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Chapter 2

Pathways from Paris

Human interference with the climate system is rapidly taking us into uncharted territory, with the potential for severe and irreversible impacts and making it harder to achieve the Sustainable Development Goals (SDGs). The Paris Agreement aims to limit average global warming to well below 2°C, a political judgement based on scientific evidence. The stringency of this mitigation goal means that countries need to strengthen mitigation action without delay. After setting out the case for urgent action and the carbon budget consistent with the goal of well below 2°C, this chapter examines the characteristics of low-emission pathways and how country diversity may impact the scale, phasing and priorities for mitigation action across countries. It then summarises projected impacts, emphasising the need for flexible, forward-looking approaches to decision-making that reflect the diversity of climate vulnerabilities and confidence levels about local and regional change. Finally, the chapter looks at how countries can get to where they need to be, supported by the mechanisms of the Paris Agreement.

This chapter sets out the case for urgent action on climate change and explains in broad terms what is required to move to low-emission, climate-resilient development pathways. The first section explains why we need to act urgently. The second section assesses the carbon budget consistent with the "well below 2°C" goal in the Paris Agreement, and how this in turn depends on developments in the non-energy sector – notably in agriculture, forestry and land-use (AFOLU). The third section examines the characteristics of low-emission pathways, taking as its core a scenario consistent with a 66% likelihood of keeping the global average surface temperature increase to below 2°C throughout the century (IEA 66% 2°C scenario) from a parallel report for the German G20 Presidency on the scale and scope of energy sector investments needed to increase the chances of reaching this goal (IEA, 2017). This section also analyses the IEA 66% 2°C scenario in the context of a broader range of scenarios achieving similar outcomes. The fourth section then examines how country diversity may affect low-emission pathways and the priorities for action across countries. Even with stringent mitigation, climate change is projected to have significant negative impacts, so countries need to enhance resilience and increase their adaptive capacity. The projected changes in regional and local conditions are far less well understood than larger-scale changes in temperature, sea-level rise and ocean acidification.[1] The fifth section summarises projected impacts and emphasises the need to develop flexible, forward-looking approaches that help us to identify robust solutions. The last section of this chapter addresses the key question of how countries can get to where they need to be from where they are now, highlighting the fundamental importance of the Paris Agreement in building trust and transparency to underpin effective international action.

Climate change – why we need to act urgently

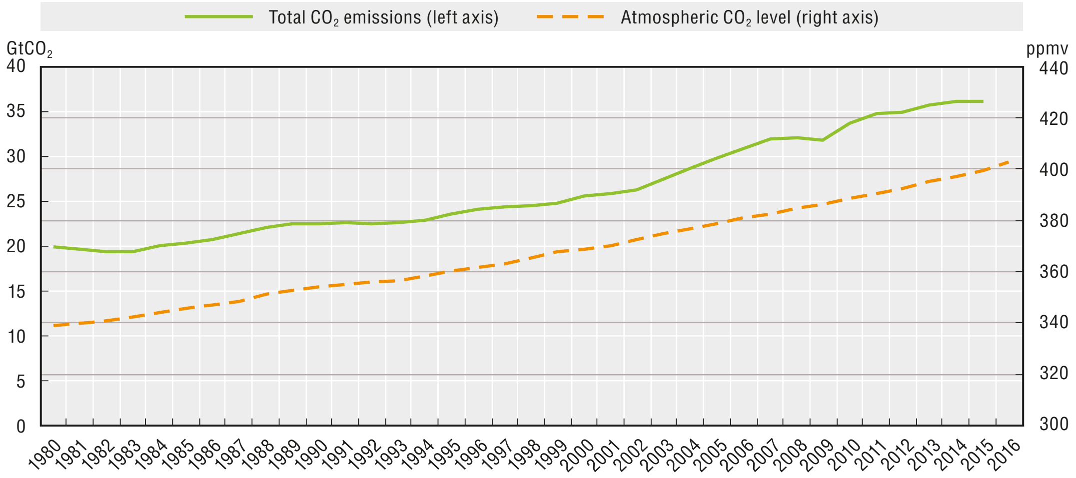
The last 60 years or so have seen unprecedented human impact on the systems that underpin life on Earth (Steffen et al., 2004). Industrial-scale agriculture and the massive use of fossil energy to drive economic growth have transformed the life chances of billions of people.[2] But they have also created an unpredictable climatic future, very different from the conditions in which humanity has thrived for the past 10 000 years. Since 1990, world GDP has more than doubled while carbon dioxide (CO_2) emissions from fossil fuel use have increased by some 60%, contributing to increasingly rapid climatic change (Figure 2.1).

Other environmental challenges have also emerged, such as ozone depletion, biodiversity loss, desertification, and local and regional pollution. Rapid progress on reducing ozone depletion has been possible, underpinned by international agreements targeting ozone depleting chemicals. Other "wicked" problems have proved more resistant to progress (Rittel and Webber, 1973). Notable among these is climate change, which both poses profound challenges to our current development paradigm and, at the same time, opens up opportunities for sustained and sustainable improvements in inclusive economic well-being.

Climate change in context

Global atmospheric concentrations of CO_2 – the major greenhouse gas (GHG)[3] – have now risen past 400 parts per million (ppm by volume) from a pre-industrial level of around 280 ppm (Figure 2.1). By 2012, the global mean surface temperature had increased by approximately 0.85°C on average from pre-industrial levels;[4] each of the last three decades has been successively warmer than any preceding decade since 1850 (IPCC, 2014a). In 2015, global mean temperatures went 1°C above pre-industrial levels for the first time, due to the combined effects of climate change and a very strong El Niño that lasted into early 2016. All but one of the 16 warmest years on record has occurred since 2001, with 2016 the hottest recorded (WMO, 2017).

Figure 2.1. **Global CO_2 emissions from fossil-fuel use and cement production, and the atmospheric concentration of CO_2**



Sources: *i)* CO_2 emissions from Olivier et al. (2016); *ii)* Global atmospheric CO_2 concentrations from NOAA (2017).

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So where might we be heading? Projections of climate change depend on inherently uncertain assumptions about human behaviour and future policy choices. It is also difficult to estimate the precise strength of the climate response to atmospheric GHG concentrations, due to the complexity of the climate system.[5] Scenario analysis has therefore been a vital analytical tool in helping us understand the range of plausible future outcomes and how these depend on future emissions of GHGs and atmospheric aerosols, land-use change, and many other socio-economic factors.

Table 2.1 shows end-of-century projections for global mean surface temperature relative to pre-industrial levels (1850-1900) from the most recent assessment by the Intergovernmental Panel on Climate Change (IPCC), for four Representative Concentration Pathways (RCPs) (IPCC, 2013).[6] The scenario associated with the lowest emissions, RCP2.6, is consistent with a policy target of limiting warming to below 2°C with greater than 66% likelihood, broadly in line with the IEA 66% 2°C scenario (IEA, 2017). None of the other RCPs deliver mean surface temperature changes of 2°C or lower.

Table 2.1. **Projected mean temperature changes relative to a pre-industrial (1850–1900) baseline**

Emissions scenario	Change in mean temperature (°C) by 2081-2100
Low scenario – RCP2.6	1.6
Medium scenario – RCP4.5	2.4
Medium to high scenario – RCP6.0	2.8
Very high scenario – RCP8.5	4.3

Note: The temperature changes for each RCP include an observational estimate of warming of 0.61°C between 1850-1900 and 1986-2005 and the mean warming across CMIP5 Global Climate Models between 1986-2005 and 2081-2100 for the RCP. Both the observed historical warming and GCM-derived components of the changes have uncertainties. These are not presented as methods are not generally available in the literature for combining the uncertainties in models and observations.
Source: IPCC (2013).

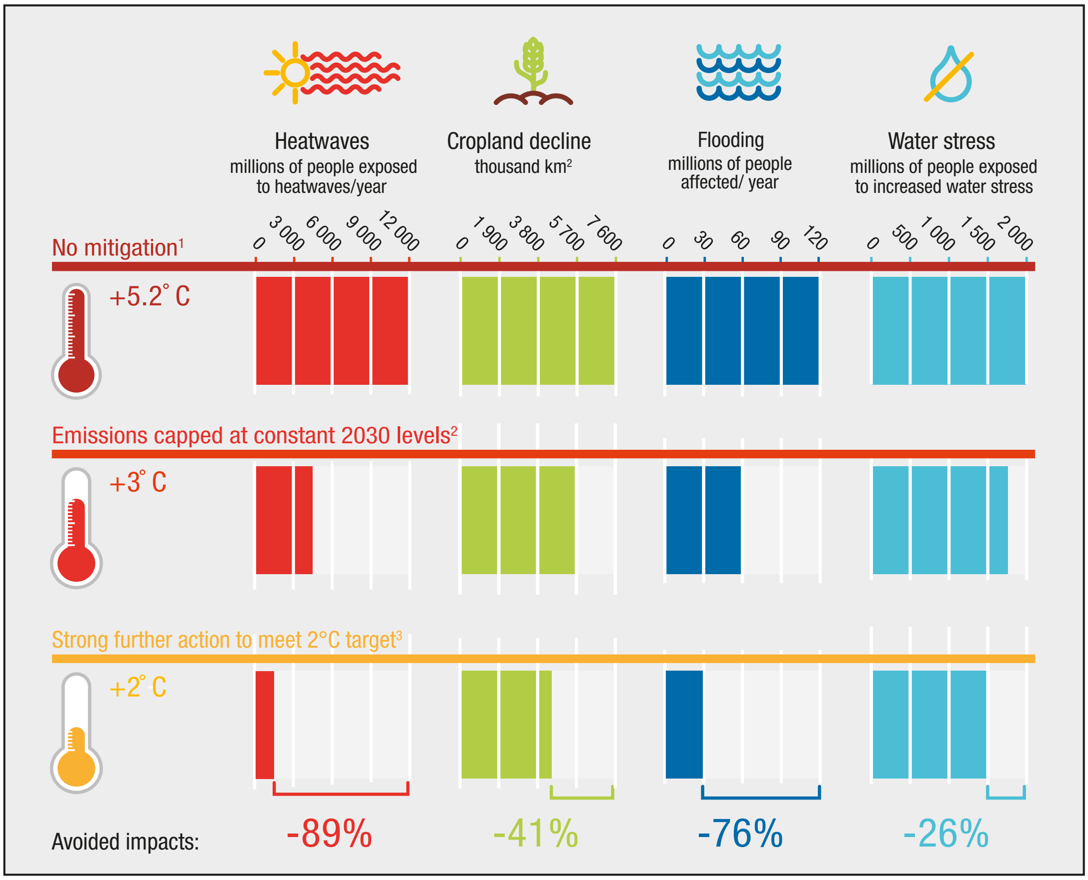
Climate risks and the benefits of mitigation

Climate change will lead not just to higher temperatures but also to rising sea levels, acidification of the oceans – with effects on marine ecosystems – and changing patterns of precipitation, as well as more extreme weather. Regions will be affected differently by these changes; regional (and smaller-scale) changes in weather patterns and precipitation are still highly uncertain (see for example, Shepherd, 2014). Changes could even take us beyond thresholds or "tipping points" in the climate system (Box 2.1). Greater levels of emissions will therefore lead to a greater likelihood of "severe, pervasive and irreversible impacts" (IPCC, 2014b).

Stringent mitigation action to limit temperature increases would moderate the physical climate impacts that countries would otherwise need to adapt to (Figure 2.2). With climate change, heat waves are likely to become more frequent and longer in duration; keeping the global average temperature increase to 2°C will significantly limit the number of people exposed to heatwaves. Similarly, climate change is very likely to increase extreme precipitation events in some regions (IPCC, 2013). Mitigation could moderate the increase in the number of people exposed to flooding, as well as limiting loss of cropland and reducing water stress.

Climate change is projected to destroy human and physical capital. How these changes translate into economic terms is an open research challenge, depending on potentially non-linear interactions between climate, ecological and social systems, as well as infrastructure networks (see Box 2.1 and Chapter 4). This makes climate change a risk management problem: the approach needs to be one of finding the most cost-effective ways to limit climate risks to a politically agreed level, informed by the best scientific evidence. Early and ambitious action on adaptation and mitigation can significantly reduce these risks.

Figure 2.2. **Estimates of climate change impacts avoided by 2100 through mitigation**



Notes: (1) Refers to RCP8.5 scenario. (2) Emissions capped 55.1 GtCO$_2$e, consistent with the NDCs, with no backtracking. (3) Strong further action for a 50% chance of meeting the 2°C target: emissions of 55.1 GtCO$_2$e in 2030, with further large reductions in GHG emissions to meet 2°C by 2100.

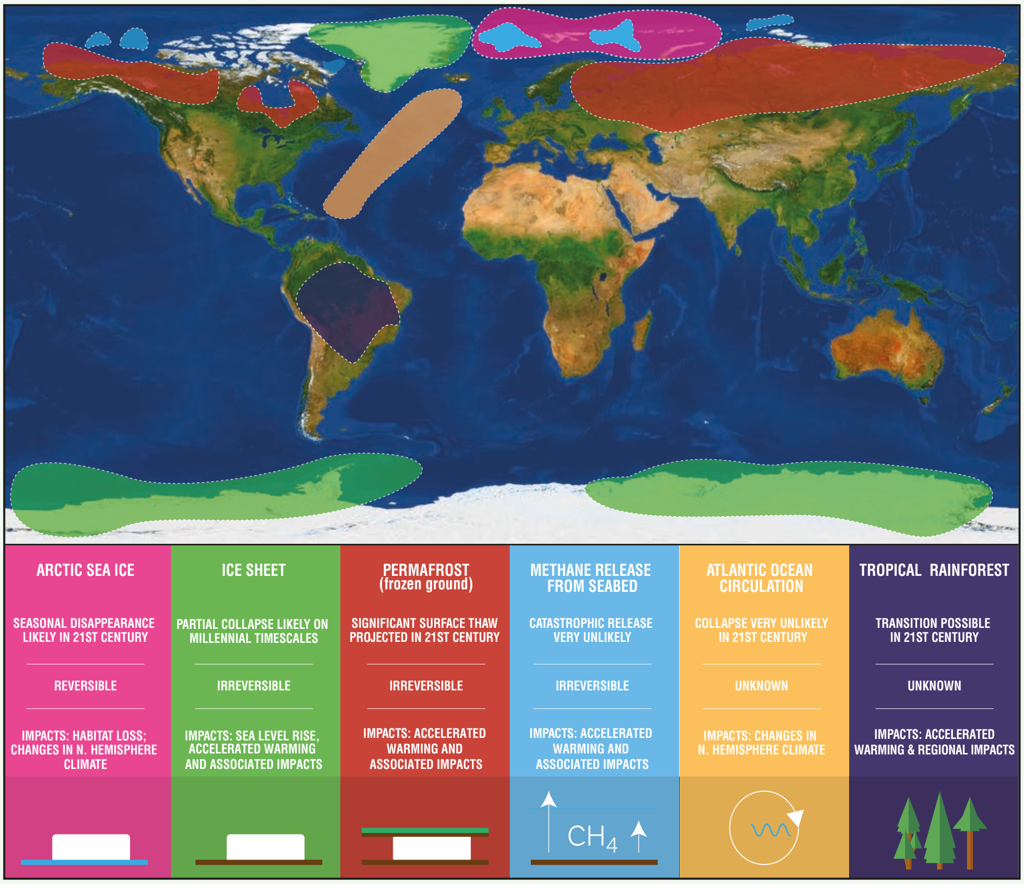
Source: AVOID2 (2015).

Box 2.1. **Thresholds for abrupt and/or irreversible change**

The level of scientific understanding of thresholds in the climate systems, as well as the physical and economic implications of crossing such thresholds, is low. Such potential changes include the collapse of the Atlantic Meridional Overturning Circulation (AMOC), the disappearance of summer Arctic sea ice, ice sheet collapse, permafrost carbon release, methane release, and tropical and boreal forest dieback.

Recent research has given greater confidence to evidence that partial irreversible loss of the West Antarctic Ice Sheet has already begun. Tropical forests are being adversely affected by drought, while AMOC weakening continues. Interaction between different thresholds will be important in determining the timescales, extent and reversibility of changes throughout the climate system. For example, increased meltwater from ice sheets will further weaken the AMOC, and this may in turn alter the position of the Intertropical Convergence Zone near the equator, affecting rainfall patterns and the health of the Amazon rainforest (Lenton et al., 2008).

Figure 2.3. **Examples of thresholds for abrupt and/or irreversible climate impacts**



ARCTIC SEA ICE	ICE SHEET	PERMAFROST (frozen ground)	METHANE RELEASE FROM SEABED	ATLANTIC OCEAN CIRCULATION	TROPICAL RAINFOREST
SEASONAL DISAPPEARANCE LIKELY IN 21ST CENTURY	PARTIAL COLLAPSE LIKELY ON MILLENNIAL TIMESCALES	SIGNIFICANT SURFACE THAW PROJECTED IN 21ST CENTURY	CATASTROPHIC RELEASE VERY UNLIKELY	COLLAPSE VERY UNLIKELY IN 21ST CENTURY	TRANSITION POSSIBLE IN 21ST CENTURY
REVERSIBLE	IRREVERSIBLE	IRREVERSIBLE	IRREVERSIBLE	UNKNOWN	UNKNOWN
IMPACTS: HABITAT LOSS; CHANGES IN N. HEMISPHERE CLIMATE	IMPACTS: SEA LEVEL RISE, ACCELERATED WARMING AND ASSOCIATED IMPACTS	IMPACTS: ACCELERATED WARMING AND ASSOCIATED IMPACTS	IMPACTS: ACCELERATED WARMING AND ASSOCIATED IMPACTS	IMPACTS: CHANGES IN N. HEMISPHERE CLIMATE	IMPACTS: ACCELERATED WARMING & REGIONAL IMPACTS

Note: There is considerable uncertainty relating to the reversibility of climate impacts. Here, impacts are considered irreversible if recovery is unlikely within 100 years after climate drops back below the relevant threshold.
Source: MOHC analysis of *i)* IPCC, 2014c and *ii)* AVOID2 WPA.5 Report.

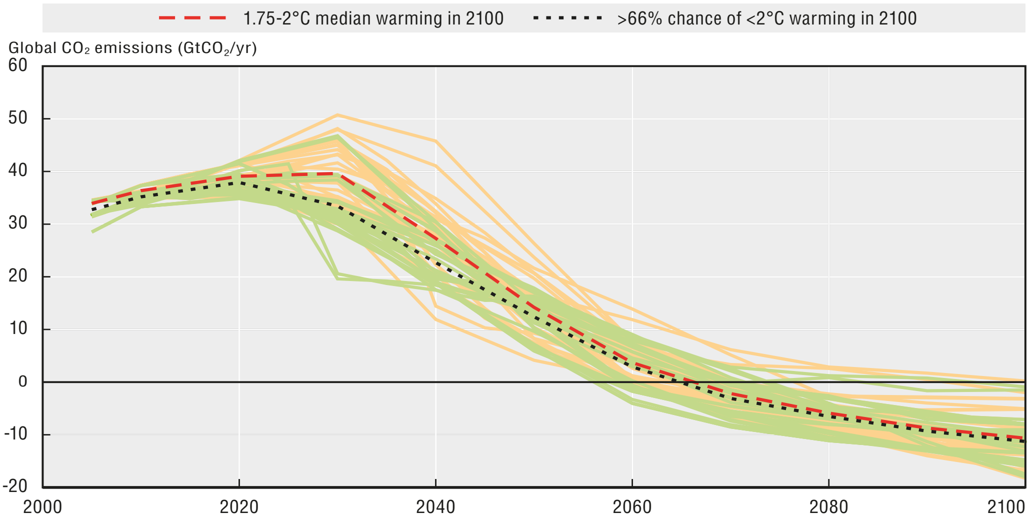
What does the Paris Agreement mean for carbon budgets?

The interpretation of "well below 2°C"

The Paris Agreement reached at the 21st Conference of the Parties to the UNFCCC (COP21) in December 2015 aims to hold the global average surface temperature increase to "well below 2°C and to pursue efforts to limit it to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change" (UNFCCC, 2015a). There is, however, no precise definition of what "well below 2°C" means.

It is not immediately obvious that the IEA 66% 2°C scenario used in the related IEA report (IEA, 2017) should be equated to a "well-below 2°C" goal. However, UK Meteorological Office Hadley Centre (MOHC) analysis of the many scenarios analysed as part of the IPCC's AR5[7] suggests that in general, scenarios delivering a greater than 66% likelihood would be somewhat more stringent in terms of emissions reductions than scenarios consistent with 1.75-2.0°C of median warming by 2100 (Figure 2.4). Most of these stringent IPCC mitigation scenarios (the thin coloured lines in Figure 2.4) rely on net negative CO_2 emissions, whereas the IEA 66% 2°C scenario assumes no net negative emissions. It is therefore reasonable to use the IEA 66% 2°C scenario as one representation of what a well-below 2°C scenario could look like, though of course there are other plausible pathways that could include net negative emissions.

Figure 2.4. **IPCC AR5 CO_2 emissions scenarios with a greater than 66% chance of staying below 2°C**



Source: IPCC AR5 Database, MOHC analysis.

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Carbon budgets and temperature goals

CO_2 is the predominant GHG, but many other gases contribute to global warming (Box 2.2). For long-lived GHGs, such as CO_2, it is the cumulative level of emissions over time that determines the contribution to climate change, not just the emissions in a given year. There is a strong linear relationship between cumulative CO_2 emissions and the increase in average surface temperatures (Wigley, Richels and Edmonds, 1996; Allen et al., 2009; IPCC, 2013; Friedlingstein et al., 2014). This means that there is an upper limit on the total cumulative CO_2 emissions over time consistent with a given temperature target – the so-called "carbon budget". This budget is not a single number but a range, reflecting uncertain projections about the emissions of non-CO_2 GHGs, as well as in the climate response to GHGs in the atmosphere.[8]

Box 2.2. **Greenhouse gases, aerosols and radiative forcing**

Climate change is due to a net imbalance in the energy flowing into the Earth system due to human modifications of the atmosphere. CO_2 is responsible for most of the warming observed since the pre-industrial period (1.68 ± 0.035 Watts per metre squared (W/m^2) in 2011 relative to 1750), but other gases play an important role in this "radiative forcing" – tipping the balance of radiation flowing into the Earth's atmosphere.

- Atmospheric concentrations of methane (CH_4) reached 1,810 parts per billion (ppb) in 2012, 2.5 times more than in 1750. Even at these small concentrations, CH_4 has contributed about 20% of the radiative forcing of CO_2 (Ciais et al., 2013).
- Atmospheric nitrous oxide (N_2O) is another important GHG, with a radiative forcing of 0.17 ± 0.03 W/m^2 in 2011 compared with the pre-industrial period. Concentrations have risen more than 20% since pre-industrial times, mostly due to increased agricultural activity, with a lesser contribution from the burning of fossil fuels and industry (Ciais et al., 2013).
- Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) contribute approximately 11% of the total radiative forcing from GHGs and also deplete stratospheric ozone (O_3). Emissions of CFCs have been drastically reduced in recent years as the Montreal Protocol has been implemented, but due to their long lifetime it will take a substantial amount of time to affect atmospheric concentrations.
- The effect of atmospheric ozone (O_3) depends on where it is situated. In the lower atmosphere, O_3 is formed when other chemical species, such as CH_4 and carbon monoxide, combine with nitrogen oxides (NOx) in sunlight, contributing to poor air quality. Stratospheric O_3 has a small cooling effect, but overall ozone has a warming effect of around 0.35 (0.15 to 0.55) W/m^2 (Myhre and Shindell, 2013).
- Aerosols are microscopic particles suspended in the atmosphere that generally cool the climate, yet some have a warming effect (e.g. black carbon). IPCC AR5 (IPCC, 2013) estimated the radiative forcing of aerosols to be -0.9 (-1.9 to -0.1) W/m^2 (Myhre and Shindell, 2013), an overall cooling effect on the climate. Aerosols and their interactions with clouds offset a substantial portion of global mean warming, but aerosols contribute the largest uncertainty to the total radiative forcing estimate.
- Land use change from human activity also affects the Earth's climate, by changing the surface albedo (how much light it reflects) and by increasing the emission of GHGs (e.g. through deforestation). Afforestation also absorbs CO_2 from the atmosphere. Land use change has significant impacts on the local water cycle and can lead to changes in rainfall in regions far away from the initial land use change (e.g. DeAngelis et al., 2010).

Carbon budgets consistent with 2°C and 1.5°C temperature targets are shown in Table 2.2, along with an indication of the likelihood of limiting warming to this level. These budgets assume non-CO_2 GHG emissions contribute the equivalent of around 420 gigatonnes of CO_2 ($GtCO_2$) (Rogelj, 2016b). The global carbon budget compatible with a greater than 66% likelihood of staying below 2°C is estimated to be 590-1 240 $GtCO_2$ from 2015 to the time of peak warming (Rogelj, 2016b). This represents roughly 15 to 30 years of fossil fuel-related CO_2 emissions at current rates – an indication of the remarkably short time remaining in which to transform the global energy system and to meet the Paris Agreement's temperature goal. Even this challenging number assumes net negative CO_2 emissions later in the century. The carbon budget to limit the temperature increase to 2°C with a 66% likelihood by 2100 is more stringent – between 470 and 1 020 $GtCO_2$.

This downwards adjustment reflects the fact that to achieve such a stringent mitigation target, modelling suggests that it would be more cost-effective to reduce emissions at a slightly lower – but still rapid – pace early on and then to compensate with "negative emissions" later in the century. Drawing CO_2 back down from the atmosphere and sequestering it safely over the long term enables such scenarios to live within their carbon budgets.[9] The most plausible options for achieving this are afforestation, bioenergy with carbon capture and storage (BECCS) and changed agricultural practices (Box 2.3).

The total carbon budget used in the IEA 66% 2°C scenario is 880 GtCO_2. This budget lies below the mid-point of the "peak warming" range (915 Gt CO_2) and above the mid-point of the range for the entire period 2015-2100 (745 Gt CO_2). The IEA 66% 2°C scenario assumes no net negative emissions. Out of this total budget of 880 GtCO_2, the IEA allocates a carbon budget of 790 GtCO_2 for the energy sector, and assumes that 90 GtCO_2 over 2015-2100 are emitted from industrial processes. Land use is assumed to generate approximately net zero cumulative emissions over the period, starting from positive emissions and becoming negative by the end of the century. Non-CO_2 GHGs are assumed to contribute around 0.5°C of warming by 2100 (IEA, 2017).

Table 2.2. **Carbon budgets from 2015 to peak warming for different temperature targets and likelihoods**

Temperature targets	>50% < 2°C	>66% < 2°C	>50% 1.5°C
Global carbon budget available from 2015 to peak warming (Gt CO_2)	990-1 240	590-1 240 [470-1 020]+	390-440

Note: Figures represent 10th-90th percentile range. The budget to peak warming may include negative emissions, but not any net negative emissions required after peak warming. +This denotes the global carbon budget over the whole period 2015-2100, taking account of net negative emissions after the peak.
Source: Adapted from Rogelj, 2016b; IPCC, 2014c.

Box 2.3. **What are negative emissions?**

Owing to the long time scales involved in the removal of carbon from the atmosphere by natural processes, recovery from an overshoot of the atmospheric CO_2 concentration may take a considerable amount of time (Lowe et al., 2009; Solomon et al., 2009). Technologies that actively remove carbon from the atmosphere – resulting in "negative emissions" – could be used to lower atmospheric CO_2 in the event of an overshoot in emissions, but could also be important in offsetting emissions from sectors where emissions reductions are more difficult (such as freight, aviation and shipping). Several options have been examined for negative emissions technologies (NETs):

- **Afforestation and reforestation (AR)** to fix atmospheric CO_2 in terrestrial biomass and soils. Potential is estimated at 4 GtCO_2/yr at a lower cost than BECCS and with land and nutrient requirements increasing with potential (Smith et al., 2015).
- **Changed agricultural practices (CAP)**, such as soil management practices that can improve soil quality by reducing soil erosion and increasing resilience to weather variability, while simultaneously contributing to food security objectives (OECD, 2015e). Soil carbon sequestration and biochar each have the potential to provide about 2.6 GtCO_2eq/yr and have fewer disadvantages than many NETs (Smith, 2016).
- **BECCS:** Farming bio-energy crops that absorb CO_2 as they grow and are then burnt for energy, with the resulting emissions captured and stored underground. Potential is estimated at around 12 GtCO_2/yr (Smith et al., 2015).
- **Direct air capture (DAC):** The use of chemicals to absorb CO_2 from the atmosphere before being stored in solid form or pumped into geological reservoirs. Potential is estimated at around 12 GtCO_2/yr but at a far greater cost and energy requirements than BECCS (Smith et al., 2015).

Box 2.3. **What are negative emissions?** *(cont.)*

- **Enhanced weathering (EW):** Natural weathering of minerals is accelerated to remove CO_2 from the atmosphere, with the products stored in soils or buried in the land surface. Potential is estimated at around 0.7 $GtCO_2$/yr (Smith et al., 2015).
- **Ocean fertilisation (OF):** Increasing the ocean's biological uptake of CO_2 by fertilising nutrient-limited areas.

These NETs each have large but varied levels of uncertainty over their social acceptability, unresolved technological issues and high costs, and variable demands for land, water, energy and fertiliser, which affect their feasibility and efficacy at scale (Smith et al., 2015). DAC is considered to have very high costs and energy requirements. EW is also a high-cost technology as well as having a limited global potential for emissions removal and significant requirements for land use. OF by contrast is seen as too risky as little is known about the ecological effect of dumping large quantities of nutrients into the sea (Schiermeier, 2007), nor does it do anything to address ocean acidification. AR and BECCS are typically the only NETs included as mitigation options in current generations of Integrated Assessment Models. The extent to which these technologies can be deployed at scale in the near- to medium-term is a key uncertainty.

Low-emission pathways

Characteristics of low-emission pathways

As can be seen from Figure 2.4 and the tight constraint on carbon budgets consistent with limiting temperature change to well below 2°C, low-emission pathways will be characterised by the following broad features:

1. A peak in global emissions as soon as possible;
2. A subsequent rapid fall in GHG emissions, particularly of CO_2 emissions;
3. Net GHG emissions approach zero or even become net negative in the second half of the century (IPCC, 2014a).

The later the peak in global CO_2 emissions, the greater the rate of emission reduction required subsequently to be consistent with the carbon budget. Options for achieving stringent mitigation goals may be lost if the peaking level is too high or too late. Delaying peaking beyond 2020 would make the Paris Agreement's goal of well below 2°C significantly more difficult to achieve, requiring even more rapid reductions of emissions and a prolonged period of net negative CO_2 emissions through major afforestation or the large-scale use of negative emissions technologies such as BECCS (Box 2.3). Action will need to come earlier and the fall-off in emissions will need to be more rapid if even more stringent targets are to be achieved (e.g. towards 1.5°C). Not reaching a global emissions peak before 2030 may preclude limiting warming to well below 2°C.

Assumptions for future non-CO_2 GHG emissions constrain the carbon budget available for the energy sector and industrial processes.[10] While CO_2 emissions will eventually need to go to zero, or below, annual emissions of short-lived GHGs such as CH_4 only need to be stabilised and can still remain positive while meeting the goal of well below 2°C (Allen et al., 2016). The higher the level at which such emissions are stabilised, however, the lower the carbon budget consistent with a given temperature goal will be (Allen et al., 2016).[11] For N_2O, a long-lived GHG, it is the cumulative level of emissions over time, not the level of emissions in a given year that matters most for maximum temperature change (Smith et al, 2012).

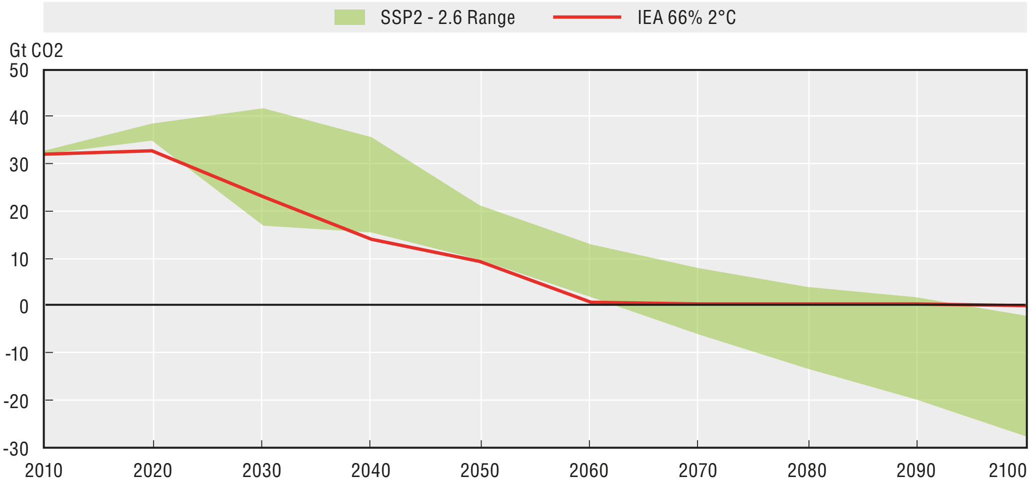
N_2O emissions are predominantly due to agriculture.[12] Population and economic growth are increasing demand for food, so N_2O emissions will continue for the foreseeable future to ensure food security, even if we can improve the efficiency of fertiliser use (Zhang et al., 2015). As a long-lived GHG, continued N_2O emissions would need to be offset by a reduction of other long-lived GHGs – for example, by greater negative emissions of CO_2.

The IEA pathways in context

Socio-economic developments, including economic and population growth and food demand, will influence whether future GHG emissions will be consistent with a well below 2°C target. The Shared Socio-Economic Pathways (SSPs, Riahi et al., 2017) provide a set of storylines exploring the implications of different assumptions about future economic growth, demographics and technical change. Together with the IPCC's RCPs, they provide a framework to analyse and evaluate the implications of climate policy in different socio-economic settings. In this section, the IEA 66% 2°C scenario is compared with modelling results[13] for a "middle-of-the-road" SSP scenario (SSP2), coupled with the IPCC's RCP 2.6 scenario (together, SSP2-2.6).[14]

Figure 2.5 shows the evolution of non-land-use CO_2 emissions for the IEA 66% 2°C scenario alongside the SSP2-2.6 comparison range. The IEA emissions numbers encompass both energy-related emissions and industrial process emissions:[15] the IEA non-land use CO_2 emissions pathway lies at the lower edge of the range of the SSP mitigation scenarios to 2050. The IEA's assumption of no net negative CO_2 emissions means that to meet the carbon budget constraint, emissions must peak earlier and lower than in the scenarios that do allow net negative emissions. The range of non-land-use CO_2 emissions in SSP2-2.6 becomes negative by the end of the century, due to extensive use of BECCs. The IEA 66% 2°C scenario rules out net negative CO_2 emissions and lies at the upper end or above the SSP2-2.6 range at the end of the century. Its lower CO_2 emissions early on allow the IEA scenario to still remain below 2°C with a 66% likelihood.

Figure 2.5. **Projections of non-land use CO_2 emissions**



Source: IIASA (n.d.) and IEA (2017).

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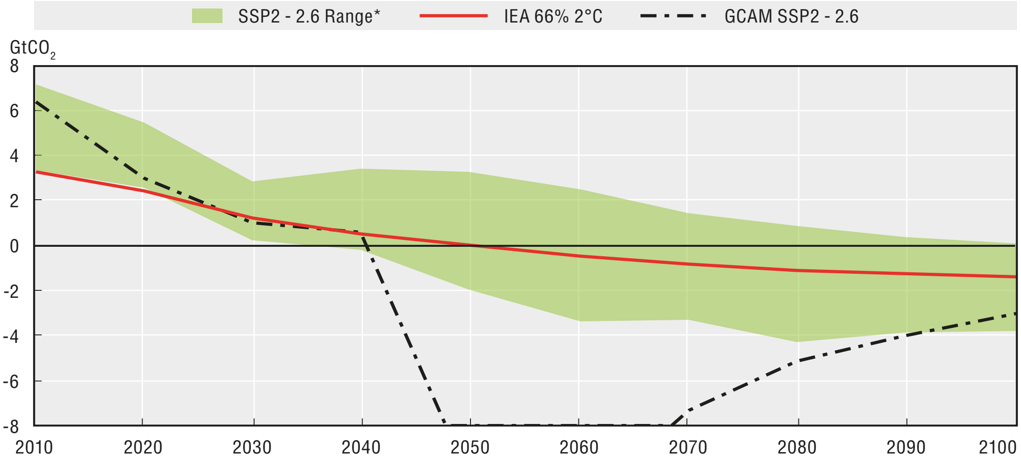
Figure 2.6 provides a similar comparison between the IEA and SSP scenarios for CO_2 emissions from land-use change. Land use in the IEA 66% 2°C scenario turns from a source to a small sink by 2050 and emissions lie well within the range of emissions in the SSP2-2.6 modelling results. The outcomes of one particular modelling realisation of SSP2-2.6 (the

GCAM model) display extreme changes in land-use emissions due to strong dependence on afforestation and the use of bioenergy (at different times) as mitigation options, which leads to steep projected increases in food prices towards the end of the century (Popp et al, 2017).[16]

Figure 2.6. **Projections of land-use change CO_2 emissions**



Notes: *SSP2 range excluding GCAM results.
Source: IIASA (n.d.) and IEA (2017).
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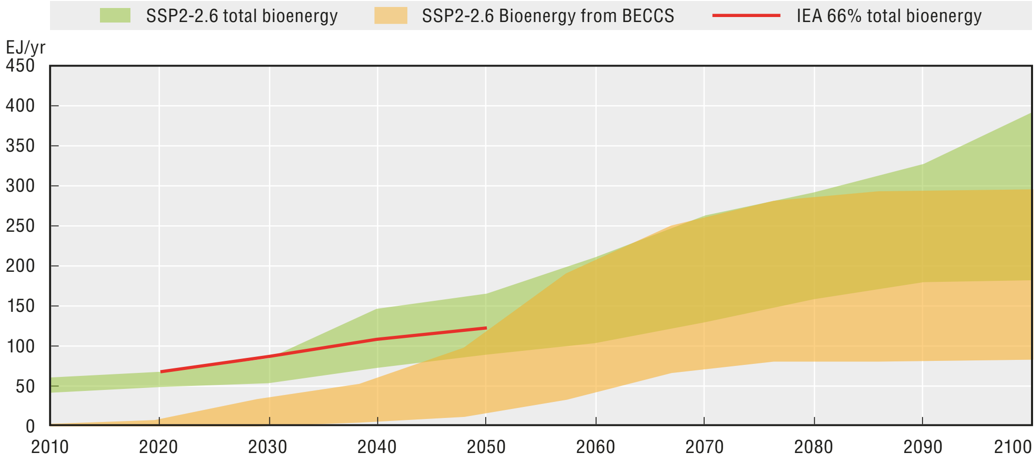
Since the IEA land-use assumption aligns better with the other model realisations of SSP2-2.6, the IEA scenario would seem to be consistent with much smaller projected increases in food prices to 2100. This conclusion is further strengthened by examining projections for total bioenergy in energy demand in these different scenarios. Again, the IEA projections for total bioenergy demand align closely with the SSP2-2.6 range to 2050 as shown in Figure 2.7. In all the SSP2-2.6 scenarios, energy from traditional biomass is projected to fall sharply after 2020, while BECCS increases rapidly. The IEA assumes a modest amount of BECCS in 2050 (about 2 exajoules (EJ)/yr in the power sector), which increases the pressure on the energy system to decarbonise earlier and faster, including through the extensive use of CCS in the industrial sector (IEA, 2017)

Figure 2.7. **Bioenergy projections in the IEA 66% and SSP2-2.6 scenarios**



Source: IIASA (n.d.) and IEA (2017).
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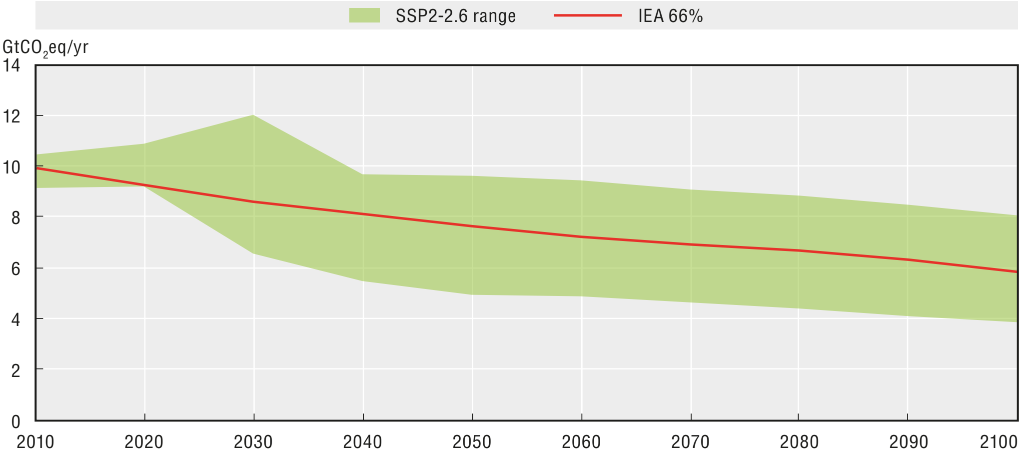
Turning to the main non-CO_2 GHGs, Figures 2.8 and 2.9 compare the range of CH_4 and N_2O emissions in the IEA 66% 2°C and the SSP2-2.6 scenarios. There is a wide range of projections and a much wider range still if we consider less stringent mitigation outcomes or other future socio-economic storylines. Any lack of progress in mitigating emissions to this level – particularly of N_2O – would clearly reduce the chances of staying below 2°C, or require offsetting net negative emissions through afforestation, BECCS or another approach.

Figure 2.8. **Methane emissions in the IEA 66% 2°C and SSP2-2.6 scenarios**

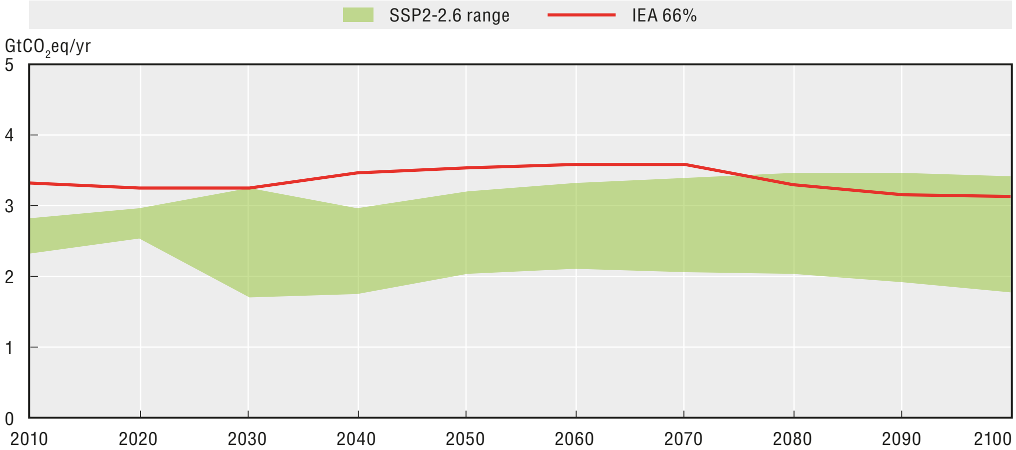


Note: uses a GWP 100 value for CH_4 of 28 (Table 8.7 of IPCC (2013)).

Source: IIASA (n.d.).

StatLink http://dx.doi.org/10.1787/888933484069

Figure 2.9. **Nitrous oxide emissions in the IEA 66% 2°C and the SSP2-2.6 scenarios**



Note: uses a GWP 100 value for N_2O of 265 (Table 8.7 of IPCC (2013)).

Source: IIASA (n.d.).

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Priorities and challenges ahead

The transformation of the energy and industrial systems over the next decades is absolutely fundamental to achieving the Paris Agreement's goal of well below 2°C and will require major structural change to overcome the carbon-intensity that is hard-wired into economies, systems and behaviours (IEA, 2017). That transformation needs to be effected within a few decades if serious climatic disruption is to be avoided. While much progress can and needs to be made now based on currently available technologies, we will also need to develop new technologies and infrastructure to bring us within reach of the very low or negative emissions required by the second half of the century.

Outside the energy and related end-use sectors, the extent of GHG emissions from AFOLU sectors will set the pace and nature of the transition needed in the energy sector. Additionally, mitigation options within the AFOLU sectors may be the critical determinant of whether these stringent mitigation scenarios are feasible, notably afforestation and avoided deforestation[17], bioenergy, BECCS and more GHG-efficient and productive agriculture. Availability of bioenergy is uncertain; estimates suggest it could account for 3% to 37% of the global energy share by 2050, and 23% to 50% of the global energy share by 2100 in a 2°C scenario, with models projecting more than half of modern biomass primary energy coming from non-OECD countries (Rose et al., 2014). The bioenergy share in the IEA 66% 2°C scenario falls within this range, as it does in IRENA's comparable scenario where bioenergy accounts for around 21% of total final energy consumption by 2050, growing from 13% today. Developments in AFOLU are highly uncertain, however, and depend on many factors including technical progress, demographics and demand side developments, such as dietary preferences (Box 2.4).

Box 2.4. **Competing priorities for land**

A central issue for the future of AFOLU emissions is how the demands for food production and for climate mitigation are managed. Food demand is projected to grow strongly through the century along with population and economic growth. The United Nations Food and Agriculture Organisation (FAO) estimates indicate that to meet the demand projected for 2050, global agricultural production must grow 60% above the level of 2005-07 (FAO, 2013). In parallel to increasing food production, reducing food losses and waste "from field to fork" would ease environmental pressures and climate impacts by improving efficiency along the food supply chain (OECD, 2016b).

Over the last five decades (between 1961-63 and 2007-09) agricultural production has increased by 170%. Increased agricultural demand has so far been met largely through improvements in yield (which accounted for 80% of the agricultural production increase), rather than land expansion (20% of the production increase) (OECD, 2012). But the rate of yield growth for most crops has been decelerating in the past few decades, even though it is still increasing in absolute terms (FAO, 2013). So without further yield improvements, demand for agricultural land is likely to grow, increasing the associated CH_4 and N_2O emissions. On the other hand, improving growth in agricultural Total Factor Productivity (TFP) through increased research, development and innovation has the potential to meet demand for food production while using fewer environmental resources and inputs, and emitting fewer GHGs (OECD, 2014). The AFOLU sectors could even become a net sink for CO_2 before the end of the century (IPCC, 2014a).

The demand for bioenergy for climate mitigation could grow rapidly through the century (Figure 2.7), raising questions about both the compatibility of large-scale bioenergy production with food security, and the sustainability of bioenergy in terms of life-cycle emissions and impacts on water and ecosystems, which will vary depending on the particular bioenergy technology and where and how it is applied.

Uses of bioenergy include fuels to replace fossil fuels, particularly in aviation and freight, heating for industrial processes, and as an input to negative emissions technologies (Box 2.3), such as BECCS. If deployed at sufficient scale, this sort of technology could deliver two major economic benefits: i) allow the transition to low-emission technologies to be more gradual than otherwise would be necessary; and ii) offset emissions from any sectors in which mitigation proved technically, economically or socially too difficult.

The greater the scale at which bioenergy is used and produced, however, the greater the tension with food security objectives, in the absence of demand-side measures such as dietary changes that reduced the relative demand for meat products, and reduced food waste (Smith et al., 2013).

Negative emissions technologies and other bioenergy uses will clearly affect other aspects of the Sustainable Development Goals, such as food production, water availability and biodiversity (Smith et al., 2013). The feasibility and acceptability of BECCS is uncertain, in terms of deployment of CCS technologies (see Chapter 6), as is the availability of arable land to meet the simultaneous demand for food production and for biomass for energy (Box 2.4). The IPCC AR5 mitigation scenarios consistent with a less than 2°C target require 210 $GtCO_2$ of BECCS annually by 2050 – which is of the same order of magnitude as the natural terrestrial and ocean carbon sinks – with cumulative global negative emissions typically up to 1,000 $GtCO_2$ over the century (Fuss et al., 2014). The sustainability of bioenergy feedstock is also a significant concern, in particular to guarantee a net zero carbon footprint. There is some degree of consensus among experts that the technical potential for sustainable bioenergy – the potential that is theoretically available before cost considerations are taken into account – is around 100 EJ per year (Creutzig et al., 2015).

In terms of energy use, the priority is to achieve rapid and transformational improvements in:

- *energy efficiency*, from the use of more efficient equipment, such as improved motors or internal combustion engines, from energy-efficient buildings and power plants, and from greater resource efficiency across the life-cycle of products (Box 2.5);
- *emissions intensity of energy*, by replacing emissions-intensive generation capacity and fuels with low-emission generation sources such as wind or solar, and the use of biofuels where they have a low life-cycle of emissions.

Box 2.5. **The importance of resource efficiency for climate goals**

Since 1990, the global use of material resources has grown broadly in line with global GDP, though slightly less rapidly. Global material resource consumption is projected to double by 2050 (OECD, 2016a). GHG emissions from the waste sector typically account for a few percent of total GHG emissions in OECD member countries, but this only represents direct emissions primarily from landfill methane emissions and incinerators. Resource efficiency improvements through an approach of "reduce, reuse and recycle" can support climate mitigation objectives and contribute to achievement of some of the SDGs.

The energy requirements and GHG emissions associated with the production, consumption and end-of-life management of materials can only be assessed by taking a systems view of the production of goods and fuels, transportation of goods, crop and food production and storage, and disposal of food and waste. The life-cycle GHG emissions arising from material management activities were estimated to account for 55% to 65% of national emissions for four OECD member countries, suggesting significant potential to reduce emissions through material resource efficiency measures (OECD, 2012). Substituting secondary, recycled materials for primary materials can significantly reduce GHG emissions (Table 2.3).

Table 2.3. Relative energy and carbon intensity of primary and secondary metal production

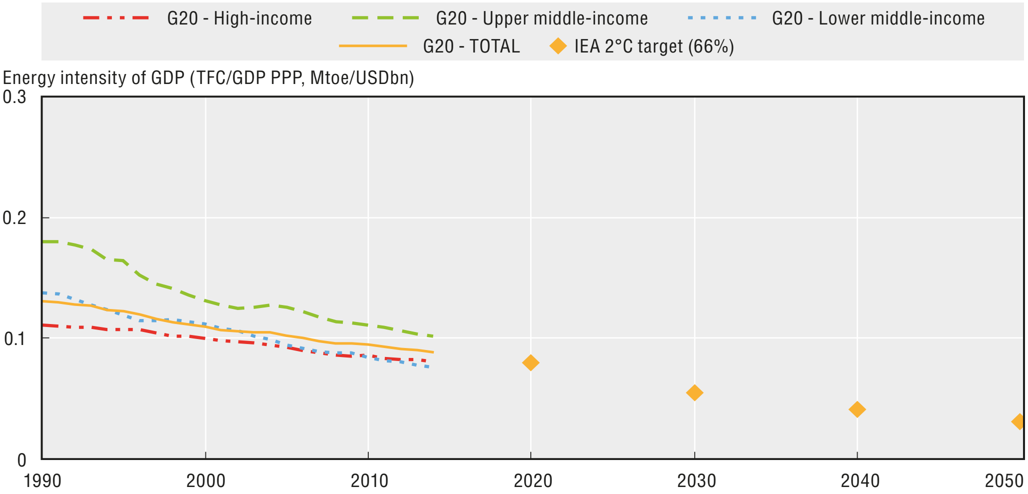
Material	Primary Energy TJ/100,000t	Secondary Energy TJ/100,000t	Primary CO_2 ktCO2/100,000t	Secondary CO_2 ktCO2/100,000t
Aluminium	4 700	240	383	29
Copper	1 690	630	125	44
Ferrous	1 400	1 170	167	70
Lead	1 000	13	163	2
Nickel	2 064	186	212	22
Tin	1 820	20	218	3
Zinc	2 400	1 800	236	56

Source: International Bureau of Recycling, 2008

Economic and population growth and increased fossil fuel use have been the main drivers behind the approximately 60% increase in global CO_2 emissions since the early 1990s. Global CO_2 emissions from energy use have increased less rapidly than GDP and energy use per unit of GDP globally has fallen by around 31%. However, at the same time, the CO_2 intensity of energy actually increased by 3%. Figures 2.10 and 2.11 show the historical performance of G20 countries on these two key measures compared with the levels projected in the IEA's 66% 2°C scenario.

The IEA estimates that the energy intensity of G20 economies would need to fall by more than 60% between 2014 and 2050 (IEA, 2017), a rate of around 3% a year from 2020 to 2050. Daunting as this sounds, it is broadly in line with historic achievements by the G20 countries. More challenging is the more than 75% reduction in CO_2 intensity of energy that is simultaneously required, an average rate of 4.4% a year from 2020 to 2050. Here historic trends are far less encouraging: achieving this scale of change will require an unparalleled increase in the deployment of low-carbon technologies (IEA, 2017).

Figure 2.10. **Energy intensity of GDP for G20 countries**



Source: World Bank (n.d.a.) and IEA (2017).

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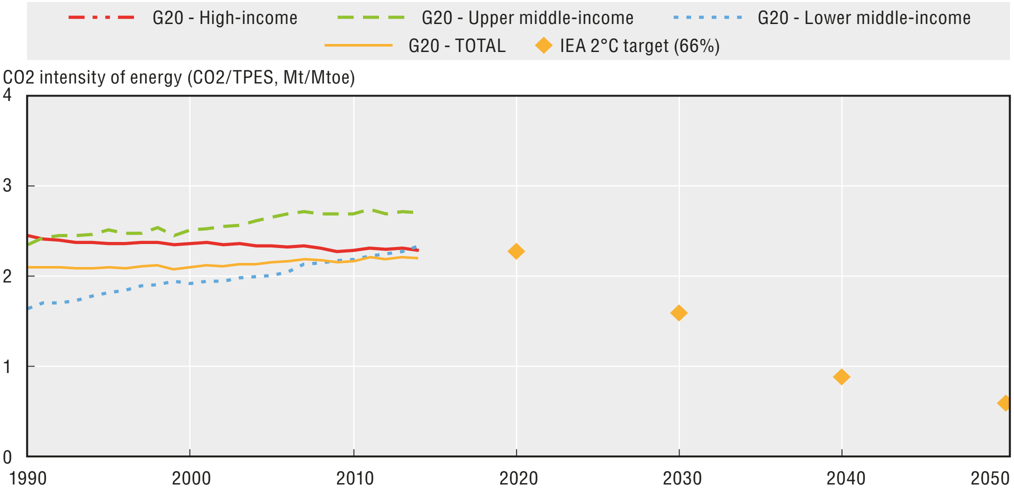
Figure 2.11. **CO_2 intensity of energy for G20 countries**



Source: World Bank (n.d.a.) and IEA (2017).

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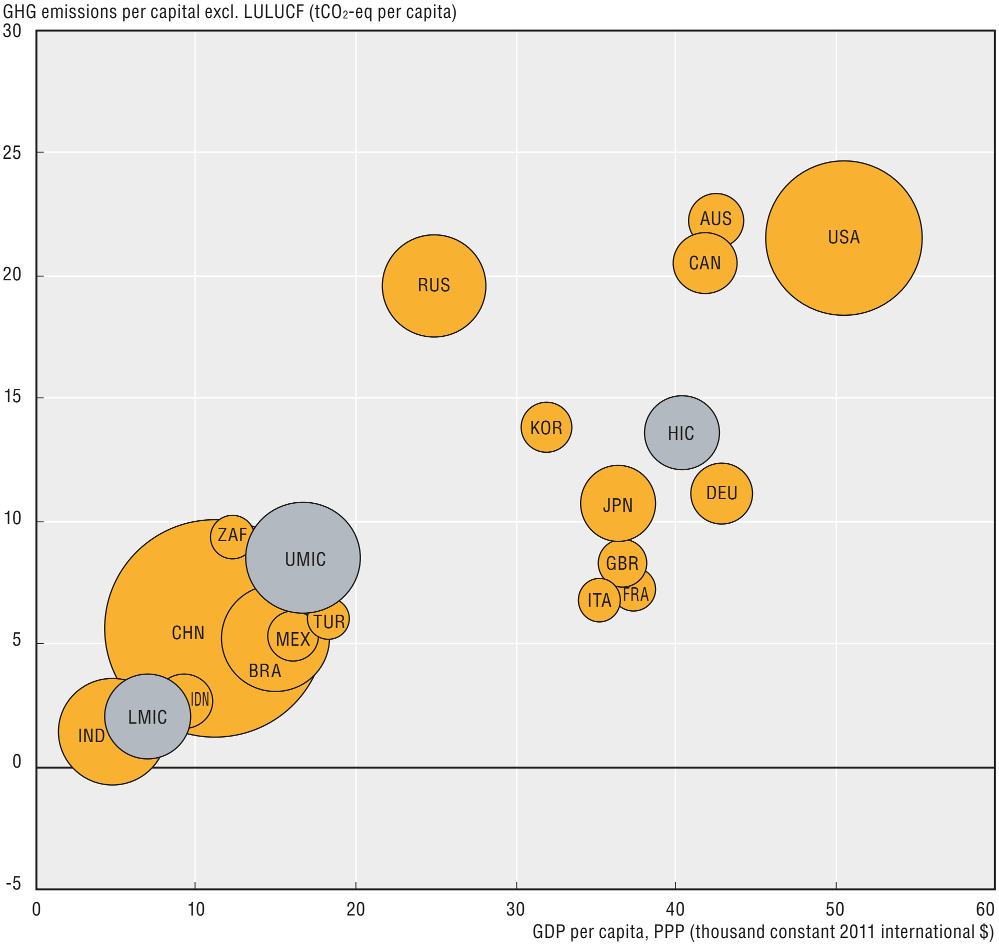
Country diversity and mitigation action

Absolute emissions reflect not just per capita income but also the size of the economy, its energy intensity and the CO_2 intensity of its primary energy supply (see above). Countries also have different income and population growth rates. These drive energy demand and future GHG emissions, as well as influence development patterns, climate resilience and adaptation capacities. Emissions from different sectors also have varying levels of importance from country to country. Finally, governance is an important factor in formulating and implementing low-emission, climate-resilient development pathways. This section analyses some of these key dimensions of country diversity.

Income levels, emissions per capita and governance

The capacity of each country to develop low-emission pathways depends on two key dimensions of country diversity: income level (GDP per capita) and average GHG emissions per person. In Figure 2.12, the size of each bubble represents the absolute level of emissions for the G20 countries (in orange), and the average emissions per G20 country included in each income group (in grey).[18] Emissions per capita are strongly correlated with GDP per person, reflecting the importance of energy to development.

Figure 2.12. **GHG per capita and GDP per capita in G20 countries, 2012**



Note: Total GHG emissions in kilotonnes of CO_2 equivalent excluding land-use, land-use change and forestry (LULUCF). Values for 2012 except for Saudi Arabia (2011) and South Africa (2007). Bubble size is proportional to total GHG emissions for countries and average emissions for income groups. HIC= High-income countries, UMIC= Upper middle-income countries; LMIC= Lower middle-income countries.

Source: UNFCCC (2016), World Bank (n.d.a.), and replies to the OECD State of the Environment Questionnaire (accessed through OECD-STAT).

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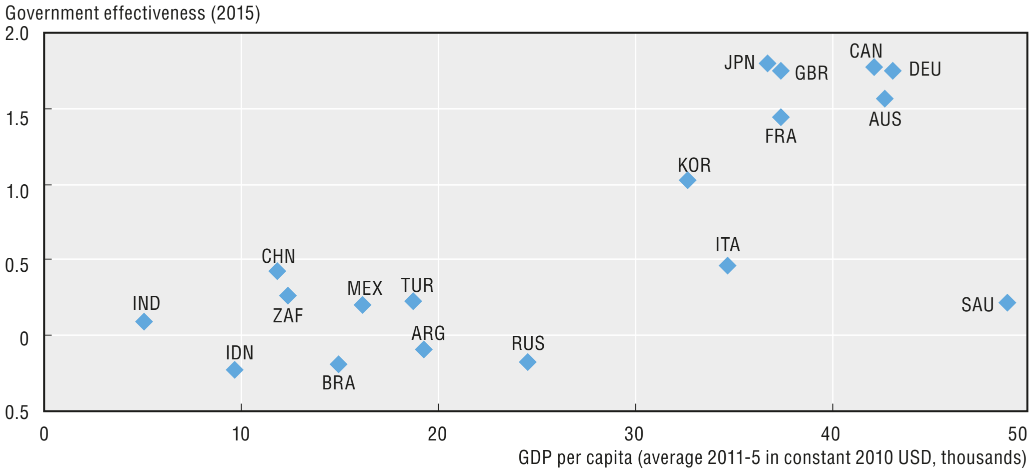
Income captures many dimensions of country capacity to mitigate and to adapt to climate change. More developed economies have higher levels of accumulated physical and human capital, financial and technological resources, and institutional capacity. Higher income levels are also highly correlated with standards of governance, as illustrated in Figure 2.13, which shows the results of a cluster analysis using six governance indicators and GDP per capita, and displays the results against just one of these, government effectiveness. Governance is a key factor underpinning effective and equitable adaptation across multiple actors and sectors in a context of uncertainty and complexity (Huitema et al., 2016). High income is also associated with greater levels of resilience, through mechanisms such as social safety nets, widespread insurance and infrastructure.

Figure 2.13. **Government effectiveness and GDP per capita**



Note: Government effectiveness is an index based on World Bank data and OECD calculations.

Source: World Bank (n.d.b.) and OECD calculations.

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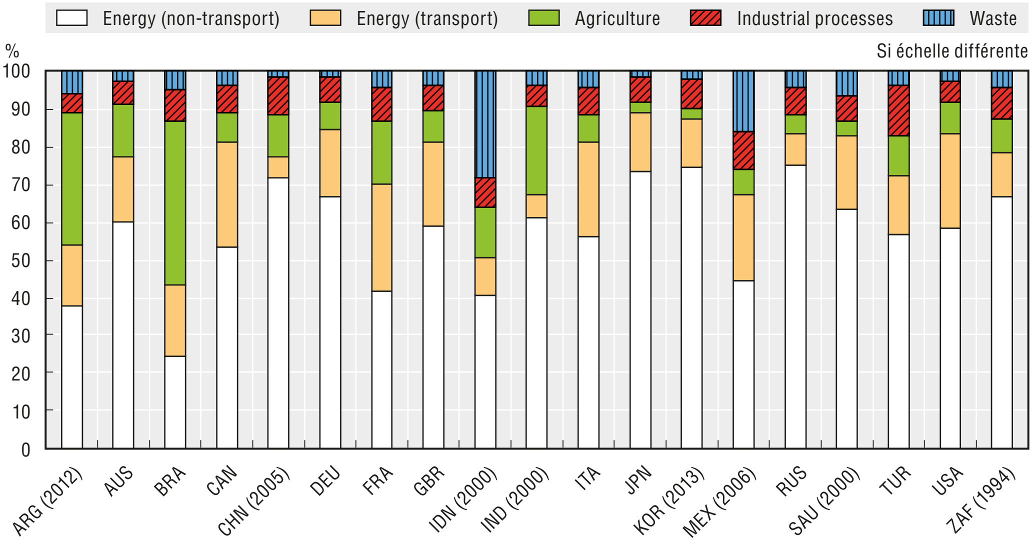
Structure of GHG emissions across the G20

Energy emissions represent the bulk of GHG emissions in G20 countries. However, emissions from other sectors make a significant contribution to overall GHG emissions, notably in Argentina, Indonesia and Brazil (Figure 2.14). Agricultural emissions are a significant proportion of emissions in Argentina, Australia, Brazil, France, India and Indonesia, and are important in several others. Hence countries will face choices over the phasing and timing of mitigation action in different sectors and on different GHGs, with early action on long-lived GHGs essential to avoid cumulative emissions incompatible with the Paris Agreement's goal of well below 2°C. Action on short-lived GHGs and other climate forcers can not only complement this but also provide significant benefits in terms of health and food security (Shindell et al., 2012).

Land-use emissions are also important. Figure 2.15 shows the relative importance of agricultural and land use, land-use-change and forestry (LULUCF) emissions, as a percentage of total GHG emissions including LULUCF across G20 countries.[19] Argentina, Brazil and Indonesia stand out, with a large share of one or both of agricultural and LULUCF emissions. In a number of countries, the sink capacity of land use (essentially negative emissions) more than offsets agricultural emissions,[20] while for three countries, combined LULUCF and agricultural emissions comprise 15% to 20% of total GHG emissions.[21] Land-use change related to commercial agricultural expansion is one of the major sources of CO_2 emissions from deforestation (Hosonuma et al., 2012), though the share of agricultural emissions is not strongly correlated with land-use emissions.

Figure 2.14. **G20 GHG emissions by sector (% of total GHG emissions excluding LULUCF)**



Notes: 1. 2014 or latest year available. 2. Emissions for Argentina, Mexico, and Saudi Arabia from UNFCC GHG profiles. Emissions for Brazil from MCTI, 2016.

Source: Data by sector from OECD, 2017; UNFCCC, 2014; MCTI, 2016.

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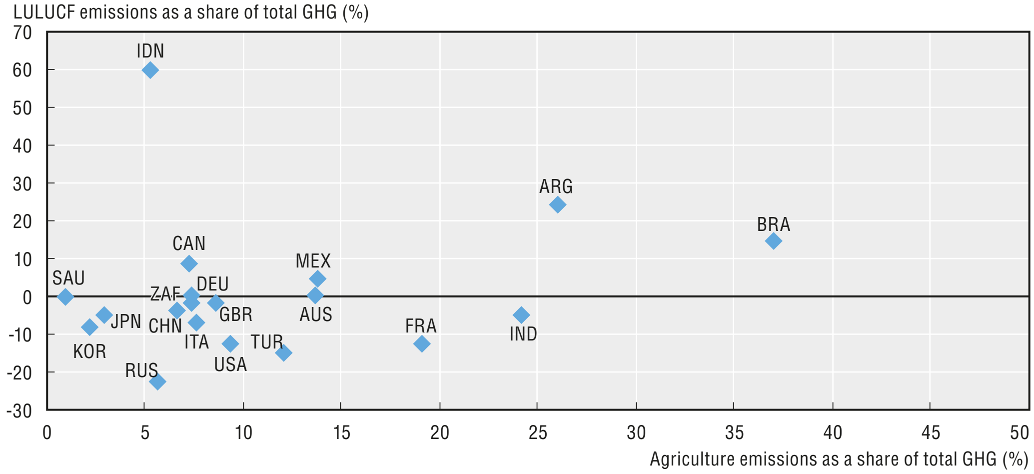
Figure 2.15. **G20 agriculture, land-use and forestry emissions as % of total GHG emissions**



Source: UNFCCC (2016), World Bank (n.d.a.), and replies to the OECD State of the Environment Questionnaire (accessed through OECD-STAT), FAO (2016).

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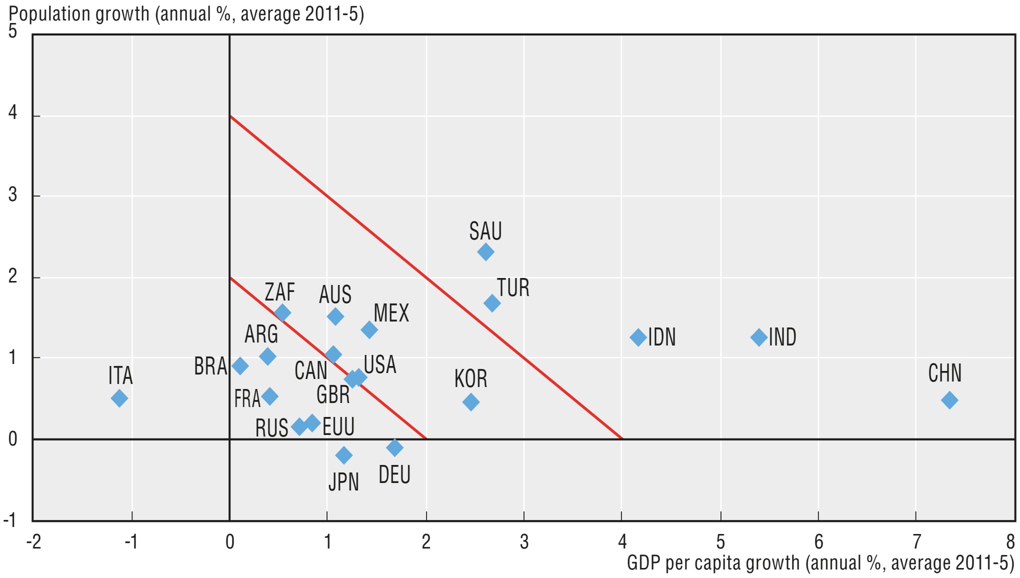
GDP, population growth and emissions

Future growth rates of energy-related emissions can be broken down into the growth rates of several different factors, including energy intensity of GDP and CO_2 intensity of energy (Blanco et al., 2014; Peters et al., 2017). So for a given rate of reduction in emissions, changes in GDP per person and in population together determine how quickly the other factors need to fall to keep on track to meet the Paris Agreement's goal of well below 2°C (Figure 2.16). Over the long term, GDP per capita growth rates may change as countries develop, but the current rates will influence the immediate challenges for countries in developing their low-emission, climate-resilient pathways. Countries such as Brazil that have experienced volatile economic growth rates, with sharp declines in growth in recent years, may change their relative position significantly. However, we expect the broad patterns to show some degree of stability over the period to 2030.

Countries fall broadly into three groups. In Brazil, France, Germany, Italy, Japan and Russia, recent combined growth rates in income per person and population are less than 2% per year. A second group of countries has combined growth rates between 2-4% per year, including Australia, Canada, Korea, Mexico, South Africa and the United Kingdom. A third group, including China, India, Indonesia, Saudi Arabia and Turkey, have combined growth rate in GDP per person and population of more than 4% per year.

Figure 2.16. **Growth rates of GDP per person and population in G20 countries, average 2011-15**



Note: Averaged over the most recent five years of data.
Source: World Bank (n.d.a).
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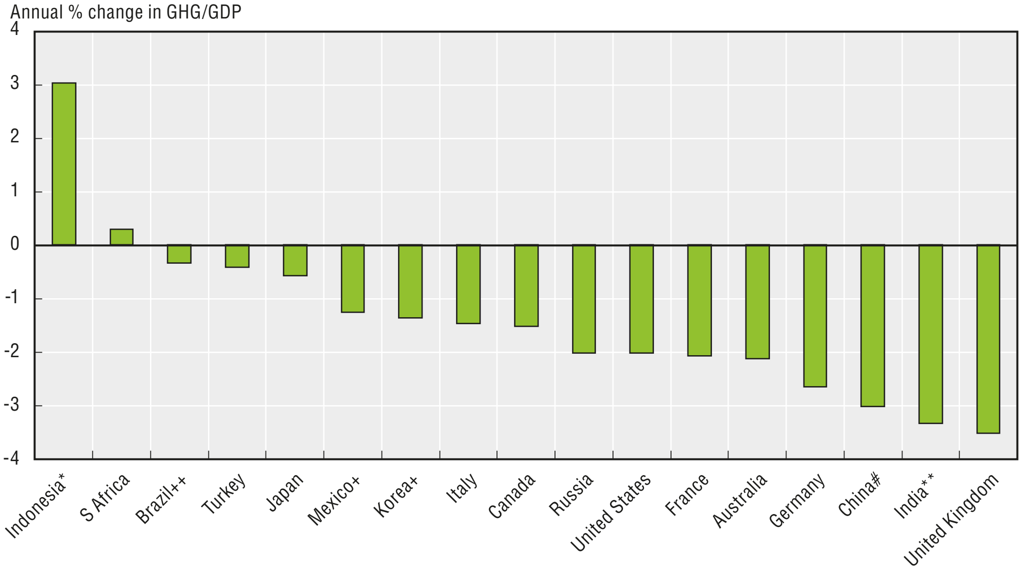
If countries were aiming at a uniform rate of reduction in energy-related CO_2 emissions, the severity of the mitigation challenge would increase from the first to the third group. However a key element of the Paris Agreement is that countries' mitigation contributions reflect "common but differentiated responsibilities and respective capabilities in the light of different national circumstances", which is reflected in the nature and level of ambition embodied in countries' Nationally Determined Contributions (NDCs) (see section below).

However, even countries with rapid GDP or population growth can make rapid reductions in emissions per unit of GDP. GHG emissions per unit of GDP decreased in nearly all G20 countries between 1990 and 2014 (Figure 2.17). As well as structural economic changes, this progress has mainly been due to a general improvement of the energy efficiency of G20 economies rather than an improvement of the carbon intensity of the energy mix. Progress has been varied, but no country has reached the levels consistent with a 66% likelihood of staying below 2°C.[22]

Figure 2.17. **Annual % change in GHG emissions per unit of GDP for selected G20 economies**



Note: Data refer to gross direct emissions excluding emissions or removals from LULUCF. The GDP used to calculate intensities is expressed in USD at 2010 prices and PPPs. The periods covered is 1990-2014 except for: *1990-2013; **1994-2000; #1994-2005; +1990-2013; ++1990-2012.

Source: UNFCCC (2016) and replies to the OECD State of the Environment Questionnaire (accessed through OECD-STAT).

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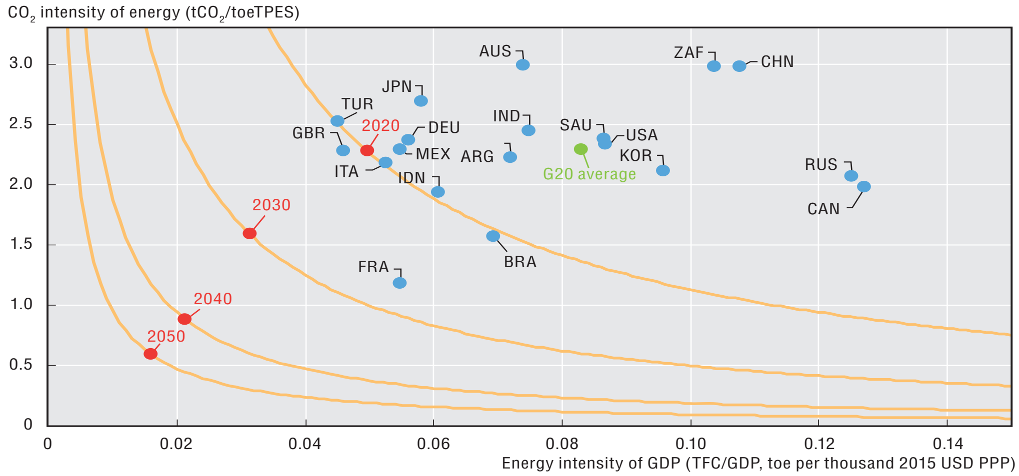
Energy intensity of GDP, CO_2 intensity of energy and energy imports across the G20

Multiplying the CO_2 intensity of energy by the energy intensity of GDP results in the CO_2 intensity of GDP for energy emissions. Figure 2.18 shows lines of constant CO_2 intensity of GDP at levels consistent with the IEA 66% 2°C scenario. Each line is labelled to show the year in which it is projected to be achieved in the IEA scenario,[23] with the data point showing the G20 average projected by the IEA. The 2014 positions of G20 countries are also plotted, highlighting the different starting points and challenges facing different countries as they choose the most appropriate pathways towards the Paris Agreement's goal of well below 2°C. These lines therefore provide a clear direction of travel for country-specific levels of energy intensity and CO_2 intensity of energy. France, for example, has both a relatively low CO_2 intensity of primary energy and energy intensity of GDP, albeit not yet at the levels needed by 2050. Brazil also has a low CO_2 intensity of energy – reflecting the current large share of low-carbon power generation (like France) and the use of bioenergy – but a slightly higher energy intensity of GDP. Further improvements in such economies will require continued investment in low-carbon generation in order to avoid moving backwards, but also priority action in other CO_2-intensive sectors that are harder to decarbonise, such as transport and industry, and continued improvements in energy efficiency.

In contrast, countries like China and South Africa have both a high CO_2 intensity of energy (reflecting coal-powered generation) and a high energy intensity of GDP. Australia also has a high CO_2 intensity but slightly lower energy intensity of GDP, while Canada and Russia have a slightly lower CO_2 intensity, but are more energy-intense economies due to factors including the climate. Of course, countries may have similar levels of energy intensity or CO_2 intensity for very different reasons,[24] and different country outcomes for energy and CO_2 intensity could be consistent with the IEA 66% 2°C scenario. But the direction of travel for all is clear.

Figure 2.18. **The carbon and energy intensity of G20 economies in 2014 and the path to 2050**



Notes: The average levels for G20 countries (excluding the European Union) refer to 2014 statistical data and the IEA 66% 2°C scenario projections for 2020, 2030, 2040 and 2050. The iso lines show other feasible combinations of CO_2 intensity and energy intensity levels. Calculations assume a constant ratio for total primary energy supply (TPES) to total final consumption (TFC). toe = tonnes of oil equivalent.

Source: Calculations based on the IEA World Indicators and IEA 66% 2°C scenario projections.

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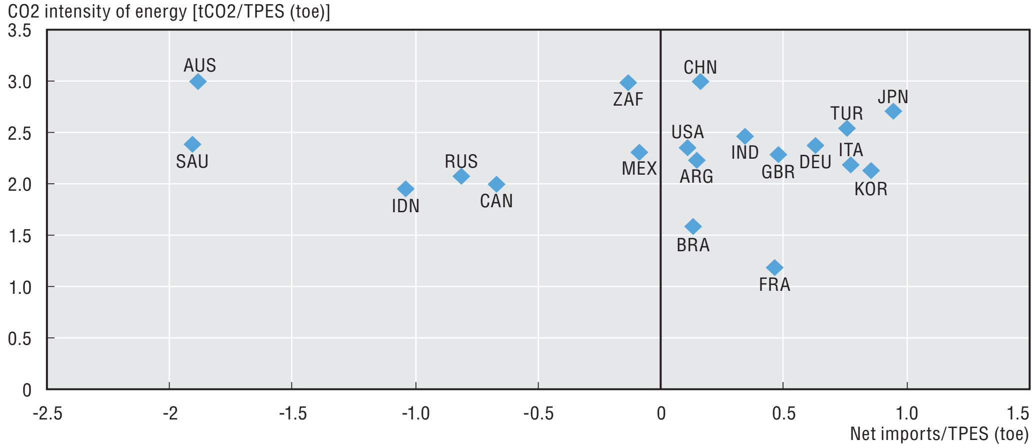
Figure 2.19. **Net energy imports and CO_2 intensity of primary energy**



Source: World Bank World Development Indicators (database, accessed February 2017); "World Energy Balances", IEA World Energy Statistics and Balances (database, accessed February 2017).

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A further important difference between countries is their position as net importers or exporters of energy (Figure 2.19). There are broadly three groups of countries. For the main net importers of energy, deploying low-carbon energy represents an opportunity in the long run to become self-sufficient in power generation, strengthening their energy security. Many of these countries also have CO_2-intensive primary energy, which means that rapid progress can be made to reduce the CO_2 intensity of electricity generation. For the second group, the main net energy exporters, the low-carbon transition represents a risk in terms of loss of export – and tax – revenues. A final group (or perhaps two sub-groups, comprising net importers and net exporters) – consists of those countries with limited net trade in energy. This may be due to the availability of significant low-carbon energy options (e.g. Brazil), but the group also includes countries with significant fossil fuel resources largely for domestic use, with limited net energy trade relative to total primary energy supply (e.g. Argentina, China, Mexico, South Africa and the United States). The challenges to decarbonisation therefore vary across countries, but are particularly significant for countries that have high CO_2 intensity of energy.

Low-emission pathways for different country groups

As countries develop their low-emission, climate-resilient pathways, an important question is whether these pathways are unique and specific to individual countries or whether groups of countries face similar challenges. Countries that have many characteristics in common could have much to gain by sharing analysis, policy development and experience as they develop their NDCs and pathways. One way of seeing what countries might have in common is to group them by income level – either Advanced (High-Income) Economies or Emerging (Middle-Income) Economies – and whether or not they are energy exporters or importers (Table 2.4).[25]

Table 2.4. **Country groupings**

Group	Advanced Exporters	Advanced Importers	Emerging Exporters	Emerging Importers
Country	Australia* Canada Saudi Arabia	France Germany Italy Japan Korea, Rep. United Kingdom United States	Indonesia Mexico Russia South Africa	Argentina Brazil China India Turkey

Source: OECD calculations. * includes New Zealand following the methodology used in the IEA 66% 2°C scenario.

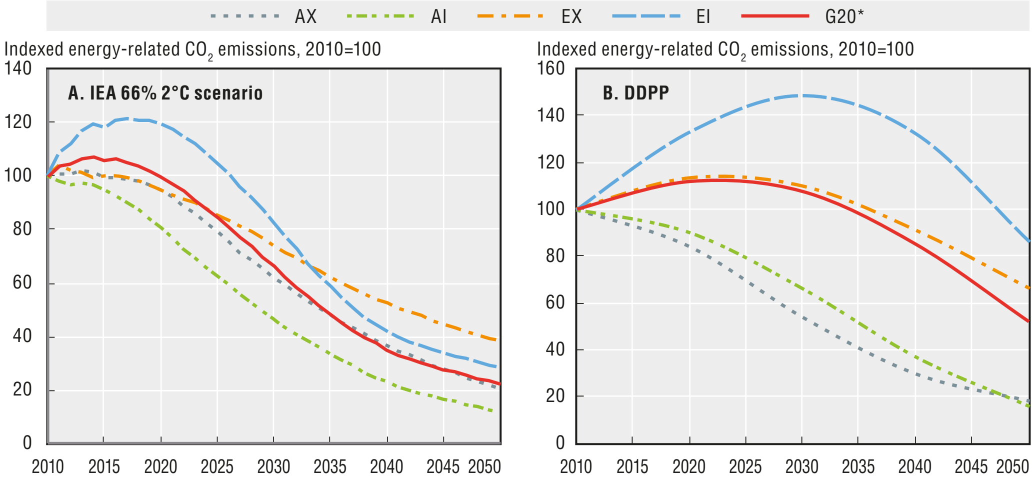
Country characteristics will shape priorities in developing and implementing low-emission, climate-resilient development pathways, as can be seen by examining the outcomes of the Deep Decarbonisation Pathways Project (DDPP). This collaborative project between country modelling teams aimed to identify practical pathways that the G20 countries in which they were based could adopt, taking seriously the GHG emissions reductions required to limit warming to 2°C or less.[26] The DDPP project involved research teams from countries representing 74% of current global CO_2 emissions.[27] Each team developed its own "bottom-up" deep decarbonisation pathway (DDP) based on a sector-by-sector analysis of the feasibility and cost of different mitigation options. Teams were "autonomous in defining their targets, choosing their analytical methods, and incorporating national aspirations for development and economic growth in their scenarios" (DDPP, 2015).

Consequently, the IEA 66% 2°C scenario is more stringent than the DDPP exercise; G20 emissions are projected to fall by almost 80% by 2050 for the IEA 66% 2°C scenario, and about 50% in the DDPP exercise. Nevertheless, both the DDPP results and the IEA 66% 2°C scenario show very different energy-related CO_2 emissions pathways across the income level and energy exporter-importer country groups. Advanced Economies (Exporters and Importers) begin rapid emissions reductions from the outset and are projected to converge at very low levels by 2050. Emissions from Emerging Economies are projected to follow very different tracks.

In the IEA 66% 2°C scenario, Emerging Exporters reduce emissions from 2015 onwards, achieving a reduction of just over 60% by 2050. In the DDPP projections, however, Emerging Exporter emissions increase to 2020 before declining by a smaller 33% by 2050. Emissions from Emerging Importers grow sharply from 2010, peaking around 2017 in the IEA 66% 2°C scenario and in 2030 in the DDPP results, but then fall more rapidly than those from

Emerging Exporters. This group achieves a more than 70% reduction in emissions by 2050 in the 66% 2°C scenario, but a less than 15% reduction in DDPP, reflecting the scale of the initial increase and the differing nature of the two exercises (Figure 2.20).

Figure 2.20. **Energy-related CO_2 emissions by income-energy group**



Note: AX: Advanced Exporters. AI: Advanced Importers. EX: Emerging Exporters. EI: Emerging Importers. G20 countries not included in Figure 2.20 (a) are: Argentina, Saudi Arabia, South Africa and Turkey. Australian emissions also include those for New Zealand since they are aggregated in the IEA modelling. Those not included in Figure 2.20 (b) are Argentina, Russia, Saudi Arabia and Turkey. G20* denotes the average across the countries where there is disaggregated data available for each exercise

Source: (a) IEA data underpinning IEA (2017) and OECD calculations. (b) DDPP (2015) and OECD calculations.

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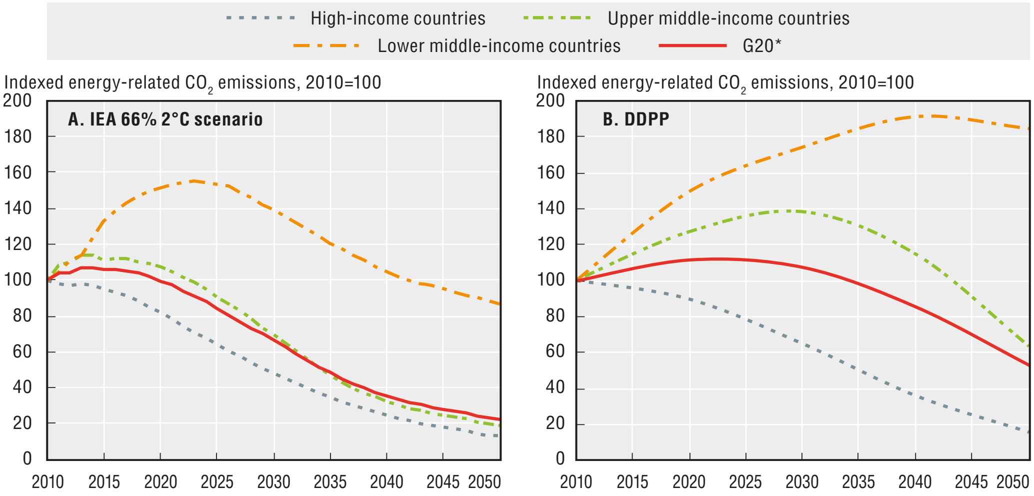
Another perspective can be gained by looking at emissions pathways just by income group (Figure 2.21). The joint mitigation-development challenge facing Lower Middle-Income countries is striking. The IEA scenario (LMIC reduction of 13%) would require significantly more stringent mitigation than in the bottom-up DDPP exercise (LMIC increase of 84%). Upper Middle-Income countries are projected to reduce emissions by 80% in the IEA 66% 2°C scenario but only by 36% in the DDPP results.

Figure 2.21. **Emissions pathways by income group in the IEA 66% 2°C and DDPP scenarios**



Note: For G20 country coverage, see note under Figure 2.20.

Source: a) IEA data underpinning IEA (2017) and OECD calculations. (b) DDPP (2015) and OECD calculations.

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Other studies have shown potential for emissions reductions to go beyond these levels by 2050 in some emerging economies, though there remain significant challenges in doing so.[28] To keep warming well below 2°C, effective transparency, review and updating processes will clearly be essential, as well as support for climate action in developing countries.

Beyond energy-related emissions, there are clear priorities for countries to preserve existing carbon stocks in forests and other ecosystems by avoiding deforestation and forest degradation and by limiting over-use of nitrogen fertilisers (Prentice, Williams and Friedlingstein, 2015). Enhancing the terrestrial sink for atmospheric CO_2 by afforestation, reforestation and better soil management practices can also make an important contribution (Mackey et al., 2013). Additionally, countries will need to place a greater priority on building resilience and adaptive capacity.

Climate-resilient pathways reflecting regional climate change

Even if global action to reduce GHG emissions increases enough to meet the Paris Agreement goal of well below 2°C, the impacts of climate change will still increase far beyond today's level. Examining the projected impacts on a regional basis can help countries to develop climate-resilient pathways.

Projected regional climate changes

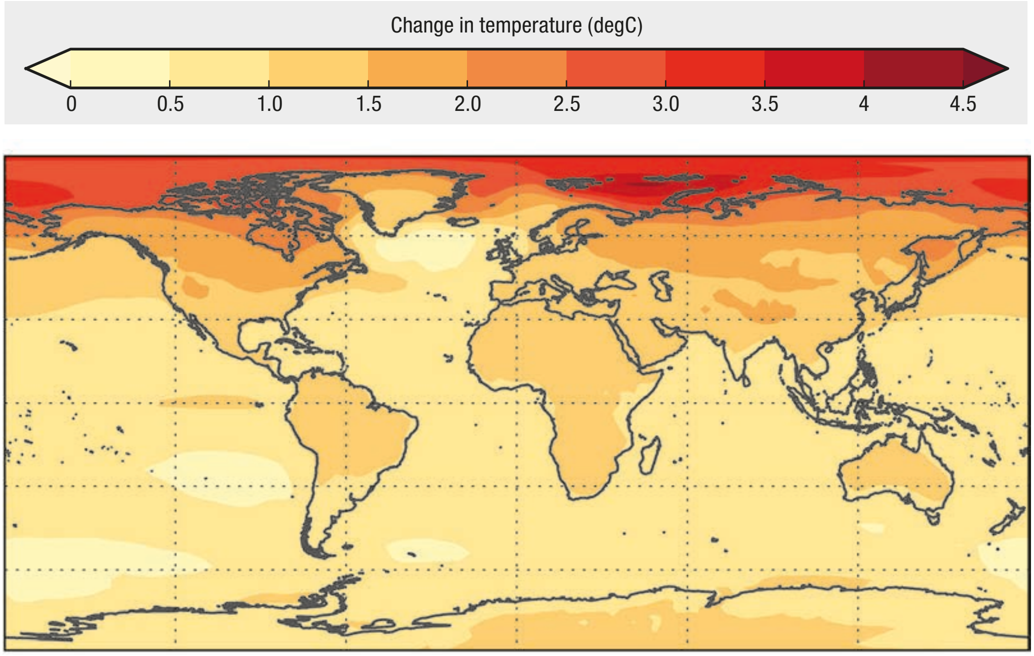
This section presents results for two different RCP scenarios simulated by a number of the climate models that informed the IPCC's Fifth Assessment Report (IPCC, 2013). The first is the RCP2.6 scenario. The second is the RCP4.5 scenario, which has mean end-of-century warming across models of 2.4°C. Both therefore have end of century warming relative to the pre-industrial time period below the level associated with the emissions pathways implied by countries' Nationally Determined Contributions (NDCs) to GHG emissions reduction post-2020, as described below. The RCP4.5 scenario is, however, broadly in line with the NDCs earlier in the century.

The following figures show maps of projected climate changes between the recent past (1986-2005) and mid-century (2046-65) for these two RCPs. The mean average change for different regions across the available climate models is shown, but individual models may give results that differ in terms of the magnitude of changes and details of the spatial patterns of change.

Temperature

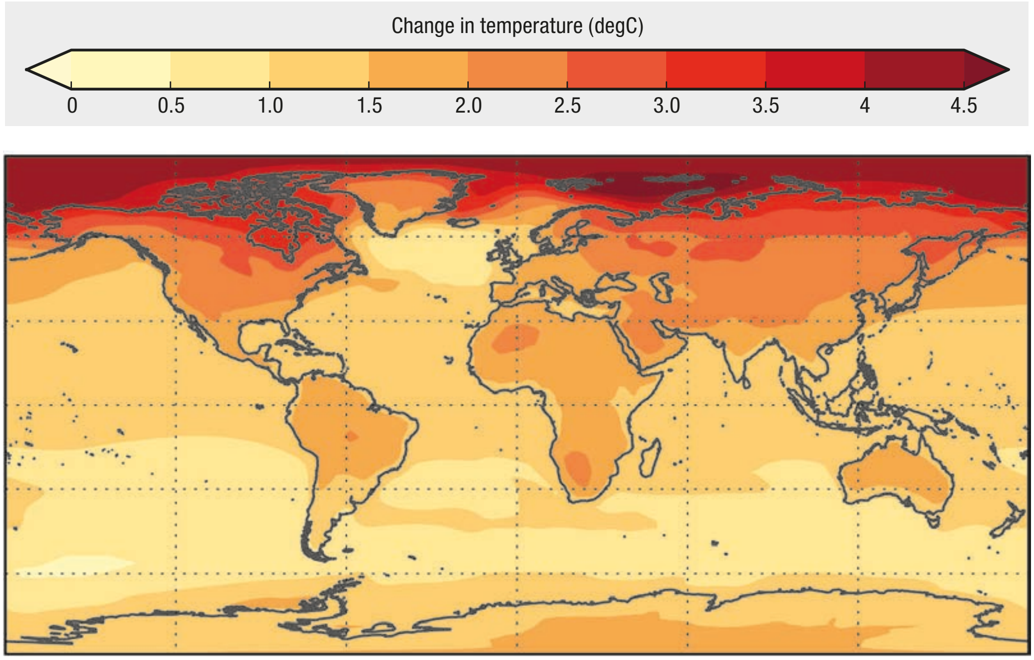
The regional pattern of projected temperature changes to mid-century (2046-65) is similar for both RCP2.6 (Figure 2.22) and RCP4.5 (Figure 2.23), but with greater changes in RCP4.5. For RCP2.6, projected regional warming values exceeding 2.5°C are confined largely to the Arctic Ocean, while in RCP4.5 projected warming exceeds 2.5°C over most of Alaska and much of Canada and Russia. Despite the greater warming in these areas, long-term warming may be more noticeable in tropical countries, such as Indonesia, where the variability in temperatures from year to year is lower. For both scenarios, model-average warming is less in the Southern Hemisphere than in the Northern Hemisphere, with warming across the Southern Hemisphere being less than 2.5°C for RCP4.5 and less than 1.5°C for RCP2.6.

Figure 2.22. **Projected absolute change in annual mean surface temperature for RCP 2.6 for the period 2046-65 relative to 1986-2005**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

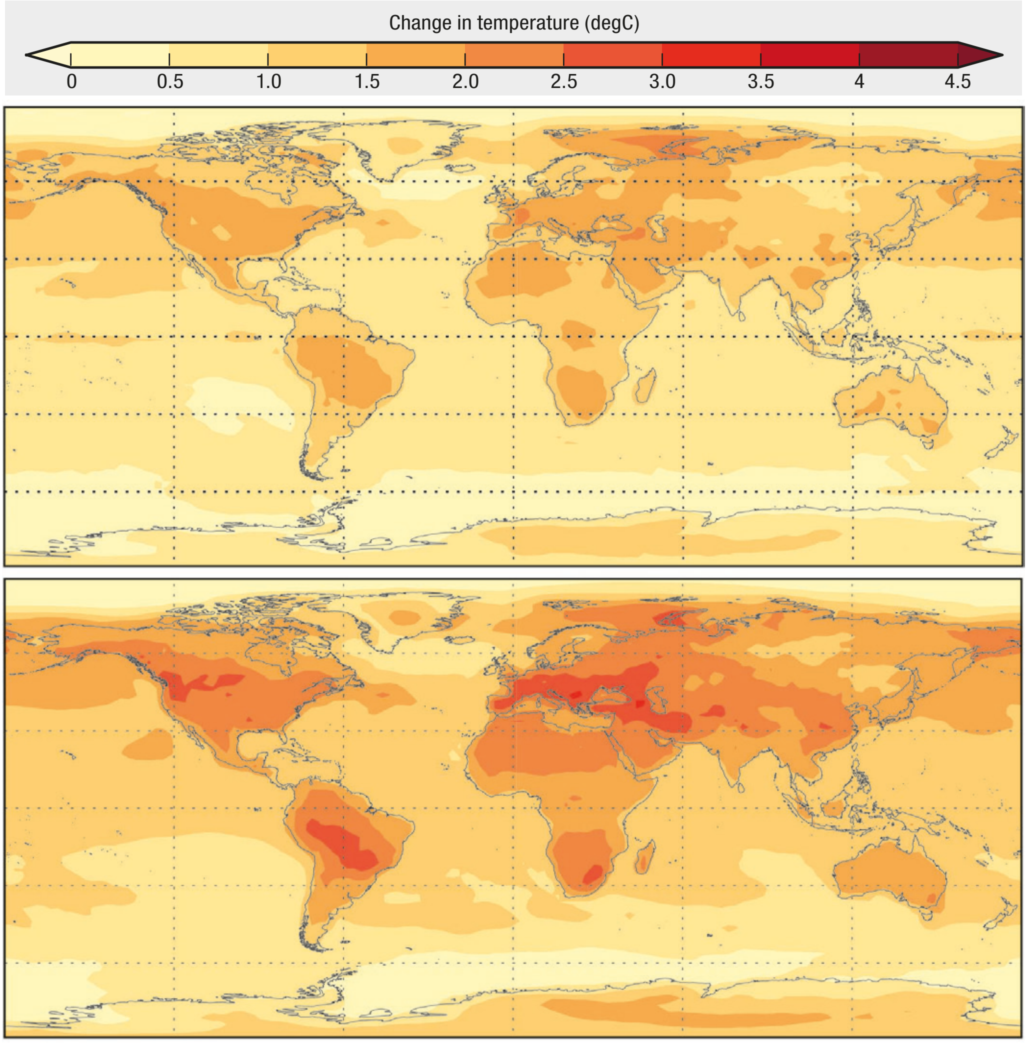
Figure 2.23. **Projected absolute change in annual mean surface temperature for RCP 4.5 for the period 2046-65 relative to 1986-2005**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

The regional pattern of changes in extreme temperatures is quite different from that for changes in annual mean temperature. For example, those regions expected to experience the greatest increases in the temperatures of very hot days differ from those expected to see the largest increases in annual mean temperatures (Figure 2.24). For both scenarios, the maximum temperature during a year is projected to increase most over parts of continental Europe, southwest Asia, North America and inland regions of South America, such as western Brazil. As for annual mean temperatures, the increase in maximum temperature during a year is projected to be greater for RCP4.5 than for RCP2.6. For example, over parts of southeast Europe the model-average increase in maximum temperatures during a year is more than 3.0°C for RCP4.5, whereas it is less than 2.5°C under RCP2.6.

Figure 2.24. **Projected changes in the maximum temperature during a year between 1986-2005 and 2046-65 for RCP2.6 (top) and RCP4.5 (bottom)**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

Precipitation

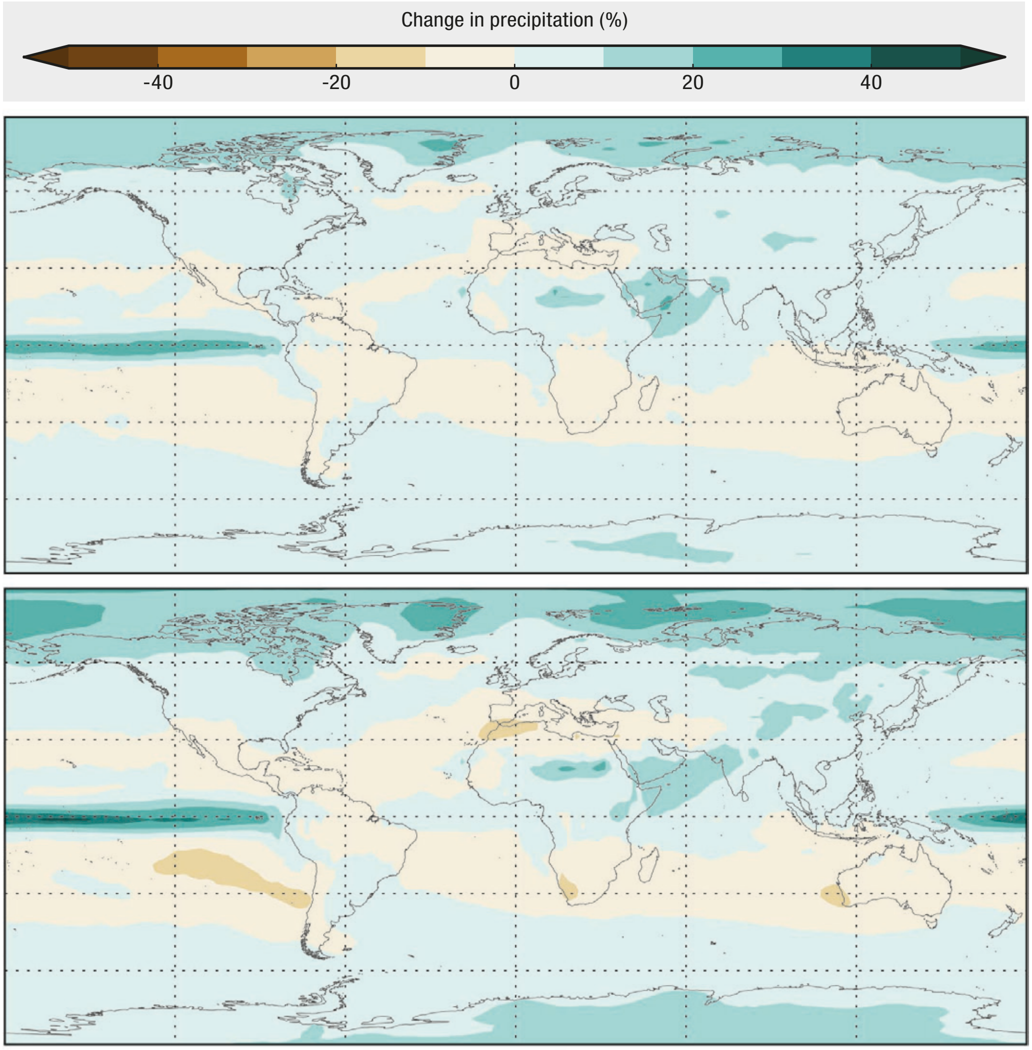
In both RCP2.6 and RCP4.5, global average annual mean precipitation is likely to increase by 2-3% on average between 1986-2005 and 2046-65 (Table 2.5). Projections are highly uncertain on the country scale, however. For most of the G20 countries, some simulations show increases in precipitation while others show decreases. Nonetheless, both scenarios show the same coherent pattern of precipitation increasing in some areas and decreasing in others, particularly northern Africa, southern Europe, Central America, northern South America, southern Africa and Australia (Figure 2.25). For RCP4.5, the greatest model-average precipitation decreases for the G20 countries – of more than 6% – are projected for some of the Mediterranean countries. The same countries are projected to experience more modest precipitation decreases for RCP2.6 of around 2% or 3%. For RCP4.5, the greatest model-average precipitation increases projected for the G20 countries – of more than 7% – are for Canada and Russia.

Table 2.5. **Projected percentage changes in global average annual mean precipitation and maximum daily precipitation total during a year between 1986-2005 and 2046-65 for RCP2.6 and RCP4.5**

	Change in annual mean precipitation		**Change in annual maximum daily precipitation total**	
Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
RCP2.6	+2.2	+0.5 – +3.8	+5.7	+2.3 - +9.1
RCP4.5	+2.6	+1.0 – +4.1	+6.8	+1.8 - +11.8

Source: MOHC analysis.

Figure 2.25. **Projected changes in annual mean precipitation between 1986-2005 and 2046-65 for RCP2.6 (top) and RCP4.5 (bottom)**



Note: Maps show average changes across available global climate model simulations.
Source: MOHC analysis.

In all G20 countries, global average extreme precipitation is expected to increase more than global average annual mean precipitation. Global average maximum daily precipitation is likely to increase by 6% on average for RCP2.6 and 7% for RCP4.5.

Climate impacts and the SDGs

The choice of development pathway will have a major influence on how climate change affects poverty levels (Hallegatte et al., 2016). In a scenario where economic growth is higher, inequality is lower and there is better provision of basic services, climate change is estimated to increase the number of people in extreme poverty in 2030 by 3 to 16 million people. By contrast, under a more pessimistic scenario, extreme poverty could increase by 35-122 million people because of climate impacts on agriculture, health, labour productivity and the incidence of natural disasters (Hallegatte et al., 2016).

Agriculture will be affected by the changes in precipitation patterns and ecosystem services that are projected to occur with climate change. IPCC (2014b) reported that negative impacts of climate change on yields of crops such as wheat and maize have been more common than positive impacts. Crop yields are projected to increase by 2050, but by less than would otherwise be the case (Ignaciuk and Mason-D'Croz, 2014). Under a very high emissions scenario (IPCC scenario RCP 8.5), climate change could increase the prices of major grains by 5-30%, leading to increases in the proportion of people suffering from malnutrition in South- and Southeast Asia, Middle East and North Africa and Sub-Saharan Africa. Without adaptation, aggregate production losses are expected for wheat, rice and maize for 2°C of local warming (Challinor et al., 2014). This applies to both temperate and tropical regions and increases over the century.

While health impacts are modest at this stage, they are projected to be a major source of harm from climate change (Smith et al., 2014). Increases in heat-related mortality are projected to outweigh the decline in cold-related mortality. The dangers of extreme heat were illustrated by the prolonged 2003 heatwave in France, which is estimated to have led to almost 20,000 excess deaths (EM-DAT, n.d.). The 2015 heat wave in India led to 2 248 deaths (EM-DAT, n.d.). In the absence of adaptation, climate change could lead to 250,000 excess deaths per year by 2050 (WHO, 2014). Climate change increases the risk of illness from food- and water-borne disease as well as the spread of vector-borne diseases, with as many as 200 million more people being at risk in 2050 (Béguin et al., 2011).

Labour productivity, particularly in warm countries with high proportions of outdoor labourers, will be reduced by 3-5% per degree for outdoor activities. The overall decline in labour productivity will be 1% in most OECD countries (OECD, 2015b). In non-OECD countries, average labour productivity is estimated to have declined by 10% during peak temperature months over the past decades, and could decline by 20% during peak months by 2050 (Dunne et al., 2013). Impacts on labour productivity are likely to disproportionately affect the poor, especially women, who tend to work in climate-sensitive sectors and have fewer resources for adaptation (Hallegatte et al., 2016). Asia and Africa will suffer the most significant effects.

Climate change will exacerbate water-related risks. Increasing demand and decreasing supply will result in water shortages. Rising sea levels will cause flooding, as will changing patterns of rainfall and extreme rainfall episodes. Water quality will also suffer. Some 3.9 billion people are projected to live in areas of severe water scarcity by 2050 (OECD, 2012). In coastal cities, annual losses from flooding could rise from USD 6 billion in 2005 to USD 1 trillion per year by 2050, if flood defences are not improved (Hallegatte et al., 2013) (Figure 2.26). The countries at greatest risk from coastal city flooding span developed and developing countries, including the United States and China.[29]

Developing climate-resilient pathways

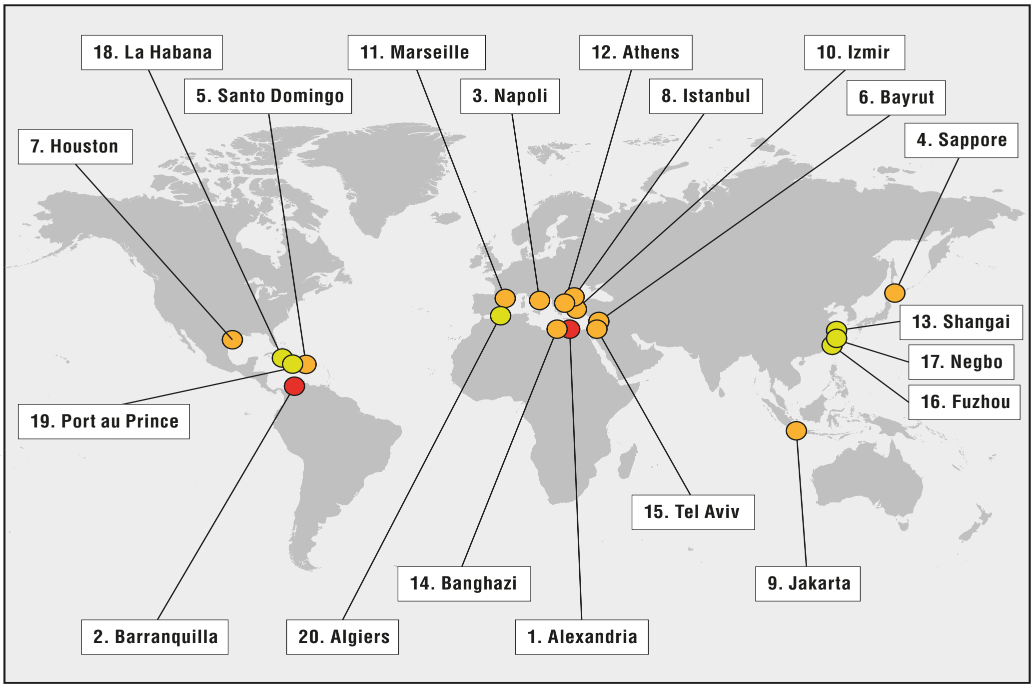
Countries' vulnerabilities to climate change are shaped by development choices, socio-economic trends and climate effects that cross borders and will demand flexible, forward-looking approaches to decision-making.

As with mitigation action, a primary determinant of countries' ability to adapt is their GDP per capita. Richer countries will be better able to adapt to the impacts of climate change than those with lower GDP per capita; they have more resources to invest in adaptation and recovery. This can be seen in the correlation between GDP per capita and standards of protection against flooding (Hallegatte et al., 2017). There are also indirect effects: richer countries tend to have higher quality institutions, leading to more rigorous planning and better implementation of policies. More developed financial markets mean that households and businesses are better able to manage the financial consequences of extreme events.

How much rainfall countries receive – and how much this is expected to change – also affects countries' ability to adapt. Climate change is expected to reduce precipitation in regions that are already severely water-stressed. Moreover, the loss of Asian and Andean glaciers will place further stress on freshwater availability in countries in South Asia and South America. The need to reconcile supply and demand will shape the range of feasible development paths, constrain some adaptation options (such as irrigation) and increase the urgency of developing an efficient policy response.

The variability of precipitation is also a key factor for adaptation. Monthly variability in water runoff, GDP per capita and investments in water security are interconnected (Sadoff et al., 2015). River basins in high-income countries tend to have less variable runoff and higher investment in water security. In contrast, river basins in low-income countries tend to feature variable runoff and low investment in water security. As climate change makes precipitation less predictable, it will be vital to enhance investment in water security to address these fluctuations.

Figure 2.26. **The 20 cities most at risk from sea-level rise**



Note: Cities where expected annual average losses increase most (in relative terms in 2050 compared with 2005) in the case of "optimistic" sea-level risk, where defence standards are held constant.

Source: Hallegatte et al., 2013. Reprinted by permission from Macmillan Publishers Ltd: Nature Climate Change 3, 802–806 copyright (2013).

Political choices will also affect countries' vulnerabilities to climate change. Countries at similar levels of economic development vary widely in the levels of climate risks that they are willing to accept: New York is protected against a 1:100 year flood while Amsterdam is protected to a standard of 1:10 000. The development path that each country pursues will affect the cost and feasibility of achieving different levels of risk reduction: for example, development in low-lying coastal areas may subsequently necessitate large investments in coastal protection, or relocation to higher ground.

Countries can reduce their vulnerability to the effects of climate change by pursuing inclusive development. Poverty, marginalisation and inequality constrain people's ability to adapt to a changing climate. The poor tend to live in higher-risk areas and have less access to public services (Hallegatte et al., 2017). Moreover, the poor and marginalised have few resources with which to cushion the impact of climate shocks, with the result that such shocks can cause long-term harm, and even transform transient poverty into chronic poverty (Olsson et al., 2014). Ensuring that development is inclusive can avoid a vicious cycle between climate change and poverty.

Box 2.6. **Adaptation pathways: the Delta programme**

The Delta programme is designed to protect the Netherlands against the risk of flooding and ensure access to fresh water. An approach called "adaptation pathways" has been used to identify different sets of policy measures that could meet these objectives, given uncertainties about how the climate, the economy and society will evolve. Multiple model runs are used to project the range of potential variables over time. Based on this process, the analysis identifies tipping points where additional or different actions may be required to ensure that the objectives are met under some scenarios.

At each tipping point, there is a range of potential options – a "decision tree". Depending on the one chosen, the options available further down the track may differ. The combinations of available options offer many different pathways, which are all projected to meet the same performance criteria. These alternative pathways can then be compared using a range of qualitative and quantitative criteria. Once a pathway has been chosen, a monitoring system is established to track changes in relevant variables and change course if needed. The involvement of relevant stakeholders is essential to ensure that the right dimensions of each decision are taken into account and that there is a shared understanding of the likely consequences of different options.

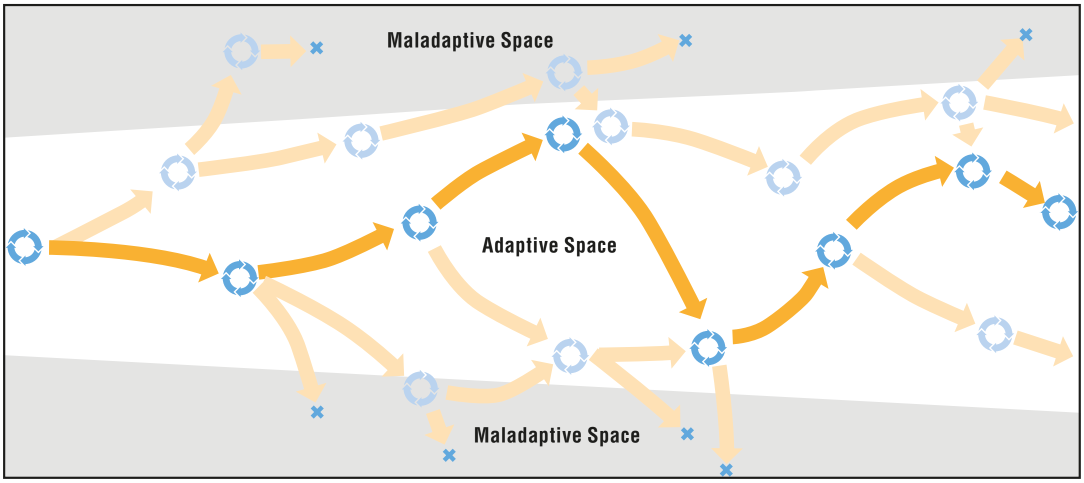
This approach directly addresses the challenge of long-term planning in an environment of pervasive uncertainty. One of its main benefits is that it ensures that the actions taken today are consistent with the longer-term objectives. It also supports a flexible response, by identifying how options will open up or preclude certain actions in the future.

Source : Haasnoot et al., 2013

Since countries' circumstances differ, so will their appropriate adaptation responses. The concept of "adaptation pathways" has been pioneered to ensure that large infrastructure projects are able to respond to changing circumstances over the course of their useful life (Box 2.6). The underlying principle is to identify the range of potential outcomes that could materialise and then work backwards to identify the range of measures that would be needed to address those outcomes. The adaptation pathway provides a formalised way of identifying sequencing, path dependencies and the points where decisions need to be made (Haasnoot et al., 2013).

At the national level, the concept of adaptation pathways provides a model for viewing adaptation as a process for adjusting to changing circumstances over time. There is a succession of decision-points over time, each of which then determines the future range of opportunities that are open to decision-makers (Wise et al., 2014) (Figure 2.28). In practice, however, the process is less straightforward, because of the need to define what constitutes successful adaptation, difficulty in measuring the current state of progress and competing views about the appropriate responses to a changing climate. Nonetheless, the underlying approach of cycles of implementing actions, learning and adjusting course provides a useful description of the adaptation process.

Figure 2.28. **Iterative decision cycles**



Source: Wise et al., 2014

National Adaptation Plans (NAPs) provide an important tool for communicating priorities and putting in place the key elements required to support adaptation. Adaptation will be the product of a multitude of decisions, ranging from farmers' choices of crops to urban planning, undertaken by a wide range of actors facing different sets of opportunities and constraints. Climate change will be just one of many factors that could influence how people respond to change. This means that it is neither possible nor desirable for every adaptation action to be dictated in a top-down manner. Instead, adaptation strategies such as NAPs should aim to strengthen the capacity of relevant decision makers to account for climate change. An important element of this is to influence investment decisions by demonstrating political commitment and setting the strategic direction for resilience at the national level.

The basis for effective adaptation is having access to suitable data in a usable form, combined with the tools to interpret the implications of climate change for the relevant decisions. These data should be regularly updated and reliable, which may require improvements in countries' statistical capacity.[30] Providing information is necessary, but not sufficient, to guarantee informed decision-making. The governance arrangements that determine how decisions are made may themselves need to be adapted to make them responsive to the effects of climate change. Action by governments may be required if inertia in existing governance systems means that they are no longer fit for purpose in a changing climate (Wise et al., 2014). For example, adopting a risk-based approach in the water sector requires involving a broader set of stakeholders, obtaining different information and changing the objective of the decision from meeting certain technical standards to achieving acceptable levels of risks. Regulatory reforms may be required to enable these changes to occur.

At the project level, there are clear metrics to assess progress and inform decision-making as part of an adaptation pathway. In contrast, the concept of national pathways cannot be readily quantified, because of the nature and diversity of actions that they include. For this reason, it is vital to use both quantitative and qualitative information to assess progress (OECD, 2015d). Relevant tools for doing so include national risk assessments, indicator sets and in-depth evaluations of large projects. This process is likely to be most effective when it is integrated into existing processes for monitoring and evaluation, rather than being implemented as a standalone system.

OECD analysis of infrastructure resilience shows that action is required across four policy areas (Vallejo and Mullan, 2017):

- supporting decision-making by providing tools and information;
- screening and factoring climate risks into public investments;
- enabling infrastructure resilience through policy and regulation;
- encouraging the disclosure of climate risks.

Spatial planning is another critical area for climate change adaptation, given that it can shape the location and design of new physical assets. There are two main challenges for spatial planning: ensuring that development is only permitted in lower-risk areas, and that the spatial plans are enforced. Unplanned urbanisation is a common feature of rapidly developing economies, with informal settlements being established in areas that are too risky for formal development, such as river banks and hillsides. As a consequence, the people with the fewest resources for managing climate risks are located in some of the highest risk areas.

Well-planned urbanisation can reduce the disparities in exposure between high-and low-income groups. Where the following conditions hold, the differences in exposure between income groups remain low (Revi et al., 2014):

- buildings meet construction standards;
- development is only permitted in lower-risk areas;
- infrastructure and basic services are provided to all.

Managing the effects of climate change on ecosystems will be an essential element of climate change adaptation pathways. Ecosystems are already under severe pressure as a result of deforestation, water pollution, over-fishing and other causes. The OECD Environmental Outlook to 2050 projected that biodiversity would decline in all world regions under business-as-usual policies. Climate change will place a further burden on ecosystems, as the rate of change exceeds plants and animals' abilities to adapt. There is already evidence of plants and animals having moved to new areas and changed their seasonal activities in response to climate change (Settele et al., 2014). Several policy options can be used to protect ecosystems from the impacts of climate change. The first priority is to strengthen efforts to alleviate the non-climate pressures on ecosystems. A crucial element of this is to mainstream biodiversity – and ecosystems more generally – into national and sectoral planning (OECD, forthcoming). Beyond this, several measures can be taken to lessen the effects of climate change on ecosystems (Settele et al., 2014):

- Adaptive landscape management: Ensure that landscape management strengthens resilience and capacity to adapt to change. Ensure that institutional arrangements, regulations and policies are designed with the expectation that ecosystems will change.
- Supporting biodiversity migration: Create and maintain migration "corridors" to support the process of ecosystem adaptation. In some cases, it may be necessary to move species to a new location.
- Off-site conservation: Preserve diversity through measures such as seed banks and breeding programmes. Several issues need to be resolved to ensure the successful reintroduction of preserved resources into the wild.

Ecosystem-based approaches can play an essential role in building resilience to the effects of climate change. In some cases, they can be cheaper and more flexible than hard infrastructure, and generate benefits beyond adaptation. For example, wetland protection or restoration can reduce flood risk, while also storing carbon and supporting biodiversity. Economic instruments such as Payments for Ecosystem Services should be used to enhance the provision of ecosystem services (OECD, 2010).

Linking adaptation and mitigation

Mitigation supports adaptation by delaying and reducing the scale of climate impacts. At a global level, this reduces the scale of the adaptation challenge. Mitigation also reduces the risk of encountering climate extremes that cannot be adapted to. In principle, credible commitments to a low-emission trajectory would reduce the total need for investments in climate change adaptation (OECD, 2015c). However, in practice this is not so simple (Wilbanks, 2005):

- *Dealing with uncertainty:* Adaptation decisions need to be made today based on expectations about the extent of future climate change. In terms of mitigation efforts, the question is then about expectations as well as outcomes, including the credibility of emissions reduction commitments.
- *Different time horizons:* Within the 2050 planning horizon, the differences are relatively modest between emissions trajectories but will become more severe over time. Implications for adaptation decisions will vary depending on the degree of lock-in.
- *Diverse actors:* Much adaptation is expected to be local and autonomous. Mitigation is focused on the main emitting sectors, while adaptation will take place in those that are most sensitive to the effects of climate change.
- *Distributional issues:* The benefits of adaptation are primarily local and near-term, while the primary benefits of mitigation are long-term and global.

At the level of specific adaptation measures, there are synergies and trade-offs. For example, half of the new coal power plants in China are being built in areas of high water stress (Luo et al., 2013). Replacing coal with wind or solar power would yield both mitigation and adaptation benefits. However, not all good things go together. Between mitigation and adaptation actions there are tensions as well as mutual benefits (Table 2.6). Inappropriate biofuels production, for example, could exacerbate problems with food security.

Table 2.6. **Potential synergies and trade-offs between adaptation and mitigation measures**

	Positive for mitigation	Potential trade-off with mitigation
Positive for adaptation	**Reduced deforestation:** Sequesters carbon and provides ecosystem services.	**Desalination:** Addresses water shortage but is energy-intensive.
	Agricultural practices (e.g. no till): Sequesters carbon and can boost farmers' incomes.	**Increased irrigation:** Helps farmers manage variable precipitation but can be energy-intensive.
	Wetland restoration: Carbon sequestration and reduced flood risk.	**Air conditioning:** Reduces the impact of high temperatures on health, but is energy-intensive.
	Renewable energy (wind, solar PV): Lower water use than thermal generation.	**Construction of hard defences:** Reduces the risk of extreme events, but GHGs are embodied in the construction.
Potential trade-off with adaptation	**Inappropriate expansion of biofuels:** Could exacerbate food price shocks if biofuels displace crops.	
	Hydropower: Could increase the complexity of managing water resources.	

To develop and implement effective climate policy, it is vital to ensure coherence between adaptation and mitigation policies.[31] At the level of individual projects, this means ensuring that the appraisal process takes into account the full range of relevant costs and benefits, including impacts on carbon emissions and on resources relevant for adaptation, such as water. Some projects will inevitably involve trade-offs; it is important that they are acknowledged to ensure that any negative impacts on mitigation or adaptation are justified.

Getting from here to there

Climate change is a global externality because GHG emissions in one country cause damages in other countries that are not currently adequately factored into decisions (Stern, 2007). Economic theory also tells us that a global public good such as a stable climate can only be delivered through effective collective action at the international level: each country is asked to incur costs to reduce emissions, but the benefits of these efforts are shared globally.[32] The costs and benefits of climate action are distributed unevenly across countries and over time, and are to some degree still uncertain. Mitigation costs fall early on, while the major benefits in terms of avoided impacts would be seen later in the century.[33] This provides incentives for countries to free-ride on the actions of others, either now or in terms of the damages that will face future generations.[34] Developed countries have been responsible for most of the cumulative CO_2 emissions so far, but developing countries will make up most future emissions. In the meantime, technological advances have massively reduced the costs of key renewable technologies.

This final section addresses the key question of how countries get to where they need to be. It discusses the NDCs, which are not aligned with a cost-effective path towards the Paris Agreement goal of well below 2°C. Finally, it underlines the fundamental importance of the Paris Agreement in efforts to build the trust and transparency needed to go beyond current levels of mitigation action.

The Nationally Determined Contributions

As part of the process of creating a new international climate agreement under the UNFCCC, each party submitted its proposed national climate action plan, known as its intended "nationally determined contribution" or NDC (Box 2.7). The Paris Agreement requires that parties "prepare, communicate and maintain" their NDCs.[35] In parallel, developed countries reaffirmed their commitment to support developing countries by mobilising USD 100 billion a year by 2020 from public and private sources. Emphasis was also placed on a just transition for workers, through the creation of good quality jobs in line with national development priorities.

The NDCs set out the post-2020 climate actions parties intend to take: for example, decarbonising energy supply through shifts to renewable energy, energy efficiency improvements, better land management, urban planning and low-carbon transport at the city level (see Annex 2.A1 for details of the G20 countries' NDCs). Taken together, the NDCs are a progression beyond current policies but are not enough to keep global warming below 2°C; they are more in line with emissions scenarios that keep the temperature rise to below 3°C in 2100 (UNEP, 2015).[36] Analysis of the NDCs suggests that emissions will continue rising to 2030 (UNFCCC, 2015b). Additionally, the NDCs imply significant variations in future carbon prices across countries, suggesting substantial potential gains to emissions trading.[37] To drive investment in low-emission technologies, the NDCs need to be both credible and backed by good domestic policy design, which includes flexibility to adjust (see Chapter 6) (Nemet et al., 2017).

In adopting a dynamic, hybrid approach – part bottom up, part top down monitoring and review of the adequacy of country efforts against global targets – parties to the UNFCCC have secured broad participation in international mitigation efforts, but at the (hopefully) short-term cost of environmental effectiveness and economic efficiency. The plateau in energy-related CO_2 emissions over the last three years is a positive sign, though it is still too early to claim that we are at a peak of total global emissions, let alone the subsequent rapid reductions required to keep warming "well below 2°C" (IEA, 2017).

Box 2.7. **G20 countries' NDCs vary widely**

The G20 countries' pledges differ in terms of the kind of emissions reduction they specify, the conditions they set, their target dates and the GHGs they cover.

An absolute emissions reduction relative to a base year. The G20 European Union countries (France, Germany, Italy and the United Kingdom) have opted for 1990 as the base year, along with the Russian Federation. This reflects the type of target and base year agreed under the Kyoto Protocol. Australia, Brazil, Canada and the United States have identified their target relative to their GHG emission levels in 2005.

A reduction in the emissions intensity of the economy relative to a base year. India, for instance, has pledged a 33-35% reduction of the emission intensity of its GDP while China aims for a 60-65% reduction. Both countries use 2005 emissions intensity of the economy as their baseline.

Emissions reduction relative to a business-as-usual scenario (without further climate policies): This is the case for the NDCs of Indonesia, Korea, Mexico, Saudi Arabia, and Turkey.

A specified emissions trajectory: South Africa has pledged a "peak, plateau and decline" of emissions, describing a path over the next 20 years. Argentina has placed an absolute cap on its 2030 emissions.

Conditionality: Several countries have set conditions for the achievement of some – or all – of their targets. These include the provision of financial, technical or capacity-building support from developed countries (e.g. for Argentina, India, Indonesia, Mexico, Saudi Arabia), the degree of the implementation of the Paris Agreement by developed countries (for South Africa). Argentina, Indonesia and Mexico have both unconditional and conditional targets, the latter requiring support from developed countries.

Target date: Most G20 countries have set 2030 as their target date. The United States and Brazil chose 2025; South Africa has target periods of 5 years going from 2020 to post-2035.

Coverage: Most G20 pledges cover the six Kyoto Protocol GHGs[38] as well as the economic sectors outlined by the IPCC.[39] Australia, Canada, the European Union, Japan, the Russian Federation, Turkey and the United States have also included nitrogen trifluoride (NF_3), added on the list of GHGs under Kyoto Phase II, in the target gases. Mexico also focuses on black carbon, while Indonesia includes only CO_2, CH_4 and N_2O.

Building on the Paris Agreement

Early efforts to forge an effective international response to climate change resulted in the 1992 UN Framework Convention on Climate Change (UNFCCC), the start of an open-ended negotiating process that led to the Paris Agreement in December 2015. The Paris Agreement aims to strengthen the international response to climate change by building on the bottom-up approach initiated at the Copenhagen COP15 meeting in 2009.[40] It also adds "an enhanced transparency framework", to help track progress of individual parties on mitigation and adaptation action as well as on support for developing countries (finance, technology and capacity-building). This framework is vital, given the evidence that trust and reciprocity are important for successful management of natural resources (Ostrom, 1990).[41] The framework will support several processes and milestones for collective stocktaking and oversight of progress made on long-term goals.[42]

An immediate priority within the UNFCCC process is to put the Paris Agreement into operation by reaching agreement on the rules and modalities for several key provisions, including those on monitoring, reporting, verification and assessing collective progress according to the timeline established at COP21.[43] Headway here is essential to build the trust needed to increase the stringency of action over time. This is the current focus of the OECD-IEA Climate Change Experts Group.

The Paris Agreement architecture has yet to demonstrate that it can catalyse the urgent and stringent mitigation action and support needed to meet the Agreement's goals. Parties must now implement their emissions limitation and reduction pledges to 2020 and their aims beyond 2020. The aggregate mitigation effect of the NDCs is inadequate, however, and countries need to scale up their efforts. Developed country support for climate action will be important, not just for mitigation but also to improve the resilience and adaptive capacity of countries facing the greatest climate challenges.

At COP21, parties were invited to communicate by 2020 the long-term low-emission development strategies they will follow up to 2050. Six countries have done so; it is crucial that more follow suit. This is an important mechanism for helping countries to align short-term actions with long-term goals and to minimise the risks of either emissions lock-in or stranded assets. One important initiative to support this and to build broader engagement and action is the 2050 Pathways Platform launched at COP22 in Marrakech, Morocco (Box 2.8).

Success will not solely depend on action at central government level. The UNFCCC process has over recent years deliberately and increasingly created mechanisms of engagement with and commitments from non-state actors, most notably under the Lima-Paris Action Agenda in the run-up to COP21, on issues as diverse as cities, private finance and forests.

Box 2.8. **The 2050 Pathways Platform**

The 2050 Pathways Platform was launched at the High-Level Event of COP22 in Marrakech. Membership is growing quickly: 22 countries, 15 cities, 17 regions and states, and 192 companies have already joined.

Short-term GHG emissions reduction targets and actions such as the NDCs need to be set and implemented consistently with the long-term global goal. Developing pathways from now until 2050 can help in envisaging the structural changes necessary to achieve net-zero GHG emissions, as opposed to incremental changes. The platform helps countries design and implement long-term deep decarbonisation strategies that will limit the average global temperature increase to well below 2°C. It does so by sharing resources (including finance and capacity building), experience and best practices. It also builds a broader constellation of cities, states, companies and investors engaged in long-term low-emission planning of their own, and in support of the national strategies. It is envisaged as a space for collective problem-solving.

Pathways to 2050 need to be socio-economic development pathways, not just GHG emission reduction pathways; adaptation is an important component. Developing 2050 pathways can help to capture the synergies between socio-economic development and climate change mitigation, for example by aligning climate action with objectives on health, innovation and food security. They are also a risk-management tool: they can avoid carbon lock-in, and therefore reduce the risk of stranded assets, by putting short-term climate actions in the context of the long-term climate transition.

Pathways to 2050 need to be co-designed – and ultimately owned – by all relevant stakeholders: not just politicians and policy-makers, but also businesses, unions, NGOs and others. They also need to be informed by the best expert knowledge and evidence. The Platform aims to leverage a range of international processes to provide: technical analysis and support; sharing lessons learned and best practices; and multi-stakeholder/cross-jurisdictional dialogues.

Source: 2050 Pathways Platform team.

Notes

1. High levels of CO_2, associated with enhanced warming, also lead to increased acidification of the ocean and impacts on corals and a wide range of marine ecosystems.
2. Yet 13 percent of the world's population lived below the international poverty line of US$1.90 per day in 2012, see World Bank (2016).
3. CO_2 contributed about 76% of global warming in 2010 (IPCC, 2013).
4. Taken here as the 1850-1900 average.
5. Scientists have more confidence in their understanding and projections of global surface temperature than of precipitation, since the latter depend on the dynamics of the atmosphere, not just on energy-balance considerations. There is also have greater confidence in projections of global or continental scale changes than at regional or local scale. Global Climate Models (GCMs) are the basis of much of the information on future climate changes presented in the IPCC's assessment reports. See Taylor, Stouffer and Meehl (2012) on the Coupled Model Intercomparison Project Phase 5 (CMIP5), which was used in IPCC AR5 (2013). Such exercises help to determine the strengths and weaknesses of the various GCMs and inform their future development.
6. The Representative Concentration Pathways (RCPs) used in the most recent IPCC AR5 report span a wide range of possible future emissions scenarios. They are used to illustrate a range of possible climate futures to 2100 (Moss et al., 2010) by specifying different concentrations of GHGs and other atmospheric constituents (such as aerosols). These scenarios are named RCP2.6, RCP4.5, RCP6.0 and RCP8.5 to reflect their impact on the net energy flows into the climate system. So RCP2.6 (4.5) would give rise to a net energy inflow to the climate system of 2.6 (4.5) Watts per square metre (Wm^2) by 2100 in the Integrated Assessment Model (IAM) used to derive them. These RCPs have been used as input to models that produce detailed simulations of the climate system.
7. In their Fifth Assessment Report, the IPCC analysed over 1 000 published emissions scenarios from integrated assessment models (IPCC, 2014a). Based on a subset of these selected for their detailed information on emissions and consistency with both historical emissions and assumptions about a feasible maximum level of negative emissions, the UK Meteorological Office Hadley Centre (MOHC) identified 39 scenarios that had a greater than 66% probability of not leading to warming above 2°C. These are shown in Figure 2.4 alongside scenarios that lead to median end of century warming of 1.75-2.0°C.
8. Estimates of the equilibrium climate sensitivity, which determines the long-run climate response to GHGs, range between 1.5°C and 4.5°C for a doubling of atmospheric CO_2 concentrations.
9. The net effect of negative emissions technologies on atmospheric concentrations is reduced by the response of the ocean and land stores of CO_2 to a reduction in atmospheric CO_2 concentration. See Mackey et al. (2013).
10. The climate effects of different GHGs relative to CO_2 are typically evaluated using the 100 year global warming potential (GWP_{100}), which also has been adopted in GHG trading schemes. However, this metric is not related to temperature outcomes, nor does it clearly highlight the need to limit cumulative CO_2 emissions (Smith et al., 2012). Indeed, there is no single metric that can equate the full climate effects of different GHGs as the appropriate metric will depend on the policy outcome sought (Shine, 2009).
11. To gain the same climatic benefit as a one-off reduction in the level of CO_2 emissions, the rate of methane emissions would need to be reduced on a permanent basis. Much of the difficulty in reducing CH_4 emissions lies in the agricultural sector and, in particular, with growing livestock numbers (Ripple et al., 2014).
12. About 70% of global N_2O emissions are due to agriculture (World Bank, 2009).
13. From the SSP Public Database Version 1.1. – see https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about
14. The climate policy assumptions for SSP2 – the SSP scenario that most closely resembles historic economic and demographic trends - include some delay in establishing global action with regions transitioning to global co-operation between 2020 and 2040, making emissions in the SSP2 baseline scenario broadly consistent with the NDCs (O'Neill et al., 2015; Riahi et al., 2017).
15. The industrial process emissions are estimated from the overall carbon budget (90 $GtCO_2$ over 2015-2100) with a starting point of 2 $GtCO_2$/yr and falling to around 1 $GtCO_2$/yr by 2050, as described on p.48 of IEA (2017).
16. Modelling approaches to land-use are highly varied – see Alexander et al. (2017).
17. In Brazil, concerted public action has led to reduced deforestation over the past few years.

18. The income groups are the standard World Bank groups, notably High-Income (HIC), Upper Middle-Income (UMIC) and Lower Middle-Income (LMIC) countries. There are no low-income countries (LIC) in the G20.
19. By including LULUCF emissions in the total, emissions increase (decrease) if land-use is a net source (sink).
20. In Japan, Korea, Russia, Turkey and the United States.
21. Canada, India and Mexico.
22. Analysis of the IPCC AR5 integrated assessment scenarios, consistent with outcomes with a greater than 66% likelihood of keeping warming below 2°C, result in total GHGs emissions in 2050 between 41%- to 72% lower than in 2010 (IPCC, 2014a), which in average annual terms requires emissions reductions between of 1.3%- to 3.1% per year. If world GDP is assumed to grow at around 3% per year, this would require the sum of the total annual reductions in the emissions intensity of GDP of some 4.3% to 6.1%.
23. The IEA's average figure for the G20 is based on more disaggregated modelling, not shown in the figure.
24. For example the use of advanced technology in some countries while other countries with a similar level of energy intensity might have developed in such a way because of constraints on energy availability.
25. Using more of the indicators discussed in this chapter would provide an alternative grouping based on cluster analysis. However there would be only minor differences, in part reflecting the importance of AFOLU emissions. To match the economic analysis in Chapter 4, which does not consider AFOLU sectors, we present the results based on this more limited number of characteristics.
26. See the Executive Summary of the 2015 DDPP report at http://deepdecarbonization.org/wp-content/uploads/2015/12/DDPP_EXESUM-1.pdf .
27. The G20 countries where no results are available are: Argentine, Russia, Saudi Arabia and Turkey.
28. See for e.g. Anandarajah and Gambhir (2014), Capros et al. (2014), Gambhir et al (2013), Pye et al. (2017), and Winkler and Marquand (2009).
29. Due to their high wealth and low protection level, three American cities (Miami, New York City and New Orleans) concentrated 31% of the losses in 2005 across the 136 cities studied. Adding Guangzhou, the four top cities accounted for 43% of global losses in that same year (Hallegatte et al., 2013).
30. A number of G20 countries have invested significantly in providing access to relevant data sources, through initiatives such as the UK's Climate Impact Programme and the climate section of the United States' US Data.Gov website. The private sector is increasingly engaged in this area, through the provision of consultancy services and provision of expertise by insurance companies.
31. Interactions between mitigation and adaptation will be explored in the 2018 IPCC special report on the impacts of global warming of 1.5°C degrees (IPCC, 2016).
32. The need for international environmental agreements to be "self-enforcing" in the face of limited sanctions had the dismaying implication that participation would be inefficiently low from a global perspective precisely when such co-operation would be of greatest environmental benefit (Barrett, 1994). Concerns about "carbon leakage" by through the off-shoring of emissions-intensive industry are a further constraint on stringent mitigation action, though at current levels of carbon prices there is little evidence that carbon leakage is a major problem, except perhaps in a few fossil-intensive industries. See for example, Branger, Quirion and Chevallier (2013) and Martin et al. (2014).
33. Leading to important debates about the right discount rate to use to estimate the social cost of carbon, see Pindyck (2013) for a discussion of this and related issues.
34. See Crampton et al., 2017.
35. NDCs representing 190 parties had been submitted as of 17 January 2017.
36. Of course, whether the NDCs are consistent with a goal of well below 2°C also depends on what happens to emissions beyond the 2025-30 period for which the NDCs are applicable. A comparison of countries' pledges with emission scenarios available in the IPCC AR5 database shows that more than three quarters of the scenarios that follow a similar emission profile to that consistent with existing NDCs to 2030 give median warming values of more than 2°C in 2100 (i.e. 50% chance of warming less than 2°C), with the vast majority giving a level of median warming between 2° and 3°C.

37. Aldy and Pizer (2016) use four integrated assessment models to assess and compare the NDCs. They estimate that countries' marginal abatement costs vary by two orders of magnitude. Marginal costs rise almost proportionally with income, while total mitigation costs also reflect carbon intensity and trade in fossil fuels. See also Bataille et al. (2016) and Rogelj et al. (2016a).
38. CO_2, CH_4, N_2O, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride.
39. See Arent and Tol (2014).
40. Concerns about "top-down" approaches crystallised at the Copenhagen UNFCCC Conference of the Parties (COP15) in 2009. Outcomes at COP16 in Cancún built on the Copenhagen Accord both in terms of a new transparency regime and a formalisation of some international pledges (e.g. on climate finance). More than 90 countries, including all major emitters, put forward pledges that took a variety of forms, mostly covering the period to 2020.
41. Ostrom (1990) highlighted the significant empirical evidence of the potential for self-organising institutions successfully to manage natural resources where there is sufficient trust and reciprocity between those involved. The likelihood of co-operation was also found to increase with factors such as: (i) reliable information about short- and long-term costs and benefits; (ii) a recognition of the importance of the resource to their own achievements and a long-term view; (iii) communication between those involved; (iv) informal monitoring and sanctioning is both feasible and considered appropriate; and (v) the existence of social capital and leadership.
42. The main milestones are the Facilitative Dialogue in 2018 and the Global Stocktakes, which will take place every five years from 2023 assess collective progress towards long term goals, including mitigation and adaptation efforts and means of implementation, and will inform Parties' future actions.
43. Countries agreed in Marrakesh at the 22nd Conference of the Parties (COP22) that this "Paris rulebook" will be finalised by the end of 2018 (COP24).

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Annex 2.A1. Summary of G20 countries' (I)NDCs

Summary of G20 countries' (I)NDCs

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
ARGENTINA	Emission ceiling	n/a	By 2030	Unconditional	To not exceed 483 MtCO_2eq	Economy-wide, including energy, industrial processes, agriculture (including cattle rearing), LULUCF, waste	CO_2, CH_4, N_2O, HFC, PFC, SF6	Action on sustainable forestry, energy efficiency, biofuels, nuclear power, renewable energy and transport modal shift	1. Early warning mechanisms and systems for response and recovery from climate disasters 2. Sustainable management of native forests 3. Water resource management 4. Crop management 5. Management of the health impacts of climate change 6. Implementation of measures to face extreme events 7. Ecosystem-based biodiversity conservation and adaptation
	Emission ceiling			Conditional on financial, technical and capacity-building support from abroad	To not exceed 369 MtCO_2eq				
AUSTRALIA	Absolute reduction from base year emissions	2005	By 2030	Unconditional	Reduction of 26-28%	Economy-wide, including energy, industrial processes and product use, agriculture, LULUCF, waste	CO_2, CH_4, N_2O, HFC, PFC, SF6, NF_3	1. Emissions Reduction Fund – provides incentives for emissions reduction activities across the economy. 2. Safeguard Mechanism – sets emissions limits for facilities emitting >100 000 tonnes per year. 3. Renewable Energy Target of 23% of electricity supply to come from renewable sources by 2020. 4. National Energy Productivity Plan to achieve a 40% improvement in energy productivity by 2030. 5. Grants for research, development, demonstration and deployment of clean energy technologies.	1. Work to build climate resilience and support adaptation to climate change. 2. Develop a National Climate Resilience and Adaptation Strategy.
BRAZIL	Absolute reduction from base year emissions	2005	By 2025	Unconditional	Reduction of 37%	Economy-wide, including emissions from forest managed areas (conservation units and indigenous lands)	Not specified	Not specified	Outlined in the National Adaptation Plan, which focuses on risk areas, housing, basic infrastructure (especially in the areas of health, sanitation and transportation).
	Absolute reduction from base year emissions	2005	By 2030	n/a	Reduction of 43% (indicative value, for reference only)				
CANADA	Absolute reduction from base year emissions	2005	By 2030	Unconditional	Reduction of 30%	Economy-wide (although excludes emissions from natural disturbances)	CO_2, CH_4, N_2O, HFC, PFC, SF6, NF_3	Regulation measures in the transport and energy sectors and with regards to renewable fuels	Not specified
CHINA	Peaking of emissions	n/a	By 2030	Not specified	n/a	Economy-wide	Not specified	ii) Increase the share of non-fossil fuels in primary energy consumption to approx. 20%. iii) Increase forest stock volume by 4.5 cubic meters compared with 2005 levels.	i) Enhance mechanisms and capacities for climate vulnerable sectors. ii) Strengthen early warning and emergency response systems.
	Emission intensity of GDP	2005	By 2030	Not specified	Reduction of 60-65%				

Summary of G20 countries' (I)NDCs *(cont.)*

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
EUROPEAN UNION	Absolute reduction from base year emissions	1990	By 2030	Not specified	Reduction of 40%	Economy-wide, including energy, industrial processes and product use, agriculture, waste, LULUCF	CO_2, CH_4, N_2O, HFC, PFC, SF6, NF_3	Not specified	Not specified
INDIA	Emission intensity of GDP	2005	By 2030	Dependent on financial, technical and capacity-building support from developed countries	Reduction of 33-35%	Economy-wide	Not specified	*i)* Achieve 40% cumulative electric power installed capacity from non-fossil fuel based energy sources by 2030. *ii)* Create an additional carbon sink of 2.53 billion tCO_2eq through afforestation by 2030. *iii)* Introduce cleaner, more efficient technologies in thermal power generation. *iv)* Promotion renewables and increase the share of alternative fuels in the country's fuel mix. *v)* Reduce emissions from the transport and waste sectors. *vi)* Promote energy efficiency. *vii)* Fully implement India's afforestation programmes.	*i)* Enhance investment in development programs in vulnerable sectors. *ii)* Develop climate-resilient infrastructure. *iii)* Enhance climate-resilience more generally.
INDONESIA	Emission reduction relative to BAU baseline	BAU scenario of 2.869 $GtCO_2$-eq in 2030	By 2030	Unconditional	Reduction of 29%	Energy (including transport), industrial processes and product use, agriculture, LULUCF, waste	CO_2, CH_4, N_2O	LULUCF: Reducing deforestation and forest degradation, restoring ecosystem functions, sustainable forest management. Energy: 23% of energy coming from new and renewable energy by 2025 Waste: Enhance management capacity of urban wastewater, reduce landfill waste, using waste for energy production	Outlined in the National Action Plan on Climate Change Adaptation. Includes local capacity strengthening, improved knowledge management, identifying synergies between the adaptation and disaster risk reduction agendas, application of adaptive technologies.
	Emission reduction relative to BAU baseline			Dependent on financial, technical and capacity-building support from developed countries	Reduction of 41%				
JAPAN	Absolute reduction from base year emissions	FY 2013	By FY 2030	Not specified	Reduction of 26%	Economy-wide: Energy (incl. CO_2 from transport), industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	INDC includes a 2030 target for *i)* final energy consumption: 326 M kl, *ii)* Japan's energy mix: 22-24% renewable energy (dominated by solar and hydropower), 2220% nuclear, 26% coal, 27% LNG, 3% oil. A detailed list of the policy measures considered for each sector is included as an annex to the NDC.	Not specified

Summary of G20 countries' (I)NDCs *(cont.)*

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
KOREA	Emission reduction relative to BAU baseline	BAU of 850.6 $MtCO_2$-eq in 2030	By 2030	Not specified	Reduction of 37%	Economy-wide, excluding LULUCF (energy, industrial processes and product use, agriculture and waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6	Use of carbon credits to achieve 2030 mitigation target. Other mitigation measures used include i) an emissions trading scheme for the industrial sector (launched in 2015), ii) renewable energy regulations for the power sector, iii) a Green Building Standards Code and a system for the Performance Evaluation of Eco-friendly Homes for the buildings sector, iv) low-carbon standards for fuel efficiency and tax incentives to purchase electric vehicles in the transport sector.	Outlined in the National Climate Change Adaptation Plan (2010). *i)* strengthening infrastructure for climate change monitoring, forecasting and analysis; *ii)* developing a management system for disaster prevention and stable water supply; *iii)* developing a climate-resilient ecosystem; *iv)* making a systemic transition to a climate-resilient social and economic structure; and *v)* enhancing the system for the management of negative impacts of climate change on health.
MEXICO	Emission reduction relative to BAU baseline	BAU scenario projecting economic growth in the absence of climate policies	By 2030	Unconditional	Reduction of 25%	Nation-wide (Energy, Industrial processes and product use, agriculture, waste, LULUCF)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6, Black carbon	Mexico's mitigation commitment includes an unconditional reduction of GHG emissions of 22% by 2030. The target increases to 25% when Black Carbon is included.	*i)* Strengthen the adaptive capacity of at least 50% the most vulnerable municipalities. *ii)* Establish early warning systems and risk management at every level of government. *iii)* Reach a rate of 0% deforestation by the year 2030.
	Emission reduction relative to BAU baseline		By 2030	Conditional on financial, technical and capacity-building support from abroad, and international agreement on carbon price, carbon border adjustments.	Reduction of 40%				
RUSSIAN FEDERATION	Absolute reduction from base year emissions	1990	By 2030	Conditional on the maximum absorbing capacity of forests	Reduction of 25-30%	Economy-wide (Energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	Not specified	Not specified
SAUDI ARABIA	Emission reduction relative to BAU baseline	BAU scenario projecting economic growth in the absence of climate policies	By 2030	Conditional on the provision of technical assistance and capacity-building	Avoid 130 $MtCO_2eq$	Not specified	Not specified	*i)* Improve energy efficiency via the expansion of the Saudi Energy Efficiency Program, which currently only focuses on industry, buildings and transport sectors. *ii)* Develop renewable energy and natural gas exploitation to diversify the energy mix. *iii)* Develop CCUS via plans to construct a CCU plant able to capture 1 500 tCO_2 per day. *iv)* Recover methane and minimise flaring.	Focus on: *i)* water and wastewater management, *ii)* urban planning, *ii)* marine protection, *iv)* reducing desertification, *v)* developing integrated coastal zone management planning, *vi)* further developing early warning systems, and *vii)* develop integrated water management planning.

Summary of G20 countries' (I)NDCs *(cont.)*

G20 ECONOMY	TYPE	BASE YEAR	TARGET DATE	CONDITIONALITY	GHG EMISSIONS MITIGATION TARGET	SECTORS COVERED	GASES COVERED	MITIGATION MEASURES	ADAPTATION MEASURES
SOUTH AFRICA	Emissions peak, plateau and decline (starting 2020 year-end)	Peak, plateau, decline	Peak: 2020-2025, Plateau 2025-2035, Decline as of 2035	Conditional on the degree of implementation of the Convention by developed countries	Peak: 398-614 $MtCO_2$-eq	Economy-wide (Energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 (with a particular focus on CO_2, CH_4, N_2O)	Carbon tax, desired emission reduction outcomes for sectors, company-level carbon budgets, regulatory standards and controls.	*i)* Develop a National Adaptation Plan *ii)* Take climate considerations into account in development policy frameworks. *iii)* Build institutional capacity for climate change response planning and implementation *iv)* Develop early warning systems for climate vulnerable sectors *v)* Develop vulnerability assessment and adaptation needs framework *vi)* Communicate on adaptation efforts
TURKEY	Emission reduction relative to BAU baseline	BAU scenario projecting economic growth in the absence of climate policies	By 2030	Not specified, although NDC mentions that the country will receive financial, technological, and capacity-building support from abroad.	Reduction of up to 21%	Economy-wide (Energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	Use of carbon credits from international market mechanisms. An exhaustive list of the measures planned by sector is listed in the INDC.	Not specified
UNITED STATES	Absolute reduction from base year emissions	2005	By 2025	Not specified	Reduction of 26-28%	Economy-wide (energy, industrial processes and product use, agriculture, LULUCF, waste)	CO_2, CH_4, N_2O, HFCs, PFCs, SF6 and NF_3	Does not intend to use international market mechanisms to reach 2025 target. Regulatory measures mitigate emissions include: *i)* fuel economy standards for light-duty and heavy-duty vehicles; *ii)* energy conservation standards for building appliances/equipment as well as building codes for building envelopes; *iii)* regulation to cut emissions from existing power plants; *iv)* methane-specific standards for landfills and the oil and gas sector *v)* the Significant New Alternatives Policy program (targets HFCs).	Not specified

Source: UNFCCC, n.d.

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