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Chapter 1: Framing and Context

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1 **Executive Summary**

2
3 **This IPCC Special Report of global warming of 1.5°C assesses the conditions under which the global**
4 **community could limit the rise in global temperatures to 1.5°C above pre-industrial levels; the impacts**
5 **of a 1.5°C world compared to higher levels of warming; and the feasibility of meeting this target while**
6 **promoting sustainable development, poverty reduction and increased equity.** It is the first in a series of
7 IPCC Special Reports to span all three IPCC working groups, and to include greater social science literature.
8 As a result, this report builds on previous IPCC assessments but also goes beyond them in review existing
9 literature on potential implementation options. The report is global in scope and includes regional analyses.
10 The primary focus is on the 21st century, with some impacts considered on multi-century timescales.

11
12 **Human-induced warming reached a global average of about 1°C above pre-industrial levels in 2016,**
13 **increasing at 0.1-0.25 °C per decade. Many regions have already experienced greater warming and**
14 **significant changes in rainfall.** Consistent with the IPCC 5th Assessment Report (AR5), warming relative to
15 pre-industrial levels is defined as the increase in global average temperature averaged over a multi-decadal
16 period relative to the 30-year reference period 1850-1879. This level and rate of warming imply that a 20%
17 reduction of global emissions from their present-day level for every tenth of a degree of warming from now
18 on, or an average compound reduction rate of 2-5% per year, would be required to limit warming to 1.5°C.

19
20 **Global warming of 1.5°C implies different levels of warming and rainfall change at the local level, and**
21 **warming in regions with human settlements will often exceed 1.5°C.** Local and traditional knowledge of
22 recent climate changes bears direct relevance to the impacts of a 1.5°C climate. Present-day climate changes
23 are not likely to be indicative of climate changes that would be realised in a global mean 1.5°C world.
24 However, large parts of the world have already experienced warming in excess of 1.5°C in at least one
25 season of the year, corresponding to over 50% of the global population for which local warming trends can
26 be calculated.

27
28 **Currently defined Nationally Determined Contributions (NDCs) specified under the Paris Agreement**
29 **will not be sufficient to create conditions for a 1.5 °C world.** Total global emissions, if expressed in terms
30 that give all climate drivers a similar global temperature impact as CO₂, must be reduced to net zero in order
31 to stabilise global average temperatures. Current patterns of population growth, fossil fuel consumption and
32 exploitation of natural resources present structural impediments to achieving ambitious global emissions
33 reduction targets.

34
35 **Climate change of 1.5°C above pre-industrial levels will disproportionately exacerbate other global**
36 **scale problems such as the degradation of ecosystems, disasters, food security, increased disease**
37 **outbreaks, and access to fresh water.** Increases in extreme events (e.g. droughts and floods) that result in
38 resource depletion, conflict and forced migration are impacting economic development worldwide, and
39 present a challenge to addressing the Sendai Framework for Disaster Risk Reduction 2015-2030. Global
40 economic growth has been accompanied by increased life expectancy, educational attainment and income.
41 But many regions are characterised by severe inequity in resource distribution that amplifies vulnerability to
42 climate change.

43
44 **Justice and equity are central to understanding the ambition of the Paris Agreement, recognising that**
45 **the impacts of climate change for warming levels beyond 1.5°C could fall disproportionately on the**
46 **poor and vulnerable.** Three key points of connection between climate change and justice are associated
47 with the conditions under which a 1.5°C world can be achieved: asymmetry in the contributions to the problem;
48 asymmetry in impacts and vulnerability, such that the worst impacts may fall on those that are least
49 responsible for the problem, including future generations; and asymmetry in the power to decide solutions
50 and response strategies. Mitigation and adaptation policies each have the potential for profound human rights
51 implications of their own, especially if framed without considerations of the complex local-national to
52 regional interlinkages and feedbacks in social-ecological systems.

53
54 **The connection between 1.5°C warming and ambitions of sustainable development are complex and**
55 **multifaceted - socially, spatially and over time.** AR5 noted that climate change constitutes a moderate

1 threat to current sustainable development and a severe threat to future sustainable development, and that ill-
2 designed responses could offset already achieved gains. However, synergies exist between achieving the UN
3 Sustainable Development Goals (SDGs) and climate responses. SDGs include the specific goals ‘Climate
4 action’ (SDG13) but also closely related goals, including ‘Affordable and clean energy’ (SDG17),
5 ‘Sustainable cities and communities’ (SDG11), ‘Responsible consumption and production’ (SDG12), and
6 others such as equality/equity goals for gender, education, income, work, and access to justice.
7

8 **Limiting global warming to 1.5°C is associated with an opportunity for innovative global, national and**
9 **subnational governance, enhancing adaptation and mitigation within the framework of sustainable**
10 **development, poverty eradication, rights, justice and equity, and synergistically linking with global**
11 **scale trends including increased urbanization and decoupling of economic growth from greenhouse**
12 **gas forcing.** Work on adaptive and flexible governance systems and policy experimentation will provide
13 key information for transitioning to a 1.5°C global warming and reducing further temperature increase.
14 Significant governance challenges include the ability to incorporate multiple stakeholder perspectives in the
15 decision-making process to reach meaningful and equitable decisions, scalar interaction and coordination
16 between the different levels of government, and the capacity to raise financing, and support for technological
17 and human resource development for such actions. Governance capacity includes the wide range of activities
18 and efforts needed to develop coordinated climate mitigation and adaptation strategies in the context of
19 sustainable development taking into account equity, justice and poverty eradication.
20

21 **Transitioning from climate planning to practical implementation is a major challenge in constraining**
22 **global temperature to 1.5°C. Barriers include finance, technology and human resource constraints plus**
23 **institutional capacity to strategically deploy available knowledge and resources.** Regional diversity,
24 including highly carbon-invested and emerging economies, are important considerations. Incorporating
25 strong linkages across sectors, devolution of power and resources to sub-national and local governments and
26 facilitating partnerships among public, civic, and private sectors will be key to implementing identified
27 response options.
28

29 **Mitigation-adaptation linkages, synergies and trade-offs, as well as the different dimensions of**
30 **feasibility, are important linking elements to sustainable development.** Feasibility is considered in this
31 report as the systems-level capacity to achieve a specific goal or target. A complete vision of the feasibility
32 question requires integration of natural system considerations into the human system scenarios, the
33 placement of technical transformations into their political, social, and institutional context, and an indication
34 that feasibility is dynamic across spatial social and temporal scales.
35

36 **Common tools for making complex policy decisions such as cost-benefit analyses are insufficient for a**
37 **1.5°C target.** For example, costs may be relatively easily quantifiable in terms of money but the impacts of
38 climate change on humans’ lives, their culture and values, or on ecosystem goods and services, may have
39 unpredictable feedback loops and impacts for other regions, making it difficult to quantify and compare. In
40 addition, costs and benefits can occur at very different times, even across different centuries for different
41 regions, in which case standard cost-benefit analyses become difficult to justify.
42

43 **Incorporating knowledge from different sources, setting a multi-faceted information channel, as well**
44 **as educating and building awareness at various levels will advance decision making and**
45 **implementation of context specific responses to 1.5°C of warming and the associated uncertainties.**
46 Reliable climate data is insufficient in many areas, especially in low-income countries. Indigenous and local
47 knowledge and experience can complement scientific data with chronological and landscape-specific
48 precision and detail that is critical for verifying climate models and evaluating climate change scenarios for
49 1.5°C warming.
50
51

1.1 Human, ecological, and physical dimensions of 1.5°C: building a knowledge base for this report

Previous IPCC reports have explicitly demonstrated evidence of human interference in the climate system. AR5 found that the average global surface temperature has reached approximately 1°C above pre-industrial levels (IPCC 2013a), and monthly average temperatures of 1.4°C above these same levels have been observed. The warming to date has generated observable impacts, and acts as an amplifier of risks for natural and human systems as noted in Chapter 3 of this report. It is this rising risk that underpins the ambition of the Paris COP21 agreement, to ‘pursue efforts to limit’ the rise in global temperatures to 1.5°C above pre-industrial levels.

This report assesses the feasibility of re-orienting global society to limit the rise in global temperatures to 1.5°C above pre-industrial levels; the effects and impacts of a 1.5°C world; the challenges of keeping within such a stringent warming target, and the consequences of failing to do so. The report is structured as a scientific assessment of the potential global response to this challenge within the specific context of sustainable development, poverty eradication, justice, equity and ethics as concrete means to articulate the long-standing ethical dilemmas posed by climate justice and the United Nations Framework Convention on Climate Change (UNFCCC) notion of equity.

To seek encompassing solutions to achieving a 1.5°C world, the assessment draws from past global assessments and knowledge of social-ecological systems as defined within the frame of the Anthropocene. The Anthropocene is used as a comprehensive interpretation of the global to local, and past–present-future human-nature interlinkages (Pattberg and Zelli 2016; Delanty and Mota 2017; Olsson et al. 2017). Climate change and other significant human imprints such as ocean acidification, land use change, biodiversity loss, sea level rise are linked to, among others, high population growth, unprecedented fossil fuel consumption and unequal exploitation of natural resources, jointly resulting in degradation of the environment and requirements for more sustainable pathways.

The assessment approach used in the report includes a framework to help the comprehension of the scale and interlinkages of the global environmental, economic, social and technical requirements that climate change raises. Complex ethical issues are brought to the fore that is both climate change and potential responses to it may exacerbate poverty, inequality and injustice, globally and locally and has implications on inter-generational justice. These present profound challenges to path-dependent governance and invites interdisciplinary research and reflection, pointing to a systems approach that takes into account social inequalities, unequal distribution of risks and ability to respond to 1.5°C warming (Dryzek 2016; Pattberg and Zelli 2016; Lövbrand et al. 2017; Bäckstrand et al. 2017). As a result, this assessment builds on the previous IPCC assessments to provide a range of pathways, including implementation strategies, on the feasibility of achieving the required substantive transformation of society to limit global warming to 1.5°C in the context of the 2030 Agenda for Sustainable Development within the complexity of the Anthropocene.

1.1.1 The challenge of 1.5°C: human rights, ethics and governance

This assessment is the response to an invitation extended to IPCC by the UNFCCC as part of the Paris COP21 Agreement that was negotiated by 195 countries. The Paris aspiration to limit warming to 1.5°C is highly ambitious and progress towards achieving this ambition is uncertain (Falkner 2016; Marquardt 2017). In 2014, AR5 identified ‘only a limited number’ of model-based scenarios that would achieve this target (IPCC 2014a). These few all assumed immediate and rapid scaling up of mitigation technologies, coupled with plunging global energy demand. Those conditions continue not to be met: global decarbonisation now stands at a rate of 1.3% per year, far below the estimated 6.3% required to stay within even a 2°C target (see Figure 2.9). The 1.5°C scenario differs from less ambitious targets in part because of the unusual scale, rapidity and coordination of any global response.

While economic growth has been accompanied by increased life expectancy, educational attainment and income, many regions are characterised by severe inequity in income distribution that amplifies vulnerability to climate change. The world population continues to rise and is projected to reach 9.7 billion by 2050

1 (United Nations 2015a) with much of this growth occurring in hazard-prone small and medium sized cities in
2 low and moderate-income countries (Birkmann et al. 2016). The urgency of keeping with the Paris
3 agreement is that the threat of 1.5°C above pre-industrial levels will likely exacerbate other global scale
4 problems such as the degradation of ecosystems, food security, increased disease outbreaks, access to fresh
5 water in different regions (FAO et al. 2015; Campbell et al. 2016).

6
7 Temperature rise to date has already resulted in profound alterations to human and natural systems, with new
8 shocks and new risks (IPCC 2014a). Many regions of the world have experienced higher warming already, at
9 different periods (Chapter 3, Section 3.3.1). Increases in extreme weather events, droughts, floods, sea level
10 rise and biodiversity loss are already affecting economic development worldwide presenting a challenge to
11 addressing the Sendai Framework for Disaster Risk Reduction (Mysiak et al. 2016) (Chapter 3, Sections 3.4
12 and 3.5). The most affected are the low and middle income countries where this has led to decline in food
13 security and has been linked to migration and poverty. Small islands and populations residing in megacities,
14 coastal regions and in high mountain ranges are some of the most affected. Efforts to curtail greenhouse gas
15 emissions without incorporating the intrinsic interconnectivity of the Anthropocene world may themselves
16 impact negatively on development ambitions of many nations.

17
18 The 1.5°C target thus raises ethical concerns that have been central to the climate debate from the outset, and
19 most recently articulated in the language of human rights (International Council on Human Rights Policy
20 2008; Adger et al. 2014). For example, how will an average global temperature rise of 1.5°C impact upon
21 human rights especially of the already vulnerable persons, that is the urban and rural poor, indigenous
22 communities, women and children? As the world advances towards 1.5°C, further deterioration of the human
23 rights may be unavoidable, although a solid knowledge base of the various social-ecological interlinkages
24 may allow for some impacts to be anticipated and pre-empted. Failure to limit warming to 1.5°C will
25 necessarily result in further extensive human rights consequences. In human rights terms, the gap between
26 1.5°C and 2°C amounts to a greater likelihood of drought, flooding, resource depletion, conflict and forced
27 migration in many parts of the world (FAO et al. 2015; Campbell et al. 2016; Office of the United Nations
28 High Commissioner for Human Rights 2009; Adger et al. 2014). Further, mitigation and adaptation policies
29 each have the potential for profound human rights implications of their own, especially if framed without
30 considerations of the complex local-national to regional interlinkages and feedback loops in social-ecological
31 systems. Without sustained technology transfer, rapid decarbonisation could slow or stall growth and
32 exacerbate poverty, especially in less wealthy countries. Adaptation measures, if they are to be effective and
33 at scale, may be intrusive and so raise questions about participation (Dryzek and Pickering 2017) and respect
34 for existing rights (Knox 2015; United Nations General Assembly 2016).

35
36 As a result, achieving the ambitions of the Paris Agreement will require unprecedented political will and
37 highly supportive innovative governance arrangements equipped with an in-depth understanding of the far
38 reaching diversity in spatial, temporal and social interconnectedness and the learning capabilities of society
39 (Delanty and Mota 2017; Olsson et al. 2017; International Bar Association 2014). These arrangements
40 include integrated reflexive policy institutions capable of operating at multiple scales (from local to regional
41 and international), to affect the far-reaching policy change required to bring about reductions in GHGs
42 consistent with a 1.5°C warmer world, while also strengthening global responses to poverty and addressing
43 associated emerging human rights issues (Dryzek and Pickering 2017; Lövbrand et al. 2017; Bäckstrand et
44 al. 2017).

45 46 47 **1.1.2 1.5°C and Pathways**

48
49 Altering or slowing the pace of current warming can be defined through mitigation pathways. Different
50 pathways are more consistent than others with the requirements for sustainable development. The conditions
51 required for achieving the 1.5°C goal include geo-physical, technological, and socio-economic dimensions
52 (described in Box 1.3). Limiting warming to 1.5°C also involves identifying advantageous technology and
53 policy levers, with which it may be possible to accelerate the pace of transformation.

1 The global commitment to 1.5°C pathways is, in part, defined by nationally determined contributions (NDC)
2 of greenhouse gas reduction. The current NDCs are not ambitious enough to secure the 1.5°C goal and are
3 currently tracking toward a warming of 3-4°C above preindustrial temperatures (Rogelj et al. 2016;
4 UNFCCC 2016). The analysis of pathways also reveals opportunities for greater decoupling of economic
5 growth from the rate of GHG emissions. Movement toward 1.5°C will require an acceleration of this trend.
6

7 The challenge is in identifying the best ways to achieve wide reaching policy change with consideration to
8 ethics and justice, the appropriate actors to lead this change, and the most effective arenas for policy action
9 to address adaptation and mitigation for a 1.5°C world within a sustainable development framework (Jordan
10 et al. 2015; Stripple and Bulkeley 2011). An option exists for strong effective earth-system governance for
11 international institutions (Biermann 2014) and ‘top-down, treaty-based’ approaches to reducing greenhouse
12 gases as opposed to non-binding, ‘pledges of intent’ with periodic review (Busby 2016). The later approach
13 underpinned the Paris Agreement of 2015 and is consistent with multi-level polycentric or decentralised
14 public and private networked governance (Stevenson and Dryzek 2013; Lövbrand et al. 2017).
15

16 The new approach signalled by the Paris Agreement does not leave mitigation entirely to bottom-up efforts
17 or top down directives. Instead, voluntary country pledges are embedded in ‘an international system of
18 climate accountability and a “ratchet” mechanism’ (Falkner 2016) and allows for actions by non-state actors
19 (Morgan and Northrop 2017).
20

21 22 **1.1.3 Sustainable Development and 1.5°C**

23
24 Despite unprecedented global wealth, the number of people living in extreme poverty and hunger remain
25 close to or around one billion (United Nations Development Programme 2014); global wealth distribution
26 has become increasingly unequal (OECD 2015). The AR5 provided insight into the geographic distribution
27 and trends of poverty patterns and addressed poverty dynamics, for example shifts between transient and
28 chronic poverty, as well as relational aspects of poverty (Olsson et al. 2014). The AR5 concluded that
29 ‘climate change and climate variability worsen existing poverty and exacerbate inequalities’ (*high*
30 *confidence*) and that climate change will ‘create new poor between now and 2100, in developing and
31 developed countries, and jeopardise sustainable development’ (*high confidence*) (Olsson et al. 2014).
32

33 The AR5 (IPCC 2014b) concluded that climate change constrains possible development paths, that synergies
34 and trade-offs exist between climate responses and socio-economic contexts, that capacities for effective
35 climate responses overlap with capacities for sustainable development, and that existing societal patterns
36 (e.g., overconsumption) are intrinsically unsustainable (Fleurbay et al. 2014). As a result, any serious
37 attempt to meet a 1.5°C target, while at the same time reducing poverty, will benefit from attentiveness to the
38 Anthropocene narrative on the past-present and future functioning of national and global economies and their
39 connections that give rise to the need for a sustainable development framework (Delanty and Mota 2017).
40

41 In this assessment, the definition of sustainable development is rooted in the 1987 report Our Common
42 Future: ‘ (...) development that meets the needs of the present without compromising the ability of future
43 generations to meet their own needs’ (World Commission on Environment and Development 1987). The
44 recent UN Sustainable Development Goals (SDGs) are an interlinked network of targets that are crucial to
45 addressing the interconnected challenges of the Anthropocene for systematic wellbeing. Building on the
46 successes and limitations of the Millennium Development Goals, the SDGs acknowledge more integrated
47 systems and lend themselves to inclusive implementation and policy integration across sectors.
48

49 SDG13 specifically requires ‘urgent action to address climate change and its impacts’, but most if not all of
50 the 17 SDGs are directly relevant to climate action. They include, for example, ending poverty and hunger,
51 reducing inequality, making cities resilient and sustainable, encouraging sustainable consumption and
52 production, making energy affordable and clean, promoting ‘decent work’ and conserving biodiversity on
53 land and sea (United Nations 2015b). The SDGs provide targets and indicators to be assessed periodically at
54 global conferences and thus provide a useful forum in which to monitor and promote efforts to manage
55 climate change sustainably.

1 Equality and equity expressed under SDGs 5 and 10 are fraught with definitional problems. Equality affords
2 all people the same status, opportunities, and rights, yet people embark from different starting points and
3 thus don't benefit the same way. In the context of global warming, the importance of equality across
4 generations has been articulated in terms of 'growth sustainability' (Llavador et al. 2015). Equity is often
5 seen synonymous with fairness and justice, entailing distributive and procedural equity as well as equity
6 between and within generations (Shelton 2007).

7
8 The interdependence of SDGs resonates strongly with the AR5 findings that climate change amplifies
9 conditions of poverty and inequality. SDGs have a strong focus on equity and environment and apply to all
10 countries as global goals (see Box 5.1) that are 'action-oriented, concise and easy to communicate, limited in
11 number, aspirational, global in nature and universally applicable to all countries while taking into account
12 different national realities, capacities and levels of development and respecting national policies and
13 priorities' (United Nations 2015b). Nevertheless, how to achieve these aspirations alongside the transitions
14 needed to secure a 1.5°C world will need careful planning.

15
16
17 An understanding of 1.5°C comes from a variety of established and emergent knowledge bases, such as the
18 Anthropocene (Olsson et al. 2017). These different knowledge bases will, together, be critical to more fully
19 realise the texture and conditions of impact, vulnerability, mitigation and strengthening of the sustainable
20 development agenda. The demands of limiting warming to 1.5°C with meaningful solutions require this
21 approach.

22 23 24 **1.2 Understanding 1.5°C: reference levels, probability, transience, overshoot, stabilization**

25 26 *1.2.1 Working definitions of 1.5°C and 2°C for use in this report*

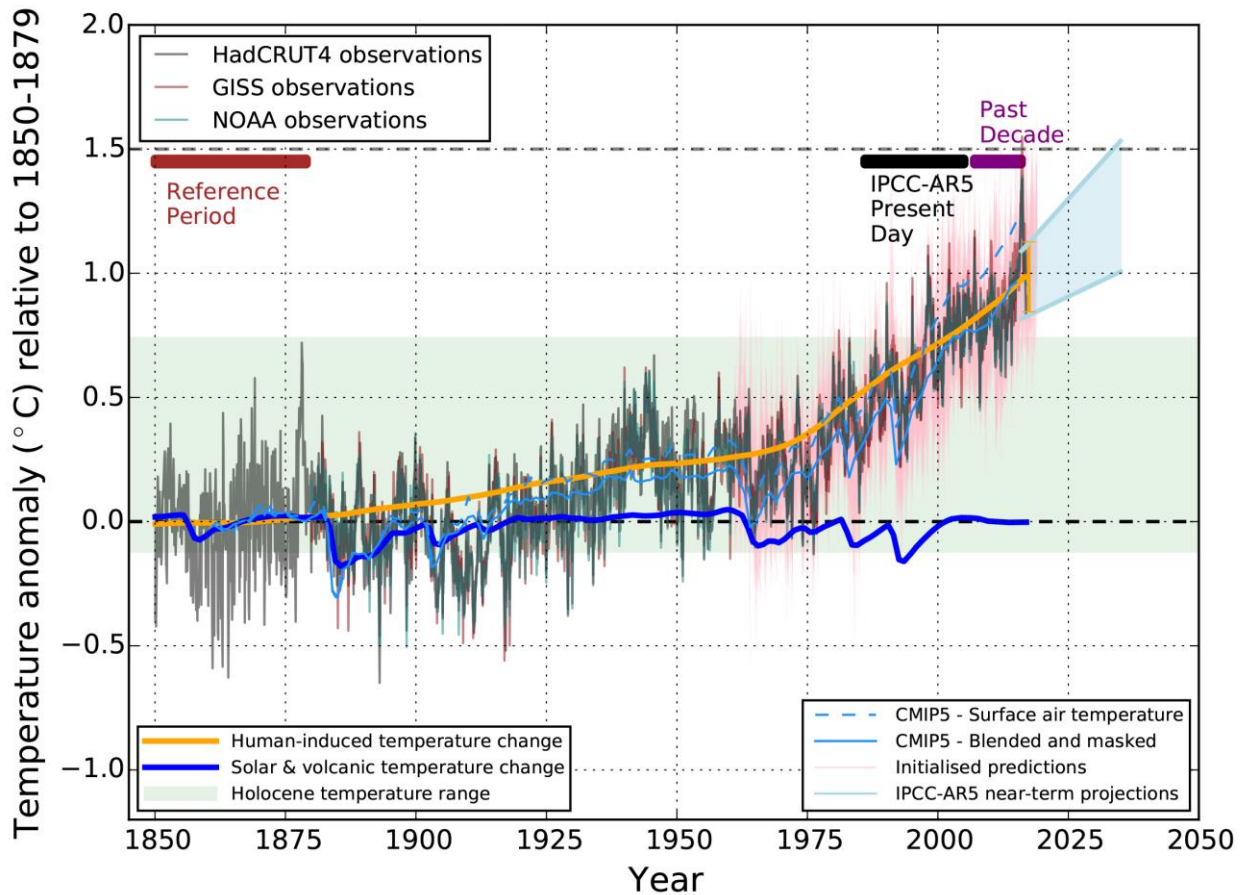
27
28 While the overall intention is clear, the Paris Agreement does not specify precisely what is meant by 'global
29 average temperature' relative to 'pre-industrial levels'. Whether or when global temperatures reach 1.5°C
30 depends to some extent on these definitions. While the ultimate decision on what definition to adopt is
31 beyond the mandate of this report, working definitions are required to ensure consistency across chapters and
32 figures. Issues affecting the definition include the choice of pre-industrial reference period, whether 1.5°C
33 refers to total or human-induced warming, and which variables and coverage are used to define global
34 average temperature change. In this section, a working definition is proposed and related to various potential
35 alternatives.

36 37 38 *1.2.1.1 Definition of global average temperature*

39 The IPCC has traditionally defined changes in observed global mean surface temperature (GMST) as a
40 weighted average of observed near-surface air temperature (SAT) changes over land and sea surface
41 temperature (SST) changes over the oceans (Morice et al. 2012). Modelling studies, with no coverage
42 constraints, have typically used a simple area average of SAT over land, sea-ice and oceans. For relatively
43 low warming levels, the difference can be significant. Cowtan et al. (2015) show that the use of blended
44 SAT/SST data gives approximately 0.1°C less warming to-date in the 5th Climate Model Intercomparison
45 Project (CMIP5) ensemble than the use of area-average SAT, while Richardson et al. (2016) show that
46 incomplete coverage reduces warming to-date by a further 0.1°C (see inset panel in Stocker et al. (2013),
47 Figure TFE8.1 and Figure 1.1). Detection and attribution studies have generally been careful to make a like-
48 for-like comparison, accounting for coverage (Tett et al. 1999; Jones et al. 2003). The simple climate models
49 used in many Integrated Assessment Models do not distinguish SAT and SST, but are typically calibrated to
50 more complex models or observations, and hence could reproduce either a pure SAT or blended SAT/SST
51 metric. Richardson et al. (2016) show that defining global temperature using a blended SAT/SST metric

1 reduces the expected transient warming under rapidly increasing forcing by approximately 10% relative to a
 2 pure SAT metric, but has less impact on the equilibrium response.
 3

4 The three GMST reconstructions used in AR5 differ in their treatment of missing data. GFDL (Vose et al.
 5 2012) estimates low-frequency changes in GMST by, in effect, equating temperature anomalies in
 6 unobserved regions with a weighted average of anomalies within $\pm 10^\circ$ in space or ± 15 years in time (decadal
 7 and shorter variations are treated separately). GISS (Hansen et al. 2010) equates unobserved temperature
 8 anomalies with the average of contemporaneous observations in the corresponding latitude band, while
 9 HadCRUT (Morice et al. 2012) equates them with the hemispheric average. Since AR5, considerable effort
 10 has been devoted to more sophisticated statistical modelling to infill missing data (Rohde et al. 2013;
 11 Cowtan and Way 2014; Jones 2016), the main impact of which is to increase the warming to date by
 12 approximately 0.1°C (Richardson et al. 2016) by placing more weight on poorly-observed but rapidly-
 13 warming polar regions. Full assessment of the reliability of these infilling methods is beyond the scope of
 14 this report, which therefore defines warming to date using blended versions of the GMST datasets with their
 15 incomplete coverage, consistent with the use of these datasets in AR5. Compared to AR5, datasets have been
 16 extended in time and some have small methodological updates such as bias adjustments (Karl et al. 2015)
 17 which affect trends over recent decades, but not warming relative to the 19th century.
 18



19 **Figure 1.1:** Evolution of global warming over the observed period. Warming is expressed as anomalies from the 1850-
 20 1879 base period for monthly means of the HadCRUT4, NOAA and GISTEMP datasets, which measure a
 21 blended mix of near surface air temperature over land and sea surface temperature over oceans. Human-
 22 induced warming (orange) and naturally-forced warming (blue) are calculated using the two time constant
 23 response model of Myhre et al. (2013) following Otto et al. (2015). Proportional uncertainty in the final
 24 human-attributable warming is set equal to that assessed in Bindoff et al. (2013). The thin blue lines show
 25 the modelled global-mean surface air temperature (dashed) and blended surface air and sea surface
 26 temperature accounting for observational coverage (solid) from the CMIP5 ensemble under the Historical
 27 and RCP8.5 scenario (Cowtan et al. 2015; Richardson et al. 2016). Pink lines show initialised predictions
 28

1 using a decadal prediction system (Smith et al. 2013a). The green shading indicates a maximum and
2 minimum temperature range from the Holocene (Marcott et al. 2013). Near-term predictions for global
3 mean warming for the 2016-2035 period from Kirtman et al. (2013) are shown in light blue. See Technical
4 Annex 1.A of this chapter for further details.
5
6

7 *1.2.1.2 Choice of reference period*

8 Any choice of reference period used to approximate ‘pre-industrial’ conditions is a compromise between
9 data coverage and representativeness. Carbon budget calculations in the AR5 (e.g., Figure SPM10 of IPCC
10 (2013a) and Table 2.2 of the IPCC (2014a)) used the 1861-1880 reference period, while the evaluation of
11 impacts in Working Group 2 (e.g., Box AR5 TS.5 Figure 1 of (Field et al. 2014)) used 1850-1900. The years
12 1880-1900 are subject to strong but very uncertain volcanic forcing, complicating their use in a reference
13 period for model-observation comparisons and studies of mitigation pathways focusing on human-induced
14 warming. Hawkins et al. (2017) note that the 1720-1800 period is more representative of pre-industrial
15 forcing conditions, at the cost of increased uncertainty in estimated warming to date.
16

17 This report adopts the compromise 30-year reference period, 1850-1879 inclusive. In this period the GMST
18 in HadCRUT4 (the only available observational dataset covering this period) is less than 0.01°C higher than
19 the 51-year 1850-1900 period, and between 0.01 and 0.02°C cooler than the 1861-80 period. The period
20 1986-2005, extensively used in AR5 as a reference period representing recent climate conditions, was
21 0.61°C warmer than 1850-1879 (with a 5-95% confidence interval of 0.55-0.67°C), indistinguishable (within
22 rounding) from the warming from 1850-1900. Hence conclusions regarding observed impacts based on the
23 1850-1900 period will also be applicable to using the 1850-1879 reference period, while the latter has the
24 clear advantage for modelling and mitigation studies of avoiding post-1880 volcanic activity. The use of a
25 consistent reference period for mitigation and impact assessment (not achieved in AR5) is strongly
26 recommended. This report uses a 30-year reference period, for consistency with the WMO definition of
27 climate, and defines ‘decades’ as starting in years ending in zero, for consistency with public understanding
28 of the term. Thus far, average temperatures of the present decade (i.e., that beginning on 1st January 2010)
29 are 0.89°C warmer than 1850-1879 in the HadCRUT4 dataset. Temperatures rose by 0.0-0.2°C prior to the
30 1850-1879 reference period (Hawkins et al. 2017; Schurer et al. 2017) relative to earlier centuries, but the
31 anthropogenic contribution to this warming is uncertain (Schurer et al. 2017).
32
33

34 *1.2.1.3 Total versus human-induced warming*

35 Total warming refers to the actual temperature change, irrespective of cause, while human-induced warming
36 refers to the component of that warming that is attributable to human activities. Total warming is timescale-
37 dependent: temperatures in individual years can fluctuate substantially around the long-term average
38 temperature or secular temperature trend due to externally driven and internally generated climate variability.
39 Studies of climate change impacts typically refer to warming levels defined by multi-decade average
40 temperatures, recognizing the inevitability of fluctuations about these averages on shorter timescales and
41 smaller spatial scales.
42

43 In the absence of strong natural forcing due to changes in solar or volcanic activity, multi-decade average
44 total warming is expected to be very similar to human-induced warming. Figure 1.1 shows, for example, that
45 human-induced warming since the 1850-1879 reference period is close to total observed warming, the net
46 contribution of natural climate variations being small once random interannual variations are averaged out,
47 while monthly temperatures fluctuate substantially around this total.
48

49 Mitigation studies focus on human-induced warming because, while past natural drivers may be included in
50 historical simulations, future natural fluctuations are both unpredictable and unaffected by mitigation policy.
51 Hence, for the purposes of this report, a ‘1.5°C world’ is defined as one in which temperatures averaged over
52 a multi-decade timescale are expected to be 1.5°C above the pre-industrial reference period or, equivalently

1 in the absence of a substantial secular trend emerging in natural forcing (for which there is no evidence at
2 present), a world in which human-induced warming has reached 1.5°C.
3

4 On this definition, global temperatures would fluctuate equally on either side of 1.5°C in the absence of a
5 large volcanic eruption (which would cause a temporary cooling). Alternative definitions, such as
6 maintaining the probability of temperatures fluctuating over 1.5°C below a specified level, are more
7 ambiguous, since they depend on the averaging timescale used and the properties of future natural or internal
8 variability. For example, the decadal predictions shown in Figure 1.1 indicate there is a substantial chance
9 (probability to be given in the SOD if the relevant publication is available) of monthly temperatures
10 fluctuating over 1.5°C between now and 2020, but this would not constitute temperatures ‘reaching 1.5 °C’
11 on our working definition. An indication of the range of natural fluctuations is given by Figure 1.1, which
12 shows observed 20-year-average temperatures varied by $\pm 0.1^\circ\text{C}$ (5-95% range), and monthly temperatures
13 by $\pm 0.2^\circ\text{C}$, around the human-induced warming trend over the period 1861-2017. Regional fluctuations
14 would be larger still.
15
16

17 *1.2.1.4 Summary*

18 For the purposes of this report, warming relative to pre-industrial levels is defined as the increase in expected
19 global average blended surface air temperature changes over land and sea surface temperature changes over
20 oceans, relative to the reference period 1850-1879, noting that incomplete coverage has under sampled polar,
21 southern hemisphere and some tropical regions in the past, but assuming full spatial coverage in future. At
22 the level of precision at which GMST can be defined, this means that 1.5°C relative to pre-industrial means
23 0.9°C warmer than 1986-2005, or 0.6°C warmer than the present decade 2010-2019.
24
25

26 *1.2.2 Global versus regional and seasonal warming*

27
28 Warming is not observed or expected to be spatially uniform, nor distributed uniformly across all months of
29 the year, and is generally expected to be greater over land than over the oceans (IPCC 2013a). Hence a 1.5°C
30 increase in GMST will be associated with warming substantially greater than 1.5°C in many land regions,
31 and less than 1.5°C in most ocean regions. This is illustrated by Figure 1.2, which shows a best-estimate of
32 the observed change in seasonal average temperatures in the June-August and December-February seasons,
33 associated with the observed 1°C rise in global temperatures relative to the 1850-1879 pre-industrial
34 reference period. Many regions, particularly in northern mid-latitude winter, have already experienced
35 regional warming in excess of 1.5°C or even 2°C. Natural climate fluctuations mean that individual seasons
36 may be substantially warmer, or cooler, than these expected long-term average changes.
37

38 There has been considerable research on the ‘time of emergence’, when the climate change signal becomes
39 significant relative to the noise of internal climate variability (Joshi et al. 2011; Mahlstein et al. 2011;
40 Hawkins and Sutton 2012; Sui et al. 2014; Lyu et al. 2014). While the signal of human influence on seasonal
41 mean temperatures (Mahlstein et al. (2011) and Figure 1.2) and temperature extremes (King et al. 2015;
42 Schleussner et al. 2017) has already emerged above the noise in many regions, particularly in the tropics, the
43 signal-to-noise for precipitation is much lower. Mahlstein et al. (2012) estimate that many regions will not
44 experience statistically significant changes until GMST warming has reached 1.4°C, but substantial changes
45 in the probability of extreme precipitation events may occur much earlier (Mitchell et al. 2016).
46
47

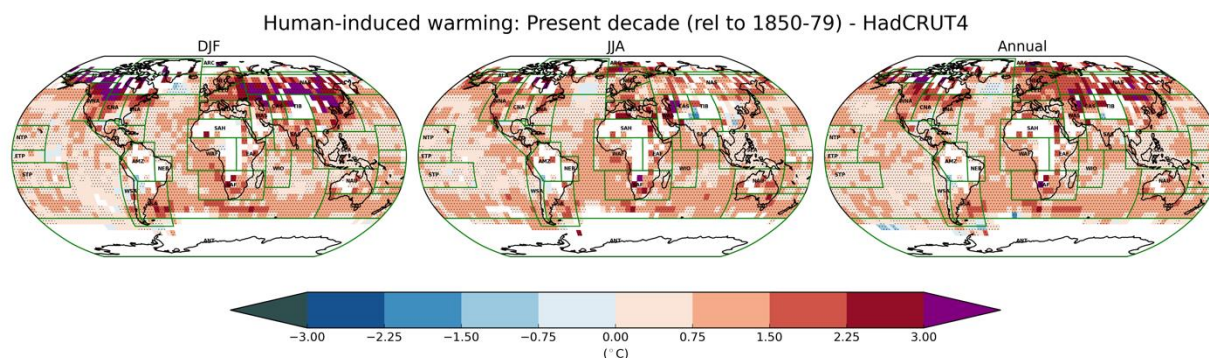


Figure 1.2: Regional human-attributable warming for the most recent decade 2007-2016 relative to 1850-1879 for the average of December, January and February (DJF – left) and for June, July and August (JJA – middle) and for the annual mean (right). Trends are evaluated by regressing regional changes in the HadCRUT4 dataset onto the human-attributable warming (orange line in Figure 1.1). Data is shown where missing data represents less than 50% of the record. Hatching indicates significance at a 10% confidence level assuming Gaussian errors. See Technical Annex 1.A of this chapter for further details.

1.2.2.1 Definition of regions

The report adopts the AR5 definition of regions that included 33 regions of land and sea areas and each of the 33 regions was provided with a name and a label (Christensen et al. 2013). Projections of change in surface temperature and precipitation show large regional variations for example, northern mid-latitude winter, have already experienced regional warming in excess of 1.5°C or even 2°C. Arctic warming is projected to increase more than the global mean, mostly because the melting of ice and snow produces a regional feedback by allowing more heat from the sun to be absorbed (Christensen et al. 2013). The Arctic region experienced its warmest year ever recorded in 2016, consistent with record low sea ice found in that region for most of the year (GISTEMP Team 2017).

1.2.3 Definition of 1.5°C consistent pathways and associated emissions

The Paris Agreement does not associate a timescale or pathway with the long-term temperature goal, so classifying temperature pathways that might be considered consistent with 1.5°C is an important task for this report. Three broad categories of temperature pathways are used in this report, associated with very different impacts and emissions: temperature stabilization, continued warming, and temperature overshoot.

The word ‘scenario’ is often used interchangeably with the word ‘pathway’. This report will not attempt to refine these definitions but, in general, pathway will be used to describe the specific evolution over time of particular climate variables, such as emissions or temperatures, while scenario will be used to refer to the underlying assumptions (see Box 1.1 on scenarios and pathways).

Figure 1.3 relates pathways of (a) temperature and (b) radiative forcing consistent with the temperature pathways shown in (a) for a given value of the Transient Climate Response (TCR), which is the relevant measure of climate response on these timescales (Frame et al. 2006; Gregory and Forster 2008; Held et al. 2010). Additional versions of Figure 1.3 corresponding to higher and lower values of the TCR are provided in Technical Annex 1.A. Panel (c) shows cumulative diagnosed CO₂-forcing-equivalent (CO₂-fe) emissions, meaning the CO₂ emissions (diagnosed with a carbon-cycle model) that would yield these radiative forcing and temperature pathways (Wigley 1998; Zickfeld et al. 2009; Manning and Reisinger 2011; Allen et al. 2017). The similarity between panels (a) and (c) shows that, to a good approximation, cumulative CO₂-fe emissions equal total anthropogenic warming multiplied by the Transient Climate Response to Emissions (TCRE) (Allen et al. 2009; Matthews et al. 2009; Gillett et al. 2013; Collins et al. 2013; Millar et al. 2016). Panel (d) shows annual CO₂-fe emissions, which are simply the time rate of change of (c). A CO₂-fe

1 emission pathway will have approximately the same impact on GMST as a corresponding pure-CO₂ pathway
2 (see Box 1.2 on metrics and balance).

3
4 The relationship between different forcing mechanisms and GMST response is further complicated by
5 efficacy considerations (Myhre et al., 2013). The same global mean radiative forcing from different
6 mechanisms (e.g., aerosol and CO₂ change) can have different transient and equilibrium GMST impacts of
7 typically 20-30% (Shindell 2014; Rotstayn et al. 2015; Marvel et al. 2016). This makes the relationship
8 between CO₂-fe emission pathways and GMST temperature somewhat dependent on the nature of the
9 scenario, but this dependence can be minimised through the use of ‘Effective Radiative Forcing’ (Myhre et
10 al. 2013).

11 12 13 *1.2.3.1 Temperature stabilization pathways*

14 The simplest 1.5°C-consistent pathway is one in which human-induced warming rises monotonically to
15 stabilise at 1.5°C. Because of the inertia of the climate, carbon cycle and energy systems, the rate of human-
16 induced warming varies slowly over decades, allowing only smooth temperature pathways if temperature
17 goals are achieved through emission reductions alone (Huntingford et al. 2017). Stabilization also has been
18 used to refer to stabilization of atmospheric greenhouse gas concentrations, which would result in continued
19 warming (see Section 1.2.4). This report will focus on temperature rather than concentration stabilization
20 pathways.

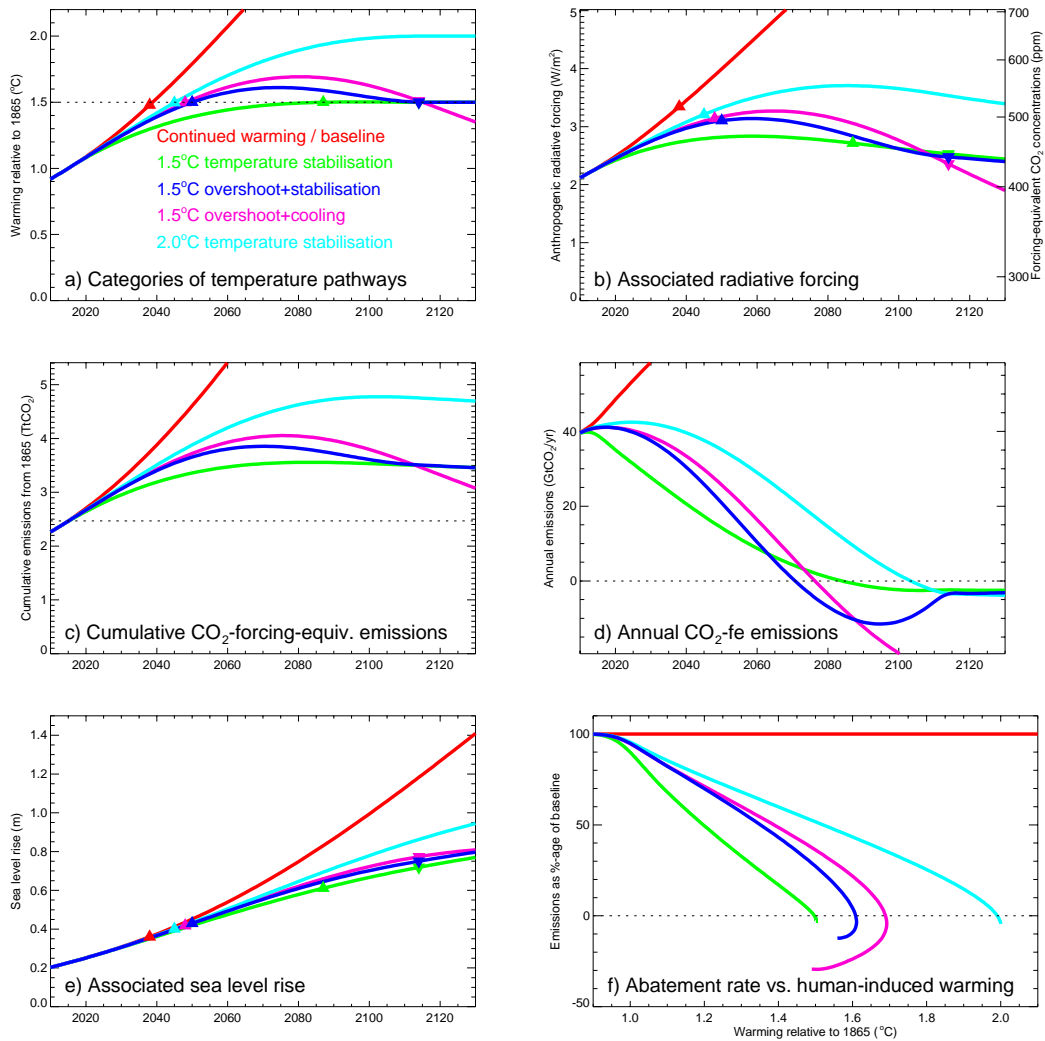
21
22 Stabilizing GMST requires net annual CO₂-fe emissions (Figure 1.3, panel d) to decline to near zero or
23 slightly below (depending on the long-term adjustment of the carbon cycle), but does not imply stabilizing
24 other aspects of climate. If other forcings are constant and positive, stable GMST implies gradually declining
25 CO₂ concentrations (panel b, and Solomon et al. (2009)), so ocean pH levels would begin to recover. Sea
26 level, represented in panel (e) by a very simple semi-empirical model (Kopp et al. 2016), would continue to
27 rise, but at substantially lower rates than would be expected under a continued warming scenario. The
28 requirement that CO₂-fe emissions must reach zero to stabilise temperatures also means that the abatement
29 rate must increase (or emissions as a percentage of baseline “no-policy” scenario must decrease) as
30 temperatures rise, to reach 100% reduction from baseline around the time of peak warming. Panel (f) shows
31 how the level and rate of change in this quantity provides an indication of expected peak warming under a
32 smooth mitigation scenario.

33 34 35 *1.2.3.2 Temperature overshoot pathways*

36 Under this category of pathway, temperatures rise above 1.5°C before peaking and declining, either to
37 converge on 1.5°C from above or to fall below it. Substantial negative CO₂-fe emissions (corresponding to
38 anthropogenic removals of CO₂) are required to draw temperatures down, so their feasibility and availability
39 limit accessible rates of temperature decline. In this report, consistency with the Paris Agreement
40 temperature goal is interpreted as implying temperatures peaking well below 2°C. Overshoot pathways are
41 referred to in this report as 1.5°C-consistent, but qualified by the amount, duration and timing of the
42 temperature overshoot, which can have a substantial impact on sea level rise (e) and many irreversible
43 climate change impacts such as species extinctions.

44 45 46 *1.2.3.3 Continued warming pathways*

47 Under this category, 1.5°C is reached and temperatures then continue to warm. An important sub-category of
48 continued warming pathways are pathways associated with baseline scenarios, in which no climate
49 mitigation policies are assumed at all, or ‘current policies’ scenarios, in which existing climate mitigation
50 policies and commitments are extrapolated into the future. Triangles in Figure 1.3 show that CO₂-fe
51 concentrations (and hence CO₂ concentrations themselves) and sea level would be very different when
52 temperatures reach 1.5°C on a continued warming pathway than when on a stabilisation pathway.
53 Upward pointing triangles in panels a, b and e show years in which 1.5°C is reached from below, while
54 downward pointing triangles indicate years it is reached from above following an overshoot.



1
 2 **Figure 1.3:** Schematic showing a) categories of temperature pathways; b) radiative forcing that would give the
 3 temperature responses in (a) with a simple climate model (Myhre et al. 2013; Millar et al. 2017) and a
 4 representative value (1.6°C) of the Transient Climate Response; c) cumulative CO₂-forcing-equivalent
 5 emissions that would give the radiative forcing in (b) with a simple carbon cycle model (Millar et al.,
 6 2017); d) annual CO₂-fe emissions that would give the cumulative emissions in (c); e) sea-level-rise in
 7 response to temperature pathways from a semi-empirical model (Kopp et al. 2016); f) Abatement rate
 8 (Emissions as a percentage of baseline no-policy scenario (100 minus Abatement Rate) plotted as a
 9 function of warming, showing how the level and rate of decrease in this quantity provides an indication of
 10 expected peak warming under a smooth mitigation scenario.

13 *1.2.3.4 Prospective versus adaptive mitigation pathways*

14 A useful distinction can be drawn between ‘prospective’ mitigation pathways, in which emissions are
 15 prescribed to limit the prospect of temperatures exceeding a given threshold at a given level of probability
 16 given current uncertainties in the climate response, and ‘adaptive’ pathways, in which it is assumed that
 17 emissions are actively adjusted in future to meet the temperature goal in the light of the emerging climate
 18 response. They show that TCR uncertainty alone means that, in a prospective pathway corresponding to two
 19 thirds chance of temperatures remaining below 1.5°C, the most likely warming is around 1.2°C while there is

1 still a non-negligible probability of temperatures exceeding 2°C (see Box 1.1 on scenarios and pathways and
2 Section 2.2).
3
4

5
6 **Box 1.1: Scenarios and Pathways**

7 Authors: Mikiko Kainuma, Elmar Kriegler, Joeri Rogelj, Kristie L. Ebi, Sabine Fuss, Keywan Riahi, Rachel
8 Warren
9

10 A **scenario** is a comprehensive, plausible, and integrated description of a possible future of the human-
11 environment system, including a narrative with qualitative trends and quantitative projections (Nakićenović
12 et al. 2000). Climate change scenarios provide a framework for developing and integrating emissions,
13 climate change and climate impact projections, including an assessment of their inherent uncertainties. The
14 long-term and multi-faceted nature of climate change requires them to describe how assumptions about
15 inherently uncertain 21st century trends of key driving forces such as population, GDP, technological
16 innovation, governance, and lifestyles influence future energy and land use, resulting emissions and climate
17 change as well as human vulnerability and exposure to climate change. Such descriptions allow climate
18 change scenarios to be used as frameworks for analysing and contrasting climate policy choices.
19

20 '**Pathway**' can have different meanings in the literature. It is often used to describe the temporal evolution of
21 a set of scenario features, such as GHG emissions and socioeconomic development. As such, it can describe
22 individual scenario components or the scenario itself. For example, the **Representative Concentration**
23 **Pathways (RCPs)** describe greenhouse gas concentration trajectories (van Vuuren et al. 2011) and the
24 **Shared Socio-Economic Pathways (SSPs)** a set of narratives of societal futures augmented by quantitative
25 projections of socio-economic determinants such as population, GDP, and urbanization (O'Neill et al. 2014;
26 Kriegler et al. 2012). Socio-economic driving forces consistent with any of the SSPs can be combined with a
27 set of climate policy assumptions that together would lead to emissions and concentration outcomes
28 consistent with the RCPs (Kriegler et al. 2014). This is at the core of the new scenario framework for climate
29 change research that aims to classify scenarios according to their similarities in the SSP and RCP dimensions
30 (Ebi et al. 2014; van Vuuren et al. 2014).
31

32 In other parts of the literature, 'Pathway' implies a solution orientation that is a scenario from today's world
33 to achieving a set of future goals. **Climate resilient development pathways** describe social and
34 governance/policy dimensions that need to be met to ensure the climate mitigation pathways fulfil the equity
35 and equality dimensions outlined in Agenda 2030 (United Nations 2015b). This includes considering the
36 conditions needed so that poorer nations are enabled to design local solutions and afford externally produced
37 technologies without developing new dependencies or high-risk pathways.
38

39 Climate change scenarios have been used in IPCC assessments since the First Assessment Report (Leggett et
40 al. 1992). The **SRES scenarios** (named after the IPCC Special Report on Emissions Scenarios, (Nakićenović
41 et al. 2000)) published in 2000 consists of four scenarios that do not take into any future measures to limit
42 greenhouse gas (GHG) emissions, but many policy scenarios have been developed based on these scenarios
43 (Morita et al. 2001). The SRES scenarios are superseded by a new set of **SSP-RCP based scenarios** (Riahi et
44 al. 2017). The **Representative Concentration Pathways (RCPs)** constitute a set of four GHG concentration
45 trajectories that jointly span a large range of plausible human-caused climate forcing ranging from 2.6 W m²
46 (RCP2.6) to 8.5 W m² (RCP8.5) by the end of the 21st century (van Vuuren et al. 2011). They were used to
47 develop new climate projections in the 5th Coupled Model Intercomparison Project (CMIP5, Taylor et al.
48 (2012)) and have been assessed in the IPCC 5th Assessment Report. RCP2.6, which in the CMIP5 ensemble
49 provides a better than two in three chance of staying below 2°C and a median warming 1.6°C relative to 1850-
50 1879 in 2100, is often used as representative of a 'well below 2°C' pathway.
51

52 Recently, the RCPs were complemented by the **Shared Socio-economic Pathways (SSPs)**, which allow to
53 structure the scenario set according to varying socio-economic challenges to adaptation and mitigation. Based
54 on five narratives, the SSPs describe alternative socio-economic futures, comprising sustainable development
55 (SSP1), regional rivalry (SSP3), inequality (SSP4), fossil-fuelled development (SSP5), and middle-of-the-road

1 development (SSP2) (Riahi et al. 2017; O'Neill et al. 2017). Socioeconomic drivers, comprising population
2 and education (KC and Lutz 2017), economic growth (Crespo Cuaresma 2017; Dellink et al. 2017; Leimbach
3 et al. 2017), and urbanisation (Jiang and O'Neill 2017), are quantified for all SSPs (Riahi et al. 2017). Based
4 on the narratives and the driver projections, SSP-based scenarios were developed for a baseline case without
5 climate policy and mitigation cases aiming to reach, *inter alia*, the end of century forcing levels of the RCPs.
6 These scenarios offer an integrated perspective on socio-economic, energy system (Bauer et al. 2017), land
7 use (Popp et al. 2017), air pollution (Rao et al. 2017) and greenhouse gas emissions developments (Riahi et al.
8 2017). A subset of SSP-based baseline and mitigation scenarios will be used to drive the next round of climate
9 change projections (CMIP6) to be assessed in the upcoming Sixth Assessment Report of the IPCC (O'Neill et
10 al. 2016). Because of their harmonised assumptions, scenarios developed with the SSPs facilitate the integrated
11 analysis of future climate impacts, vulnerabilities, adaptation, and mitigation.

12
13 This report focuses on scenarios that could limit the global mean surface air temperature increase to 1.5°C
14 above preindustrial. Other scenarios are also addressed, including baseline scenarios that assume no climate
15 policy; scenarios that assume some kind of continuation of current climate policy trends and plans, many of
16 which are used to assess the implications of the NDCs; and (well below) 2°C scenarios. A distinction must
17 be drawn between 'efficient' baseline scenarios, in which resources are deployed efficiently in the future
18 without regard to their climate impact, and 'business-as-usual' scenarios in which current trends and policies
19 are extrapolated. The distinction is important because mitigation scenarios typically assume efficient
20 resource allocation subject to a climate constraint, so an efficient baseline is needed for a like-for-like
21 comparison. These other scenarios are used to provide context for the mitigation and adaptation actions in a
22 1.5°C scenario. Even though this report focuses on global mitigation scenarios, regional, national and local
23 scenarios are important to understand the challenges of achieving a 1.5°C target and are thus indispensable
24 when assessing implementation.

25
26 Different climate policies result in different temperature pathways, which result in different climate impacts.
27 Temperature pathways are classified into continued warming pathways (in the cases of baseline and
28 reference scenarios), temperature stabilization and temperature overshoot pathways relative to the 1.5°C and
29 2°C temperature targets. In the case of overshoot, net negative CO₂ emissions are required to remove excess
30 CO₂ from the atmosphere.

31
32 Emission scenarios can be classified as 'prospective' or 'adaptive'. Prospective scenarios are estimated by
33 calculating the emissions consistent with a given prospect or probability, such as a 50:50 or two thirds
34 chance, of staying below a temperature limit, given current knowledge of the climate system response.
35 Adaptive scenarios foresee emission plans evolving to stay below the temperature limit as new information
36 about the climate response emerges. The 1.5°C pathways assessed in Chapter 2 of this report are prospective.
37 The differences between climate impacts at different warming levels assessed in Chapter 3 are better related
38 to adaptive pathways. Unless otherwise qualified, the 'impacts of 1.5°C warming' refers to climate impacts
39 in a world that has succeeded in holding warming to 1.5°C, whatever the response, not climate impacts in a
40 world that has simply taken measures required, in the light of current knowledge of the climate response, to
41 limit the prospect of temperatures exceeding 1.5°C to a particular probability. The latter would also include
42 (and might indeed be dominated by) the impacts of other warming levels that might emerge in such a
43 prospective scenario.

44 45 46 47 *1.2.3.5 Impacts at 1.5°C associated with different pathways*

48 Impacts that occur when GMST reaches 1.5°C under a continued warming or overshoot pathway may be
49 very different from those on a 1.5°C temperature stabilization pathway, since surface temperatures are not in
50 equilibrium with atmospheric composition. To illustrate this point, triangles in Figure 1.3, panels (b), (e) and
51 (f) correspond to years in which temperatures reach 1.5°C in panel (a). In particular, CO₂ concentrations will
52 be higher, and sea level and, potentially, mean precipitation (Pendergrass et al. 2015) both lower as
53 temperatures warm past 1.5°C than they are as temperatures stabilise at 1.5°C, leading to very different

1 impacts on agriculture, some forms of extreme weather, and marine and terrestrial ecosystems (James et al.
2 2017; Mitchell et al. 2016).

3 4 5 *1.2.3.6 Cumulative budgets for CO₂ and CO₂-forcing-equivalent emissions*

6 The AR5 noted that there is a simple, near-linear relationship between cumulative CO₂ emissions and CO₂-
7 induced warming (Allen et al. 2009; Matthews et al. 2009; Zickfeld et al. 2009), characterised by the
8 Transient Climate Response to Emissions, or TCRE. At that time, the notion of a cumulative carbon budget
9 could not be extended to non-CO₂ agents because the majority of these are relatively short-lived climate
10 forcers (SLCFs) and hence do not accumulate in the climate system. Shine et al. (2005), Lauder et al. (2013)
11 and Allen et al. (2016), observe that an approximate equivalence can be drawn between cumulative
12 emissions of CO₂ and changes in emission rates of SLCFs, allowing the construction of CO₂-forcing-
13 equivalent (CO₂-fe) emissions (Wigley 1998; Zickfeld et al. 2009; Manning and Reisinger 2011; Allen et al.
14 2017), defined as the CO₂ emission pathway that results in the same radiative forcing as a multi-gas
15 pathway, assuming efficacies are close to unity (see Section 1.2.3). Because the climate response to CO₂-fe
16 emissions is, by construction, the same as the response to CO₂, the same near-linear relationship holds: total
17 human-induced warming is equal to cumulative CO₂-fe emission multiplied by the TCRE.

18
19 This simple relationship helps frame the mitigation challenge. In an exponential temperature stabilization
20 pathway, total future warming is given by the current rate of warming divided by the rate per year at which
21 warming slows down (just as the stopping distance of a car is determined by the current speed divided by the
22 deceleration rate). Human-induced warming is currently approximately 1°C (Otto et al. 2015) and increasing
23 at 0.1-0.25°C per decade (Kirtman et al. 2013; Hausteine et al. 2017 and Figure 1.1). To limit total warming
24 to 1.5°C via an exponential stabilization pathway, this rate of warming must decrease by 2-5% yr⁻¹ from now
25 on, which would mean the annual rate of CO₂-fe emissions henceforth also being reduced by 2-5% yr⁻¹. The
26 current level and rate of increase of human-induced warming are therefore critically important in
27 determining how fast CO₂-fe emissions need to be reduced to avoid overshooting a temperature goal.

28 29 30 *1.2.4 Definition of ‘balance’ and net zero emissions*

31
32 Article 4 of the Paris Agreement acknowledges that, ‘in order to achieve the long-term temperature goal (...)
33 Parties aim to (...) achieve a balance between anthropogenic emissions by sources and removals by sinks of
34 greenhouse gases in the second half of this century’. This report will examine the scientific basis of what is
35 meant by ‘balance’ in the context of 1.5°C and how ‘balance’ relates to the temperature goals articulated in
36 Article 2 of the Agreement. A number of interpretations are possible, but in this report, ‘balance’ will
37 generally be interpreted in terms of a sustained combination of emissions and removals that results in stable
38 GMST (Fuglestad et al. 2017).

39
40 On multi-century timescales, natural processes that remove CO₂ permanently from the active carbon cycle
41 are so slow that balance requires net global anthropogenic CO₂ emissions close to zero (Archer and Brovkin
42 2008; Matthews and Caldeira 2008; Solomon et al. 2009). Hence any remaining anthropogenic CO₂
43 emissions will need to be compensated for by an equal rate of anthropogenic carbon dioxide removal (CDR),
44 using measures such as bioenergy with carbon capture and sequestration (BECCS), large-scale afforestation,
45 biochar enhanced soil sequestration, direct air capture or ocean alkalisation (Chapter 4, Section 4.3.6).

46
47 For greenhouse gases other than CO₂, ‘balance’ for temperature stabilization requires net zero total
48 anthropogenic CO₂-fe emissions (by definition, CO₂-fe emissions affect temperatures like CO₂), but this
49 need not imply zero anthropogenic emissions of individual gases or zero total CO₂-equivalent emissions if
50 equivalence is defined using the conventional Global Warming Potential (see Box 1.2). Sustained constant
51 emissions of a short-lived climate forcer (SLCF) such as methane could be consistent with gradually
52 declining atmospheric concentrations (Shine et al. 2005; Rogelj et al. 2015a; Schleussner et al. 2016b) and
53 no additional contribution to warming. Even though equivalent to a zero rate of CO₂-fe emissions, such a

1 constant emission of an SLCF could still represent a mitigation opportunity, since reducing it would lead to
2 cooling.

3
4 Changes in anthropogenic emissions of non-greenhouse gas SLCFs, such as sulphur dioxide, black carbon
5 and non-methane ozone precursors also affect the ability to meet temperature goals. Although such
6 emissions are not explicitly covered in Article 4 of the Paris Agreement, they contribute to total
7 anthropogenic CO₂-fe emissions, so changes in all these can be included in the definition of balance.

8
9 Another interpretation of Article 4 might be that sources and sinks of greenhouse gases balance in such a
10 way that the equivalent atmospheric CO₂ concentration is stabilised. This, however, implies continued
11 warming (see Section 1.2.5) which is not consistent with a focus on temperature goals. Should temperatures
12 exceed 1.5°C, returning global temperature to 1.5°C would require anthropogenic cooling of the climate
13 system, or net negative CO₂-fe emissions through some combination of anthropogenic removals of long-
14 lived greenhouse gases and falling anthropogenic emissions of SLCFs. Hence achieving 'balance' in the
15 sense of net zero CO₂-fe emissions represents a necessary, but potentially not sufficient, condition for
16 achieving the 1.5°C temperature goal, if net-negative CO₂-fe emissions are required to return temperatures to
17 1.5°C under an overshoot scenario.
18
19

20 **Box 1.2:** Long-lived and short-lived climate forcers, emission metrics and emissions 'balance'

21 Authors: Piers Forster, Myles Allen, Elmar Kriegler, Joeri Rogelj, Seth Schultz, Drew Shindell, Kirsten
22 Zickfeld

23
24 It is often useful to compare emissions of different anthropogenic forcers using simplified indicators,
25 whether in terms of their effects on climate or their socioeconomic impacts (Clarke et al. 2014; Myhre et al.
26 2013). Metrics such as the Global Warming Potential are used in multi-gas policy frameworks such as the
27 Kyoto Protocol and successive climate agreements, to compare emissions from different sectors and regions
28 (Weyant et al. 2006) and as a measure of exchange within many integrated assessment models (Myhre et al.
29 2013; Reisinger et al. 2012; Smith et al. 2013b; Klein et al. 2014a). Metrics are also used to represent multi-
30 gas pathways in terms of so-called 'CO₂-equivalent' emissions (Clarke et al. 2014). As no two emissions
31 have the same broad range of effects, the choice of metric represents value judgements over what is equated
32 and what time frames are considered. Unified frameworks of GHG metrics have linked metric choice to the
33 intended use and the admissible level of uncertainty about metric values (Richard et al. 2012; Deuber et al.
34 2013).
35

36 Examples of physical impact metrics are the Global Warming Potential (GWP) and the Global Temperature
37 Change Potential (GTP), and of socio-economic impact metrics the Global Cost Potential (GCP) and the
38 Global Damage Potential (GDP). GWP is the ratio between the integrated radiative forcing due to a unit
39 mass emission of a particular gas and the integrated radiative forcing of a unit mass emission of carbon
40 dioxide over a given time period. The GTP compares the endpoint temperature change, the GCP employs a
41 cost effectiveness framework and the GDP compares marginal climate-related damages from emission
42 increases. To date, UNFCCC protocols have adopted GWPs over a 100 year time period to account for a
43 basket of greenhouse gases based on either IPCC SAR or AR4 values. IPCC WG3 reports have used the
44 same metric to evaluate CO₂-equivalent emissions. The GWP can be calculated to a higher degree of
45 certainty than the other metrics but is somewhat removed from both the resultant climate impact of an
46 emission and any policy interventions (Myhre et al. 2013). It is also increasingly misleading as an indicator
47 of impact on GMST under ambitious mitigation scenarios (Allen et al. 2017). Metrics used in policy often
48 lag behind the research-base. For example, the carbon cycle response for non-CO₂ gases was preliminarily
49 included into GWP estimates in IPCC AR5 (Myhre et al. 2013), raising GWP values (which have since been
50 updated in Gasser et al. 2017), but is not yet accounted for in policy.
51

52 CO₂-forcing-equivalent (CO₂-fe) emissions (Wigley 1998; Manning and Reisinger 2011; Allen et al. 2017)
53 are defined as the CO₂ emissions that give the same radiative forcing pathway that results from a non-CO₂ or
54 multi-gas emission pathway. They are computed directly from radiative forcing using a carbon cycle model.
55 While they are therefore subject to modelling uncertainty, CO₂-fe emissions do not depend on a choice of

1 metric and indicate more directly how different emissions contribute to global mean surface temperature
2 (GMST) change.
3

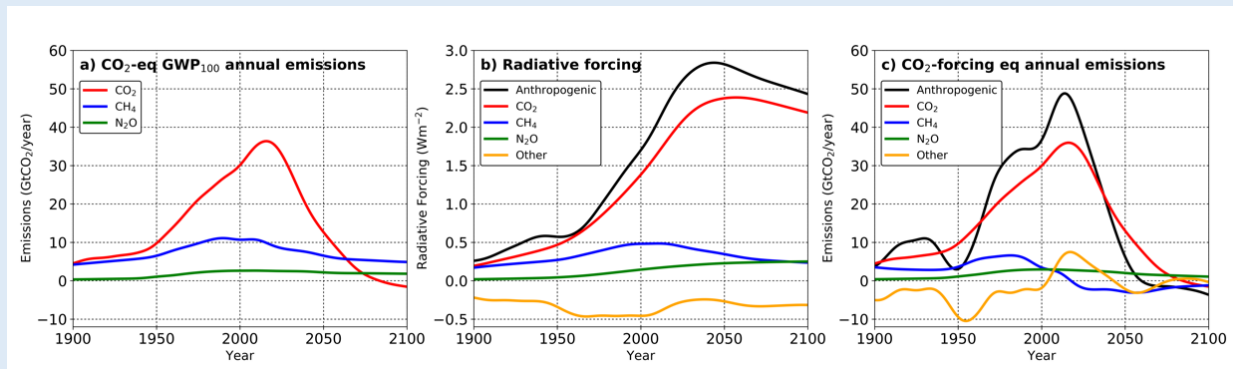
4 A clearly defined policy goal or implementation strategy narrows the range of suitable metrics. A
5 temperature goal as articulated within Article 2 of the Paris Agreement would point to a temperature change
6 metric, although other considerations such as limiting the climate damages up to the temperature goal or
7 during a temporary overshoot of the goal remain relevant. GTP has the limitation of focusing on the
8 temperature at a single point in the future, which may neither reflect the actual policy goal nor the success or
9 failure of staying on track towards this goal. An alternative approach is to use a metric that approximates
10 CO₂-fe emissions, which have (by construction) the same impact as CO₂ on radiative forcing and GMST
11 over all timescales. Allen et al. (2016a) show how the GWP metric can be modified to achieve this
12 approximately. They define a GWP* metric that equates a sustained one-tonne-per-year increase in the
13 emission rate of a short-lived climate forcer (SLCF) with the emission (as a one-off pulse) of $GWP_H \times H$
14 tonnes of CO₂, where GWP_H is the value of that short-lived component's GWP for a time-horizon H . Both of
15 these have a similar impact on GMST over a broad range of timescales.
16

17 It may be desirable to consider more than GMST in the definition of metrics. Even if GMST is stabilised,
18 sea-level rise and associated impacts will continue (Stern et al. 2014). Within the broader context of
19 sustainable development articulated in the Paris Agreement, there are many possible alternative narratives of
20 impacts. In particular, early action on short-lived climate forcers (including actions that may warm the
21 climate such as reducing SO₂ emissions) may have considerable societal co-benefits such as reduced air
22 pollution and improved public health with associated economic benefits (Shindell et al. 2016; OECD 2016).
23 Valuation of broadly defined social costs is another emission metric that attempts to account for many of
24 these additional non-climate factors along with climate-related impacts (Shindell 2015; Sarofim et al. 2017;
25 Shindell et al. 2017). For any given sector and/or state it may also be more or less economically viable to
26 target mitigation of particular gases over CO₂ mitigation measures. In addition, balanced contributions to
27 global mean temperature change do not imply balanced contributions to many other impacts, such as ocean
28 acidification or agricultural yields even for well-mixed greenhouse gases.
29

30 To achieve stable GMST, a combination of emissions that achieves sustained net zero CO₂-fe emissions is
31 required. To a fair degree, this can be approximated by net zero emissions measured by GWP* (Allen et al.
32 2017). In a steady state, this means near-zero net emissions of long-lived greenhouse gases (CO₂ and gases
33 with lifetimes of a century or more, such as nitrous oxide) and near-constant net emissions of SLCFs. Within
34 the categories of long-lived gases and SLCFs there would still be scope for temporary trade-offs (Smith et al.
35 2012, and Daniel et al. 2012), but compensating for substantial continued net emissions of long-lived
36 greenhouse gases with continually falling emissions of SLCFs would not be possible, since it is unfeasible to
37 reduce the rate of emission of most SLCFs below zero (with the possible exception of methane – see
38 Boucher and Folberth 2010). To achieve a peak and decline in GMST net CO₂-fe emissions have to become
39 negative, and this also applies in approximation to GWP*.
40

41 Box 1.2, Figure 1 shows emissions of and radiative forcing due to CO₂, methane and nitrous oxide under the
42 RCP2.6 mitigation scenario, contrasting CO₂-equivalent computed with AR5 GWP₁₀₀ values (Myhre et al.
43 2013) with CO₂-fe emissions computed with a simple carbon cycle model (Millar et al. 2017). Note that
44 falling methane emissions over the coming decades equate to negative CO₂-fe emissions, in that only active
45 removal of CO₂ would have the same impact on radiative forcing and GMST as a reduction in methane
46 emissions. Traditional metrics such as GWP₁₀₀ are adequate for representing the GMST impact of long-lived

1 gases but become increasingly unrepresentative of forcing and temperature impact of SLCFs under
 2 ambitious mitigation scenarios.
 3



4
 5
 6 **Box 1.2, Figure 1:** (a) emissions of CO₂, methane and nitrous oxide under the RCP2.6 mitigation scenario expressed as
 7 CO₂-equivalent using GWP₁₀₀; (b) radiative forcing resulting from these emissions, plus other (primarily aerosols and
 8 ozone) and the total anthropogenic forcing; (c) CO₂-forcing-equivalent emissions, defined (Wigley 1998) as the CO₂
 9 emissions that give the radiative forcing pathways shown in the central panel, derived using a simple climate-carbon-
 10 cycle model (Millar et al. 2017).
 11

12 1.2.5 Definitions of warming commitment

14 The question of whether meeting the 1.5°C target is ‘feasible’ implicitly includes the notion of warming
 15 ‘commitment’, or unavoidable future warming. This commitment arises due to inertia in the physical Earth
 16 system, but also due to technological, economic, institutional and behavioural inertia.
 17
 18

19 Geophysical warming commitment is defined as the unavoidable future warming resulting from geophysical
 20 inertia. The most widely used variant of geophysical warming commitment is the ‘constant composition
 21 commitment’, which is the remaining warming if atmospheric composition and hence radiative forcing were
 22 stabilised at the current level (Collins et al. 2013). The former has often been used to illustrate inertia in the
 23 physical climate system, primarily associated with slow heat uptake by the ocean (the so-called warming ‘in
 24 the pipeline’ (Hansen et al. 2005)). This type of commitment includes the climate system response to past
 25 emissions, as well as the response to future emissions that are required to maintain a constant atmospheric
 26 composition, and is therefore ill suited to estimate a lower bound on future warming resulting from
 27 geophysical inertia alone.
 28

29 Another variant of geophysical warming commitment is the ‘zero emissions commitment’, which defines the
 30 remaining warming if future anthropogenic emissions of greenhouse gases and aerosol precursors were
 31 eliminated (Collins et al. 2013). The zero emissions commitment, although based on highly idealised
 32 assumptions, has value as it allows one to clearly isolate the climate system response to past emissions from
 33 socio-economic assumptions about future emissions. The magnitude and sign of the zero emissions
 34 commitment depend on the mix of gases considered because of different lifetimes¹ and signs of radiative
 35 forcing. For CO₂, where the elevated atmospheric concentration change from an emission has a lifetime of
 36 decades to millennia (Eby et al. 2009), the commitment from past emissions ranges from slightly negative
 37 (i.e., a slight cooling after emissions cease) to zero (Gillett et al. 2011; Matthews and Zickfeld 2012; Lowe et
 38 al. 2009; Frölicher and Joos 2010), implying no future warming from past CO₂ emissions. This near-zero
 39 warming commitment for CO₂ arises from the near cancellation between declining radiative forcing in
 40 response to the elimination of CO₂ emissions (cooling effect) and the delayed temperature response to
 41 previously increasing radiative forcing from CO₂ (warming effect) (Solomon et al. 2009).
 42
 43

¹ We here refer to the atmospheric lifetime of the atmospheric CO₂ perturbation, rather than the turnover time in the atmosphere.

1 For greenhouse gases with a short atmospheric lifetime (order of decades or less) such as methane (CH₄) the
2 warming commitment is negative, implying cooling if future emissions of these gases are eliminated
3 (Matthews and Zickfeld 2012; Frölicher and Joos 2010). This cooling arises from a rapid decline in radiative
4 forcing, which dominates over the delayed warming response to previously increasing radiative forcing.
5 Substances with a short atmospheric lifetime and negative radiative forcing such as sulphate aerosols have a
6 positive warming commitment, as elimination of the radiative ‘dimming’ effect of these aerosols results in
7 rapid warming over about a decade (Frölicher and Joos 2010; Matthews and Zickfeld 2012). Estimates of the
8 warming commitment from eliminating sulphate aerosols is uncertain due to large uncertainties in radiative
9 forcing (Myhre et al. 2013). Using a range of sulphate aerosol radiative forcings consistent with temperature
10 observations, Matthews and Zickfeld (2012) estimate a total geophysical warming commitment from GHGs
11 and sulphate aerosol emissions up to year 2010 of 0.3°C (0.25-0.5°C) over the decade immediately following
12 elimination of emissions. This warming is followed by a cooling due to decline in radiative forcing of non-
13 CO₂ GHGs, with the temperature response converging to that from elimination of CO₂ alone after about a
14 century. The radiative forcing from sulphate aerosols has decreased over the last decade (Myhre et al. 2017)
15 suggesting a lower warming commitment from elimination of sulphate aerosols than estimated in Matthews
16 and Zickfeld (2012).

17
18 Geophysical warming commitment can be thought of as the minimum warming commitment, absent inertia
19 in the socio-economic system, and absent active removal of CO₂ from the atmosphere by human activities.
20 However, existing infrastructure, technologies, policies, institutions, and behavioural and social norms
21 constrain the rate and magnitude of future GHG emission reductions. These constraints determine the GHG
22 emissions reductions that are feasible in the near- and medium term and define the warming commitment
23 resulting from socio-economic inertia (referred to as the ‘feasible scenario commitment’; (Hare and
24 Meinshausen 2006)).

25
26 Three main types of inertia in the socio and techno-economic system have been identified in the literature:
27 infrastructural and technological, institutional, and behavioural (Seto et al. 2016). Infrastructural and
28 technological inertia arises from the long lifetime and large investments associated with energy
29 infrastructure. For instance, unless power plants will be retrofitted with carbon capture and sequestration
30 (CCS) or operable infrastructure decommissioned early, existing infrastructure can be expected to contribute
31 CO₂ emissions and warming for many decades. Davis et al. (2010) estimate 0.2-0.5°C future warming from
32 existing GHG emitting energy infrastructure (as of 2009). Pfeiffer et al. (2016) gave a similar range from
33 present infrastructure.

34
35 In contrast to infrastructure and technological inertia, ‘institutional inertia is an intended feature of
36 institutional design, not an unintended by-product of systemic forces’ (Seto et al. 2016). Institutional inertia
37 arises because ‘powerful economic, social, and political actors seek to reinforce a status quo that favours
38 their interests against impending change or to create and then stabilise a new, more favourable, status quo’
39 (Seto et al. 2016). The transition to a low-carbon trajectory is also hampered by behavioural inertia. Two
40 factors contribute to this inertia: psychological processes and social structure. Habits, aversion to take risks
41 and the necessity of collective action to solve the climate change problem (giving the feeling to individuals
42 that they have little control over the problem) can lock in carbon intensive behaviours (Seto et al. 2016).
43 Also, individual behaviour is embedded in social norms and processes that change only slowly in response to
44 changes in the technological and political environment (Seto et al. 2016). The emission pathways and
45 unavoidable warming from such inertia has not yet been quantified.

46
47 One way of visualising this commitment is the notion of a ‘stopping distance’: under a smooth temperature
48 stabilisation pathway, future warming is approximately equal to the current rate of human-induced warming
49 divided by the average compound rate at which warming decreases from now on, or the rate of decrease of
50 CO₂-forcing-equivalent emissions. If emissions decrease by at most 4% per year, for example, (a typical
51 capital turnover time in the energy industry), then a current warming rate of 0.1-0.25°C per decade (Kirtman

1 et al. 2013) implies a stopping distance (committed future warming) of at least 0.25-0.6°C, consistent with
2 Davis et al. (2010) and Pfeiffer et al. (2016).
3
4

5 **1.3 Multiple dimensions of impacts at 1.5° C and beyond**

6
7 The impacts of climate change throughout the world are projected to be uneven and in some instances, very
8 localised. Impacts are consequences not only of rising temperatures, sea level and ocean acidification, but
9 also of shifting rainfall patterns and extreme events such as floods, droughts, and heat waves, all of which
10 occur within the background of natural climate variability (IPCC 2012a, 2014c). Impacts of climate change
11 occur across all continents and across the oceans, affecting many sectors including natural and managed
12 ecosystems, urban and rural areas, economic services, human health, livelihoods and poverty, and human
13 security (IPCC 2014a). Many impacts have been formally attributed to anthropogenic global warming and
14 the increasing greenhouse gas concentrations due to human activities (Hansen et al. 2016; Rosenzweig et al.,
15 2008), but other forcings play major roles, such as land use change (e.g., Pitman et al., 2011; Ward et al.
16 2014), atmospheric pollution (e.g., aerosols; Menon et al. 2002), and irrigation (Thiery et al. 2017).
17

18 The reference to ‘1.5°C above pre-industrial’ is part of the Paris Agreement and thus a target defined in the
19 context of UNFCCC COP21 negotiations; but what do we mean when we say ‘impacts of 1.5 °C’?
20 Differentiating the impacts of 1.5°C from those of 2°C does not imply a scientific statement of safe vs.
21 unsafe conditions of environmental change. For a number of systems, the differential impacts of 1.5°C and
22 2°C have been found to reach the upper limit of current natural variability, for example for heat-related
23 extremes in tropical regions (Schleussner et al. 2016a) or for ecosystem change in the Mediterranean Basin
24 (Guiot and Cramer 2016). For this Special Report, we propose that ‘impacts at 1.5°C’ refers to *the impacts*
25 *when the expected global average of near-surface air temperature is 1.5°C above the pre-industrial period*
26 *(1850-1879) subject to similar natural forcing*. The same principle applies to impacts at 2°C, and by
27 examining impacts at 1.5°C vs. 2°C, this report quantifies the avoided impacts by maintaining global
28 temperature increase at or below 1.5°C. Chapter 3 presents an in-depth analysis of changes in impacts at
29 1.5°C vs. 2°C and higher levels of warming.
30

31 Observed impacts may be attributed formally to various climate drivers. While objective detection and
32 attribution techniques are commonly used within the physical climate sciences to attribute the likelihood of
33 particular events to anthropogenic warming (e.g., Hansen and Stone 2016), detection and attribution can also
34 come from more subjective forms of knowledge, such as community knowledge of impacts. Although a
35 region may not be classified as being impacted from a climatological perspective, local community
36 knowledge of impacts (i.e., subjective knowledge) can be equally important (Brinkman et al. 2016; Kabir et
37 al. 2016). That is, there are many drivers of ‘impact experience’.
38

39 Impacts are multi-dimensional; hence, there is no universal, value-neutral metric of total or aggregate
40 impact. While some dimensions of impacts are obvious (space, time, sector), others are less so (probability,
41 equity), but all relevant to UNFCCC climate policy. This multi-dimensionality is particularly important
42 because at these levels of warming, impacts may still be comparatively small or even positive when
43 measured along certain dimensions (e.g., expansion of the growing season). The weight assigned to different
44 dimensions could eventually affect the sign of the aggregate or total impact in a particular region or sector.
45
46

47 **1.3.1 Physical Dimensions of Impacts**

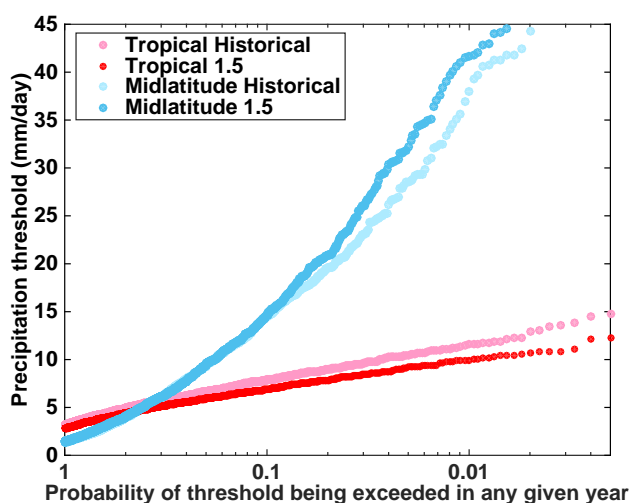
48 *1.3.1.1 Spatial and temporal distribution of impacts*

49 The spatial and temporal distributions of impacts are key considerations in understanding what 1.5°C
50 impacts mean for people. Many regions are already 1.5°C warmer with respect to the pre-industrial period
51 (Figure 1.2). Therefore, local/regional impacts of a global mean warming of 1.5°C can be higher (or, in
52 fewer instances, lower) than 1.5°C. Consequently, the time of occurrence of 1.5°C above pre-industrial
53 levels will vary widely for different regions, depending on different emissions pathways, with some regions,
54 for example parts of Africa, warming faster than others (Niang et al. 2014; Déqué et al. 2016). Also,
55

1 warming or rainfall changes may differ substantially for different seasons. At global warming of 1.5°C, some
 2 seasons will be substantially warmer than 1.5°C above pre-industrial (Seneviratne et al. 2016).

5 1.3.1.2 Implications of 1.5°C for extreme events and associated impacts

6 For most regions, any increase in global mean temperature implies substantial increases in the occurrence of
 7 some extreme events (Karmalkar and Bradley 2017; Fischer and Knutti 2015; King et al. 2017). Overall, a
 8 1.5°C world as compared to a 2°C world will have very different impacts in terms of extreme events (see
 9 Chapter 3). In some regions, warming may also imply decreased occurrence of some extremes, such as cold
 10 extremes in high-latitude regions (Seneviratne et al. 2012). Understanding the impact of an additional 0.5°C
 11 warming on impacts associated with weather extremes demands an understanding not only of the distribution
 12 of the relevant extreme events in the present climate, but also of vulnerabilities and thresholds, and the extent
 13 to which human and natural systems may be impacted as certain classes of weather events become more or
 14 less frequent.



17
 18
 19 **Figure 1.4:** Illustration of the variety of impacts of 1.5 degrees of warming on weather extremes. Dots show the
 20 probability of daily rainfall exceeding a threshold in any given year in two South American locations, both
 21 for the decade 2005-2015 and for a representative decade in a 1.5°C world: it shows how the distribution
 22 of rainfall in the present climate, as well as the climate change signal, affects how risks may be expected
 23 to change. In the mid-latitude location (blue) the intensity of extreme daily rainfall events increases, by up
 24 to 5mm per day for the most intense events, but because this “return-time” graph is relatively steep
 25 (corresponding to a ‘fat-tailed’ distribution, with frequent extremes), this increase corresponds to a
 26 relatively modest (less than a factor of 2) increase in the risk of any particular threshold being exceeded.
 27 In the particular tropical location shown (red), the intensity of extreme precipitation events in this season
 28 actually falls by much less than 5mm per day, but because this return-time graph is shallow (a ‘thin-tailed’
 29 distribution), these changes are associated with much larger changes (in this case reductions) in the
 30 probability of thresholds being exceeded.

32 Figure 1.4 shows the probability of daily rainfall exceeding a threshold in any given year in two South
 33 American locations, both for the decade 2005-2015 and for a representative decade in a 1.5°C world: it
 34 shows how the distribution of rainfall in the present climate, as well as the climate change signal, affects how
 35 risks may be expected to change. In the mid-latitude location (blue) the intensity of extreme daily rainfall
 36 events increases, by up to 5 mm per day for the most intense events, but because this ‘return-time’ graph is
 37 relatively steep (corresponding to a ‘fat-tailed’ distribution, with frequent extremes), this increase
 38 corresponds to a relatively modest (less than a factor of 2) increase in the risk of any particular threshold
 39 being exceeded. In this tropical location (red), the intensity of extreme precipitation events in this season
 40 actually falls by much less than 5 mm per day, but because this return-time graph is shallow (a ‘thin-tailed’

1 distribution), these changes are associated with much larger changes (in this case reductions) in the
2 probability of thresholds being exceeded.

3 4 5 *1.3.1.3 Non-temperature related impacts*

6 Although the focus of this special report is on 1.5°C of global warming, it is important to note that many
7 impacts do not depend on warming alone. Changes to the hydrological cycle affect rainfall and soil moisture
8 availability and it is estimated that more than two billion people live in highly water stressed areas (Oki and
9 Kanae 2006). Several impacts depend on atmospheric composition, for example, increasing atmospheric
10 carbon dioxide levels leading to ocean acidification (Hoegh-Guldberg et al. 2007). It is also important to
11 contrast impacts which are driven by long-term changes in ocean heat content, for example ice-sheet melt
12 and sea-level rise (Bindoff et al. 2007; Chen et al. 2017), *versus* impacts which depend directly on air
13 temperature, for example heat waves (Matthews et al. 2017; Meehl and Tebaldi, 2004). Impacts may also be
14 triggered by combinations of these factors, including ‘impact cascades’, that is through secondary
15 consequences of changed systems. Changes in agricultural water availability caused by upstream changes in
16 glacier volume are a typical example. Recent studies also identify compound events, that is when impacts are
17 induced by the combination of several climate events (AghaKouchak et al. 2014; Martius et al. 2016;
18 Zscheischler and Seneviratne 2017).

19 20 21 *1.3.1.4 Probability and uncertainty of impacts*

22 Uncertainties in projections of future climate change come from a variety of different sources, including the
23 assumptions made regarding future emission pathways (Moss et al. 2010), the inherent limitations and
24 assumptions of the climate models used for the projections, downscaling methods (Ekström et al. 2015), and
25 the uncertainties in the impact models (e.g., Asseng et al. (2013)). The trajectory of climate change also
26 affects uncertainty with respect to impacts. For example, the impacts of overshooting 1.5°C and later
27 stabilization, compared to stabilization at 1.5°C without overshoot may differ in magnitude as well as
28 uncertainty as some ecosystems may not be able to recover after the overshoot (assessed in detail in Chapter
29 3). Changes in mean precipitation, for example, are found to be smaller as 1.5°C is passed on a continued-
30 warming pathway than after equilibrium is reached (Pendergrass et al. 2015), so estimation of impacts of
31 1.5°C on the basis of extrapolation from recent observed impacts, or even from impacts when temperatures
32 reach 1.5°C on a potential overshoot pathway, could yield an underestimation of actual expected impacts at
33 1.5°C temperature stabilisation (Schleussner et al. 2017)

34 35 36 *1.3.2 Different dimensions of ecosystem impacts*

37
38 Impacts of climate change on most ecosystems occur in addition to the variability caused by growth,
39 phenology, population dynamics and other natural processes, rendering impacts at lower levels of warming
40 more difficult to distinguish from natural variability. The same degree of warming can be lethal during some
41 phase of the life of an organism and irrelevant during another. Many ecosystems (notably forests) undergo
42 long-term successional processes characterised by varying levels of resilience to environmental change over
43 time, including the possibility of abrupt changes, for example as a consequence of unusual drought events.
44 Another specificity with ecosystem consequences of climate change are the important feedbacks which can
45 occur, for example, in terms of changing water and carbon fluxes through impacted ecosystems – these can
46 amplify or dampen atmospheric change. For example, of particular concern, is the response of the world’s
47 temperate forests ecosystems, which play key roles as carbon sinks (Luysaert et al. 2008; Magnani et al.
48 2007; Pan et al. 2011).

49 50 51 *1.3.2.1 Drivers of ecosystem impacts*

52 Besides changes in temperature and (for land ecosystems) rainfall, most ecosystems are influenced by other
53 variables. For example, ecosystem impacts are often driven or exacerbated by heavy weather events such as
54 hurricanes/tropical cyclones (Gardner et al. 2005). As stated in Section 1.3.1.3, ocean acidification is driven
55 by increasing atmospheric CO₂ concentrations (e.g., Hoegh-Guldberg et al., 2007), which then impacts

1 marine ecosystems. In addition to these, human use or other human impacts play a major role which can
2 even dominate over change in climate. Quantifying ecosystem impacts at 1.5°C, 2°C and beyond is therefore
3 particularly challenging.
4
5

6 *1.3.2.2 Cumulative impacts, permanence and irreversibility*

7 Impacts can be cumulative (Halpern et al. 2008) and their total impact can be greater than the sum of its
8 parts. For example, in an assessment of cumulative human impacts to the California current marine
9 ecosystems, Halpern et al. (2009) found that climate change was the top threat among several other
10 anthropogenic factors (e.g., nutrient inputs, coastal engineering impacts etc.). In the context of 1.5°C and
11 2°C worlds (see Box 3.12), these cumulative impacts need to be accounted for.
12

13 Another key consideration is the resilience of ecosystems that may decline at higher levels of warming.
14 Ecosystem resilience is generally defined as the ability of ecosystems to resist, or recover after a disturbance,
15 e.g., a heat wave. An example are reef ecosystems, with some studies suggesting that reefs will change,
16 rather than disappear entirely, and particular species showing greater tolerance to coral bleaching than others
17 (Pörtner et al. 2014). A key issue is therefore whether ecosystems such as coral reefs survive an overshoot
18 scenario, and to what extent would they be able to recover after stabilization at 1.5°C or higher.
19
20

21 *1.3.3 Human dimensions of impacts including vulnerability and adaptation*

22
23 There is increasing evidence that climate change is having observable and often disastrous effects on human
24 communities, especially where settlements coincide with climate-sensitive physical conditions and socio-
25 economic/political constraints (IPCC 2014c; World Bank 2013; IPCC 2012a). The character and severity of
26 impacts from climate extremes depend not only on the extremes themselves but also on exposure,
27 vulnerability and adaptive capacity.
28
29

30 *1.3.3.1 Sectoral impacts, human settlements, and adaptive capacity*

31 The impact of 1.5°C warming will affect a range of infrastructure systems and the built environment, natural
32 resources development and provisions capacities, as well as agricultural production systems. The impacts on
33 human systems vary temporally and spatially under conditions of a 1.5°C warmer world. Some parts of the
34 globe have already experienced over 1.5°C of regional warming. Given the vulnerability of some locations,
35 these impacts could result in intergenerational consequences.
36

37 The magnitude and consequences of climate impacts vary across the range of human settlement types.
38 Density and risk exposure, infrastructure vulnerability and resiliency, and governance capacity drive the
39 differential impacts (Revi et al. 2014; Dasgupta et al. 2014; Rosenzweig et al. 2015). Adaptive capacity to a
40 1.5°C world will vary markedly for individual sectors and across sectors such as water supply, public health,
41 infrastructure, ecosystems and food supply. Additionally, the adaptive capacity of human settlements,
42 especially in highly populated urban regions poses several equity, social justice and sustainable development
43 issues.
44

45 The IPCC (2013) and World Bank (2013) underscored the non-linearity of projected risks and impacts as
46 temperature rises from 2°C to 4°C of warming, in particular in relation to water availability, heat extremes or
47 the bleaching of coral reefs. More recent studies and analysis (James et al. 2017; Schleussner et al. 2016a)
48 deal with the responses and effects of a 1.5°C and 2°C warming, with the same message of non-linearity of
49 effects, although some changes are found to be mostly linear such as changes in the temperature of hot
50 extremes (Seneviratne et al. 2016) (assessed in Chapter 3). For some extremes, non-linearity may ensue from

1 the framing of the investigated question, for instance when using threshold-based indices to define extreme
2 events (Whan et al. 2015).

3 4 5 *1.3.3.2 Poverty, equity, justice and sustainable development*

6 Climate change disproportionately affects the most vulnerable segments of society, in both urban and rural
7 areas (Rosenzweig et al., 2015; IPCC, 2014b; World Bank, 2013)). These populations, communities, and
8 institutions often lack adaptive capacity to increased climate risk and new or emerging risks. Climate change
9 is projected to slow down economic growth and make poverty reduction more difficult for a warming of
10 2°C, a substantial threat to the sustainable development of most of the vulnerable countries. As a corollary,
11 these adverse projected climate impacts ‘could still be avoided by holding warming below 2°C’ (World Bank
12 2013). Furthermore, differences in vulnerability and exposure to climate change arise from non-climatic
13 factors and from multi-dimensional inequalities, which are often produced by uneven development
14 processes, leading to differential risks from climate change (Olsson, L. et al. 2014).

15 16 17 **1.4 1.5°C in the context of strengthening the global response to the threat of climate change, 18 sustainable development, and efforts to eradicate poverty, with consideration for ethics and 19 equity**

20
21 The connection between 1.5°C warming and ambitions of sustainable development are complex and
22 multifaceted. Mitigation-adaptation linkages, synergies and trade-offs and the different dimensions of
23 feasibility are important linking elements to sustainable development. The IPCC AR5 acknowledged that
24 ‘adaptation and mitigation have the potential to both contribute to and impede sustainable development, and
25 sustainable development strategies and choices have the potential to both contribute to and impede climate
26 change responses’ (Denton et al. 2014). This report assesses where the key trade-offs and opportunities for
27 synergy are present. Climate mitigation and adaptation measures and actions can be put into place by
28 identifying specific patterns of development and governance that may differ amongst all world regions. This
29 section details the various implementation options, enabling conditions, capacities and types of knowledge
30 that can allow institutions, communities and societies at large to respond to the 1.5°C challenge in the
31 context of sustainable development. Justice, equity and ethics are recognised as issues of paramount
32 importance in reducing vulnerability and eradicating poverty.

33
34 Meeting the goal of limiting global temperature rise to 1.5°C is a challenging task, which will be constrained
35 by several dimensions of feasibility. The report defines the feasibility as the systems-level capacity to
36 achieve a specific goal or target (for more discussion see Box 1.3 on feasibility²). From an energy balance
37 perspective, certain temperature targets are ‘physically feasible’, depending on the concentrations of CO₂ and
38 other radiatively important aerosols and gases (IPCC 2013a). In addition, more aggressive pathways will
39 require new technology that may or may not be ‘technically feasible’ (IPCC 2014c; Rogelj et al. 2015). For
40 policy makers, the ‘economic feasibility’ is also important, and because of environmental damages from
41 some proposals, some pathways may not be socially acceptable (Smith et al. 2016). A need also exists for a
42 governance structure which allows for appropriate ‘institutional feasibility’ for any policy to reach a
43 particular temperature target (Schloss 2016; Planton 2013).

44 45 46 *1.4.1 Justice, equity and ethics*

47
48 The 1.5°C target raises ethical concerns that have been central to the climate debate from the outset, most
49 recently articulated in the language of human rights (Adger et al. 2014; Humphreys 2010; Knox 2015). For
50 example, how will an average global temperature rise of 1.5°C impact upon the human rights of specific
51 persons: their rights to water, shelter, food, health and life, the rights of migrants, of refugees, of indigenous

² The term, as used in this report, does not directly incorporate concepts of nested uncertainty across its multiple dimensions. Instead, the term is used to refer to assessments of the possibility of a particular outcome given a set of other assumptions.

1 persons, of women and children? Poverty, inequity, and injustice, which are intrinsically linked to climate
2 change, are incompatible with sustainable development (O' Brien et al. 2012). As indicated by Stern 2014,
3 climate change is a problem of risk management on an immense scale and the consequences of business-as-
4 usual could significantly threaten human security in a variety of ways including the displacement of
5 hundreds of millions of people that may lead to severe and prolonged conflict (Ionesco et al. 2016). Risks on
6 this scale raise deep questions about ethical perspectives relating to the distribution of impacts associated
7 with climate change and responsibilities for its cause, and preferentially impact on the poor and
8 disenfranchised (Reckien et al. 2017). Focusing on the rights and responsibilities of people as the core policy
9 question may help to clarify the root causes of climate risks, their distribution and management across a
10 range of social groups and geographies³.

11
12 Questions of justice and fairness are central to climate change debates and response efforts across
13 geographies and generations. Mention of human rights by the Paris Agreement is a major step to addressing
14 these questions (Savaresi 2016). Most fundamentally, how can the action to achieve 1.5°C targets be
15 consistent with protection of human rights? Three key points of connection between climate change and
16 justice that need to be attended in the quest for a 1.5°C target have been noted (Okereke 2010; Harlan et al.
17 2015; Ajibade 2016; Savaresi 2016; Reckien et al. 2017). The first is the asymmetry in contributions to the
18 problem. The second is the huge asymmetry in impact - a problem that is exacerbated because the worst
19 impact tends to fall on those that are least responsible for the problem. Conditions of climate dislocation are
20 an acute example of this inequity and forced migration (Ionesco et al. 2016). Intergenerational equity issues
21 also need to be considered here. The third point of connection in the climate-justice nexus is asymmetry in
22 power to decide solutions and response strategies. This relates to the possibility by the more powerful actors
23 and stakeholders to have greater influence on setting the agenda to their advantage. Hence a justice framing
24 offers a useful organizing framework for understanding the asymmetry between the distributions of benefits
25 and costs in relation to climate change (Aaheim et al. 2016; Schleussner et al. 2016a). In addition, existing
26 multi-level inequalities including in the form of technology, finance, human capital and governance
27 constrain approaches to address the 1.5°C challenge despite INDCs where each country pledges what is
28 possible in its capacity. Concerns around justice are central to the debates about mitigation, adaptation and
29 climate governance as they open up opportunities to discuss who cuts emissions, who pays for the pollution,
30 whose knowledge counts and who has the capability to respond to the problem and benefit most (Schroeder
31 et al. 2012; Ajibade 2016; Reckien et al. 2017). For example, without sustained technology transfer, rapid
32 decarbonisation can be expected to slow or stall growth and exacerbate poverty, especially in less wealthy
33 countries (Humphreys 2017).

34
35 Justice considerations need to be an integral part of efforts to mitigate and adapt to a 1.5°C warming, at the
36 global as well as sub-national levels (Shue 2014). Equity and fairness are important elements of the justice
37 framing in climate change research, and relate to both procedural justice (i.e., participation in decision
38 making) and distributive justice (i.e., how costs and benefits of climate actions are distributed) (Savaresi
39 2016; Reckien et al. 2017). This framing recognises that climate change presents significant threats to future
40 wellbeing in that future generations are likely to be vulnerable to climate impacts and are least represented in
41 current decisions that shape future outcomes. Klinsky and Winkler (2014) draws on Sen and Nussbaum's
42 capabilities approach to argue that differentiated responsibility alone is not sufficient to address the 'trio' of
43 climate equity challenges: unequal climate impacts, development status, and responsibility. They suggest
44 'operationalizing' equity by including a notion of capabilities in addressing domestic climate policies in the
45 context of carbon constraints and climate impacts.

46
47 Ethical consideration also can be extended to the natural world, although different interpretations exist. For
48 example within Environmental ethics. there are those who emphasise nature, argue that ecosystems have a
49 right to exist in their natural state (Attfield 2014). Intergenerational equity argues that we should leave the
50 natural state as much as possible for future generations. However, there other approaches that are linked to
51 social-ecological system view, for instance, the implications of climate change on natural resources with

³ Human rights include the right to development, equitable benefits and burdens, participatory, transparent and accountable decisions on climate change, gender equity, and education rights.

1 respect to indigenous people. Overall, the impacts of climate change onto humans and ecosystems are not
2 equally distributed, because some humans or ecosystems may be more vulnerable to climate change (Agard
3 and Schipper 2014; Savaresi 2016).

6 **1.4.2 Governance**

8 A significant challenge in meeting the 1.5°C target is focused on the governance capacity of institutions to
9 develop, implement and evaluate the needed changes within diverse and highly interlinked global social-
10 ecological systems (Busby 2016). Governance capacity includes the wide range of activities and efforts
11 needed to develop coordinated climate mitigation and adaptation strategies in the context of sustainable
12 development taking into account equity, justice and poverty eradication. Significant governance challenges
13 include ability to incorporate multiple stakeholder perspectives in the decision-making process to reach
14 meaningful and equitable decisions, scalar interaction and coordination between the different levels of
15 government, and the capacity to raise financing, and support for technological and human resource
16 development for such actions.

18 A systematic review of the literature (Kivimaa et al. 2017) suggests that major policy transformations to low
19 carbon transitions require policy experimentation as an explicit approach to governance. Extensive trials and
20 smaller experiments, strengthen policy and capacity, and help overcome barriers and complex,
21 multidimensional climate challenges. As a result adaptive and flexible governance systems will be key to
22 transitioning to a 1.5°C global warming and reducing further temperature increase.

24 To date, it is not certain that the voluntary mechanisms of the Paris Agreement will be sufficient to achieve
25 the ambitions of the Paris Agreement (Falkner 2016; Lövbrand et al. 2017). The Agreement's compliance
26 mechanism is 'expert based' and 'facilitative in nature' rather than mandatory (Article 15 (2) cited in (Falkner
27 2016)). Other international frameworks including the Sendai Framework of Disaster Risk Reduction
28 (UNISDR 2015) provide an opportunity for advancing climate adaptation and resilience since it is assumed
29 that through risk reduction, climate change adaptation can be enhanced (Mysiak et al. 2016).

31 Policy arenas, governance structures and robust institutions are key enabling conditions for transformative
32 climate action in achieving the global response to 1.5°C warming. A range of high and some middle income
33 cities provide examples of how government and community response can simultaneously make meaningful
34 contribution to adaptation and mitigation goals. Conversely, the risk of climate change will escalate in
35 countries with severe governance failure (IPCC 2012a; Oppenheimer et al. 2014; Revi et al. 2014) and
36 climate change threat may also weaken governance, for example triggering conflict or migration and
37 deepening vulnerability (Voski 2016).

39 Adaptation incorporates changes on modes of governance (Klein et al. 2014b). It is through governance that
40 justice, ethics and equity within the adaptation-mitigation-sustainable development nexus can be addressed
41 (Stechow et al. 2016). This can be illustrated in cities where different management solutions can have
42 implications for equity as is the case of the privatization of water supply and sanitation services (Revi et al.
43 2014). Governance is critical to the response to 1.5°C warming given the diversity of organizations and
44 actors at national and global level that have a role in the climate change challenge (Busby 2016). Governance
45 capacity plays a critical role in a range of key contexts including the realization of the Nationally Determined
46 Contributions (NDCs), small island states, highly vulnerable sites, low carbon and zero carbon cities.

49 **1.4.3 Transformation, Transformation Pathways, and Transition**

51 Embedded in the 1.5°C goal is the opportunity for intentional societal transformation. The pace and process
52 of transformation is varied and multifaceted. Fundamental elements of 1.5°C -related transformation will
53 include a decoupling of economic growth from carbon emissions, leap frogging development to new and
54 emerging low and zero carbon technologies, and synergistically linking climate action to global scale trends
55 that will further enhance the prospects for meaningful climate action. The rate of change within systems or

1 its resilience can occur gradually or be punctuated by rapid change, particularly when linked with disruptive
2 technological innovation. Incremental change can set in motion larger scale transformations in systems.
3 Incremental transformation is key when designing, planning, and improving implementation options at local
4 level (e.g., in urban areas, see Box 4.14 on Cities).

5
6 System-level analyses of adaptation (Solecki et al. 2017) and mitigation transition pathways highlight the
7 importance of root, contextual, and proximate drivers that when acting together promotes increased
8 opportunity for societal transformation. The connection between transformative climate action and
9 sustainable development illustrates a complex coupling of systems that have important spatial and time scale
10 lag effects and implications for process and procedural equity. Early warning signals of system change
11 including system instability, increased fluctuation, and slowing response rates provide important sign posts
12 for potential transition pathways and of use by decision makers and policy makers to advance climate
13 adaptation and mitigation agendas. Extreme events are associated with windows of transformational change.
14 Historical analogues provide insights into the process of societal transformation coming in response to
15 external and internal system dynamics (IPCC 2012a).

16
17
18 **Box 1.3:** Feasibility and limiting global temperature increases to 1.5°C

19
20 Authors: William Solecki, Linda Steg, Henri Waisman, Anton Cartwright, Wolfgang Cramer, James Ford,
21 Kejun Jiang, Joana Portugal Pereira, Joeri Rogelj

22
23 A central question coming from the Paris Climate Agreement is how achievable or feasible is it to keep
24 warming well below 2°C and pursue efforts to limit it to 1.5°C (Schellnhuber et al. 2016; Schleussner et al.
25 2016a). This cross-chapter Box assessed the notion of feasibility specifically in the context of limiting
26 temperature increase to 1.5°C above pre-industrial levels. The aim here is to disentangle what is behind this
27 rather abstract idea and to move it toward a more tangible, policy-relevant understanding, and thereby further
28 revealing enabling conditions of making the transition to a 1.5°C world. The Box does not directly address
29 what is feasible and whether limiting warming 1.5°C is possible, generally (or with no overshoot or
30 overshoot, specifically); but, instead focuses on how feasibility could be considered and put in practice.

31
32 **Three dimensions of feasibility**

33
34 This approach of the ‘feasibility’ question starts from a given condition - in this case the requirements of
35 1.5°C world - and aims to reveal the policy implications and enabling conditions of different trajectories
36 compatible with this objective, building on back casting techniques, as theorised in (Robinson 1982). This
37 seminal paper points notably to the need to analyse not only the technical transformation in the system, but
38 also ‘the social, environmental, economic, political, and technological implications of the scenarios’.

39
40 A large literature exists on technical feasibility studies of ambitious climate targets, and is primarily based on
41 engineering and economic knowledge with a focus on quantifiable technical, economic and environmental
42 implications (IPCC 2013b, 2014c). A complete vision of the feasibility question requires integration of
43 natural system considerations into the human system scenarios (Robinson 1990) and the placement of
44 technical transformations into their political, social, and institutional context (Nilsson et al. 2011; Schubert
45 et al. 2015; Andrews-Speed 2016). This notably requires a closer synthesis of different perspectives on the
46 ‘feasibility’ question to reflect the societal and governance transitions implied by different visions of low-
47 emission futures (Söderholm et al. 2011). Combining different methods and approaches, like quantitative
48 modelling and more qualitative storylines, is key to build robust and integrated visions useful for
49 stakeholders and practitioners and to inform climate transition pathways governance (Fortes et al. 2015;
50 Turnheim et al. 2015). This integrated approach to ‘feasibility’ is essential to inform on the potential
51 synergies and conflicts between different policy objectives (e.g., investments in near term emissions
52 reduction vs. long term emissions reduction) (Hildingsson and Johansson 2016).

53
54 To reflect on these different aspects characterizing the pathways to a 1.5°C world, we decompose the
55 feasibility discussion into three dimensions: 1) geophysical and environmental dimensions, which questions

1 the capacities of physical systems (including response to negative implications) to meet the requirements of
2 achieving the condition of 1.5°C; 2) technological and economic dimensions, which investigates the nature
3 of the enabling conditions in technical and economic systems; and 3) social and institutional dimensions,
4 which captures the evolutions in the social and institutional context that are required to create the space for
5 the deep socio-technical changes implied by these scenarios.

6 7 **Aim of feasibility framing**

8
9 The assessment of feasibility is not a matter of answering by ‘yes’ or ‘no’ regarding the feasibility of limiting
10 warming to 1.5°C; it is rather a frame to organise the different types of enabling conditions for
11 transformations compatible with a 1.5°C world. The above three dimensions of feasibility speak to different
12 disciplines - physical sciences, engineering/economists perspectives, and social sciences - each having their
13 specific approaches to the question and considering different types of base assumptions and requirements
14 corresponding to their entry point into the feasibility discussion.

15
16 The purpose of distinguishing these three feasibility dimensions is multiple. Key is to acknowledge a
17 comprehensive set of enabling conditions to limiting temperature increase to 1.5°C above pre-industrial
18 levels, and to understand how different feasibility dimensions are related. These will help clarify the
19 communication of opportunities and challenges associated with the feasibility in each community of interest.
20 One's entry point to the question of feasibility and the conditions in which one is interested will influence
21 who they engage with the concept of feasibility and the associated operational indicators. Another objective
22 is to try to bridge the gap in understanding between different communities, by streamlining the discussion of
23 feasibility along the organizing principle of the three distinct categories. In this way, ‘feasible’ pathways,
24 including options and limitations, can be articulated and recognised in terms that can be easily understood by
25 a broad spectrum of relevant communities including the policy stakeholders, practitioners, and private sector
26 decision-makers, and serve as a guide for them in what to do to secure feasibility. It will be important to
27 define indicators and metrics of the feasibility dimensions that are transferable as much as possible to within
28 specific communities and across communities including national and sub-national government officials,
29 NGO members, and the private sector.

30 31 **Process of feasibility framing**

32
33 Each feasibility dimension and their associated enabling conditions have embedded within system level
34 functions that could include linear and non-linear connections and feedbacks. It is through these systems
35 level mechanisms that conditions of feasibility can be more fully understood. For example, more rapid
36 deployment of technology and larger installations (e.g., new large scale energy mega-projects) implies
37 increased costs and reductions in social acceptability and hence a potential reduction in feasibility. Case
38 studies can demonstrate system level interactions between the feasibility dimensions and conditions for
39 positive or negative feedback effects. System level interactions amongst feasibility of mitigation, climate
40 adaptation, and sustainable development and the sustainable development goals will be especially important
41 to consider. Data quality and scenario and pathway projections are another important elements associated
42 with the application of the feasibility concept. For example, statements of uncertainty, likelihood and risk
43 will influence how feasibility measures and their multiple interactions are defined and interpreted by user
44 communities.

45
46 The conditions of feasibility also are highly dynamic and varied across temporal and spatial contexts,
47 especially under potential conditions of overshoot or no overshoot. Guidance on feasibility should elucidate
48 the distinction between the near-term (i.e., within the next several years to decade or two) and long-term
49 (i.e., over the next several decades) dimensions of feasibility. For instance, actions taken to promote a near-
50 term trajectory of emissions reduction consistent with pursuing 1.5°C could negatively impact the
51 opportunity for longer-term feasibility. Some dimensions might be more time sensitive than others (i.e., if
52 conditions are such that it is no longer geophysical feasible to achieve a particular interpretation of a 1.5°C
53 world, social and institutional feasibility will be no longer relevant). This cascading effect will be important
54 for understanding the comparative importance of different metrics or indicators of feasibility.

1 Feasibility is spatially variable and scale dependent, which has implications for its validity at the global-
2 scale. What could be considered feasible in some regions of the world might be not feasible in others. The
3 spatial variation of feasibility for example will be dependent on regional scale environmental resource limits,
4 social organization and conditions of urbanization, and financial and institutional capacities among other
5 factors. Regional feasibility is not necessarily additive to the global scale and vice versa. System boundaries
6 are especially important here as certain technologies, for instance, may be feasible in one region, but not on a
7 global scale. In Europe, it may be possible that bio-energy with carbon capture and storage (BECCS)
8 technology could be deployed quickly but there is limited biomass available regionally thereby limiting the
9 feasibility of the approach in this regional context. It should be noted that some integrated assessment
10 models (IAMs) do not account for this type of BECCS life cycle assessment footprint and as a result do not
11 translate full system emissions projections. Many other spatial differences that influence regional
12 understanding of feasibility such as economic wealth, institutional and governance capacity and culture are
13 also present and need to be recognised.

14 **The feasibility discussion in this report**

15 The feasibility discussion is one of the organizing principles for this 1.5°C report. The three basic
16 dimensions of feasibility are presented in Box 1.3, Table 1 below. Different dimensions of feasibility are
17 considered in the different chapters, which provide a deeper analysis into specific conditions associated to
18 these specific dimensions. Chapter 2 focuses largely on geophysical and technological feasibility, Chapter 3
19 on environmental feasibility, Chapter 4 on technological, economic, social and institutional feasibility,
20 Chapter 5 on social and institutional feasibility.

21 For each dimension in Box 1.3, Table 1, several characteristics and relevant metrics and indicators are listed
22 corresponding to existing measures of geophysical and environmental limits, amount of technology required,
23 investments and institutional arrangements needed, and enhancement of social and economic conditions,
24 among other variables. Each dimension can be distilled down to several characteristics each with a lengthy
25 list of potential empirical measures (e.g., indicators and metrics). The empirical measures provided are but a
26 sample of variables that could be considered. The list includes many variables for which attribute data
27 already are being collected or could be easily collected in the future.

Dimensions	Characteristics	Empirical Measures
Geophysical and Environmental	Geophysical	<ul style="list-style-type: none"> - Proportion of the change required; warming commitment - Rate of land use change - Is there enough geological storage capacity? - Physical feasible - C geological storage capacity (Is there opportunity in for geophysical capture?)
	Environmental - Ecological	<ul style="list-style-type: none"> - Capacity of ecological systems - Limits of mitigation/adaptation in ecosystems - Risks of responsive options - Tipping points - reversibility of ecosystems - Are future emissions compatible with 1.5 degrees? At what probability? - Risks associated to irreversible changes
Technological and Economic	Technological	<ul style="list-style-type: none"> - Has the technology been deployed? - How quickly different types of technologies can be implemented? - Are there technical resources available? - Historical analogues for curves of deployment/implementation - How long does it take to bring immature technologies to large-scale deployment? - What are the needed investment on R&D?
	Economic	<ul style="list-style-type: none"> - Required investment flows and costs of response options - Transition costs through time and regional dimensions - Availability of financing resources and financial mechanisms to enable transitions - International and national flows/governmental and private flows - <i>Mal-mitigation</i> and maladaptation; risks; Unforeseen impacts including stranded assets - Differential effects of competitiveness - Benefits/tradeoffs -e.g.: economic development, GDP, poverty alleviation, employment impacts - Alternative growth models/SSPs
Social and Institutional	Social/cultural	<ul style="list-style-type: none"> - Social capacity and adaptive capacity - Public acceptability and social disruptiveness - Behavioural responses (communities and private sector) - Equity/social inclusion/distributional impacts - Cultural specificities - Human rights including Inter-generational - Speed of social practices and changes - Regional dimensions - sub-national, national, regional - Health benefits and risks
	Institutional	<ul style="list-style-type: none"> - Political economy and transparency - Political support - Market structures, market failure and missing markets - Rate of institutional change - Administrative traditions and institutional capacity - Civil society engagement - Interaction between multi-levels of governance

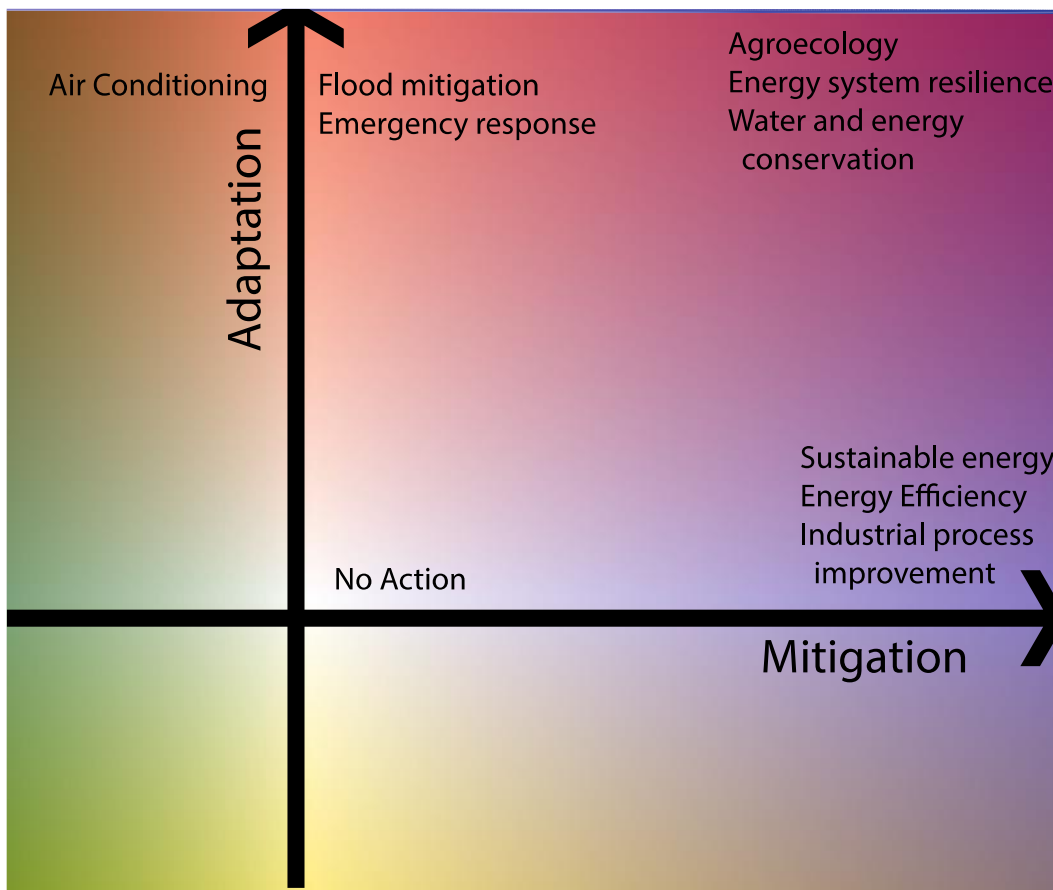
Box 1.3, Table 1: Dimensions of feasibility

1.4.4 Trade-offs and synergies of adaptation, mitigation and sustainable development

Multiple climate responses including mitigation and adaptation often occur simultaneously, each with varying affects (Figure 1.5) and different pathways that would limit warming to 1.5°C (Kainuma et al. 2017) versus 2°C. For example, subsistence farmers are more sensitive to precipitation changes than farmers in regions with advanced irrigation techniques. Yet, the ability to adapt to climate change, or adaptive capacity of these advanced irrigation techniques can build resilience to weather or other hazards but also require greater carbon emissions (Agard and Schipper 2014). From the mitigation side, it is important to reduce emissions of CO₂ and other greenhouse gases (IPCC 2014a). Even if low CO₂ trajectories are achieved, impacts of climate change on humans and ecosystems will require adaptation (IPCC 2014c). Extreme measures could be undertaken to avoid climate change. These include carbon dioxide removal (CDR), whereby CO₂ is actively removed and stored (Rockström et al. 2016), or solar radiation management (SRM, see Section 1.4.5), where deliberate changes to the earth’s albedo are undertaken (IPCC 2012b) (see Box 4.13). None-the-less, mechanisms exist to respond to climate change that will enhance both mitigation and adaptation and, with appropriate governance, also provide for social justice, equity and ethics (Stechow et al. 2016) (Figure 1.5). Solar radiation management strategies which press against socially acceptable and physical limits, provide a clear example of the constraints and capacities of governance with respect to decision-making equity, and integrating levels of uncertainty into the decision-making process.

Urban areas exemplify how synergies between mitigation and adaptation can be enhanced. There is value in examining the two together since urban areas are balancing between adaptation and mitigation and have to negotiate trade-offs at different scales. ‘Based on the content analysis of urban studies, it appears that drivers of conflicts can be understood through the consideration of multiple scales and cross-scale interactions (cf. Cash et al. 2006) on which adaptation and mitigation policies are being implemented and practical actions taken’ (Landauer et al. 2015).

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Figure 1.5: Schematic of some adaptation and mitigation options, showing examples of those that serve both to help adaptation (red) and mitigation (blue), as well as those that may only help one or the other (yellow/orange). Hamin and Gurran (2009), quoted in (Landauer et al. 2015)) provide an example: if adaptation can reduce the cost of mitigation or vice versa, or a situation where an adaptation strategy supports the mitigation strategy at the local level. In the upper right zone adaptation-mitigation synergies can be established. For instance, water and energy conservation systems can bring benefits for both. Conserving forest ecosystems in the peri-urban areas of the city can capture CO₂ and rainfall preventing potential floods and landslides within the city. Other measures and actions can only address either adaptation or mitigation goals (upper left and lower right).

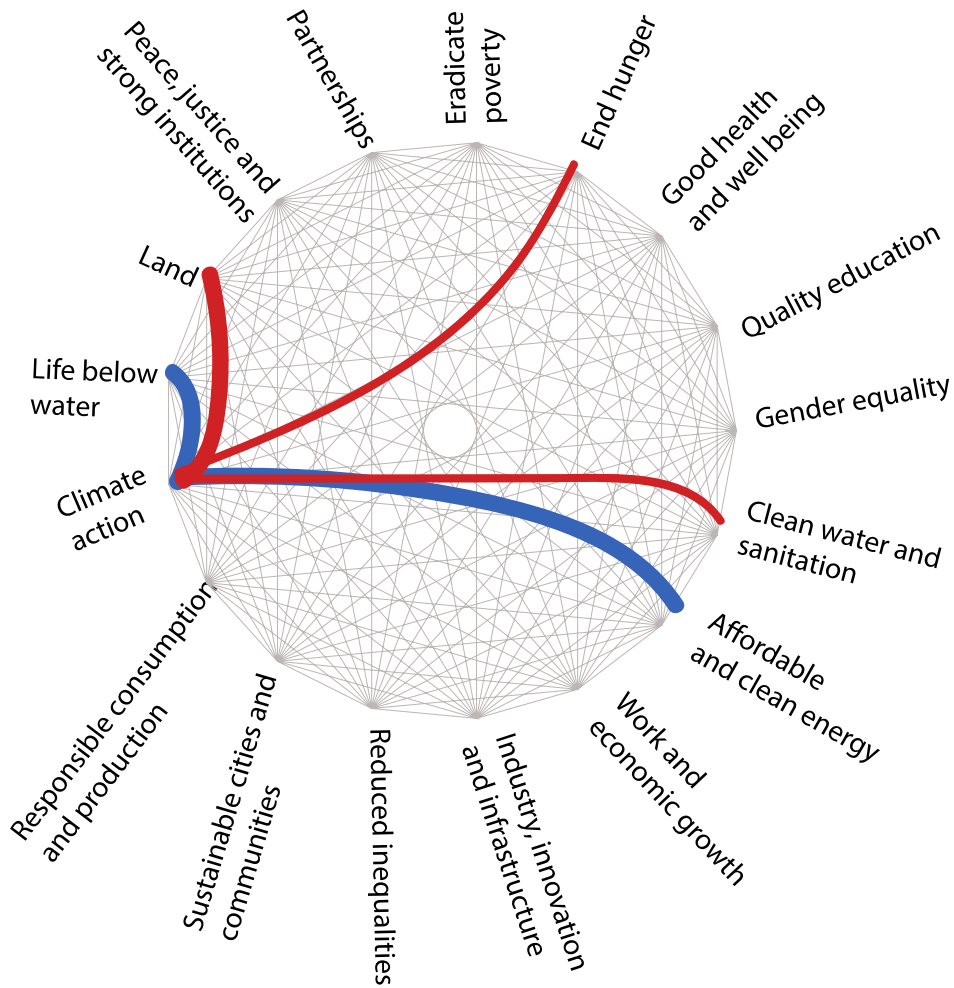
In September 2015, the international community endorsed a universal agenda entitled "Transforming our World: the 2030 Agenda for Sustainable Development", widely known as the Sustainable Development Goals (SDGs⁴) which provide a framework for addressing the 1.5°C target. The SDGs include specific goals for climate action (Goal 13), access to affordable and clean energy (Goal 7), sustainable consumption and cities (Goals 11 and 12), and equality/equity goals for gender education, income, work, and access to justice (Goal 5 and transcending several other goals). In addition Denton et al. 2014 noted that climate change constituted "a moderate threat to current sustainable development and a severe threat to future sustainable

⁴ The 17 goals and 169 targets to be met by 2030 were developed with widespread participation and were adopted in 2012 under the rubric of goals for people, prosperity, peace, partnerships and the planet. The preamble to the SDGs announces 'to take the bold and transformative steps which are urgently needed to shift the world onto a sustainable and resilient path'. With their explicit aim to 'leave no one behind', the SDGs provide a promising basis for addressing inclusive growth, shared prosperity, and multidimensional inequalities (UNRISD 2016). They are seen as an 'indivisible' package of goals that need to be pursued in an integrated way (Coopman et al. 2016); yet, the policy challenges to realise this integration are enormous.

1 development" (*high confidence*) and that "ill-designed responses" could "offset already achieved gains"
2 (Denton et al. 2014).

3
4 The Sendai Framework for Disaster Reduction 2015-2030 (UNISDR 2015) focuses on building resilient
5 human settlements to reduce the vulnerability to disaster and enhances the capacity to reach the SDGs.
6 Some of the SDGs are likely to be enhanced by strong climate change response, but some SDGs may be
7 more difficult to achieve with a strong climate mitigation response, and may become less likely with a
8 stronger climate response (1.5 *versus* 2°C) (Figure 1.6). For example, if an intensive land-based approach is
9 used for climate mitigation, this can place pressure on food security (Smith et al. 2016) or many strong
10 mitigation pathways are expensive, thus reducing the likelihood of poverty eradication, depending on the
11 financial burden sharing pathway used (Nilsson et al. 2017; Stechow et al. 2016).

12
13 Conversely, multiple examples of synergies exist between achieving SDGs and climate responses. For
14 instance, converting to sustainable energies can enhance the energy security of a society and protect the
15 ecosystem services offered by land and ocean environment (Figure 1.6). In addition, adaptive capacity and
16 resilience is enhanced in societies with a broad access to education and infrastructure. Since urbanization is
17 occurring at an accelerating rate, the interactions between urbanization, sustainable development and climate
18 response needs to be considered (Reckien et al. 2017). Simultaneously considering how to achieve an
19 ambitious low climate trajectory and achieve the SDGs is a centre point of this report (Figure 1.6).
20 Intuitively, it is likely that addressing these multiple goals simultaneously is more likely to achieve a cost-
21 effective and socially acceptable solution, than addressing these goals piecemeal (Stechow et al. 2016),
22 although there may be different synergies and trade-offs between a 2°C (Stechow et al. 2016) and a 1.5°C
23 goal (Kainuma et al. 2017).



Positive interactions: Synergies
 Negative interactions: Trade-offs

Example for land based mitigation option

Figure 1.6: A framework for evaluating the impact of different climate response pathways on the multiple dimensions of the Sustainable Development Goals. For each goal, positive or negative impacts for each climate action can be estimated, highlighting the climate response pathways that require trade-offs versus those that have the most synergies. An example is shown of a land-based mitigation strategy for climate change. Positive interactions (synergies) are shown with a blue line, negative interactions (trade-offs) are shown with red, and the strength of the interaction is shown with a bolder line).

1.4.5 Solar Radiation Management

Solar Radiation Management (SRM), also referred to as ‘sunlight reduction methods’ involves deliberate changes to the albedo of the Earth system, with the net effect of reducing the amount of solar radiation reaching Earth’s surface (Smith and Rasch 2013). One of the most commonly proposed SRM techniques involves the artificial emission of aerosols into the stratosphere (Rasch et al. 2008), referred to as Sulphate Aerosol Injections (SAI), to essentially mimic the effect of volcanic eruptions in reducing global average temperatures. Other related approaches exist, which involve increasing the albedo of the land surface, for example *via* changes in the albedo of agricultural land or urban areas (Davin et al. 2014; Hirsch et al. 2017; Irvine et al. 2011). These land-surface radiation management methods have a smaller spatial footprint, because the forcing is more restricted in space (although the same overall radiative principles apply). The land-surface radiation management approaches are potentially better suited than SAI to affect local and regional temperature (Seneviratne et al. 2017) but would have at most only a negligible effect on global temperature, and are thus addressed here separately from other SRM approaches (see also Sections 3.7.2.1

1 and 3.7.3 in Chapter 3 for more background on this topic). Traditionally considered SRM approaches, such
2 as SAI, would, on the other hand, have a global footprint on climate. While this may make global SRM seem
3 attractive for counteracting increased greenhouse gas forcing, there are serious shortcomings when
4 considering effects on the water cycle and on regional scale, as detailed in Chapter 3.

5
6 Consistent with previous IPCC reports (IPCC 2012b), SRM does not fall within the usual definition of
7 adaptation or mitigation. Therefore, SRM is not investigated as a mitigation option in Chapter 2 of this
8 report, which makes use of IAMs, amongst other tools, to investigate different mitigation pathways to
9 achieve the 1.5°C target. SRM is nonetheless sometimes proposed as a means to address climate impacts
10 (Crutzen 2006), and the associated risks and impacts (both biophysical and social) need to be carefully
11 reviewed. This is carried out in Chapter 3, which reviews the direct and indirect impacts of SRM at the
12 regional scale, for example changes in precipitation patterns and ocean acidification. Chapter 4 reviews the
13 social, cost, governance, and ethical issues associated with SRM, and Chapter 5 discusses SRM implications
14 relevant to SDGs, with particular focus on how these relate to food production, ocean acidification,
15 partnerships, and potential health impacts via changes in ozone. Finally, since this by no means covers all
16 aspects of SRM, several related topics are covered in Box 4.2, including, the global impacts of SRM (i.e.,
17 changes to the global circulation and associated impacts on precipitation, cloud coverage, etc.), the
18 effectiveness of different SRM techniques in reducing global mean temperatures, and the implications of
19 termination-effects associated with SRM.

20 21 22 **1.4.6 Implementation and policies**

23
24 There is growing literature that suggests the costs of policies that eliminate GHGs may be small or negative,
25 ‘and that policies to expand renewable energy also make them cheaper’, for example in some cases of
26 providing renewable energy compared to fossil fuels (Patt 2017). Transitioning from climate planning to
27 practical implementation is a major challenge identified for constraining global temperature to 1.5°C. This is
28 due to several barriers including finance, technology and human resource constraints plus institutional
29 capacity to strategically deploy available knowledge and resources (Mimura et al. 2014). Uncertainties in
30 climate change at different scales, different capacities to respond coupled with the complexities of social-
31 ecological systems point to a need for diverse implementation options within and among different regions
32 involving different actors. The tremendous regional diversity between highly carbon-invested economies and
33 emerging economies are important considerations for sustainable development and equity in achieving the
34 1.5°C goal. Key sectors such, as urban systems, food security and water supply also are critical to these
35 connections. Incorporating strong linkages across sectors, devolution of power and resources to sub-national
36 and local governments and facilitating partnerships among public, civic, and private sectors will be key to
37 implementing identified response options. The implementation process of climate policy is not well
38 understood let alone when it comes to integrating other territorial, urban and sectoral policies like disaster
39 risk reduction measures and how also public participation mechanisms can contribute to addressing
40 vulnerabilities to climate-related hazards (Forino et al. 2017).

41
42 Implementation options could be informed by Chapter 20 of IPCC AR5 key message that: ‘To promote
43 sustainable development within the context of climate change, climate-resilient pathways may involve
44 significant transformations. Transformations in economic, social, technological, and political decisions and
45 actions can enable climate-resilient pathways’ (Denton et al. 2014).

46 47 48 **1.5 Assessment frameworks and emerging methodologies that integrate climate change mitigation** 49 **and adaptation with sustainable development**

50
51 The information for the report is global in scope and includes regional analysis. The report provides
52 synthesis of municipal, sub-national, and national case studies. Global level statistics including physical
53 science and social science data are presented and as well as detailed and illustrative case study material of
54 particular conditions and contexts. The time scale of the assessment is the 21st century and includes focus on
55 the near-term, medium term, and long term. It is recognised that the occurrence of a 1.5°C world is spatial

1 and temporally uneven with some part of the earth's surface already experiencing that level of annual
2 warming. Similarly, wide spatial variation exists with respect to level of economic development, sustainable
3 development, and adaptation capacity. The spatial and temporal contexts are illustrated throughout the
4 chapters including Chapter 2's assessment tools that include dynamic projections of carbon budgets and
5 mitigation costs, Chapter 4's mitigation potential assessment framework, and Chapter 5's linkage of the share
6 sustainability pathways (SSPs), sustainable development goals (SDGs), and the connection to social
7 innovation.

8
9 Depending on policies and investments adopted, emission reductions required for a 1.5°C world and the
10 associated adaptation to resulting impacts present variable multidimensional costs and benefits in different
11 regions and countries at the technological, economic and socio-cultural level as well as with natural systems
12 (Admiraal et al. 2016; Rose et al. 2017). Actions and strategies for a 1.5°C world will be translated from
13 local to global scales and originate from international agreements that could be interpreted at the local level.
14

15 **1.5.1 Multidimensional costs and benefits**

16
17 Common tools for making difficult policy decisions include cost-benefit analyses, whereby the costs of
18 impacts are compared to the benefits from different response actions (IPCC 2014c). However, for the case of
19 climate change in the Anthropocene these tools can be difficult to use because of the disparate impacts
20 versus costs and the complex interconnectivity within the global social-ecological system. For example,
21 costs may be relatively easily quantifiable in terms of money, but the impacts of climate change may be on
22 humans' lives, their culture and values or ecosystem goods and services and may have unpredictable
23 feedback loops and impacts on other regions, making it difficult to quantify and compare (IPCC 2014c). In
24 addition, costs and benefits can occur at very different times, even across different centuries for different
25 regions, for which case, standard cost-benefit analyses become difficult to justify (Dietz et al. 2016; IPCC
26 2014c). For example, the cost of catastrophic events could be unpredictable, and result not only in large
27 impacts on the region directly affected but could also extend to other areas, for example through trade
28 linkages and or increased susceptibility to further impacts, even those less severe (Hsiang et al. 2017;
29 Schlessner et al. 2016a).

30
31 Climate change tends to enhance pre-existing inequalities, between regions and within countries, elevating
32 losses in already disadvantaged areas due to low adaptive capacity but also the skewed distribution of risks
33 as is the case for many developing regions (Aaheim et al. 2016; Hsiang et al. 2017; Schlessner et al. 2016a).
34 However, in this case, where a deliberate effort is required to constrain the temperature to 1.5°C, costs and
35 benefits will also be related to transitioning approaches adopted to move from high to low emission
36 investments. This is likely to result in losses and opportunities for different sectors, for example fossil fuel
37 related industries versus green oriented ones, socio-economic groups and locations within a country and or
38 region and stretching beyond due to existing strong global interlinkages and inequalities (Aaheim et al. 2016;
39 Admiraal et al. 2016; Hsiang et al. 2017).
40

41
42 Significant benefits in investing on a low emissions development pathway are more likely to be experienced
43 by future generations requiring sacrificial approach for the current society (Admiraal et al. 2016). While
44 large-scale intervention in the Earth's climatic system (e.g., geoengineering) could give rise to far reaching
45 costs, some going beyond the current generation, in addition to anticipated benefits. Available higher global
46 welfare losses are indicated for the 2°C post-2030 pathway pointing to a possible rise in cost with further
47 constraining of warming that will be politically challenging (Rose et al. 2017).
48

49 Cost and benefits of a 1.5°C world could be estimated taking into account the above noted constraints, for
50 example for desired development framework such as under the Agenda 2030 sustainable development
51 pathways. Flexibility in policy at multiple scales to facilitate appropriate timing, required, innovations and
52 technology as well as conducive economic and socio-cultural environment to emerge will be key to
53 balancing costs and benefits across scales for different systems and sectors (Admiraal et al. 2016).

1.5.2 *Types of knowledge and evidence used in the report*

Different types of knowledge and evidence within the Anthropocene context are used in this assessment. The Anthropocene, which in earth system science is considered a paradigm that marks a unique geological era strongly defined by human activity, is growing to be a powerful cultural model that contemporary societies can use to interpret social-ecological system in light of on-going major shifts and explore sustainable solutions (Delanty and Mota 2017). Within this framing, the assessment is achieved using two broad sources of knowledge and evidence: peer reviewed scientific literature and grey-unpublished literature.

Peer-reviewed literature includes the following types of knowledge and evidence: 1) State of knowledge on the physical climate system and human induced changes, and associated impacts and vulnerabilities and adaptation options, established from work based on empirical evidence, simulations, modelling and scenarios with emphasis on new information since the publication of the IPCC AR5 to the cut-off date for this report, May 2018; 2) Human and social science theory and knowledge from lived experiences of climate change risks and vulnerability in the context of social-ecological system, development, equity and justice and the role of governance; within this is co-production of local knowledge that incorporates indigenous knowledge systems; and 3) Mitigation pathways based on climate projections in the future.

The grey literature category also extends to empirical observations, interviews and results from models found in, for example, theses, technical and consultancy reports and conference papers, government reports, industries, reports from development agencies and non-governmental organisations (NGOs) and other sources. The assessment does not cover un-written evidence and does not utilise media based reports and newspaper publications. In addition to the overall scarcity of published literature on 1.5°C warming, with exception to Australia and to some extent China, publications from the South, the most vulnerable, are far lower in the geopolitics of documented knowledge (Czerniewicz et al. 2017).

A holistic knowledge base as well as new and adaptable institutional structure at different scales will be required to create, for example, the required policy and legal frameworks, and establish resources for implementing various response options to the 1.5°C warming (James et al. 2017). Incorporating knowledge from different sources and setting a multi-faceted information channel, and educating and building awareness at various levels will advance decision making and implementation of context specific response to 1.5°C warming and associated uncertainties (Somanathan et al. 2014) (see also Box 1.4 on the role of community knowledge).

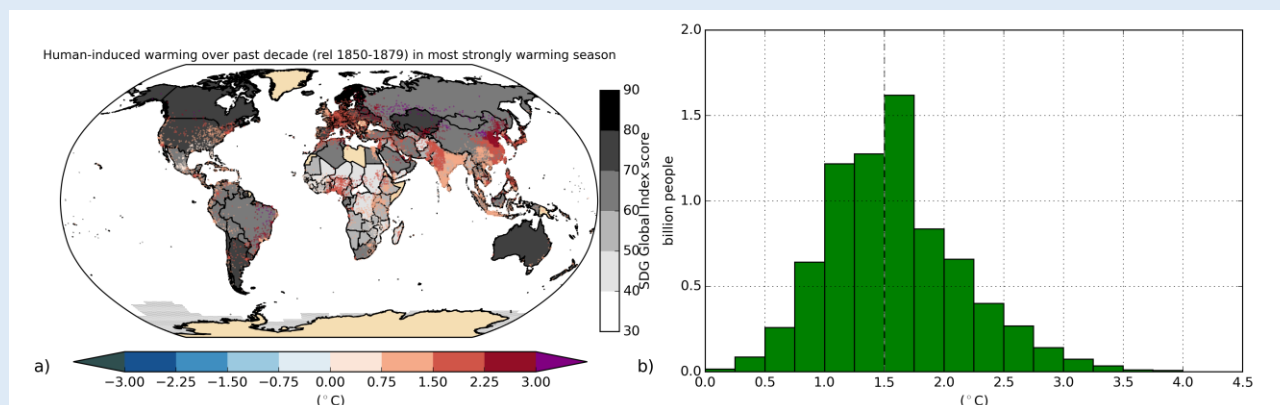
Box 1.4: Experiencing 1.5°C - Opportunities and challenges of visualizing a 1.5°C world: The potential role of community knowledge

Information about regional climate change impacts is limited and there are large uncertainties where this information is produced in addition to research gaps on the rate of change and regional dimensions on the impacts of 1.5°C (Hulme 2016; James et al. 2017). Indigenous and local knowledge (i.e., traditional ecological knowledge) and experience, though less documented, offers valuable insights and can complement scientific data with chronological and landscape-specific precision and detail that is critical for verifying climate models and evaluating climate change scenarios (Fernández-Llamazares et al. 2015; Reyes-García et al. 2015). Indigenous and local knowledge comprises customary knowledge-practice-belief systems about the relationships of living beings (including humans) with one another and their environment (i.e., social - ecological systems) emerging through adaptive processes and culturally transmitted over generations (McMillen et al. 2014). While scientifically observed climate data tends to be limited in many areas or absent especially in developing countries such as Central Africa and Central America, there are people with relevant data and information in these areas although the accuracy of this information is not always verified (Reyes-García et al. 2015; Czerniewicz et al. 2017).

Local and traditional knowledge of recent climate changes bears direct relevance to the impacts of a 1.5°C climate. Whilst, present-day climate changes are not likely to be indicative of climate changes that would be

1 realised in a global-mean 1.5°C world, particularly when multiple climate variables are considered
 2 (Dahinden et al. 2017), large parts of the world have already experienced warming in excess of 1.5°C in at
 3 least one season of the year, corresponding to over 70% of the global population for which local warming
 4 trends can be calculated (Box 1.4 Figure 1). Since experiences of climate impacts today are heterogeneous
 5 (as they will be in a future 1.5°C world), the value of traditional knowledge related to climate is being more
 6 widely considered as critical to understanding the climate change impacts at regional and local level and in
 7 developing local climate change adaptation plans and strategies that sustain resilience of social-ecological
 8 systems at the interconnected local, regional and global scales (Nakashima et al. 2012; Carter et al. 2014).
 9 While traditional knowledge is being more widely considered as critical to developing local climate change
 10 adaptation plans and strategies, it either exists in grey literature outside of peer-reviewed process or remains
 11 in oral form and, in most cases, falls outside the scope of scientific literature on climate change impacts and
 12 mitigation (Leon et al. 2015).

13
 14 Savo et al. (2016) gathered observations covering 137 countries involving more than 90,000 people whose
 15 traditional ways of life rely on nature and where weather stations are absent to fill a knowledge gap in
 16 climate change science, which is dominated by data and computer models. They found observations from
 17 nearly 70 percent of those interviewed generally aligned with data and models developed to predict changes
 18 in the climate and this has also been established among the Nepalese community perceptions of changing
 19 weather patterns (Ministry of Science Technology and Environment 2015). This is equally so for indigenous
 20 people in the Pacific Islands with rich understanding of atmospheric, weather, and seasonal cycles based on
 21 long-term observations that have been used to develop customary calendars that include expectations of
 22 weather (e.g., wet and dry seasons) in planting and harvest of breadfruit (*Artocarpus altilis*), or the rising and
 23 spawning of the palolo sea worm (*Eunice viridis*) (McMillen et al. 2014).
 24



25
 26
 27 **Box 1.4, Figure 1:** Realised experience of present-day warming. Panel a): colours indicate human-induced warming in
 28 over the past decade (2007-2016) relative to 1850-1879 for the most strongly warming season at any location using the
 29 GISTEMP dataset (Hansen et al. 2010b). The density of dots indicates the population (2015) in any 1°x1° grid box.
 30 Warming trends are calculated in an identical way to Figure 1.2. The underlay shows SDG Global Index Score ranks at
 31 a country level indicating performance across 17 sustainable development goals. Yellow shading indicates missing data.
 32 Panel b) shows a histogram for the data shown in panel a). Approximately 50% of the global population have already
 33 experienced at least one season with human-attributable warming above 1.5°C for the average of the last decade. See
 34 Technical Annex of this chapter for further details.
 35

36
 37
 38 **1.6 Consideration and communication of confidence, uncertainty and risk**

39
 40 Careful consideration and clear communication of levels of confidence and uncertainty is fundamental to the
 41 work of the IPCC. This Special Report relies on the IPCC’s uncertainty guidance provided in Mastrandrea et
 42 al. (2011), building on IPCC (2005), Manning et al. (2004) and Moss and Schneider (2000), that was the
 43 basis for the consistent treatment of uncertainty in AR5. Some simplifications and clarifications are proposed

1 to address the specific circumstances of this Report. The AR5 relied on two metrics for communicating the
2 degree of certainty in key findings:

- 3
- 4 • Qualitative expressions of confidence in the validity of a finding based on the amount of and level of
5 agreement in the evidence available; and
- 6 • Quantitative expressions of likelihood or probability of specific events or outcomes.
- 7

8 In both cases, specific terms were adopted to ensure consistency of language across chapters and Working
9 Groups, but differences of practice emerged, with greater use of confidence expressions by Working Groups
10 2 and 3, and likelihood by Working Group 1. This is a cross-Working Group report with a need for
11 consistent practice spanning physical climate; impacts, vulnerabilities and risks; and mitigation options. For
12 reasons given below, the authors of this Special Report express their key findings using qualitative
13 expressions of confidence and numerical ranges where possible. Following the practice in AR5 Working
14 Groups 2 and 3, and in contrast to Working Group 1, the use of probabilistic (likely, etc.) qualifiers is
15 generally avoided in Executive Summaries and the Summary for Policymakers. Where findings explicitly
16 concern probabilities, or frequency of occurrence within an ensemble, these are given numerically or using
17 phrases such as ‘even chance’ or ‘two in three chance’ to avoid any ambiguity.

18 ***Background – confidence scale:***

19
20
21 Five qualifiers are used to express levels of confidence in key findings, ranging from very low, through low,
22 medium, high, to very high. The assessment of confidence involves at least two dimensions (see Figure 1.7),
23 one being the type, quality, amount or internal consistency of individual lines of evidence, the second being
24 the level of agreement between different lines of evidence. Very high confidence findings must either be
25 supported by a high level of agreement across multiple lines of mutually independent and individually robust
26 lines of evidence or, if only a single line of evidence is available, by a very high level of understanding of the
27 processes underlying that evidence. High confidence implies either high agreement across different lines of
28 evidence that may be individually less robust, or lower agreement but greater individual robustness. There
29 are multiple ways of supporting a medium confidence qualifier, and further explanation may be required to
30 elaborate whether the issue is lack of agreement between, or the robustness of, different lines of evidence.
31 Findings of low or very low confidence are presented only if they address a topic of major concern.

32 ***Background – likelihood scale:***

33
34
35 The IPCC uses a calibrated language scale to communicate assessed probabilities of outcomes, ranging from
36 exceptionally unlikely (<1%), extremely unlikely (<5%), very unlikely (<10%), unlikely (<33%), about as
37 likely as not (33-66%), likely (>66%), very likely (>90%), extremely likely (>95%) and virtually certain
38 (>99%). These terms are normally only applied to findings associated with high or very high confidence.
39 Where findings are based on frequencies within model ensembles, calibrated uncertainty language is not
40 used to communicate those frequencies unless these are assessed (with other lines of evidence) to correspond
41 to probabilities in the real world. Figures and text in AR5 normally use 5-95% confidence intervals for
42 observable quantities and the 5-95% frequency interval for ranges of model ensembles.

43 ***Challenges in the context of this Special Report:***

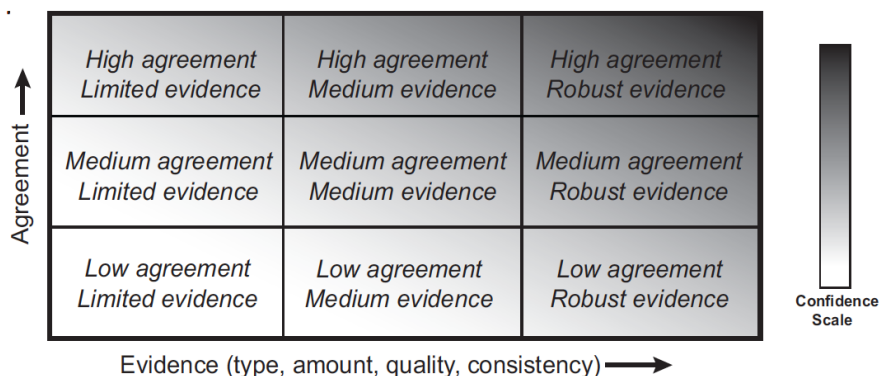
44
45
46 Three specific challenges arise in the treatment of uncertainty and risk in this report. First, the timetable on
47 which this report is being compiled and the current state of the academic literature on 1.5°C mean that
48 findings based on multiple lines of robust evidence for which quantitative probabilistic results can be
49 expressed may be very few, and those that can be made may not be the most policy-relevant. This introduces
50 a communication challenge: in AR5, whenever a likelihood assessment was given, it could be assumed that it
51 was associated with high or very high confidence, and hence this was not stated. When findings are
52 presented at various levels of confidence, it may not always be clear to the reader that those that omit a
53 confidence qualifier are implicitly high or very high confidence. While stressing that this does not entail a
54 revision to the well-established uncertainty guidance, in this Special Report an effort is made to avoid
55 relying on implicit confidence qualifiers: if a qualifier is intended, then it is stated explicitly. Double-

1 qualified expressions that combine both likelihood and confidence language can, however, easily become
 2 impenetrable (e.g., very likely (medium confidence)): hence, where possible, key findings are expressed in
 3 this report using confidence qualifiers alone with numerical expressions of frequency or probability as
 4 appropriate.
 5

6 Second, many of the most important findings of this Special Report are highly conditional precisely because
 7 they refer to ambitious mitigation scenarios. This also presents challenges in communication with
 8 probabilistic language. The risks associated with 4°C of warming may not be very different from the risks
 9 associated with a scenario that is expected to result in 4°C of warming, but which might result in 3°C or 5°C
 10 depending on the global climate response. This is not true of ambitious mitigation scenarios: the range of
 11 risks associated with 1.5°C of global temperature increase may be very different from the risks associated
 12 with a scenario that has an even chance of meeting the 1.5°C goal. In the first case, risks are conditioned on
 13 the global temperature goal actually being met, while in the second, they also need to allow for a substantial
 14 chance of warming exceeding 2°C because of uncertainty in the global temperature response. Such
 15 conditional probabilities often depend strongly on how conditions are specified, such as how temperature
 16 goals are met, whether through early emission reductions, greater reliance on negative emissions following
 17 an overshoot, or later reductions coupled with a low climate response. Hence whether a certain risk is
 18 deemed likely or very likely at 1.5°C may depend strongly on how 1.5°C is specified, whereas a statement
 19 that a certain risk may be substantially higher at 2°C relative to 1.5°C may be much more robust. Again, this
 20 cautions against the use of probabilistic language to convey highly conditional probabilities in situations
 21 where the precise specification of the conditions may not be transparent.
 22

23 Third, the traditional application of probabilistic language in IPCC applies to relatively passive systems, such
 24 as the projected response of the climate system to a specific emissions scenario. Achieving ambitious
 25 mitigation goals will require active, goal-directed efforts aiming explicitly for specific outcomes and
 26 incorporating new information as it becomes available. The focus of uncertainty shifts from the climate
 27 outcome itself to the level of mitigation effort that may be required to achieve it. The interpretation of
 28 probabilistic statements about future actions, which may in turn be informed by these statements, is clearly a
 29 challenge. It may also be unnecessary: in the context of robust decision-making, many near-term policies
 30 that are needed to keep open the option of achieving 1.5°C are the same, regardless of the actual probability
 31 that the goal will be met.
 32

33 In the light of these challenges, it is proposed to present summary findings in this report as far as possible
 34 using confidence language, using numerical ranges and probabilities where appropriate, avoiding the use of
 35 double-qualified statements.
 36
 37



38
 39
 40 **Figure 1.7:** The two dimensions of evidence and agreement together determine the level of confidence in a key
 41 finding, adapted from Mastrandrea et al. (2011). This figure illustrates how, while there are relatively few
 42 ways of supporting a "very high confidence" or "very low confidence" statement, there are multiple ways
 43 of supporting a "medium confidence" statement.
 44
 45

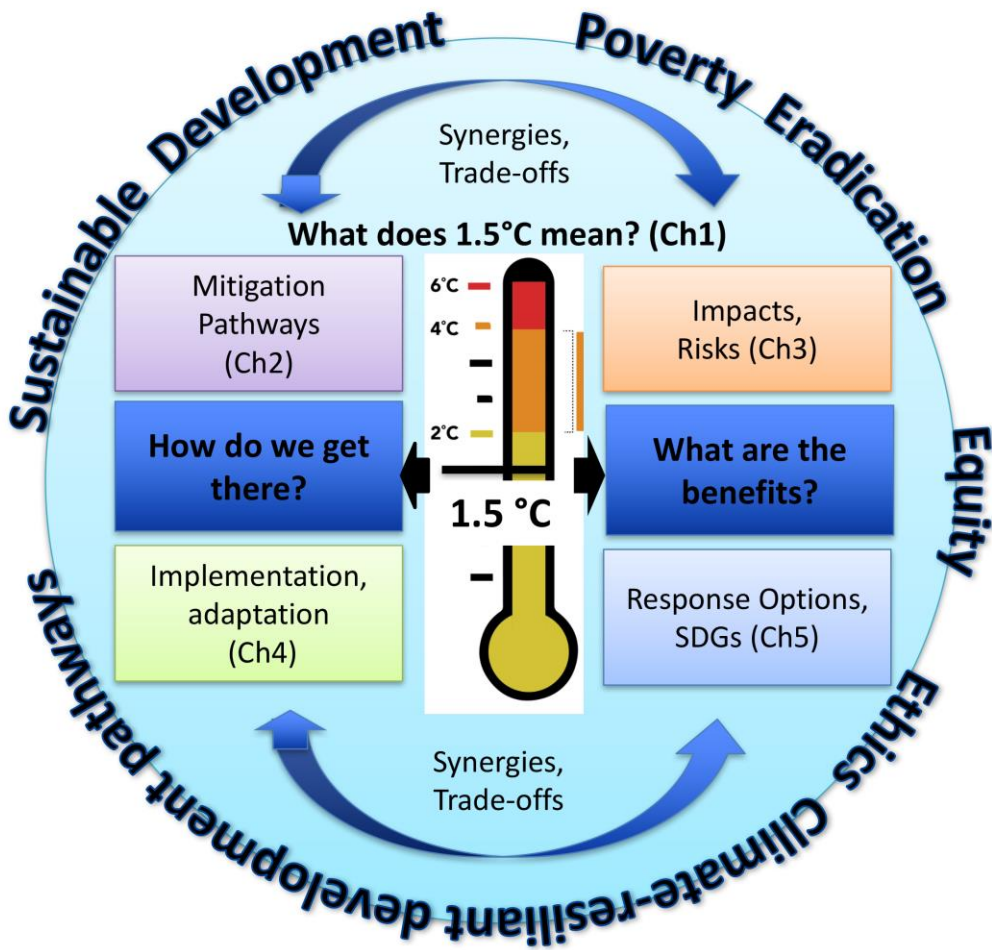
1.7 Storyline of the report

The thrust of this report, as illustrated in Figure 1.8, is to establish feasible options for the global community, within the context of the Sustainable Development Goals (SDGs), to limit the global temperature increase to 1.5°C above pre-industrial levels and address adaptation to the associated impacts inclusive of poverty eradication, equity and ethics issues. The report consists of five chapters and a summary for policy makers. The report has a set of Boxes to elucidate specific or cross-cutting themes, frequently asked questions for each chapter and a glossary.

Chapter 1, on Framing and context has seven major sections that are linked to the remaining four chapters forming the body of the report. The introduction section of Chapter 1 serves to situate the assessment within social-ecological systems in the context the Anthropocene. It points to the central role of governance in constraining global temperatures to 1.5°C warming and responding to associated impacts within the sustainable development framework. The next section, key to the whole report, focuses on understanding 1.5°C, global versus regional warming and linkages to 1.5°C -consistent pathways and associated emissions, further developed in Chapter 2. The section on multiple dimensions of impacts at 1.5°C opens the way to Chapter 3 on impacts of 1.5°C global warming on natural and human systems, and coupled social-ecological systems. The section on strengthening the global response to the threat of climate change is the basis for Chapters 4 and 5 and, respectively, cover implementing the global response to the threat of climate change, and sustainable development, poverty eradication and reducing inequalities in the context of 1.5°C global warming. Chapter 1 also provides a framing on assessment methods used in the report and approaches to communicating confidence, uncertainty and risk.

The report flows from this initial framing to Chapter 2 and ‘how 1.5°C global warming could be achieved’, where greenhouse gas emissions consistent with warming of 1.5°C and characterizing mitigation and development pathways that are compatible with a 1.5°C world are covered. Chapter 2 also assesses technological, environmental, institutional and socio-economic opportunities and challenges related to 1.5°C pathways and goes beyond the normal IPCC WGII treatment with an emphasis on sustainable developed in mitigation pathways. In the light of the Chapter 2 assessment, impacts and risks of 1.5°C global warming on social-ecological systems are assessed in Chapter 3. This third chapter is focused on observed and attributable global and regional climate changes and impacts, vulnerabilities and the adaptation experiences to key global and regional impacts and risks at 1.5°C. It links adaptation potential and limits to adaptive capacity. In this context, avoided impacts and reduced risks at 1.5°C compared with 2°C and comparative higher levels of warming. The assessment of system level conditions including timeframes, slow versus fast onset impacts, irreversibility and tipping points are included.

Chapter 4 and 5 focus on development-linked solutions and implications for the near term and longer term. Chapter 4 considers the costs and benefits of 1.5°C warming, synergies, trade-offs and an integration of adaptation-mitigation-development, and addresses governance approaches and implementation strategies cognizant of equity and justice. The chapter has a section on case studies for implementation of adaptation and mitigation options at different scales and circumstances, and lessons learned that will be valuable to strengthening the global response to climate change. Chapter 5 covers linkages between achieving SDGs and 1.5°C. Positive and unintended effects of adaptation and mitigation response measures and pathways for a 1.5°C warmer world are examined, with implications for sustainable development, poverty eradication, and reducing inequalities, as well as for the SDGs. The chapter discusses opportunities and challenges for climate-resilient development pathways, supported through emerging evidence from case studies from national to community scales.



1
2
3
4

Figure 1.8: Schematic storyline figure for the rest of the report.

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- 40
- 41
- 42

1 **Technical Annex 1.A**

2 3 Technical Note for Figure 1.1

4
5 Observational data is taken from the Met Office Hadley Centre
6 (<http://www.metoffice.gov.uk/hadobs/hadcrut4/>), National Oceanic and Atmospheric Administration
7 (NOAA) ([https://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-](https://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp)
8 [noaaglobaltemp](https://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp)) and NASA's Goddard Institute for Space Studies (<https://data.giss.nasa.gov/gistemp/>). The
9 GISTEMP and NOAA observational products (which begin in 1880) are expressed relative to 1850-1879
10 by first expressing all three time series relative to a common 1961-1990 base period before subtracting off
11 the anomaly between this period and the 1850-1879 average in the HadCRUT4 product. All available data is
12 used, through to the end of 2016, in all cases.

13
14 CMIP5 multi-model means, light blue dashed (full field surface air temperature) and solid (masked and
15 blended as in Cowtan et al. (2015)) are expressed relative to a 1861-1880 base period and then expressed
16 relative to the 1850-1879 reference period using the anomaly between the periods in the HadCRUT4
17 product.

18
19 The light green "Holocene" shading is derived from the "Standard5x5Grid" reconstruction of Marcott et al.
20 (2013) (expressed relative to 1850-1879 using the HadCRUT4 anomaly between this reference period and
21 the 1961-90 base period of the data). The vertical extent is determined by the maximum and minimum
22 temperature anomalies in the dataset in the period between 10,000 years before present (present is defined as
23 1950) and 1850. Marcott et al. (2013) report data with a periodicity of 20 years, so the variability shown by
24 the green shading is not directly comparable to the higher frequency variability seen in the observational
25 products which are reported every month), but this Holocene range can be compared to the emerging signal
26 of human-induced warming.

27
28 Pink lines show the first two years of a series of initialised (with prior climate observations) predictions with
29 a multi-model ensemble of decadal prediction systems (Smith et al. 2013a). Model data is reported as
30 anomalies relative to the model climatology over the 1981-2010 period, which is then expressed relative to
31 1850-1879 using the HadCRUT4 anomalies between these periods. Only the first two years of each
32 integration is shown. Prediction start dates range from 1960-2017.

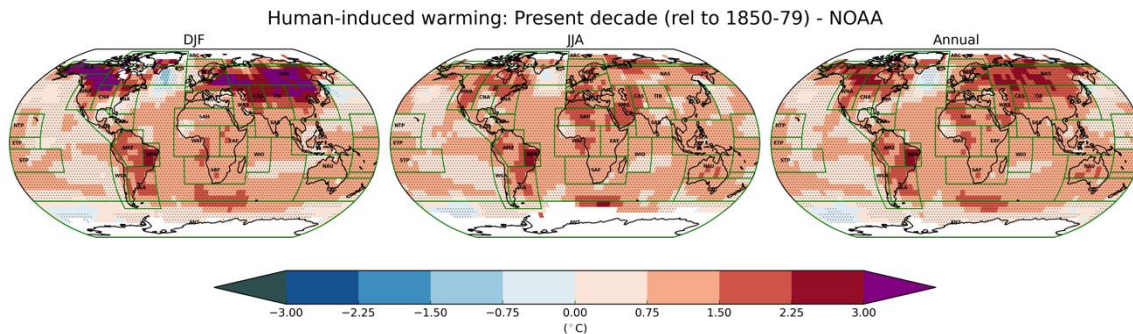
33
34 Near term predictions from IPCC-AR5 (Kirtman et al. 2013), for the period 2016-2035 were estimated to be
35 *likely* (>66% probability) between 0.3°C and 0.8°C above the 1986-2006 average, assuming no climatically
36 significant future volcanic eruptions. We construct straight lines that have gradients consistent with the upper
37 and lower ends of this prediction range where the 1986-2006 average is calculated using the HadCRUT4
38 product. These are shown as the thick turquoise lines, with shading between them.

39
40 Best-estimate human-induced temperature change (thick orange line) and solar & volcanic temperature
41 change (thick dark blue line) are estimated using the method of Otto et al. (2015). Best-estimate historical
42 radiative forcings, extended until the end of 2016, are taken from Myhre et al. (2013), incorporating the
43 significant revision to the methane forcing proposed by Etminan et al. (2016). The 2-box thermal impulse-
44 response model used in Myhre et al. (2013), with modified thermal response time-scales to match the multi-
45 model mean from Geoffroy et al. (2013), is used to derive the shape to the global mean temperature response
46 time series to total anthropogenic, and combined volcanic and solar forcing. Both of these time series are
47 expressed as anomalies relative to their simulated 1850-1879 averages and then used as independent
48 regressors in a multi-variate linear regression to derive scale factors on the two time series that minimise the
49 residual between the combined forced response and the HadCRUT4 observations (expressed as anomalies
50 relative to 1850-1879). The error bar on the 2016 attributed human-induced warming is derived using the
51 same proportional uncertainty as the $\pm 0.1^\circ\text{C}$ (*likely*) uncertainty in the 0.7°C best-estimate anthropogenic
52 warming trend over 1951-2010 period assessed in Bindoff et al. (2013).

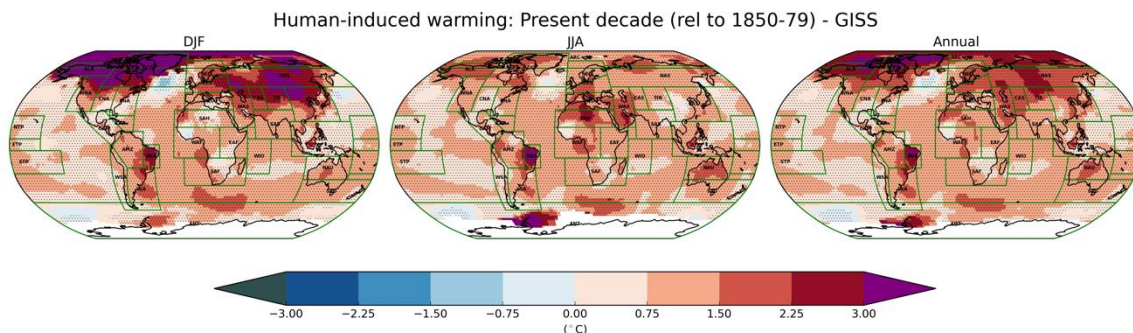
1 Technical Note for Figure 1.2

2
 3 Regional attributable human-induced warming shown in Figure 1.2 is derived using a similar method to the
 4 calculation of human-induced warming in Figure 1.1. At every grid box location in the native HadCRUT4
 5 resolution, the time series of local temperature anomalies in the HadCRUT4 dataset (expressed relative to the
 6 local 1850-1879 average) are regressed onto the global human-induced warming time series shown in Figure
 7 1.1 (assuming a Gaussian error structure) using all available data points. This linear regressed relationship
 8 between these two quantities is then used to estimate the human-induced warming relative to 1850-1879 at
 9 this location. The maps in Figure 1.2 show the average of local human-induced over the 2007-2016 period.
 10 Trends are only plotted only where over 50% of the entire observational record at this location is available.
 11 Stippling indicates the linear trend between local warming and global human-induced warming is significant
 12 at a 10% level using a one-sided Student-t test. The “JJA” and “DJF” maps take seasonal averages
 13 (June/July/August and December/January/February respectively) of the data at every grid box for use in the
 14 regressions, whilst the “Annual” map uses annual mean.

15
 16 Supplementary maps are included below for the NOAA and GISSTEMP observational data, which use
 17 infilled data to achieve a higher level of coverage than HadCRUT4. The regression of local temperature
 18 anomalies onto the global mean human-induced warming (recalculated using the NOAA and GISS global
 19 mean observations respectively), allows local human-induced warming to be expressed relative to 1850-1879
 20 despite these records beginning in 1880.



22
 23 **Technical Annex 1.A, Figure 1:** Human-induced warming for the average of 2007-2016 relative to 1850-1879
 24 calculated for the NOAA observational dataset as for Figure 1.2.



26
 27 **Technical Annex 1.A, Figure 2:** Human-induced warming for the average of 2007-2016 relative to 1850-1879
 28 calculated for the GISSTEMP observational dataset as for Figure 1.2.

1 *Technical note for Figure 1.3*

2

3 Construction of figure 1.3

4

5 Panel a: Idealised temperature pathways computed by specifying the level of human-induced warming in
6 2015, $T_{2015} = 1^{\circ}\text{C}$, with temperatures from 1865 to 2015 given by a single-term polynomial: $T =$
7 $T_{2015}((t - 1865)/150)^{\gamma}$, with γ set to give a rate of human-induced warming in 2015 of $0.17^{\circ}\text{C}/\text{decade}$.
8 Temperatures from 2016-2115 set by fitting a smooth 4th-order polynomial to prescribed temperatures in
9 2050 and 2115 and a prescribed gradient in 2115. Gradient is held constant after 2115. Colours are used to
10 illustrate different temperatures pathways, and are consistent in all panels. Upward-pointing triangles
11 indicate years in which 1.5°C is reached from below, and downward-pointing arrows indicate years in which
12 1.5°C is reached from above.

13

14 Panel b: Radiative forcing F that would give the temperature profiles shown in panel a, computed using a 2-
15 time-constant climate response function (Myhre et al. 2013), with Equilibrium Climate Sensitivity (ECS) of
16 2.7°C and Transient Climate Response (TCR) of 1.6°C and other parameters as given in Millar et al. (2017).
17 Equivalent CO_2 concentrations given by $C = 278 \times \exp(F/5.4)$ ppm.

18

19 Panel c: Cumulative CO_2 -forcing-equivalent emissions, or the CO_2 emission pathways that would give the
20 CO_2 concentration pathways shown in panel b, computed using a simple carbon cycle model (Myhre et al.
21 2013), modified to account for changing CO_2 airborne fraction over the historical period (Millar et al. 2017).

22

23 Panel d: Annual CO_2 -forcing-equivalent emissions, or the time-derivative of c.

24

25 Panel e: Possible pathways of sea level rise computed from temperature pathways shown in panel a using
26 semi-empirical model of Kopp et al. (2016).

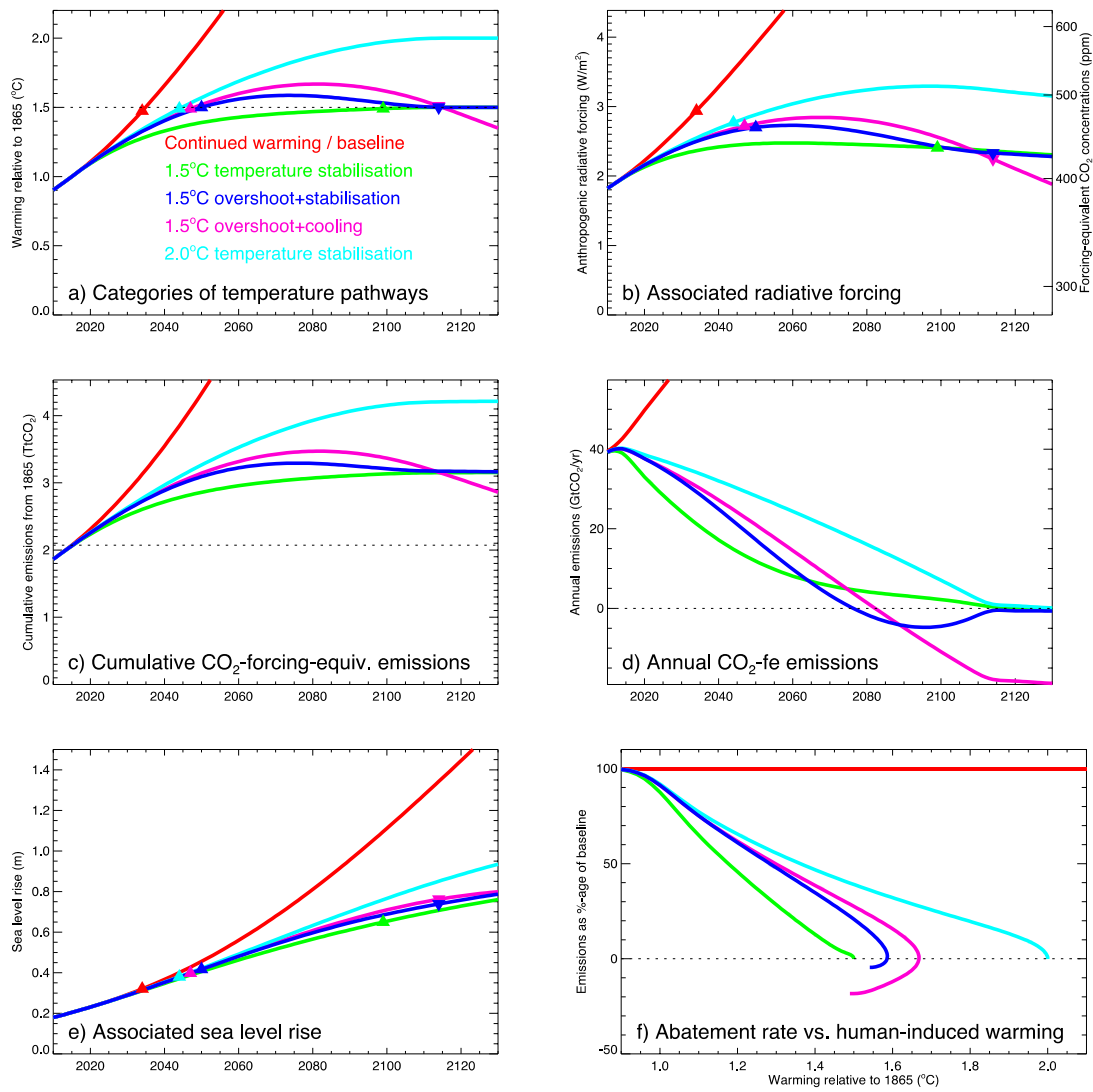
27

28 Panel f: Emissions as a percentage of baseline emissions for the pathways shown in panel a plotted against
29 temperatures shown in panel a.

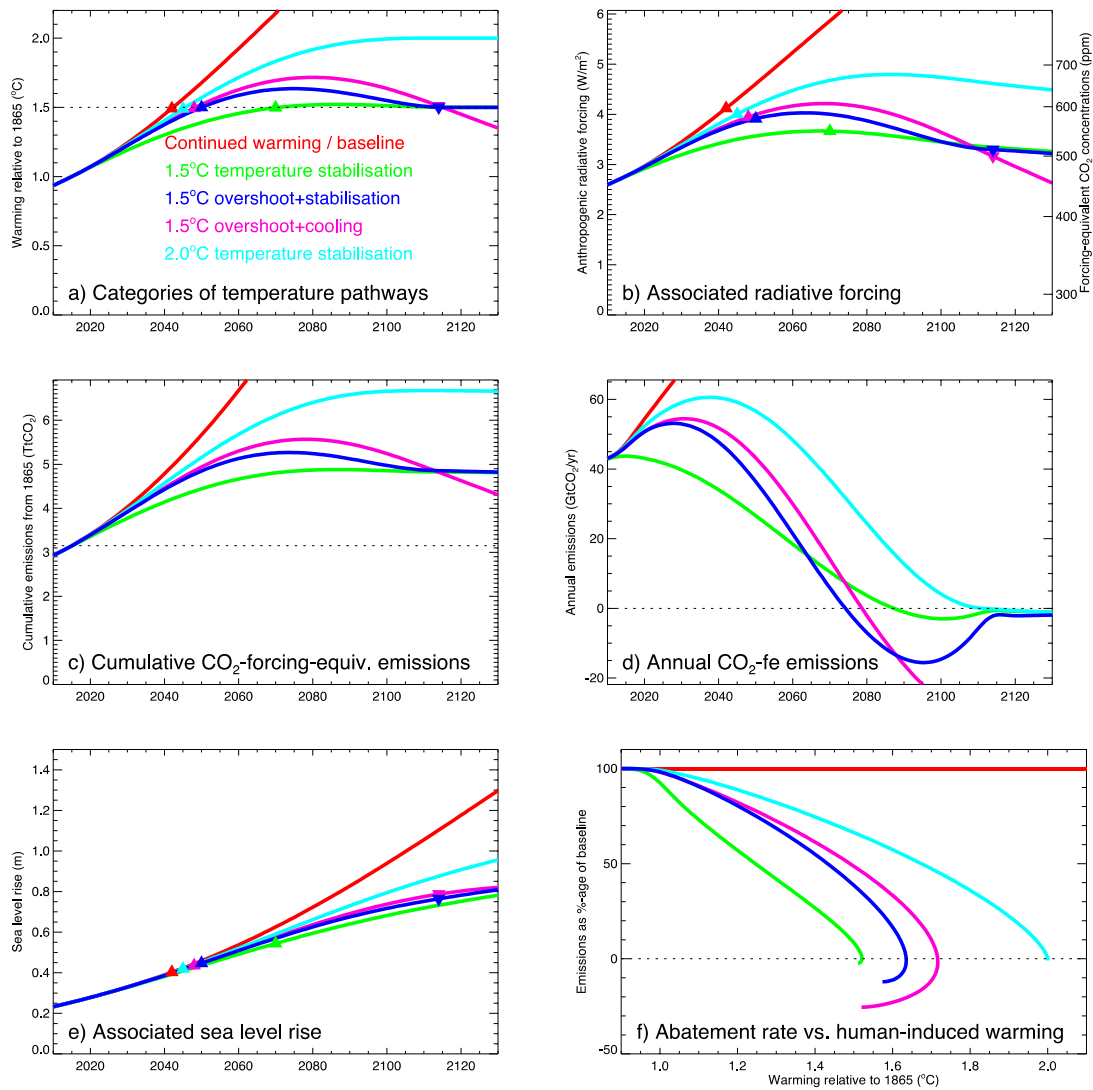
30

31 Variants of the figure are shown below corresponding to a higher and lower climate response (Higher:
32 $\text{ECS}=3.1^{\circ}\text{C}$, $\text{TCR}=1.9^{\circ}\text{C}$, human-induced warming rate in 2015 of $0.2^{\circ}\text{C}/\text{decade}$; lower: $\text{ECS}=2.2^{\circ}\text{C}$,
33 $\text{TCR}=1.3^{\circ}\text{C}$, human-induced warming rate in 2015 of $0.13^{\circ}\text{C}/\text{decade}$). Warming to 2100 and 2050 and
34 temperature gradients in 2100 vary in the baseline pathway in proportion to TCR. All other pathways are
35 specified as in standard version. Note how emissions must fall much faster under a higher climate response
36 to meet a given temperature goal (panel d), but proportionality of cumulative emissions to warming (panel c)
37 still holds, as does the near-straight decline of emissions as a percentage of baseline (panel d).

38



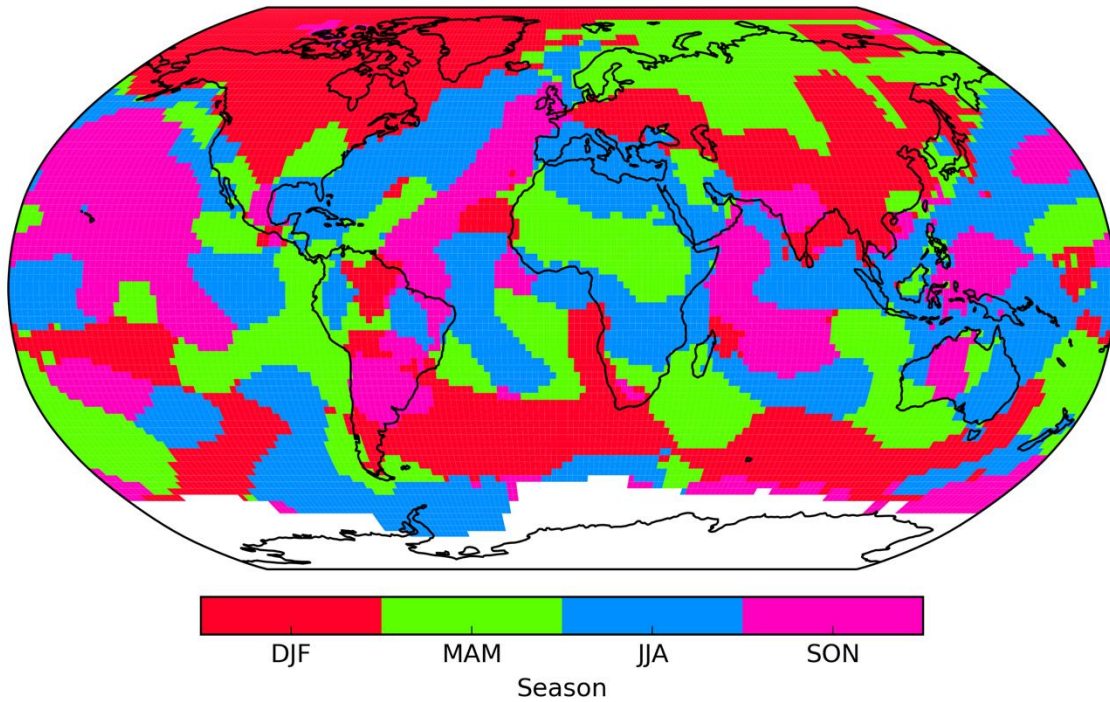
1
2 **Technical Annex 1.A, Figure 3:** Version of figure 1.3 corresponding to a higher climate response.



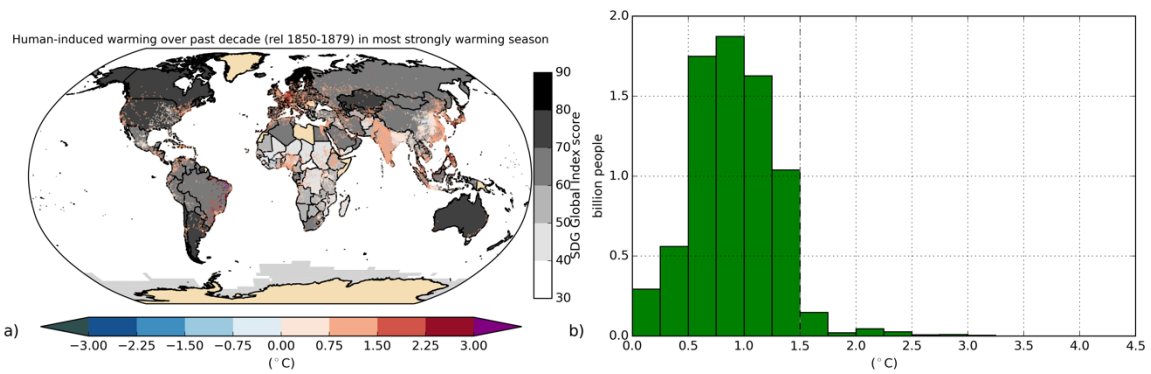
1
2 **Technical Annex 1.A, Figure 4:** Version of figure 1.3 corresponding to a lower climate response

3
4
5 *Technical Note for Box 1.4 Figure 1*

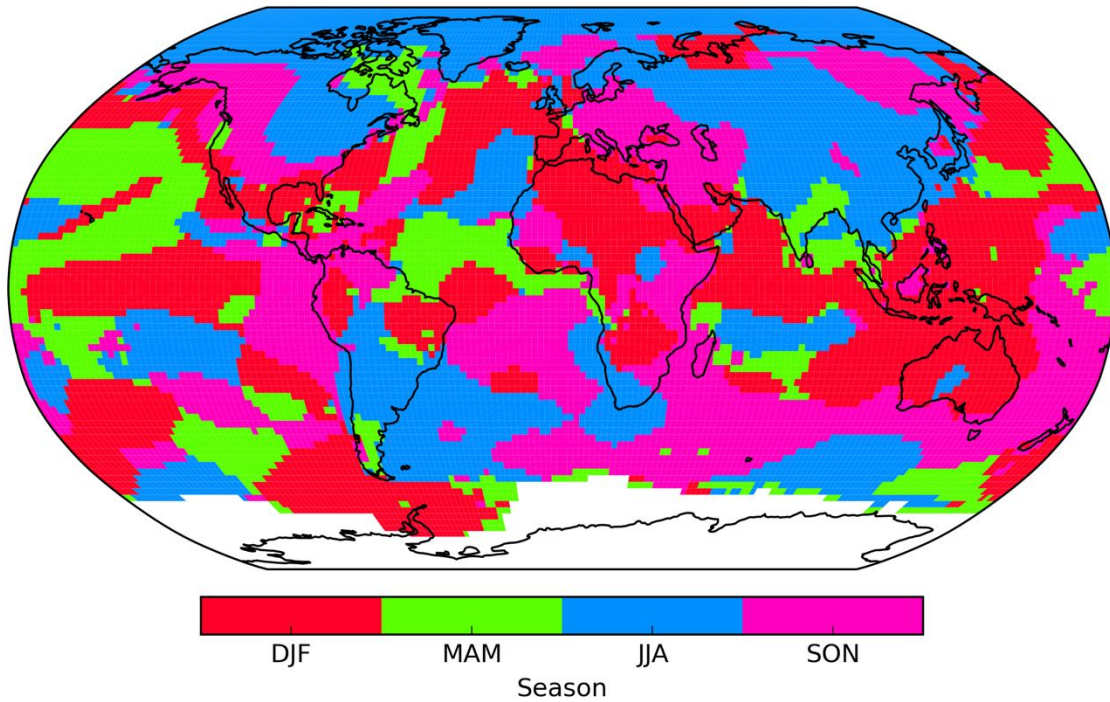
6
7 Human-induced warming is calculated for the GISTEMP dataset at every location and for each season as in
8 Figure 1.2. The season with the greatest warming at every location (averaged over the 2007-2016 period) is
9 selected to give the colour of the dots at that grid box. This field is then regridded to the 1°x1° grid of the
10 population density data, taken from Doxsey-Whitfield et al. (2015) for 2015. The density of scatter points in
11 each 1°x1° grid box is proportional to the population in the grid-box, up to a maximum of 50, associated
12 with the greatest population grid box. For grid-boxes below the minimum population threshold to guarantee
13 a point is plotted (approximate 650,000), the probability that a dot is plotted reduces with the population in
14 the grid-box. The SDG Global Index Score ranks country performance across 17 sustainable development
15 goals. The goals cross-cut the three dimensions of sustainable development – environmental sustainability,
16 economic growth, and social inclusion. It has a maximum value of 100. Figure 1.SM.5 shows the month of
17 maximum warming in each grid-box used in Figure 1 of Box 1.4. Figure 1.SM.6 is identical to Figure 1 of
18 Box 1.4, but now shows the season with the least human-induced warming at each location.
19



1
2 **Technical Annex 1.A, Figure 5:** Season of greatest human-induced warming over the present decade (2007-2016)
3 relative to 1850-1879.
4



5
6 **Technical Annex 1.A, Figure 6:** As for Figure 1 Box 1.4, but for the least warming season.
7



1
2 **Technical Annex 1.A, Figure 7:** Season of least human-induced warming over the present decade (2007-2016) relative
3 to 1850-1879.
4
5
6