Chapter 1: Framing and Context

Coordinating Lead Authors: Myles Allen (UK), Opha Pauline Dube (Botswana), William Solecki (USA)

Lead Authors: Fernando Aragón-Durand (Mexico), Wolfgang Cramer (France), Mikiko Kainuma (Japan), Jatin Kala (Australia), Natalie Mahowald (USA), Yacob Mulugetta (UK), Rosa Perez (Philippines), Graciela Raga (Mexico), Morgan Wairiu (Solomon Islands), Kirsten Zickfeld (Canada)

Contributing Authors:

Review Editors: Ismail A. Elgizouli (Sudan), Andreas Fischlin (Switzerland), Xuejie Gao (China)

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Executive Summary

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

In December 2015, the *Paris Agreement* was negotiated by representatives of 195 countries at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) to undertake ambitious efforts towards mitigation of greenhouse-gas emissions, adaptation and finance, to start in 2020. The Agreement stresses the need of early action on greenhouse gas emissions with the objective of "holding the increase in the global average surface temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C". Furthermore, the Agreement establishes the global goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" and contains important signals that fast implementation of technical and policy measures to cut emissions will require adequate and opportune financing, transfer of technology and the identification of actions that would be beneficial for the climate, health and food security, while supporting sustainable development. This report directly responds to this charge and is designed to provide the knowledge base for this effort. This framing chapter provides the conditions and parameters of this knowledge base and assesses the unique opportunity for synergistic actions to achieve the goals of the Paris Agreement within the context of sustainable socio-economic development, poverty reduction and a substantive transformation of society.

The year 2015 also brought about extraordinarily significant advances to shared global challenges and to a self-realization that may pave the way to solutions. The realization that the world is now formed by socio-ecological systems and that we may have entered a new geological epoch, the Anthropocene, defined by unprecedented human influence on natural systems attested by e.g. climate change. This report scientifically assesses the effects and impacts that the world will face when the global surface temperature reaches 1.5 °C above pre-industrial level and seeks to strengthen the global response to this challenge in the context of sustainable development, poverty eradication, justice, equity and ethics. The results of this assessment provide ample evidence for an urgent need for action.

Previous IPCC reports have explicitly demonstrated evidence of human interference in the climate system to an extent that the average global surface temperature has reached approximately 1 °C above pre-industrial levels (IPCC 2013), while individual monthly average temperatures of 1.4 °C above these same levels have been observed. This increase has generated observed impacts (Chapter xx, Section xxx) and acts as an amplifier of risks for natural and human systems (Chapter xx, Section xxx), motivating early action to at least limit the rise in global temperatures to 1.5 °C above pre-industrial levels. Some regions of the world have locally experienced higher warming already, at different periods, but this should not be confused with a global temperature of 1.5 °C above pre-industrial levels (Chapter xx, Section xxx below). However, increases in extreme weather events, droughts, floods, sea level rise and biodiversity loss are already affecting economic development worldwide (Chapter xx, Section xxx). This is mostly in the developing world where this has to some extent been linked to migration and poverty. Small islands and populations residing in megacities, coastal regions and in high mountain ranges are some of the most affected.

Over the last two decades economic growth has been accompanied by increased life expectancy, educational attainment and income, but many regions are still subject to 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 (United Nations 2015) with much of this growth occurring in hazard-prone small and medium sized cities in low and moderate income countries (Birkmann et al. 2016). This combined with other challenges such as conflicts, low development and challenges of globalization will act together with the threat of 1.5 °C above pre-industrial levels to exacerbate problems of food security and access to fresh water in different regions (FAO et al. 2015; Campbell et al. 2016). Recognizing these impacts and vulnerabilities has come with the realization that adaptation is pertinent and, more importantly, that it is not possible to separate climate change from development.

In the context of rapid, global urbanization, cities and everyday urban life embody both significant challenges and solution spaces for 1.5 °C efforts. Using urbanization as an example, there is a clear trend in the migration of populations towards large urban centers in many regions (e.g. LAC is 79% urban) and by 2050 urban dwellers will reach 80% of global population (United Nations 2015). The deterioration of air quality in megacities affect human health, already stressed by urban heat island effects (World Health Organization 2016). As a result, in the context of rapid, global urbanization, there is a need for an integrated framework of coordinated management of climate and air quality mitigation, recognizing that integrated policies can significantly reduce the cost of achieving objectives related to both areas. In particular, the transportation sector in megacities is "primed" for undergoing a transformative change to low- or no-carbon emissions that will result in a substantial improvement in the health and quality of life of hundreds of millions. Energy generation to cover the demands of urban populations is a huge sector also with a high potential to transition to low-carbon transformation. Similarly, sewage and the solid waste offer another climate mitigation opportunity in the path to sustainable development, justice and ethics in megacities.

The understanding of 1.5 °C comes from a variety of established and emergent knowledge bases. These different knowledges together will be critical to more fully realize the texture and conditions of impact, vulnerability, mitigation and the strengthening of the sustainable development agenda. The demands of the 1.5 °C challenge and conditions to define meaningful solutions requires this approach.

1.2 Understanding 1.5 °C; reference levels, probability, transience, overshoot, stabilization

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

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

1.2.1.1 Choice of variable

The IPCC has traditionally defined changes in observed global average temperature as the average of northern and southern hemispheric changes, each compiled as an area-weighted average of observed near-surface air temperature (SAT) changes over land and sea surface temperature (SST) changes over the oceans (Hansen et al. 2010; Morice et al. 2012). This report assumes that this practice will continue, but with improved data coverage in Arctic and Antarctic regions. Modeling studies, with no coverage constraints, have typically used a simple area average of SAT over land, sea-ice and oceans. For relatively low warming levels, the difference can be significant: Cowtan et al. (2015) show that the use of blended SAT/SST data gives approximately 0.1 °C less warming to date in the CMIP5 ensemble than the use of area-average SAT, while Richardson et al. (2016) show that incomplete coverage reduces warming to date by a further 0.1 °C (see inset panel in Stocker et al. (2013), figure TFE8.1 and Figure 1.1). Detection and attribution studies have generally been careful to make a like-for-like comparison, accounting for coverage (Tett et al. 1999; Jones et al. 2003). The simple climate models used in many Integrated Assessment Models do not distinguish SAT and SST, but are typically calibrated to more complex models or observations, and hence could reproduce either a pure SAT or blended SAT/SST metric. Richardson et al. (2016) show that defining global temperature using a blended SAT/SST metric reduces the expected transient warming under rapidly increasing forcing by approximately 10% relative to a pure SAT metric, but is not expected to impact the equilibrium response.

[INSERT FIGURE 1.1 HERE]

Figure 1.1: Evolution of global warming over the observed period. Warming is expressed as anomalies from the 1861-1880 base period (green shading) for monthly means of the HadCRUT4, NOAA and GISS datasets, which measure a blended mix of near surface air temperature over land and sea surface temperature over oceans. Human-attributable warming (orange) and naturally-forced warming (blue) are calculated using the two time constant response model of Myhre et al. (2013) following Otto et al. (2015). Proportional uncertainty in the final human-attributable warming is set equal to that from Bindoff et al. (2013). The purple lines show the modelled global-mean surface air temperature (dashed) and blended surface air and sea surface temperature accounting for observational coverage (solid) from the CMIP5 ensemble under the Historical and RCP8.5 scenario.

1.2.1.2 Choice of reference period

Any choice of reference period represents a compromise between data coverage and representativeness of pre-industrial conditions. In this report, we propose, where possible, to use 1861-80, as used in the carbon budget calculations in AR5 (e.g. figure SPM10 of IPCC (2013) and Table 2.2 of the IPCC (2014a)), representing the earliest period for which near-global observations are available that was not subject to strong volcanic activity. Years after 1880 are subject to strong but very uncertain volcanic forcing, complicating their use in a reference period. Temperatures rose by approximately 0.1 °C over the century prior to 1861, but less than half of this warming is estimated to be anthropogenic.

1.2.1.3 Total, expected or human-induced warming

Total warming refers to the actual temperature change, irrespective of cause; expected warming excludes random or unpredictable natural climate fluctuations; and human-induced warming refers to the component that is attributable to human activity. Total warming is timescale-dependent: temperatures in individual years can fluctuate substantially around the long-term expected temperature due to externally driven and internally generated climate variability. While recognizing that many systems are impacted by total changes, irrespective of cause, studies of climate change impacts typically refer to warming levels defined by multi-decade average temperatures, consistent with the traditional WMO definition of "climate", which is approximately equal to expected warming.

Mitigation studies focus on human-induced warming because, while natural drivers may be included in historical simulations used to initialize them, possible future natural fluctuations, either internally generated or externally forced, are neglected as both unpredictable and unaffected by mitigation policy. Given that overall warming due to changes in solar and volcanic activity from 1861 to present is small, there is little practical difference between expected and human-induced warming. This equivalence would need to be reconsidered should a predictable secular trend in natural forcing emerge in future, but there is no evidence for this at present. Hence, for the purposes of this report, a "1.5 °C world" is defined as one in which expected temperatures are 1.5 °C above the pre-industrial reference period or, practically equivalently, in which human-induced warming has reached 1.5 °C.

On this definition, global temperatures would fluctuate equally on either side of 1.5 °C above the reference period in the absence of a large volcanic eruption (which would cause temporary cooling). Alternative definitions, such as maintaining the probability of temperatures fluctuating over 1.5 °C below a specified level, are more ambiguous, since they depend on the averaging timescale used and the properties of future natural variability. An indication of the range of natural fluctuations is given by Figure 1.1, which shows observed 20-year-average temperatures varied by ±0.1 °C (5-95% range), and monthly temperatures by ±0.2 °C, around the human-induced warming trend over the period 1861-2017. Regional fluctuations would be larger still.

1.2.1.4 Summary

For the purposes of this report, warming relative to pre-industrial levels is defined as the increase in expected global average blended surface air temperature changes over land and sea surface temperature changes over oceans, relative to the reference period 1861-80, and assuming full spatial coverage in future (extending past coverage would exclude rapidly-warming polar regions).

1.2.2 Global versus regional and seasonal warming

Warming is not observed or expected to be spatially uniform, nor distributed uniformly across all months of the year (IPCC 2013). This is illustrated by Figure 1.2, which shows a best-estimate of the observed change in seasonal average temperatures in the June-August and December-February seasons, associated with the observed 1 °C rise in global temperatures relative to the 1861-80 reference period. Many regions, particularly in northern mid-latitude winter, have already experienced regional warming in excess of 1.5 °C or even 2 °C. Natural climate fluctuations mean that individual seasons may be substantially warmer, or cooler, than these expected long-term average changes [perhaps add some text on magnitude and timescales of unpredictable regional climate fluctuations, e.g. Deser et al. (2012), in the FOD].

[INSERT FIGURE 1.2 HERE]

Figure 1.2: Regional human-attributable warming in 2016 relative to 1861-1880 for the average of December, January and February (DJF – left) and for June, July and August (JJA – 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 of linear trends at a 10% confidence level assuming Gaussian errors.

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.

1.2.3.1 Temperature stabilization pathways

The simplest 1.5 °C-consistent pathway is one in which human-induced warming rises monotonically to stabilize on 1.5 °C. Because of the inertia of the climate, carbon cycle and energy systems, the rate of human-induced warming varies slowly over decades, allowing only smooth temperature pathways if temperature goals are achieved through emission reductions alone. Given human-induced warming is currently approximately 1 °C and increasing at almost 0.2 °C per decade, a reduction in this rate of warming at an average rate of 4% per year from now on is required to stabilize temperatures at 1.5 °C without overshoot (see Figure 1.3). Sea-level rise would continue after temperature stabilization, albeit at a decreasing rate.

Stabilization has often in the past been used to refer to stabilization of atmospheric greenhouse gas concentrations, which would result in continued warming over multi-decade to centennial timescales. In view of the focus on temperature goals, this report will focus on temperature rather than concentration stabilization scenarios, but the word stabilization will be qualified where necessary to avoid confusion.

1.2.3.2 Temperature overshoot pathways

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

1.2.3.3 Continued warming pathways

Under this category, 1.5 °C is reached and temperatures then continue to warm. Impacts may be very different from a 1.5 °C temperature stabilization scenario, particularly if warming is relatively rapid, since surface temperatures are not in equilibrium with atmospheric composition. In particular, CO_2 concentrations will be higher under a continued warming scenario when temperatures reach 1.5 °C than they would be under a temperature stabilization scenario, leading to very different ecosystem and agricultural impacts. While continued warming scenarios are widely used to assess the impacts of 1.5 °C because of the lack of available temperature stabilization scenarios, they are not referred to in this report as 1.5 °C-consistent pathways.

An important sub-category of continued warming pathways are baseline scenarios, in which either no climate mitigation policies are assumed at all, or existing climate mitigation policies and commitments are extrapolated into the future. A distinction must be drawn between "efficient" baseline scenarios, in which resources are deployed efficiently in the future without regard to their climate impact, and "business-as-usual" scenarios in which current trends and policies are extrapolated. The distinction is important because mitigation scenarios typically assume efficient resource allocation subject to a climate constraint, so an efficient baseline is needed for a like-for-like comparison.

[INSERT FIGURE 1.3 HERE]

Figure 1.3: Schematic showing categories of temperature pathways, with associated CO_2-equivalent emissions, cumulative emissions and sea-level-rise from a semi-empirical model (Kopp et al. 2016).

1.2.3.4 Precautionary versus adaptive mitigation scenarios

A useful distinction can be drawn between precautionary mitigation scenarios, in which emissions are prescribed to achieve a temperature goal at a given level of probability, such as maintaining temperatures below 1.5 °C with 66% probability given current uncertainties in the climate response, and adaptive mitigation scenarios, in which it is assumed that emissions are actively adjusted in future to meet the temperature goal in the light of the emerging climate response. In precautionary scenarios, emissions are prescribed and the uncertainty is in the climate response. Uncertainty in the transient climate response alone means that the most likely warming in a precautionary "66% chance below 1.5 °C" scenario is around 1.2 °C, while there is still a non-negligible probability of temperatures exceeding 2 °C. In adaptive scenarios, the uncertainty is in future emissions rather than future temperatures (including whether potentially required rates of emission reductions are achievable), so the temperature outcome is effectively certain, apart from natural climate fluctuations. Impact studies implicitly assume adaptive mitigation, because they consider the implications if the temperature goal is actually met, rather than undershot at a given level of probability, while the majority of mitigation studies to date have taken a precautionary approach to scenario development.

1.2.3.5 Cumulative emission budgets

The AR5 drew attention to the fact that there is a simple, near-linear relationship between cumulative CO_2 emissions and CO_2-induced warming (Allen et al. 2009; Matthews et al. 2009; Zickfeld et al. 2009), characterized by the Transient Climate Response to Emissions, or TCRE. At that time, the notion of a cumulative carbon budget could not be extended to non-CO_2 agents because the majority of these are relatively short-lived climate pollutants (SLCPs) and hence do not accumulate in the climate system. Allen et al. 2016, drawing attention to a point made implicitly in Shine et al. (2005), observe that an equivalence can be drawn between cumulative emissions of CO_2 and changes in emission rates of SLCPs, which opens the possibility of a cumulative CO_2-equivalent emission budget consistent with different levels of warming and a given value of the TCRE.

1.2.4 Definition of "balance" and net zero emissions

Article 4 of the Paris Agreement acknowledges that, "in order to achieve the long-term temperature goal … Parties aim to … achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century…" This report will clarify what is meant by "balance" in the context of 1.5 °C.

For CO_2 alone, the interpretation of "balance" is unambiguous. On multi-century timescales, natural processes that remove CO_2 permanently from the active carbon cycle are so slow that balance means net zero global anthropogenic CO_2 emissions (Archer and Brovkin 2008; Matthews and Caldeira 2008; Solomon et al. 2009). Net zero emissions means that any remaining anthropogenic CO_2 emissions will need to be compensated for by an equal rate of anthropogenic CO_2 removal, using measures such as bioenergy with carbon capture and sequestration (BECCS), large-scale afforestation, biochar enhanced soil sequestration, direct air capture or ocean alkalinization. On shorter timescales, CO_2-induced warming also remains approximately constant for many decades after achieving net zero anthropogenic CO_2 emissions because of compensation between continuing adjustments in the climate system and carbon cycle (Section 1.2.5), but other aspects of climate would not be constant: sea level would continue to rise and ocean alkalinity would begin to recover.

For other greenhouse gases, "balance" need not necessarily be interpreted as implying zero anthropogenic emissions at the level of individual gases. Sustained emissions of a greenhouse gas at a rate (in tonnes per year) a few percent below the excess atmospheric load above pre-industrial levels (in tonnes) divided by the gas lifetime (in years) is consistent with gradually declining atmospheric concentrations (Shine et al. 2005; Rogelj et al. 2015; Schleussner et al. 2016) and no additional contribution to warming. Because it is inversely proportional to the gas lifetime, this "balanced" emission rate may be substantial for a short-lived climate pollutant (SLCP) such as methane, but is near zero for a long-lived or cumulative pollutant such as nitrous oxide. Note that this requires the interpretation of "balance" to include natural sinks. Even though a constant emission of an SLCP might not be contributing to additional warming, it could still represent a mitigation opportunity, since reducing it would lead to a near-term cooling.

For a combination of gases, if "balance" is interpreted as reducing the rate of human-induced warming (currently about 0.18 °C per decade) to zero, which is required for temperatures to peak any level, it requires near-zero net emissions of long-lived pollutants (CO_2 and gases with lifetimes of a century or more, such as nitrous oxide) over multi-decadal timescales, such that any residual anthropogenic sources of these gases would need to be balanced by anthropogenic removals of an equivalent amount (in terms of their impact on temperature) of other long-lived pollutants. It also requires constant net emissions of SLCPs, such that any increase in emission rate of one SLCP would need to be compensated for by an equivalent decrease in emission rate of another SLCP. Within (but not between, for reasons given in Smith et al. 2012, and Daniel et al. 2012) the categories of long-lived pollutants and SLCPs, equivalence can be defined to a reasonable approximation using the standard GWP100 metric (Allen et al. 2016, and see Box 1.1). An increasing rate of net emissions of SLCPs could be compensated for by net negative emissions (anthropogenic removals) of long-lived pollutants and still yield stable temperatures, but compensating for substantial continued net emissions of long-lived pollutants with continually falling emissions of SLCPs would not be possible, since it is impossible to reduce the rate of emission of most SLCPs below zero (with the possible exception of methane – see Boucher and Folberth 2010).

[START BOX 1.1 HERE]

Box 1.1: Long-lived and short-lived climate pollutants and emission metrics

[END BOX 1.1 HERE]

Another interpretation of Article 4 might be that sources and sinks of greenhouse gases balance in such a way that the equivalent atmospheric CO_2 concentration is stabilized. However, stabilization of CO_2-equivalent concentration implies continued warming (see Section 1.2.5) which is not consistent with a focus on temperature goals.

Should temperatures exceed 1.5 °C, then returning them to 1.5 °C would require the rate of human-induced warming to pass through zero and become negative. For this to occur, emissions would need to be reduced below the net zero level implied by this interpretation of "balance", through some combination of anthropogenic removals of long-lived pollutants and falling anthropogenic emissions of SLCPs. Hence achieving "balance" in the sense described here represents a necessary, but potentially not a sufficient, condition for achieving the 1.5 °C temperature goal.

1.2.5 Definitions of warming commitment

The question of whether the 1.5 °C target is attainable implicitly includes the notion of warming "commitment", or unavoidable future warming. This arises due to inertia in the physical Earth system, but also due to technological, economic, institutional and behavioral inertia.

Geophysical warming commitment is defined as the unavoidable future warming from past anthropogenic emissions of greenhouse gases (GHG) and aerosol precursors. It is also referred to as "zero emissions commitment" in the literature (Gillett et al. 2011; Matthews and Caldeira 2008; Matthews and Zickfeld 2012; Plattner et al. 2008; Zickfeld et al. 2013), as it can be quantified in climate model simulations by setting future GHG emissions to zero. The magnitude and sign of the geophysical warming commitment depend on the gas because of different atmospheric lifetimes and signs of radiative forcing. For CO_2, which has an atmospheric lifetime of centuries to millennia (Eby et al. 2009), the geophysical warming commitment ranges from slightly negative (i.e. a slight cooling after emissions cease) to zero, implying no future warming from past CO_2 emissions (Gillett et al. 2011; Matthews and Zickfeld 2012). This near-zero warming commitment for CO_2 arises from the near cancellation between declining radiative forcing in response to the elimination of CO_2 emissions (cooling effect) and the delayed temperature response to previously increasing radiative forcing from CO_2 (warming effect) (Solomon et al. 2009).

A widely discussed variant is the "constant composition commitment" (Meehl et al. 2005, 2007), which is the remaining warming if atmospheric composition and hence radiative forcing were stabilized at the current level. This is less policy-relevant, because maintaining constant atmospheric composition would require a specific combination of non-zero emissions that does not correspond to any scenario.

For greenhouse gases with a short atmospheric lifetime (order decades or less) such as methane (CH_4) the warming commitment is negative, implying cooling if future emissions of these gases are eliminated. This cooling arises from a rapid decline in radiative forcing, which dominates over the delayed warming response to previously increasing radiative forcing. Substances with a short atmospheric lifetime and negative radiative forcing such as sulphate aerosols have a positive warming commitment, as elimination of the radiative "dimming" effect of these substances results in rapid warming over about a decade. Estimates of the warming commitment from sulphate aerosols is uncertain due to large uncertainties in radiative forcing (Myhre et al. 2013). Using a range of sulphate aerosol radiative forcings consistent with temperature observations, Matthews and Zickfeld (2012) estimate a total geophysical warming commitment from GHGs and sulphate aerosol emissions up to year 2010 of about 0.3 °C (0.25-0.5 °C) over the decade immediately following elimination of emissions, although about half of this additional warming persists for only a few decades.

Geophysical warming commitment can be thought of as the minimum warming commitment, absent inertia in the socio-economic system (i.e. the future warming we could expect if we were to eliminate all GHG emissions tomorrow). However, existing infrastructure, institutions, and behavioral and social norms constrain the rate and magnitude of future GHG emission reductions. Three main types of inertia in the socio and techno-economic system have been identified in the literature: infrastructural and technological, institutional, and behavioral (Seto et al. 2016). Infrastructural and technological inertia arises from the long lifetime and large investments associated with energy infrastructure. Unless power plants will be retrofitted with carbon capture and sequestration (CCS) or operable infrastructure decommissioned early, existing infrastructure can be expected to contribute CO_2 emissions and warming for many decades. Davis et al. (2010) estimate 0.2-0.5 °C future warming from existing GHG emitting energy infrastructure (as of 2009), confirmed and updated by Pfeiffer et al. (2016).

In contrast to infrastructure and technological inertia, "institutional inertia is an intended feature of institutional design, not an unintended by-product of systemic forces" (Seto et al. 2016). Institutional inertia arises because "powerful economic, social, and political actors seek to reinforce a status quo that favors their interests against impending change or to create and then stabilize a new, more favorable, status quo" (Seto et al. 2016). The transition to a low-carbon trajectory is also hampered by behavioral inertia. Two factors contribute to this inertia: psychological processes and social structure. Habits, aversion to take risks and the necessity of collective action to solve the climate change problem (giving the feeling to individuals that they have little control over the problem) can lock in carbon intensive behaviors (Seto et al. 2016). Also, individual behavior is embedded in social norms and processes that change only slowly in response to changes in the technological and political environment (Seto et al. 2016).

1.3 Multiple dimensions of impacts at 1.5 °C and beyond

The impacts of climate change throughout the world are projected to be uneven and very localized. Impacts are consequences not only of rising temperatures and sea level, but also shifting trends in rainfall patterns, extreme events and physical impacts such as floods, droughts, and heat waves (IPCC 2012, 2014b). Impacts of climate change occur across the regions of the global and affect sectors including natural ecosystem and managed systems, urban and rural areas, economic services, human health, livelihoods and poverty, and human security (IPCC 2014b). Many impacts have been formally attributed to global warming and the increasing greenhouse gas concentrations due to human activities, but other forcings play major roles, such as land use change, atmospheric pollution and others.

The reference to 1.5°C is a decision made in the context of UNFCCC negotiations; but what do we mean when we say impacts of 1.5°C? Differentiating it from 2°C does not imply a scientific statement of safe vs. unsafe environmental conditions. For example, Schleussner et al. (2016), assessed the differential impacts of 1.5 °C and 2°C and concluded that for heat-related extremes, the additional 0.5°C increased global warming represents the upper limit of current natural variability and a new climate norm, particularly in tropical regions. For this Special Report, we propose that "impacts at 1.5°C' refers to the impacts when the expected global average of near-surface air temperature is 1.5° degrees above a pre-industrial period subject to similar natural forcing."

Impacts are multi-dimensional; hence, there is no universal, value-neutral metric of impact. While some of these dimensions are obvious (space, time, sector), others are less so (probability, equity, anthropocentricity), but they are all relevant to the climate discussion. This multi-dimensionality is particularly important for 1.5 °C and 2 °C because at these levels of warming, impacts may still be very small or even positive when measured along certain dimensions. The weight assigned to different dimensions could eventually affect the sign of the aggregate or total impact. For example, estimating the impacts of sea-level rise on property value would depend heavily on whether some form of "equity weighting" is applied to the total monetary value, or aggregate total loss.

[INSERT FIGURE 1.4 HERE]

Figure 1.4: Place holder for a Schematic diagram to illustrate the point, e.g. heat wave risk as an example of an impact that increases more rapidly with warming, while mid-latitude extreme precipitation risk increases approximately linearly, because of the different shapes of the tails of the temperature and precipitation distributions.

1.3.1 Detection and attribution of impacts

Observed impacts may be attributed formally to various climate drivers. While objective detection and attribution techniques are commonly used within the physical climate sciences to attribute the likelihood of particular events to anthropogenic warming (e.g., Stott et al. 2004), detection and attribution can also come from more subjective forms of knowledge, such as community knowledge of impacts. These types of knowledge are equally important and need to be considered within the context of a 1.5 °C world, but the challenge is how to include multiple forms of knowledge. Although a region may not be classified as being impacted from a climatological perspective, local community knowledge of impacts (i.e., subjective) is equally important (Brinkman et al. 2016; Kabir et al. 2016). That is, there are many drivers of “impact experience”.

1.3.2 Physical Dimensions of Impacts

1.3.2.1 Spatial and temporal distribution of impacts

The spatial and temporal distribution of impacts are key considerations in understanding what 1.5 °C impacts mean for people. Several regions are already 1.5 °C warmer with respect to the pre-industrial period (Figure 1.2). Therefore, local impacts of a global mean warming of 1.5°C can well be higher (or, in fewer instances, lower) than 1.5°C globally.

Intertwined with the spatial distribution of impacts is the temporal aspect (IPCC 2013). The time of occurrence of 1.5°C above pre-industrial levels will vary for different regions, with some regions, for example parts of Africa, warming faster (Niang et al. 2014; Déqué et al. 2016). This raises adaptation and intergenerational issues. Also, the seasonal cycle of temperature or rainfall will change, as projected for Mediterranean climates. At global warming of 1.5 °C, some seasons will be substantially warmer than 1.5 °C above pre-industrial, for example the southwest of Western Australia (Andrys et al. 2016), which experiences a typical Mediterranean climate.

1.3.2.2 Implications of 1.5 °C for extreme events and associated impacts

Warming by 1.5 °C has very important implications for changes in extremes at the tail of the event probability distribution. Any increase in the global mean temperature implies a much larger probability of temperature extremes. Specifically, a 1.5 °C world as compared to a 2 °C world will have very different impacts in terms of extreme events. This report further builds on IPCC SREX report by specifically examining the impacts of 1.5 °C versus 2 °C of warming with respect to weather and climate extremes.

[INSERT FIGURE 1.5 HERE]

Figure 1.5: Placeholder for schematic showing differences in tails of the temperature distribution for a 1.5 °C versus 2.0 °C world.

1.3.2.3 Non-temperature related impacts

Although the focus of this special report is on 1.5 °C of warming, it is important to acknowledge that not all impacts depend on warming alone, e.g., sea-level rise and ice-sheet melt depend on integrated temperature. Hence, some climate studies use the concept to the “degree year”, which is generally defined as the time integral over which the amount of global mean temperature exceeds a threshold, which has been adjusted for climate sensitivity (Smith and Rasch 2013). Such metrics are particularly relevant to overshoot scenarios. Other impacts also depend on atmospheric composition and forcing (e.g., ocean acidification and some extreme temperature and rainfall indices). Additionally, it is important to contrast temperature-related impacts (e.g. annual rainfall, extreme events) with impacts due to integrated temperature (e.g. ice-sheet melt and sea level rise). For example, some of the non-temperature impacts manifest earlier under transient warming, some are irreversible (i.e. species extinction) and others can be reversed to some extent.

1.3.2.4 Probability and uncertainty of impacts

This section will briefly discuss what the definition of 1.5 °C used in this report (defined in earlier section) implies in terms of probability and uncertainties associated with impacts.

1.3.2.5 Deterministic (e.g. sea level rise) versus stochastic (e.g. extreme weather) impacts

The capacity and conditions for modeling future physical climate impacts varies significantly. Deterministic models define potential conditions of gradual and uni-directional climate-related changes while stochastic models are used to construct estimates of future frequency for more acute and likely high consequence events such as extreme weather events, including cyclonic storms, intense precipitation events, and extreme heat events. The different modeling domains present a range of uncertainty measures and likelihood conditions that must be recognized when examining climate conditions under 1.5 °C and the difference between 1.5 °C and 2 °C.

1.3.2.6 Permanence and irreversibility

Conditions of permanence and irreversibility are two key parameters of physical climate impacts.

1.3.3 Human Dimensions of Impacts, including adaptive capacity

The adaptive capacity of different sectors to a 1.5 °C world will vary markedly between different sectors, for example, water supply, public health, infrastructure, ecosystems, food supply. Additionally, the adaptive capacity of human settlements, especially in highly populated urban regions poses several equity and social justice issues.

1.3.3.1 Sectoral impacts

The climate change impact of 1.5 °C will affect a range of infrastructure systems and the built-up environment, natural resources development and provisions capacities, as well as agricultural production systems. Climate related shifts including changes in seasonality, temperature regimes, and water availability have resulted in a variety of documented effects. The sensitivity of human systems to these changes to a 1.5 °C world as well as 2 °C is investigated in this report.

1.3.3.2 Spatial and temporal dimensions

The human system impacts vary temporally and spatially under conditions of a 1.5 °C world. Some parts of the globe have already experienced over 1.5 °C of regional warming. Given the vulnerability of some sites, these impacts result in intergenerational consequences.

1.3.3.3 Human settlements

The magnitude and consequences of climate impacts vary across the range of human settlement types. Density and risk exposure, infrastructure vulnerability and resiliency, and governance capacity drive the differential impacts. Global scale urbanization places significant stress on capacity of cities to respond to climate risk, especially in small and medium sized cities in low and middle income countries where rate of population growth and climate exposure is especially significant.

1.3.3.4 Poverty, equity and justice

Climate change impacts disproportionately affect the most vulnerable segments of society. These populations, communities, and institutional often lack adaptive capacity to increased climate risk and new or emergent risks.

1.3.4 Ecosystem Impacts

Temperature-related (e.g. precipitation); integrated temperature (e.g. ice-sheet melt) and non-temperature-related (e.g. ocean acidification).

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

The connection between 1.5 °C warming and ambitions of sustainable development are complex and multifaceted. This connection can be better understood from mitigation-adaptation linkages, synergies and trade-offs and the different dimensions of feasibility. IPCC AR5 acknowledged that "adaptation and mitigation have the potential to both contribute to and impede sustainable development, and sustainable development strategies and choices have the potential to both contribute to and impede climate change responses" (Denton et al. 2014). A goal of this report is to articulate where the key tradeoffs and opportunities for synergy are present. Adequate mitigation and adaptation measures and actions can be put into place by identifying specific patterns of development and governance that indeed differ amongst all world regions. This section details the various implementation options, enabling conditions, capacities and types of knowledge that can allow institutions, communities and societies at large to respond to the 1.5 °C challenge in the context of sustainable development. Issues of justice, equity and ethics are recognized as of paramount importance to reduce vulnerability and eradicate poverty. The section begins by highlighting the four dimensions of feasibility with respect to global warming of 1.5 °C.

1.4.1 The different dimensions of "feasibility"

Reaching the target of only a 1.5 °C rise in temperature remains a challenging task, which will be constrained by several dimensions of feasibility. The report defines the feasibility as the systems-level capacity to achieve a specific goal or target. The term does not explicitly incorporate uncertainty and likelihood and assesses all other things equally would a particular outcome be possible. From an energy balance perspective, certain temperature targets are "physically feasible", depending on the concentrations of CO_2 and other radiatively important aerosols and gases (IPCC 2013). In addition, more aggressive pathways will require new technology that may or may not be "technically feasible" (IPCC 2014c; Rogelj et al. 2015). For policy makers, the "economic feasibility" is also important, and because of environmental damages from some proposals, some pathways may not be socially acceptable (Smith et al. 2016). There is also a need for a governance structure which allows for appropriate "institutional feasibility" for any policy to reach a particular temperature target (Planton 2013).

1.4.2 The adaptation-mitigation-sustainable development nexus: tradeoffs, synergies and co-benefits

Responding to climate change needs to occur using multiple approaches (Figure 1.6). From the mitigation side, the most important is to reduce emissions of CO_2 and other greenhouse gases (Planton 2013). Even if low CO_2 trajectories are achieved, there will be impacts of climate change onto humans and ecosystems, which will require adaptation (Planton 2013). It may be required that extreme measures be undertaken in order to avoid climate change, either through Carbon Dioxide Removal (CDR), whereby carbon dioxide is actively removed and stored (Rockström et al. 2016), or Solar Radiation Management (SRM), where deliberate changes to the earth's albedo are undertaken (The Royal Society 2009). Never-the-less there are mechanisms to respond to climate change that will enhance both mitigation and adaptation and with appropriate governance also provide for social justice, equity and ethics (Figure 1.6).

[INSERT FIGURE 1.6 HERE]

Figure 1.6: Schematic of some adaptation and mitigation options, showing examples of those that serve both to help adaptation and mitigation (figure needs to be redone for this report).

The impacts of climate change onto humans and ecosystems are not equally distributed, because some humans or ecosystems may be more vulnerable to climate change (Agard and Schipper 2014). For example, subsistence farmers are more sensitive to precipitation changes than farmers in regions with advanced irrigation techniques. The ability to adapt to climate change, or adaptive capacity, can build resilience to weather or other hazards (Agard and Schipper 2014).

At the same time as humans are responding to the challenges of climate change, the UN has also established the Sustainable Development Goals (SDG) (UN 2016) to be reached by 2030. The legacy of the goals will be carried forward into the next decades as well. The SDGs include the eradication of poverty, hunger and wars, gender and economic equity, improved health and education, access to clean water and environment, among other ambitious, yet vital goals. Some of these goals are likely to be enhanced by strong climate change response, but some SDGs may be more difficult to achieve with a strong climate mitigation response. For example, if bioenergy and carbon capture and storage is used for climate mitigation, this can place pressure on food security (Smith et al. 2016) or many strong mitigation pathways are expensive, thus reducing the likelihood of poverty eradication (Stechow et al. 2016).

Conversely, multiple examples of synergies exist between achieving SDGs and climate responses. For instance, converting to sustainable energies can enhance the energy security of a society and protect the ecosystem services offered by land and ocean environment. In addition, adaptive capacity and resilience is enhanced in societies with a broad access to education and infrastructure. Since urbanization is occurring at an accelerating rate, the interactions between urbanization, sustainable development and climate response needs to be considered. Simultaneously considering how to achieve an ambitious low climate trajectory and achieve the SDGs is a center point of this report (Figure 1.7). Intuitively, it is likely that addressing these multiple goals simultaneously is more likely to achieve a cost-effective and socially acceptable solution, than addressing these goals piecemeal (Stechow et al. 2016).

[INSERT FIGURE 1.7 HERE]

Figure 1.7: A framework for evaluating the impact of different climate response pathways on the multiple dimensions of the Sustainable Development Goals: needs to be edited for inclusion). For each goal, positive or negative impacts for each climate action can be estimated, highlighting the climate response pathways that require tradeoffs versus those that have the most synergies.

Common tools for making difficult policy decisions include cost-benefit analyses, whereby the costs of impacts are compared to the benefits from different actions (IPCC 2014c). However, for problems such as climate change or sustainable development these tools can be difficult to use because of the disparate impacts versus costs. For example costs may be relatively easily quantifiable in terms of money, but the impacts of climate change may be on humans lives, their culture and values or ecosystem impacts, which are difficult to quantify and compare (IPCC 2014c). In addition, costs and benefits can occur at very different times, even across different centuries, for which case, standard cost-benefit analyses become difficult to justify (IPCC 2014c).

1.4.3 Implementation and governance

The major challenge is transitioning from planning to practical implementation of identified climate responses and this is due to several barriers including finance, technology and human resource constrains plus institutional capacity to strategically deploy available knowledge and resources (AR5 Chapter 15). Uncertainties in climate change at different scales, different capacities to respond coupled with the complexities of social-ecological systems point to a need for diverse implementation options within and among different regions involving different actors. The tremendous regional diversity including highly carbon invested economies and emerging economies are important considerations for the 1.5 °C – sustainable development connection and equity. Key sectors such, as urban systems, food security and water supply also are critical to the connections. Incorporating strong linkages across sectors, devolution of power and resources to sub-national and local governments and facilitating partnerships among public, civic, and private sectors will be key to implementing identified response options. Implementation options could be informed by Chapter 20 of IPCC AR5 key message that: "To promote sustainable development within the context of climate change, climate-resilient pathways may involve significant transformations. Transformations in economic, social, technological, and political decisions and actions can enable climate-resilient pathways" (Denton et al. 2014).

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

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

Solar radiation management strategies which press against socially acceptable and physical limits, provides another example of the constraints and capacities of governance with respect to decision-making equity, and integrating levels of uncertainty into the decision-making process.

1.4.4 Timescales and transformation

The pace and process of transformation is varied. The report recognizes that the rate of change within systems can occur gradually or be punctuated by rapid change. Incremental change can set in motion larger scale transformations. The debate on resilience-transformation, as this incremental process has been identified (e.g. in urban areas), is key when designing, planning, and improving implementation options at local level. The connection between climate action and sustainable development illustrates a complex coupling of systems that have important spatial and time scale lag effects. Early warning signals of system change provide important sign posts for potential transition pathways and of use by decision makers and policy makers.

1.4.5 Enabling an adaptive response to emerging trends and extreme events

A critical element defining the connection between 1.5 °C and sustainable development is the capacity of institutional actors to adaptively respond timely to new challenges and opportunities. Extreme events approached through disaster risk reduction can play a key role in motivating climate response with respect to financing, technology advancement and transfer, and capacity building and governance. Emerging trends and extreme events are utilized to building institutional capacities and human resource at local, national and global level to plan, implement and monitor climate responses.

1.4.6 Justice, equity and ethics

Poverty, inequity, and injustice are incompatible with sustainable development (O' Brien et al. 2012). As indicated by Stern 2014 and many others, the science informs us that the climate change is a problem of risk management on an immense scale; and the consequences of business-as-usual could significantly threaten human security i.e. amounting to the displacement of hundreds of millions of people that may lead to severe and prolonged conflict. Risks on this scale raise deep questions about ethical perspectives relating to the distribution of impacts associated with climate change and responsibilities for its cause, and preferentially impact on the poor and disenfranchised. Thus, focusing on the rights and responsibilities of people as the core policy question, rather than physical and ecological infrastructures, may help to clarify the root causes of climate risks, their distribution and management across a range of social groups and geographies. Human rights include the right to development, equitable benefits and burdens, participatory, transparent and accountable decisions on climate change, gender equity, and education rights.

Questions of justice and fairness are central to climate change debates and response efforts across geographies and generations. Most fundamentally, how can the action to achieve 1.5 °C targets be consistent with protection of human rights? Okereke (2010) outlines three key points of connection between climate change and justice from the international regime (UNFCCC) perspective. The first is the asymmetry in contributions to the problem. The second is the huge asymmetry in impact – a problem that is exacerbated because the worst impact tends to fall on those that are least responsible for the problem. Conditions of climate dislocation are an acute example of this inequity and forced migration. Intergenerational equity issues also need to be considered here. The third point of connection in the climate-justice nexus is asymmetry in power to decide solutions and response strategies. This relates to the possibility by the more powerful actors and stakeholders to have greater influence on setting the agenda to their advantage. Hence a justice framing offers a useful organizing framework for understanding the asymmetry between the distributions of benefits and distribution of costs in relation to climate change. In addition, existing inequalities, technology, finance, human capital and governance constrain any level approach to addressing the 1.5 °C despite e.g. INDCs where each country pledges what is possible in its capacity. Concerns around justice are central to the debates about mitigation, adaptation and climate governance as they open up opportunities to discuss who cuts emissions, who pays for the pollution, whose knowledge counts and who has the capability to respond to the problem (Schroeder et al. 2012).

Shue (2014) points for justice considerations to be an integral part of humanity's efforts to mitigate and adapt to climate change, at the global as well as sub-national levels. Equity and fairness are important elements of the justice framing in climate change research, and relate to both procedural justice (i.e. participation in decision making) and distributive justice (i.e. how costs and benefits of climate actions are distributed). This framing recognizes that climate change presents significant threats to future wellbeing in that future generations are likely to be vulnerable to climate impacts and are least represented in current decisions that shape future outcomes.

Further, environmental ethics argues that ecosystems have a right to exist in natural state; intergenerational equity says we should leave natural state as much as possible for future generations.

1.4.7 Multidimensional costs and benefits

The costs and benefits of a 1.5 °C world will be multidimensional and will occur at a variety of spatial and temporal contexts. Actions and strategies will be translated from local to global scales and originate from international agreements that could be interpreted at the local level. Policies implemented at the local level enable the condition to allow for an increase of the ambition of response and transformative action. Examples include application of technology innovation aspects (funding, governance), air pollution control policies, and low carbon economy initiatives.

1.5 Assessment frameworks and emerging methodologies that integrate climate change mitigation and adaptation with sustainable development

The section examines the transferability of assessment and methodologies for evaluating 1.5 °C conditions and pathways. Assessment frameworks and emerging methodologies that integrate mitigation and adaptation with sustainable development and enable the evaluation of outcomes are an important component of understanding the implication of a 1.5 °C world. The literature of 1.5 °C is rapidly developing and broadly used in the report. The understanding of 1.5 °C is expanded through use of model-based, empirically-based and expert judgment-based approaches to "downscale" existing literature for 1.5 °C assessment.

1.5.1 Building on AR5 and SREX

The assessment approaches or methodologies and tools used in AR5 and SREX for impacts and mitigation pathways included large-scale computer models, referred to as Integrated Models (IM) or its subset, the Integrated Assessment Models (IAM); Coupled Model Intercomparison Project (CMIP); Shared Socioeconomic Pathways (SSP); case studies and regional analyses. Building on these tools, this report provides new information on assessing 1.5 °C for climate change impacts and mitigation especially the information about emissions pathways, energy and land-use transitions, and aggregate economic costs of mitigation.

A new generation of 1.5 °C scenarios from Integrated Assessment Models (IAMs) were developed and concluded that to meet the long term goal of 1.5 °C in the Paris Agreement, net emissions would need to reach zero by 2050, and then go below zero in the second half of the century (2100) (see Advance Project, http://www.fp7-advance.eu/). Due to the scale of the challenge for achieving 1.5°C, 80% of global integrated assessment models use Negative Emissions Technologies (NETs) in their simulations (Hampton 2016). Integrated energy–economy–environment scenarios that keep warming to below 1.5 °C by 2100 show a faster scale-up of mitigation action in most sectors and the move from a 2 °C- to a 1.5 °C-consistent world will be achieved mainly through additional reductions of CO_2 (Rogelj et al. 2016).

Mitchell et al. (2016) pointed out that many experiments, for example, the CMIP, are not specifically designed to run simulations and projections for informing the 1.5 °C world and thus the design of the half a degree additional warming, projections, prognosis and impacts (HAPPI) experiment. The HAPPI provides a framework for the generation of climate data describing how the climate, and in particular extreme weather, might differ from the present day in worlds that are 1.5 and 2.0 °C warmer than pre-industrial conditions (Déqué et al. 2016). The SSPs are also part of the new scenario framework that combines the Representative Concentration Pathways (RCPs) in order to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development (Riahi et al. 2015).

1.5.2 Types of knowledge and evidence used in the report

Within this framing, the report provides an assessment of four levels of knowledge sources: 1. State of knowledge of changes in the physical climate system, and associated impacts and vulnerabilities with emphasis on new information since the publication of the IPCC's Fifth Assessment Report (AR5) and the cutoff date April 2018; 2. Grey literature such as reports from government and industry; 3. Social science literature knowledge; 4. Mitigation pathways based on projections in the future; and, 5. Co-production local knowledge.

An appropriate knowledge base plus 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. Incorporating knowledge from different sources and setting a multi-faceted information channel, 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 (AR5 Chapter 15, 2014).

[START BOX 1.2 HERE]

Box 1.2: Experiencing 1.5 °C - Opportunities and challenges of visualizing a 1.5 °C world using observations of climate impacts today; climate change and variability to date; extreme weather and the potential role of community knowledge

Literature or information about regional climate change impacts is limited and there are research gaps on the rate of change and regional dimensions on the impacts of 1.5 °C. Traditional knowledge and experience 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 (Raygorodetsky 2011). Fernández-Llamazares et al. (2015) defines Traditional Ecological knowledge (TEK) as "knowledge obtained from observation, experiences, oral history and accumulation." Western climate data tends to be limited or absent from places like Central Africa, Central America and the Himalayas but there are people with relevant data and information. Savo et al. (2016) gathered observations covering 137 countries involving more than 90,000 people whose traditional ways of life rely on nature and where weather stations are absent to fill a knowledge gap in climate change science, which is dominated by data and computer models. They found some 70 percent of those interviewed had witnessed changes in seasons, rainfall patterns and temperature. The observations generally align with data and models developed to predict changes in the climate. McMillen et al. (2014) reported that in some regions like Oceania, indigenous people used climate observations to develop customary calendars that include expectations of weather (e.g., wet and dry seasons) in phonological characteristics of fruiting of breadfruit (Artocarpus altilis), or the rising and spawning of the palolo sea worm (Eunice viridis).

[INSERT FIGURE BOX1.2 FIGURE 1 HERE]

Box 1.2, Figure 1: Realized experience of present-day warming. Colors indicate human-induced warming in 2016 (relative to 1861-1880) for the most strongly warming month at any location. The density of dots indicates the population (2015) in any 1°x1° grid box. Warming trends are calculated in an identical way to Figure 1.2. Hatched areas indicate regions where over 50% of the temperature record is missing and warming trends are not calculated.

[INSERT FIGURE BOX1.2 FIGURE 2 HERE]

Box 1.2, Figure 2: Probability density function for the data shown in Figure 1 of this box. Approximately 80% of the global population that live in regions for which local warming trends can be calculated have already experienced over 1.5 °C of warming in at least 1 month of the year.

The value of traditional knowledge related to climate is being more widely considered as critical to understanding the climate change impacts at regional and local level and in developing local climate change adaptation plans and strategies that sustain resilience of social-ecological systems at the interconnected local, regional and global scales (Nakashima et al. 2012). In their review of 10,660 observations from 2,230 localities in 137 countries, Savo et al. (2016) reported extensive impacts of climatic changes on both wild and domesticated plants and animals and threaten the food security of local communities. Their finding suggested that climate change is disrupting community's livelihoods and that local observations can make an important contribution to understanding climate change impacts on ecosystems and societies and adaptation options. For example, they reported that the Sweden's Sami herders, were abandoning traditional ways due to changes in ice formation and weather, whilst in Bangladesh, an upsurge of strong winds and storms was forcing some fishermen to moor their boats rather than set out to sea.

While traditional knowledge is being more widely considered as critical to developing local climate change adaptation plans and strategies, it either exists in grey literature outside of peer-reviewed process, or remains in oral form and in most cases falls outside the scope scientific literature on climate change impacts and mitigation (Leon et al. 2015).

[END BOX 1.2 HERE]

1.5.3 Assessment across space and timescales (Assessment and methodologies across space and timescales)

Information for the report is global in scope and includes regional analysis. The report provides synthesis of municipal, sub national, and national case studies. The time scale of the assessment is the 21st century.

1.5.4 System-level framing: Anthropocene, transition theory, transformative change

The assessment of the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty requires a holistic approach that integrates across time and geographical scales of the related socio-economic and biophysical issues. This assessment is therefore amenable to the concept of the Anthropocene, emerging to be considered as a new geological era, serving to convey the unprecedented human-role in the observed changes on the biophysical systems such as impacts of climate extremes, ocean acidification, species extinction and sea level rise that have wide implications on the socio-cultural and economic systems. The Anthropocene helps in understanding the culmination of past and present human-environmental relations across scale providing for an opportunity to better visualize the future and minimizing pitfalls.

Despite the diverse and sometimes controversial views on the interpretation of the Anthropocene concept, emerging literature point to its relevance to climate change. This is because human-driven climate change expresses the depth of the global interlinkages within the human and nature entanglement that are an embodiment of the Anthropocene concept. Further, the factor that humans have the capability to change the environment on geological scales justifies human capability to establish solutions at a global level to the climate change challenge (Harrington 2015). For example, a search for a global response to climate change entails identifying ways of motivating shifts or transformations within the human-nature interactions that could reduce the threat of climate change, enhance sustainable development and limit global inequalities. One of the questions to be addressed by this assessment is how, under the Anthropocene, can mitigation and adaptation be better integrated with sustainable development to minimize negative environmental impacts and reduce poverty?

1.5.5 Transformation, Transformation Pathways, and Transition

This report assesses how the global society can transform to meet the condition of a 1.5 °C world. The IPCC in AR5 defines transformation as a change in the fundamental attributes of natural and human systems. The AR5 also defines a transformation pathway as the trajectory taken over time to meet different goals for GHG emissions, atmospheric concentrations, or global mean surface temperature change that implies a set of economic, technological and behavioural changes. This can encompass changes in the way energy and infrastructure are used and produced, natural resources are managed and institutions are set up and in the pace and direction of technological change. Within the report transformation pathways are defined in baseline and reference, levels, emission scenarios, mitigation scenarios, RCPs and SSPs. The process of transformation includes system level transitions from one regime to another. These transitions can be gradual or abrupt. The report assesses the different physical and societal contexts for transitions.

1.5.6 Building social, institutional and knowledge capital

Multiple types of knowledge, meanings and beliefs, different actors and institutions attach to climate threats, risks and responses, and how these different knowledge interact when building awareness and capacities are important for meeting the challenge posed by a 1.5 °C target. The report assessment incorporates local observational community knowledge and policy/institutional knowledge. Requirements for educating and building awareness include emerging cultural norms and behaviour associated with discourses, narratives of a 1.5 °C world. The report also assesses how these discourses are expected to change and how will they be impacted and communicated. Climate risk communication strategies are central to equipping policy debates and the decision-making process.

1.6 Consideration and communication of confidence, uncertainty and risk

Careful consideration and clear communication of levels of confidence and uncertainty is fundamental to the work of the IPCC. This Special Report relies on the IPCC's uncertainty guidance provided in Mastrandrea et al. (2011), building on IPCC (2005), Manning et al. (2004) and Moss and Schneider (2000), that was the basis for the consistent treatment of uncertainty in AR5. Some simplifications and clarifications are proposed to address the specific circumstances of this Report. The AR5 relied on two metrics for communicating the degree of certainty in key findings:

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

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

1.6.1 Background – confidence scale:

Five qualifiers are used to express levels of confidence in key findings, ranging from "very low", through "low", "medium", "high", to "very high". The assessment of confidence involves at least two dimensions (see Figure 1.8), one being the type, quality, amount or internal consistency of individual lines of evidence, the second being the level of agreement between different lines of evidence. Very high confidence findings must either be supported by a high level of agreement across multiple lines of mutually independent and individually robust lines of evidence or, if only a single line of evidence is available, by a very high level of understanding of the processes underlying that evidence. High confidence implies either high agreement across different lines of evidence that may be individually less robust, or lower agreement but greater individual robustness. There are multiple ways of supporting a "medium confidence" qualifier, and further explanation may be required to elaborate whether the issue is lack of agreement between, or the robustness of, different lines of evidence. Findings of low or very low confidence are presented only if they address a topic of major concern.

1.6.2 Background – likelihood scale:

The IPCC uses a calibrated language scale to communicate assessed probabilities of outcomes, ranging from exceptionally unlikely (<1%), extremely unlikely (<5%), very unlikely (<10%), unlikely (<33%), about as likely as not (33-66%), likely (>66%), very likely (>90%), extremely likely (>95%) and virtually certain (>99%). These terms are normally only applied to assessed probabilities supported by several, or one very well understood, robust lines of evidence (hence findings associated with high or very high confidence). Where findings are based on frequencies within model ensembles, calibrated uncertainty language is not used to communicate those frequencies unless these are assessed (with other lines of evidence) to correspond to probabilities in the real world. Figures and text in AR5 normally use 5-95% confidence intervals for observable quantities and the 5-95% frequency interval for ranges of model ensembles. These may be interpreted as "very likely" intervals in the first case, but not in the second unless supported by additional lines of evidence.

1.6.3 Challenges in the context of this Special Report:

Three specific challenges arise in the treatment of uncertainty and risk in this report. First, the timetable on which this report is being compiled and the current state of the academic literature on 1.5 °C mean that findings based on multiple lines of robust evidence for which quantitative probabilistic results can be expressed may be very few, and those that can be made may not be the most policy-relevant. This introduces a communication challenge: in AR5, whenever a likelihood assessment was given, it could be assumed that it was associated with high or very high confidence, and hence this was not stated. When findings are presented at various levels of confidence, it may not always be clear to the reader that those that omit a confidence qualifier are implicitly high or very high confidence (or, worse, that the "high confidence" qualifier comes to be used only to distinguish statements that are not "very high confidence"). While stressing that this does not entail a revision to the well-established uncertainty guidance, in this Special Report an effort is made to avoid relying on implicit confidence qualifiers: if a qualifier is intended, then it is stated explicitly. Double-qualified expressions that combine both likelihood and confidence language can, however, easily become impenetrable (e.g. "very likely (medium confidence)"): hence, where possible, key findings are expressed in this report using confidence qualifiers alone with numerical expressions of frequency or probability as appropriate.

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

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

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

[INSERT FIGURE 1.8 HERE]

Figure 1.8: The two dimensions of evidence and agreement together determine the level of confidence in a key finding, adapted from Mastrandrea et al. (2011). This figure illustrates how, while there are relatively few ways of supporting a “very high confidence” or “very low confidence” statement, there are multiple ways of supporting a “medium confidence” statement. Note: this figure could be turned on its corner, so the grid is diagonal and the isolines of shading/confidence are horizontal.

1.7 Storyline of the report

This report is formed by 5 chapters in addition to the summary for policy makers. The report has a series of boxes to elucidate specific or cross-cutting themes and in addition each chapter has a section on frequently asked questions. This Chapter 1, on Framing and context and is followed by Chapter 2 that is focused on Mitigation pathways compatible with 1.5 °C in the context of sustainable development. Impacts of 1.5 °C global warming on natural and human systems are then covered in Chapter 3 of the report. Chapter 4 is about Strengthening and implementing the global response to the threat of climate change. While the final Chapter, 5, covers sustainable development, poverty eradication and reducing inequalities in the context of 1.5 °C global warming.

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