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Introduction

Scientific and Political Drivers for the Paris Agreement

A. Background and Role of Science

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1. Introduction

This chapter describes how science has influenced the Paris Agreement. While science had played a fundamental role for the United Nations Framework Convention on Climate Change (UNFCCC) from the start, its role became particularly significant during the preparation of the Paris Agreement, where a new science–policy interface enabled improved collaboration between the scientific community spearheaded by the Intergovernmental Panel on Climate Change (IPCC) and the policy community generally and negotiators more specifically. The structured expert dialogue (SED) of the 2013–2015 review of the UNFCCC was pivotal in this regard, and it was effectively synchronized with the negotiation process for the 2015 Paris Agreement.

2. The role of science in understanding climate change

Without science we would not understand whether recent extreme weather events, such as heat waves or heavy rainfalls, would have anything to do with a change in climate, whether temperatures have actually risen relative to earlier times or whether these are all just weather fluctuations within normal boundaries. Thanks to careful scientific investigations carried out for more than a century, building on nineteenth-century discernments, climate science has progressed and matured rapidly in recent years, so that we now understand such phenomena considerably better.

Repeated analysis does not only tell us that the climate has been changing since pre-industrial times, but perhaps most importantly that the human influence on the climate is *extremely likely*[1] the dominant cause behind these trends, notably since

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[1] Uncertainty estimates by IPCC use a particular terminology: *extremely likely* means a probability of 95–100%.

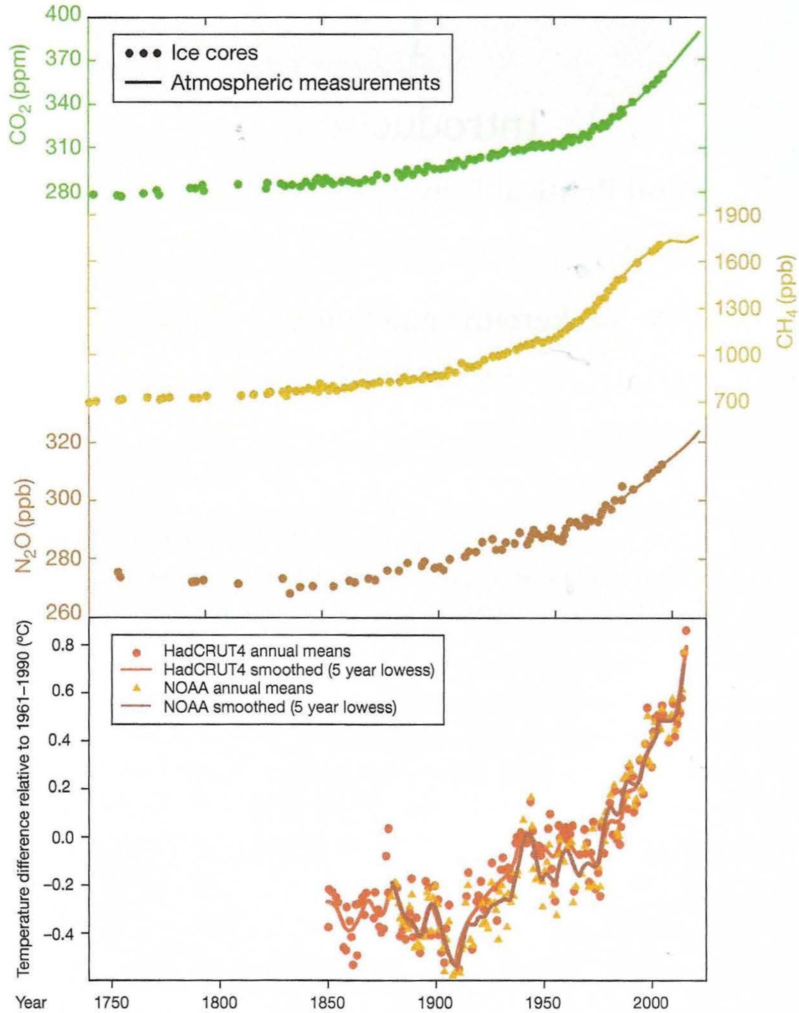

Figure 1.1 *Top*: Observed changes in atmospheric GHG concentrations for carbon dioxide (CO_2, green), methane (CH_4, orange), and nitrous oxide (N_2O, red). Data from ice cores (symbols) and direct atmospheric measurements (lines) are overlaid.[a] *Bottom*: Annual global mean air temperature changes as measured from 1880 to 2015 relative to the mean temperature of the base period 1961–1990.[b]

[a] IPCC, *Climate Change 2014: Synthesis Report* (n 2) 44, Figure 1.3, and Figure SPM.1. See also IPCC, *Climate Change 2013: The Physical Science Basis* (n 5) 2.2, 6.2, 6.3, Figure 6.11.

[b] Data sets University of East Anglia HadCRUT4 Climatic Research Unit, 'HadCRUT4 Temperature' *University of East Anglia* (2016) https://crudata.uea.ac.uk/cru/data/temperature/ (last accessed 10 February 2017) and NOAA, 'Climate at a Glance' *National Centers for Environmental Information* (2016) http://www.ncdc.noaa.gov/cag/ (last accessed 21 February 2017).

the second half of the last century.[2] Most accurate measurements, eg of atmospheric greenhouse gas (GHG) concentrations and isotopic signatures, show that humankind has begun to change the chemical composition of the atmosphere significantly (eg for the key GHG CO_2 by about 40 per cent since pre-industrial times, Figure 1.1 top). This

[2] IPCC, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, R K Pachauri and L A Meyer (eds) CUP 2014).

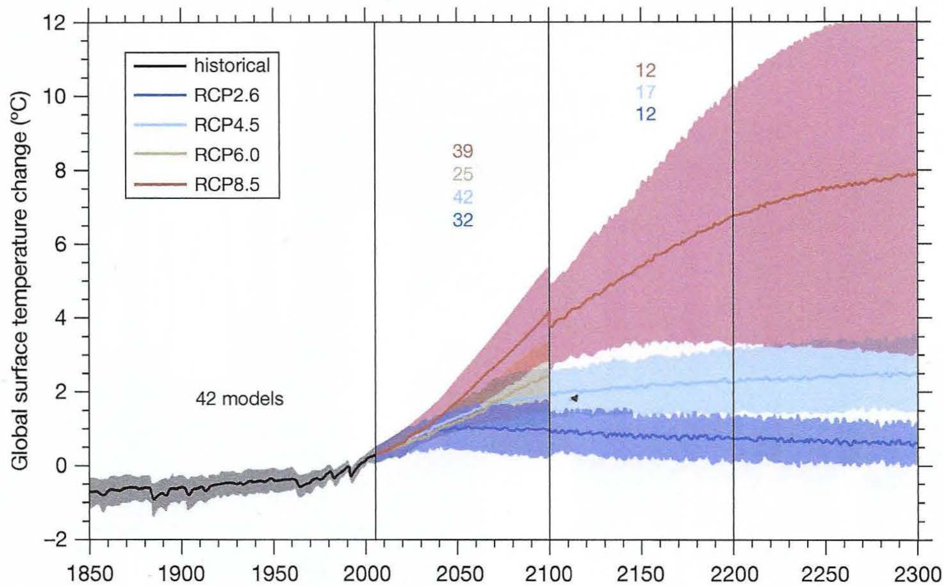

Figure 1.2 Global annual mean surface air temperature anomalies (relative to 1986–2005 until year 2300) from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Projections for the multi model mean (solid lines) and the 5–95 per cent range of individual models (shading, numbers stand for number of models contributing to different phases) are given for four (twenty-first century) respectively three (beyond 2100) scenarios (Representative Concentration Pathways (RCPs)), which differ in terms of mitigation efforts.[a]

[a] M Collins and others, 'Long-Term Climate Change: Projections, Commitments and Irreversibility' in Thomas F Stocker and others (eds), *Climate Change 2013: The Physical Science Basis Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)* (CUP 2013) 1029.

increases the amount of solar energy trapped by the planet's atmosphere near the surface of the Earth. From ice-core studies we know that the currently measured GHG levels are unprecedented over the past 800,000 years.[3]

Observations of global mean air temperature (Figure 1.1 bottom), of sea level rise, and of changes in the cryo- and biosphere confirm that the heat trapping caused by the altered atmosphere is happening[4] and is already having significant and attributable consequences in many sectors and regions across the globe.[5] Scenarios without climate policies show that this warming will continue (Figure 1.2), eventually leading

[3] See eg J Jouzel and others, 'Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years' (2007) 317 Science 793; L Loulergue and others, 'Orbital and Millennial-Scale Features of Atmospheric CH4 over the Past 800,000 Years' (2008) 453(7193) Nature 383 and D Lüthi and others, 'High-Resolution Carbon Dioxide Concentration Record 650,000–800,000 Years before Present' (2008) 453(7193) Nature 379.

[4] The IPCC estimated in 2012 that mean global warming at the Earth's surface relative to pre-industrial levels was 0.85 °C. See IPCC, *Climate Change 2014: Synthesis Report* (n 2) 40.

[5] IPCC, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC, *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (C B Field and others (eds), CUP 2014) and IPCC, *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (V R Barros and others (eds), CUP 2014).

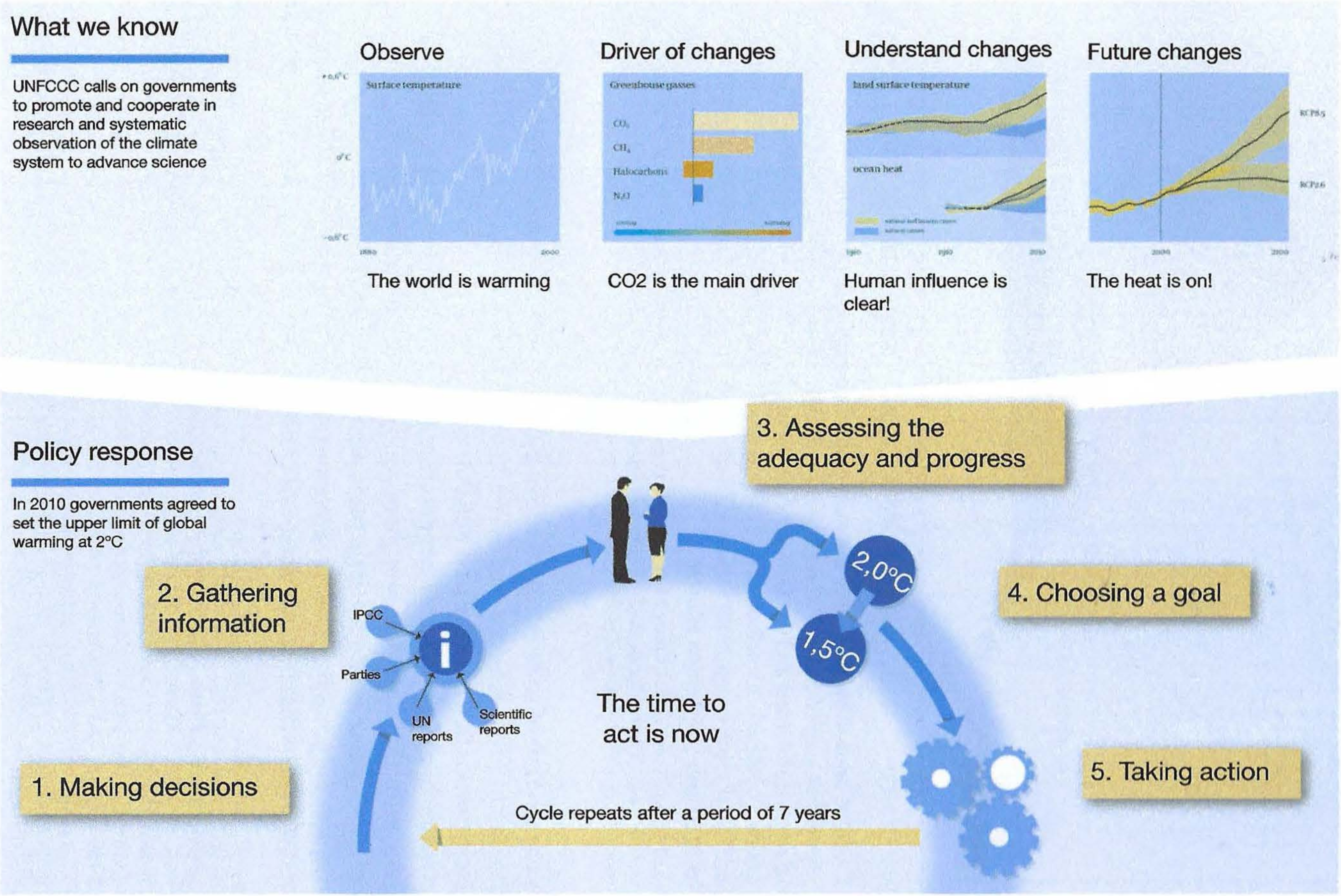

Figure 1.3 Nature of the 2013–2015 review of the UNFCCC, of which the structured expert dialogue (SED) formed an essential part (see text, after a UNFCCC poster).

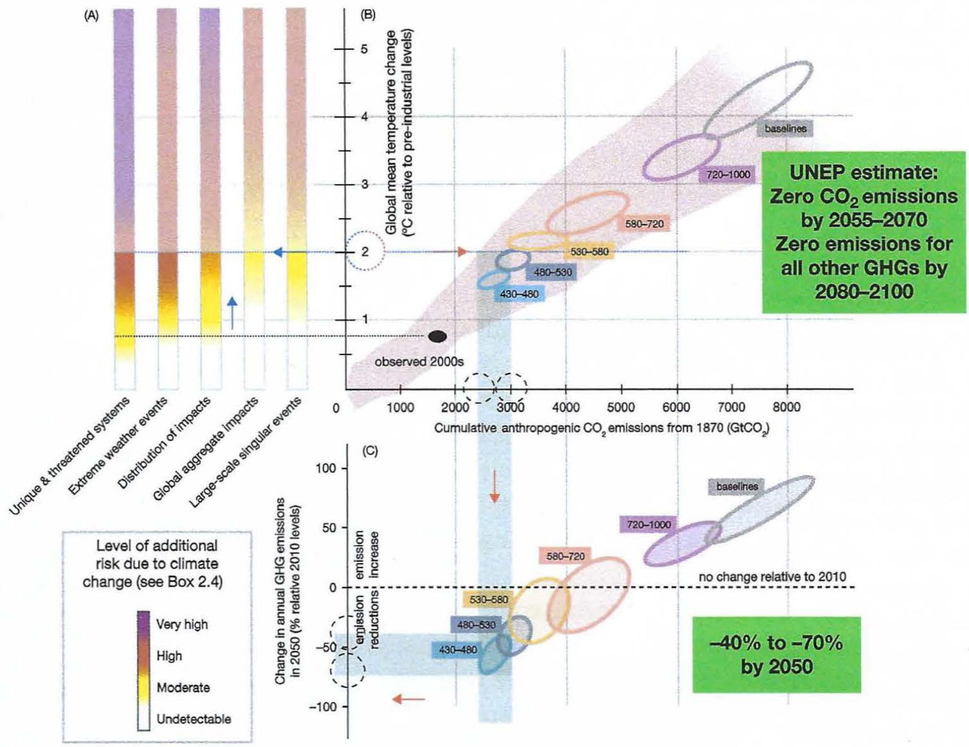

Figure 1.4 The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050.[a]

[a] After Figure 1.4, *Report on the Structured Expert Dialogue on the 2013–2015 Review of the United Nations Framework Convention on Climate Change* (UNFCCC) (2015 FCCC/SB/2015/INF.1, UNFCCC, Subsidiary Body for Implementation (SBI) and Subsidiary Body for Scientific and Technological Advice (SBSTA), Bonn, Germany) 9 http://unfccc.int/6911.php?priref=600008454 (last accessed 10 February 2017) and Figure SPM.10, IPCC, *Climate Change 2014: Synthesis Report* (n 2). See also UNEP, *The Emissions Gap Report 2015* (2015 UNEP, Nairobi, Kenya) 8 http://www.pbl.nl/en/publications/the-emissions-gap-report-2015 (last accessed 10 February 2017).

to irreversible and fundamental changes in the climate system. The warmer it gets, the higher the climate risks, since the associated impacts will become more negative.[6] The scientific findings from the IPCC's Fifth Assessment Report (AR5) also conclude that limiting global warming to avoid climate risks[7] requires the global community to stay within a particular carbon budget,[8] which implies a radical departure from past emission trends[9] (see Figure 1.4).

[6] See eg IPCC, 'Summary for policymakers' in C B Field and others (eds), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A* (n 5) 1.

[7] IPCC, *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Parts A and B* (n 5).

[8] IPCC, *Climate Change 2013: The Physical Science Basis* (n 5).

[9] IPCC, *Climate Change 2014: Mitigation. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (O Edenhofer and others (eds), CUP 2014).

Of course, all these scientific insights have little effect on policy if they stay within the scientific realm only. Rather, science has to be linked to policy, a process in which the IPCC plays a critical role. It does so by understanding the scientific needs of policy-makers, by providing a solid scientific basis for policy-making, and by effectively communicating this scientific basis to policy-makers.

3. The Intergovernmental Panel on Climate Change and science

The IPCC was endorsed by the United Nations General Assembly and formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). It is mandated—currently by 195 governments—to assess climate change science and consists of three working groups and a Task Force on National Greenhouse Gas Inventories (TFI). Working Group I (WG I) assesses the physical scientific basis of the climate system and climate change. Working Group II (WG II) assesses the impacts on, adaptation to, and vulnerability of natural and human systems to climate change. Working Group III (WG III) assesses the mitigation of climate change.

The IPCC produces its assessment reports in cycles of six to seven years. In each cycle it prepares a comprehensive assessment report (AR) and often also a few smaller topical special reports (SRs). Furthermore, the IPCC can prepare technical papers on narrow topics of particular urgent interest in a shorter time, but they have to be derived from existing, already adopted, and approved reports. The TFI prepares IPCC Guidelines and reports on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.

The IPCC has the role of linking science with policy. It does not undertake any research on its own, and consequently depends on and is limited by the research results that the scientific community produces. In addition to the main function of providing the best scientific knowledge for decision-making, the IPCC has also fulfilled a role in standardizing scenarios, eg its Special Report on Emissions Scenarios (SRES),[10] which helped the scientific community in all its facets to come up with research results that can be easily compared.

Since its inception, the IPCC assessments have refrained from policy prescription. All IPCC reports are prepared instead to serve as a scientific basis—yet a maximally robust one—for policy-making. They strive for utmost policy relevance while avoiding the recommendation of particular policies. The result is a clear division of labour between the IPCC and UNFCCC, leaving actual policy choices to the UNFCCC.

The IPCC is well respected as the ultimate authority for providing the best possible relevant assessments of current scientific knowledge for the purpose of climate policy-making. It is respected equally by the scientific community and the UNFCCC, including its subsidiary bodies, the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI). IPCC findings have been respected as authoritative and robust, and thereby have been instrumental in global climate change policy-making. The first example would be the adoption

[10] N Nakicenovic and others (eds), *Special Report on Emissions Scenarios (IPCC)* (CUP 2000).

of the UNFCCC itself, which took place four years after the inception of the IPCC. Other examples include the Kyoto Protocol from 1997 following the publication of the IPCC Second Assessment Report (SAR) in 1996, the negotiation of the rule book for the Kyoto Protocol in 2001 following the IPCC Third Assessment Report (TAR) in 2001, the Bali Roadmap from 2007 following the publication of the IPCC Fourth Assessment Report (AR4) in 2007, and the Paris Agreement 2015 following the publication of IPCC Fifth Assessment Report (AR5) in 2013/2014.

While the IPCC Panel makes its decision autonomously, the UNFCCC has repeatedly invited the IPCC to prepare particular reports and the IPCC has generally been responsive to these invitations. This was most recently the case for the invitation made by COP 21 in Paris to the IPCC to provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global GHG emission pathways.[11] During its forty-third session in Nairobi, Kenya, 11–13 April 2016, the IPCC Panel decided to prepare such a special report.[12]

A popular misconception is that the IPCC is responsible for identifying a specific limit to the global mean air temperature increase as a long-term global goal (LTGG), for example 2 °C or 1.5 °C, assuming such a limit could be based on or justified by science alone.[13] However, that is not the case for many reasons.

A first reason is that many climate change impacts exhibit only a gradual response to the degree of warming where non-linearities are often very difficult to identify. No particular threshold value stands out that would be common to a majority of impacts.

A second reason is that GHG emissions do not remain where emitted but mix in the global atmosphere within a couple of years. While countries' contributions to a global climatic change are immediate, the impacts from the associated degree of global mean warming differ among countries, regions, and sectors and are typically delayed by decades, in some cases even centuries. Therefore, issues of fairness arise, since the polluters often differ from those impacted. Countries, companies, and individuals emit different amounts into a common atmosphere, and the resulting impacts vary strongly among and within countries without correlation to the source of emissions. In short, impacts are disconnected from where and when the causal emissions were made. Moreover, the capacity of individual countries to deal with these impacts varies as well.

A third important reason is that risk assessments and value judgments about danger have to be conducted at a global level, but do require regional and local level involvement. This involvement produces necessarily a multi-dimensional evaluation that is far from trivial to aggregate at the global level where the UNFCCC positions its ultimate objective of a GHG stabilization 'at a level that would prevent dangerous anthropogenic interference with the climate system'.[14]

[11] Decision 1/CP.21 para 21.

[12] 43rd Session of the IPCC (11–13 April 2016) Nairobi, Kenya, Decisions adopted by the Panel, Decision IPCC/XLIII-6 www.ipcc.ch/meetings/session43/p43_decisions.pdf (last accessed 21 February 2017).

[13] See eg the Copenhagen Accord, which refers to science twice in paragraph 2 when introducing the objective 'to hold the increase in global temperature below 2 degrees Celsius', and similarly in paragraph 15 where 'strengthening the long-term goal' to 1.5°C is addressed. Decision 2/CP.15, Copenhagen Accord, FCCC/CP/2009/11/Add.1 (30 March 2010) paras 2, 15.

[14] UNFCCC art 2.

IPCC assessments typically first provide information on the latest observations, measurements, and otherwise gathered statistics, plus the climate change relevant processes taking place in relevant natural and human systems. Based on all this information extrapolations, so-called scenario-based projections into the future for global warming and its impacts are made, using sophisticated models and/or expert judgment. Assessment also means to provide this information not only in form of quantitative figures, but also to estimate associated uncertainties and the reliability of the data and information.

A typical example of such findings is shown in Figure 1.2, depicting global mean air temperature changes as observed in the past, as well as extended by projections of future climate change over the next three centuries. Different colours show the simulated global warming, depending on differing assumptions about future emissions (red represents a business as usual (BAU) scenario that reaches global warming of ~8.3°C by 2300 (best estimate, 4.7°C by 2100) and blue a scenario with ambitious mitigation representing global warming that is *likely*[15] to stay below 2°C relative to pre-industrial levels). The graph also illustrates two other important aspects. The first is the fact that the future climate depends significantly on climate policies. This means that such projections into the future must not be confused with predictions. Rather, they merely attempt to answer what-if questions, ie what happens if a particular policy were to be implemented given current scientific understanding of how the climate system works. Secondly, uncertainties naturally increase significantly as projections reach further into the future.

4. The science–policy interface towards Paris

The UNFCCC deals with science in various ways. First, the SBSTA forms the interface to any scientific knowledge. Special events where IPCC experts present their findings and workshops where delegates get in direct contact with scientists on particular issues of current interest are forums in which policy relevant scientific information enters the negotiation process and can be discussed in detail with negotiators.

The SBSTA is also responsible for specific permanent agenda items in the form of so-called science work streams, which provide opportunities for continuous input of scientific information: In the past there were the following work streams: (i) research[16] with the SBSTA research dialogue, (ii) systematic observation[17] for discussing worldwide collected data, and (iii) cooperation with the IPCC,[18] which all facilitated appropriate considerations of scientific information by UNFCCC's policy-making, first by the SBSTA, sometimes also by ad hoc groups, and by the COP itself. An example of such an ad hoc group was the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP). Its mandate included that its process was to be informed by

[15] Uncertainty estimates by IPCC use a particular terminology: *likely* means a probability of 66–100%.
[16] Research home page: http://unfccc.int/3461.php (last accessed 10 February 2017).
[17] Systematic observation home page: http://unfccc.int/3462.php (last accessed 10 February 2017).
[18] Cooperation with IPCC home page: http://unfccc.int/1077.php (last accessed 10 February 2017).

the Fifth Assessment Report of the IPCC, the outcomes of the 2013–2015 review, and the work of the subsidiary bodies.[19]

At COP 16 in 2010, in the Cancún Agreements, parties agreed on a LTGG to reduce GHG emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels[20] (see also Figure 1.3). Yet, since a significant number of parties questioned the particular limit of 2°C as being too high,[21] an agreement could only be reached by mandating a periodic review of that LTGG 'in the light of the ultimate objective of the Convention,[22] and overall progress towards achieving it, in accordance with the relevant principles and provisions of the Convention'.[23]

The first review was the 2013–2015 review[24] (Figure 1.3). Building on the Cancún Agreements' requirement that the review should take into account 'the best available scientific knowledge, including the assessment reports of the Intergovernmental Panel on Climate Change',[25] the subsequent two COPs further elaborated the details.[26] In particular, COP 18 decided in 2012 in Doha on the final format of the review, notably to engage in the SED[27] 'to assist the subsidiary bodies with the preparation and consideration'[28] of the best available scientific knowledge, at a time when the publication of the IPCC AR5 would be completed (2013–2014). In this context, it is also worth noting that COP 17 confirmed 'that the first review should start in 2013 and should be concluded by 2015, when the Conference of the Parties (ie COP 21) shall take appropriate action based on the review'.[29] This did set from the very beginning the stage for the Paris Agreement and the role science should play in its development.

5. Policy options and best available science

Many voices had argued for many years that the UNFCCC's Article 2 would require a LTGG set in a quantitative manner. However, it took parties fifteen years to reach agreement on a LTGG defined by a limit for global mean air temperature increase relative to pre-industrial levels.

One reason for this is the fact that policy-making is of course not done by merely setting a goal. The pathways to a particular goal, regardless of its specific nature, require also a considerate and broad assessment of necessary preconditions, implications, and

[19] Decision 1/CP.17, Establishment of the Ad hoc Working Group on the Durban Platform for Enhanced Action, FCCC/CP/2011/9/Add.1 (15 March 2012) para 6. See also ADP home page at http://unfccc.int/6645.php (last accessed 10 February 2017).

[20] Decision 1/CP.16, The Cancún Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (Cancún Agreements), FCCC/CP/2010/7/Add.1 (15 March 2011) para 4.

[21] ibid. [22] UNFCCC art 2. [23] See the Cancún Agreements (n 20) para 138.

[24] See the 2013–2015 Review's home page http://unfccc.int/6998.php (last accessed 10 February 2017).

[25] ibid and the Cancún Agreements (n 20) para 139(a).

[26] Decision 2/CP.17, Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention, FCCC/CP/2011/9/Add.1 (15 March 2012) section VII (paras 157–67) and Decision 1/CP.18, Agreed outcome pursuant the Bali Action Plan, FCCC/CP/2012/8/Add.1 (28 February 2013) section VII (paras 79–91).

[27] Decision 1/CP.18 (n 26) para 85. See Structured Expert Dialogue's home page http://unfccc.int/7521.php (last accessed 10 February 2017).

[28] Decision 1/CP.18 (n 26) para 86. [29] Decision 2/CP.17 (n 26) para 158.

side-effects from following that path. For responsible policy-making, these pathways are as important as the goal itself.

In 2012, COP 18 set up two themes within the mandate of the 2013–2015 review: (theme 1) 'the adequacy of the long-term global goal in the light of the ultimate objective of the Convention' and (theme 2) 'Overall progress made towards achieving the long-term global goal, including a consideration of the implementation of the commitments under the Convention'.[30]

Towards Paris, the SED of the 2013–2015 review offered policy-makers and experts an opportunity to engage in a face-to-face dialogue on these themes based on best available knowledge. Figure 1.4 shows the IPCC findings on the links between risk avoidance (top left, part A) as determined by a policy choice of a particular limit such as 1.5°C, or 2°C (the latter shown by arrows and circles) for global warming; the associated carbon budget[31] (top right, part B) as implemented by particular consistent mitigation pathways (bottom right, part C), and the associated mitigation imperatives (green boxes) as discussed during the SED (see also Box 1.1, message 2).

Based on observed impacts, an assessment of projected future risks from climate change, and limits to adaptation, the IPCC conducted an assessment of the climate change impacts on the globe, on regions, and on sectors in the form of 102 identified key risks as provided by the WG II Report. This risk framework was then condensed into five areas of concern at the global level (Figure 1.4 part A, shown as five vertical bars). The degree of global average warming from 0 to 5.5°C relative to pre-industrial levels is shown as a scale along those bars from mid graph to the graph's top. From left to right the bars represent:

(1) unique and threatened systems such as coral reefs
(2) extreme weather events such as heat waves or heavy rainfall events
(3) distribution of impacts raising issues of fairness and equity
(4) global aggregate impacts on the global economy and
(5) abrupt and/or irreversible changes such as an accelerated increase in sea level or large-scale changes in ocean currents or crossing of other tipping points in the climate system.[32]

Colours in the bars indicate levels of additional risk due to climate change,[33] ie the 'warmer' the colour, the higher the risk. The pale section (very top of part A) illustrates the risks avoided from those five reasons for concern, assuming sufficient mitigation efforts are taken to limit global warming in such a manner (here shown only for the 2°C limit).

[30] Decision 1/CP.18 (n 26) para 79.

[31] The carbon budget is given by the cumulative total anthropogenic CO_2 emissions from 1870 to some point in the future. Keeping total emissions within the budget allows limiting mean global warming at any given value, eg 1.5°C, 2°C, or 3°C.

[32] Examples are the slowing down of the Atlantic Meridional Overturning Circulation or the collapse of ice sheets from West Antarctica.

[33] White: undetectable; yellow: moderate; red: high; bluish red: very high risks.

The top right panel of Figure 1.4 (part B) shows the link between any degree of warming (common vertical scale with part A) and the associated carbon budget (horizontal scale of part B). This link can be made for any limit, enabling policy choices over a wide range of temperature goals. The actual carbon budget with its uncertainties is shown as a grey range and its confidence limits with grey circles (here again for this emphasis is shown only for the 2°C limit).

Actual, feasible emission pathways consistent with such a carbon budget and warming limit are shown in the bottom right (part C). Again, a common scale is used: the horizontal scale of cumulative anthropogenic GHG emissions since 1870. Part C expresses the carbon budget in terms of emission reductions by 2050 as a percentage of the 2010 emission levels. A grey bar plus grey circles illustrate the associated uncertainties of the chosen particular mitigation effort (shown only for the 2°C limit).

Such scientific findings as contained in AR5 pertaining to the globe and specific regions and sectors plus inputs from United Nations agencies and related organizations such as CBD, FAO, GEF, IEA, UNCCD, UNEP, WMO, and the World Bank informed policy-makers about the possible prerequisites, implications, and outcomes of particular policy choices made in the above context. They also show that a reduction of GHG emissions by 40 per cent to 70 per cent in 2050 relative to emission levels in 2010 is required, and that carbon neutrality[34] beyond[35] plus zero emissions towards the end of the century are required for all other GHGs in order for the global community to achieve a LTGG of well below 2°C (ie to keep global mean temperatures, eg *likely* below 2°C above pre-industrial levels). Moreover, computations of mitigation pathways showed that for most LTGGs, including a limit of 3°C, a radical and immediate deviation from BAU would be required (Box 1.1, messages 2, 6, 8, and 9).

A second, equally important topic for the SED concerned adaptation, its role in reducing risks, and more generally issues related to the potential for and limitations of adaptation. Since adaptation varies among and within regions and nations, generalizations are very difficult to make, yet science clearly indicates significant adaptation needs, in particular in least developed countries. Despite the fact that the science in this field is still in its infancy,[36] latest findings were carefully presented and discussed during the SED for optimal balance between the mitigation and adaptation themes of the review (Box 1.1, SED messages 3, 4, 5, 9, and 10).

The overall summary contained ten messages written in form of boxes and each coming with a headline statement, summarizing the entire three years of the SED dialogue (Box 1.1).

[34] Carbon neutrality means that CO_2 net-emissions reach a value of zero.

[35] That is, between 2055–2070. See UNEP, UNEP, *The Emissions Gap Report 2015* (2015 UNEP, Nairobi, Kenya) 8 http://www.pbl.nl/en/publications/the-emissions-gap-report-2015 (last accessed 10 February 2017).

[36] For example, the first UNEP gap report on adaptation appeared only in 2014, UNEP, *The Adaptation Gap Report 2014* (2014) 88 http://web.unep.org/adaptationgapreport/2014 (last accessed 10 February 2017).

Box 1.1 The ten headlines of the ten messages from the technical summary of the SED of the 2013–2015 review of the UNFCCC[a]

1. A long-term global goal defined by a temperature limit serves its purpose well.
2. Imperatives of achieving the long-term global goal are explicitly articulated and at our disposal, and demonstrate the cumulative nature of the challenge and the need to act soon and decisively.
3. Assessing the adequacy of the long-term global goal implies risk assessments and value judgments not only at the global level, but also at the regional and local levels.
4. Climate change impacts are hitting home.
5. The 2 °C limit should be seen as a defence line.
6. Limiting global warming to below 2 °C is still feasible and will bring about many co-benefits, but poses substantial technological, economic and institutional challenges.
7. We know how to measure progress on mitigation but challenges still exist in measuring progress in adaptation.
8. The world is not on track to achieve the long-term goal, but successful mitigation policies are known and must be scaled up urgently.
9. We learned from various processes, in particular those under the Convention, about efforts to scale up provision of finance, technology and capacity-building for climate action.
10. While science on the 1.5 °C warming limit is less robust, efforts should be made to push the defence line as low as possible.

[a] Technical summary, Report on the Structured Expert Dialogue on the 2013–2015 Review of the United Nations Framework Convention on Climate Change (UNFCCC) (2015 FCCC/SB/2015/INF.1, UNFCCC, Subsidiary Body for Implementation (SBI) and Subsidiary Body for Scientific and Technological Advice (SBSTA), Bonn, Germany) 9 http://unfccc.int/6911.php?priref=600008454 (last accessed 10 February 2017), 4–34.

The following points, which were particularly decisive for the Paris Agreement, may illustrate the role of science for policy-making further:

- While the UNFCCC's Article 2 calls for the stabilization of GHG concentrations in the atmosphere without specifying a particular level, the latest findings of IPCC demonstrate that net zero emissions, ie a limited finite carbon budget, are inevitable for any stabilization effort (Box 1.1, message 2). IPCC WG I—using a wide set of observations and scenarios—showed that cumulative emissions and degree of global warming are nearly linearly related[37] and warming is irreversible unless negative emissions[38] allow for removing excess CO_2 from the atmosphere back into geological or other permanent deposits.

[37] Figure 1.4, part B. See IPCC, *Climate Change 2014: Synthesis Report* (n 2) SPM.5(b).

[38] Negative emissions are characterized by negative CO_2 net-emissions, ie emissions reach not only a value of zero but are reversed by actively removing CO_2 from the atmosphere and sequestering carbon on geological time scales in other parts of the Earth.

- IPCC experts also showed that recent warming has already increased risks in all sectors and regions significantly, although the manner and scale will vary, as will the degree of attribution to human causes. All this means that 'Climate change impacts are' already 'hitting home' under the current global mean warming of 0.85°C (Box 1.1, message 4). This means that a LTGG of 2°C must not be misunderstood as a safe 'guardrail', but should rather be seen 'as a defence line' (see also Box 1.1, message 5).
- While acknowledging all the many efforts by parties and other actors already underway including those taking place under the auspices of UNFCCC (Box 1.1, messages 7 and 9), the progress made so far falls short of what needs to be done, being 'not on track to achieve the long-term global goal' (Box 1.1, message 8), and notably also in the area of adaptation (Box 1.1, message 7). Not only do current emission trends and their extrapolations into the near future show a significant gap between those emission levels and what is needed to limit global warming to well below 2°C,[39] but adaptation efforts lag often significantly behind what would be needed to reduce the imminent climate risks. Yet, 'successful mitigation policies are known and must be scaled up urgently' and are 'still feasible and will bring about many co-benefits', including reducing the need for adaptation, despite posing 'substantial technological, economic and institutional challenges' (Box 1.1, message 6).
- Given the above insights, the SED concluded on the specifics of the adequacy of the LTGG[40] and the possible strengthening of the LTGG to 1.5°C as mandated by COP 16,[41] COP 17,[42] and COP 18[43] that more robust science would be needed on a warming limit of 1.5°C (Box 1.1, message 10).

The COP 21 'also notes that much greater emission reduction efforts will be required than those associated with the intended nationally determined contributions'[44] to keep global warming well below 2°C, let alone to limit it to 1.5°C. In total, intended nationally determined contributions (INDCs) were estimated to lead to GHG emissions of 55 $GtCO_2eq$ in 2030, whereas a 2°C compatible pathway would constrain these emissions to 40 $GtCO_2eq$.

All of this significantly contributed to the dynamics (see Chapter 4) that led to the formula eventually agreed in the Paris Agreement to limit mean global warming to well below 2°C with a view to pursue 'efforts to limit the temperature increase to 1.5°C above pre-industrial levels'.[45] The aforementioned invitation by COP 21 to IPCC to prepare a special report in 2018 includes also a request to estimate the maximum emissions by 2030, which are compatible with a LTGG of 1.5°C,[46] for which IPCC AR5 could provide only limited information (Box 1.1, message 10).

Given the current nexus of adaptation and mitigation (see Chapter 12), together with the INDCs as presented to the world before the negotiations in Paris, the world

[39] UNEP, *The Emissions Gap Report 2015* (n 37). [40] Decision 1/CP.18 (n 26) para 79.
[41] See the Cancún Agreements (n 20) paras 4, 139(iv).
[42] Decision 2/CP.17 (n 26) para 106(d). [43] Decision 1/CP.18 (n 26) preamble.
[44] Decision 1/CP.21 para 17. [45] Paris Agreement art 2. [46] Decision 1/CP.21 para 17.

is clearly not yet on track to achieve the LTGG as defined by the Paris Agreement, in terms of mitigation, adaptation, and finances. While both adaptation and mitigation can to some extent complement each other in reducing risks from climate change, an improved understanding of potential and limitations of both mitigation and adaptation is needed. Ambitious mitigation comes with its own risks, eg side-effects from negative emission technologies, which need to be well understood to allow for decisions on strengthening the LTGG possibly to 1.5°C, which, in turn, may remain a feasible option only if that decision is made in the first years of the Paris Agreement.

For all efforts aimed at closing these gaps and raising ambitions in mitigation and adaptation, scientific knowledge is needed. This calls for a continued use and possibly further strengthening of the science–policy interface, perhaps building on what took place during the SED. Although not yet decided as of this writing, the next review as mandated by COP16 in Cancún, is expected to take place starting in 2022. In addition, the Paris Agreement states that science provides input[47] to facilitate the global stock take as staged the first time for 2023[48] and every five years thereafter. Similarly, a preliminary facilitative dialogue 'to take stock of the collective efforts of Parties in relation to progress towards the LTGG'[49] is planned for 2018. The SR IPCC on a 1.5°C world and possible paths towards it will be an important input into the global stocktake.

All this does not only challenge policy-making, but also scientific research having mostly studied low-end scenarios with a limit for global warming of 2°C but rarely below. It is to be hoped that all involved actors attentively learn from these developments in time and that the first global stocktake can start its work based on a comprehensive solid and robust scientific decision basis, in the form of the IPCC's Sixth Assessment Report (AR6).

[47] Paris Agreement art 14.1. [48] ibid art 14. [49] Decision 1/CP.21 para 20.