The Emissions Gap Report

Are the Copenhagen Accord pledges sufficient to limit global warming to 2° C or 1.5° C?

A preliminary assessment

November 2010

ADVANCE COPY

Foreword

Achim Steiner,
UN Under-Secretary-General, UNEP Executive Director

Climate change represents one of the greatest challenges but also an inordinate opportunity to catalyse a transition to a low carbon, resource-efficient Green Economy.

This report informs Governments and the wider community on how far a response to climate change has progressed over the past 12 months, and thus how far the world is on track to meet wider goals.

The pledges associated with the Copenhagen Accord of 2009 are the point of departure for this report. What might be achieved in terms of limiting a global temperature rise to 2° C or less in the twenty-first century and in terms of setting the stage for a Green Economy?

And what remains to be done—what is the gap between scientific reality and the current level of ambition of nations? The analysis focuses on where global emissions need to be in around 10 years time to be in line with what the science says is consistent with the 2° C or 1.5° C limits, and where we expect to be as a result of the pledges.

If the highest ambitions of all countries associated with the Copenhagen Accord are implemented and supported, annual emissions of greenhouse gases could be cut, on average, by around 7 gigatons (Gt) of CO_2 equivalent by 2020.

Without this action, it is likely that a business-as-usual scenario would see emissions rise to an average of around 56 Gt of CO_2 equivalent by around 2020. Cuts in annual emissions to around 49 Gt of CO_2 equivalent would still however leave a gap of around 5 Gt compared with where we need to be—a gap equal to the total emissions of the world's cars, buses and trucks in 2005.

That is because the experts estimate that emissions need to be around 44 Gt of CO_2 equivalent by 2020 to have a likely chance of pegging temperatures to 2° C or less.

However, if only the lowest ambition pledges are implemented, and if no clear rules are set in the negotiations, emissions could be around 53 Gt of CO_2 equivalent in 2020—not that different from business as usual—so the rules set in the negotiations clearly matter.

This report, the result of an unprecedented partnership between UNEP and individuals from 25 leading research centres, underlines the complexity of various scenarios.

The Emissions Gap Report emphasizes that tackling climate change is still manageable, if leadership is shown. In Cancun action on financing, mitigation and adaptation need to mature and move forward—supported perhaps by action on non-CO_2 pollutants such as methane from rubbish tips to black carbon emissions.

Above all, Cancun must demonstrate to society as a whole that Governments understand the gaps left by Copenhagen. But at the same time remain committed to counter climate change while meeting wider development goals.

Acknowledgements

The United Nations Environment Programme (UNEP) would like to thank the Steering Committee, all the lead and contributing authors, and the Secretariat for their contribution to the development of this report.

The following individuals and/or organizations have provided scientific input to the report. Authors have contributed to this report in their individual capacity and their organizations are mentioned for identification purposes.

Steering Committee Members: Joseph Alcamo, Chair (UNEP), Kilaparti Ramakrishna (UNEP), Bert Metz (European Climate Foundation), Suzana Kahn Ribeiro (COPPE, Federal University of Rio de Janeiro), Anand Patwardhan (Indian Institute of Technology Bombay), Adrian Fernandez (Instituto Nacional de Ecologia, Mexico) and Julia Martinez (Instituto Nacional de Ecologia, Mexico).

Lead Authors: Michel den Elzen (PBL Netherlands Environmental Assessment Agency), William Hare (Potsdam Institute for Climate Impact Research), Niklas Höhne (Ecofys), Kelly Levin (World Resources Institute), Jason Lowe (Met Office, Hadley Centre), Keywan Riahi (International Institute for Applied Systems Analysis), Joeri Rogelj (ETH Zurich), Elizabeth Sawin (Climate Interactive), Chris Taylor (Grantham Research Institute, LSE), Detlef van Vuuren (PBL Netherlands Environmental Assessment Agency), Murray Ward (Global Climate Change Consultants).

Contributing Authors: Valentina Bosetti (Fondazione Eni Enrico Mattei), Claudine Chen (Potsdam Institute for Climate Impact Research), Rob Dellink (Organisation for Economic Co-operation and Development), Jørgen Fenhann (UNEP Risoe), Claudio Gesteira (COPPE, Federal University of Rio de Janeiro), Tatsuya Hanaoka (National Institute for Environmental Studies), Mikiko Kainuma (National Institute for Environmental Studies), Jiang Kejun (Energy Research Institute), Emanuele Massetti (Fondazione Eni Enrico Mattei), Ben Matthews (UCLouvain, Centre for Earth and Climate Research), Caspar Olausson (Danish Energy Agency), Brian O'Neill (National Center for Atmospheric Research), Nicola Ranger (Grantham Research Institute, LSE), Fabian Wagner (International Institute for Applied Systems Analysis), Zhao Xiusheng (Tsinghua University).

Secretariat: Ramzi Elias, Project Manager (European Climate Foundation), Maria Blazogiannaki (European Climate Foundation), Harsha Dave (UNEP), Ernest Imbamba (UNEP).

Production team: Fanina Kodre-Alexander, Kelvin Memia, Amos Muema, Elijah Munyao, Enid Ngaira and Geoffrey Thompson (UNEP).

UNEP would also like to thank the following individuals from around the world for their valuable comments, provision of data and valuable advice: Dan Bernie (Hadley Centre), Greg Briner (Organisation for Economic Co-operation and Development), Alex Bowen (Grantham Research Institute, LSE), Marcel Brinkman (McKinsey & Company), Christa Clapp (Organisation for Economic Co-operation and Development), John Christensen (UNEP), Volodymyr Demkine (UNEP), Thomas Færgeman (Concito), Richard Folland (Climate Strategies), Giacomo Grassi (Joint Research Center, European Commission), Nora Greenglass (Woods Hole Research Center), Joerg Haas (European Climate Foundation), Markus Hagemann (Ecofys), Trevor Houser (Peterson Institute for International Economics), Maryna Karavai (UNEP Risoe), Jacob Krog Søbygaard (Danish Energy Agency), Emilio Lebre La Rovere (COPPE, Federal University of Rio de Janeiro), Arkadiy Levintanus (UNEP), Malte Meinshausen (Potsdam Institute for Climate Impact Research), Sara Moltmann (Ecofys), Tom Phillips (McKinsey & Company), Michiel Schaeffer (Climate Analytics), Lori Siegel (Climate Interactive), Bob Ward (Grantham Research Institute, LSE), Kaveh Zahedi (UNEP)

Contents page

Three online appendices accompany this report

Appendix 1: Further detail on the four pledge cases and the differences between estimates
Appendix 2: Detailed information about countries’ pledges
Appendix 3: Detailed information about the studies reviewed

Available at www.unep.org/publications/ebooks/emissionsgapreport

Glossary

Annex I Target	For the purpose of this report, the quantified economy-wide emission reduction targets submitted by UNFCCC Annex I countries to the Copenhagen Accord's Appendix I.
Conditional Pledge	Pledges made by some countries that are contingent on the ability of national legislatures to enact the necessary laws, ambitious action from other countries, realization of finance and technical support, or other factors.
Copenhagen Accord	The 15th Conference of the Parties to the UNFCCC took note of this agreement in Copenhagen, Denmark in December 2009. The Accord includes two appendices listing Annex I and non-Annex I pledges, which are analysed in this report.
Cumulative Emissions	Sum of annual global greenhouse gas emissions over a period of time. Because many greenhouse gases persist in the atmosphere for a long time, cumulative emissions greatly influence concentrations and therefore temperature.
Double Counting	In the context of this report, double counting refers to a situation in which the same emission reductions are counted towards meeting two countries' pledges.
Emission Pathway	The trajectory of annual global greenhouse gas emissions over time.
Energy and Industry CO_2 Emissions	CO_2 emissions from the energy and industry sectors. These are often referred to in this report when describing emission reduction rates and negative emissions
Feasible Rates of Emission Reduction	The average annual rate of emission reductions assumed feasible given assumptions about technological development, economic costs, and/or socio-political factors.
Global (total) Greenhouse Gas Emissions	Emissions from all sectors and all greenhouse gases
Integrated Assessment Models	Models of climate change that seek to combine knowledge from multiple disciplines in formal integrated representations. As such they describe the full chain of climate change, including relevant linkages and feedbacks between socio-economic and biophysical processes.
Likely Chance	A greater than 66 per cent likelihood. Used to convey the probabilities of meeting temperature limits.
Lenient LULUCF Credits	Credits given for carbon removals from existing forests or other sinks that would have occurred without policy intervention.
Lenient Rules	Pledge cases with maximum Annex I "lenient LULUCF credits" and surplus emissions units.
Medium Chance	A 50 to 66 per cent likelihood. Used to convey the probabilities of meeting temperature limits.

Negative Emissions	Either globally or for a particular sector, the emissions that could occur if, in a given period, the removal of greenhouse gases from the atmosphere as a result of anthropogenic activities is greater than the addition of anthropogenic emissions into it.. Note that in this report negative energy and industry CO_2 emissions are often mentioned.
Non-Annex I Action	For the purpose of this report, those emission reduction actions submitted to the UNFCCC by non-Annex I countries and listed in the Copenhagen Accord's Appendix II.
Offsets	A general term referring to credits that offset the need to reduce emissions elsewhere.
Overshoot Pathway	An emission pathway wherein a selected target (concentration or temperature) is exceeded for a period of time, but is eventually met.
Pledge	For the purpose of this report, pledges include Annex I targets and non-Annex I actions as included in Appendix I and Appendix II, respectively, to the Copenhagen Accord.
Scenario	A description of how the future may unfold based on 'if-then' propositions. A scenario in the context of this report consists typically of a representation of an initial socio-economic situation and a description of the key driving forces and future changes in emissions, temperature or other climate change-related variables.
Strict Rules	Pledge cases in which the impact of "lenient LULUCF credits" (see definition above) and surplus emissions units are set to zero.
Stylized Pathways	These are results from carbon cycle and climate models that are designed to better understand the relationships between emissions and temperatures, but do not explicitly incorporate assumptions about technological, economic or socio-political feasibility of emission reductions.
Surplus Emission Units	After the first commitment period of the Kyoto Protocol (2008-2012), according to Article 3, paragraph 13, Parties holding emission units not required for compliance with their commitments are able to carry over these units for future use or sale. These are called "surplus emission units". There is also the possibility that new surplus emission units will be created in the second commitment period, when targets are set below business-as-usual expectations.
Temperature Limits	Targets for maximum global average temperature increase above pre-industrial levels.
20th-80th percentile range	Results that fall within the 20-80 per cent range of the frequency distribution of results in this assessment.
Unconditional Pledges	Pledges made by countries without conditions attached.

Acronyms

AAU	Assigned Amount Unit
BECCS	Bioenergy combined with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CO_2e	Carbon dioxide equivalent For the purpose of this report, greenhouse gas emissions (unless otherwise specified) are the sum of the basket of greenhouse gases listed in Annex A of the Kyoto Protocol, expressed as carbon dioxide equivalent. The carbon dioxide equivalent of the various gases is computed by using the global warming potentials published in the Second IPCC Assessment Report.
COP	Conference of the Parties to the UN Framework Convention on Climate Change
GDP	Gross Domestic Product
Gt	Gigatonne (1 billion metric tonnes)
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land-Use Change and Forestry
Mt	Megatonne (1 million metric tonnes)
RCPs	Representative Concentration Pathways. RCPs form an important element of the new scenarios used for assessment of climate change.
UNFCCC	UN Framework Convention on Climate Change

Technical Summary

The Emissions Gap Report

Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2° C or 1.5° C?

A Preliminary Assessment

The Copenhagen Accord declared that deep cuts in global emissions are required *"so as to hold the increase in global temperature below 2 degrees Celsius".* The Accord called for an assessment that would consider strengthening the long-term goal including *"temperature rises of 1.5 degrees".* Since December 2009, 140 countries[1] have associated themselves with the Copenhagen Accord. Of these, 85 countries have pledged to reduce their emissions or constrain their growth up to 2020.

The question remains, however, whether these pledges are sufficient to achieve the Accord's temperature limits, or if there will be a gap between what is needed and what is expected as a result of the pledges.

Many scientific groups have identified global emission pathways[2], or emissions trajectories, that are consistent with various temperature limits, while others have estimated global emissions in 2020 based on the Copenhagen Accord pledges. Some groups have calculated both. Not surprisingly, different groups have come up with different estimates. The range of estimates is caused, for example, by the fact that some of the pledges have conditions attached, such as the provision of finance and technology or ambitious action from other countries. This leads to a range of potential outcomes rather than a single estimate.

To understand and interpret the range of results coming from different studies, the United Nations Environment Programme (UNEP), in conjunction with the European Climate Foundation and the National Institute of Ecology, Mexico, convened a six-month preliminary assessment of these studies. This assessment aims to provide policy-makers with an overview of results from various studies, as well as their areas of agreement and disagreement. Individuals from twenty-five groups have contributed to the assessment and co-authored this publication. This report is a summary of that work.

Notably, the 2020 emissions reduction pledges analysed in this report were not decided under a quantitative top-down approach to emissions management — one that starts with temperature limits for which the mitigation effort is distributed among countries by

[1] As of 12 November 2010.

[2] An "emission pathway" shows how emissions change into the future

negotiation. Therefore, at this time we are only analysing the effect of the offers brought forward by countries in the form of pledges under the Copenhagen Accord.[3]

This assessment addresses four main questions:

- What 2020 emission levels are consistent with the 2° C and 1.5° C limits[4]?
- What are the expected global emissions in 2020?
- How big is the "emissions gap"?
- How can the gap be reduced?

Key findings

- Studies show that emission levels of approximately 44 gigatonnes of carbon dioxide equivalent ($GtCO_2e$) (range: 39-44 $GtCO_2e$*) in 2020 would be consistent with a "likely" chance of limiting global warming to 2° C.
- Under business-as-usual projections, global emissions could reach 56 $GtCO_2e$ (range: 54-60 $GtCO_2e$) in 2020, leaving a gap of 12 $GtCO_2e$.
- If the lowest-ambition pledges were implemented in a "lenient" fashion**, emissions could be lowered slightly to 53 $GtCO_2e$ (range: 52-57 $GtCO_2e$), leaving a significant gap of 9 $GtCO_2e$.
- The gap could be reduced substantially by policy options being discussed in the negotiations:
    - By countries moving to higher ambition, conditional pledges
    - By the negotiations adopting rules that avoid a net increase in emissions from (a) "lenient" accounting of land use, land-use change and forestry activities and (b) the use of surplus emission units
- If the above policy options were to be implemented, emissions in 2020 could be lowered to 49 $GtCO_2e$ (range: 47-51 $GtCO_2e$), reducing the size of the gap to 5 $GtCO_2e$. This is approximately equal to the annual global emissions from all the world's cars, buses and transport in 2005 – But this is also almost 60 per cent of the way towards reaching the 2° C target.
- It will also be important to avoid increasing the gap by "double counting" of offsets.
- Studies show that it is feasible to bridge the remaining gap through more ambitious domestic actions, some of which could be supported by international climate finance.

---

[3] We note that this is a technical report that explores possible outcomes associated with the implementation of the Copenhagen Accord. It is not intended to legitimize the Accord, nor does it constitute an endorsement of a pledge-and-review architecture vis-à-vis a target-based approach for emission reductions. In addition this report is not intended to advocate any particular policy or emissions pathway.

[4] Although the Copenhagen Accord is not explicit about the baseline against which temperature increase should be measured, we have assumed that it is pre-industrial levels.

- With or without a gap, current studies indicate that steep emission reductions are needed post 2020 in order to keep our chances of limiting warming to 2° C or 1.5° C.

** Range here refers to the “majority of results”, i.e. their 20th and 80th percentile.*
*** “Lenient” in this report is used to refer to the situation in which LULUCF accounting rules and the use of surplus emission units result in a net increase in emissions*

What 2020 emission levels are consistent with the 2° C and 1.5° C limits?

Box 1: Method for assessing emission levels consistent with temperature limits

In this assessment we examine two groups of pathways: (1) pathways produced by integrated assessment models (IAM), which simulate the energy-economic system including the turnover of energy infrastructure; and (2) "stylized" pathways, produced by other models that do not explicitly model the change in the energy system or feasibility of emission reduction rates. We focus on results from IAMs because they are able to actually describe the system's response to different policies and measures and emission-related targets (see Box 2). However, we also draw on "stylized" scenarios in order to better understand the theoretical rates of emission reduction and magnitude of negative emissions needed to be consistent with particular temperature limits.

A total of 223 emission pathways produced by 15 modelling groups have been analysed[5]. We account for many, but not all, sources of the uncertainty of models and data by compiling results from a number of studies and identifying conclusions that appear robust.

1. The level of human-induced global warming is primarily determined by the cumulative emissions over time, i.e. when emissions peak, at what level, and how fast they decline thereafter*.*

The total stock of greenhouse gases in the atmosphere has a strong effect on climate forcing related to climate change. This stock is determined by the accumulated emissions of greenhouse gases in the atmosphere. It follows that cumulative emissions have a profound influence on the long-term increase of global temperature[6].

An important point is that several different emission pathways can result in the same cumulative emissions over a period of time. But not all pathways are considered equally feasible; some are thought to be constrained by an upper ceiling on the rate of emission reductions due to technological, economic, social and political factors. Hence, the feasibility of reduction rates plays a central role in determining which 2020 emission levels are consistent with temperature limits. Also important are assumptions about the feasibility of "negative emissions", i.e. the net removal of carbon dioxide (CO_2) from the atmosphere through, for example, planting forests or capturing CO_2 from biomass (see Box 3).

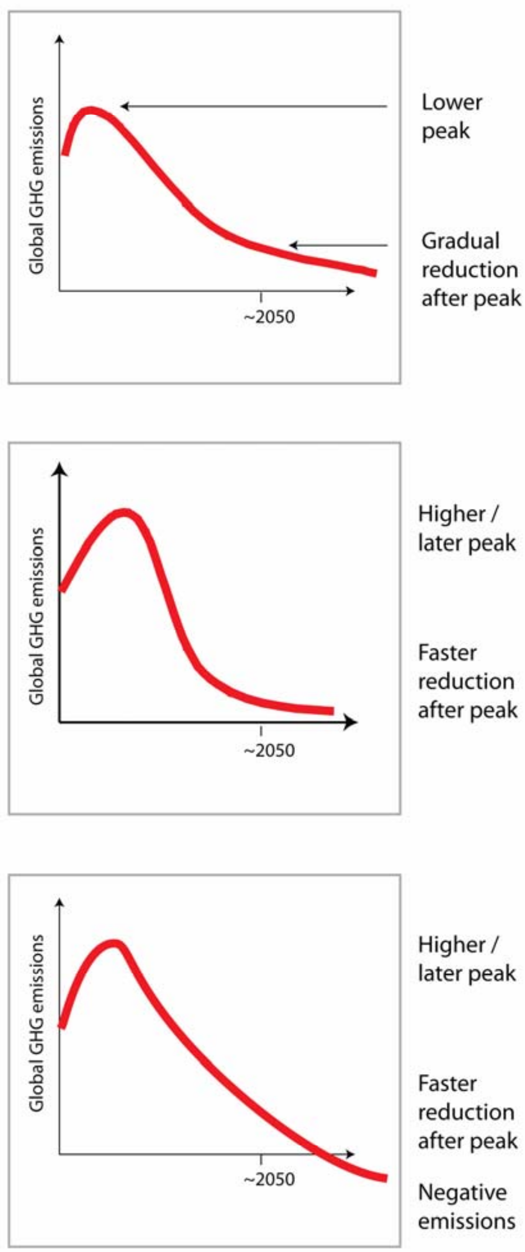
Studies show that there is a trade-off between the timing of the peak and the rate of decrease in emissions afterwards – the sooner and lower the peak, the slower the rate of decrease can be afterwards. Conversely, the longer the peak is delayed and the higher it is, the faster emissions must decline afterwards, and/or the stronger the negative emissions over the long term, in order to stay within the temperature limit (see Figure A).

Many recent modelling studies have assumed that it would be unrealistic for global emissions to immediately start decreasing (because of political and economic factors) and therefore have focused on scenarios in which global emissions continue to increase for a few years and then decrease sharply afterwards.

[5] Detail on the studies reviewed can be found in Chapters 2 and 3 of the full report.

[6] It is important to note that a number of other factors, such as the level of sulphate aerosols and the shape of the pathway, also have a significant influence on the maximum temperature increase.

Figure A: Illustration of different pathway types for the same temperature increase. See Point 1 for explanation.



Box 2: Understanding temperature limits

A temperature increase of 2° C or 1.5° C represents an increase in global average near surface temperature compared with pre-industrial times. This is meant to be an indicator of local climate changes. Importantly, a 2° C or 1.5° C global average increase can translate into much higher temperature changes locally.

There are significant uncertainties in the relationship between temperature, emission pathways, cumulative emissions, and atmospheric concentrations. Therefore, in this assessment, each emission pathway is associated with a range of probabilities for temperature, reflecting uncertainties in the carbon cycle and many other aspects of the climate system. Hence, an emission pathway is associated with probabilities of staying within a range of different temperature changes.

To illustrate, an emission pathway that has a 50 per cent chance of limiting warming to under 2° C, may also have a 5 per cent probability that warming will exceed 3° C and, say, a 10 per cent probability of staying below 1.5° C. Similarly, an emission pathway that has a 66 per cent chance of staying under 2° C, may also have a probability of less than 3 per cent that warming will exceed 3° C and, say, a 20 per cent probability of staying below 1.5° C.

In this assessment we focus on emission pathways that lead to a global average temperature increase of less than 2° C over this century with a "likely" chance (greater than 66 per cent probability) and then explain how they would be different for a "medium" chance (50-66 per cent probability). In addition we examine pathways in which the temperature changes are below 1.5° C by the end of the century, but "overshoots" this value for part of the century.

2. Emission pathways consistent with a "likely" chance of meeting the 2° C limit generally peak before 2020, have emission levels in 2020 around 44 $GtCO_2e$ (range: 39-44 $GtCO_2e$[7]), have steep emission reductions afterwards and/or reach negative emissions in the longer term.

Emission pathways assessed in this report that provide a "likely" (greater than 66 per cent) chance of staying within the 2° C limit, have the following characteristics:

- A peak in global annual emissions[8] before 2020.
- 2020 global emission levels of around 44 $GtCO_2e$ (range: 39-44 $GtCO_2e$).[9]
- Average annual reduction rates of CO_2 from energy and industry between 2020 and 2050 of around 3 per cent (range: 2.2 to 3.1 per cent)[10].
- 2050 global emissions that are 50-60 per cent below their 1990 levels.
- In most cases, negative CO_2 emissions from energy and industry starting at some point in the second half of the century.

---

[7] All ranges given in this report represent the 20th and 80th percentiles of results, unless otherwise stated. This range has been chosen to reflect the majority of results of the analysis.

[8] Global annual emissions consist of emissions of the "Kyoto basket of gases" coming from energy, industry and land use.

[9] These are rounded numbers. If numbers with one decimal place were shown it would be clear that the upper end of the range is slightly greater than 44 $GtCO_2e$ and the median slightly smaller than 44. The fact that both the median and upper end of the range are 44 indicates that many of the estimates were close to 44.

[10] Throughout this report emission reduction rates are given for carbon dioxide emissions from energy and industry and expressed relative to 2000 emission levels except when explicitly stated otherwise

Accepting a "medium" (50-66 per cent) rather than "likely" chance of staying below the 2° C limit relaxes the constraints only slightly: emissions in 2020 could be 1 $GtCO_2e$ higher, and average rates of reduction after 2020 could be 2.5 per cent per year (range 2.2-3.0 per cent). Nevertheless, global emissions still need to peak before 2020 in the majority of cases.

3. It turns out that the 2020 emission levels with a *"likely"* chance of staying within the 2° C limit can be about the same as those with a *"medium" or lower* chance of meeting the *1.5 °C* target. However, to have a higher chance of meeting the 1.5° C target the emission reduction rates after 2020 would have to be much faster.

In this assessment we have identified some emission pathways that keep the increase in temperature below 1.5° C by 2100, but "overshoot" this limit by a small amount for a few decades prior to 2100. However, the chance of doing so is low (range: 27-35 per cent probability). The emission levels in 2020 of these pathways are about the same as those in Point 2 above, i.e. they are consistent with a likely chance of staying below the 2° C limit throughout the twenty-first century.[11]

In addition, the most ambitious "stylized" pathways show that staying within the 1.5° C limit with overshoot (and with a "medium" or "likely" chance) have emission reduction rates after 2020 that are at the high end or faster than presently found in the IAM literature. Lower emission levels in 2020 would allow slower emission reduction rates after 2020.

These findings should be considered preliminary, however, as few studies have explicitly looked at the question of achieving the 1.5° C target.

4. The range in results stems from uncertainties of assumptions and models used for calculations.

The range in estimates of emission levels comes from model uncertainties including the omission of feedback phenomena in the climate system and (in some models) the impact of aerosols on climate forcing. The uncertainty of key assumptions, such as baseline emissions, also has an influence on calculations.

Box 3. What are feasible emission reduction rates? What are negative emissions?

The behaviour of the climate system dictates that future temperatures will be strongly influenced by emissions throughout the coming decades. Hence, the consistency of 2020 emissions with a given temperature limit can only be judged if emissions after 2020 are taken into account. For that reason it is important to know the feasible rates of emission reductions after 2020. Feasibility refers to whether a particular emission pathway is considered achievable. It depends upon technical, economic, political and social constraints and the extent of mitigation policy. Some of these factors, in particular technological and economic feasibility, can be represented in models such as integrated assessment models (IAM). These include assumptions about the maximum feasible rate of introducing technology, maximum costs of technologies, feasibility of specific system configurations, and limits regarding behavioural changes. Another important factor determining the maximum emissions reduction rate is the typical lifetime of machinery and infrastructure. These lifetimes are important if mitigation strategies aim to avoid premature replacement of capital, which is often considered to be very expensive. Other factors, such as political or social attitudes, might also influence the rate of emission reductions, but they are usually not taken into account by IAMs.

[11] One IAM pathway has been identified that has a "medium" chance of complying with the 1.5° C limit by 2100 (with some overshoot for a few decades) and shows emission reduction rates considered feasible in the IAM literature. See Chapter 2, full report.

There are different views about feasible emission reduction rates. The highest average rate of emission reductions over the next four to five decades found in the IAM literature is around 3.5 per cent per year. This would imply a decarbonisation rate (the rate of decrease in emissions per unit of GDP) of more than 6 per cent per year. Historically (1969-2009), a decarbonisation rate of about 1% has been seen globally. However, it is important to note that expectations about feasibility can change with future developments in technology, attitudes, and economics.

One of many important elements related to the feasibility of emission pathways is negative emissions. Many of the scenarios compiled in this assessment show global negative carbon dioxide (CO_2) emissions (from energy and industry) from mid-century onwards in order to achieve the temperature limits examined here[12].

Global negative CO_2 emissions would occur if the removal of CO_2 from the atmosphere is greater than the emissions into it. This might be achievable through large-scale afforestation efforts, for example. Many models assume a large deployment of bioenergy combined with carbon-capture-and-storage (BECCS) technology in order to achieve negative emissions. The feasibility of large scale bioenergy systems is related to its sustainability, including the availability of sufficient land and water, its impact on biodiversity, and the productivity of biomass.

If negative CO_2 emissions at a significant scale are not possible, then the options for meeting the limits are substantially constrained.

What are the expected global emissions in 2020?

5. Global emissions in 2020 will depend on the pledges implemented and the rules surrounding them. On one hand, emissions in 2020 could be as low as 49 $GtCO_2e$ (range: 47-51 $GtCO_2e$) when countries implement their conditional pledges with “strict” accounting rules. On the other hand, they could be as high as 53 $GtCO_2e$ (range: 52-57 $GtCO_2e$) when countries implement unconditional pledges with “lenient” accounting rules.

As a reference point, without pledges global greenhouse gas emissions may increase from 45 $GtCO_2e$ in 2005 to around 56 $GtCO_2e$ in 2020 (range: 54-60 $GtCO_2e$) according to business-as-usual projections. These results come from thirteen studies that have been reviewed in this assessment.

Results show that the pledges, if implemented, are expected to reduce global emissions in 2020 compared to business-as-usual projections. How much lower will depend on:

i. Whether countries implement their unconditional (lower ambition) or conditional (higher ambition) pledges. Conditions attached to the pledges include, for example, the provision of adequate climate finance and ambitious action from other countries.

ii. The extent to which accounting rules for land use, land-use change and forestry (LULUCF) can be used to weaken the mitigation targets of industrialized countries. This could occur if credit is given for LULUCF activities that would have happened in any case without further policy intervention.

iii. The extent to which surplus emissions units, particularly those that could be carried over from the current commitment period of the Kyoto Protocol, are used to meet industrialized country targets.

12 In this assessment, seventy-five per cent of scenarios with a “likely” chance of staying below 2° C and fifty per cent of the scenarios that have a “medium” chance of staying below 2° C.

For the purposes of this report, we have developed four cases that provide a range of plausible outcomes from the UNFCCC negotiations, each with different combinations of the factors mentioned above. We use the term "lenient rules" to refer to cases in which countries maximise the use of surplus emission units and "lenient LULUCF credits", and thereby weaken mitigation targets.[13] We use "strict rules" for the cases in which they do not[14].

> *Case 1 – "Unconditional pledge, lenient rules"*: If countries implement their unconditional pledges and are subject to "lenient" accounting rules (as explained in the paragraph above), global emissions are expected to be about 53 $GtCO_2e$ in 2020 (range: 52-57 $GtCO_2e$), or about 3 $GtCO_2e$ lower than business-as-usual projections.
>
> *Case 2 – "Unconditional pledge, strict rules"*: If countries implement their unconditional pledges and are subject to "strict" accounting rules (as explained in the paragraph above), global emissions are expected to drop to 52 $GtCO_2e$ (range: 50-55 $GtCO_2e$).
>
> *Case 3 – "Conditional pledge, lenient rules"*: If countries implement their higher ambition, conditional pledges and are subject to "lenient" accounting rules, global emissions are expected to drop to 51 $GtCO_2e$ (range: 49-53 $GtCO_2e$)
>
> *Case 4 – "Conditional pledge, strict rules"*: If countries implement their higher ambition, conditional pledges, and are subject to "strict" accounting rules, global emissions are expected to drop to 49 $GtCO_2e$ in 2020. (range: 47-51 $GtCO_2e$).

Thus, under the most ambitious outcome, the pledges could result in 2020 emissions that are 7 $GtCO_2e$ lower than business-as-usual.

6. Emissions could be lower or higher than these estimates, as a result of other factors. Emissions could be higher if offsets were to be "double-counted" towards both industrialized and developing country pledges or if pledges were to be ineffectively implemented. Emissions could be lower as a result of international climate finance for further mitigation efforts, or if countries were to strengthen their pledges, or if domestic activities went beyond their pledges.

The estimates reflected in the four cases do not take into account all factors that could affect emissions in 2020.

Two factors could increase emissions and lessen the impact of the pledges. If industrialized countries were to use offsets to meet their targets, and the developing countries that supplied the offsets also counted them towards their pledges, then emissions would be higher than estimated in Point 5. This "double counting" of offsets could increase emissions in 2020 by up to 1.3 $GtCO_2e$ in 2020. Similarly, if domestic policies were to be ineffective in meeting the pledges, emissions could be higher in 2020.

There are also factors that could further decrease emissions in 2020. If substantial international funds were to become available as agreed to in the Copenhagen Accord, emissions could be as much as 2.5 $GtCO_2e$ lower in 2020 than in the four cases above.

---

[13] Credits given for carbon removals from existing forests or other sinks that would have occurred without policy intervention. See Chapter 3, full report for more detail on the "lenient" and "strict" definitions.

[14] Note that surplus emission units and credits given for LULUCF activities do not necessarily weaken mitigation targets.

Similarly, if domestic policies went beyond international pledges or if pledges were strengthened, emissions could be substantially lower.

7. A number of uncertainties lead to a significant range in estimates of expected 2020 emissions.

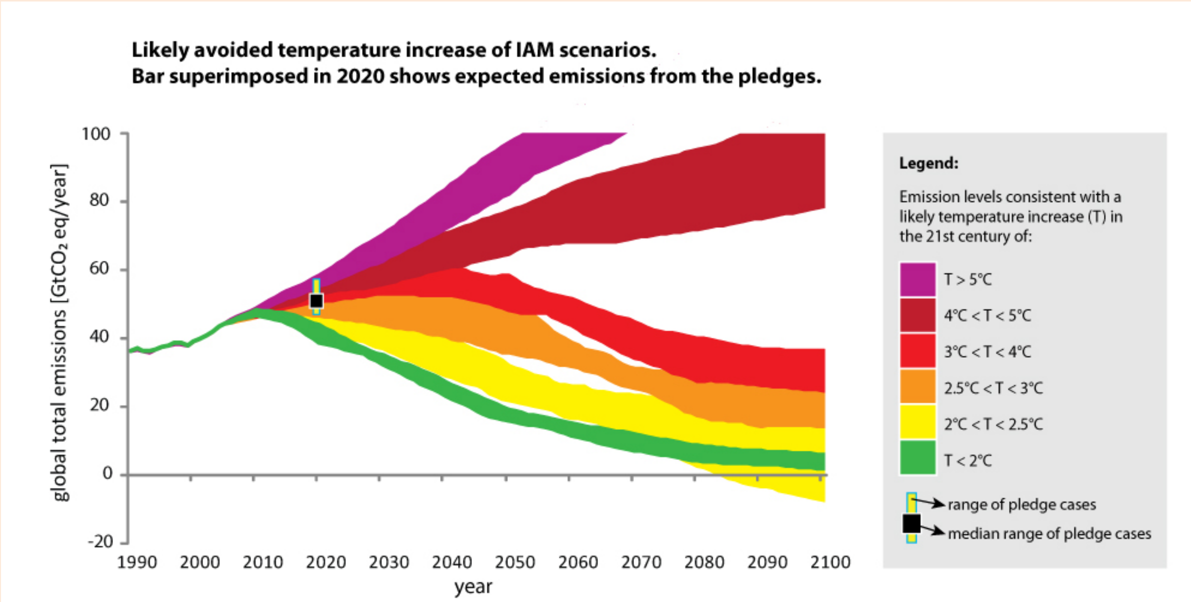
There is a large range between different groups' estimates for 2020 emission levels, even under the same assumptions regarding conditionality of pledges and accounting rules (range: -4 to +8 $GtCO_2e$ around the median estimate, depending on the case). The range of estimates is caused, for example, by differences in the underlying data sets, the treatment of emissions from LULUCF, the estimates of emissions from international transport, and the assumptions made about business-as-usual emissions growth of developing countries.

Box 4. What are the temperature implications of present pledges?

It is not possible to precisely answer the above question because the trend in temperature will strongly depend on the pathway of emissions after 2020. But results from integrated assessment models give us a hint at the range of pathways that could occur between 2020 and 2100. If we start at the level of emissions expected from the Copenhagen Accord pledges in 2020 and then follow the range of these pathways through to 2100, we find that they imply a temperature increase of between 2.5 to 5°C before the end of the century (see Figure B). The lower bound is the case in which emissions are fairly stringently controlled after 2020, and the upper in which they are more weakly controlled. In other words, emission levels in 2020 implied by current pledges do not seem to be consistent with 2° C or 1.5° C temperature limits. To stay within these limits, emission levels would have to be lower in 2020 and then be followed by considerable reductions.

Figure B – Temperature increases associated with emission pathways and compared to the expected emissions from the pledges: Coloured bands show groups of IAM emission pathways that have approximately the same "likely" avoided temperature increase in the twenty-first century. Specifically the coloured bands show the 20th to 80th percentile range of the IAM pathways associated with those temperature increases[15]. Superimposed on top of the pathways is the range of estimated emissions resulting from the Copenhagen Accord pledges. The small black bar shows the range of median estimates from the four pledge cases. The thin blue bar represents the wider range of estimates associated with those four cases (the 20th to 80th percentile range).

[15] The gaps between the coloured bands come about because this report mainly compiled pathways from low greenhouse gas stabilisation scenarios



How big is the "emissions gap"?

8. A "gap" is expected in 2020 between emission levels consistent with a 2° C limit and those resulting from the Copenhagen Accord pledges. The size of the gap depends on the likelihood of a particular temperature limit, and how the pledges are implemented. If the aim is to have a "likely" chance (greater than 66 per cent) of staying below the 2° C temperature limit, the gap would range from 5-9 $GtCO_2e$, depending on how the pledges are implemented.

As a reference point, we saw in Point 2 that to have a "likely" chance of staying below the 2° C temperature limit, global emissions should be around 44 $GtCO_2e$ (range: 39-44 $GtCO_2e$). But according to business-as-usual projections global emissions in 2020 may be around 56 $GtCO_2e$ (range: 54-60 $GtCO_2e$). This leaves a gap of about 12 $GtCO_2e$ (range: 10-21 $GtCO_2e$).

The four pledge cases, each with different assumptions about the future outcome of the UNFCCC negotiations, result in different gaps as follows[16]:

> *Case 1 – "Unconditional pledges, lenient rules"*. The gap would be reduced down to 9 $GtCO_2e$ (range: 8-18 $GtCO_2e$) or about 3 $GtCO_2e$ below business-as-usual.

[16] All cases refer to emission levels consistent with a "likely" chance of staying below 2^{o} C.

Case 2 – "Unconditional pledges, strict rules". The gap would be about 8 $GtCO_2e$ (range: 6-16 $GtCO_2e$), or about 4 $GtCO_2e$ below business-as-usual.

Case 3 – "Conditional pledges, lenient rules". The gap would be about 7 $GtCO_2e$ (range: 5-14 $GtCO_2e$) or about 5 $GtCO_2e$ below business-as-usual.

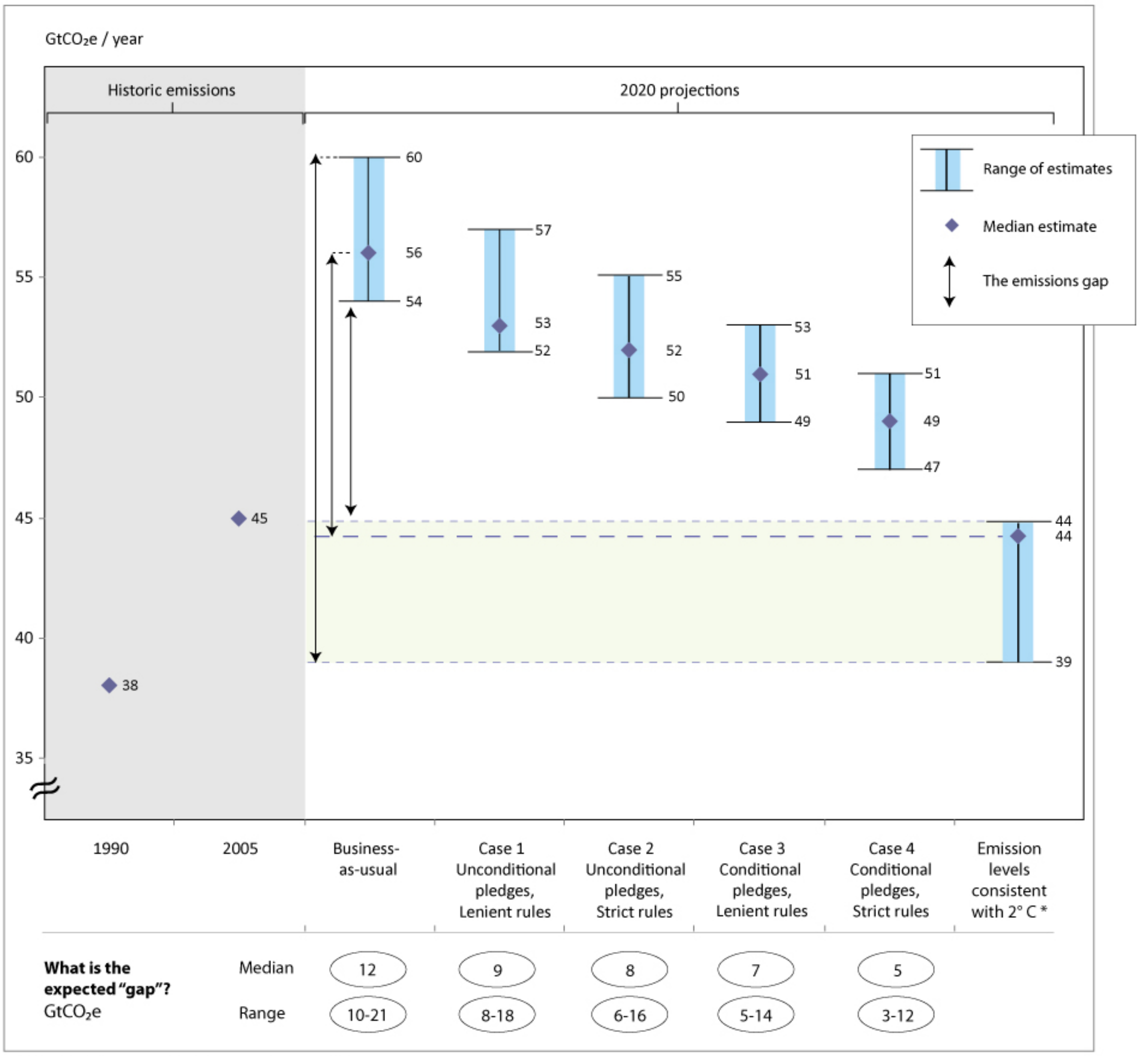
Case 4 – "Conditional pledges, strict rules". The gap would be about 5 $GtCO_2e$ (range: 3-12 $GtCO_2e$). This is about 7 $GtCO_2e$ lower than business-as-usual, and almost 60 per cent of the way to the 2° C levels. Although the gap would be considerably narrower than the business-as-usual case, it would still be as large as the total greenhouse gas emissions from the European Union in 2005 or from global road transport emissions in that year.

These results can be seen in Figure C.

Double-counting of international emission offsets could also increase the gap up to 1.3 $GtCO_2e$. This is a real risk since the Copenhagen Accord does not include rules regarding the use of international offsets.

As a final point here, to have a *"medium"* rather than a *"likely"* chance of staying within the 2° C limit, global emissions in 2020 can be about 1 $GtCO_2e$ higher and the gap also narrows by about 1 $GtCO_2e$.

Figure C: Comparison of expected emissions in 2020 with the emission levels consistent with a "likely" chance of meeting the 2° C limit. The figure compares the expected emissions in 2020 resulting from the four pledge cases with the emission levels consistent with a "likely" chance of meeting the 2° C limit. The median estimates and range of estimates (20th to 80th percentile) are shown. The gap between expected emissions and the 2° C levels is given below in each case.



* A "likely" chance of limiting warming to 2° C by 2100

9. There are considerable uncertainties around the estimates of the gap.

Since the emissions gap is the difference between emission levels for different temperature targets and expected emissions in 2020, the gap also inherits the uncertainties of these two components. The reader will note that the range around median estimates (Figure C) is not symmetric; the lower bound extends about 1-2 $GtCO_2e$ below the median, whereas the upper bound rises 7-9 $GtCO_2e$ above it (for a "likely" chance of staying below 2^oC). One way to interpret this skewed range is that the gap may turn out to be higher rather than lower than the median.

This assessment focuses on the majority (20^{th} – 80^{th} percentile) of emission pathways. But there are obviously also results outside of this range. In the extreme case, if we combine the highest 2°C emission levels with the lowest estimate of expected emissions, the gap disappears. At the opposite extreme, if we combine the lowest 2°C emission levels with the highest estimate of expected emissions, the gap would be greater than 20 $GtCO_2e$.

How can the gap be reduced?

10. Various international policy actions are available to close the gap.

a) Reducing the gap through higher ambition pledges.

The gap can be reduced by around 2-3 $GtCO_2e$ (with a range of estimates from 2 to 5 $GtCO_2e$) by moving from the unconditional (lower ambition) pledges to the conditional (higher ambition) pledges.

- Industrialized countries: The majority of this reduction would come from industrialized countries, whose pledges are sometimes conditional on the ambitious action of other countries or on domestic legislation.
- Developing countries: A smaller, but still important, part of the reduction would come from developing countries, whose pledges are sometimes conditional on the adequate provision of international climate finance or technology transfer.

b) Reducing the gap by tightening the rules

The gap can be reduced by around 1-2 $GtCO_2e$ by ensuring that “strict” rules apply to the use of LULUCF credits and surplus emission units.

- LULUCF accounting: If industrialized countries apply “strict” accounting rules to minimise the use of what we refer to as ‘lenient LULUCF credits’[17] , they would strengthen the effect of their pledges and thus reduce the emissions gap by up to 0.8 $GtCO_2e$.
- Surplus emission units: Likewise, if the rules governing the use of surplus emission units under the Kyoto Protocol were designed in a way that would avoid the weakening of mitigation targets, the gap could be reduced by up to 2.3 $GtCO_2e$. These include units carried over from the current commitment period and any potential new surpluses created in the next.

We note that policy options (a) and (b) are interdependent and so their benefits cannot necessarily be added together. But we estimate that the two options combined could reduce

[17] Credits given for carbon removals from existing forests or other sinks that would have occurred without policy intervention

emissions by around 4 $GtCO_2e$ in 2020 (with a range of estimates of 4-6 $GtCO_2e$) compared with the least ambitious case (case 1).

In addition, the risk of the gap increasing in size can be avoided if the negotiations set rules regarding international offsets to prevent them from being counted towards both industrialized and developing country pledges. “Double-counting” would increase the gap by up to 1.3 $GtCO_2e$.

11. It is feasible to close the remaining gap through further mitigation actions by countries, some of which could be supported by international climate finance.

If the above measures were to be taken, there might still be a gap of 5 $GtCO_2e$ compared with a 2° C limit. This gap could be closed if countries were to adopt more ambitious actions or pledges. The results from integrated assessment models (IAM) suggest that it is possible to reach emission levels where there is no gap, using mitigation measures that are economically and technologically feasible. .

Analysis also shows that international climate finance in line with the Copenhagen Accord could help achieve some of these reductions in developing countries.

12. Studies show that laying the groundwork for steep rates of emissions reduction from 2020 onwards would be necessary for staying within a limit of 2° C and even more so for 1.5° C, whatever the outcome of the pledges.

The results of the IAM pathways that have a “likely” (greater than 66 per cent) or even “medium” (50-66 per cent) chance of limiting temperature increase to 2° C show average annual emission reduction rates of greater than 2 per cent per year after 2020. Achieving this over the long-term would be unprecedented because, on the contrary, global emissions have almost continuously grown since the industrial revolution.

The higher the emissions in 2020, the faster the rate of decline required thereafter to meet temperature targets. Therefore, if targets are to be met, it will be essential to lay the groundwork now for such rates of reduction. This can be done, for example, by avoiding lock-in of high carbon infrastructure with long life-spans and developing and introducing advanced clean technologies.

1. Introduction

***Lead authors**: Kelly Levin, Murray Ward*

***Contributing authors**: Claudio Gesteira, Fabian Wagner*

1.1. COPENHAGEN, TEMPERATURE LIMITS AND PLEDGES

Following the 15th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, forty-two[18] industrialized countries submitted quantified economy-wide emission targets for 2020. In addition, forty-three[19] developing countries submitted nationally appropriate mitigation actions for inclusion in the Appendices to the 2009 Copenhagen Accord.[20] These pledges[21] have since become the basis for analysing the extent to which the global community is on track to meet long-term temperature goals as outlined in the Copenhagen Accord:

> *(Para 1)…To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change.*
>
> *(Para 2)…We agree that deep cuts in global emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity.*
>
> *(Para 12)…We call for an assessment of the implementation of this Accord to be completed by 2015, including in the light of the Convention's ultimate objective. This would include consideration of strengthening the long-term goal referencing various matters presented by the science, including in relation to temperature rises of 1.5 degrees Celsius.*

This publication aims to assess the following questions: are countries' pledges of action collectively consistent with and, if implemented, likely to achieve the 2° C and 1.5° C temperature goals? If not, how big is the gap between emission levels consistent with these temperature goals and the emissions expected as a result of the pledges?

Notably, the 2020 emission reduction pledges were not decided through a quantitative top-down approach to emissions management, i.e. one that would begin with agreed-upon temperature limits and then be followed by negotiation to distribute the burden of emission reductions necessary to meet these limits. Therefore, at this time we can only analyse the

---

18 http://unfccc.int/home/items/5264.php

19 http://unfccc.int/home/items/5265.php

20 http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf#page=4

21 For the purposes of this report, pledges include Annex I targets and non-Annex I actions.

emerging “global deal” on climate change by summing pledges from the bottom up—in other words, based on offers already brought forward voluntarily by countries.

Box 1a: Understanding temperature limits

A warming limit of 2° C or 1.5° C refers to the increase in global annual average near surface temperature compared with pre-industrial times. This temperature is intended to be an indicator for local changes in a wide range of observable quantities, such as precipitation. It is important to note that a 2° C global average rise can translate into much larger (or smaller) temperature changes in different latitudes and elevations. Moreover, undesirable impacts will generally be driven by local climate changes (e.g. changes in rainfall patterns) and often by changes in extremes in different seasons rather than by annual average temperature values.

There are significant uncertainties in the relationship between temperature, emission pathways, cumulative emissions, and atmospheric concentrations. Therefore, in this assessment, each emission pathway is associated with probabilities of staying within a range of temperature limits. These probabilities reflect the uncertainties in the carbon cycle as well as many other aspects of the climate system. To illustrate, an emission pathway that has a 50 per cent chance of limiting warming to under 2° C may also have a 5 per cent probability that warming will exceed 3° C and, say, a 10 per cent probability of staying below 1.5° C. If we then consider an emission pathway that has a 66 per cent chance of being under 2° C, it may also have a probability of less than 3 per cent that warming will exceed 3° C, and, say, a 20 per cent probability of staying below 1.5° C.

Therefore, it is not possible to guarantee that a particular emission pathway will achieve a temperature limit of 2° C or 1.5° C, and probabilities of achievement are used instead. In this assessment we focus on two temperature limits, 2° C and 1.5° C; and two probabilities of meeting them – a “likely” chance (probability greater than 66 per cent) and a “medium” chance (probability between 50-66 per cent).

1.2. SCOPE OF THE REPORT

This report addresses many of the key issues raised by the Copenhagen Accord. For example, the emission pathways consistent with temperature limits and the expected emissions in 2020 based on current pledges. Furthermore, it examines whether there is a gap between emission levels consistent with temperature limits and expected emissions, and furthermore, the increases in temperature consistent with such a gap in emissions. Outside the scope of the report are issues related to the comparability and equity of pledges.

1.3. A MULTI-DIMENSIONAL CHALLENGE

In assessing these issues we are confronted with a series of highly complex issues, which result from both scientific and political factors.

In **Chapter 2**, we focus on the likelihood of various emission pathways staying within temperature limits. For these pathways we identify the period in which emissions peak, the level of emissions in 2020, and the corresponding emission reduction rates after 2020. Results include emission pathways from integrated assessment models (IAM) and carbon cycle and climate models. Also discussed are current views about the feasibility of emission reductions and negative emissions, as well as factors determining long-term temperature, including cumulative emissions.

Chapter 3 reviews estimates of global emission levels in 2020 based on country emission pledges. Among the factors influencing these estimates are whether pledges are independent of, or conditional on, other countries' actions, financing or technological support. For industrialized countries, key factors include: the accounting procedures for emissions or uptake of carbon from land use, land-use change and forestry (LULUCF); the potential for international climate finance, as agreed in the Copenhagen Accord to enable further emission reductions; the carry-over of emission reduction units from the first commitment period of the Kyoto Protocol (2008-2012); and the potential double counting of offsets with emission reductions from non-Annex I countries' actions. Emission estimates are also influenced by the uncertainty of base year emissions and by assumptions needed for filling in sectoral or other gaps in the emission estimates of various groups.

The pledges of industrialized countries are fairly easy to convert into emission estimates because they are usually related to historic emissions. However, more assumptions are needed to make this conversion for developing countries because their pledges have usually been pegged to economic, demographic or other projections.

Chapter 4 builds upon the previous two chapters by examining a possible "emissions gap" in 2020 between emission levels consistent with temperature limits and expected emissions resulting from the pledges. It then goes on to explore policy options for narrowing the size of the gap.

Chapter 5 goes a step further by reporting on possible long-term temperature changes following from current pledges.

The online version of the report[22] contains three appendices with additional information about emission pledge calculations in this report. Appendix 1 provides detail on the differences between the four pledge cases described in Chapter 3 and the uncertainties around them. Appendix 2 provides a country-by-country analysis of the pledges of the largest emitting countries. Appendix 3 compares the findings of modelling groups that have assessed country pledges.

22 www.unep.org/publications/ebooks/emissionsgapreport

2. Which emission pathways are consistent with a 2° C or 1.5° C temperature limit?

Lead authors: *William Hare, Jason Lowe, Joeri Rogelj, Elizabeth Sawin, Detlef van Vuuren*

Contributing authors: *Valentina Bosetti, Tatsuya Hanaoka, Jiang Kejun, Ben Matthews, Brian O'Neill, Nicola Ranger, Keywan Riahi*

2.1 INTRODUCTION

This chapter identifies future emission pathways that are consistent with a 2° C or 1.5° C temperature limit. Many scenarios and pathways for annual global emissions of greenhouse gases have been published in the scientific literature to explore possible long-term trends in climate change. This literature has been used in this report to understand the kind of pathways consistent with the goal of limiting global temperature increase to less than 2° C or 1.5° C above pre-industrial levels.

Among the different studies of future emission pathways, two main types can be identified. The first type is produced by integrated assessment models (IAM), which simulate both future climate and future socio-economic systems, including the emissions of greenhouse gases from industry and power generation, agriculture, forestry and other land use activities (see for example Clarke et al. 2009, Edenhofer et al. 2010, van Vuuren et al. 2007). IAMs take into account assumptions about technological and economic constraints and so, to some extent, provide a view on what are "feasible" emission reductions. The second type of pathway, described here as "stylized", explores more directly the relationship between emissions and temperature, for example by making assumptions about the timing and magnitude of peak emissions and rates of reduction[23] following the peak. These are pathways produced by models that do not explicitly simulate change in the energy system or feasibility of emission reduction rates. "Stylized" pathways are designed to better understand the temperature outcomes resulting from emission pathways computed by carbon cycle and climate models, without making assumptions about how those emissions are produced (see for example Lowe et al. 2009, Meinshausen et al. 2009).

Although both approaches provide important insights and findings, only results from IAMs are used here for quantitative analysis, unless otherwise stated.

Scenarios published by IAMs in the literature mostly look into optimal pathways to achieve a certain long-term target and not into the question of what emission range in 2020 would achieve a temperature limit. For this reason, we have assembled a large set of scenarios computed with various objectives in mind, and have tested them to see if they are consistent with temperature limits. The combination of these scenarios provides insight into the full range of 2020 emissions consistent with long-term temperature limits. It is possible that other feasible pathways will be identified by modelling groups, once they begin to run their models to explore the full 2020 emissions range.

---

[23] Throughout this report emission reduction rates are given for carbon dioxide emissions from energy and industry and expressed relative to 2000 emission levels except when explicitly stated otherwise.

Although IAM studies have paid little explicit attention to the question of the range of 2020 emissions consistent with temperature limits, there are some studies of stylized pathways that have done this (Bowen and Ranger 2009, Meinshausen et al. 2009).

In our quantitative assessment of IAM results we have attempted to take the differences between studies (in terms of uncertainties of various input assumptions and different approaches) into account by re-analysing the results of these studies using a common set of assumptions about base year emissions, coverage of non-CO_2 gases, carbon cycle assumptions and interpretation of climate goals (as explained in Box 2a). These re-analysed pathways have been evaluated in terms of their consistency with a 2° C and 1.5° C limit. An important factor here is that projections of the future climate all contain uncertainty (Meehl et al. 2007). This means that when discussing the possibility of satisfying a particular temperature limit, it is necessary to express the result in terms of a probability. As explained in Box 2a, the MAGICC model (Meinshausen et al. 2008) has been used here to take into account some of this uncertainty.

2.2 WHAT DETERMINES LONG-TERM TEMPERATURE?

Many greenhouse gases emitted by human activities have long atmospheric residence times and alter the Earth's energy balance. In addition, the average temperature of the Earth typically adjusts only slowly to changes in the energy balance (Lowe et al. 2009, Solomon et al. 2009). These slow-change processes imply that decision makers need to take into account long-term effects of current and near term emissions (National Research Council 2009). This is even more important as many impacts of climate change are potentially adverse and/or irreversible (at least on time scales of relevance to society).

A number of recent studies have shown that one of the strongest predictors of temperature increase within the twenty-first century is the cumulative emissions of greenhouse gases[24], especially CO_2 (Allen et al. 2009, IPCC 2007b, Matthews and Caldeira 2008, Matthews et al. 2009, Meinshausen et al. 2009, Van Vuuren et al. 2008). Cumulative emissions are determined by the annual emissions over time. In ambitious mitigation scenarios, the following factors play an important role in determining the cumulative emissions:

- the year in which global emissions peak
- the emission level at the peak
- the pathway of global annual emissions after the peak.

For the same cumulative emissions, a higher and/or later emissions peak means faster reductions after the peak than for earlier and/or lower peaks in emissions.

However, all three factors are bounded by feasibility considerations, including economic and/or technological constraints (see Section 2.3). For instance, there are constraints on how fast high-carbon energy infrastructure can be replaced with low-carbon infrastructure (for example, coal-fired power plants with renewable energy production).

[24] The shape of the emission pathway of short-lived greenhouse gases and forcing agents has more influence on the degree of temperature change than long-lived agents. Different emission pathways of short-lived gases (even if they have similar cumulative emissions) influence the temperature increase in different ways (Shine et al. 2005). The assessments in this study include the combined effects of both short and long-lived greenhouse gases and forcing agents.

As a consequence, there is a limited range of 2020 emissions that are consistent with a 2° C or 1.5° C limit, given current assumptions about the feasibility of emission pathways post 2020.

In addition, the probability of exceeding a particular temperature level varies according to the cumulative emissions level—for a higher degree of confidence in staying within a particular temperature limit, a lower cumulative emissions level is required. Pathways with later or higher peaks also reduce, or even eliminate, the "margin of error", should future advances in climate science or additional evidence of the risks of climate change convince citizens and policymakers that more ambitious targets for limiting climate change are needed (Lowe et al. 2009).

2.3 CURRENT ESTIMATES OF FEASIBILITY

The implications of 2020 emission levels for long-term temperature outcomes depend importantly on how much and how fast it is considered feasible to reduce emissions before, and particularly beyond 2020. Feasibility (i.e. considerations on whether a particular emission pathway is possible to achieve) is a subjective concept that has to take into account several factors: technological, economic, political and social. Technological feasibility refers to whether technologies exist, and can be scaled-up fast enough, to produce enough low-carbon energy to meet demand. Economic feasibility refers to whether or not the cost of doing so is considered prohibitively high. Political feasibility includes factors, such as whether the assumed extent of participation in emission reduction efforts across countries (or economic sectors) is plausible and whether the time required to develop institutions that would facilitate this participation is reasonable. Finally, social feasibility refers to whether measures to control emissions would be acceptable to society, for example after taking into account their implications for equity or for non-climate environmental consequences.

IAMs can account for several of these factors by representing inertia of technological and social systems. Examples include assumptions about the maximum feasible technology penetration rates, maximum cost, feasibility of specific system configurations, and maximum speed of behavioural changes.

The results of IAMs are, therefore, helpful in informing our view on feasibility and, hence, are the primary source of quantitative information used in this assessment. However, it should be noted that they do not set "hard laws" on feasibility. On the one hand, they are based on our *current* understanding of technological and economic constraints, which could change; therefore the range of emission pathways considered feasible could shrink or expand over time. For instance, the models do not include the possibility of the development of "game-changing" new technologies currently unforeseen. On the other hand, feasibility also depends on societal and political factors that are not typically considered in IAMs (Bosetti et al. 2010, Ha-Duong et al. 1997, Ha-Duong and Treich 2004). Recently, IAM studies have explored the influence of participation of different countries in model comparison studies (Clarke *et al.* 2009) and this could reduce the range of pathways considered feasible.

One important factor determining the maximum emission reduction rate is the lifetime of machinery and infrastructure: this can be decades or even centuries for building stock and urban infrastructure; around 40 years for power stations; 20 to 40 years for manufacturing equipment; up to 20 years for heating devices; and 10 to 20 years for passenger vehicles, but much longer for transport infrastructure (Philibert 2007). These lifetimes are critically important, if mitigation strategies aim to avoid premature replacement of capital and the high costs associated with it. For illustration, carbon dioxide emissions from energy and industry would decline by about 3 per cent per year if no new emission-producing infrastructure were to be built (adapted from Davis et al. 2010). In the assessed IAM literature on mitigation scenarios, the highest average rate of total emission reduction over the next 4 to 5 decades is about 3.5 per cent per year (den Elzen et al. 2010)[25].

To put this in context, a global CO_2 emission reduction rate of 3 per cent would require a rate of decrease in emissions per unit of GDP (or decarbonization rate) of almost 6 per cent for an assumed annual rate of global GDP growth of 3 per cent. Ranger et al. (2010) show that there is very little precedent for such high rates of emission reductions amongst the top 25 emitters. The global decarbonization rate over the 1969-2009 period was 1 per cent on average, although this was in the absence of strong international climate policies. In a society that places the highest possible priority on reducing emissions, the normal capital turnover rate could possibly be increased. However, some studies suggest that higher annual reduction rates of up to about 6 per cent per year are possible for a limited time in certain circumstances, but only when the conditions have been put in place for rapid investment in decarbonization of the energy sector (e.g. Edenhofer et al. 2009). The feasibility of achieving emission reduction rates of 3 per cent or more per year for CO_2 emissions from energy and industry is highly uncertain, given political and societal constraints and the fact that emission reductions are not likely to be distributed evenly across nations.

Lastly, it should be noted that most of the pathways consistent with the temperature limits in this report include negative global emissions of CO_2 from energy and industry beginning in the 2060s and 2070s. Understanding the feasibility of negative emissions is therefore crucial for assessing the chances of meeting the 2° C and 1.5° C temperature limits: if negative emissions of a significant scale are not possible, then our options for meeting the targets are significantly constrained. Global net negative emissions occur when the removal of CO_2 from the atmosphere due to anthropogenic activities is greater than the anthropogenic emissions into it. One way to achieve this (and assumed by many IAMs) is through the implementation of bioenergy combined with carbon capture and storage (BECCS). This involves using large amounts of biomass to generate energy, and then capturing and safely storing underground or elsewhere CO_2 released by combustion. Since biomass takes up CO_2 from the atmosphere in the course of its growth, and since the CO_2 taken up is stored underground, BECCS in effect removes CO_2 from the atmosphere (Azar et al. 2010). Direct air capture of CO_2 and other technologies may also lead to negative emissions, but are currently not included in IAMs. The feasibility of large scale bioenergy systems, whether used in conjunction with CCS or not, is related to factors such as availability of land and water, impacts on biodiversity, and biomass productivity.

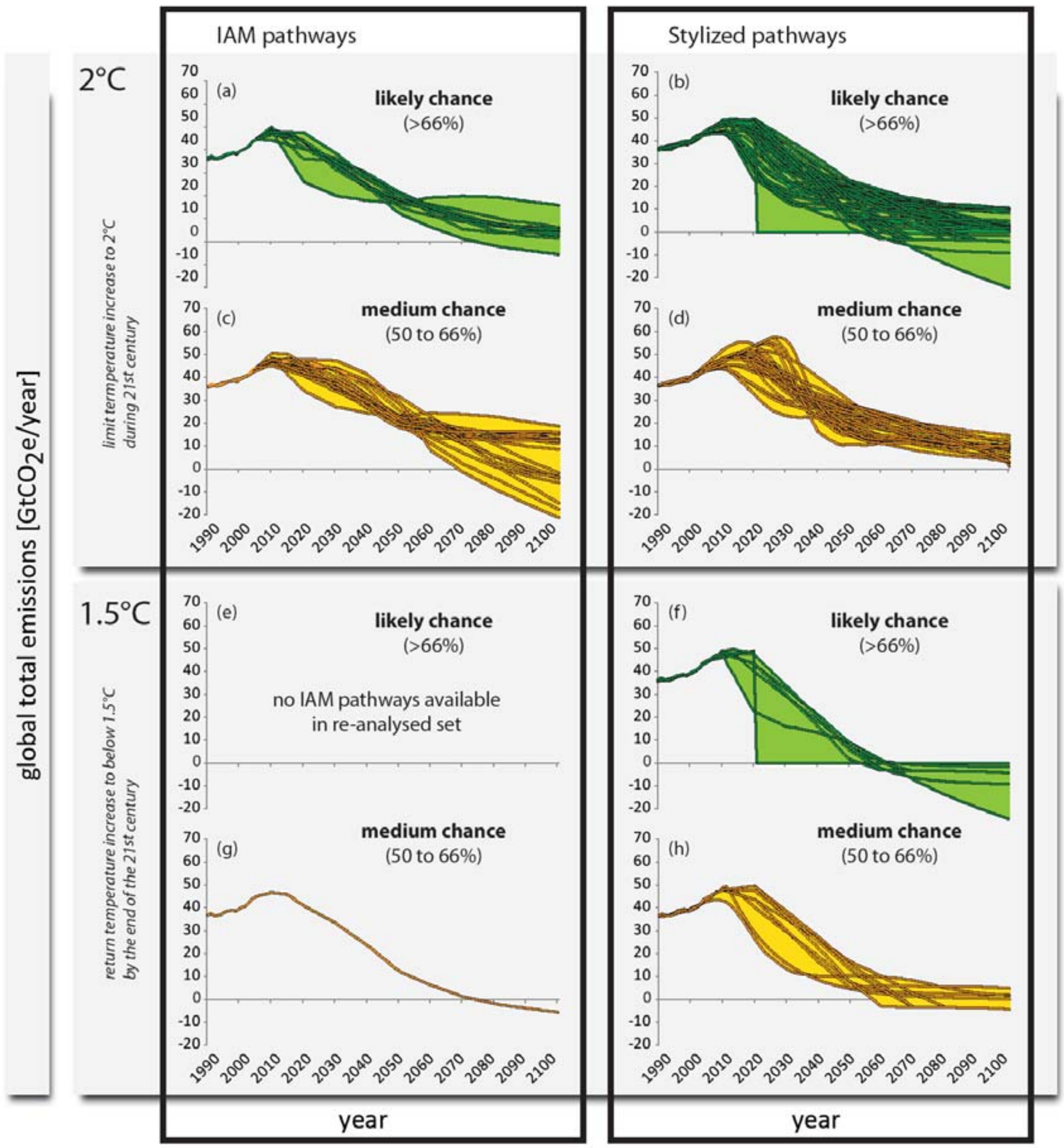
2.4 WHAT EMISSION PATHWAYS AND EMISSION LEVELS IN 2020 ARE CONSISTENT WITH 2° C AND 1.5° C LIMITS?

This section explains how the re-analysed IAM pathways relate to 2020 emission levels, and how these levels relate to the subsequent evolution of pathways that are consistent with the 2° C and 1.5° C temperature limits. Findings from "stylized" pathways are also discussed, because they add to our understanding of emission pathways consistent with temperature

25 In our set of re-analysed IAM pathways, the fastest reduction rate of energy and industrial emissions is 3.6 per cent (O'Neill et al. 2009). In this report, we usually refer to reduction rates of energy and industrial carbon dioxide emissions, rather than *total* emission reduction rates.

limits. It is shown that expected levels of global emissions in 2020 carry important information for policymakers about the feasibility, scale and magnitude of actions required afterwards to limit global temperature increase.

Figure 1: Overview of global greenhouse gas emissions in $GtCO_2e$/year of IAM emission pathways (panels a, c, e and g at the left) and "stylized" emission pathways (panels b, d, f and h at the right). These are pathways that have been re-analysed in this assessment and that meet the 1.5° and 2° C temperature limits with a particular probability. The area in between the pathways is shaded for clarity. Green pathways meet the temperature limits with a "likely" chance (greater than 66 per cent) (panels a, b, e and f) and orange/yellow pathways with a "medium" chance (50 to 66 per cent) (panels c, d, g and h). The methods used to produce the Figure are detailed in Box 2a. Note that these are global *total* emissions (land use, energy and industry). Later in the chapter we refer to negative emissions of CO_2 from energy and industry only, hence the discrepancy between the number of pathways showing negative emissions in this chart and in Table 1



Box 2a: Method for identifying emission pathways

For the purpose of this assessment we collected a total of 223 emission pathways. Of these 126 were IAM emission pathways published by 15 modelling groups[26], of which 113 explored low greenhouse gas concentration targets while taking into account some assumptions about technological and socio-economic inertia, whereas the remaining 13 represent scenarios without strong mitigation policy. These IAM pathways had varied rates of emission reductions across regions, sectors and gases in order to minimise costs. Of the 223 pathways, 97 were "stylized" pathways[27] which did not make assumptions about technological and economic feasibility, but identified the emission pathways that corresponded to particular temperature targets based on carbon cycle and climate models.

We have evaluated the probability of each of the pathways meeting a 2° C and 1.5° C limit. In order to make results more comparable, we have adjusted the pathways so that they have the same emission levels in 2000 and 2005. Emissions for these years were taken from the multi-gas emissions inventory developed as part of the "Representative Concentration Pathways" (RCPs) scenario exercise (Granier et al. submitted, Meinshausen et al. submitted). When a particular pathway lacked the emissions of a particular substance (e.g. sulphate aerosols, organic carbon, black carbon or atmospheric ozone precursors), these data were taken from the RCP3-PD scenario (van Vuuren et al. submitted). It should be noted that the RCP-3PD scenario assumes strong environmental policies and this is consistent with the aim of this report to identify mitigation pathways that stay within a 2° C or 1.5° C limit. Ozone depleting substances controlled by the Montreal Protocol are assumed to follow a gradual phase-out during the twenty-first century.

The temperature calculations of the harmonised emission pathways were made more comparable by using a single model MAGICC 6.3 (Meinshausen et al. 2009, Meinshausen et al. 2008) to calculate the probabilistic temperature outcome up to 2100 for each emission pathway.

A joint probability distribution of the most important climate response uncertainties has been used, with climate sensitivity uncertainties closely reflecting the estimate provided by the IPCC (IPCC 2007c)[28].This distribution gives the probability of a particular response of temperature to emissions. Because a probability distribution rather than a single number is used for the climate sensitivity factor, temperature outcomes are expressed in terms of probabilities, for example, "emission pathways with a medium chance of staying below a 2° C limit". The emission pathways were put into different categories according to temperature limits (1.5° and 2° C), their probability of meeting the limit (50-66 per cent, greater than 66 per cent), the assumed technologies (e.g. negative emissions or not), and whether they are "stylized" or IAM pathways.

We also performed a sensitivity analysis by analysing 11 recalibrated versions of the climate model to explore alternative values of the climate sensitivity distribution that have been published (see Meinshausen et al. 2009). For emission pathways that give around a "medium" chance of meeting a 2° C limit during the twenty-first century, the sensitivity studies lead to a spread in the median projected temperature of only ±0.2° C.

It is important to note that although we have harmonised the pathways for comparability, some uncertainties remain, for example, about future levels of anthropogenic aerosols, soot and organic carbon.

---

26 Studies underlying the IAM emission pathways can be found in the literature (Clarke et al. 2007, Clarke et al. 2009, Edenhofer et al. 2009, Edenhofer et al. 2010, Fujino et al. 2006, IPCC 2007a, O'Neill et al. 2009, Riahi et al. 2007, Smith and Wigley 2006, van Vuuren et al. 2007, Wise et al. 2009).

27 Studies underlying the "stylized" pathways are found in the literature (Bowen and Ranger 2009, den Elzen et al. 2007, Lowe et al. 2009, Meinshausen et al.2009, Ranger et al. 2010, Rogelj et al. 2010a, Rogelj et al. 2010b, Schaeffer and Hare 2009), as well as the methodology used in this report for possible complementary pathways (Meinshausen et al. 2006).

28 The climate sensitivity distribution used for the analysis throughout this report is the "illustrative default" case as described in Meinshausen et al. (2009).

The climate model used in this study has previously been validated and shown to credibly reproduce observed climate changes when driven by historic emissions or forcings. However, like other climate models it does not include all of the physical processes that could affect the real climate in future. For instance, there is no treatment of extra carbon release from melting permafrosts.

Our quantitative assessment of IAM pathways found a notable number and range of emissions that are consistent with the temperature limits of interest in this report, even after re-analysis. In the text we focus on the median and range of the “majority of results”, with the range corresponding to the 20th to 80th percentile of outcomes. Results at either end of this range are not necessarily invalid or incorrect, and are also discussed in the text.

Assessment of the pathways consistent with 2° C

Of all IAM emission pathways that were included in our quantitative assessment, 9 were found to have a “likely” chance (greater than 66 per cent) of limiting warming to less than 2° C above pre-industrial levels. The results of our quantitative assessment (Table 1) show that the majority of emission pathways with a “likely” chance of meeting the 2° C limit show the following characteristics:

- A peak in global greenhouse gas emissions before 2020 and in general earlier in the decade;
- 2020 global greenhouse gas emission levels of 44 $GtCO_2e$ (median), with a range[29] of 39-44 $GtCO_2e$[30];
- Average annual reduction rates of CO_2 emissions from energy and industry between 2020 and 2050 of around 3 per cent (range of 2.2-3.1 per cent)
- 2050 global emissions that are 50-60 per cent below their 1990 levels; and
- In most cases, negative CO_2 emissions from energy and industry beginning in the 2060s to 2070s[31].

A further 18 IAM pathways were found to have a “medium” chance (50-66 per cent) of staying below a temperature increase of 2° C. The 2020 emission levels are similar (median 45 $GtCO_2e$, range 42-46), while the emission reduction rate between 2020 and 2050 is lower (2.5 compared with 3 per cent per year), Half of these “medium” chance pathways involve net negative CO_2 emissions from energy and industry, beginning between the mid-2050s and mid-2070s[32].

[29] Ranges here, and in the following text, refer to the “majority of results”, that is, between the 20th and 80th percentile of results, unless otherwise specified.

[30] Note, these are rounded numbers. If numbers with one decimal place were shown it would be apparent that the upper end of the range is above slightly above 44 and the median slightly below. The fact that both the median and the upper end of the range round to 44 indicates that many of the estimates were close to 44.

[31] 2 of the 9 scenarios do not rely on negative CO_2 emissions from energy and industry to meet the 2° C limit and are associated with low 2020 emission levels of 26 and 36 $GtCO_2e$. Note that Figure 1 does not depict this level of negative emissions since that figure shows global *total* emissions rather than CO_2 emissions from energy and industry, which are described here.

[32] Note that Figure 1 does not depict this level of negative emissions since that figure shows global *total* emissions rather than CO_2 emissions from energy and industry, which are described here.

In general, “medium” chance pathways for 2° C differ from “likely” chance pathways either by having higher emission levels in 2020 but the same rates of emission reductions afterwards, or having the same emission levels in 2020 but slower reduction rates afterwards. “Likely” chance pathways also rely more often on negative emissions.

The re-analysed set of “stylized” pathways (not included in Table 1) shows that, if emissions ranged up to 50 $GtCO_2e$ in 2020, average reduction rates of up to 4 per cent per year would be needed in the 2020-2050 period to meet the 2° C limit (Rogelj et al. 2010b, Schaeffer and Hare 2009)[33]. The high end of these reduction rates is currently not found in the IAM literature. These pathways also require large negative emissions in the second half of this century to meet the temperature limit.

Another important message from analysing IAM emission pathways is that they suggest that it is economically and technologically feasible to achieve substantial emission reductions. This implies that it is possible to reach emission levels consistent with a 2° C target (i.e. approximately 44 $GtCO_2e$ in 2020).

To have a higher confidence of staying below a 2° C limit, it seems essential to deploy negative emission technologies (to reduce CO_2 from energy and industry) in the second half of the century, that is, unless emission levels are significantly below 44 $GtCO_2e$ in 2020.

Assessment of the pathways consistent with 1.5° C

None of the IAM or “stylized” pathways in this assessment lead to temperature increases below 1.5° C throughout this century. One IAM study published by Magné et al. (2010) depicts an emission pathway with a “medium” chance of achieving the 1.5° C target by the end of the century and has 2020 emissions of 41 $GtCO_2e$. These results suggest that after a small (0.1° C) transient overshoot of the temperature limit of about half a century, the temperature increase by the end of the twenty-first century could be brought back to below 1.5° C with a “medium” chance. In general, the IAM pathways that meet the 2° C limit with a “likely” chance also meet the 1.5° C target by 2100 but with a lower probability of 30 per cent (range 27-35 per cent for the 20th-80th percentile) and with a median temperature peak at some point in the twenty-first century of between 1.6° C and 1.7° C.

A few studies have used stylized pathways to explore the achievement of a 1.5° C limit in more detail (Ranger et al. 2010, Schaeffer and Hare 2009). The stylized pathways included in this assessment suggest that limiting warming to 1.5° C by 2100 (with a “medium” to “likely” chance) means 2020 emission levels of 40 to 48 $GtCO_2e$ (20th-80th percentile range), and reduction rates of 3 to 5 per cent per year in the 2020-2050 period (Schaeffer and Hare 2009). These pathways would also employ negative CO_2 emissions in the second half of this century. As discussed in Section 2.3, the feasibility of achieving such high emission reduction rates is difficult to assess and they are not found in the current literature of IAM results.

[33] In the literature, two studies of “stylized pathways” have explicitly focused on the question of emission pathways consistent with the 2° C limit (Bowen and Ranger 2009 and Meinshausen et al. 2009).

Table 1: Re-analysis results of IAM pathways with 2° C characteristics.

2° C pathways	Number of pathways	Peak year period*	2020 total emission levels ($GtCO_2e$)**		Average energy and industry CO_2 reduction rate from 2020 to 2050 (% of 2000 levels / yr)		Decade in which global energy and industry CO_2 emissions turn negative	
			Median	Range***	Median	Range***	Median	Range***
"Likely" chance (greater than 66 per cent) of staying below 2° C during twenty-first century								
Without negative CO_2 emissions from energy and industry	2	2010-20	**31**	26-36	**0.9**	0.6-1.2	**N/A**	N/A
With negative CO_2 emissions from energy and industry	7	2010-20	**44**	41-{44-44}-48	**3.0**	2.8-{2.9-3.2}-3.2	**2070**	2050-{*2060-2070*}-2080
Full IAM set	9	2010-20	**44**	26-{39-44}-48	**3.0**	0.6-{2.2-3.1}-3.2	**N/A**	N/A
"Medium" chance (50 to 66 per cent) of staying below 2° C during twenty-first century								
Without negative CO_2 emissions from energy and industry	9	2010-20	**44**	34-{42-45}-48	**2.4**	0.8-{2.2-2.7}-3.1	**N/A**	N/A
With negative CO_2 emissions from energy and industry	9	2010-20	**45**	41-{42-46}-48	**2.5**	1.3-{2.3-3.2}-3.6	**2060**	2050-{*2050-2060*}-2070
Full IAM set	18	2010-20	**45**	34-{42-46}-48	**2.5**	0.8-{2.2-3.0}-3.6	**N/A**	N/A

* Because IAM pathways provide emissions data only for 5-year or 10-year increments, the encompassing period in which the peak in global emissions occurs is given. The peak year period given here reflects the 20th-80th percentile range. Note that pathways with a "likely" chance show peaks earlier in the decade, whilst those with a 'medium' chance are spread across the whole decade.
** For comparison: the median of current (2010) emissions in the harmonised IAM set is 48 $GtCO_2e$.

*** Range is presented as the (minimum value - {20th percentile - 80th percentile} - maximum value). Only minimum, maximum and median values are given for the subsets with very few pathways

Results from low and high ends of emissions range in 2020

In the text we have focused on the "majority of results" of the re-analysed IAM pathway set (the median and 20th to 80th percentile range). However, results outside this range are also valid and provide useful information.

We first consider the *high end* of the range of expected emissions in 2020 represented by results from van Vuuren et al. 2007 for a "likely" chance to stay below a 2°C limit, and O'Neill et al. 2009 for a "medium" chance. At this end of the range emissions are 48 $GtCO_2e$. For a "likely" chance to achieve the temperature target, average reduction rates between 2020 and 2050 (of CO_2 emissions from energy and industry) are 3.2 per cent per year, and for a medium chance 3.6 per cent per year[34]. These set the upper range of emissions and reduction rates.

34 The seemingly counterintuitive difference in reduction rates is explained by the different shape of the post 2020 emission pathways. Van Vuuren et al. (2007) show emissions declining shortly after 2020 and hence have a lower rate of reduction with a high likelihood of limiting temperature increase than O'Neill et al. (2009), which decline later but faster and deeper.

The *low end* of the range shows that relatively low emission reduction rates between 2020 and 2050 are sufficient to reach the temperature limit, if 2020 emission levels are at the low end of the range. Some pathways, for example in Barker and Scrieciu (2010) and Clarke et al. (2009), indicate 2020 emission levels of 26-36 $GtCO_2e$. These results suggest that it may be technologically and economically feasible to reduce global emissions by 2020 by substantially more than the majority of IAM pathways assume.

Box 2b. Overshooting of 2° C Temperature limits

Model results show that temperature trends could overshoot and then drop again below temperature limits as a result of natural "sinks" acting to gradually reduce the atmospheric burden of the greenhouse gases over time. However, since this process occurs slowly, it is expected that once temperatures overshoot a target, they will take decades to drop below the target (Lowe et al. 2009). This process could be accelerated if negative CO_2 emissions were achieved as discussed earlier (Azar et al. 2006, Azar et al. 2010).

Overshoot pathways often arise in three different contexts: (1) deliberate policy choice to minimise mitigation costs; (2) failure to meet certain emission targets or goals; or (3) late participation by all major emitters in global mitigation efforts (Clarke et al. 2009, van Vliet et al. 2009). While deliberate overshoot may minimise mitigation costs over time, it does run the risk of lock-in of further fossil fuel use and thereby limiting the rate at which emissions can decline in subsequent years.

In the assessed IAM pathway set, four pathways have a temporary temperature overshoot before dropping below 2° C again. [35]. All of these pathways have global negative CO_2 emissions to help achieve the target. In these pathways the constraint on 2020 emissions is relaxed slightly, and the peak is postponed to 2020 and beyond.

Delayed action may have economic benefits (as noted above), but also has risks associated with the higher, albeit temporary, temperatures. These include higher mitigation costs over the long term and later and larger damages from climate change impacts. Huntingford and Lowe (2007) argue that there are significant risks from exceeding temperature limits during overshoot scenarios, due to uncertainty about so-called tipping points. An additional risk of overshooting temperature limits is that positive feedbacks, not known in advance, might result in a larger temperature increase than anticipated.

2.5 GAPS IN KNOWLEDGE AND FURTHER WORK

The ability to assess pathways consistent with specific temperature limits depends on understanding both the climate system and the global energy system, as well as the ways in which each responds to change over time.

Important uncertainties exist in our understanding of the climate system. We have accounted for some of this uncertainty by examining the probability of meeting particular temperature limits. Future shifts in the underlying probability distributions, as a result of improved understanding of parameters and/or feedbacks in the climate system, could change the expected probability with which a certain pathway would meet a specified temperature limit. There is also much uncertainty around the issue of how rapidly temperatures may be reduced after overshooting, and the reversibility of associated climate system changes.

[35] In addition to the 27 of the 126 IAM pathways that are able to meet the 2° C limit during the twenty-first century without a temperature overshoot and with a probability higher than 50 per cent.

Our understanding of the feasibility of pathways is also incomplete. Many of the pathways assessed here were not designed to specifically investigate the limits to feasible emission reductions, and none of the studies were designed explicitly to explore the full range of emissions in 2020 that would be consistent with long-term temperature limits. Research specifically targeted to address these questions would improve our understanding of which pathways can feasibly achieve temperature targets.

In addition, emission pathways now considered infeasible could become feasible if variables such as population growth rate, consumption of energy, aerosol emissions, economic growth and technological developments turn out to be different from the assumptions used in current studies. Other factors could also make emission pathways feasible such as the willingness of society to take "extreme" action by retiring energy infrastructure before the end of its useful lifetime, or by making significant lifestyle changes. Similarly, the pathways thought to be feasible in this report could in practice be unachievable, if, for example, participation in mitigation efforts was limited across sectors and countries, or if technological and socio-economic barriers were more severe than expected.

Given these uncertainties, it will be crucial over time to re-evaluate the emission pathways consistent with particular temperature limits and to inform the policy community accordingly.

3. What are the expected global emissions in 2020?

***Lead authors**: Niklas Höhne, Chris Taylor*

***Contributing authors**: Claudine Chen, Rob Dellink, Michel den Elzen, Jørgen Fenhann, Claudio Gesteira, Kelly Levin, Emanuele Massetti, Caspar Olausson, Murray Ward, Zhao Xiusheng*

3.1 INTRODUCTION

Nearly 140 countries have associated themselves with the Copenhagen Accord and over 80 countries, representing about 80 per cent of global emissions, have appended targets (Annex I countries) and/or mitigation actions (non-Annex I countries). The aim of this chapter is to assess the published analyses and to explore what these targets and actions (collectively referred to as "pledges")[36] are likely to lead to in terms of 2020 emissions[37]. Three appendices to this Chapter are available online[38]. Appendix 1 provides detail on the differences between the four cases and the uncertainties around them. Appendix 2 provides a country-by-country analysis of the pledges of the largest emitting countries. Appendix 3 compares the modelling groups' findings and details the adjustments made to their data to ensure consistent comparisons. Chapter 4 then goes on to combine these results with those of the previous chapter on emission pathways in order to assess the extent to which these pledges are consistent with a 2° C or 1.5° C pathway.

Estimating 2020 emissions, based on countries' pledges or submissions to the Copenhagen Accord, is not a simple task. This Chapter explains in detail that it involves *inter alia*: information on the historical, current and future growth of countries' emissions; interpretations in the cases in which countries have submitted a range of pledges; assumptions on the precise meaning of those pledges where countries have not been specific; and uncertainties in the underlying data used by modelling groups.

Therefore, we separate the emission estimates that are driven by distinct policy choices, either nationally or in the negotiations, from what is driven by different modelling assumptions. We first present the results of this analysis and then move on to explore the modelling uncertainties around them.

---

36 Please note that the pledges incorporated in the Copenhagen Accord in early 2010 have not changed through the 2010 negotiations' cycle

37 Whilst this assessment focuses on the pledges submitted to the Copenhagen Accord, in one instance, for Indonesia, modelling groups have analysed a conditional pledge announced by the President but not included in the Copenhagen Accord submission. The impact of that pledge is included in the two conditional pledge cases presented in this Chapter.

38 www.unep.org/publications/ebooks/emissionsgapreport

3.2 GLOBAL AGGREGATE EMISSIONS RESULTING FROM THE PLEDGES

For this assessment, the analyses of 13 modelling groups have been reviewed[39]. Of these, nine groups have performed a global analysis and four have focused on either Annex I or a subset of other countries. These groups have made different assumptions about how the conditionality of pledges plays out in global emissions. Hence, adjustments have been made to the various estimates, in order to facilitate a meaningful comparison. The adjustments made are briefly explained in Box 3a and detailed in the appendices available online[40]. The aim has been to construct a set of pledge cases with estimates of different 2020 emission levels.

Box 3a: Explanation of the four pledge cases and calculation method

In this chapter we have constructed four distinct pledge cases that could result from different policy choices of Governments or from different outcomes of the negotiations. These four cases are combinations of the following two interdependent factors:

Unconditional versus conditional pledges: We have distinguished between countries' unconditional and conditional pledges. Several industrialized countries have made pledges conditional on actions from other countries or the passing of domestic legislation, and developing countries' pledges are often conditional on finance or technology transfer. We have made common assumptions as to whether a country's pledge is deemed conditional or not (detailed in Appendix 2) and applied that to all modelling groups' estimates. We have then summed the estimates to create a global total, which also includes international transport emissions. Note that where a country does not have an unconditional pledge (e.g. Canada, Japan, US and South Africa) the business-as-usual estimate for that country is assumed for the unconditional case reflected in Figure 2. [41]

"Lenient" versus "strict" rules: We have adjusted these results to take into account the maximum[42] impact of two unresolved issues in the negotiations: LULUCF accounting and the use of surplus emissions units. These issues have the potential to displace mitigation action in other sectors and thus lead to higher global emissions in 2020. The adjustments made are based on a review of existing literature and are reflected in the two "lenient" pledge cases (the "strict rules" cases do not include any impact from these issues). Specifically, for LULUCF accounting we have applied a maximum expected impact of 4.2 per cent of 1990 Annex I emissions annually in 2020 (approximately 0.8 $GtCO_2e$). We assumed that credits of this magnitude would be given for carbon removals from existing forests or other sinks that would have occurred without further policy interventions (see Box 3b). For surplus emissions units, we have made two adjustments: the first for the expected impact of surplus emissions units "carried over" or "banked" from the first commitment period and used in the next. We have applied the maximum expected impact of 1.3 $GtCO_2e$ on 2020 emissions. The second adjustment is to account for any new surplus units that are expected to be generated in the next commitment period as a result of the pledges from Russia, Ukraine and Belarus remaining above business-as-usual. The expected impact of these depends on the modelling assumptions of each

39 Namely: Climate Action Tracker (CAT) by Ecofys, Climate Analytics and PIK; Climate Interactive (the C-ROADS model); Climate Strategies; FEEM (the WITCH model); IIASA (the GAINS model); Grantham Research Institute (LSE); OECD (the ENV-linkages model); PBL Netherlands Environmental Assessment Agency (the FAIR model); Peterson Institute for International Economics (PIIE); Project Catalyst; the AVOID research programme (led by the Met Office Hadley Centre); UNEP Risoe; and the World Resources Institute (WRI).

40 www.unep.org/publications/ebooks/emissionsgapreport

41 Given that these countries are implementing and/or planning some domestic policies, this is a very cautious assumption (e.g. for the USA see Bianco and Litz (2010)).

42 A maximum impact is taken in order to show an upper bound for what 2020 emissions could be under these cases.

group and ranges up to 1 $GtCO_2e$ in 2020.[43] A more detailed description of these issues and adjustments is available in Appendix 1.

In order to make consistent comparisons across modelling groups, we have had to adjust the global emission estimates of some groups to ensure that all sectors and countries are covered. In the case where data were missing (e.g. international transport emissions), we have added the median value of other modelling groups' data. In addition, in order to ensure a consistent comparison with the results from Chapter 2 we have harmonised the data for the same 2005 emissions used in that chapter. These adjustments result in slightly different emission levels for each of the groups compared with those included in their publications. Appendix 3 provides more detail on the differences between modelling groups' findings and the adjustments made.

In Figure 2 we show median results for each case to reflect the clustering of results from modelling groups. In the text we report the 20th and 80th percentile range to reflect the majority of the results.

To estimate emissions expected in 2020 we have to make assumptions about the policy choices of governments. Since these choices are uncertain we specify four different cases, each giving a different combination of choices (Box 3a). The results for emissions are as follows (and are summarised in Figure 2):

As a reference point, without pledges global greenhouse gas emissions may increase from 45 $GtCO_2e$ in 2005 to around 56 $GtCO_2e$ in 2020 (with a range[44] of 54-60 $GtCO_2e$) according to business-as-usual projections.

– *Case 1 – "Unconditional pledges, lenient rules"*: this case would occur if countries stick to their lower-ambition pledges and are subject to "lenient" accounting rules. By this we mean that Annex I countries maximise the use of surplus emission units and "lenient LULUCF credits" (see Box 3b) to meet their targets.. In this case, the median estimate of emissions in 2020 is 53 $GtCO_2e$ per year, with a range of 52-57 $GtCO_2e$.

– *Case 2 – "Unconditional pledges, strict rules"*: This case would occur if countries stick to their lower-ambition pledges and are subject to "strict" accounting rules. By this we mean that the use of surplus units and "lenient LULUCF credits" is assumed to be zero. In this case, the median estimate of emissions in 2020 is 52 $GtCO_2e$, with a range of 50-55 $GtCO_2e$.

– *Case 3 – "Conditional pledges, lenient rules"*: This case would occur if countries moved to their higher-ambition pledges (as conditions are either met or relaxed), but are subject to "lenient" accounting rules (as explained in case 1 above). This case was included because some of the more ambitious pledges of Annex I countries are conditional on some use of these credits or carry-over of surplus units (e.g. European Union, Russia). In this case, the median estimate of emissions in 2020 is 51 $GtCO_2e$, with a range of 49-53 $GtCO_2e$.

– *Case 4 – "Conditional pledges, strict rules"*: This case would occur if countries moved to their higher-ambition pledges, and are subject to "strict" accounting rules

43 Note that in computing the emissions for the "lenient" cases we have applied the adjustments noted in this box for LULUCF accounting and surplus emission units. H owever, if those adjustments resulted in Annex I emissions being higher than their business-as-usual projections then we capped emissions at that level. Hence the adjustments noted in this box are not additive.

44 Henceforth, in this chapter all ranges refer to the 20th-80th percentile, unless otherwise specified.

(as explained in case 2 above). In this case, the median estimate of emissions in 2020 is 49 $GtCO_2e$, with a range of 47-51 $GtCO_2e$.

It is worth noting that there is the possibility of higher global emissions if international offsets are counted towards both industrialized and developing countries' pledges (the so-called "double counting" of offsets). It should also be noted that in some countries the impact of existing domestic policies or national plans could lead to lower emissions than the conditional pledges submitted to the Copenhagen Accord. International climate finance could also leverage further mitigation and lower emissions. All these issues have been analysed and found to have a significant effect on 2020 emissions. However, they are not included in any of these cases but are discussed as additional factors in Section 3.4 below.

From the analysis of these four cases it is interesting to note that the international policy options being discussed in the UNFCCC negotiations, and inherent in these cases, can significantly reduce the level of emissions in 2020. The most ambitious of the cases (case 4) is expected to be 7 $GtCO_2e$ lower than business-as-usual emissions (range of 6-9 $GtCO_2e$ lower).

For Annex I countries, in the least ambitious case ("unconditional pledges, lenient rules"), emissions are estimated to be 6 per cent above 1990 levels (range of 1-12 per cent above) or equivalent to business-as-usual emissions in 2020. In fact, in many cases the use by Annex I countries of surplus units and "lenient LULUCF credits" provides more overall emission units than needed. This could result in higher emissions after 2020 if those units were to be banked for use in the following period.

In the most ambitious case ("conditional pledges, strict rules"), Annex I emissions in 2020 are expected to be 16 per cent below 1990 levels (range of 15-18 per cent below) and 20 per cent below business-as-usual emissions (range of 17-26 per cent).

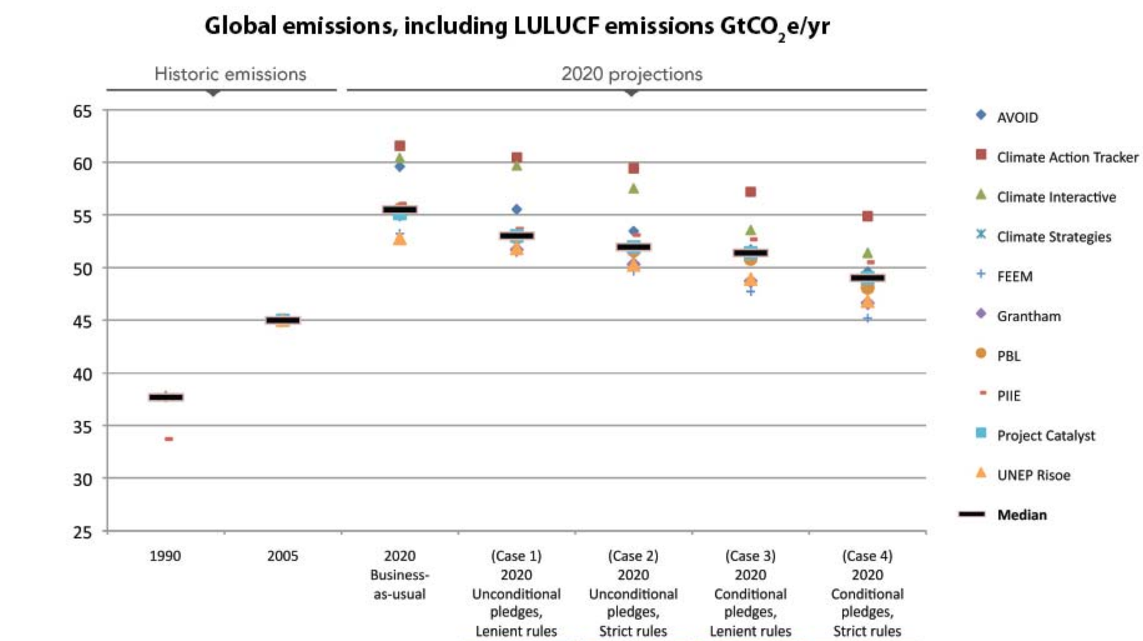
For non-Annex I countries, in the least ambitious case ("unconditional pledges") emissions are estimated to be 7 per cent lower than business-as-usual emissions (range of 6-8 per cent lower). In the most ambitious case ("conditional pledges"), non-Annex I emissions are 9 per cent lower than business-as-usual (range of 8-9 per cent lower).

This implies that the aggregate Annex I countries' emission goals are less ambitious than the 25-40 per cent reduction by 2020 (compared with 1990) suggested in the IPCC Fourth Assessment Report (IPCC 2007a). Collectively the non-Annex I countries' goals are less ambitious than the 15-30 per cent deviation from business-as-usual which is also commonly used as a benchmark (den Elzen and Höhne 2008, 2010). Whilst these values are helpful as a benchmark, it should be noted that, as described in chapters 2 and 4, various other emission pathways are consistent with the 2° C and 1.5° C temperature limits.

The cases presented in Figure 2 will be taken forward into the next chapter, which compares global emissions projections for 2020 with the emission pathways associated with limiting temperature rise to 2° C or 1.5° C. There are many possible combinations of the uncertainties considered in the preceding section that may lead to different 2020 emissions. However, the four cases presented above represent a reasonable summary of the potential low and high ambition outcomes that may be associated with the pledges.

Several options exist for policymakers to influence the final global 2020 emission level by delivering on their highest announced ambition and ensuring that accounting rules do not displace mitigation, and by finding ways to deliver further ambition either domestically, through finance or in sectors not currently covered.

Figure 2. Global emissions resulting from the four pledge cases, as found by different modelling groups



	1990	2005	2020 Business-as-usual	(Case 1) 2020 Unconditional pledges, Lenient rules	(Case 2) 2020 Unconditional pledges, Strict rules	(Case 3) 2020 Conditional pledges, Lenient rules	(Case 4) 2020 Conditional pledges, Strict rules
n[3]	4	9	9	9	9	9	9
High	37.9	45.0	61.6	60.6	59.4	57.2	54.9
80th	37.8	45.0	59.9	57.1	55.1	53.0	50.9
Median	37.7	45.0	55.5	53.0	51.9	51.4	49.0
20th	36.1	45.0	54.3	51.8	50.3	48.8	46.7
Low	33.7	45.0	52.8	51.4	49.7	47.7	45.2

All emissions in this figure and chapter refer to $GtCO_2e$ (gigatonnes or billion tonnes of carbon dioxide equivalent)—the global warming potential-weighted sum of the six Kyoto greenhouse gases, that is, CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, including LULUCF CO_2 emissions.
n = number of studies; High = maximum of full range; Low = minimum of full range; 20th-80th = 20th and 80th percentile values of the range
1. The data presented in the table have been harmonised to a common emissions level in 2005 (45 $GtCO_2e$) in order to make these data more comparable to results in Chapter 2.
2. The range in 1990 emissions stems from the use of different data sources and assumptions especially for non-Annex I countries.
3. In the set of studies examined in this report, nine modelling groups have analysed the impact of pledges at the global level, while four have analysed only a subset of countries.

3.3 ANALYSIS OF DIFFERENCES BETWEEN ESTIMATES

The range between modelling groups' estimates can be split into three categories:

1) Differences between the four pledge cases,
2) Differences between estimates for the same pledge case, and
3) Other factors that could affect emissions

More detail on each of these issues and, where appropriate, the sources of estimates can be found online[45] in Appendix 1. Figure 3 summarises the impact of these differences on the emissions of the four pledge cases, together with the further uncertainties described in the next section.

1) Differences between the four pledge cases

The four cases presented in Figure 2 are characterised by different assumptions on the conditionality of both Annex I and non-Annex I countries' pledges, LULUCF accounting rules and on the use of surplus units from the first commitment period and the possible creation of new surplus in the future. An overview of the impact of these assumptions is provided below – Appendix 1 has more details:

Unconditional versus conditional pledges

If countries were to move from unconditional to conditional pledges global emissions would be around 2-3 $GtCO_2e$ lower (with a range of estimates of 2-5 $GtCO_2e$). This breaks down as follows (numbers in parentheses show the annual 2020 emission reductions associated with moving from case 1 to 3 or from case 2 to 4 in Figure 2):

- Conditionality of Annex I (industrialized) countries (0 to -2.7 $GtCO_2e$)[46]: A significant number of Annex I countries have made pledges that are conditional on the actions of others or on the passing of domestic legislation. In some instances, countries also have unconditional pledges that will be implemented even if those conditions are not met.
- Conditionality of non-Annex I (developing) countries (0 to -0.7 $GtCO_2e$)[47]: As was the case for the Annex I countries, some non-Annex I countries have included a range in their submissions, with the upper end of the range often being conditional on climate finance.

"Lenient" versus "strict" rules

If the rules in the negotiations regarding the use of LULUCF credits and surplus emission units were to be set in a "strict" rather than "lenient" manner, emissions could be around 1-2 $GtCO_2e$ lower. This breaks down as follows (numbers in parentheses show the maximum possible increase in annual 2020 emissions reflected in the "lenient" cases)

- LULUCF accounting rules (0 to +0.8 $GtCO_2e$): The accounting rules that determine the extent to which LULUCF activities in Annex I countries could be used to meet their respective targets for the period after 2012 are still being negotiated. Most proposals in the negotiations would limit the number of "lenient LULUCF credits" by using historical or reference level baselines (see Box 3b).

[45] www.unep.org/publications/ebooks/emissionsgapreport

[46] 2.7 $GtCO_2e$ is the median estimate of the studies. It does not exactly match the 2-3 $GtCO_2e$ reflected in the median estimate of Figure 2 due to the distribution of the sample for global emissions. See Appendix 1 for details.

[47] 0.7 $GtCO_2e$ is the median estimate of the studies. It does not exactly match the 1-2 $GtCO_2e$ reflected in the median estimate of Figure 2 due to the distribution of the sample for global emissions. See Appendix 1 for details.

– Surplus emission units

- Carry-over of surplus units from the first commitment period (0 to +1.3 $GtCO_2e$): Surplus emission units can arise due to some countries exceeding their targets in the first commitment period. Countries with surplus units can also "bank" them and use them for meeting their target in a following commitment period post-2012, or sell them to other countries for their compliance.

- Creation of new surplus units in a possible second commitment period: (0 to +1.0 $GtCO_2e$)[48]: Further surplus emission units can occur through some countries being allocated emission units significantly above the estimated business-as-usual level in a possible second commitment period. These units can be used by countries to meet their targets, or sell to other countries for their compliance.

It should be noted that the above issues are interdependent and will result in different emission reductions depending on the order in which they are implemented. Hence the numbers presented above cannot simply be added together and are, therefore, not easily traceable to the median results reflected in Figure 2 above[49]. In the reviewed studies, the total impact from these options (if taken together) would be a reduction in global emissions of 4 $GtCO_2e$ (reflected in the move from Case 1 to 4 in the table), with a full range across studies of 3-8 $GtCO_2e$.

Box 3b: Further explanation of LULUCF accounting in "lenient" and "strict" rules

LULUCF accounting systems should provide credits for proven CO_2 removals from new or enhanced sinks as a result of further policy intervention. Credits for such activities would result in CO_2 removals from the atmosphere that could contribute to meeting, and thus should be counted towards, targets[50].

The "strict" rules cases developed in this chapter reflect situations in which LULUCF credits such as those described above are provided. For calculation purposes, the quantity of LULUCF credits is set to zero in these cases – although some credits could occur. This is accurate because the resulting target emission level is the same and therefore it is not necessary to estimate the possible quantity of these LULUCF credits.

In the "lenient" case, on the other hand, we assume that credits are given for CO_2 removals by sinks that are expected to occur anyway in the absence of additional policy (e.g. from forests existing prior to 1990). Given that these direct-human induced emission removals are anyway part of the baseline emissions,[51] the use of such credits would increase the estimate of 2020 global emissions. In this assessment we call such credits *"lenient LULUCF credits"*. Specifically, we assume that "lenient LULUCF credits" of up to 0.8 $GtCO_2e$ per year in 2020 could be generated in the "lenient" cases shown in Figure 2. See Appendix 1 for details.

---

48 Note that only some modelling groups have analyzed this, so for many groups the assumed impact of this is zero. These groups assume that no extra units are assigned for targets above business-as-usual. However, of the six modelling groups that did analyse this, estimates suggest that it could have as much as a +1 $GtC0_2e$ impact in 2020 (in the conditional pledge cases) – see Appendix 1 for more detail.

49 The distribution of the sample also complicates this, making it difficult to trace the numbers back to Figure 2.

50 For the same emission target these credits would allow correspondingly higher emissions in other sectors compared to the situation in which such LULUCF credits were not used to meet the target. In this case, from a global accounting sense, the final net emission level would be the same, assuming that target is met (i.e. would have a "net-zero" effect on the target)

51 Or are considered by carbon cycle models as CO_2-uptake by the terrestrial biosphere in response to elevated CO_2 concentrations

2) Differences between estimates for the same pledge case

Figure 2 shows that there is sometimes a large difference between modelling groups' estimates of the same cases. The main reasons for these differences are described below and, where possible, the uncertainty that each implies for 2020 global emissions. Numbers in parentheses give the range of 2020 emission estimates in Figure 2 that could be attributed to each of these reasons.

- LULUCF emissions (±4 $GtCO_2e$): Global emissions from LULUCF are subject to a high level of uncertainty, which the IPCC estimates to be ±4 $GtCO_2e$. There is particular uncertainty around anthropogenic emissions from peat lands. Lastly there is an uncertainty around how modelling groups treat the LULUCF emissions from Annex I countries, in particular. LULUCF emission uncertainty may be partially reflected in the range of estimates from different modelling groups.
- Baseline emissions (-3.4 to +2.4 $GtCO_2e$): Modelling groups have used different assumptions regarding non-Annex I countries' business-as-usual emission projections and Annex I countries' base year emissions (e.g. whether LULUCF CO_2 is included or not). Moreover, the quantification of emission reductions due to carbon intensity targets (measured as improvement in emissions per unit of GDP) poses additional uncertainties.
- Non-covered sectors and countries (-1.1 to +2.7 $GtCO_2e$): There is often a significant range in the emissions estimates for sectors not included under national pledges, such as emissions from international aviation and maritime transport (bunkers) and for countries without pledges. The results from different studies will vary, since some have explored the impact of mitigation policies of only a subset of countries.

3) Other factors that could affect emissions

There are_a number of other factors not reflected in the range of estimates under each of these cases, but which could have a large impact on 2020 emissions. Modelling groups have generally not factored these issues into their central estimates for emissions resulting from the pledges—although many of the groups have estimated the impact of these issues separately. These factors include the following. Numbers in parentheses give the maximum annual 2020 emissions impact on the four cases:

- Double counting of offsets (0 to +1.3 $GtCO_2e$): The potential for double counting of offsets towards both industrialized and developing country pledges, is a major source of uncertainty not reflected in Figure 2. This could occur if industrialized countries use offsets to meet their targets and that these same offsets also counted towards developing country pledges. A simple estimate of the risk of double counting can be made by assuming that 33 per cent of the deviation of Annex I emissions from business-as-usual is covered by offsets and that all of those are also counted towards non-Annex I goals. This would lead to emissions being around 1.3 $GtCO_2e$ higher (as compared to the “conditional pledge, strict rules” case)[52]

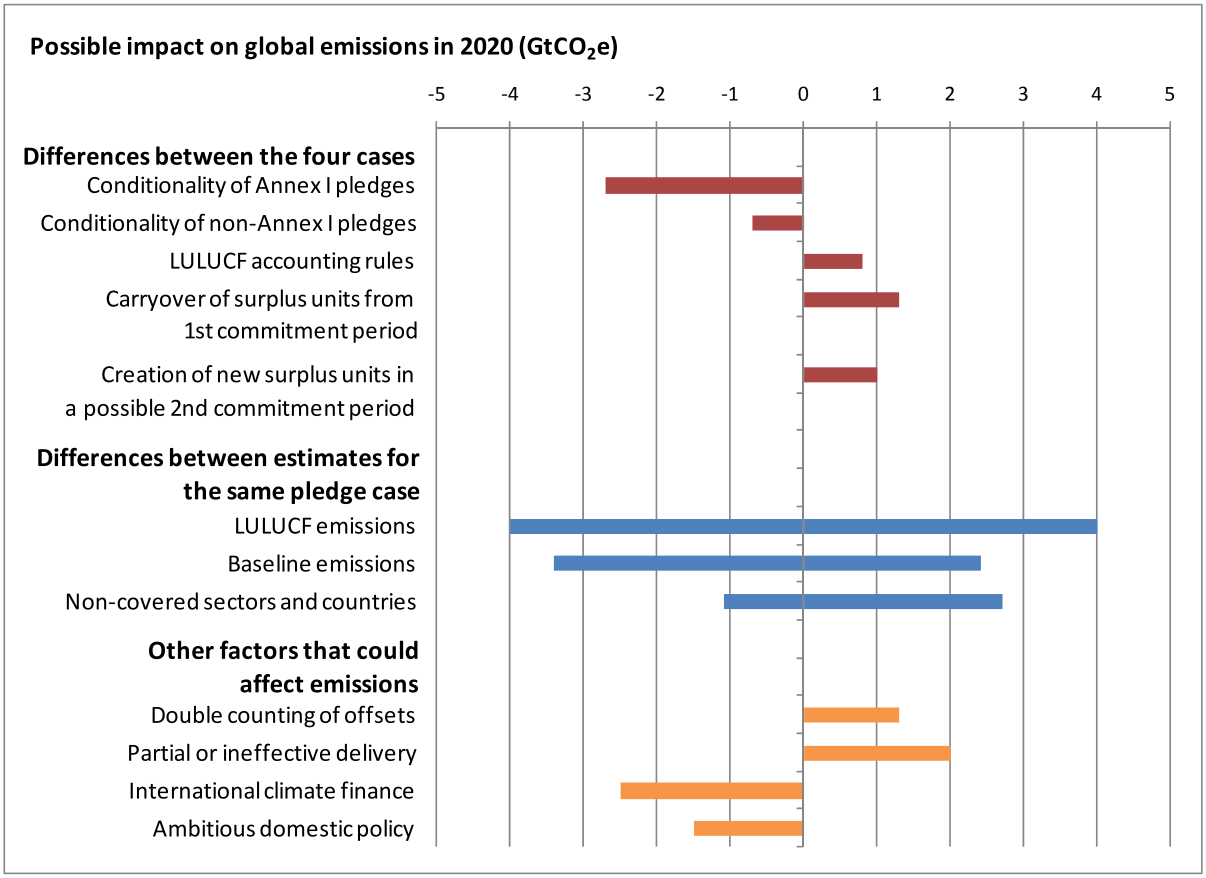
– Partial or ineffective delivery (0 to +2.0 $GtCO_2e$): Any failure to carry out policies would undermine national efforts and lead to higher 2020 emissions; this would push countries’ emissions back towards business-as-usual. Conversely, well-designed policies that spur innovation and investment could mean that goals are exceeded. All analyses covered in Figure 2 assume that countries will meet their targets. A crude assessment of the risk of partial implementation can be made by assuming that a certain proportion of the deviation from global business-as-usual is not delivered. Using 25 per cent would lead to estimates of 2020 emissions around 2.0 $GtCO_2e$ higher than in Figure 2 (as compared to the ”conditional pledge, strict rules” case).

– International climate finance (0 to -2.5 $GtCO_2e$): International climate finance could leverage further emission reductions beyond the conditional pledges of countries or in countries that have not yet specified mitigation actions. The upper bound of -2.5 $GtCO_2e$ is found by a study that assumes that 25 per cent of Copenhagen Accord financing in 2020 will be used for additional mitigation actions (Carraro and Massetti, 2010).

– Ambitious domestic policy (0 to -1.5 $GtCO_2e$): Certain countries have domestic plans that include mitigation actions that some analysts estimate to be more ambitious than the Copenhagen Accord pledges. The three modelling groups that have analysed this issue estimate that this could lead to emissions being up to 1.5 $GtCO_2e$ lower than the Copenhagen Accord pledges would suggest.

[52] Note also that if offset credits are provided for activities that are not “additional” to expected baselines, even higher total emissions would result.

Figure 3: Summary of the maximum impact of differences and uncertainties on global 2020 emissions. There is a strong interaction between these factors and the effects are therefore not additive. Hence, no estimate of their total impact is given.



Box 3c: Under what circumstances would the Copenhagen Accord pledges lead to a peak in global emissions before 2020?

Most of the emission pathways consistent with a likely chance of meeting the 2º C limit show emissions peaking before 2020 (see Chapter 2). Hence, peaking is an important indicator of whether pledges are consistent with the 2º C limit.

Making an assessment of whether global emissions peak between now and 2020 requires understanding of where the emissions will be in 2020, as well as their trajectory in the interval between now and then. If the emissions in 2020 are close to or below current levels, then it is possible that emissions will peak over this period. Estimates of current (2009) emission levels are around 48 $GtCO_2e$ (Manning et al. 2010). Since only the most ambitious of the pledge cases comes close to current levels, we expect that this pledge case is the one most likely to result in a peak in emissions before 2020. By contrast, the least ambitious pledge case ("unconditional pledges, lenient rules") results in a strong increase in emissions and is therefore the least likely to peak before 2020.

It should be noted that, it is also possible that emissions could peak before 2020, but still remain significantly above current levels in 2020. This could occur, for example, if the emission reduction policies are only introduced or start to take significant effect towards the end of this decade. However, it is difficult to assess the likelihood of this from the pledges alone.

4. What is the emissions gap?

***Lead authors**: Michel den Elzen, Keywan Riahi*

***Contributing authors**: William Hare, Niklas Höhne, Mikiko Kainuma, Jiang Kejun, Chris Taylor, Zhao Xiusheng*

4.1 INTRODUCTION

This section assesses the potential “emissions gap” between expected emissions based on country pledges and emission levels in 2020 consistent with 2° and 1.5° C limits. For this purpose, we build upon the results in chapters 2 and 3.

As pointed out in Chapter 2, the emission levels consistent with temperature limits depend on the desired likelihood of meeting particular limits, the feasible pace of emission reductions post 2020, and the availability of technology to achieve, for example, negative emissions (Chapter 2, Table 1).

It was explained in Chapter 3 that expected emissions in 2020 depend on whether unconditional or conditional pledges are followed and on the outcome of a number of issues under negotiation, in particular that of LULUCF accounting and surplus emission units (Chapter 3, Figure 2). Given the uncertainty of both expected emissions and emission levels consistent with temperature limits, we do not make a single estimate of the potential gap. Instead, we assess the likely range of the gap based on combinations of assumptions about both expected emissions and emission levels corresponding to temperature targets[53].

4.2 FINDINGS FOR 2° C

Table 2 summarises the gaps that result from four different interpretations of how the pledges are followed, and for a “likely” (greater than 66 per cent) and a “medium” (50-66 per cent) chance of staying below 2° C.

In Chapter 2 it was shown that emission levels of 44 $GtCO_2e$ in 2020 (range of 39-44 $GtCO_2e$)[54] are consistent with a “likely” chance of limiting global warming to 2° C.

In Chapter 3, four pledge cases or possible negotiation outcomes were identified. Here we compare the gap in 2020 between expected emissions based on these cases and emission levels identified in Chapter 2. As a reference point, business-as-usual emissions in 2020 would result in a gap of 12 $GtCO_2e$ (range of 10-21 $GtCO_2e$).

– *Case 1 – “Unconditional pledges, lenient rules”*. Countries implement their lower-ambition pledges and maximise the use of “lenient LULUCF credits”[55] and surplus emissions units to meet their goals. In this case, the gap is 9 $GtCO_2e$ with a range of

53 However, it is important to note that the results in Chapter 2 do not take into account some other important sources of uncertainty, such as the effects in the future of different potential levels of anthropogenic aerosols—these may also affect the assessment of the gap.

54 As in previous chapters, this and following ranges refer to the 20^{th} and 80^{th} percentile of results, unless otherwise specified.

55 Credits given for carbon removals from existing forests or other sinks that would have occurred without policy intervention and are likely to be included in the baseline of models.

8-18 $GtCO_2e$. The unconditional pledges would thus reduce the gap by about 20 per cent compared to business-as-usual.

– *Case 2 – "Unconditional pledges, strict rules".* Countries implement their lower-ambition pledges but do not use "lenient LULUCF credits" and surplus emission units to meet their goals. In this case, the gap narrows to 8 $GtCO_2e$ (range of 6-16 $GtCO_2e$). Compared to business-as-usual, this is equivalent to achieving about 30 per cent of the overall mitigation effort towards 2° C by 2020.

– *Case 3 – "Conditional pledges, lenient rules".* Countries implement their higher-ambition pledges and make maximum use of "lenient LULUCF credits" and surplus emissions units. In this case, the gap is reduced to 7 $GtCO_2e$ (range of 5-14 $GtCO_2e$). Compared to business-as-usual, this is equivalent to achieving about 35 per cent of the overall mitigation effort towards 2° C by 2020.

– *Case 4 – "Conditional pledges, strict rules".* Countries not only implement their higher-ambition pledges, but also do not use "lenient LULUCF credits" and surplus emission units to meet their goals. The result is a further narrowing of the gap to 5 $GtCO_2e$ (range of 3-12 $GtCO_2e$). This corresponds to the smallest gap assessed in Table 2, and is equivalent to reducing the overall mitigation effort towards 2° C by almost 60 per cent compared to business-as-usual in 2020. As a point of reference, the remaining gap is about the level of emissions in the European Union in 2005 or from the world's road transport in that same year.

Hence, moving from (lower-ambition) unconditional pledges to (higher-ambition) conditional pledges narrows the gap by about 2 to 3 $GtCO_2e$—the majority of this reduction would come from industrialized countries, whose pledges are sometimes conditional on the ambitious action of other countries or on domestic legislation. A smaller, but still important, part of the reduction would come from developing countries, whose pledges are sometimes conditional on the adequate provision of international climate finance or technology transfer.

In addition, the gap can be reduced by around 1 to 2 $GtCO_2e$ by ensuring that "strict" rules apply to the use of LULUCF credits and surplus emission units. If industrialized countries apply "strict" accounting rules to minimise the use of what we refer to as "lenient LULUCF credits", they would strengthen the effect of their pledges and thus reduce the emissions gap by up to 0.8 $GtCO_2e$. Likewise, if the rules governing the use of surplus emission units under the Kyoto Protocol were designed in a way that would avoid the weakening of mitigation targets, the gap could be reduced by up to 2.3 $GtCO_2e$. These include units carried over from the current commitment period and any potential new surpluses created in the next. See Chapter 3 for more details[56].

There are also a number of important factors, mentioned in Chapter 3, that could increase or decrease the gap and that are not included in these cases. The double counting of international offsets towards both industrialized and developing countries' goals could reduce the overall amount of mitigation and thus increase the gap by up to 1.3 $GtCO_2e$. Conversely, the implementation of ambitious existing national plans, beyond what is included in the Copenhagen Accord, could narrow the gap by up to 1.5 $GtCO_2e$ (as compared to the fourth pledge case).

[56] Note that the 0.8 and 2.3 $GtCO_2e$ numbers indicate the maximum possible impact expected from these issues and cannot simply be added together. The median impact of moving from "lenient" to "strict" accounting rules is found to be 1-2 $GtCO_2e$. See Chapter 3 for more details.

To have a *"medium"* rather than a *"likely"* chance of staying below 2° C, the emission levels for the pledge cases can be about 1 $GtCO_2e$ higher, and the corresponding gap 1 $GtCO_2e$ lower for all pledge cases (Table 2).

Explanation of the range of results of the emissions gap for 2° C

The range of the gap presented for the different cases in Table 2 is based on the "majority of results" (20^{th} to 80th percentile) across both the pledges and the 2° C emission levels. The upper bound estimate of the gap combines low 2° C emission levels (20th percentile) with high emissions from pledges (80th percentile). As explained in Chapter 2, emission levels consistent with the 2° C limit tend to be lower in 2020 when followed by comparatively slower emission reduction rates thereafter, or when negative emissions are not achieved over the long run.

Conversely, at the low end of the gap range we find a combination of higher 2° C emission levels in 2020 and low expected emissions as a result of the pledges. Emission levels that are consistent with 2° C tend to be higher in 2020 when reduction rates are comparatively high after 2020 (3.1 per cent per year) and/or it is assumed that negative emissions take effect over the long run. Under these conditions, emissions can afford to be higher in 2020, since they will be reduced more quickly afterwards.

The size of the gap is therefore strongly dependent on expectations about emission reduction rates after 2020 and the prospects for negative emissions later in the century. Both depend, of course, on the rate of technological development.

In addition, the reader will note that the range around median estimates is not symmetric; the lower bound extends by about 1-2 $GtCO_2e$ below the median, whereas the upper bound rises 7-9 $GtCO_2e$ above it (for a "likely" chance). This is found for all the pledge cases examined and arises because of the skewed distribution of pledge estimates with a more pronounced tail on the upper bound. One interpretation of this skewed range is that the gap may in reality tend to be on the higher side of the median.

This chapter has so far focused on the "majority of results" (20^{th} to 80th percentile of estimates). Results outside this range indicate that emission levels for a "likely" chance of staying below 2° C could be as high as 48 $GtCO_2e$ (Chapter 2), while at the same time expected emissions under case 4 ("conditional pledges, strict rules") could, according to one estimate, be as low as 45 $GtCO_2e$ in 2020. Under these conditions, no gap exists. On the other hand, looking at the other end of the range, we find 2° C emission levels for a "likely" chance of staying below the 2° C limit can range as low as 26 $GtCO_2e$, while the highest estimate of emissions under case 1 of the pledge cases ("unconditional pledges, lenient rules") is 61 $GtCO_2e$, resulting in a gap as high as 35 $GtCO_2e$.

4.3 FINDINGS FOR 1.5° C

There is no emission pathway in the assessed IAM literature of Chapter 2 that achieves the 1.5° C limit with a "likely" (greater than 66 per cent) chance and only one study in this literature depicts an emission pathway consistent with a medium (50-66 per cent) chance of meeting the 1.5° C limit (Magné et al. 2010). The IAM pathways assessed that meet the *2° C* limit with a "likely" chance suggest, however, that after a small (0.1-0.2° C) transient overshoot of the 1.5° C target, the temperature increase by the end of the twenty-first century could drop below 1.5° C, *but with a lower probability.* These pathways reach the 1.5° C target in the long-term with a median probability of 30 per cent (range of 27-35 per cent).

Reaching 1.5° C with these lower probabilities would thus leave a similar emissions gap in 2020 as the one for a “likely” chance for 2° C. However, having a “likely” chance of reaching the 1.5° C target would require higher rates of emission reductions after 2020 (and correspondingly high rates of technological development and deployment) than those reported in the IAM literature.

Table 2. The global gap (in $GtCO_2e$ per year) between emission levels for staying below 2° C (with a “likely” (greater than 66 per cent) and a “medium” (50-66 per cent) chance) and expected emissions as a result of the Copenhagen Accord pledges. All estimates in this table are derived from the results of chapters 2 and 3. Values in bold correspond to medians, and numbers in brackets correspond to 20th to 80th percentile of estimates. Numbers in italics give the adjusted 2020 emission levels for expected emissions from the pledges and emission levels from the pathways.

Pledge case	"Likely" chance (>66%) to stay below 2°C *(2020 emissions: 44 [39-44])*		"Medium" chance (50 to 66%) to stay below 2°C *(2020 emissions: 45 [42-46])*	
Business as usual *2020 emissions: 56 [54-60])*	**12**	[10-21]	**11**	[8-18]
Unconditional pledge, Lenient rules *(2020 emissions: 53 [52-57])*	**9**	[8-18]	**8**	[6-15]
Unconditional pledge, Strict rules *(2020 emissions: 52 [50-55])*	**8**	[6-16]	**7**	[4-13]
Conditional pledge, Lenient rules *(2020 emissions: 51 [49-53])*	**7**	[5-14]	**6**	[3-11]
Conditional pledge, Strict rules *(2020 emissions: 49 [47-51])*	**5**	[3-12]	**4**	[1-9]

4.4 CONCLUSIONS

We have seen in this chapter that a global emissions gap is likely between expected emissions as a result of the pledges and emission levels consistent with the 2° C limit in 2020. But our analysis of options for implementing the Copenhagen Accord pledges has also shown that this gap could be narrowed through any of the following policy options[57]:

1. *Implement conditional pledges:* If all countries were to move to their conditional (high ambition) pledges, it would significantly narrow the 2020 emissions gap towards 2° C. The gap would be reduced by about 2 to 3 $GtCO_2e$, with most of the emission reductions coming

[57] Note that options 1 and 2 are non-additive as their impact depends on the order in which they are implemented. We find that the median impact of these two options together is 4 $GtCO_2e$ in 2020 (shown by moving from the “unconditional pledges, lenient rules” case to the “conditional pledges, strict rules” case) with a 20th to 80th percentile range across groups of 4-6 $GtCO_2e$

from industrialized countries and a smaller, but important, share coming from developing countries. This would require that conditions on those pledges be fulfilled. These conditions include expected actions of other countries as well as the provision of adequate financing, technology transfer and capacity building. Alternatively it would imply that conditions are relaxed or removed.

2. *Minimise the use of "lenient LULUCF credits" and surplus emission units*: If industrialized countries applied strict accounting rules to minimise the use of "lenient LULUCF credits" and avoided the use of surplus emissions units for meeting their targets, they would strengthen the effect of their pledges and thus reduce the emissions gap in 2020 by about 1 to 2 $GtCO_2e$ (with up to 0.8 $GtCO_2e$ coming from LULUCF accounting and up to 2.3 $GtCO_2e$ from surplus emissions units[58]).

3. *Avoid double-counting of offsets:* Double-counting of offsets could lead to an increase of the gap of up to 1.3 $GtCO_2e$, depending on whether countries implement their unconditional or conditional pledges (there is likely to be greater demand for offsets in the higher-ambition, conditional case). Hence avoiding double-counting could be an important policy option.

4. *Implement measures beyond current pledges:* The scenarios assessed in Chapter 2 indicate that it is technically possible to reduce emissions beyond present national plans in 2020. These scenarios show that the gap could be closed, and that emission levels consistent with 2° C could be achieved through the implementation of a wide portfolio of mitigation measures, including energy efficiency and conservation, renewables, nuclear, carbon capture and storage, non-CO_2 emissions mitigation, hydro-electric power, afforestation and avoided deforestation.

5. *Lay the groundwork for faster emission reduction rates after 2020:* Emission pathways consistent with a 2° C temperature limit are characterized by rapid rates of emission reductions post 2020 (of greater than 2.2 per cent per year). Such reduction rates on a sustained time-scale would be unprecedented historically. Therefore it is critical to lay the groundwork now for faster post 2020 emission reductions, for example, by avoiding lock-in of high-carbon infrastructure with long lifespans, or by developing and demonstrating advanced clean technologies.

---

[58] Note that the 0.8 and 2.3 $GtCO_2e$ numbers indicate the maximum possible impact expected from these issues and cannot simply be added together. The median impact of moving from "lenient" to "strict" accounting rules is found to be 1-2 $GtCO_2e$. See Chapter 3 for more details.

5. Twenty-first century temperature projections associated with the pledges

Lead authors: *William Hare, Jason Lowe, Joeri Rogelj, Elizabeth Sawin, Detlef van Vuuren*

Contributing authors: *Valentina Bosetti, Tatsuya Hanaoka, Jiang Kejun, Ben Matthews, Brian O'Neill, Nicola Ranger, Keywan Riahi*

5.1 INTRODUCTION

In the previous chapter (Chapter 4), it has been shown that, in the majority of cases, there is a gap between the 2020 emission levels expected as a result of the current pledges and the emission levels that would be consistent with either a 2° C or 1.5° C limit. For a "likely" chance of meeting the 2° C limit, the size of the gap can range between 5 and 9 $GtCO_2e$ (range of 3-18 $GtCO_2e$) depending on the pledge case under consideration.

There is also widespread interest in the implications of 2020 pledges for long-term temperature change. Because future temperature increase is highly dependent upon cumulative emissions after 2020, it is not possible to link unambiguously current pledges with a future temperature outcome or likelihood without making assumptions about post 2020 emission levels. However, it is possible to compare 2020 emissions with IAM scenarios associated with different levels of future warming. Each of these IAM scenarios result in an emission pathway consistent with assumptions about technological and economic development. These emission pathways then lead to different levels of temperature increase in the twenty-first century. Superposition of the 2020 pledge estimates on the IAM pathways provides insight into possible long term temperature trends consistent with the pledges.

5.2 PLEDGES IN 2020 AND TWENTY-FIRST CENTURY TEMPERATURES

In Figure 4, a set of 126 IAM emission pathways (see Box 2a) have been assembled that give rise to a range of likely future temperatures from below 2° C to more than 5° C. Since the emission pathways have all been generated by IAM models, the rates of decline in annual emissions in each of these scenarios are constrained by assumptions about technological and/or economic feasibility embedded in these models. Superimposed on these pathways is a bar representing the range of 2020 expected emissions derived from the pledge cases in Chapter 3.

Figure 4 shows that the range of 2020 emission levels resulting from the pledges tends to be consistent with the IAM pathways that have a likely temperature increase ranging from 2.5° C to 5° C. This is consistent with the findings in chapters 2, 3 and 4. This broad range of temperatures results from a variety of assumptions about post 2020 policy, technological and economic development.

As discussed in previous chapters, this does not mean that current pledges preclude meeting the 2° C limit. However, achieving this goal from the level of emissions resulting from the pledges would involve faster rates of decline, or greater negative emissions than included in most of the scenarios in Chapter 2. This could involve factors not assumed in the

IAM scenarios considered in this report such as development of new technologies or higher economic expenditures.

One clear implication of Figure 4 is that a "likely" chance of meeting a 2° C or 1.5° C limit will require attention to two factors:

- Implementing and strengthening 2020 emissions pledges: Implementation of the "conditional pledges, strict rules" case would bring emissions in 2020 to about 49 $GtCO_2e$ (range of 47-51 $GtCO_2e$) compared with the 44 $GtCO_2e$ (range of 39-44 $GtCO_2e$) that would give a "likely" chance of meeting the 2° C limit. Hence, strengthening the pledges would be needed in order to close the gap when considering the majority of results.
- Laying the policy and investment groundwork for faster and deeper reductions in post 2020 emissions: Since all the pathways that have a "likely" chance of achieving temperature limits show strong declines in emissions after 2020 it will be important to achieve faster and deeper emission reductions post 2020.

These conclusions also hold for a "medium" chance of meeting the 2° C limit.

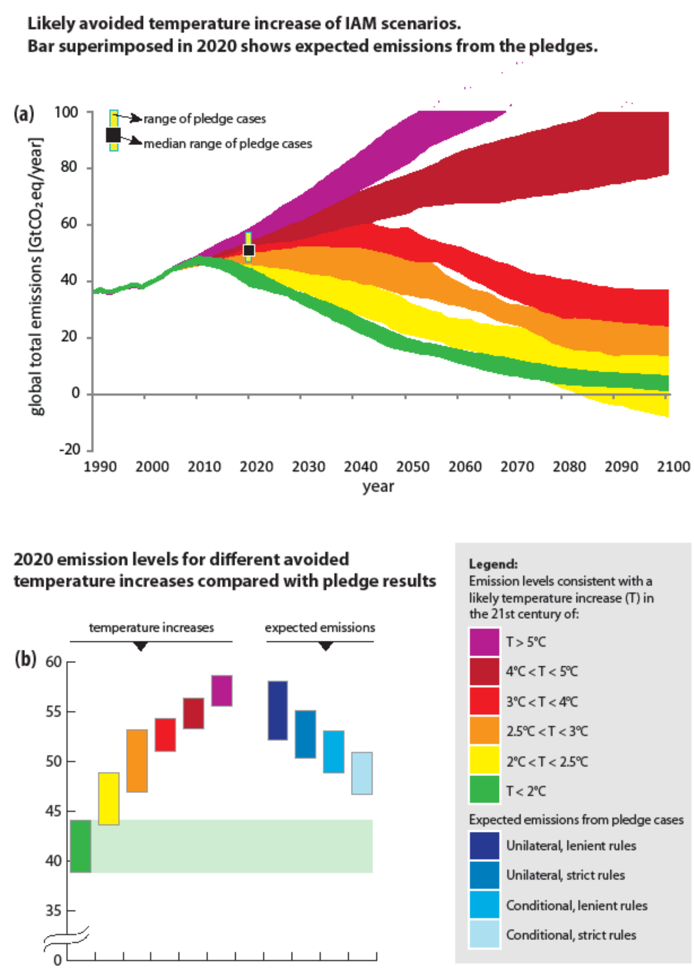


Figure 4: Temperature increases associated with emission pathways and compared to the expected emissions from the pledges

(a) Coloured bands show IAM emission pathways over the twenty-first century. The pathways were grouped based on ranges of "likely" avoided temperature increase in the twenty-first century. Emission corridors were defined by, at each year, identifying the 20th to 80th percentile range of emissions and drawing the corresponding coloured bands across the range. Wide gaps are visible between the coloured bands because most of these scenarios aim for low greenhouse gas emission targets and because only the 20th to 80th percentile of results are shown. The small black bar represents the range of the median estimates of the pledge cases from Chapter 3 in 2020. The thin blue bar represents the range from the 80th percentile of the "unconditional pledges, lenient rules" case to the 20th percentile of the "conditional pledges, strict rules" case.

(b) The coloured bars on the left hand side of this panel show the range (20th to 80th percentile) of 2020 emission levels from the IAM pathways consistent with a "likely" chance of avoiding different temperature increases—as shown in panel (a). The right hand side of panel (b) compares these emissions corridors with the 20th to 80th percentile ranges of expected emissions resulting from the four pledge cases developed in Chapter 3.

5.3 CONCLUSIONS

The majority of results in this report show that emissions in 2020 expected from the Copenhagen Accord pledges are higher than emission levels consistent with a “medium” or “likely” chance of staying below 2° C and 1.5° C. At the same time they also show that the range of 2020 emission levels from the Copenhagen Accord pledges tends to be consistent with the IAM pathways that have “likely” temperature increases of 2.5° C to 5° C up to the end of the twenty-first century.

However, this does not mean that a 2° C goal is infeasible. The IAM literature shows that it remains possible to meet the temperature limits reviewed here, but the emission reduction rates required post 2020 are at the high end of what is currently assumed in the IAM literature to be technologically and economically feasible. The IAM literature also shows that options might be limited after 2020: a full range of low-emission technologies would have to be available and broad participation in global efforts to reduce emissions would be needed (Calvin et al. 2009, Clarke et al. 2009, Krey and Riahi 2009, van Vliet et al. 2009). Pathways capable of meeting the 2° C and 1.5° C limits require significant effort to develop technologies for achieving negative CO_2 emissions from energy and industry starting shortly after mid-century.

Commencing with such fast rates of emission reduction in 2020 and maintaining them for decades will require significant changes in underlying infrastructure and policy. Thus, if it is desired to meet temperature targets, two things appear to be required: first, countries would have to increase the ambition of their 2020 pledges; and second, society would have to put in place the policy, research, and investment processes to support and sustain such a rapid decline in emissions. Rapid rates of emission reduction will also require sustained global effort and cooperation, since action by only a small subset of countries will not be enough to reach temperature targets (Calvin et al. 2009, Clarke et al. 2009, Clarke and Weyant 2009, Krey and Riahi 2009, van Vliet et al. 2009).

In order to bring emissions in line with IAM pathways that meet a 2° C limit, there is a need to not only implement current pledges fully, but also to raise the ambition of those pledges and lay the groundwork for faster and deeper reductions of post 2020 emissions. Going further in the short term and achieving stronger cuts to lower levels in 2020 would leave open more possibilities to meet temperature limits and would allow more flexibility in choosing a post 2020 pathway for global emissions.

References

REFERENCES FOR CHAPTER 2:

Allen M.R., Frame D.J., Huntingford C., Jones, C.D., Lowe, J.A., Meinshausen, M. and Meinshausen, N. (2009)."Warming caused by cumulative carbon emissions towards the trillionth tonne", *Nature* 458(7242): 1163-1166.

Azar, C., Lindgren, K., Larson, E. and Mollersten, K. (2006). "Carbon capture and storage from fossil fuels and biomass - Costs and potential role in stabilizing the atmosphere", *Climatic Change,* 74(1-3), 47-79.

Azar, C., Lindgren, K., Obersteiner, M., Riahi, K., van Vuuren, D., den Elzen, K., Möllersten, K. and Larson, E. (2010). "The feasibility of low CO2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS)", *Climatic Change,* 100(1), 195-202.

Barker, T. and Scrieciu, S. (2010). "Modeling Low Climate Stabilization with E3MG: Towards a 'New Economics' Approach to Simulating Energy-Environment-Economy System Dynamics", *The Energy Journal* 31(Special Issue): 137-164.

Bossetti, V., Carraro, C. and Tavoni, M. (2010). *Alternative Paths Toward a Low Carbon World (June 16, 2010).* FEEM Working Paper No. 62.2010; CMCC Research Paper No. 85.

Bowen, A. and Ranger, N. (2009). *Mitigating climate change through reductions in greenhouse gas emissions: the science and economics of future paths for global annual emissions.* London, UK: Grantham Research Institute for Climate Change and the Environment.

Clarke, L., Edmonds, J., Jacoby, H., Pitcher, H., Reilly, J. and Richels, R. (2007). *Scenarios of the Greenhouse Gas Emission and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.* Washington, USA: Department of Energy, Office of Biological & Environmental Research.

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S. and Tavoni, M. (2009). "International climate policy architectures: Overview of the EMF 22 International Scenarios", *Energy Economics* 31(Supplement 2): S64-S81.

Davis, S.J., Caldeira, K. and Matthews, H.D. (2010). "Future CO2 Emissions and Climate Change from Existing Energy Infrastructure". *Science* 329(5997): 1330-1333.

den Elzen, M., Meinshausen, M. and van Vuuren, D. (2007). "Multi-gas emission envelopes to meet greenhouse gas concentration targets: Costs versus certainty of limiting temperature increase", *Global Environmental Change-Human and Policy Dimensions* 17(2): 260-280.

den Elzen, M.G.J., van Vuuren, D.P. and van Vliet, J. (2010). "Postponing emission reductions from 2020 to 2030 increases climate risks and long-term costs", *Climatic Change* 99(1-2): 313-320.

Edenhofer, O., Carraro, C., Hourcade, J-C., Neuhoff, K., Luderer, G., Flachsland, C., Jakob, M., Popp, A., Steckel, J., Strohschein, J., Bauer, N., Brunner, S., Leimbach, M., Lotze-Campen, H., Bossetti, V., de Cian, E., Tavoni, M., Sassi, O., Waisman, H., Crassous-Doerfler, R., Monjon, S., Dröge, S., van Essen, H., del Río, P. and Türk, A. (2009).. *RECIPE - The Economics of Decarbonization. Synthesis Report.*

Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., Chateau, B., Criqui, P., Isaac, M., Kitous, A., Kypreos, S., Leimbach, M., Lessmann, K., Magne, B., Scrieciu, S., Turton, H. and van Vuuren, D. (2010). "The Economics of Low Stabilization: Model Comparison of Mitigation Strategies and Costs", *The Energy Journal* 31(Special Issue): 11-48.

Fujino, J., Nair, R., Kainuma, M., Masui, T. and Matsuoka, Y. (2006) "Multi-gas Mitigation Analysis on Stabilization Scenarios Using Aim Global Model". *The Energy Journal* 0(Special I): 343-354.

Granier, C., Bessagnet, B., Bond, T., D'Angiola, A., Gon, H.G.v.d., Frost, G., Heil, A., Kainuma, M., Kaiser, J., Kinne, S., Klimont, Z., Kloster, S., Lamarque, J.F., Liousse, C., Matsui, T., Meleux, F., Mieville, A., Ohara, T., Riahi, K., Schultz, M., Smith, S., Thomson, A.M., Aardenne, J.v. and Werf, G.v.d. (submitted) "Evolution of anthropogenic and biomass burning emissions at global and regional scales during the 1980-2010 period". *Climatic Change*.

Ha-Duong, M., Grubb, M. and Hourcade, J. (1997). "Influence of socioeconomic inertia and uncertainty on optimal CO_2-emission abatement", *Nature* 390(6657): 270-273.

Ha-Duong, M. and Treich, N. (2004). "Risk Aversion, Intergenerational Equity and Climate Change". *Environmental and Resource Economics* 28(2): 195-207.

Huntingford, C. and Lowe, J. (2007). ""Overshoot" Scenarios and Climate Change". *Science* 316(5826): 829b-.

IPCC (2007a). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA: Cambridge University Press.

IPCC (2007b). *Climate Change 2007: Synthesis Report*, Cambridge, UK and New York, USA: Intergovernmental Panel on Climate Change.

IPCC (2007c). *Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report.,* Cambridge, UK and New York, USA: Cambridge University Press.

Lowe, J.A., Huntingford, C., Raper, S.C.B., Jones, C.D., Liddicoat, S.K. and Gohar, L.K. (2009). "How difficult is it to recover from dangerous levels of global warming?", *Environmental Research Letters* 4(1): 014012.

Magné, B., Kypreos, S. and Turton, H. (2010). "Technology Options for Low Stabilization Pathways with MERGE". *The Energy Journal* 31(Special Issue): 83-107.

Matthews, H.D. and Caldeira, K. (2008). "Stabilizing climate requires near-zero emissions", *Geophysical Research Letters* 35(4).

Matthews, H.D., Gillett, N.P., Stott, P.A. and Zickfeld, K. (2009). "The proportionality of global warming to cumulative carbon emissions", *Nature* 459(7248): 829-832.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M. and Noda, A. (2007). "Global Climate Projections" in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., eds., *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, 747-846.

Meinshausen, M., Hare, B., Wigley, T.M.L., van Vuuren, D., den Elzen, M.G.J. and Swart, R. (2006). "Multi-gas emission pathways to meet climate targets" *Climatic Change* 75(1): 151-194.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J. and Allen, M.R. (2009). "Greenhouse-gas emission targets for limiting global warming to 2°C", *Nature* 458(7242): 1158-1162.

Meinshausen, M., Raper, S.C.B. and Wigley, T.M.L. (2008). "Emulating IPCC AR4 atmosphere-ocean and carbon cycle models for projecting global-mean, hemispheric and land/ocean temperatures: MAGICC 6.0", *Atmospheric Chemistry and Physics Discussions* 8: 6153–6272.

Meinshausen, M., Smith, S.J., Calvin, K., Daniel, J.S., Lamarque, J-F., Matsumoto, K., Montzka, S., Raper, S.C. B., Riahi, K., Thomson, A., Velders, G.J.M. and van Vuuren, D.P. (submitted). "The RCP Greenhouse Gas Concentrations and their Extensions from 1765 to 2500. *Climatic Change*.

National Research Council (2009). *Informing Decisions in a Changing Climate,* Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education, ed., Washington, DC: The National Academies Press.

O'Neill, B.C., Riahi, K. and Keppo, I. (2009). "Mitigation implications of midcentury targets that preserve long-term climate policy options". *Proceedings Of The National Academy Of Sciences Of The United States Of America* 107(3): 1011-1016.

Philibert, C. (2007). *Technology penetration and capital stock turnover: Lessons from IEA scenario analysis*. Paris: IEA.

Ranger, N., Gohar, L., Lowe, J., Bowen, A. and Ward, R. (2010). *Mitigating climate change through reductions in greenhouse gas emissions: is it possible to limit global warming to no more than 1.5°C? - Policy brief*. Grantham Research Institute.

Riahi, K., Gruebler, A. and Nakicenovic, N. (2007). "Scenarios of long-term socio-economic and environmental development under climate stabilization". *Technological Forecasting and Social Change (Special Issue: Greenhouse Gases - Integrated Assessment)* 74(7): 887-935.

Rogelj, J., Chen, C., Nabel, J., Macey, K., Hare, W., Schaeffer, M., Markmann, K., Höhne, N., Krogh Andersen, K. and Meinshausen, M. (2010a). "Analysis of the Copenhagen Accord pledges and its global climatic impacts—a snapshot of dissonant ambitions", *Environmental Research Letters* 5(3): 034013.

Rogelj, J., Nabel, J., Chen, C., Hare, W., Markmann, K., Meinshausen, M., Schaeffer, M., Macey, K. and Hohne, N. (2010b). "Copenhagen Accord pledges are paltry". *Nature* 464(7292): 1126-1128.

Schaeffer, M. and Hare, W. (2009). *How feasible is changing track? Scenario analysis on the implications of changing emission tracks after 2020, from an insufficient global deal on 2020 reductions, to 2°C and 1.5°C pathways*. The Climate Institute.

Shine, K. P., Fuglestvedt, J.S., Hailemariam, K. and Stuber, N. (2005). "Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases", *Climatic Change* 68(3): 281-302.

Smith, S.J. and Wigley, T.M.L. (2006). "Multi-gas Forcing stabilisation with the MiniCAM", *The Energy Journal.* Multi-Greenhouse Gas Mitigation and Climate Policy(Special Issue 3): 373-392.

Solomon, S., Plattner, G.K., Knutti, R. and Friedlingstein, P. (2009). "Irreversible climate change due to carbon dioxide emissions". *Proceedings of the National Academy of Sciences of the United States of America,* 106(6): 1704-1709.

van Vliet, J., den Elzen, M.G.J. and van Vuuren, D.P. (2009). "Meeting radiative forcing targets under delayed participation". *Energy Economics* 31(Supplement 2): S152-S162.

van Vuuren, D., Stehfest, E., den Elzen, M., Kram, T., van Vliet, J., Beltran, A. M., Deetman, S., Oostenrijk, R. and Isaac, M. (submitted). "RCP3-PD: Exploring the possibilities to limit global mean temperature change to less than 2°C". *Climatic Change*.
van Vuuren, D.P., den Elzen, M., Lucas, P., Eickhout, B., Strengers, B., van Ruijven, B., Wonink, S. and van Houdt, R. (2007). "Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs". *Climatic Change* 81(2): 119-159.
van Vuuren, D.P., Meinshausen, M., Plattner, G.K., Joos, F., Strassmann, K.M., Smith, S.J., Wigley, T.M.L., Raper, S.C.B., Riahi, K., de la Chesnaye, F., den Elzen, M.G.J., Fujino, J., Jiang, K., Nakicenovic, N., Paltsev, S. and Reilly, J.M. (2008). "Temperature increase of 21st century mitigation scenarios". *Proceedings of the National Academy of Sciences* 105(40): 15258-15262.
Wise, M.A., Calvin, K.V., Thomson, A.M., Clarke, L.E., Bond-Lamberty, B., Sands, R.D., Smith, S.J., Janetos, A.C. and Edmonds, J.A. (2009). "Implications of limiting CO_2 concentrations for land use and energy". *Science* 324(5931): 1183-1186.

REFERENCES FOR CHAPTER 3 (and appendices):

Baker, A. (2010). *Interpreting Emission Pledges: the Need for a Common Accounting Framework*. Climate Strategies. See www.climatestrategies.org
Bianco, N. and Litz, F. (2010). *Reducing Greenhouse Gas Emission in the United States: Using Existing Federal Authorities and State Action*. World Resources Institute. See www.wri.org.
Carraro, C. and Massetti, E. (2010). *Beyond Copenhagen: A Realistic Climate Policy in a Fragmented World*. FEEM Note di Lavoro No. 136.
Climate Interactive, Climate Scoreboard, see http://www.climateinteractive.org/scoreboard
ClimateWorks Foundation (2010). *Taking stock – the emission levels implied by the pledges to the Copenhagen Accord*. Project Catalyst Briefing paper, see www.project-catalyst.info.
Dellink, R., Briner, G. and Clapp, C. (2010). *Costs, Revenues, and Effectiveness of the Copenhagen Accord Emission Pledges for 2020*. OECD Environment Working Papers, No. 22, OECD Publishing. http://dx.doi.org/10.1787/5km975plmzg6-en
den Elzen, M.G.J., Hof, A.F., Mendoza Beltran, A., Roelfsema, M., van Ruijven, B.J., van Vliet, J., van Vuuren, D.P., Höhne, N. and Moltman, S. (2010a). *Evaluation of the Copenhagen Accord: Chances and risks for the 2°C climate goal*. Netherlands Environmental Assessment Agency (PBL). Bilthoven, the Netherlands, PBL Report 500114017/2010, See www.pbl.nl\en
den Elzen, M.G.J., Roelfsema, M. and Slingerland, S. (2010b). "Dealing with surplus emissions in the climate negotiations after Copenhagen: What are the options for compromise?". *Energy Policy* 38: 6615–6628.
den Elzen, M.G.J., and Höhne, N. (2008). Reductions of greenhouse gas emissions in Annex I and non-Annex I countries for meeting concentration stabilisation targets. *Climatic Change* 91: 249–274.
den Elzen, M.G.J., and Höhne, N. (2010). "Sharing the reduction effort to limit global warming to 2°C". *Climate Policy 10*: 247–260.
Houser, T. (2010). *Copenhagen, the Accord and the way forward*. Peterson Institute for International Economics. Policy Brief 10-5. See www.iie.com/
IPCC (2007a). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA: Cambridge University Press.
Joosten, H. (2009), *The Global Peatland CO_2 Picture*. Wetlands International. See www.wetlands.org
Levin, Kelly and Bradley, R.. (2010). *Comparability of Annex I Emission Reduction Pledges*. WRI Working Paper. World Resources Institute, Washington DC. Available online at http://www.wri.org
Lowe, J.A., Gohar, L.K., Huntingford, C., Good, P., Bernie, D., Pardaens, A., Warren, R. and Raper, S. *Are the emission pledges in the Copenhagen Accord compatible with a global aspiration to avoid more than 2°C of global warming? A technical note from the AVOID programme*. Met Office Hadley Centre, Exeter, U.K. See http://ensembles-eu.metoffice.com/avoid/.
Manning, M. R., Edmonds, J., Emori, S., et al. (2010). "Misrepresentation of the IPCC CO_2 emission policy options". *Nature Geoscience* 3: 376-377.
Moltmann, S., Hagemann, M., Eisbrenner, K. and Höhne, N. (2009). *Linking national climate and sustainable development policies with the post-2012 climate regime. Proposals in the energy sector for Brazil, China, India, Indonesia, Mexico, South Africa and South Korea*. Ecofys and Wuppertal Institute. PECSDE082822 Cologne, Germany.
Point Carbon (2009). "Assigned Amount Unit: Seller/buyer analysis and impact on post-2012 climate regime". Point Carbon, see: www.pointcarbon.com.
Rogelj, J., Meinshausen, M., Nabel, J. et al. (2010), "Copenhagen Accord pledges are paltry", *Nature Report* 464: 1126-1128.

Stern, N. (2009). *Action and ambition for a global deal in Copenhagen*. Centre for Climate Change Economics and Policy Grantham Research Institute on Climate Change and the Environment in collaboration with the United Nations Environment Programme (UNEP), see www.cccep.ac.uk .

Stern, N. and Taylor, C. (2010). *What do the Appendices to the Copenhagen Accord tell us about global greenhouse gas emissions and the prospects for avoiding a rise in global average temperature of more than 2°C?*. Centre for Climate Change Economics and Policy Grantham Research Institute on Climate Change and the Environment in collaboration with the United Nations Environment Programme (UNEP), see www.cccep.ac.uk.

UNEP (2010). Information note "How Close Are We to the Two Degree Limit?", Information note for the UNEP Governing Council Meeting & Global Ministerial Environment Forum, February, 2010.

UNFCCC Secretariat (2010). Information note "Compilation of pledges for emission reductions and related assumptions provided by Parties to date and the associated emission reductions", FCCC/KP/AWG/2010/INF.2.

Wagner, F. and Amann, M. (2009). *Analysis of the proposals for GHG reductions in 2020 made by UNFCCC Annex I Parties: Implications of the economic crisis*.

WWF International (2010). *Plugging the gap: an easy guide to a safe climate future.*

REFERENCES FOR CHAPTER 4:

Magné, B., Kypreos, S. and Turton, H. (2010). "Technology Options for Low Stabilization Pathways with MERGE". *The Energy Journal* 31(Special Issue): 83-107.

REFERENCES FOR CHAPTER 5:

Calvin, K.V., Edmonds, J.A., Bond-Lamberty, B., Clarke, L.E., Kim, S.H., Kyle, G., Smith, S.J, Thomson, A.M. and Wise M.A. (2009). "2.6: Limiting Climate Change to 450 ppm CO2 Equivalent in the 21st Century"., *Energy Economics* 31(Supplement 2): S107-S120.

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S. and Tavoni, M. (2009). "International climate policy architectures: Overview of the EMF 22 International Scenarios", *Energy Economics* 31(Supplement 2): S64-S81.

Clarke, L. and Weyant, J. (2009). "Introduction to the EMF 22 special issue on climate change control scenarios", *Energy Economics* 31(Supplement 2): S63-S63.

Krey, V. and Riahi, K. (2009). "Implications of delayed participation and technology failure for the feasibility, costs, and likelihood of staying below temperature targets--Greenhouse gas mitigation scenarios for the 21st century", *Energy Economics* 31(Supplement 2): S94-S106.

van Vliet, J., den Elzen, M.G.J. and van Vuuren, D.P. (2009). "Meeting radiative forcing targets under delayed participation", *Energy Economics* 31 (Supplement 2): S152-S162.