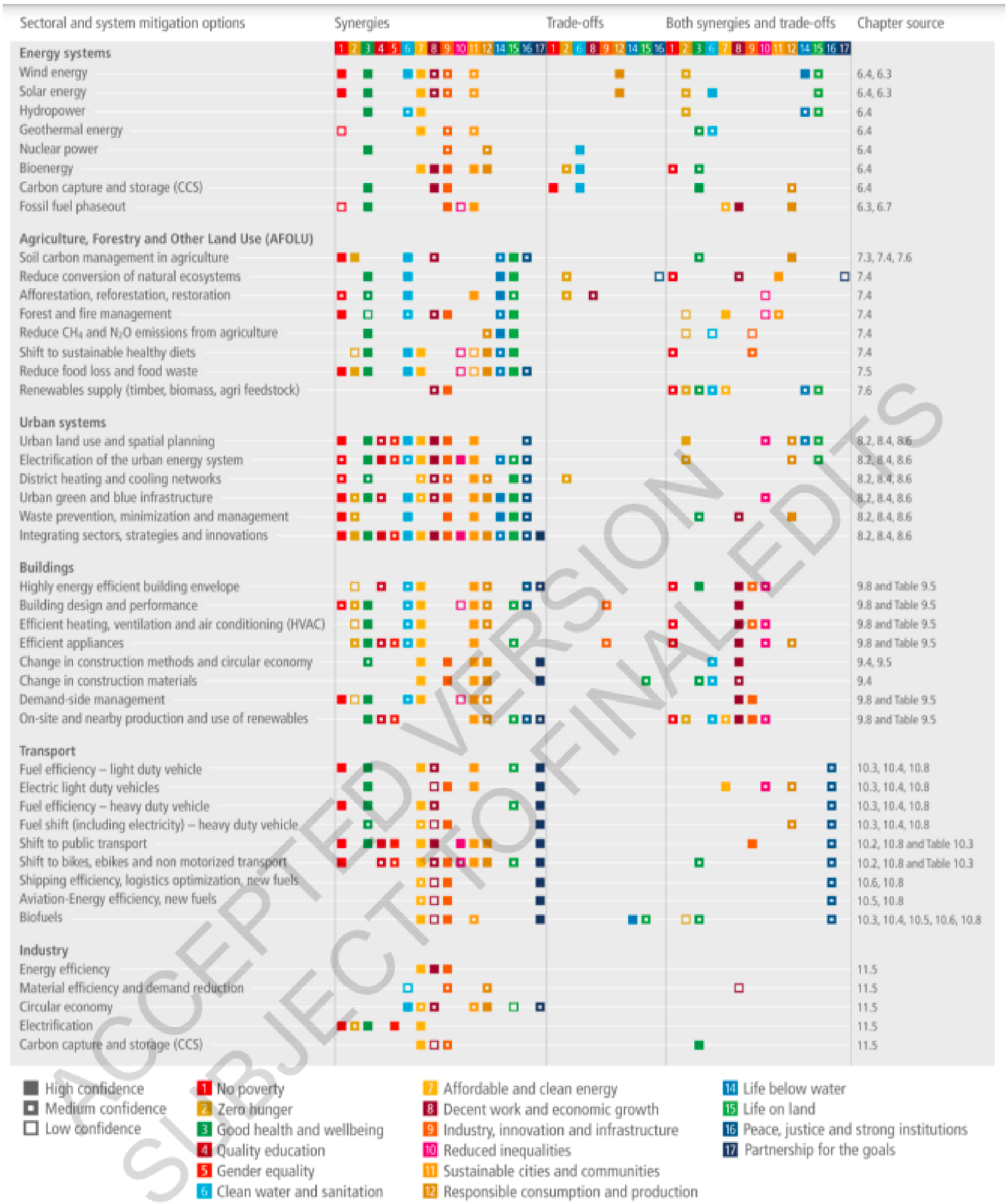


Figure 17.1 Trade-offs and synergies between sectoral mitigation options and the SDGs

Figure 6: Trade-offs and synergies between mitigation options and the SDGs. Source: IPCC 2022b, chapter 17

Authors
Thomas Hirsch, with support of Antonella Kania and Jaume Marques, Climate & Development Advice
www.climate-development-advice.de

Edited by
Jaime Fernandez Medina, Brot für die Welt

Proof reading

Paula McDiarmid

Herausgeber

Brot für die Welt
Evangelisches Werk für Diakonie
und Entwicklung e. V.
Caroline-Michaelis-Straße 1
10115 Berlin

Tel + 49 30 65 211 0
Fax + 49 30 65 211 3333
jaime.fernandez@brot-fuer-die-welt.de
www.brot-fuer-die-welt.de

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