

SCIENTIFIC ADVISORY PANEL BRIEFING

KEY MESSAGES FROM THE IPCC 1.5°C SPECIAL REPORT

The IPCC 1.5°C Special Report includes several key messages linking climate change mitigation and clean air, including the role of non-CO₂ emissions such as short-lived climate pollutants (SLCPs) like methane, black carbon, and hydrofluorocarbons.

The report connects mitigation policies and sustainable development, and the need for an integrated approach.

These include:

1. **The path we take to reach the 1.5°C target is crucial** for both climate and other development impacts. Only scenarios with low- or no-temperature overshoot beyond the 1.5°C guardrail are consistent with achieving global Sustainable Development Goals (SDGs).
2. **Current mitigation ambition is insufficient** to put the world on a safe path and no scenarios reviewed for the Special Report were able to achieve a 1.5°C pathway if additional mitigation ambition is delayed to 2030.

We must change course on emissions in the next decade. And this means:

3. **We must address all climate forcing emissions, including SLCPs.** The Special Report emphasizes the need for specific measures, such as those targeted by the CCAC, to significantly reduce SLCP sources that won't be reduced by the broader transformation and decarbonization of the energy sector.
4. **Climate change, air pollution, and sustainable development are linked.** An integrated multiple-benefits approach enables ambitious action by maximizing multiple-benefits and avoiding negative trade-offs.
5. **Focus on solutions that deliver multiple-benefits** for air pollution and other development goals, which will enable countries to make ambitious commitments and take faster action.

SAP main message to the CCAC

As the only global coalition dedicated to delivering fast action solutions that produce multiple-benefits for both climate and clean air, the CCAC is well positioned to help countries deliver on many of the key recommendations of the IPCC 1.5°C Special Report.

The Coalition, through its 'Multiple-Benefits Pathway Framework' and its 'Supporting National Action and Planning on SLCPs (SNAP)' initiative – offers tools and methodologies to help countries develop more ambitious Nationally Determined Contributions (NDCs) by quantifying how these will improve local air quality and meet many of their sustainable development goals.

SAP recommendations to the CCAC

The Coalition could use the additional encouragement from the 1.5°C report to work with more countries and partners to enhance capacity in the air pollution, sustainable development, and climate mitigation and adaptation communities.

The Coalition could promote the broader use of integrated multiple-benefits assessment tools in a way that enables countries to identify and select solutions where fast action can be taken, and which will deliver multiple benefits that further support increased political ambition to reduce the rate of warming.

The Coalition could direct the SAP to continue to identify, examine, and apply metrics and methodologies for quantifying the multiple-benefits of action, building on the 2017 SAP workshop on *Metrics and Inventory Development* in Ottawa, Canada. This could include metrics for vector borne diseases, health impacts of heat stress, crop impacts of heat and water stress, distributional impacts, and economic costs and benefits.

DETAILED BRIEFING

1. The path we take to reach the 1.5°C target is crucial

The 2015 Paris Agreement established an ambitious temperature target of 1.5°C, but did so in the context of broader international goals of sustainable development and poverty eradication.¹ The IPCC 1.5°C Special Report therefore recognizes that there are many paths the world can take to achieve our global temperature goals,² but only those that maintain global temperatures below 1.5°C throughout the century, or limit temperature overshoot, are consistent with maximising broader sustainable development objectives (see Figure 1).^{3,4}

Following a path which allow temperatures to overshoot 1.5°C, even if they eventually return within this century, will result in potentially significant and irreversible impacts for society, infrastructure and the climate. These include negative changes in agricultural production, marine and terrestrial ecosystems, increases in some forms of extreme weather events, an increased rate of sea-level rise and higher cumulative sea-levels, and an increased risk of passing thresholds for irreversible climate impacts.^{5,6} Furthermore, limited overshoot pathways “rely on large-scale deployment of Carbon Dioxide Removal (CDR) measures, which are uncertain and entail clear risks.”⁷

The Special Report notes that even a 1.5°C pathway will not eliminate the negative impacts of climate change, but limiting warming to 1.5°C instead of 2°C or higher “would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities.”⁸ Following a 1.5°C path instead of a 2°C path could:

- Avoid ~0.1m of global sea-level rise by 2100, resulting in up to 10 million fewer people being exposed to related risks such as saltwater intrusion, flooding, and damage to infrastructure.^{9,10}
- Prevent the melt of an estimated permafrost area of 2 million km² and substantially reduce the probability of an ice-free Arctic.^{11,12}
- Avoid 110 to 190 million premature deaths over the century from reduced air pollution^{13,14}, and many other health consequences from increased warming.
- Avoid a one-third decline in per capita crop production projected for Southeast Asia by 2040.¹⁵

FAQ2.1: Conceptual pathways that limit global warming to 1.5°C

Two main pathways illustrate different interpretations for limiting global warming to 1.5°C. The consequences will be different depending on the pathway

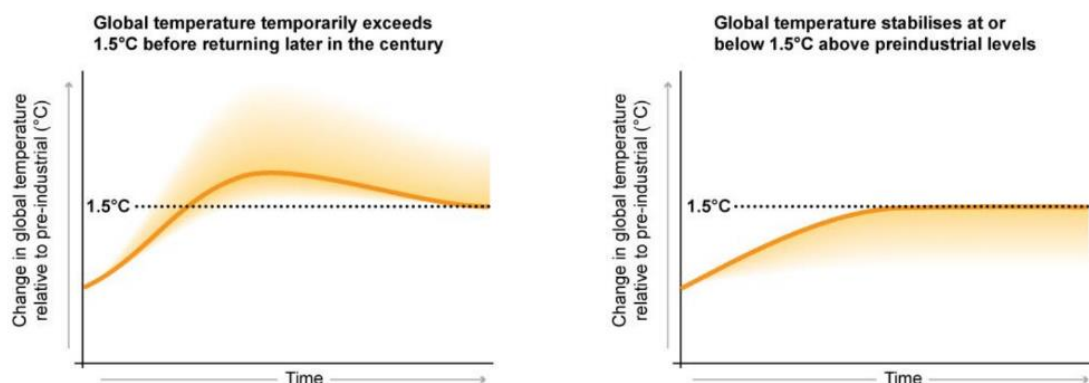


Figure 1: Two main pathways for limiting global temperature rise to 1.5°C above pre-industrial levels are discussed in this Special Report. These are: stabilising global temperature at, or just below, 1.5 °C (right) and global temperature temporarily exceeding 1.5 °C before coming back down later in the century (left). (Source: IPCC SR1.5°C, 2018)

2. Current mitigation ambition is insufficient to put the world on a safe path

In 2017, human-induced warming reached 1°C above pre-industrial temperatures.¹⁶ However, more than a fifth of the global population already lives in regions that experience warming greater than 1.5°C in at least one season of the year.¹⁷ If the current rate of annual warming of 0.2°C per decade continues, global average temperature will reach 1.5°C by 2040 (see Figure 2).¹⁸ Pledges contained within current NDCs are insufficient to put the world on a course to 1.5°C, even with the maximum rates of change post-2030 available in the models.¹⁹

It is worth noting that global temperatures could pass the 1.5°C guardrail substantially sooner if emissions do not decrease. For example, the 1.5°C guardrail could be crossed as early as 2030 if emissions follow the high emissions RCP8.5 scenario from the IPCC's 5th Assessment Report.²⁰ Following such a scenario, even for a short period, would make achieving a 1.5°C pathway virtually impossible.

FAQ1.2: How close are we to 1.5°C?

Human-induced warming reached approximately 1°C above pre-industrial levels in 2017

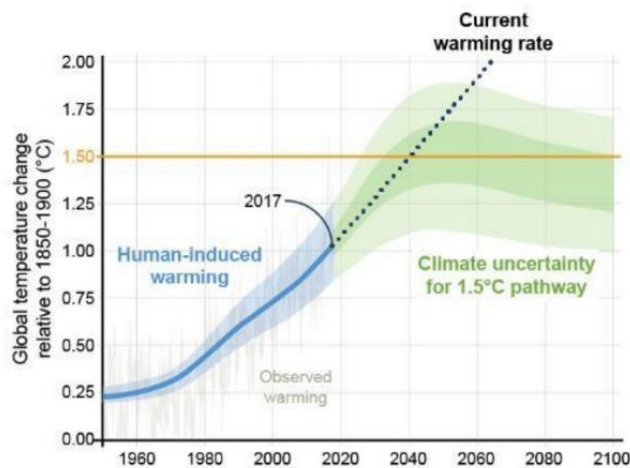


Figure 2: Human-induced warming reached approximately 1°C above pre-industrial levels in 2017. At the present rate, global temperatures would reach 1.5°C around 2040. (Source: IPCC SR1.5°C, 2018)

3. Addressing all relevant emissions, including short-lived climate pollutants is necessary

The Special Report concludes that reaching a sustainable mitigation pathway to 1.5°C can only be achieved with deep and simultaneous reductions of CO₂ and all non-CO₂ climate forcing emissions, including short-lived climate pollutants like methane, hydrofluorocarbons and black carbon (see Figure 3).

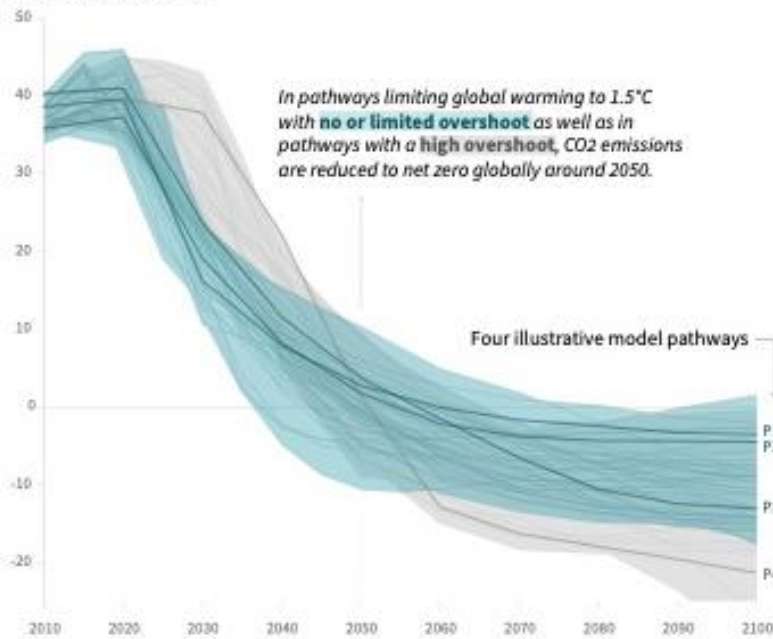
While rapid mitigation of CO₂ emissions is critical for controlling long-term warming, fast action to address emissions of short-lived climate pollutants contribute significantly to limiting warming in the near-term.²¹ Rapidly reducing short-lived climate pollutants is critical for slowing the rate of warming over the next few decades and will help limit near-term climate and ecosystem impacts and, increase the ability of communities and ecosystems to adapt.²²

Global emissions pathway characteristics

General characteristics of the evolution of anthropogenic net emissions of CO₂, and total emissions of methane, black carbon, and nitrous oxide in model pathways that limit global warming to 1.5°C with no or limited overshoot. Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals. Reductions in net emissions can be achieved through different portfolios of mitigation measures illustrated in Figure SPM.3b.

Global total net CO₂ emissions

Billion tonnes of CO₂/yr



Timing of net zero CO₂

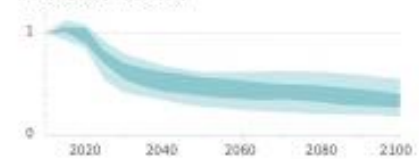
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios



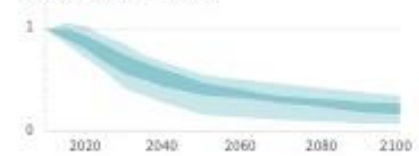
Non-CO₂ emissions relative to 2010

Emissions of non-CO₂ forcers are also reduced or limited in pathways limiting global warming to 1.5°C with no or limited overshoot, but they do not reach zero globally.

Methane emissions



Black carbon emissions



Nitrous oxide emissions

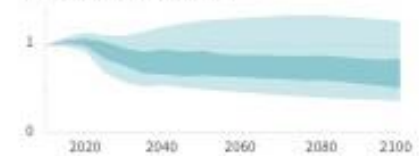


Figure 3. Global emissions pathway characteristics. The main panel shows global net anthropogenic CO₂ emissions in pathways limiting global warming to 1.5°C with no or limited (less than 0.1°C) overshoot and pathways with higher overshoot. The shaded area shows the full range for pathways analyzed in this report. The panels on the right show non-CO₂ emissions ranges for three compounds with large historical forcing and a substantial portion of emissions coming from sources distinct from those central to CO₂ mitigation. Shaded areas in these panels show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. (Source: IPCC SR1.5°C, 2018)

Box 1 - Dedicated SLCP Measures Can Deliver Near-term Mitigation

Global deployment of dedicated SLCP measures can support and potentially exceed the near-term methane, black carbon, and HFC mitigation called for in the SR1.5°C scenarios.

Methane: The scenarios used in the SR1.5°C report include a 37% (21-65%) reduction in methane emissions by 2030 compared to 2010. A recent analysis by the SAP indicates that dedicated methane measures could achieve most or all of the reductions that occur within the 1.5°C scenarios (CCAC Annual Science Update, 2018).

The majority of this abatement can be achieved with interventions in oil, gas, and waste sectors. Emissions from oil and gas production could be reduced by nearly 70%, gas distribution systems by 95%, coal mines and long-distance natural gas distribution by more than 50%. These reductions would have the added benefits of capturing the wasted energy sources. In the waste sector, emissions from industrial and municipal waste could be reduced by more than 80%.

Aggressive methane mitigation could achieve even larger reductions than those identified in the 1.5°C scenarios. The 1.5°C pathways assume significant continuing methane emissions because the models used have very conservative estimates of the capacity to reduce methane emissions from the agricultural sector. Recent studies indicate that agricultural methane emissions can be significantly reduced with existing measures. Indeed, bottom up studies find substantially greater methane mitigation potential in the agricultural sector (*UNEP Emission Gap Report, 2017 see Fig 4.2*). This would provide a significant additional near-term mitigation benefit, with additional benefits for agriculture and health.

Black Carbon: The scenarios used in the SR1.5°C report include a 35% (10-66%) reduction in emissions by 2030 compared to 2010. Recent analysis by the SAP indicates that dedicated black carbon measures could reduce anthropogenic black carbon emissions in 2030 by more than 60%, with some studies indicating an 80% reduction is possible by 2030 (*Stohl et al., 2015; Klimont et al., 2017*).

Significant reductions are achievable from all major black carbon emitting sources. Industrial sector emissions could be reduced by more than 75% by deploying measures such as improved brick kilns and coke ovens. Emissions from households could be reduced by 60% by improving traditional biomass cooking and heating stoves, converting to LPG, and eliminating the use of coal stoves and kerosene wick lamps. Transport sector emissions could be reduced by 50% by eliminating high-emitting diesel vehicles and applying EURO-VI diesel vehicle emissions standards. Emissions from burning of municipal solid waste and agricultural residue could be eliminated entirely.

HFCs: The scenarios used in the SR1.5°C report include a 70-80% reduction in emissions by 2050 compared to 2010. Recent analysis shows that HFC emissions could be reduced by more than 90% by applying currently commercially available and already tested and implemented alternative refrigerants (*Höglund-Isaksson et al., 2017*). Significant additional mitigations and development benefits could be captured by simultaneously increasing the energy efficiency of the cooling and refrigeration technologies.

Providing clean, efficient cooling for all is one of the 21st century's biggest multiple-benefits opportunities because it can "low[er] near-term GHG emissions, increase sustainability co-benefits and could keep the 1.5°C limit within reach" (*UNEP Emissions Gap Report, 2018*).

4. The next decade is crucial for changing course on emissions

Staying on a 1.5°C path requires reducing global anthropogenic CO₂ emissions by about 45% by 2030 (compared to 2010) and reaching net zero by around 2050.²³ Emissions of non-CO₂ climate forcers must also be reduced as far as possible (see Box 1 for analysis of SLCP mitigation potential). Black carbon, methane and hydrofluorocarbons must be reduced between one and two thirds of current emissions.^{24,25}

- Methane - 37% (18-65%) reduction in emissions by 2030 compared to 2010;²⁶
- Black carbon - 35% (10-66%) reduction in emissions by 2030 compared to 2010;²⁷
- HFCs - 75-80% reduction in emissions by 2050 compared to 2010.²⁸

The necessary decrease in emissions is so significant that waiting until 2030 to increase mitigation ambition beyond current NDC mitigation pledges is too late. No scenarios reviewed for the Special Report were able to achieve the 1.5°C pathway if mitigation is delayed.

Achieving these reductions requires massive transformations in the energy, industry, transport, buildings, agriculture, forestry and other land-use (AFOLU) sectors.²⁹ Emissions of CO₂, SLCPs and other air pollutants are closely linked and often co-emitted, so many mitigation measures will reduce emissions of multiple pollutants. Addressing coal-fired power plants and emissions from the transport sector, for example, will simultaneously reduce emissions of CO₂ and non-CO₂ forcers.³⁰ However, the Special Report emphasizes the need for specific, targeted measures, such as those targeted by the Climate and Clean Air Coalition to significantly reduce SLCP sources that are not reduced via decarbonization of the energy sector (see box 1).³¹

5. Climate change, air pollution, and sustainable development are closely linked, and the multiple-benefits of actions can be significant

The Special Report recognizes that climate change and air pollution are closely linked as they are typically driven by the same emission sources.³² Similarly, there are strong links between climate change mitigation, adaptation, and achievement of the UN Sustainable Development Goals, including health (e.g. from improved air quality) and energy access (e.g. from replacing traditional cookstoves).^{33,34} This interlinkage can exacerbate the impacts of poorly designed policies resulting in negative trade-offs, but is also an opportunity to amplify the multiple-benefits of our actions to catalyze even greater mitigation ambition.

Many of the actions needed to stay on a 1.5°C pathway will likely result in significant near-term multiple-benefits for sustainable development and climate adaptation, but some actions may also negatively impact other sustainable development goals resulting in trade-offs.³⁵ The Special Report recognizes that actions undertaken purely for local sustainable development justifications can produce important climate mitigation and adaptation benefits.³⁶ Early action on short-lived climate pollutants, for example, can produce multiple benefits for clean air, public and ecosystem health, and associated economic benefits.^{37,38,39}

Not only are the benefits of short-lived climate pollutant measures high but the costs are very low. The models used for the Special Report optimize actions based on mitigation costs alone without accounting for the benefits of avoided damages. Even by this measure, short-lived climate pollutant controls are some of the most cost effective, and models assume that they'll be implemented to the fullest extent possible.



Indicative linkages between mitigation options and sustainable development using SDGs (The linkages do not show costs and benefits)

Mitigation options deployed in each sector can be associated with potential positive effects (synergies) or negative effects (trade-offs) with the Sustainable Development Goals (SDGs). The degree to which this potential is realized will depend on the selected portfolio of mitigation options, mitigation policy design, and local circumstances and context. Particularly in the energy-demand sector, the potential for synergies is larger than for trade-offs. The bars group individually assessed options by level of confidence and take into account the relative strength of the assessed mitigation-SDG connections.

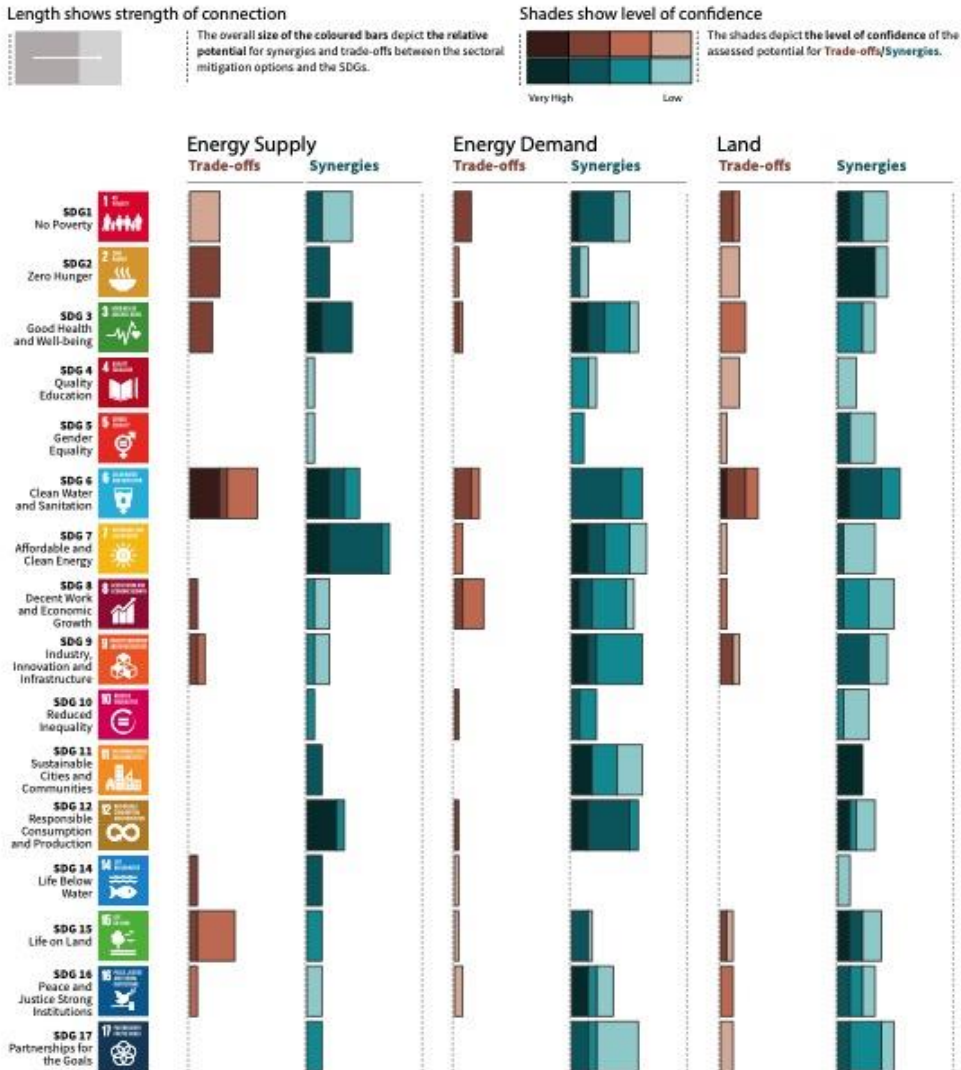


Figure 4. Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs). The bars denote the strength of the connection, and do not consider the strength of the impact on the SDGs. The energy demand sector comprises behavioural responses, fuel switching and efficiency options in the transport, industry and building sector as well as carbon capture options in the industry sector. Energy supply comprises biomass and non-biomass renewables, nuclear, CCS with bio-energy, and CCS with fossil fuels. Land comprises agricultural and forest options, sustainable diets & reduced food waste, soil sequestration, livestock & manure management, reduced deforestation, afforestation & reforestation, responsible sourcing. (Source: IPCC SR1.5°C, 2018)

6. An integrated multiple-benefits approach enables ambitious action

“Progress along these pathways involves inclusive processes, institutional integration, adequate finance and technology, and attention to issues of power, values, and inequalities to maximize the benefits of pursuing climate stabilisation at 1.5°C and the goals of sustainable development at multiple scales of human and natural systems from global, regional, national to local and community levels.”⁴⁰

The Special Report calls for countries to undertake an integrated approach where the multiple-impacts and benefits of climate change mitigation, adaptation, and sustainable development actions are examined, and appropriate strategies planned to maximize synergies and avoid or mitigate trade-offs.^{41,42,43} Understanding the interactions between these factors is key for selecting mitigation options and coordinating policies that maximize synergies and minimize trade-offs towards the 1.5°C and sustainable development objectives.⁴⁴

Leveraging these multiple benefits can reduce the cost of achieving the sustainable development goals⁴⁵ and increase the social, institutional, and economic feasibility of additional necessary action.⁴⁶ However, poorly designed actions can exacerbate negative trade-offs, slow or retard action and could pose challenges, “... especially - notes that “international cooperation is a critical enabler for developing countries and vulnerable regions to strengthen their action for the implementation of 1.5°C-consistent climate responses, including through enhancing access to finance and technology and enhancing domestic capacities, taking into account national and local circumstances and needs.

Box 2: The Multiple-Benefits Pathway Framework can empower countries to deliver necessary near-term mitigation ambition

The CCAC's multiple benefits pathway framework is an integrated approach that links strategies to reduce emissions of CO₂, Short-Lived Climate Pollutants (SLCPs), and other air pollutants. It allows for the identification of mitigation strategies that can maximise health improvements and other key local development priorities, and at the same time significantly reduce the rate or warming in the near-term (next 25 years) and long term (to 2100).

The framework was developed to empower countries to take action immediately and showcase strategies that can significantly reduce climate and air pollution impacts in the near term – with immediate benefits to health – and every year after action is taken. These actions complement strategies to safeguard the climate over the longer term.

The multiple benefits pathway framework responds to the Paris Agreement's long-term temperature goals and puts additional focus on saving lives and reducing temperature increase. For many countries with high methane and BC emissions, the largest reductions in near-term temperature is likely to come from implementing SLCP measures. However, for other countries, such as Norway, with low SLCP and air pollutant emissions, CO₂ reductions give the largest reduction in both near-term and long-term temperatures. Therefore, this framework emphasises the societal goals (local and global) rather than the strategies.

The CCAC has worked on a practical application of the framework using different tools – such as the LEAP-IBC tool – that can be applied by practitioners in countries, sub-national regions or cities. This framework was first applied at a global scale as a methodology underpinning the 2011 UNEP and WMO Integrated Assessment of Black Carbon and Tropospheric Ozone. It has also been applied at the regional scale as the methodology for the 2018 CCAC Assessment of SLCPs in Latin America and the Caribbean and the 2018 Asia-Pacific Solutions Report.

Currently 12 CCAC countries are using the framework in the CCAC initiative Supporting National Action and Planning on SLCPs (SNAP). Norway employed a similar methodology in their 2014 analysis of short-lived climate forcers (SLCFs).

NOTES

¹ IPCC, 2018: Chapter 1. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. World Meteorological Organization, Geneva Switzerland, pp 9. (“The Paris Agreement makes particular reference to the principle of equity, within the context of broader international goals of sustainable development and poverty eradication.”).

² IPCC, 2018: Chapter 2, pp. 84. (“There is robust evidence and high agreement in the pathway literature that multiple strategies can be considered to limit warming to 1.5°C (see Sections 2.1.3, 2.3 and 2.4). Together with the extensive evidence on the existence of interactions of mitigation measures with other societal objectives (Section 5.4), this results in high confidence that the choice of mitigation portfolio or strategy can markedly affect the achievement of other societal objectives.”).

³ IPCC, 2018: Chapter 1, pp. 5. (“Ambitious mitigation actions are indispensable to limit warming to 1.5°C while achieving sustainable development and poverty eradication (high confidence). ... This report focuses on ‘climate-resilient development pathways’, which aim to meet the goals of sustainable development, including climate adaptation and mitigation, poverty eradication and reducing inequalities. But any feasible pathway that remains within 1.5°C involves synergies and trade-offs (high confidence). Significant uncertainty remains as to which pathways are more consistent with the principle of equity. {1.1.1, 1.4}.”).

⁴ IPCC, 2018: Chapter 2, pp. 89. (“This IPCC special report identifies two main pathways that explore global warming of 1.5°C. The first involves global temperature stabilising at or below before 1.5°C above preindustrial levels. The second pathway sees warming exceed 1.5°C around mid-century, remain above 1.5°C for a maximum duration of a few decades, and return to below 1.5° before 2100. The latter is often referred to as an ‘overshoot’ pathway. Any alternative situation in which global temperature continues to rise, exceeding 1.5°C permanently until the end of the 21st Century, is not considered to be a 1.5°C pathway.”).

⁵ IPCC, 2018: Chapter 1, pp. 19. (“Hence impacts that occur when GMST reaches 1.5°C could be very different depending on the pathway to 1.5°C. CO₂ concentrations will be higher as GMST rises past 1.5°C (transient warming) than when GMST has stabilized at 1.5°C while sea level and, potentially, global mean precipitation (Pendergrass et al., 2015) would both be lower (see Figure 1.4). These differences could lead to very different impacts on agriculture, on some forms of extreme weather (e.g., Baker et al., 2018), and on marine and terrestrial ecosystems (e.g., Mitchell et al., 2017,)Box 3.1). Sea level would be higher still if GMST returns to 1.5°C after an overshoot (Figure 1.4, paneled), with potentially significantly different impacts in vulnerable regions. Temperature overshoot could also cause irreversible impacts (see Chapter 3)”).

⁶ IPCC, 2018: Chapter 3, pp. 8. (“Future risks at 1.5°C will depend on the mitigation pathway and on the possible occurrence of a transient overshoot (*high confidence*). The impacts on natural and human systems would be greater where mitigation pathways temporarily overshoot 1.5°C and return to 1.5°C later in the century, as compared to pathways that stabilizes at 1.5°C without an overshoot. The size and duration of an overshoot will also affect future impacts (e.g. loss of ecosystems, *medium confidence*). Changes in land use resulting from mitigation choices could have impacts on food production and ecosystem diversity {Sections 3.6.1 and 3.6.2, Cross Chapter boxes 7 and 8 in this Chapter}.”).

⁷ IPCC, 2018: Chapter 2, pp. 4. (“Limiting warming to 1.5°C depends on greenhouse gas (GHG) emissions over the next decades, where 37 lower GHG emissions in 2030 lead to a higher chance of peak warming being kept to 1.5°C (*high confidence*). Available pathways that aim for no or limited (0–0.2°C) overshoot of 1.5°C keep GHG 39 emissions in 2030 to 25–30 GtCO₂e yr⁻¹ in 2030 (interquartile range). This contrasts with median estimates 40 for current NDCs of 50–58 GtCO₂e yr⁻¹ in 2030. Pathways that aim for limiting warming to 1.5°C by 2100 41 after a temporary temperature overshoot rely on large-scale deployment of Carbon Dioxide Removal (CDR) 42 measures, which are uncertain and entail clear risks. {2.2, 2.3.3, 2.3.5, 2.5.3, Cross-Chapter Boxes 6 in 43 Chapter 3 and 9 in Chapter 4, 4.3.7}.”).

⁸ IPCC, 2018: Chapter 5, pp. 4. (“Limiting global warming to 1.5°C rather than 2°C would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities (medium evidence, high agreement). Impacts avoided with the lower temperature limit could reduce the number of people exposed to climate risks and vulnerable to poverty by 62 to 457 million, and lessen the risks of poor people to experience food and water insecurity, adverse health impacts, and economic losses, particularly in regions that already face development challenges (medium evidence, medium agreement) {5.2.2, 5.2.3}. Avoided impacts between 1.5°C and 2°C warming would also make it easier to achieve certain SDGs, such as those that relate to poverty, hunger, health, water and sanitation, cities, and ecosystems (SDGs 1, 2, 3, 6, 12, 14, and 15) (medium evidence, high agreement) {5.2.3, Table 5.2 available at the end of the chapter}.”).

⁹ IPCC, 2018: SPM, pp. 9. (“Model-based projections of global mean sea level rise (relative to 1986–2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, 0.1 m (0.04–0.16 m) less than for a global warming of 2°C (medium confidence). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (medium confidence). {3.4.4, 3.4.5, 4.3.2}”).

¹⁰ IPCC, 2018: SPM, pp. 10. (“Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and

damage to infrastructure (high confidence). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement (medium confidence). (Figure SPM.2) {3.4.5, Box 3.5}”).

¹¹ IPCC, 2018: Chapter 3, pp. 9. (“Many impacts are projected to be larger at higher latitudes due to mean and cold-season warming rates above the global average (*medium confidence*). High-latitude tundra and boreal forest are particularly at risk, and woody shrubs are already encroaching into tundra (*high confidence*). Further warming is projected to cause greater effects in a 2°C world than a 1.5°C world, for example, constraining warming to 1.5°C would prevent the melting of an estimated permafrost area of 2 million km² over centuries compared to 2°C (*high confidence*) {3.3.2, 3.4.3, 3.4.4}.”).

¹² IPCC, 2018: Chapter 3, pp. 140-141. (“The probability for an ice-free Arctic in September at 1.5°C of global warming is low and substantially lower than for the case of 2°C of global warming (*high confidence*) (Screen and Williamson, 2017; Jahn, 2018; Niederdrenk and Notz, 2018; Section 3.3.8). There is, however, a single study that questions the validity of the 1.5°C threshold in terms of maintaining summer Arctic Ocean sea-ice (Niederdrenk and Notz, 2018).”).

¹³ IPCC, 2018: Chapter 5, pp. 27. (“Recent multi-model comparisons indicate that mitigation pathways consistent with 1.5°C would result in higher synergies with air pollution compared to pathways that are consistent with 2°C (Figures 5.4 and 5.5). Shindell et al. (2018) indicate that health benefits worldwide over the century of 1.5°C pathways could be in the range of 110 to 190 million fewer premature deaths compared to 2°C pathways.”).

¹⁴ IPCC, 2018: Chapter 3, pp. 11. (“Any increase in global warming (e.g., +0.5°C) will affect human health (*high confidence*). Risks will be lower at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*), particularly in urban areas because of urban heat islands (*high confidence*). Risks also will be greater for ozone-related mortality if the emissions needed for the formation of ozone remain the same (*high confidence*), and for undernutrition (*medium confidence*). Risks are projected to change for some vector-borne diseases such as malaria and dengue fever (*high confidence*), with positive or negative trends depending on the disease, region, and extent of change (*high confidence*). Incorporating estimates of adaptation into projections reduces the magnitude of risks (*high confidence*) {3.4.7, 3.4.7.1}.”).

¹⁵ IPCC, 2018: Chapter 3, pp. 141-142. (“For Southeast Asia, a 2°C warming by 2040 indicated a one-third decline in per capita crop production (Nelson et al., 2010) associated with general decreases in crop yields. However, under 1.5°C of warming, significant risks for crop yield reduction in the region are avoided (Schleussner et al., 1 2016b).”).

¹⁶ IPCC, 2018: Chapter 1, pp. 4. (“Human-induced warming reached approximately 1°C (±0.2°C *likely* range) above pre-industrial 9 levels in 2017, increasing at 0.2°C (±0.1°C) per decade (*high confidence*). Global warming is 10 defined in this report as an increase in combined surface air and sea surface temperatures averaged 11 over the globe and a 30-year period. Unless otherwise specified, warming is expressed relative to the 12 period 1850-1900, used as an approximation of pre-industrial temperatures in AR5.”).

¹⁷ IPCC, 2018: Chapter 1, pp. 45. (“Over a fifth of the global population live in regions that have already experienced warming in at least one season that is greater than 1.5°C above pre-industrial levels.”).

¹⁸ IPCC, 2018: Chapter 1, pp. 45. (“In the decade 2006–2015, warming reached 0.87°C (±0.12°C) relative to 1850–1900, predominantly due to human activity increasing the amount of greenhouse gases in the atmosphere. Given that global temperature is currently rising by 0.2°C (±0.1°C) per decade, human-induced warming reached 1°C above pre-industrial levels around 2017 and, if this pace of warming continues, would reach 1.5°C around 2040.”).

¹⁹ IPCC, 2018: Chapter 2, pp. 89. (“If current pledges for 2030 are achieved but no more, researchers find very few (if any) ways to reduce emissions after 2030 sufficiently quickly to limit warming to 1.5°C. This, in turn, suggests that with the national pledges as they stand, warming would exceed 1.5°C, at least for a period of time, and practices and technologies that remove CO₂ from the atmosphere at a global scale would be required to return warming to 1.5°C at a later date.”).

²⁰ IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

²¹ IPCC, 2018: Chapter 4, pp.7. (“Though CO₂ dominates long-term warming, the reduction of warming Short-Lived Climate Forcers (SLCFs), such as methane and black carbon, can in the short term contribute significantly to limiting warming to 1.5°C.”).

²² IPCC, 2018: Chapter 4, pp. 7. (“Reductions of black carbon and methane would have substantial co-benefits (*high confidence*), including improved health due to reduced air pollution. This, in turn, enhances the institutional and socio-cultural feasibility of such actions.”).

²³ IPCC, 2018: SPM, pp. 14. (“In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO₂ emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range). For Non-CO₂ emissions in pathways that limit global warming to 1.5°C show deep reductions that are similar to those in pathways limiting warming to 2°C. (*high confidence*).”).

²⁴ IPCC, 2018: Chapter 4, pp. 7. (“Though CO₂ dominates long-term warming, the reduction of warming Short-Lived Climate Forcers (SLCFs), such as methane and black carbon, can in the short term contribute significantly to limiting warming to 1.5°C.”).

²⁵ IPCC, 2018: Chapter 2, pp. 36. (“SLCP emissions decrease greatly across 1.5°C-consistent and 2°C-consistent pathways available in the literature. For BC, interquartile ranges of emissions reductions across pathways are 16–34% and 48–58% in 2030 and 2050, respectively, relative to 2010. Fluorinated gases are reduced by ~75-80% relative to 2010 by 2050.”).

²⁶ SR1.5 methane emissions scenarios database (provided by Drew Shindell, Nov 2018)

²⁷ SR1.5 black carbon emissions scenarios database (provided by Drew Shindell, Nov 2018); and IPCC, 2018: Chapter 2, pp. 36. ("Black Carbon (BC) emissions reach similar levels across 1.5°C-consistent and 2°C-consistent pathways available in the literature, with interquartile ranges of emissions 34 reductions across pathways of 16–34% and 48–58% in 2030 and 2050, respectively, relative to 2010 (Figure 35 2.7). Recent studies have identified further reduction potentials for the near term, with global reductions of about 80% being suggested (Stohl et al., 2015; Klimont et al., 2017).").

²⁸ IPCC, 2018: Chapter 2, pp. 38. ("Emissions of fluorinated gases (IPCC/TEAP, 2005; US EPA, 2013; Velders et al., 2015; Purohit and 1 Höglund-Isaksson, 2017) in 1.5°C-consistent pathways are reduced by roughly 75–80% relative to 2010 levels (interquartile range across 1.5°C-consistent pathways) in 2050, with no clear differences between the classes. Although unabated HFC evolutions have been projected to increase (Velders et al., 2015), the Kigali Amendment recently added HFCs to the basket of gases controlled under the Montreal Protocol (Höglund-Isaksson et al., 2017). As part of the larger group of fluorinated gases, HFCs are also assumed to decline in 1.5°C-supplementary chapters consistent pathways. Projected reductions by 2050 of fluorinated gases under 1.5°C-consistent pathways are deeper than published estimates of what a full implementation of the Montreal Protocol's Kigali Amendment would achieve (Höglund-Isaksson et al., 2017), which project roughly a halving of fluorinated gas emissions in 2050 compared to 2010.").

²⁹ IPCC, 2018: Chapter 2, pp. 23. ("Limiting global mean temperature increase at any level requires global CO₂ emissions to become net zero at some point in the future (Zickfeld et al., 2009; Collins et al., 2013). At the same time, limiting the residual warming of short-lived non-CO₂ emissions, can be achieved by reducing their annual emissions as far as possible (Section 2.2, Cross-Chapter Box in Chapter 1). This will require large-scale transformations of the global energy-agriculture-land-economy system, affecting the way in which energy is produced, agricultural systems are organised, and food, energy and materials are consumed" (Clarke et al., 2014).").

³⁰ IPCC, 2018: Chapter 2, pp. 36. ("CO₂ and SLCF emissions reductions are connected in situations where SLCF and CO₂ are co-emitted by the same process, for example, with coal-fired power plants (Shindell and Faluvegi, 2010) or within the transport sector (Fuglestvedt et al., 2010). Many CO₂-targeted mitigation measures in industry, transport and agriculture (Sections 2.4.3–4) hence also reduce non-CO₂ forcing (Rogelj et al., 2014b; Shindell et al., 2016).").

³¹ IPCC, 2018: SPM, pp. 14. ("Modelled pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon (35% or more of both by 2050 relative to 2010). These pathways also reduce most of the cooling aerosols, which partially offsets mitigation effects for two to three decades. Non-CO₂ emissions can be reduced as a result of broad mitigation measures in the energy sector. In addition, targeted non-CO₂ mitigation measures can reduce nitrous oxide and methane from agriculture, methane from the waste sector, some sources of black carbon, and hydrofluorocarbons. Improved air quality resulting from projected reductions in many non-CO₂ emissions provide direct and immediate population health benefits in all 1.5°C model pathways. (*high confidence*)").

³² IPCC, 2018: Chapter 5, pp. 27. ("Greenhouse gases and air pollutants are typically emitted by the same sources. Hence, mitigation strategies that reduce GHGs or the use of fossil fuels typically also reduce emissions of pollutants, such as particulate matter (e.g., PM_{2.5} and PM₁₀), black carbon (BC), sulphur dioxide (SO₂), nitrogen oxides (NO_x), and other harmful species (Clarke et al., 2014) (Figure 5.3), causing adverse health and ecosystem effects at various scales (Kusumaningtyas and Aldrian, 2016).").

³³ IPCC, 2018: SPM, pp. 21. ("1.5°C pathways have robust synergies particularly for the SDGs 3 (health), 7 (clean energy), 11 (cities and communities), 12 (responsible consumption and production) and 14 (oceans) (*very high confidence*). Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes (*high confidence*).").

³⁴ IPCC, 2018: Chapter 2, pp. 7. ("Limiting warming to 1.5°C can be achieved synergistically with poverty alleviation and improved energy security and can provide large public health benefits through improved air quality, preventing millions of premature deaths. However, specific mitigation measures, such as bioenergy, may result in trade-offs that require consideration.").

³⁵ IPCC, 2018: Chapter 1, pp. 35. ("The responses chosen could act to synergistically enhance mitigation, adaptation and sustainable development or they may result in trade-offs which positively impact some aspects and negatively impact others. Climate change is expected to increase the likelihood of not achieving the Sustainable Development Goals (SDGs), while some strategies limiting warming towards 1.5°C are expected to significantly lower that risk and provide synergies for climate adaptation and mitigation (Chapter 5).").

³⁶ IPCC, 2018: Chapter 5, pp. 45. ("Pursuing sustainable development will influence emissions, impacts and vulnerabilities. Responses to climate change in the form of adaptation and mitigation will also interact with sustainable development with positive effects, known as synergies, or negative effects, known as trade-offs.").

³⁷ IPCC, 2018: Chapter 1, pp. 28. ("Emission reductions can interact with other dimensions of sustainable development (see Chapter 5). In particular, early action on some SLCFs (including actions that may warm the climate such as reducing SO₂ emissions) may have considerable societal co-benefits such as reduced air pollution and improved public health with associated economic benefits (OECD, 2016; Shindell et al., 2016)").

³⁸ IPCC, 2018: Chapter 4, pp. 44. “Reductions in SLCFs can provide large benefits towards sustainable development, beneficial for social, institutional and economic feasibility. Strategies that reduce SLCFs can provide benefits that include improved air quality and crop yields, energy access, gender equality and poverty eradication.”)

³⁹ IPCC, 2018: Chapter 4, pp. 7. (“Reductions of black carbon and methane would have substantial co-benefits (high confidence), including improved health due to reduced air pollution. This, in turn, enhances the institutional and socio-cultural feasibility of such actions. Reductions of several warming SLCFs are constrained by economic and social feasibility (low evidence, high agreement). As they are often co-emitted with CO₂, achieving the energy, land and urban transitions necessary to limit warming to 1.5°C would see emissions of warming SLCFs greatly reduced. {2.3.3.2, 4.3.6}”).

⁴⁰ IPCC, 2018: Chapter 1, pp. 42.

⁴¹ IPCC, 2018: Chapter 5, pp. 21. (“Understanding the positive impacts (synergies) but also the negative impacts (trade-offs) is key for selecting mitigation options and policy choices that maximise the synergies between mitigation and developmental actions” (Hildingsson and Johansson, 2015; Nilsson et al., 2016; Delponte et al., 2017; van Vuuren et al., 2017b; McCollum et al., 2018).”).

⁴² IPCC, 2018: Chapter 5, pp. 45. (“Responses to climate change can be planned to maximize synergies and limit trade-offs with sustainable development.”).

⁴³ IPCC, 2018: Chapter 4, pp. 10. (“The issue is whether aligning 1.5°C-consistent pathways with the Sustainable Development Goals (SDGs) will secure support for accelerated change and a new growth cycle (Stern, 2013, 2015). It is difficult to imagine how a 1.5°C world would be attained unless the SDG on cities and sustainable urbanisation is attained in developing countries (Revi, 2016), or without reforms in the global financial intermediation system.”)

⁴⁴ IPCC, 2018: Chapter 2, pp. 85. (“The choice of mitigation portfolio or strategy can markedly affect the achievement of other societal objectives. Understanding mitigation-SDG interactions is key for selecting mitigation options that maximise synergies and minimize trade-offs towards the 1.5°C and sustainable development objectives.”).

⁴⁵ IPCC, 2018: Chapter 5, pp. 21. (“Adopting stringent climate mitigation options can generate multiple positive non-climate benefits that have the potential to reduce the costs of achieving sustainable development (IPCC, 2014b; Ürge-Vorsatz et al., 2014, 2016; Schaeffer et al., 2015; von Stechow et al., 2015).”).

⁴⁶ IPCC, 2018: Chapter 4, pp. 44. (“Reductions in SLCFs can provide large benefits towards sustainable development, beneficial for social, institutional and economic feasibility. Strategies that reduce SLCFs can provide benefits that include improved air quality (for example (Anenberg et al., 2012)) and crop yields (for example (Shindell et al., 2012)), energy access, gender equality and poverty eradication (for example (Shindell et al., 2012; Haines et al., 2017)).”).

⁴⁷ IPCC, 2018: Chapter 1, pp. 5.