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Bridging the Emissions Gap

A UNEP Synthesis Report

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Glossary and Acronyms

Annex I Countries The industrialized countries (and those in transition to a market economy) which took on obligations to reduce their greenhouse gas emissions under the United Nations Framework Convention on Climate Change.

Black Carbon A form of air pollution produced by incomplete combustion of fuels. It is produced especially by diesel-powered vehicles, open biomas burning, cookstoves, and other sources.

'Bottom up' model A model which represents reality by aggregating characteristics of specific activities and processes, considering technological, engineering and cost information.

Business-As-Usual A scenario used for projections of future emissions assuming no action, or no new action, is taken to mitigate emissions.

Carbon Credits Tradable permits which aim to reduce greenhouse gas emissions by giving them a monetary value.

Carbon Dioxide Equivalent A simple way to place emissions of various climate change agents on a common footing to account for their effect on climate. It describes, for a given mixture and amount of greenhouse gas, the amount of carbon dioxide that would have the same global warming ability, when measured over a specified timescale. 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.

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.

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.

Greenhouse Gases covered by the Kyoto Protocol Include the six main greenhouse gases, as listed in Annex A of the Kyoto Protocol, namely: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulphur hexafluoride (SF_6).

Integrated Assessment Models Models of climate change that seek to combine knowledge from multiple disciplines in the form of equations and/or algorithms. As such, they describe the full chain of climate change, including relevant linkages and feedbacks between socio-economic and biophysical processes.

Kyoto Protocol An international environmental treaty intended to reduce greenhouse gas emissions. It builds upon the United Nations Framework Convention on Climate Change.

Leakage Carbon leakage is defined as the increase in CO_2 emissions occuring outside of countries taking domestic mitigation action.

Lenient Rules Pledge cases with maximum Annex I "lenient LULUCF credits" and surplus emissions units.

Likely Chance A greater than 66 per cent likelihood. Used in this report to convey the probabilities of meeting temperature limits.

Medium Chance A 50 to 66 per cent likelihood. Used in this report to convey the probabilities of meeting temperature limits.

Montreal Protocol A multilateral environmental agreement dealing with the depletion of the earth's ozone layer.

Non-Annex I Countries A group of developing countries that have signed and ratified the United Nations Framework Convention on Climate Change. They do not have binding emission reduction targets.

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 of the Copenhagen Accord.

Radiative Forcing Radiative Forcing (RF) is the global mean radiation imbalance over the long-term radiation 'budget' of the earth's atmosphere from the pre-industrial period. A positive forcing warms the system, while a negative forcing cools it.

Scenario A description of how the future may unfold based on 'if-then' propositions. Scenarios typically include 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" and surplus emissions units are set to zero.

'Top down' model A model which applies macroeconomic theory, econometric and optimization techniques to aggregate economic variables. Using historical data on consumption, prices, incomes, and factor costs, top-down models assess final demand for goods and services, and supply from main sectors, such as the energy sector, transportation, agriculture, and industry.

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

BAU	Business-As-Usual
CAEP	Committee on Aviation Environmental Protection
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CFC	Chlorofluorocarbons
CO_2e	Carbon Dioxide Equivalent
COP	Conference of the Parties to the United Nations Framework Convention on Climate Change
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Gt	Gigatonne (1 billion metric tonnes)
HFC	Hydrofluorocarbon
IAM	Integrated Assessment Model
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land-Use Change and Forestry
NAMA	Nationally Appropriate Mitigation Action
UNFCCC	United Nations Framework Convention on Climate Change

Foreword

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

"There is abundant evidence that emission reductions of between 14 to 20 Gt of CO_2 equivalent are possible by 2020 and without any significant technical or financial breakthroughs needed"

Nearly 20 years after governments established the UN Framework Convention on Climate Change and 14 years following the agreement of the Kyoto Protocol, nations gather in the South African coastal city of Durban to resume the crucial climate negotiations.

Keeping average global temperature rise below 2°C has become the focus of international efforts crystallized first in Copenhagen in 2009, and reaffirmed in Cancún last year.

This report outlines how far the current commitments and pledges of developed and developing nations can take the world in terms of achieving the 2°C limit or less, and the gap that remains between ambition and reality.

The analysis presented in "Bridging the Emissions Gap" has involved an unprecedented effort of climate modelling centres world-wide convened by the UN Environment Programme (UNEP).

Last year's report - the first in this series - underlined that in order to have a likely chance of keeping within the 2°C limit this century, emissions in 2020 should not be higher than 44 Gt of CO_2 equivalent.

It suggested that if all the commitments and pledges were met in full, emissions would stand at around 49 Gt – a gap of 5 Gt needing to be bridged.

The analysis presented in this year's report indicates that the gap has got larger rather than smaller, standing at around 6 Gt by around 2020. This is because new information has been included in the analysis.

Nevertheless, the report strikes an optimistic note by showing that greater leadership and ambition can bridge the gap and dramatically increase the chances of avoiding dangerous climate change.

Indeed, there is abundant evidence that emission reductions of between 14 to 20 Gt of CO_2 equivalent are possible by 2020 and without any significant technical or financial breakthroughs needed.

This is confirmed by action across key sectors ranging from electricity production, industry and transport to buildings, forestry, agriculture and waste management. The aviation and shipping sectors also have a technical potential to contribute a further emissions reduction of about 0.3–0.5 Gt of CO_2 equivalent in 2020.

Accelerated action on, for example, Hydroflurocarbons (HFCs) and air pollutants such as black carbon, also offer important complimentary options for combating climate change in the near term while delivering multiple, Green Economy benefits with respect to improved air quality and reduced crop damage.

The window for addressing climate change is rapidly narrowing but equally the options for cost effective action have never been more abundant.

This report speaks to an emissions gap that urgently needs addressing. In doing so, it also speaks to a political and leadership gap which Durban needs to assist in bridging.

Executive Summary

Global climate policy has advanced on several fronts over the past few years and this report deals with two developments of particular importance – The readiness of countries to pledge to new emission reductions, and the agreement among countries to an important global climate target. In December, 2009, countries were encouraged to submit pledges for reducing greenhouse gas emissions for the year 2020 as part of the Copenhagen Accord. Subsequently, 42 industrialized countries and 44 developing countries submitted pledges. At the climate conference in Cancún one year later, parties formally recognised country pledges and decided "to hold the increase in global average temperature below 2°C above pre-industrial levels". They also left open the option for "strengthening the long-term global goal on the basis of best available scientific knowledge including in relation to a global average temperature rise of 1.5°C". An obvious and basic question is, to what extent will the country pledges help to meet the 2°C and 1.5°C targets?

A year ago, UNEP convened 25 scientific groups to assess this question. In their "Emissions Gap Report" released in December, 2010, the scientists reported that a gap was expected in 2020 between expected emissions and the global emissions consistent with the 2°C target, even if pledges were implemented fully. After receiving the report, policymakers requested UNEP to prepare a follow-up document which not only updates emission gap estimates, but more importantly, provided ideas on how to bridge the gap. This present report is a response to this request. To do the work UNEP has convened 55 scientists and experts from 28 scientific groups across 15 countries.

This report first reviews and summarizes the latest scientific studies of the gap. It then tackles the question – How can the gap be bridged? – by examining the question from different vantage points: From that of global integrated assessment models, from bottom-up studies of individual economic sectors, and from published work on the mitigation potential in international aviation and shipping emissions. These different perspectives provide a rich body of information on how to plausibly bridge the emissions gap in 2020 and beyond.

1. Is it possible to bridge the emissions gap by 2020?

The answer to this question is, yes. **Many different scientific groups have confirmed that it is feasible to bridge the emissions gap in 2020 between business-as-usual emissions and emission levels in line with a 2°C target.**

The gap can be bridged by making realistic changes in the energy system, in particular, by further increasing its efficiency and accelerating the introduction of renewable energies (See point 3).

From the viewpoint of different sectors of the economy, the gap can be bridged by pursuing a wide range of technically feasible measures to reduce emissions in different sectors (See point 3).

Furthermore, policy instruments to realize these emission reductions have already been applied successfully in many countries and sectors.

2. What is the emissions gap in 2020?

Although the country pledges help in reducing emissions to below a business-as-usual level in 2020, they are not adequate to reduce emissions to a level consistent with the 2°C target, and therefore lead to a gap. Estimates of this gap (6-11 $GtCO_2e$) are larger than reported in the 2010 UNEP Emissions Gap report (5-9 $GtCO_2e$) but are still within the range of uncertainty of estimates.

The size of the gap depends on the extent to which the pledges are implemented and how they are applied, what accounting rules are assigned, and the desired likelihood of staying below a particular temperature limit.

As a reference point, the gap would be about 12 $GtCO_2e$ (range: 9-18 $GtCO_2e$) between business-as-usual emissions (i.e if no pledges are implemented) and emissions consistent with a "likely" chance (greater than 66 per cent) of staying below the 2°C temperature target. This figure is nearly as large as current total greenhouse gas emissions from the world's energy supply sector.

Four cases are considered which combine assumptions about pledges (unconditional or conditional) and rules for complying with pledges (lenient or strict). (For an explanation, see footnote[1]).

Under Case 1 – "Unconditional pledges, lenient rules", the gap would be reduced to about 11 $GtCO_2e$ (range: 7-16 $GtCO_2e$) or to a rounded value[2] of 2 $GtCO_2e$ below business-as-usual (earlier estimate = 9 $GtCO_2e$).

Under Case 2 – "Unconditional pledges, strict rules", the gap would be about 9 $GtCO_2e$ (range: 6-14 $GtCO_2e$), or 3 $GtCO_2e$ below business-as-usual (earlier estimate = 8 $GtCO_2e$).

Under Case 3 – "Conditional pledges, lenient rules", the gap would also be about 9 $GtCO_2e$ (range: 6-14 $GtCO_2e$) or 3 $GtCO_2e$ below business-as-usual (earlier estimate = 7 $GtCO_2e$).

Under Case 4 – "Conditional pledges, strict rules", the gap would be about 6 $GtCO_2e$ (range: 3-11 $GtCO_2e$) (earlier estimate = 5 $GtCO_2e$). This is 6 $GtCO_2e$ lower than business-as-usual conditions, and of the same magnitude as current total greenhouse gas emissions from the world's entire transport sector. On the positive side, fully implementing the pledges halves the gap from business-as-usual conditions; in other words, brings emissions 50 per cent of the way to the 2°C target.

The gap could still be 1-2 Gt CO_2e larger if double counting of emissions reductions by developed and developing countries due to the use of the carbon market is not ruled out and if the additionality of CDM projects is not improved.

The estimate of the size of the gap has increased mostly because of two factors:

(1) some developing countries have increased the baseline to which their pledges are connected, which reduces the effect of these pledges;
(2) the Kyoto Protocol surplus emissions are estimated to be higher because of the economic recession, which reduces the effect of pledges in the "lenient rules" cases.

To stay within the 2°C limit, global emissions will have to peak soon

Emission pathways consistent with a "likely" chance of meeting the 2°C target have a peak before 2020[3], and have emission levels in 2020 around 44 $GtCO_2e$ (range: 41-46 $GtCO_2e$). Afterwards, global emissions steeply decline (an average of 2.6 % per year, with a range of 2.2-3.1 %)[4], and/or reach negative emissions in the longer term.

Accepting a "medium" (50-66 %) rather than "likely" chance of staying below the 2°C target relaxes the constraints slightly: emissions in 2020 could be 2 $GtCO_2e$ higher, and average rates of global reduction after 2020 could be 2.5 per cent per year (range 2.2-2.9 %). Nevertheless, global emissions still need to peak before 2020.

A 1.5°C target can also be met, but it won't be easy

With regards to a 1.5°C target, the 2020 emission levels with a "likely" chance of staying within the 2°C limit are about the same as those with a "medium" or lower chance of meeting the 1.5°C target. However, to meet the 1.5°C target the emission reduction rates after 2020 would have to be even faster than for a 2°C target.

To stay within the 2°C limit, global emissions in 2050 will have to be considerably lower than now

As far as emissions in 2050 are concerned, to have a likely chance of complying with the 2°C target, total greenhouse gas emissions in 2050 must be about 46% lower than their 1990 level, or about 53% lower than their 2005 level.

3. How can the gap be bridged?

The gap can be narrowed by resolving some immediate climate negotiation issues. Possible actions to narrow the gap include:

- Implementing the more ambitious "conditional" pledges. This would reduce the gap by 2-3 $GtCO_2e$
- Minimizing the use of "lenient Land Use, Land Use Change and Forestry (LULUCF) credits" and surplus emission credits. This would reduce the gap by 2-3 $GtCO_2e$
- Avoiding the double-counting of offsets and improving the additionality of CDM projects. Double-counting could increase the gap by up to 2 $GtCO_2e$.

1. In this report, an "unconditional" pledge is one made without conditions attached. A "conditional" pledge might depend on the ability of a national legislature to enact necessary laws, or may depend on action from other countries, the provision of finance, or technical support. "Strict" rules mean that allowances from LULUCF accounting and surplus emission credits will not be counted as part of a country meeting their emissions reduction pledges. Under "lenient" rules, these elements can be counted.
2. Two is computed by subtracting the unrounded numbers of Case 1 emissions (10.5, rounded to 11 in the text) from BAU emissions (12.4 rounded to 12 in text). 12.4 – 10.5 = 1.9, which is rounded to 2 in text.
3. Global annual emissions consist of emissions of the "Kyoto basket of gases" coming from energy, industry and land use.
4. 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.

Modelling studies show that it is feasible to bridge the gap: **Global integrated assessment models indicate that it is possible, with technically and economically feasible measures, to bridge the emissions gap in 2020 between business-as-usual emissions and emissions consistent with the 2°C target. In particular, intervening in the energy system can be a successful strategy for reducing emissions.**

Nine different scientific groups have used global integrated assessment models to identify low emission pathways consistent with the 2°C target. Thirteen scenarios from these groups have been reviewed in this report. All of these scenarios reduce greenhouse gas emissions to the 2020 level consistent with a 2°C target, principally by modifying the energy system. Looking across these studies, they achieve low emissions in 2020 by a combination of the following:

- Improving energy efficiency: Primary energy production is up to 11% lower than business-as-usual levels in 2020 (with one study 18% lower). The amount of energy used per unit GDP decreases around 1.1 - 2.3% per year from 2005 to 2020.
- Producing up to 28% of total primary energy from non-fossil fuel energy sources in 2020. (As compared to 18.5% in 2005).
- Producing up to 17% of total primary energy in 2020 from biomass. (As compared to about 10.5% in 2005).
- Producing up to 9% of total primary energy in 2020 with non-biomass renewable energy (solar, wind, hydroelectricity, other). (As compared to about 2.5% in 2005).
- Reducing non-CO_2 emissions up to 19% relative to business-as-usual in 2020 (with one estimate of 2%).

It is important to note that the preceding numbers are maximum values for the different mitigation options, and that different mitigation scenarios had different mixes of these options. For example, different scenarios had varying percentages of biomass and non-biomass renewable energy. In fact, every scenario had a different mix indicating that there are many pathways to bridging the gap.

Globally, the marginal costs of these packages of measures range from about US $25 to US $54 per ton of equivalent carbon dioxide removed, with a median value of US $38 per ton (with one estimate of US $15, and another of US $85).

Detailed studies of different sectors also show that it is feasible to bridge the gap: **A review of these studies confirms that pursuing a wide range of technically feasible measures can deliver more than enough emission reductions to fully close the gap between business-as-usual emissions and emissions in line with the 2°C target.**

Many 'bottom-up' studies have been carried out that articulate the potential to reduce emissions in various economic sectors. These studies differ from the analyses of global integrated assessment models by focusing on individual sectors. A review of these studies shows the following potential for reducing global emissions in 2020:

- The electricity production sector: 2.2 to 3.9 $GtCO_2e$ per year through more efficient power plants, introducing renewable energy sources, introducing carbon-capture-and-storage, and fuel shifting.
- The industrial sector: 1.5 to 4.6 $GtCO_2e$ per year through improvements in energy efficiency, fuel switching, power recovery, materials efficiency improvements, and other measures.
- The transportation sector (excluding aviation and shipping): 1.4 to 2.0 $GtCO_2e$ per year through improvements in fuel efficiency, adoption of electric drive vehicles, shifting to public transit, and use of low carbon fuels.
- The buildings sector: 1.4 to 2.9 $GtCO_2e$ per year through improvements in the efficiency of heating, cooling, lighting, and appliances, among other measures.
- The forestry sector: 1.3 to 4.2 $GtCO_2e$ per year through a reduction in deforestation, and changes in forest management that increase above and below ground carbon stocks.
- The agriculture sector: 1.1 to 4.3 $GtCO_2e$ per year through changes in cropland and livestock management that reduce non-CO_2 emissions and enhance soil carbon.
- The waste sector: about 0.8 $GtCO_2e$ per year through improved wastewater treatment, waste gas recovery from landfills, and other measures.

The total emission reduction potential of these sectors in 2020 adds up to about 16 ± 3 $GtCO_2e$ (the full range is 16 ± 7 $GtCO_2e$. The reduced range assumes that not all sectors are at the high end of their range simultaneously). Adding the aviation and shipping sectors sum up to a total emission reduction potential of 17 ± 3 $GtCO_2e$ (the full range is 17 ± 7).

Marginal costs of reduction extend up to around 50 - 100 US$/t$CO_2$e.

One conclusion is that the 12 GtCO_2e emissions gap in 2020 (between business-as-usual emissions and emission levels in line with the 2°C target), can be bridged by realizing the mid-range estimate of the emission reduction potential.

There is also potential to reduce international emissions from aviation and shipping

Emissions from the aviation and shipping sectors are a special case compared with other sectors because a large fraction of global civil aviation and shipping emissions are "international" and not fully attributable to a particular country. International emissions have not been included in the Kyoto Protocol targets for Annex I countries and they do not fall under country pledges. Therefore, we take a separate look at potential emission reductions from these sectors.[5]

As of 2006, 62% of the emissions from aviation were international, and as of 2007, 83% from shipping were international. The 2005 emissions from global civil aviation were about 0.6 GtCO_2 per year and about 1.0 GtCO_2 per year from global shipping. Together they account for about 5% of global CO_2 emissions. Business-as-usual projections for 2020 are about 0.6 to 1.2 GtCO_2 per year from aviation and 1.1 to 1.3 GtCO_2 per year from shipping.

Many studies have examined the potential for reducing emissions from these sectors. Options for reducing emissions from both sectors include improving fuel efficiency and using low-carbon fuels. For the shipping sector, another promising and simple option is to reduce ship speeds.

Summed together, the two sectors are estimated to have a potential for reducing emissions in 2020 of about 0.3 to 0.5 GtCO_2e, which is *additional* to the potential of other sectors reported in bottom-up studies, leading together to a total of 17 ±3 GtCO_2e.

Bridging the gap is possible in many ways

To sum up, policymakers have many options for narrowing and closing the emissions gap in 2020.

They can agree within the context of climate negotiations to implement their more ambitious "conditional" pledges, and in fulfilling these pledges they could minimize the use of "lenient LULUCF credits" and surplus emission credits. They could also agree to avoid the double-counting of offsets and make these offsets really additional.

They could target their energy systems and make them more efficient in 2020 than they otherwise would be under "business-as-usual" conditions. Other goals would be to produce a larger share of their total primary energy from non-fossil fuel sources, with more primary energy from modern biomass and other sources of renewable energy in some combination. They could also reduce their non-CO_2 emissions significantly.

By making energy use more efficient, and accelerating the use of renewable energy, they will be able to substantially reduce emissions coming from their electricity production, industrial, transportation, buildings, aviation and shipping sectors. But many other measures are also feasible for these sectors.

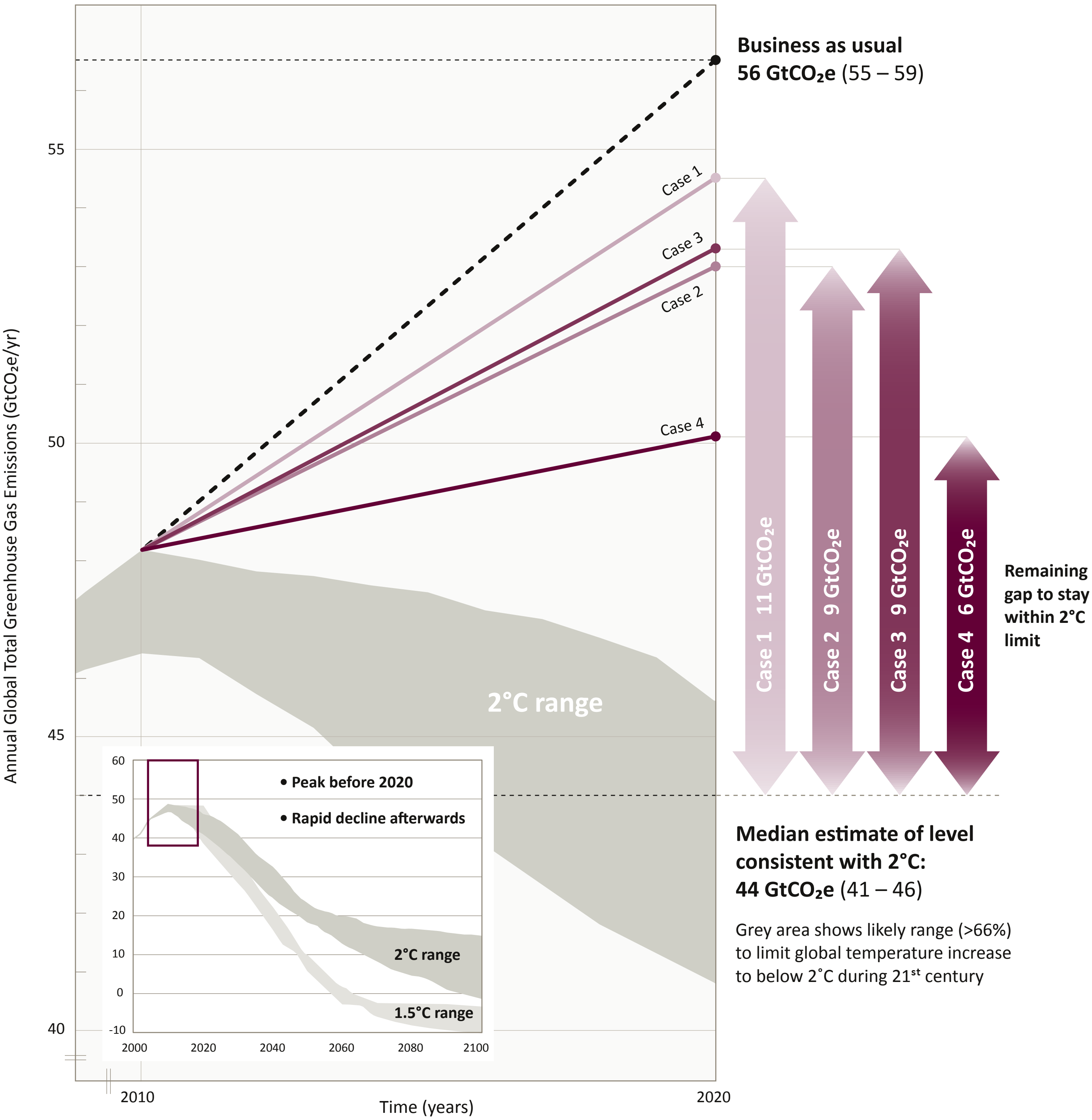
Policymakers could also pursue better management as a strategy for reducing emissions from the forestry, agricultural and waste sectors. Reducing deforestation and improving forestry management would increase carbon stocks relative to a baseline, and changing farm and waste management practices would, in particular, be an effective strategy for reducing non-CO_2 emissions.

Based on the large body of scientific studies reviewed in this report, it is clear that no major technological breakthrough will be needed to substantially reduce emissions by 2020. A great potential already exists to reduce emissions, and costs of these reductions are not prohibitive. Indeed, a wide range of policy instruments for mitigating greenhouse gas emissions have already been adopted and are in use in many different sectors and countries throughout the world, and these instruments are successful in reducing emissions.

And if the potential for reducing global emissions was to be realized, then the world would be on track to keep the rise in average global temperature to below 2.0 or 1.5 degrees by 2020. It would still be possible to bridge the emissions gap in 2020 and stay on a pathway to long-term climate protection.

5. Note: the potential emission reductions in the transportation sector noted in the previous section do not take into account aviation and shipping.

The emissions gap



Case 1 – Unconditional pledges, lenient rules
If countries implement their lower-ambition pledges and are subject to "lenient" accounting rules, then the median estimate of annual GHG emissions in 2020 is 55 $GtCO_2e$, within a range of 53 – 57$GtCO_2e$.

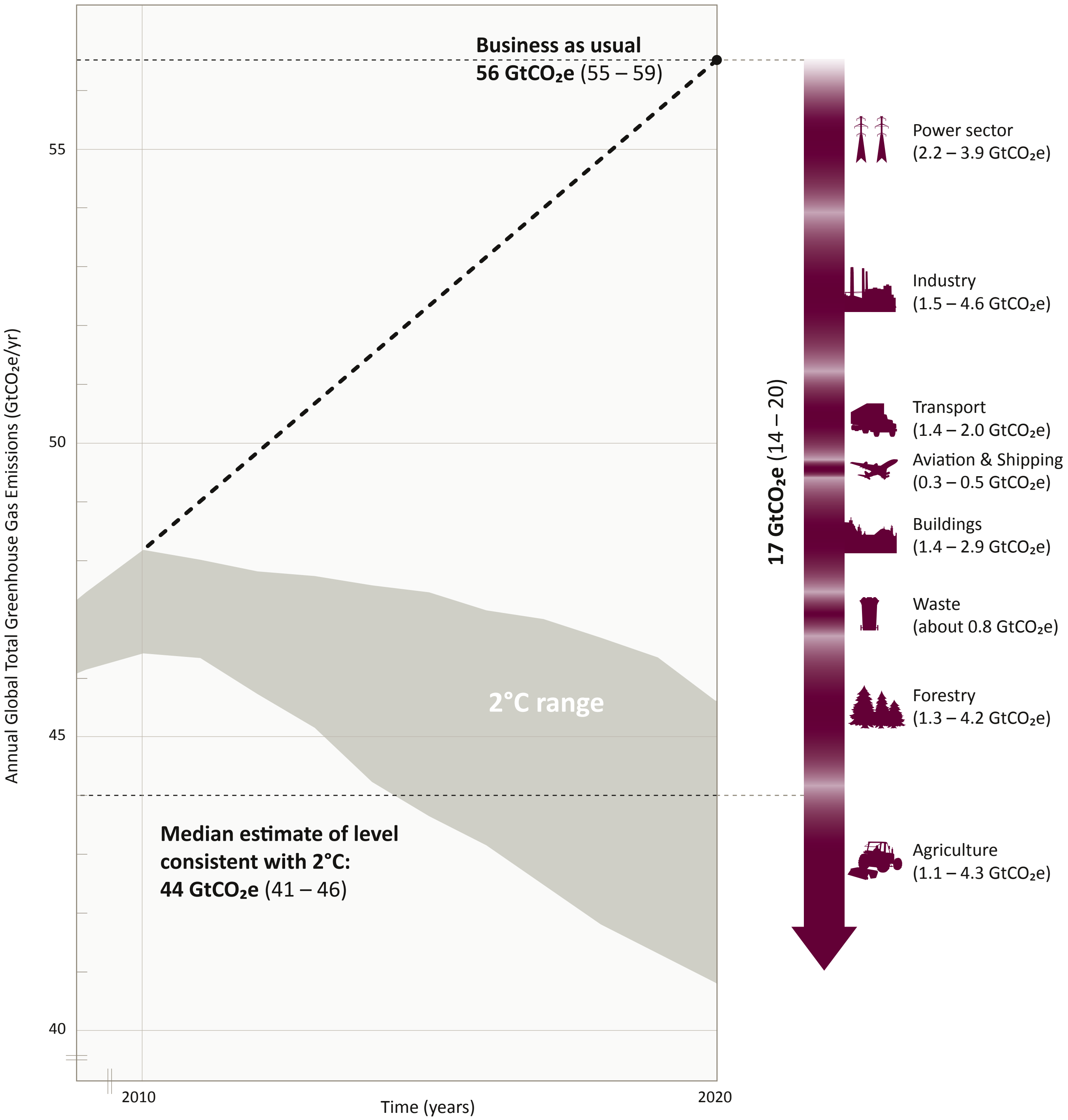
Case 2 – Unconditional pledges, strict rules
This case occurs if countries keep to their lower-ambition pledges, but are subject to "strict" accounting rules. In this case, the median estimate of emissions in 2020 is 53 $GtCO_2e$, within a range of 52 – 55 $GtCO_2e$.

Case 3 – Conditional pledges, lenient rules
Some countries will be more ambitious with their pledges. Where this is the case, but accounting rules are "lenient", median estimates of emissions in 2020 are 53 $GtCO_2e$ within a range of 52 – 55 $GtCO_2e$. Note that this is higher than in Case 2.

Case 4 – Conditional pledges, strict rules
If countries adopt higher-ambition pledges and are also subject to "strict" accounting rules, the median estimate of emissions in 2020 is 51 $GtCO_2e$, within a range of 49 – 52 $GtCO_2e$.

Please note: All emission values shown in the text are rounded to the nearest gigatonne.

How the bridge the gap: What the sectoral studies say



How to bridge the gap: What the global mitigation scenarios say

Improving energy efficiency

Improving energy efficiency so that primary energy production is up to 11% lower than business-as-usual levels in 2020 (with one study 18% lower). The amount of energy used per unit GDP decreases around 1.1 – 2.3% per year from 2005 to 2020.

Non fossil fuel energy sources

Producing up to 28% of total primary energy from non-fossil fuel energy sources in 2020. (As compared to 18.5% in 2005).

Energy from biomass

Producing up to 17% of total primary energy in 2020 from biomass. (As compared to about 10.5% in 2005).

Renewable energy (solar, wind, hydro)

Producing up to 9% of total primary energy in 2020 with non-biomass renewable energy (solar, wind, hydroelectricity, other). (As compared to about 2.5% in 2005).

Reduce non-CO_2 emissions

Reducing non-CO_2 emissions up to 19% relative to business-as-usual in 2020 (with one estimate of 2%).

Chapter 1:

Introduction

At Cancún in December, 2010, the international community took some important steps towards climate protection. Countries agreed that *"deep cuts in global greenhouse gas emissions are required … with a view … to hold the increase in global average temperature below 2°C above pre-industrial levels".* They further agreed that *"Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity".* Moreover, they left open the option of *"strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5°C"* (UNFCCC, 2010a).

The 2°C and 1.5°C targets had already been referred to a year earlier in the Copenhagen Accord of 2009 (UNFCCC, 2009). But in addition to incorporating temperature targets, the Accord also encouraged countries to submit "pledges", i.e. proposals for emission reductions for the year 2020. Since Copenhagen, 42 industrialized countries have submitted quantified economy-wide emission targets for 2020. In addition, 44 developing countries submitted so-called Nationally Appropriate Mitigation Actions (NAMAs) for inclusion in the Appendices to the 2009 Copenhagen Accord. These pledges have since become the basis for analysing the extent to which the global community is on track to meet long-term temperature goals. They were later 'anchored' in the 2010 Cancún Agreement (UNFCCC, 2010a, UNFCCC, 2011a, UNFCCC, 2011b) in December 2010.

With the international community agreeing to a temperature target on one hand, and to pledges for reducing emissions in 2020 on the other, it was not surprising that many asked, "Are the pledges consistent with the temperature target?" and "How close will the pledges bring global emissions to the level consistent with the 2°C target?"

To tackle these questions, the United Nations Environment Programme (UNEP), in collaboration with the European Climate Foundation and the National Institute of Ecology (Mexico), convened 25 scientific groups to compile an "Emissions Gap Report". In their report, released in December, 2010, the scientists predicted a gap between emissions expected after the pledges were fulfilled and emission levels consistent with the 2°C target. After receiving the report, policymakers requested UNEP to prepare a follow-up document which not only updates emission gap estimates, but more importantly, provides ideas on how to bridge the gap. This present report is a response to this request. To do the work, UNEP has convened 55 scientists and experts from 28 scientific groups across 15 countries.

This report first reviews and summarizes the latest scientific studies of the gap. Many new studies are incorporated into the re-assessment of the gap. It then tackles the question – How can the gap be bridged? – by examining the question from different vantage points: From that of global integrated assessment models, from bottom-up studies of individual economic sectors, and from published work on the mitigation potential in international aviation and shipping emissions. Altogether, these different perspectives provide a wealth of information and insight into how the gap can be bridged in 2020, and how the world can get onto a pathway leading to long-term climate protection.

Chapter 2:

The Emissions Gap – an update

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2.1 The emissions gap: an update

This chapter provides an update to The Emissions Gap Report (UNEP, 2010) (see Box 1). The aim is to provide readers with the most current information about the size of the gap between expected emissions in 2020 according to country pledges and the emissions consistent with the 2°C target. As in The Emissions Gap Report, this chapter identifies future emission pathways that are consistent with a 2°C or 1.5°C temperature limit (section 2.2) followed by an analysis of expected global emissions in 2020 based on countries' emission reduction pledges (section 2.3) and the resulting gap (section 2.4) in terms of annual global greenhouse gas (GHG) emissions. Emissions are measured in units of carbon dioxide equivalent for the gases covered by the Kyoto Protocol and reported under the UNFCCC (UNFCCC, 2002).[6]

The data and information presented is based on an analysis of three kinds of information:

A. Emissions pathways

Global emissions pathways analysed in this report are calculated by what are called Integrated Assessment Models (IAMs), and take into account population growth, economic growth, different patterns of energy use, land use, industrial production, etc. The Emissions Gap Report incorporated data from 17 IAMs. This update includes an additional three. Information from the same models is also used for the analysis in Chapter 3.

B. Projections of global temperature change

The global temperature change over time expected from these emissions pathways is worked out from what are called global climate models. Consistent with the approach for The Emissions Gap Report, this study uses a reduced complexity climate model (Meinshausen *et al.,* 2011*)* which takes into account the uncertainties in the carbon cycle, climate and climate sensitivity.

C. Analysis of pledges

Various approaches are used to assess global greenhouse gas emissions by 2020 assuming that countries fully implement their emission reduction pledges. This update includes the analysis from 13 research groups, of which five updated their analysis since last year. Most groups analysed only the pledges themselves and did not attempt to quantify whether the national policies in place are sufficient to meet these pledges.

2.2 Scenarios consistent with temperature targets

2.2.1. Greenhouse gas emissions, concentrations and global temperatures in 2010

Total anthropogenic emissions at the end of 2009 were estimated at 49.5 $GtCO_2e$ (Montzka *et al.*, 2011). These emissions include CO_2 from fossil fuel use and from land use, as well as emissions of methane, nitrous oxide and other greenhouse gases covered by the Kyoto Protocol. Such a comprehensive estimate is not yet available for 2010.

6. If not stated otherwise, all emissions in this report refer to $GtCO_2e$ (gigatonnes or billion tonnes of carbon dioxide equivalent) – the global warming potential-weighted sum of the greenhouse gases covered by the Kyoto Protocol, that is CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, and include emissions from land use, land-use change and forestry (LULUCF).

Box 1: The Emissions Gap Report 2010 in summary

The 2009 Copenhagen Accord recognizes that deep cuts in global greenhouse gas emissions are required "so as to hold the increase in global temperatures below 2 degrees Celsius". The Emissions Gap Report, published in December, 2010, informed policymakers and the wider community on how far a response to climate change had progressed over the previous 12 months, giving an overview of results from the work of 10 different international scientific groups. Published by the United Nations Environment Programme (UNEP), in conjunction with the European Climate Foundation and the National Institute of Ecology, Mexico, the report addressed five questions:

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

The report found that if global emissions do not exceed 44 gigatonnes of carbon dioxide equivalent (ranging from 39 to 44 $GtCO_2e$) in 2020 and global emissions are rapidly reduced afterwards; then it is "likely" that global warming will be limited to 2°C. A "likely" chance has greater than 66% probability.

What are the expected global emissions in 2020, if the pledges announced by countries are fulfilled?

According to The Emissions Gap Report, if emissions pledges announced by countries are fulfilled, global emissions are expected to increase to between 49 $GtCO_2e$ according to the most ambitious pledges and measured under strict accounting rules; and 53 $GtCO_2e$ in 2020 according to the least ambitious pledges and more lenient accounting rules. Business-as-usual (BAU) emissions in 2020 are estimated to be 56 $GtCO_2e$ (ranging from 54 to 60 $GtCO_2e$).

How big is the emissions gap?

The gap would range from 5-9 $GtCO_2e$, depending on how the pledges were implemented and which accounting rules would be decided upon within the UN Framework Convention on Climate Change (UNFCCC). Double counting of international emissions offsets could increase the gap by up to 1.3 $GtCO_2e$ and there are no rules preventing this. As a reference point, if no pledges were acted on (i.e. BAU conditions), the gap would be 12 $GtCO_2e$.

What do the pledges suggest about future temperature changes?

The Emissions Gap Report used emissions pathways from Integrated Assessment Models and calculated the expected temperatures from those pathways. Pathways that had the level of emissions expected from the Copenhagen Accord pledges in 2020 were found to imply a temperature increase of between 2.5 to 5°C before the end of the century. The lower bound was the case in which emissions are fairly stringently controlled after 2020, and the upper bound was the case in which emissions were more weakly or not controlled.

How can the gap be minimized and what are the policy options to do so?

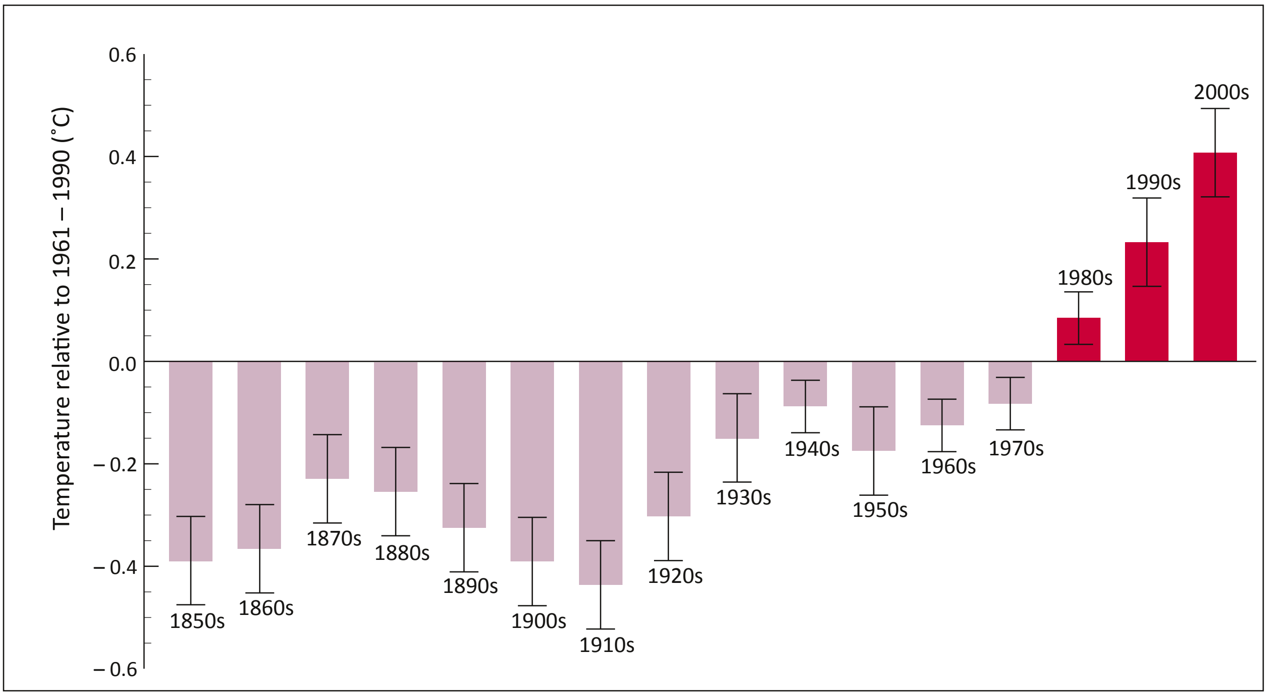
The Emissions Gap Report found that countries can reduce the gap from 9 to 5 $GtCO_2e$ by adopting their higher ambition pledges (a gain of around 2-3 $GtCO_2e$) and by the international community agreeing to the more stringent accounting rules for implementing the pledges (a gain of 1-2 $GtCO_2e$). That said, a gap of 5 $GtCO_2e$ would still remain.

Nevertheless, energy-related CO_2 emissions in 2010 were the highest on record, rising again after a dip in 2009. The dip is understood to have been caused by the global economic crisis (IEA, 2011). The year 2010 was also ranked as the highest or second highest for global near-surface temperatures, according to the three leading datasets of global near surface temperature[7]. However, it is important to emphasise that year-to-year variations in temperature are expected and it is the longer-term trend that provides a more reliable guide to global warming. Looking at decades as a whole and using information from the UK Met Office's and the University of East-Anglia Climate Research Unit's global temperature dataset (Brohan, 2006), the 2000's were found to be the hottest decade in the instrument temperature record (see Figure 1).

The average concentration of carbon dioxide in the troposphere in 2010 was 388.5 ppm, estimated from globally averaged marine surface data. The average concentrations of methane and nitrous oxide measured at Mace Head in Ireland during the period October 2009 to September 2010 were 1870 ppb and 323 ppb respectively. Measurements for these gases at Cape

7. HadCRUT3 (http://www.metoffice.gov.uk/climatechange/science/monitoring/hadcrut3.html) covers the period 1850 to present and is updated monthly. NOAA NCDC (http://www.ncdc.noaa.gov/cmb-faq/anomalies.php) covers the period from 1880. NASA GISS (http://data.giss.nasa.gov/gistemp/) also covers the period from 1880.

Figure 1: Decadal near-surface global average temperature anomaly, depicted relative to the temperature during the period 1961-1990. Source: adapted from Menne & Kennedy, 2010



Grim in the Southern Hemisphere over the same period were 1748 ppb and 322 ppb. Together these produce a radiative forcing of around 2.4 W/m^2. Additional radiative forcing of around 0.7 W/m^2 is provided by a range of other greenhouse gases including tropospheric ozone, CFCs and HCFCs.[8] Some of the forcing is offset by the cooling effect of short-lived atmospheric aerosol particles.

The global mean equilibrium surface temperature increase above pre-industrial temperatures for greenhouse gas concentrations of 450 ppm CO_2e is about 2.1°C (best guess). The radiative forcing of such a concentrations level is about 2.6 W/m^2 (IPCC, 2007). Limiting long-term global temperature increase to below 2°C with a likely (greater than 66%) chance would imply greenhouse gas concentrations at equilibrium to be around 415 ppm CO_2e (Rogelj *et al.*, forthcoming). This corresponds to a net radiative forcing at equilibrium of about 2.1 W/m^2.

2.2.2 Combining socio-economic and climate-system modelling

Limiting global temperature increase to a given maximum level depends on the interplay between physical and socio-economic constraints. The cumulative emissions of long-lived greenhouse gases, such as carbon dioxide, are a proxy for the global temperature increase at timescales of decades to a century (Meinshausen *et al.*, 2009, Allen *et al.*, 2009, Zickfeld *et al.*, 2009, Matthews *et al.*, 2009). While emission pathways (i.e. possible evolutions of annual global greenhouse gas emissions over time) can have similar cumulative emissions, they can be very different in terms of cost and feasibility.

Integrated Assessment Models, which model aspects of the required technological and socio-economic transitions to achieve a specific emissions path, therefore provide important complementary information. In this report we look at emission pathways that sample a large range of possible future evolutions of the greenhouse gases covered by the Kyoto Protocol. The analysis does not explicitly look at policy options for short-lived species like black carbon that are not covered by the Kyoto Protocol. For the purpose of calculating temperature increase we apply one reduction scenario for these species to all emission pathways (see online appendix on methodology and Rogelj *et al.*, 2011).

Integrated Assessment Models help in generating scenarios, i.e. consistent representations of plausible future development and emissions. Within these models, certain emission pathways are considered infeasible (i.e. not possible to achieve) because they contradict the assumptions about either how quickly new technologies can be scaled up, or existing technologies can be replaced, or the extent to which changes in behaviour can be induced. Scenarios may also be considered infeasible if the real-world ability to come to a political consensus on emission reductions and reduction mechanisms is missing.

8. http://cdiac.ornl.gov/pns/current_ghg.html

But this is typically not included in IAMs (Bosetti *et al.*, 2010, Ha-Duong and Treich, 2004). IAMs model feasible emission pathways over the entire twenty-first century. However, because of their prominence in international climate policy, we zoom in at the 2020 and 2050 emission ranges.

The above factors of technological, economic, political and social feasibility are not governed by "hard laws". As new evidence becomes available – in particular on the ability or inability to implement policies – the range of emission pathways considered feasible may change over time. For example, most emission pathways in the literature aim at attaining cost optimal paths over the entire twenty-first century. Also other trajectories are possible, for example with higher emissions in 2020 but a steeper decline afterwards, which would come with higher costs and are generally more difficult to implement technologically. Literature which exhaustively explores these aspects of near-term flexibility is in preparation and not considered in this report. On the other hand, as indicated above, consideration of political and social feasibility could also narrow the emission range in 2020 required to be consistent with a 2°C trajectory.

2.2.3 What emissions pathways and emission levels are consistent with 2°C and 1.5°C limits?

2020 emission levels in line with 2°C and 1.5°C

Updated results from IAMs do not show fundamental differences with the figures presented for the year 2020 in The Emissions Gap Report. This is despite the inclusion of 28 new scenarios, and the exclusion of 9 scenarios because their 2010 emissions were no longer consistent with historical estimates (see Table 1, Figure 2 and Figure 3, and online appendix on methodology).

As in The Emissions Gap Report, if global emissions do not exceed 44 $GtCO_2e$ in 2020 and emissions are sharply reduced afterwards; then it is "likely" that global warming can be limited to 2°C during the 21st century. A "likely" chance has greater than 66% probability. However, the range surrounding this global emissions value (44 $GtCO_2e$) has changed in this update and is now 41 to 46 $GtCO_2e$, compared with 39 to 44 $GtCO_2e$ in The Emissions Gap Report.

When accepting a "medium" chance (50 to 66 %) of achievement[9], median total global greenhouse gas emissions in 2020 move to 46 $GtCO_2e$ (range 45 to 49 $GtCO_2e$).

Since The Emissions Gap Report, no new pathways were found which can limit global warming to below 1.5°C by the end of the century and no pathways were excluded. The assessment on this issue therefore remains unchanged: 2020 emissions consistent with a "medium" or lower chance of staying below 1.5°C being comparable to the earlier "likely" 2°C range of 2020 emissions (44 $GtCO_2e$ with a range of 39 to 44 $GtCO_2e$), but with significantly higher yearly reduction rates after 2020.

2050 emission levels in line with 2°C and 1.5°C

For global temperatures to have a "likely" chance to stay below 2°C, greenhouse gas emissions in 2050 should be lower than 21 $GtCO_2e$ (a range of 18 to 23 $GtCO_2e$, see Table 1 and Figure 3). This is equivalent to an approximate emissions reduction of 45% relative to 1990 levels (range of 35 to 50%, rounded to the nearest 5%). If total global emissions in 2050 do not exceed 26 $GtCO_2e$ (range 24 to 29 $GtCO_2e$), then they are consistent with a "medium" chance (50 to 66%) that the global temperature increase can be kept below 2°C.

Global peaking, reduction rates and negative emissions

For both the "likely" and the "medium" chance pathways in our set, global emissions peak in the decade between 2010 and 2020 in the majority of cases (see Table 1). Median global average emission reduction rates between 2020 and 2050 are slightly higher in the "likely" pathways set (2.6%) than in the set with a "medium" chance to achieve the 2°C target (2.5%).

The "likely" 2°C pathways in our set reach global net negative carbon dioxide emissions from fossil fuel and industry before the end of the century in more than 50% of the cases. This means that in these pathways, more carbon dioxide is removed from the atmosphere than is emitted into it. This scenario is possible by combining energy generation from biomass with the capture and storage of the carbon dioxide produced in this process (see also Chapter 3).

2.2.4 Discussion

In this update, there are 23 pathways having a "likely" chance to limit global temperature increases to below 2°C. This compares with 9 pathways in The Emissions Gap Report. The additional information available about possible futures consistent with 2°C, changes the ranges only slightly (Tebaldi & Knutti, 2007).

9. The definition of a "medium" likelihood is consistent with UNEP (2010). The IPCC guidance on uncertainty does not define such a category, but defines "about as likely as not" as 33 to 66% probability.

Keeping emissions within a specific range in 2020 is not sufficient to assure that the world is following a global emission pathway which is consistent with 1.5 or 2°C. Global average temperature increase is mainly governed by emissions *after* 2020. Figure 2 and Figure 3 (left panel) show that pathways in which the 2020 emissions are consistent with a "likely" chance to achieve the 2°C target, could still lead to higher temperature increases by the end of the 21st century. This is because there are still multiple pathways that can be followed afterwards. In 2050 the ranges of emissions consistent with certain temperature limits overlap much less (see Figure 3, right panel).

Since cumulative emissions determine the global temperature increase, pathways with emissions in 2020 at the *high* end of the range in line with 2°C have to make up for that and are typically followed by 2050 emission levels at the *lower* end of the 2050 range (for example, 46 $GtCO_2e$ for a "likely" chance in 2020 gives 18 $GtCO_2e$ in 2050).

Table 1: Overview of key characteristics of pathways reviewed in this report with a "likely" (greater than 66 per cent) or a "medium" (50 to 66 per cent) chance of limiting global temperature increase to below 2°C during the 21st century, respectively.

Number of pathways [-]	**Peaking decade*** [year]	**Total GHG emissions in 2020** [$GtCO_2e$]		**Total GHG emissions in 2050** [$GtCO_2e$]		**Average energy and industry related CO_2 emission reduction rates between 2020 and 2050 [% of 2000 emissions/year]**	
		Median	Range**	Median	Range**	Median	Range**
"Likely" chance (>66%) to limit global temperature increase to below 2 °C during 21st century							
23	2010-2020	44	26-(41-46)-49	21	12-(18-23)-32	2.6	0.6-(2.3-3.1)-3.6
"Medium" chance (50 to 66%) to limit global temperature increase to below 2 °C during 21st century							
17	2010-2020	46	42-(45-49)-50	26	20-(24-29)-32	2.5	2.0-(2.2-2.9)-3.6

* 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.
** Range is presented as the minimum value – (20th percentile – 80th percentile) – maximum value

Figure 2: Temperature increases associated with emission pathways as a function of the transient shapes of emission pathways: Coloured ranges show the 20 to 80 percentile ranges of the sets of IAM emission pathways that have approximately the same "likely" avoided temperature increase in the 21st century. Dashed lines show the median transient emission pathways for each temperature level, respectively. Figure includes the emissions in 2020 resulting from the pledges described in section 2.2.

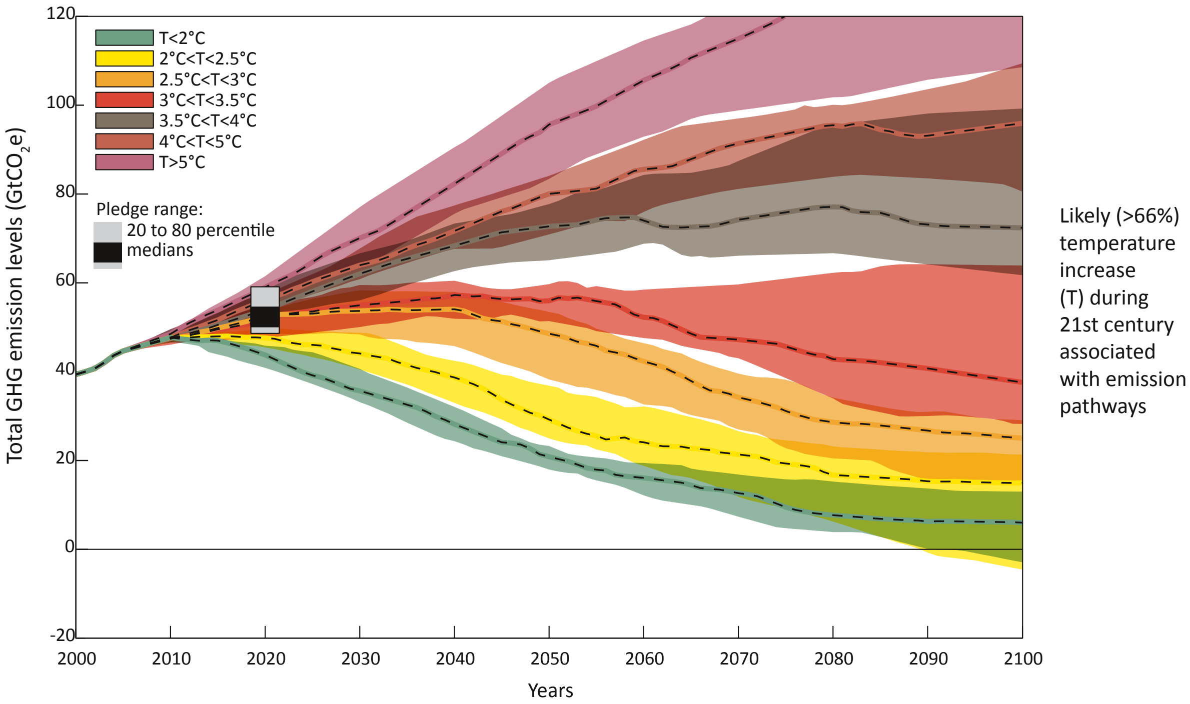
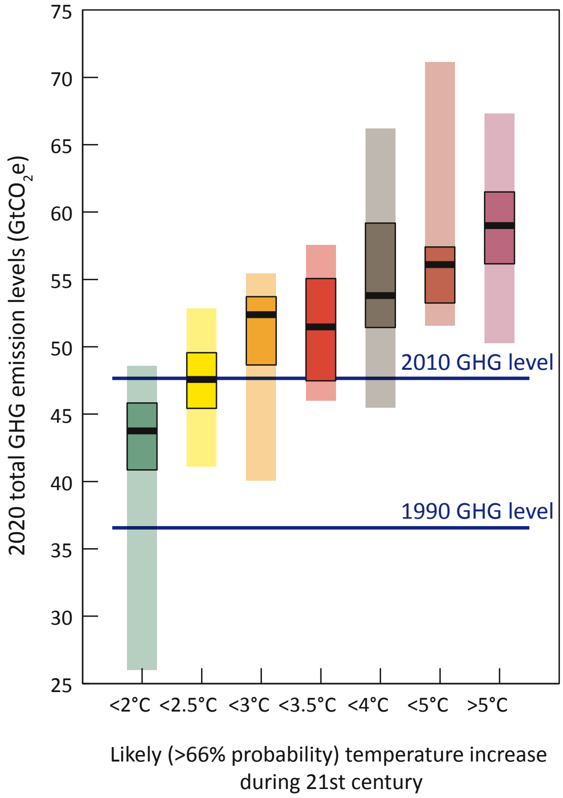
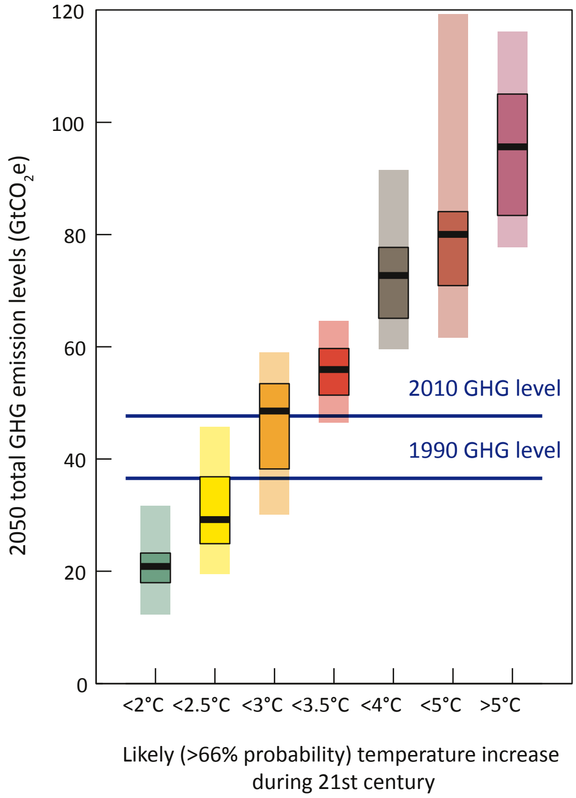


Figure 3 : Temperature increases associated with the different emissions pathways in the years 2020 (left) and 2050 (right): Thick, black lines show the median values, dark shaded areas represent the 20th to 80th percentile range, and light shaded ones the minimum maximum range. Note that the colour-coded legend can be found in Figure 2





2.3 National emission reduction pledges and expected emissions in 2020: an update

Since November 2010, no country has changed its emission reductions pledge. Some countries, however, have clarified their assumptions and specified the methods by which they would like emissions accounted for. For example, Australia has provided its interpretation on how to account for its base year under the Kyoto Protocol and Brazil has provided a new estimate for its business-as-usual (BAU) emissions, to which its pledge is to be applied. These changes lead to higher global emissions totals (i.e. less reductions) for the cases that assume pledges are met.

Global emissions in 2020 will depend on pledges implemented and the rules on how these pledges will be accounted for.

An "unconditional" pledge is one made without conditions attached. A conditional pledge on the other hand might depend on the ability of a national legislature to enact necessary laws, or may depend on action from other countries, the provision of finance, or technical support.

International rules on how emission reductions are to be measured after the first commitment period of the Kyoto Protocol have not yet been defined. Rules for Annex I countries exist under the Kyoto Protocol until 2012. Rules for developing countries are not available. The Emissions Gap Report and this update describes four cases of expected emissions in 2020, based on whether pledges are conditional, or not; and whether accounting rules are strict or more lenient (see Box 2 and Table 2).

2.3.1 Four "cases" of expected emissions in 2020

Case 1 – "Unconditional pledges, lenient rules":

If countries implement their lower-ambition pledges and are subject to "lenient" accounting rules, then the median estimate of annual GHG emissions in 2020 is 55 Gt CO_2e, within a range of 53-57 GtCO_2e.

Case 2 – "Unconditional pledges, strict rules":

This case occurs if countries keep to their lower-ambition pledges, but are subject to "strict" accounting rules. In this case, the median estimate of emissions in 2020 is 53 GtCO_2e, within a range of 52-55 GtCO_2e.

Case 3 – "Conditional pledges, lenient rules":

Some countries will be more ambitious with their pledges. Where this is the case, but accounting rules are "lenient", median estimates of emissions in 2020 are 53 GtCO_2e within a range of 52-55 GtCO_2e

Case 4 – "Conditional pledges, strict rules":

If countries adopt higher-ambition pledges and are also subject to "strict" accounting rules, the median estimate of emissions in 2020 is 51 GtCO_2e, within a range of 49-52 GtCO_2e.

Box 2: Defining "strict" rules and "lenient" rules

Climate change negotiations have yet to agree to rules that account for two elements that can influence the amount of allowed greenhouse gas emissions. First, rules have not been agreed to account for emissions from land use, land-use change and forestry (LULUCF). Secondly, rules have not been agreed for using surplus emissions credits, which will occur when countries exceed their emissions reduction targets.

The Emissions Gap Report and this update define "strict" rules to mean that allowances from LULUCF accounting and surplus emission credits will not be counted as part of a countries meeting their emissions reduction pledges. Under "lenient" rules, these elements can be counted.

As a reference point, without the Copenhagen pledges, global greenhouse gas emissions may increase from 45 GtCO_2e in 2005 to 50 GtCO_2e in 2009 to around 56 GtCO_2e in 2020 (within a range of 55-59 GtCO_2e) according to BAU projections.

Note also that the impact of "lenient" or "strict" rules on the resulting emissions in 2020 is potentially very sizeable. In fact, we find that the "lenient" use of LULUCF credits and surplus emission units could completely cancel out the impact of the Annex I pledges in the unconditional case, and significantly reduce their impact in the conditional case. Whilst we have deliberately assumed a maximum possible impact of these two issues in the two "lenient" pledge cases, it is important to note this finding, as the rules surrounding these two issues may be finalised over the course of 2012.

It is also important to note that the gap could be significantly larger, if emission reductions in developing countries that are supported by developed countries through offsets, for example, using the Clean Development Mechanism, are counted towards meeting both countries' pledges (see use of offsets below).

2.3.2 Land use, land-use change and forestry (LULUCF): an update

Countries still have to agree on accounting rules that will determine the extent to which LULUCF activities in Annex I countries could be used to meet their respective targets for the period after 2012. In principle, LULUCF

Table 2: Emissions in 2020 assuming countries implement their pledges

Historical emissions $GtCO_2e$				**Emissions in 2020 $GtCO_2e$**				
1990			2005	BAU	Unconditional pledge		Conditional pledge	
					Lenient rules (case 1)	Strict rules (case 2)	Lenient rules (case 3)	Strict rules (case 4)
Global (incl. LULUCF)	Number of modelling groups	*5*	*10*	*10*	*10*	*10*	*10*	*10*
	Maximum	*37.8*	*45.0*	*62.2*	*60.2*	*56.7*	*55.0*	*52.7*
	80^{th} percentile	*37.7*	*45.0*	*59.1*	*56.7*	*55.3*	*54.8*	*51.8*
	Median	*37.7*	*45.0*	*56.4*	*54.5*	*53.0*	*53.3*	*50.1*
	20^{th} percentile	*36.9*	*45.0*	*54.8*	*52.8*	*51.6*	*51.7*	*48.6*
	Minimum	*33.7*	*45.0*	*52.8*	*51.4*	*49.7*	*49.2*	*45.2*

The range in 1990 emissions stems from the use of different data sources and assumptions especially for non-Annex I countries. In order to ensure a consistent comparison of the pathways and pledges we have harmonized the data for the same 2005 emissions of 45 $GtCO_2e$. A recent estimate of 2009 emissions is 49.5 $GtCO_2e$, but that was not used by the modeling groups.

accounting systems need to accurately and consistently describe changes in emissions or removals of carbon dioxide and other greenhouse gases attributed to human activity only. There are at present no consistent and reliable models that can isolate changes in emissions not related to human activities. Current proposals for accounting rules therefore use recent historical levels to set reference levels from which to assess changes in activities.

Many options for accounting rules are being considered in the climate negotiations. The aggregate impact of these options for Annex I countries is variable. It could result in pledged emissions going down by 0.2 $GtCO_2e$; or increasing by 0.6 $GtCO_2e$[10] (Primap, 2010). This represents a shift in the estimate since the 2010 report and is mainly due to changes in updated LULUCF data provided by countries. In this update we use a value of 0.6 $GtCO_2e$ increase for the "lenient" case, 0.2 $GtCO_2e$ lower than in The Emissions Gap Report.

Some of the latest submissions of countries on their reference levels for forest management[11] are substantially different from reported levels of this activity over the past 10 years (2000-2009). These reference levels are in effect a BAU scenario. Such a scenario translates to a net emissions increase of 0.7 $GtCO_2e$ relative to the annual average over 2000-2009[12]. Thus, the adoption of these reference levels implies either the endorsement of higher emissions in this sector, or, if removals continue along the historical trend (i.e. lower than the reference levels), a larger number of credits.

2.3.3 Updating surplus emissions

Some countries will exceed their emissions reduction targets under the first commitment period of the Kyoto Protocol, and may even continue to reduce their emissions beyond their 2020 target, either through policy action or for reasons unrelated to climate change policy. Where this is the case, they can carry-over, or bank these "surplus emission units" for use in the following commitment period. Surplus emissions can be sold or used domestically to meet future mitigation commitments up to 2020. If this happens, then estimates of 2020

10. Two groups have provided quantification of LULUCF accounting, the Joint Research Centre (JRC), and the PRIMAP group at the Potsdam Institute for Climate Impact Research (PIK-PRIMAP). JRC estimates a range of 0.16 $GtCO_2e$/yr in debits to 0.48 $GtCO_2e$/yr in credits calculated over the period 2013-2020, for four options for forest management, most in the current negotiation text (These options are the current Kyoto Protocol cap, a discount factor of 85%, reference levels, and net-net compared to the first commitment period). Their estimate for the year 2020 is a range of 0.21 $GtCO_2e$ in debits to 0.42 $GtCO_2e$ in credits. PIK-PRIMAP estimates a range of 0.02 to 0.6 $GtCO_2e$ in credits, for these same options over the period 2013-2020.
11. Based on a decision in Cancún, Parties provided in early 2011 their preferred forest management reference levels for the period 2013-2020. These reference levels underwent an expert review process that was completed in October 2011. Some Parties have resubmitted their forest management reference levels. Most countries chose a forwarded projected reference level, while three other countries chose different options: Japan – current Kyoto rules, Norway, Russian Federation, Ukraine and Belarus – net-net accounting against 1990. See: http://unfccc.int/meetings/ad_hoc_working_groups/kp/items/5896.php
12. http://www.climateactiontracker.org/CAT_update_Bonn_2011-06-16.pdf

emissions increase, because these surplus emission units can be used to comply with the pledges, instead of domestic emission reductions.

The total emissions surplus by 2012, at the end of the first commitment period, is estimated to be 11.4 $GtCO_2e$ (range 9 to 13 $GtCO_2e$) (PointCarbon, 2009, Bosetti *et al.*, 2010, den Elzen *et al.*, 2010, World Bank, 2011). We translate this into an annual supply of surplus emission units of 2.9 $GtCO_2e$ in the year 2020, by assuming the 11.4 $GtCO_2e$ are used increasingly over time between 2012 and 2020, with a maximum in 2020. The use distribution would look like a wedge, i.e. an increasing linear distribution (see Rogelj *et al.*, 2010a, Rogelj *et al.*, 2010b). This 2.9 $GtCO_2e$ is used in the "lenient rules" cases and replaces the 1.3 $GtCO_2e$ used in The Emissions Gap Report, which was based on an even distribution over the period. A large share of the surplus allowances originates from Russia. If Russia does not use their allowances domestically for the 2020 target and does not sign on for a second commitment period of the Kyoto Protocol (therefore, being unable to sell such allowances), then the supply of surplus emissions would be reduced from 2.9 to 1.5 $GtCO_2e$.

The impact of surpluses strongly depends on whether countries will buy such surpluses. Currently, the largest potential buyer, the USA, does not have a federal law that would allow buying such units, but may have state-level laws. Canada has aligned its position with the USA. The EU also does not allow surplus allowances to be used to comply with its unconditional pledge to reduce emissions by 20% before 2020. Japan has bought such allowances in the past but has so far not made a clear statement for its 2020 pledge. Hence, the net impact of use of surplus allowances could be substantially lower than the projected 2.9 $GtCO_2e$ in 2020. In the UNFCCC negotiations, options to limit the carry-over of surplus allowances are being discussed.

2.3.4 The use of offsets potentially widens the gap

A further issue still to be resolved is the potential to double count emissions reductions. Some developed countries, for example, will achieve their emissions reduction targets in part by purchasing carbon credits from developing countries. Developing countries meanwhile will achieve their pledge in part by enacting measures resulting in the sale of carbon credits to developed countries. The four pledge cases in The Emissions Gap report and in this update do not assess the impact of such double counting but in the absence of international rules it is likely that both sets of countries will want to claim credits for what is essentially the same project or activity.

If we simply assume that international emissions offsets could account for 33% of the difference between Annex I BAU and pledged emission levels by 2020; and if we assume that all of these are counted twice, then global emissions would be 1.3 $GtCO_2e$ higher (in the "conditional pledge, strict rules" case). A recent study (Erickson *et al.*, 2011) estimates a figure of 1.6 $GtCO_2e$ using assumptions on demand and supply of offsets.

The four pledge cases also do not account for the risk that more offset credits are generated than are actually reduced. Project activities need to be "additional" to an expected development without the project. Such comparison with a hypothetical case is difficult and there is indeed evidence that a significant share of CDM projects is not additional (Haya, 2009). Assuming this share to be 25% by 2020, we estimate that up to 0.4 $GtCO_2e$ of offsets could be non-additional.

The use of offsets (double counting and non-additionality) could lead to an increase of emission levels by up to 2 $GtCO_2e$.[13]

2.3.5 Leakage effects potentially widen the gap

Most of the models used in this update do not assess "leakage effects" (Burniaux and Oliveira-Martins, 2000). Leakage effects are actions to *reduce* greenhouse gas emissions in one country that lead to an *increase* in emissions elsewhere.

The models implicitly assume that the emissions of countries without a pledge will follow a BAU pathway. However, this may not be the case. Several studies published in 2011 indicate that emissions in countries without a pledge may be higher because of the impact of emission reductions in developed countries. But they also show that leakage rates vary widely. One study for example estimates a leakage rate of 13% or 0.55 $GtCO_2e$ (Peterson *et al.*, 2011); another 16% (Bollen *et al.*, 2011)[14]. At the lower end is an assessment of around 1%, or 0.05 $GtCO_2e$ (Dellink *et al.*, 2011) and comparable numbers computed by McKibbin *et al.* (2011).

13. The combined potential effect of double counting and non-additionality can be smaller than the sum of the two individual potential effects, because two different accounting systems can be used for the offsets and for the pledges. If a project does not result in additional reductions, it could be the case that these reductions are not counted towards meeting the country's pledge because the accounting for the pledge is done at the national level, e.g. with national energy statistics.

14. Bollen *et al.* (2011) find that the targets for China and India are not binding and assume no targets for other non-Annex I countries, and hence have only mitigation in the Annex I region. The 16% is thus with respect to Annex I emission reductions.

Box 3. Why different modelling groups arrive at different results

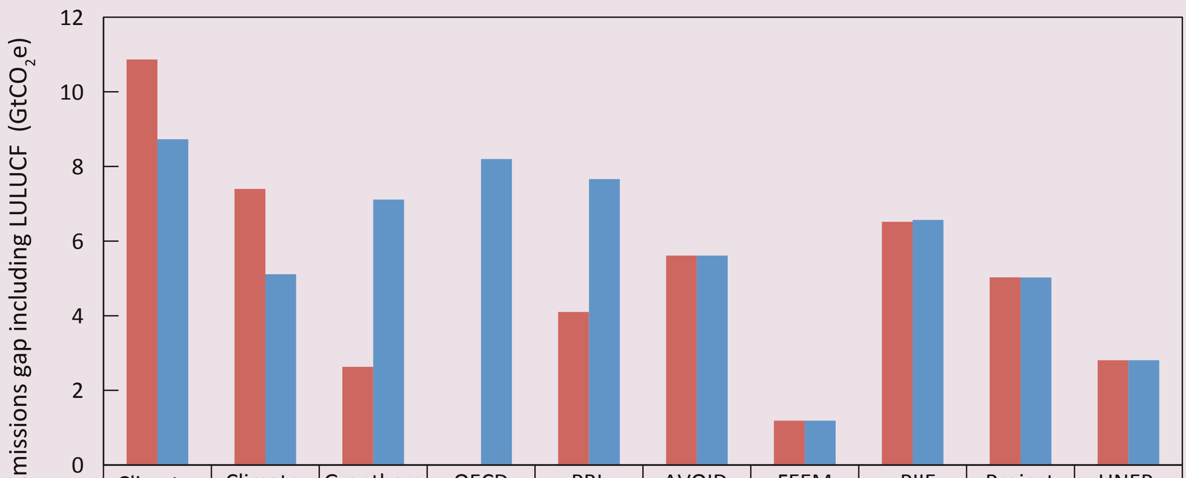
Analyses of countries pledges reviewed in this update were carried out by a number of modelling groups around the world. They are: the AVOID programme of the UK Met Office (Lowe *et al.*, 2010); Climate Action Tracker by Ecofys, Climate Analytics and Potsdam Institute for Climate Impact Research, PIK (updated based on Climate Action Tracker, 2009, Rogelj *et al.*, 2010b, Rogelj *et al.*, 2010a), Climate Interactive (C-ROADS), (Sterman *et al.*, undated), Climate Strategies (Climate Strategies, 2010), Fondazione Eni Enrico Mattei (FEEM) (Carraro & Massetti, forthcoming), IIASA with the GAINS model (Wagner & Amann, 2009), Grantham Research Institute, London School of Economics (updated based on Stern & Taylor, 2010), OECD (Dellink *et al.*, 2011), PBL Netherlands Environmental Assessment Agency (den Elzen *et al.*, 2011) Peterson Institute for International Economics (Houser, 2010), Project Catalyst by the Climate Works Foundation (ProjectCatalyst, 2010), UNEP Risoe centre, (http://www.unep.org/climatepledges/), World resources Institute (Levin & Bradley, 2010) (for details see online appendix and Höhne *et al.*, 2011).

Estimating 2020 emissions, based on countries' pledges or submissions to the Copenhagen Accord and Cancún Agreements involves among others: information on the historical, current and future development of countries' emissions; interpretation of the pledges 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 including the exact accounting rules; and uncertainties in the underlying data used by modelling groups. This is why the 13 modelling groups that have prepared such analyses do not all arrive at the same results.

Since the publication of The Emissions Gap Report, five of the thirteen groups have updated their results. The results for all other groups submitted in 2010 remain unchanged in this update. Of the 13 groups only 10 were used to assess the global total, because the remaining three had limited geographical coverage.

Figure 4 provides an estimation of the emissions gap in 2020 for the unconditional, strict rules (case 4) as analysed in 2010 and 2011 based on the data from the different modelling groups.

Figure 4 : Estimation of the emissions gap in 2020 ($GtCO_2e$) for the conditional, strict rules case (case 4) as analysed in 2010 and 2011 based on the data from different modelling groups



	Climate Action Tracker	Climate Interactive	Grantham	OECD	PBL	AVOID	FEEM	PIIE	Project Catalyst	UNEP Risoe
2010 Analysis	11	7	3		4	6	1	7	5	3
2011 Analysis	9	5	7	8	8	6	1	7	5	3

2.3.6 Additional action and climate financing – potentially decreases the gap

In some developing countries existing domestic policies or national plans could lead to emissions that are even lower than the conditional pledges submitted under the Copenhagen Accord and the Cancún Agreements – by up to 2 $GtCO_2e$ in total (e.g. den Elzen *et al.*, 2011). Present discussions on international climate finance may in addition result in further emissions reductions in developing countries. One study estimates an effect of up to 2.5 $GtCO_2e$ (Carraro & Massetti, 2011). All these issues have been analysed and found to have a significant effect on 2020 emissions. However, they are not included in any of the pledge cases.

2.3.7 Aggregated results for Annex I and Non-Annex I countries

For Annex I countries, in the least ambitious case ("unconditional pledges, lenient rules"), emissions are estimated to be equivalent to BAU emissions in 2020, i.e. 4% below to 11% above 1990 levels. In the most ambitious case, Annex I emissions in 2020 are expected to be 16-18% below 1990 levels. For non-Annex I countries, in the less ambitious cases emissions are estimated to be 6-7% lower than BAU emissions, in the ambitious cases 8-9 per cent lower than BAU. This implies that the aggregate Annex I countries' emission goals – even in the most ambitious scenario – are less ambitious than the 25-40% reduction by 2020 (compared with 1990) suggested in the IPCC Fourth Assessment Report (Gupta *et al.*, 2007). Similarly, the non-Annex I countries' goals are, collectively, less ambitious than the 15-30% deviation from BAU which is also commonly used as a benchmark (den Elzen & Höhne, 2008, den Elzen & Höhne, 2010).

2.4 The emissions gap

This chapter aims to see whether, since The Emissions Gap Report's publication in December, 2010, there have been any changes to the "gap" between projected global emissions in 2020 and the level of emissions consistent with keeping the global temperature rise to no more than 2°C relative to pre-industrial levels.

As a reference point, BAU emissions in 2020 will be 56 $GtCO_2e$ – a figure unchanged from The Emissions Gap Report within a range of 55 to 59. The required level of emissions that would most "likely" constrain the rise in global temperatures to 2°C is 44 $GtCO_2e$ within a range of 41 to 46. The gap under BAU would therefore be 12 $GtCO_2e$.

Under the four different interpretations of how the pledges would be followed (section 2.3), the emissions gap is 6 to 11 $GtCO_2e$ within a full range of 3 to 16 $GtCO_2e$ (Figure 5). This compares with an emissions gap of 5 to 9 $GtCO_2e$ within a full range of 3 to 18 in The Emissions Gap Report.

Figure 5 summarises the gaps that result from four different interpretations of how the pledges are followed, and for a "likely" (greater than 66 %) and a "medium" (50-66 %) chance of staying below 2°C.

Some elements that are *not* included in the four cases do have the potential to further *increase* or *decrease* the gap. Double counting of offsets could increase the gap by 1.6 $GtCO_2e$. The non-additionality of offsets could also increase the gap by 0.4 $GtCO_2e$. Countries not meeting their pledges as assumed in all studies could further increase the gap. Given the absence of international rules on these issues and the strong interest of many developed countries to continue using offsets, such increases are rather likely. Elements that are not included in this gap calculation that could *decrease* the gap are additional effects of international climate financing or countries over-achieving their pledges.

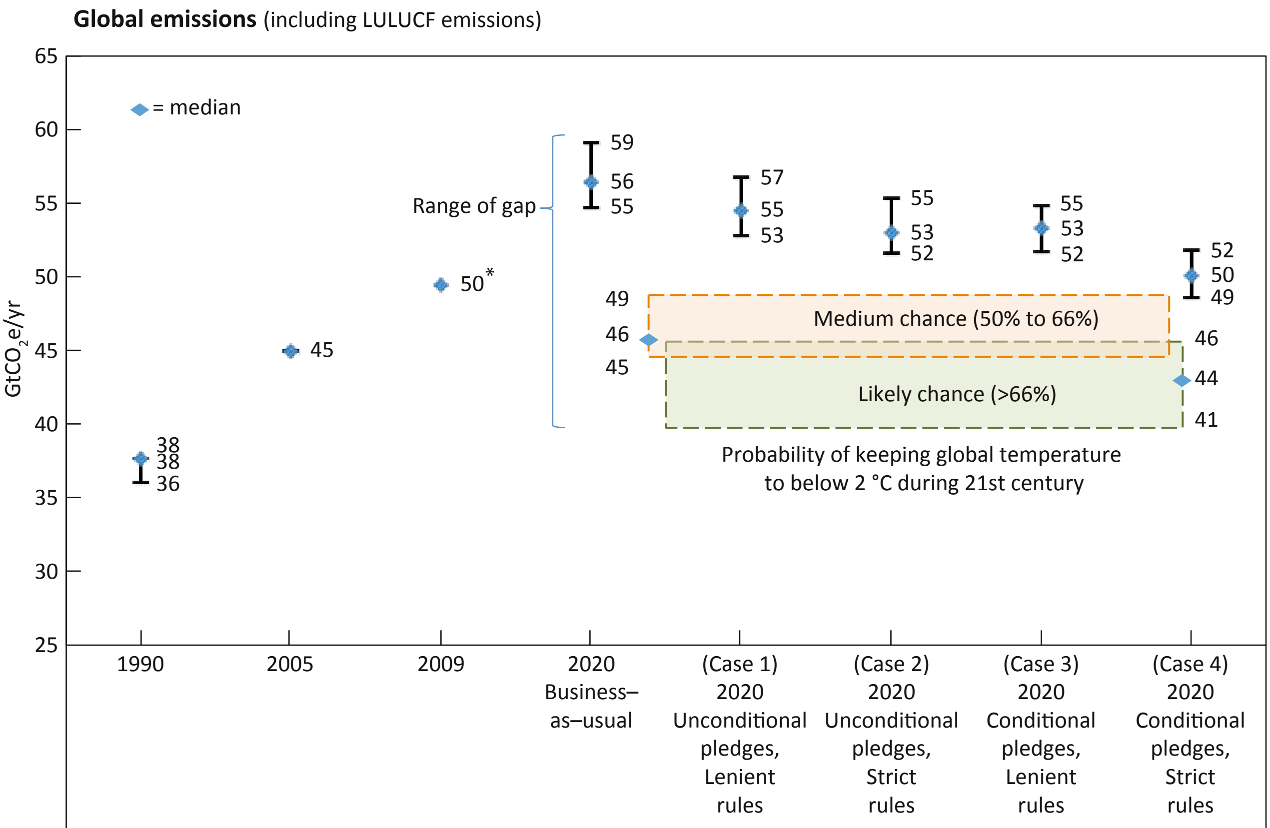
Since the Emissions Gap Report, the gap has increased by 1 to 2 $GtCO_2e$ across all cases. However, the increase in the size of the gap is still smaller than the uncertainty range between different models.

2.4.1 Why has the gap increased?

There are a number of reasons why the gap has increased:

- Countries have not changed their pledges to reduce emissions, but some countries clarified their pledges and published BAU emissions, which increased the assessment of the emission level allowed under the pledges for some studies.
- Half of the modelling groups considered have changed their underlying BAU scenarios for greenhouse gas emissions, some effectively increasing it, and therefore increasing the gap. Two modelling groups (PBL and Grantham) now use generally higher assumptions on BAU economic and emission growth, in particular in developing countries. In their assessment, the gap has widened by about 2-4 $GtCO_2e$. The emissions gap calculated by a third group (Climate Action Tracker) has remained relatively high, but decreased compared to The Emissions Gap Report. This is because Climate Action Tracker's analysis already included high BAU assumptions. In this update, it has lowered BAU for some countries, but increased BAU assumptions for China and Brazil. One group decreased the gap (Climate Interactive), because it adjusted the underlying BAU. One new group was included (OECD) that has a gap larger than the median. The analysis here uses the updated and the unchanged studies. Projections of future emissions remain uncertain, especially in these economically unstable times.

Figure 5. The emissions gap for a "medium" and "likely" chance of meeting 2°C



		BAU	Case 1	Case 2	Case 3	Case 4
What is the expected "gap" for a "likely" chance of staying below 2°C? (In parenthesis figure of the 2010 assessment)	Median gap ($GtCO_2e$)	12 (12)	11 (9)	9 (8)	9 (7)	6 (5)
	Gap range ($GtCO_2e$)	9-18 (10-21)	7-16 (8-18)	6-14 (6-16)	6-14 (5-14)	3-11 (3-12)
What is the expected "gap" for a "medium" chance of staying below 2°C?	Median gap ($GtCO_2e$)	10	9	7	7	4
	Gap range ($GtCO_2e$)	6-14	4-12	3-10	3-10	0-7

* The difference between the 2009 value shown here and the value shown in the figures on page 12 and 13 stems from the use of different data sources and assumptions. A recent estimate indicates 2009 emissions to be 49.5 $GtCO_2e$ (rounded to 50 $GtCO_2e$), but this was not included in the models used in the figures on page 12 and 13 (see Section 2.2 for more details).

2.4.2 Immediate policy options to narrow the gap

Policies exist to help bridge the gap, though in terms of the time available there is now one less year to do so. Moreover, the available options are also fewer. For example, nine scenarios considered to be feasible to bridge the gap in The Emissions Gap report are no longer feasible as they assume changes in the year 2010 that are inconsistent with the observed development.

Immediate policy options to narrow the gap related to the pledges include:[15]

- **Implement (the more ambitious) conditional pledges:** The gap would be reduced by about 2 to 3 $GtCO_2e$. This would require that conditions pledges be fulfilled. These conditions include expected actions of other countries as well as the provision of adequate financing, technology transfer and capacity building.

15. The effects of individual elements overlap. Therefore, the values stated in the paragraphs are not additive.

Alternatively, it would imply that conditions for some countries are relaxed or removed.

- **Minimise the use of 'lenient LULUCF credits' and surplus emission units:** If industrialized countries apply strict accounting rules to minimise the use of 'lenient LULUCF credits' and avoid 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 2 to 3 $GtCO_2e$ (with up to 0.6 $GtCO_2e$ coming from LULUCF accounting and up to 3.0 $GtCO_2e$ from surplus emissions units).
- **Avoid the double counting of offsets:** Double counting of offsets could lead to an increase of the gap by up to 1.6 $GtCO_2e$, depending on whether countries implement their unconditional or conditional pledges (there is likely to be a greater demand for offsets in the higher-ambition, conditional case). Hence avoiding double counting could be an important policy option. The way to realise this would be an international decision that offset reductions can only be counted once. Financing countries could make financing of emission reductions transparent and specify whether emission reductions will count towards their own target.
- **Ensuring strict additionality of offsets:** Reform of the current international offset mechanism, the Clean Development Mechanism (CDM) is under discussion. If this reform can tighten the additionality of certified reductions, this could save up to 0.4 $GtCO_2e$.
- **Implement measures that go beyond current pledges and/or strengthen pledges:** The mitigation scenarios indicate that it is technically possible and economically feasible to reduce emissions beyond present national plans in 2020 (see also chapter 3). As an example, if Annex I countries would reduce their emissions by 25% below 1990 in 2020, it would decrease the gap by an additional 1.6 $GtCO_2e$ beyond the strict conditional case. At 40% below 1990 it would be 4.5 $GtCO_2e$. Some national or regional emission scenario studies for developed and developing countries show the possibility of reducing emissions further than the pledges if more policies and actions were implemented.

Findings of the UNEP report on short-lived GHG species (UNEP, 2011), such as black carbon and tropospheric ozone, have shown that mitigation of such short-lived species can complement although not replace mitigation of long-lived GHG species, such as carbon dioxide. Deep and immediate carbon dioxide reductions are required to protect long-term climate. However, reducing short-lived climate forcers now would slow down the rate of temperature change, which is very important for minimizing short-term climate impacts and avoiding climate thresholds.

The assessment described in the sections above quantifies the gap between pathways in line with 2°C and the pledges of countries under the UNFCCC, taking into account all Kyoto GHGs. Methane is at the same time part of this basket and highlighted in UNEP (2011) as a mitigation option to reduce concentrations of tropospheric ozone. Policies targeting emission reductions of methane can therefore often be accounted towards the 2020 pledges of countries. Both UNEP (2011) and this study affirm that such enhanced mitigation of methane is beneficial for long-term climate goals as long as it is not used to replace mitigation of CO_2 and other long-lived GHGs.

Emission pathways consistent with a 2°C or 1.5°C temperature limit are characterized by rapid rates of emission reduction post-2020. Such high reduction rates on a sustained time-scale will be challenging and 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 a long lifespan, or by developing and demonstrating advanced clean technologies (see also chapter 3).

Chapter 3:

How to bridge the gap - what the scenarios and studies say

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3.1 Introduction

Chapter 2 updated the Emissions Gap Report (UNEP, 2010) and compared projections of global emissions of greenhouse gases under four different sets of pledge assumptions with emissions consistent with 2°C and 1.5°C targets. It was found that the gap in 2020 would be between 6 and 11 $GtCO_2e$ under different pledge assumptions, and 12 $GtCO_2e$ assuming business as usual conditions under which no pledges are acted on.

This chapter explores how to bridge the gap, and takes two approaches to do so:

(1) Results from Global Assessment Models. The first approach is to review selected emission scenarios computed by global assessment models (see section 3.2). The scenarios reviewed have in common that they all comply with the goal of staying below a 2°C increase over the 21st century (the "2°C target"). This set of scenarios overlaps with those reviewed in Chapter 2. The scenarios are generated by first setting a climate target (usually a carbon dioxide stabilization goal) and then using the models to compute a "least cost package" of emission mitigation measures that comply with the target. Since the scenarios stay within the 2°C target, they also bridge the gap between BAU emissions in 2020 and the emissions in line with the 2°C target. Hence the package of mitigation measures identified in the scenarios can be viewed as successful examples of how to close the gap. In this chapter we will refer to these scenarios as "mitigation scenarios".

(2) Sectoral Studies. The second approach is to review detailed studies of emission reduction potentials in various economic sectors up to a certain marginal cost level (see section 3.3). When added up, these estimates give an indication of the total potential for reducing global emissions in 2020. The total potential can then be compared to the 2020 gap to determine whether or not the gap can be bridged. In this chapter we refer to these figures as "estimates from sectoral studies".

3.2 Results from global mitigation scenarios

This section describes potential reductions in greenhouse gas emissions based on scenarios compatible with the 2°C target. It addresses two key questions:

1. What are the packages of mitigation measures that can bridge the gap in 2020 between BAU and emissions consistent with the 2°C target?
2. How do estimates compare across models?

Nine different modelling groups have identified technically-feasible measures to reduce greenhouse gas emissions in line with the 2°C target. Thirteen scenarios from these nine groups are reviewed in this section (see Table 3). Scenarios used in this chapter overlap with those in Chapter 2, but are not exactly the same.[16] In this chapter we analyze both mitigation scenarios and the BAU scenarios upon which they are based. The mitigation scenarios identify packages of mitigation measures that lead to emissions consistent with the 2°C target. Below, we identify these mitigation measures for 2020. The measures can be summarized as (1) improved energy efficiency, as indicated by reduced primary energy use and decreasing energy intensity, (2) a low-emission energy mix, and (3) reduction of non-CO_2 greenhouse gas emissions.

16. Both chapters use only scenarios that comply with the 2°C target. Chapter 2 uses only scenarios that cover all greenhouse gases, whereas Chapter 3 also considers scenarios with only CO_2 emissions. Chapter 3 uses only results that are available with sectoral detail. A further difference is that all scenarios in Chapter 2 were harmonised with the same emissions in 2005, while this was not done in Chapter 3. This is why some of the mitigation scenarios in Chapter 3 have emissions above the 80th percentile range given in Chapter 2.

Table 3. Changes to economic and energy indices needed to close the global emissions gap in 2020.

	Annual economic growth rate from 2005 to 2020 (%)	Global primary energy consumption in 2020 (EJ)	Reduction in primary energy below "current policy" or BaU scenario (%)	Share of global primary energy consumption by different technologies in 2020 (%)						Reduction in non-CO_2 emissions below "current policy" or BaU scenario (%)	Marginal abatement cost (US$/ tCO_2e)	CO_2 emissions from fossil fuels and industry in 2020 ($GtCO_2e$)		Emissions of all greenhouse gases covered by the Kyoto Protocol in 2020 ($GtCO_2e$)	
				Biomass without CCS	Biomass with CCS	Non-biomass renewables (wind, solar, hydro, geothermal)	Fossil without CCS	Fossil with CCS	Nuclear			Emissions	Reduction below BAU	Emissions	Reduction below BAU
AIM-Enduse [1)]	2.60%	508	7.9%	11.7%	0.0%	5.3%	76.6%	0.0%	6.3%	9.6%	85	29	6	42	9
DNE21[2)]	2.81%	596	8.0%	9.0%	0.0%	2.4%	82.0%	0.0%	6.7%	17.3%	25	35	6	44	9
GCAM[3)]	2.42%	584	7.2%	14.5%	0.2%	3.0%	76.1%	0.2%	6.0%	18.9%	28	33	6	45	12
IMAGE[4)]	3.12%	566	6.4%	9.6%	0.0%	3.4%	79.9%	0.5%	6.6%	1.8%	42	34	4	49	4
MESSAGE[5)]	2.59%	539	9.5%	10.2%	0.0%	5.5%	76.9%	0.7%	6.7%	10.1%	30	31	8	47	10
REMIND[6)]	3.40%	563	17.8%	8.6%	3.6%	4.7%	72.9%	3.0%	7.3%	19.1%	54	29	16	39	25
GEA-Supply[7)]	2.59%	548	8.1%	10.2%	0.0%	5.8%	75.0%	1.2%	7.7%	15.5%	45	31	9	48	13
GEA-Mix[7)]	2.59%	531	8.4%	9.9%	0.0%	5.7%	76.5%	0.8%	7.1%	15.0%	34	31	8	48	11
GEA-Efficiency[7)]	2.59%	496	5.5%	7.4%	0.0%	5.1%	80.9%	0.0%	6.7%	12.2%	14	31	4	48	6
Energy [r]evolution[8)]	3.30%	525	10.0%	13.4%	0.0%	7.8%	75.1%	0.0%	3.8%	-	-	27	6	-	-
Advanced energy [r] evolution[8)]	3.30%	516	11.4%	13.7%	0.0%	9.4%	73.1%	0.0%	3.8%	-	-	25	8	-	-
IEA WEO 2010[9)]	3.60%	592	5.1%	10.9%	0.0%	5.0%	77.0%	0.0%	7.1%	-	45	32	4	-	-
The Energy Report[10)]	3.10%	495	9.0%	17.0%	0.0%	7.0%	72.0%	0.0%	4.0%	-	-	-	-	-	-

Results of Asia Modelling Exercise: 1: Akashi *et al.* (forthcoming), 2: Wada *et al.* (forthcoming), 3: Eom *et al.* (forthcoming), 4: van Ruijven *et al.* (forthcoming), 5: van Vliet *et al.* (forthcoming), 6: Luderer *et al.* (forthcoming), 7: Riahi *et al.* (2011)
Scenarios that consider only energy and industry related emissions: 8: Krewitt, *et al.* (2010), 9: IEA (2010b), 10: Deng *et al.* (2010)

3.2.1 Closing the emissions gap (I): emissions and costs

Table 3 describes 13 emission scenarios that comply with the 2°C target and close the gap between BAU emissions and the 2°C target in 2020. Four scenarios only cover energy-related CO_2 emissions. Each of the scenarios has a slightly different figure for economic growth between 2005 and 2020 and a different figure for primary energy consumption in 2020.

The lowest estimate of emissions from fossil fuels and industry is 25 $GtCO_2e$ (Krewitt *et al.*, 2010). The highest is 35 $GtCO_2$ (Wada, *et al.*, forthcoming). This compares to a BAU scenario of emissions from fossil fuels and industry of 33 to 46 $GtCO_2$[17].

For scenarios with all greenhouse gases covered by the Kyoto Protocol, emissions are between 39 and 48 $GtCO_2e$ in 2020 compared to a BAU of 52 to 64 $GtCO_2e$. Altogether, the scenarios in Table 3 achieve the 2°C target with emissions 4 to 25 $GtCO_2e$ lower than BAU conditions in 2020, equivalent to 9-13% below BAU (with one estimate, 25% below).

The cost of the packages of measures ranges from 25 US$/$tCO_2e$ to 54 US$/$tCO_2e$ (with one estimate of 14 US$/$tCO_2e$ and another of 85 US$/$tCO_2e$), with a median value of 38 US$/$tCO_2e$.

The scenario with the lowest carbon price (GEA-Efficiency, Riahi *et al.*, 2011) assumes extreme changes to the world's energy mix, including significant breakthroughs in energy efficiency, motivated by efforts to decrease air pollution and to improve energy security. It also assumes a very low BAU emissions scenario.

The mitigation scenario with the highest carbon price (Akashi *et al.*, forthcoming) assumes the application of costly innovative technologies which pushes up the price of carbon reductions.

Figure 6 shows the greenhouse gas emissions for BAU and mitigation cases for the scenarios of Table 3, for which all greenhouse gases were available[18]. The coloured ranges are the 20th-80th percentile ranges from Chapter 2. It can be seen that the mitigation scenarios in Chapter 2 are collectively somewhat higher than the range of scenarios from this Chapter 3. This would mean that the gap between BAU emissions and the 2°C target in 2020 would be somewhat smaller for the set of scenarios in this Chapter than in Chapter 2.

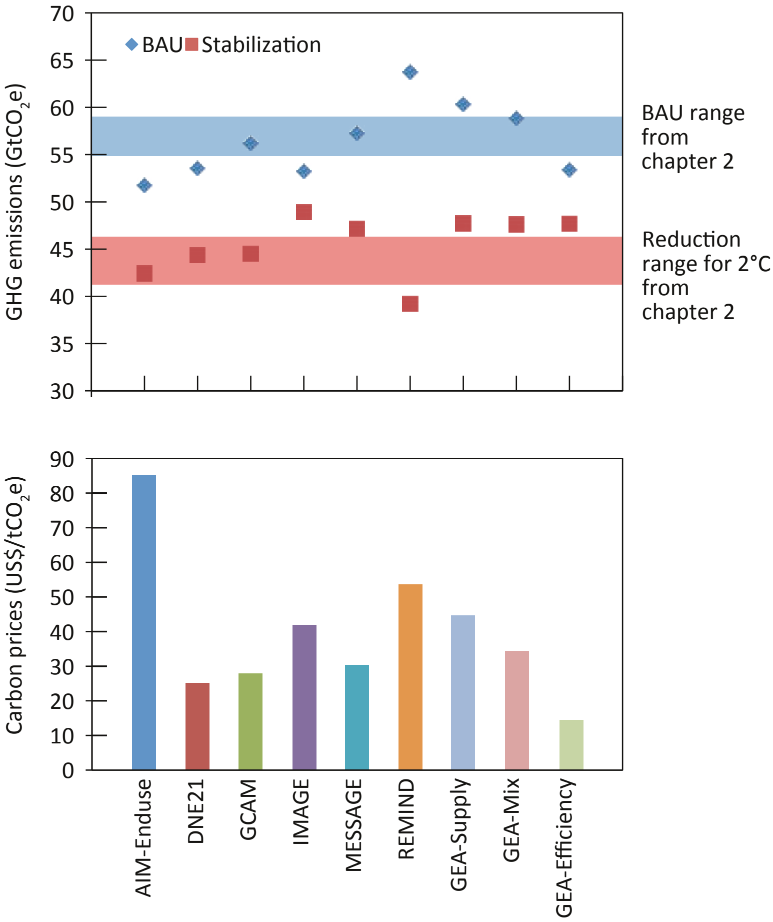
3.2.2 Closing the emissions gap (II): improving energy efficiency

Improving energy efficiency, or likewise decreasing energy use, is of course an effective way to reduce greenhouse gas emissions (assuming other factors remain constant). One indicator of improving energy efficiency is comparing total primary energy use in the mitigation scenarios to a BAU case. In 2020, primary energy use in the mitigation scenarios was 5 -11% lower than in the BAU case, except for one scenario which had 18% lower energy use. These lower levels of energy use were achieved mostly through energy-saving technologies.

Another indicator of improving energy efficiency is a decrease in energy intensity of the economy over time. For the different mitigation scenarios, energy use per unit GDP decreased from 1.1 to 2.3% per year[19] between 2005 to 2020. Meanwhile, the CO_2 intensity of energy (emissions of CO_2 per unit energy) decreased in many scenarios up to 1.0% per year. Faster decreases in CO_2 intensity are expected after 2020 due to the accelerated introduction of renewable energy and CCS.

Figure 7 shows energy efficiency results for 2020 for three different sectors. It is clear from this figure that the models used to generate the scenarios make very

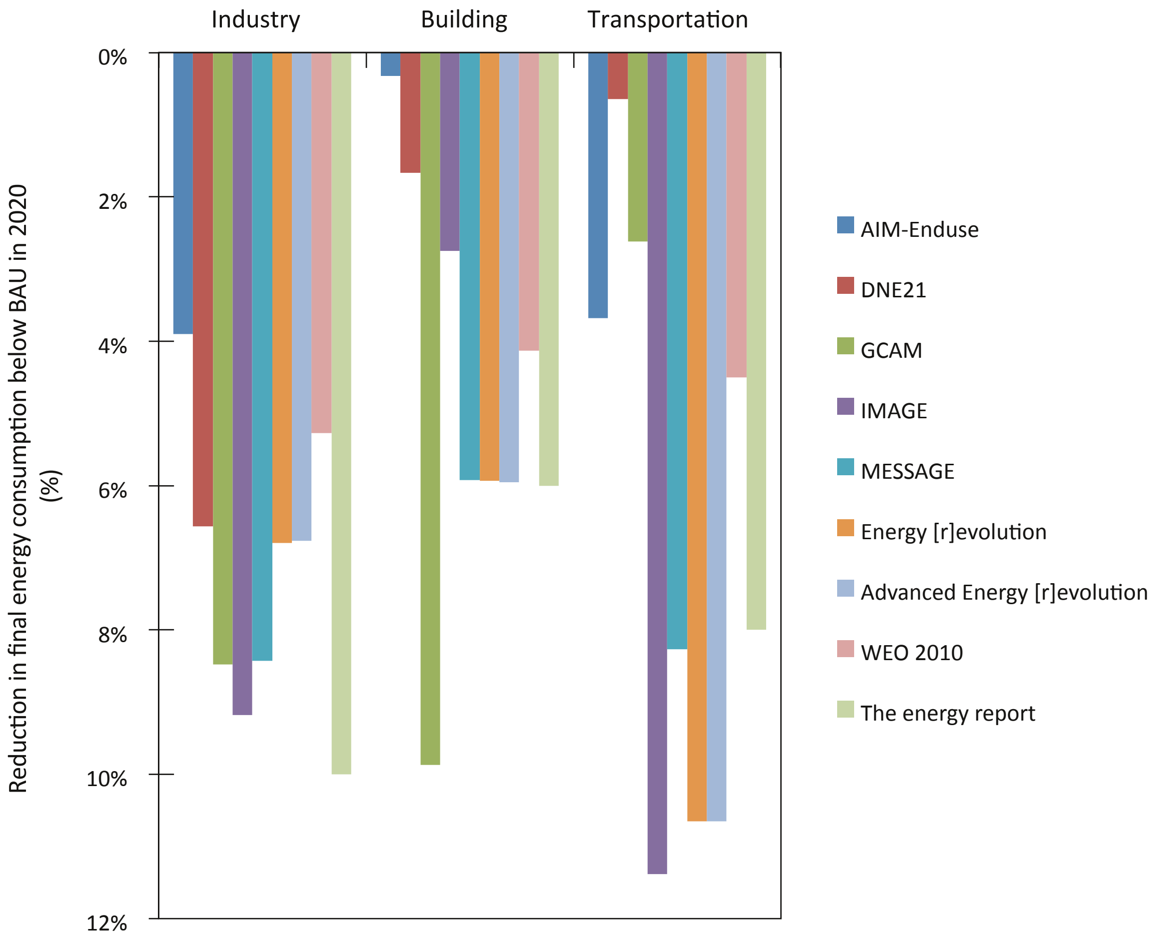
Figure 6. Global greenhouse gas emissions from the BAU and mitigation scenarios with corresponding marginal abatement costs in 2020 for models that considered all greenhouse gases



17. Excluding the Energy Report (Deng *et al.*, 2010)

18. Other scenarios only cover energy-related CO_2 emissions.

Figure 7. Reduction potential of final energy by sector below BAU in 2020 (REMIND and GEA are not included, as such data were not available)



different assumptions about which sector can most economically reduce energy use. All mitigation scenarios assume a substantial reduction of energy in the industrial sector. For the different mitigation scenarios, the reduction of energy use relative to the BAU case is 4% to 10% in the industrial sector, 0.3 % to 10% in the buildings sector, and 1% to 11% in the transportation sector.

3.2.3 Closing the emissions gap (III): lower-emission energy mixes

The energy mix also has a major influence on the magnitude of emissions. In general, emissions are assumed to drop when fossil fuel energy sources are replaced by non-fossil fuel sources (biomass, non-biomass renewables and nuclear). Emissions also decrease under certain kinds of fuel shifting, especially from coal to gas.

For the set of mitigation scenarios, the share of total primary energy from non-fossil fuel energy sources ranged between 18 to 28% in 2020. This is somewhat larger than the 2005 share of around 17 to 20%[19]. All scenarios indicate an increase in energy from renewables between 2005 and 2020, though the range is quite wide, from 2 EJ to 52 EJ.

The share of total primary energy from biomass in 2020 ranges from 7 to 17%, compared with 9 to 12% in 2005. The reduced use of biomass in the short-term in the GEA-efficiency scenario is due to the successful adoption of energy access policies and the resulting substitution of traditional biomass by modern and clean fuels in the developing world.

The share of non-biomass renewables, such as wind, solar and hydropower, ranges from 2 to 9% of total primary energy in 2020 as compared to 2 to 3% in

19. The figure for 2005 is taken from results from the Asia Modelling Exercise and GEA. The base year for “Energy [r]evolution” is 2007 and for “WEO 2010” it is 2008. The energy intensity of Energy [r]evolution, Advanced Energy [r]evolution and WEO 2010 scenarios are 2.6%, 2.7% and 2.3% respectively.

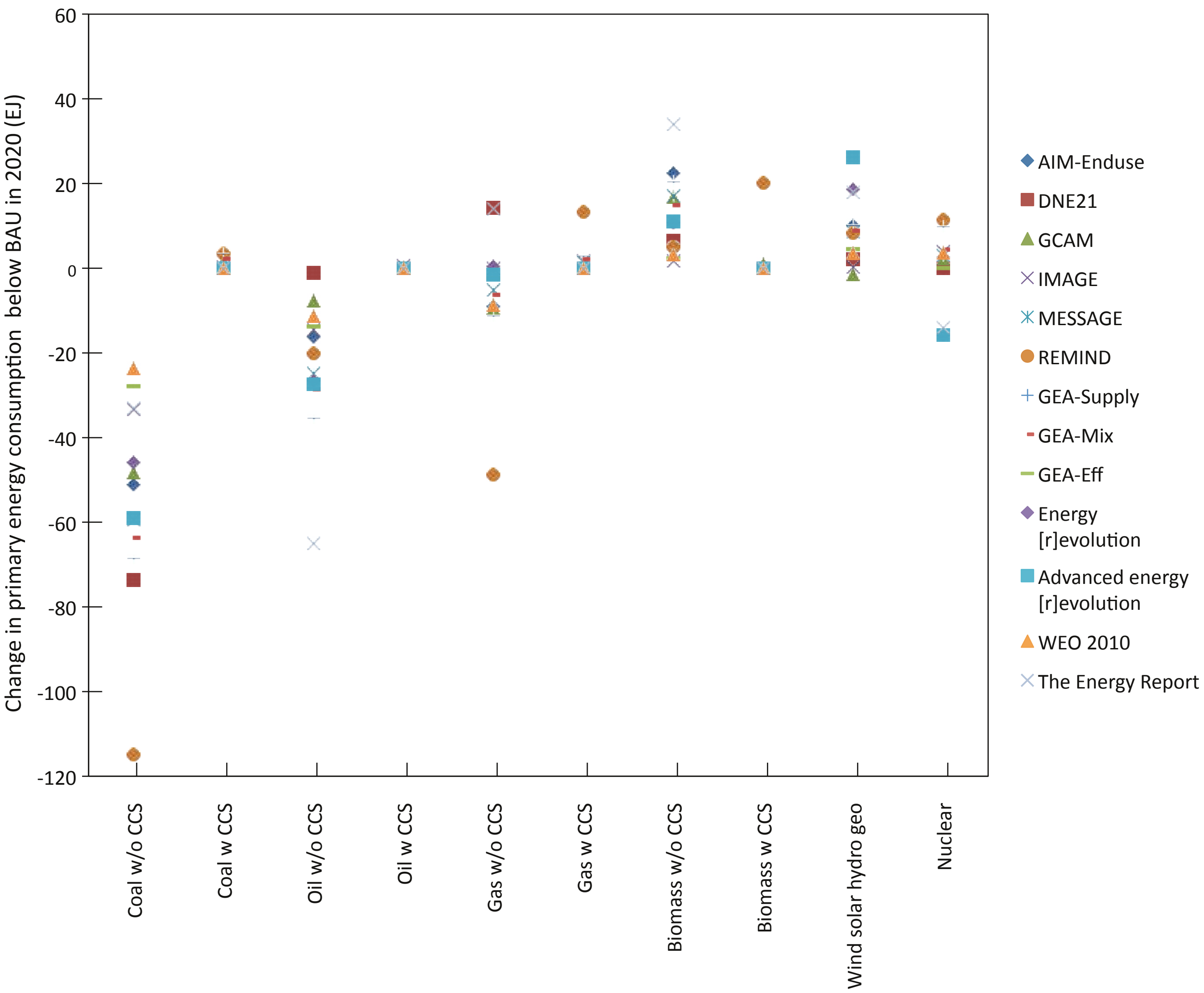
2005. All scenarios indicate an increase in non-biomass renewables from the base year. Nine scenarios whose base year is 2005 indicate increases ranging from 3 to 21 EJ between 2005 and 2020. The DNE21 mitigation scenario computes the lowest share of non-biomass renewables (2%) in part, because it achieves lower emissions through a large shift from coal to gas.

All 13 scenarios are expecting a shift away from “coal without carbon capture and storage (CCS)” to other energy sources, resulting in an average reduction of coal use from 24 EJ to 115 EJ below BAU in 2020 (Figure 8). Some scenarios (REMIND and GCAM) compute that a small amount of energy will be provided by “coal with CCS” in 2020. Energy provided by oil is computed to fall by 1 EJ to 35 EJ below BAU in 2020. Some models compute an increase in energy from gas, and others a decrease compared to BAU. The scenarios also differ in their views of the future contribution of nuclear energy, ranging from a decrease of 14 EJ to an increase of 10 EJ over BAU. One scenario expects a contribution in 2020 of 20 EJ from “biomass with CCS”, and another a contribution of 26 EJ by non-biomass renewables.

3.2.4 Closing the emissions gap (IV): reducing non-CO_2 greenhouse gas emissions

Greenhouse gases other than carbon dioxide, such as methane and nitrous oxide and fluorinated gases, (commonly referred to as “non-CO_2” gases) make up about one-quarter of current total greenhouse gas emissions (US EPA, 2011), and are also expected to make a significant contribution to future emissions. Although the sources of non-CO_2 greenhouse gas emissions vary widely, the models used to compute the scenarios make very

Figure 8. Change of primary energy consumption below BAU in 2020 from scenarios included in Table 3



simple assumptions about mitigation measures for these gases, typically assigning a single removal rate to the entire set of non-CO_2 greenhouse gases. For the mitigation scenarios, non-CO_2 greenhouse gas emissions were 9.6 to 19.1% lower than the BAU scenarios, with one scenario having 1.8% lower emissions.

3.3 Options and emission reduction potentials by sector

This section explores the contribution of individual sectors to bridging the emissions gap. The analysis is based on analytical work on a sectoral level and includes:

- The main emission reduction options
- Total size of emission reductions achievable by 2020, compared to a BAU scenario.

The definition of achievable emission reduction potential varies between the sectoral studies. Achievable here means that the emission reductions are technologically possible, and that certain constraints, e.g. the rate of stock turnover, is taken into account. Most of the studies take into account cost cut-offs, typically between 50 and 100 US$/t$CO_2$e, either explicitly or implicitly. And it is assumed that the potential can be realized if the political willingness is there.

3.3.1 The electricity production sector

The major emissions reduction options for the electricity sector can be categorized as follows:

- Fuel shifting, mainly from coal to gas
- More energy from renewable sources (hydropower, onshore and offshore wind, solar photovoltaic (PV), concentrating solar power, geothermal, wave and tidal power)
- Nuclear energy
- Carbon capture and storage (CCS)
- More efficient fossil power plants

In addition, the more efficient use of electricity can contribute to reducing emissions from the power sector. This will not be dealt with here, but within the sectors that use energy.

Fuel shifting

There are no accurate estimates of the emission reduction potential from changing between fossil fuels (known as fuel shifting). However, it can be said that most of the shift is likely to be from coal to natural gas. The World Energy Outlook (IEA, 2010b) estimates that coal-based power generation will increase by 42% by 2020 in the Current Policies scenario. If all these power plants would be built to use natural gas, it would lead to an emission reduction of 1.9 GtCO_2e in 2020 over BAU in the absence of any other reduction option. However, other emission reduction options could be implemented in parallel, which is why we estimate that greenhouse emissions savings from fuel shifting will be less, and in the order of 0.5 - 1.0 GtCO_2e.

Renewable energy sources

Renewable energy for power generation has grown rapidly over the past decade (REN21, 2011). This is because, over the past 30 years, technologies have steadily improved, costs are coming down, and government policies in this area have expanded (Arent *et al.*, 2011). The quantity of wind-powered electricity production has grown by 27% per year from 2005 to 2010, and the production of photovoltaic electricity has grown by 49% per year in the same period (REN21, 2011). The share of hydropower in global electricity production is now 16% and from "new" renewable sources 3.3% (REN21, 2011).

The IPCC special report on renewable energy sources (IPCC 2011) presents four scenarios with the contribution of renewable energy sources to global electricity production, ranging from 21 to 38% in 2020. Other recently published scenarios suggest that the contribution of renewable energy sources to electricity production in 2020 could be 32% (Deng *et al.*, 2011) or 33 to 38% (Krewitt *et al.*, 2010). The highest estimates would lead to an extra electricity production of 4000 TWh. This could result in an emission reduction potential of 1.5 – 2.5 GtCO_2e.[20]

Nuclear

The electricity production with nuclear power has remained stable over the past several years, amounting to 13% of global electricity production in 2011. In its 2010 World Energy Outlook, the International Energy Agency projects the contribution of energy from nuclear power in 2020 as between 12.5% to 14.5% of the global total electricity production (IEA, 2010b). This represents an increase in production of between 35-40% between 2008 and 2020.

A recent study showed limited progress (Deutch et al., 2009). Another study, taking into account recent slow speed of nuclear construction in comparison to announcements, suggest that nuclear capacity worldwide will decline (Deutsch et al., 2009). To our knowledge, no analysis has yet been performed on the global impact of the Fukushima incident on the development of nuclear

20. Assuming that the realizable potential is between 60 and 100%, and that fossil-fuel based power generation is avoided with an average emission factor of 610 g/kWh

power. Given these uncertainties we do not specify a reduction potential for nuclear power.

CCS

The application of CCS is currently mostly confined to demonstration projects. Currently, 14 projects are operational or under construction: together they are expected to capture 0.03 GtCO_2e per year upon completion. An additional 74 projects are in preparation or being planned (Global CCS Institute, 2011). If all were realized and were, on the average, the same size as the current demonstration projects, this would lead to a *capture* of nearly 0.2 Gt. Net avoided emissions are somewhat less, because the capture process reduces energy efficiency. On the basis of a strong introduction scenario defined by Hendriks (2007), an avoided CO_2 emission of 0.4 Gt in 2020 can be calculated. We take an emission reduction potential of 0.2 – 0.4 GtCO_2e (technical potential) in 2020 for CCS in the power sector, which is more optimistic than most of the scenarios given in section 3.2.

More efficient fossil power plants

No estimates were available on the global mitigation potential from improving the energy efficiency of fossil power plants.

Emission reduction potential

Based on the above, the total emission reduction potential derived for the electricity production sector is between 2.2 and 3.9 GtCO_2e.

3.3.2 Options in the industry sector

Greenhouse gas emissions from industry are dominated by two main sources: the first of these is greenhouse gas emissions from the direct use of fossil fuels (e.g. energy intensive industry such as iron and steel, pulp and paper, as well as cement); the second is the indirect use of fossil fuels via electricity consumption (air-handling, compressed air, space conditioning and lighting). Smaller sources of greenhouse gas emissions in industry include 'non-energy' uses of fossil fuels, such as the use of fossil fuels as feedstocks in chemicals processing; as well as emissions from industrial processes such as the use of calcium carbonate in cement manufacturing. Industry also emits different non-CO_2 greenhouse gases.

Emission reduction options

Due to the diversity of production processes and energy end-uses, there are numerous mitigation options for the industrial sector. Some options are generic and sector wide (e.g. improvements in electric motor driven systems) and some are specific to a certain production process (e.g. for iron and steel or cement). Greenhouse gas emissions can be reduced by:

- Improvements in energy efficiency
- Fuel switching to energy sources with lower emissions (natural gas, biomass, low carbon electricity, geothermal/solar heat, etc.)
- Power recovery through co-generation, pressure recovery turbines, gasification, etc.
- Materials efficiency, waste minimization, recycling and recovery to eliminate energy intensive primary extraction and conversion steps
- Product change and substitution
- CO_2 sequestration

More fundamental technical changes will be needed in the long term after 2020, when energy efficiency and fuel switching are exhausted. Such long-term technical options include new types of cements/concretes, geo/solar thermal heat, and hydrogen from renewable sources for reducing iron ore or for producing nitrogen fertilisers.

Emission reduction potential

The potential for reducing emissions and associated costs from industry by 2020 or later is difficult to estimate because of the diversity and complexity of the industrial sector. Scenario analyses provide an indication of the quantity of greenhouse gases that could be saved in the industrial sector. The IPCC, for example, has calculated that between 3 and 6.3 GtCO_2e per year could be saved by 2030 under one scenario; and that under another scenario, between 2 and 5.1 GtCO_2e per year at a cost of less than US$100/t$CO_2$e (IPCC, 2007a). "Bottom-up" analyses are generally based on what is called "best practice" or "best available technology" as well as assumptions about possible penetration rates in different time frames (IPCC, 2007a, Deng *et al*., 2010). No recent bottom-up estimates are available, but the significant savings potentials of the above mentioned scenarios are confirmed, e.g. (UNIDO, 2010).

The total emission reduction potential derived for the industry sector is between 1.5 and 4.6 GtCO_2e in 2020, assuming that 60 – 80% of the above mentioned potential for 2030 can be realized by 2020. Taking into account that a substantial part of the potential for 2030 consists of retrofitting, this suggests that substantially more than half of the 2030 potential can be realized by 2020.

3.3.3 Options in the transportation sector

Emission reduction options

Options to reduce greenhouse gas emissions in the transport sector include improvements in vehicle fuel efficiency, early adoption of electric drive vehicles, development of low carbon fuels, massive modal shift to public transit and freight rail, and activity reduction.

Technology options to reduce greenhouse gas emissions from on-road vehicles basically involve making them more energy efficient, and reducing the carbon intensity of their fuels. Conventional wisdom holds that consumers and transport operators would demand fuel-efficient equipment to reduce transportation costs. In reality, in the absence of fuel efficiency or greenhouse gas regulations, the uptake of efficiency technologies in fleet-wide fuel economy has varied significantly from market to market and has depended largely on fuel pricing (including subsidies on fuels) and income growth. While efficiency has improved in the past, it has been in some cases offset by higher vehicle performance, additional features, size, and weight, see e.g. Lutsey (2010).

To date, the most extensive efforts to limit the increase in transportation emissions have been via improvements in the fuel efficiency of cars (light-duty on-road vehicles). Recently approved vehicle fuel efficiency standards in the US, EU, and China – already accounted for in the base case – will reduce emissions by about 0.3 $GtCO_2e$ in 2020 (ICCT, forthcoming). Much greater effort, however, is needed to bridge the emissions gap by 2020.

If there are no additional emission reduction policies globally, then transportation emissions are projected to increase to about 11 $GtCO_2e$ in 2020 (ICCT, forthcoming).[21] Although developed countries will be responsible for about half of the global emissions by 2020, about 80% of the growth in transport emissions between now and 2020 will take place in developing countries. Passenger cars, heavy-duty trucks, and aviation will be responsible for about 70% of this growth (ICCT, forthcoming). Without strong measures these trends will not be reversed.

Emission reduction potential

According to a preliminary analysis by the International Council on Clean Transportation (ICCT), the potential to reduce emissions from the transportation sector (excluding aviation and shipping, see Chapter 4) by 2020 is about 1.7 $GtCO_2e$. The majority of this reduction could come from technology options, including expanded use of biofuels and improved vehicle efficiency (ICCT, forthcoming). A breakdown of this potential is as follows: on-road: 0.4 $GtCO_2e$; biofuels: 0.15 $GtCO_2e$; modal shift: 0.8 $GtCO_2e$; activity reduction: 0.25 $GtCO_2e$. This estimate is higher than a previous estimate contained in the 4th Assessment Report of the IPCC (IPCC, 2007a). But the 2007 assessment underestimated the potential for emission reductions in heavy-duty vehicles and in rail transport. Also, modal split changes were not included.

One important opportunity often overlooked for reducing energy use and emissions from the transport sector is "sustainable" city design. Research has shown that a denser settlement pattern can reduce average trip distances and make walking, bicycling, and energy-efficient public transportation a more practical option for city residents and visitors. This reduces dependence on private vehicles which tend to use more energy and produce more emissions per passenger-km than alternative modes of mobility.

The total emission reduction potential derived for the transportation sector (excluding aviation and shipping) is between 1.4 to 2.0 $GtCO_2e$, taking the mitigation potential from ICCT with a generic uncertainty range of about 20%.

3.3.4 Options in the buildings sector

Emission reduction options

According to the IPCC's Fourth Assessment Report (IPCC, 2007b), in the medium term the buildings sector could contribute the largest and most cost-effective potential to closing the emissions gap compared to other sectors. Several studies have since confirmed this (IEA, 2008). Since the IPCC Fourth Assessment Report, the frontiers of building energy efficiency have been significantly extended through advances in building design and operation, progress in cooling and heating technologies, increases in know-how and information technology, and enlightened policies for managing energy in buildings.

For example, one-quarter of new residential floorspace in Austria use less than 15 $kWh/m^2/yr$ (Haus der Zukunft, 2011)[22], which is less than one-tenth of the present stock average of Central European buildings (Harvey, 2009, Ürge-Vorsatz *et al.*, 2011). Thousands of projects have demonstrated that all types of existing buildings can be retrofitted to consume significantly less energy for heating in cold and temperate climates. Such orders of magnitude reductions are more challenging in those climates that need energy for cooling. However, advances in information technology, incorporation of locally-based design ideas, renewable energy, and advanced shading/ventilation do enable low energy buildings in hotter climates (e.g. see Filippin & Beascochea, 2007, Schuetze & Zhou, 2009, UNEP, 2011).

Very energy efficient buildings, or buildings that produce more energy than they consume (energy-plus or net energy supplying buildings), are being built at an increasing rate around the world. Also increasing in number are the mandates, commitments and standards

21. Including aviation and shipping

22. Austria has highest passive house density in Europe: about 2.5 million m^2 (all types of buildings) for 8.4 million Inhabitants while Germany, has 3.4 million m^2 (Bauer, 2011). There are about 17000 low-energy buildings in Germany and Austria (Bertez, 2009).

to construct such buildings (net zero energy or net zero carbon) (IEA, 1995, Parker *et al.,* 2001, Iqbal, 2004, Christian, 2005, Norton & Christensen*,* 2006, Mrkonjic, 2006, US DOE, 2008, Zhu *et al.,* 2009, Wang *et al.,* 2009, Miller & Buys*,* 2010, Ürge-Vorsatz *et al.,* 2011).

Emission reduction potential

For this assessment we compared various recent studies of the emission reduction potential from the buildings sector (IEA, 2006, IIASA, 2007, IEA, 2008, Laustsen, forthcoming, Harvey, 2010, IEA, 2010a, Ürge-Vorsatz *et al.,* undated). The scenarios are not always directly comparable. Emissions from the buildings sector are usually separated into those originating from thermal comfort services (heating and cooling), and those coming from the use of hot water and electrical appliances. Some studies included only part of these emissions. Studies also vary in assumptions about the level of decarbonisation in electricity production, which is important for indirect emissions from the building sector. As for the other sectors, some studies provide technical potential, while others provide economic potential up to a maximum cost level, e.g. 100 US$/t$CO_2$e.

According to most studies, by 2020 mitigation measures in heating and cooling can reduce respective final energy consumption by approximately 25% (20% – 29%), as compared to respective baselines. Accordingly, the emission reduction potential from heating and cooling (typical baseline energy 80 EJ, average emission factor between 70 and 110 kgCO_2/GJ) is 1.1 – 2.6 GtCO_2.

Stock turnover in buildings is very slow and most scenarios assume an acceleration in the construction rate of high-performance buildings. In general, it is noted that high performance buildings will make a major contribution to reducing energy use by 2020, although by 2030 their impact could be much bigger. The studies also show that current policies risk "locking in" the construction of buildings that are much less energy efficient than they could be.

The potential contribution of electrical devices (appliances, lighting, ITC and media equipment) to closing the gap is more difficult to assess due to the multiplicity and diversity of equipment, their short lifetime and turnover as well as their dynamic development; in addition to the poor worldwide coverage of data on their stocks, efficiencies, market turnovers and usages. The Global Energy Assessment (see Ürge-Vorsatz *et al.,* 2011) however concludes that energy-efficient appliances can cut CO_2 emissions by 2020 by approximately 25%, or 0.3 GtCO_2e if emission factors are kept constant.

The emission reduction potential provided above for 2020 is significantly lower than that provided in the Fourth Assessment Report of the IPCC (IPCC, 2007a) (4 GtCO2e in 2020 for marginal costs up to 100 US$/tCO2e), because of the following reasons:

- Different estimation methods were used: IPCC values were aggregated from regional studies, whereas values here are from a comparison of global studies. The estimates are also based on different assumptions of the greenhouse gas emissions avoided per unit of energy saved.
- Less time is available to implement reductions: At the time of the IPCC report, models were more optimistic about short-term emission reductions. Recent studies assume mitigation efforts to start a few years later, which has a significant effect on the short term potential by 2020. But studies are still in agreement that substantial reductions can be made in the longer term.

Based on the above, the total emission reduction potential derived for the buildings sector is 1.4 – 2.9 GtCO_2e.

3.3.5 Options in the forestry and agriculture sectors

Emission reduction options

Mitigation options in the forestry sector include reducing emissions from deforestation and forest degradation and enhancing carbon sequestration by undertaking afforestation and agroforestry projects, and through the sustainable management of new and existing forests (Nabuurs *et al.*, 2007).

Agricultural mitigation measures include changes in cropland management and livestocking practices that enhance soil carbon as well as reducing non-CO2 greenhouse gas emissions. These include:

- Reduced tillage
- Reduced and improved fertilizer management
- Irrigation management
- Enteric and manure emissions management through changes in feed and handling
- Grazing and grassland soil management.

Forestry and agricultural residues or products could also be used as a bio-energy feedstock in order to displace fossil fuels. However, this option is not included in the mitigation potential calculations of this section.

Emission reduction potential

Very few estimates of emissions reductions are available for either sector for 2020. Therefore, we adjust the more available estimates from 2030 for estimating the potentials in 2020.

The IPCC (Nabuurs *et al.* 2007) estimates the emission reduction potential from forestry to be in the range of 1.3 to 4.2 GtCO_2e in 2030 at carbon prices of up to 100 US$/t$CO_2$e. A carbon price of 20 US$/t$CO_2$e would achieve 50%

of the medium estimate of these emission reductions. Nabuurs *et al.* (2007) base their calculations of the economic potential of forestry mitigation options mainly on bottom-up assessments which tend to yield lower results compared to top-down modelling approaches.

Estimating the potential for emission reductions from agriculture is more complex and more uncertain than it is for forestry. The IPCC (Smith *et al.*, 2007) estimates the potential range of reducing agricultural emissions to be 1.5-1.6, 2.5-2.7, and 4.0-4.3 $GtCO_2e$ at carbon prices of up to 20, 50 and 100 US$/t CO_2e. However, there is limited evidence and medium agreement for these estimates, such that the ± 1 standard deviation range is broad, e.g. 2.3 to 6.4 $GtCO_2e$ for 100 US$/$tCO_2e$.

Golub *et al.* (2009) is one of the few studies that provides reduction potentials for 2020. Using a top-down economy-wide economic framework that accounts for global interactions between agriculture and forestry (via input, commodity, and international markets), they estimate global mitigation potential of approximately 0.8 $GtCO_2e$ for agriculture and 8.5 $GtCO_2e$ for forestry at about 20 US$/$tCO_2e$, increasing to 1.1 and 9.6 $GtCO_2e$ at 27 US$/$tCO_2e$. Note that the Golub *et al.* agricultural abatement does not include all the soil carbon management possibilities noted by Smith *et al.* (2007). Note also, however, that the Golub *et al.* estimates assume an immediate and global GHG price signal and no market implementation and transaction costs.

It turns out that top-down global studies that look for least-cost opportunities to reduce emissions in all sectors tend to find a lower potential for the forestry and agriculture sectors, as compared to the numbers citied above. For example, Nabuurs *et al.* (2007) suggest a central estimate of about 0.7 $GtCO_2e$ in 2030 from forestry. Smith *et al.* (2007) estimate reductions of methane and nitrous oxide emissions from crops and livestock of 0.3–1.5 $GtCO_2e$ globally in 2030 with carbon prices up to 20 US$/$tCO_2e$, and 0.6–1.9 $GtCO_2e$ with carbon prices up to 50 US$/$tCO_2e$.

While the above estimates suggest that there is a large but uncertain potential for emission reductions from forestry and agriculture by 2020, there are significant challenges to realizing it: e.g., the uncertainty of emission estimates, the lack of policy coordination between various institutions, the lack of readiness for implementation, the question of net greenhouse gas benefits of various measures outside of the sectors, the implications on welfare, and the question of public acceptance.

Based on these findings, the emission reduction potential in 2020 derived for forestry is 1.3 – 4.2 $GtCO_2e$, which is roughly equal to that estimated by the IPCC (2007a) for 2030. The emission reduction potential in 2020 derived for agriculture is 1.1 – 4.3 $GtCO_2e$, based on IPCC values for 2030, but with a smaller value for the lower end of the range taken from Golub *et al.* (2009). Note that for forestry this does not include top-down estimates, which would increase the forestry range to 8.5 $GtCO_2e$ at 20 US$/$tCO_2e$.

3.3.6 Options in the waste sector

Emission reduction options

Methane constitutes some 90% of greenhouse emissions from waste. Half of methane emissions are from landfill and 40% come from wastewater. The remaining (nearly 10%) of greenhouse emissions from waste are nitrous oxide (N_2O) from wastewater, together with a small contribution of CO_2 which is emitted when plastics and synthetic textiles are incinerated.

Emission reduction options are widely available and have relatively low costs. They include: landfill gas recovery and utilization (fully commercial since 1975); the design and implementation of landfill “biocovers” to optimize methane oxidation; technologies for waste incineration and wastewater treatment; as well as technologies such as composting, anaerobic digestion and reuse/recycling, all of which prevent waste from going to land-fills. Each of these can be cost-effectively implemented for the dual purposes of improved waste management and mitigation of greenhouse gas emissions.

According to the IPCC’s Fourth Assessment Report, the contribution of the waste sector to greenhouse gas emissions was estimated in 2005 to be 1.3 $GtCO_2e$ (Bogner *et al.*, 2007). Based on business-as-usual case, these emissions are projected to rise to about 1.7 $GtCO_2e$ in 2020 (Monni *et al.*, 2006; US EPA, 2011), and most of this rise is expected to come from developing countries.

Emission reduction potential

In terms of the costs of abatement, the range of estimates is wide. Delhotal *et al.* (2006) estimate that the costs for greenhouse gas abatement from landfill gas utilization ranges from a gain of 20 US$/$tCO_2e$ to a cost of 70 US$/$tCO_2e$. According to the same study, costs for landfill gas flaring are 25 US$/$tCO_2e$; 240-270 US$/tCO_2e for composting; 40-430 US$/$tCO_2e$ for anaerobic digestion; 360 US$/$tCO_2e$ for mechanical and biological treatment and 270 US$/$tCO_2e$ for incineration. Monni *et al.* (2006) have developed baseline and mitigation scenarios for the costs of solid waste management. Delhotal *et al.* (2006) and Monni *et al.* (2006) conclude that substantial emissions reductions can be achieved at low or negative costs (less than 20-30 US$/$tCO_2e$). Both studies also assume the same capital costs across all regions, but use regionalized labour costs for operations and maintenance. At higher costs, more significant reductions are possible from solid waste management (more than 80% from baseline emissions), with most of the additional reduction coming from incineration. These mitigation measures not only reduce methane but in some cases also reduce fossil fuel consumption when the recovered methane is used as an energy source.

Based on the above, the total emission reduction potential derived for the waste sector is around 0.8 $GtCO_2e$. This assumes an 80% reduction below the baseline of landfill emissions only (1.0 $GtCO_2e$, Bogner *et al.*, 2007). In addition there may be some potential to reduce the remaining non-landfill emissions.

3.3.7 Total emission reduction potential

The emission reduction potentials identified in this section are listed in Table 4. As seen from this table, the uncertainty range in the sectors is high, leading to a high range in the overall estimate. The full range is 16 ± 7. But assuming that not all uncertainties are at their high end simultaneously, we find a smaller range of 16 ± 3, which we consider a more reasonable estimate of the uncertainty.[23] Regardless of the span of uncertainty, the mid-range estimate (16 $GtCO_2e$) is large enough to bridge the 12 $GtCO_2e$ gap in 2020 between BAU emissions and the emissions level consistent with the 2°C target. Marginal costs of reduction range up to about 50 - 100 US$/$tCO_2e$. (In the studies reviewed, costs are either explicitly specified or implicitly assumed.)

This figure should not be considered as a stand-alone figure, but primarily to confirm that sufficient reduction potential is available to close the emissions gap. One of the reasons for this caution is that the BAU scenarios are not necessarily consistent across the sectors. In addition, the definition of what is achievable varies greatly among the studies. Nevertheless, most studies take into account cost cut-offs of around 50 and 100 US$/$tCO_2e$, as noted above. Another qualification is that strong policy efforts are necessary to achieve emission reduction potentials, although as said below, climate policies and measures have already become wide-spread around the world.

The present analysis shows that in many cases not much new material is available in addition to the 4th Assessment Report of the IPCC (IPCC, 2007a). In other cases, newer studies came to different conclusions than the IPCC in 2007. In particular, the estimates of emission reduction potential for the building sector for 2020 presented here are lower than previously estimated. Recent studies assume mitigation efforts to start a few years later, which has a significant effect on the short term potential by 2020. But the studies still agree that substantial reductions can be made in the long term.

3.4 Conclusions

The mitigation scenarios from the global integrated assessment models show that it is technologically and economically feasible to bridge the gap in 2020 between BAU emissions and emission levels consistent with the 2°C target. They show that the gap can be closed at marginal costs of around 38 US$/$tCO_2e$ (range 15-85 US$/$tCO_2e$).

An important finding from the review of the mitigation scenarios is that intervening in the energy system in particular can be a successful strategy for reducing emissions. But many different combinations of interventions are possible – improving energy efficiency, introducing different low-emission energy mixes, and reducing non-CO_2 greenhouse gas emissions. No single approach dominates the portfolio of measures identified

Table 4. Sectoral greenhouse gas emission reduction potentials in 2020 compared to BAU, at costs typically between 50 and 100 US$/$tCO_2e$, either explicitly or implicitly.

Sector	Emission reduction potential in 2020 ($GtCO_2e$)
Power sector	2.2 – 3.9
Industry	1.5 – 4.6
Transportation (excluding aviation and shipping)	1.4 – 2.0
Buildings	1.4 – 2.9
Forestry	1.3 – 4.2
Agriculture	1.1 – 4.3
Waste	around 0.8
Total (excluding aviation and shipping)	**16 ± 3** (Assuming not all uncertainties at their high end simultaneously. Full range = 16 ± 7)[24]
Total (including aviation and shipping from Chapter 4, and rounding)	**17 ± 3** (Assuming not all uncertainties at their high end simultaneously. Full range = 17 ± 7)[24]

23. It is unlikely that all or several sectors will be simultaneously at the high ends of their uncertainty range. Therefore, assuming that the uncertainties are independent between sectors (which may hold under many cases) we can apply an error propagation rule to calculate the range of the sum of the sectors (the square root of the sum of the squares of the range for each sector). This gives a reduced range of ± 3.

24. See previous footnote

in these scenarios. Most scenarios show an increase in the application of renewable energy sources, but to a widely varying extent. Also all scenarios show an additional improvement of energy efficiency compared to BAU: 5 to 11% (with one study indicating a reduction of 18%). Most scenarios show an increase in the use of natural gas and all scenarios see a decrease of the use of coal. With only one exception, CCS does not play a role as emission reduction technologies in 2020.

The sectoral bottom-up analysis confirms the potential to close the gap. For all sectors, substantial emission reduction potentials are found, with a total in the range of 16 ± 3 $GtCO_2e$ compared to BAU in 2020. (This sum does not include aviation and shipping which is dealt with separately in Chapter 4). These potentials can be realized at marginal costs of reduction up to about 50-100 US$/ tCO_2e and assuming that strong, long-term and sector-specific policies are in place at global and national levels. Delays in taking action will reduce the emission reduction potential because less time will be left to implement measures.

The good news is that a wide range of policy instruments for mitigating greenhouse gas emissions have already been adopted and are in use in many different sectors and countries throughout the world, and these instruments are successful in reducing emissions (e.g., Gupta *et al.,* 2007, Billet & Bowerman 2009, WEC, 2010).

As an overall conclusion, this chapter shows that policymakers and stakeholders have a degree of flexibility in choosing from a wide variety of options that add up to significant total emission reductions. Furthermore, the potential for reducing emissions is sufficient enough to bridge the gap in 2020 between BAU emissions and the emissions consistent with a 2°C/1.5°C temperature target.

Chapter 4:

International Emissions

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4.1 Introduction

In The Emissions Gap Report (UNEP, 2010), international emissions of CO_2 from aviation and shipping were not specifically discussed. Emissions from aviation and shipping are considered in this chapter since international emissions cannot be part of UNFCCC member states' pledges because they are the only sectors not covered by developed country's commitments under the Kyoto Protocol. Article 2.2 of the Protocol states that: "The Parties included in Annex I shall pursue limitation or reductions of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively."

Thus, this chapter addresses them separately. Furthermore:

- Emissions are significant: the combined civil emissions from these two sectors in 2005 were approximately 1.6 $GtCO_2e$ and represented 5.4% of total CO_2 emissions (from fossil fuel usage, cement production and gas flaring[25]);
- International emissions dominate total emissions, being 62% of total aviation in 2006 (ICAO, 2010a) and 83% of total shipping emissions in 2007 (Buhaug *et al.*, 2009);
- Integrated Assessment Models (IAMs) used for estimating the magnitude of the emissions gap (Chapters 2 and 3) include emissions from aviation and shipping only as part of a broader transport sector.

This chapter, however, addresses total *global* emissions from these sectors as opposed to 'international emissions' as defined by the Kyoto Protocol, following the practice of IAMs and scientific assessments of impacts. In addition, these industries are global in nature; abatement measures of an operational or technical nature do not lend themselves to differentiation between international and domestic emissions.

Apart from the long-term warming caused by CO_2 emissions, both shipping and aviation have significant non-CO_2 emissions and effects that impact upon radiative forcing in both positive (warming) and negative (cooling) ways. Overall, aviation's non-CO_2 effects generate significant additional warming over shorter timescales (Lee *et al.*, 2009). Shipping has short-term, local cooling effects but these do not outweigh the longer-term warming effect of CO_2. These effects are not dealt with further here but assessments are provided by Lee *et al.* (2010) for aviation and by Eyring *et al.* (2010) for shipping.

In the following section, we describe baseline (2005) emissions, review available projections of emissions for aviation and shipping from the literature, and assess the measures available for emission reductions beyond BAU developments, as well as policies to drive them. Finally, we provide an evaluation of how emissions from these sectors could be reduced beyond BAU and how implementation of further measures could contribute towards closing the gap between pledges and emissions consistent with the 2°Ctarget.

4.2. Baseline emissions and future projections

4.2.1 Baseline emissions for 2005

Aviation. Baseline emissions of CO_2 from aviation in 2005 were 0.74 $GtCO_2e$, using International Energy Agency data on kerosene fuel sales, which includes civil and military uses (IEA, 2009). Civil (only) aviation emissions in 2005 are likely to have been approximately 0.63 $GtCO_2$[26] (ICAO, 2010a) and were 2.1% of global emissions of CO_2.

25. http://cdiac.ornl.gov/ftp/ndp030/global.1751_2008.ems

26. This number is slightly larger than that estimated with complex bottom-up inventory models, but such models are known to have a small but significant low bias because of incomplete coverage of movements, simplifications regarding routing assumptions and holding patterns, etc. and have been factored up by a best estimate for 2006 (ICAO, 2010a), which is unlikely to be significantly different from 2005.

Shipping. In contrast to aviation, IEA fuel sales data under-report shipping emissions for a number of known reasons (see Buhaug *et al.*, 2009). The 2005 best estimate used activity-based methods and is taken from the Second IMO Greenhouse Gas Study (Buhaug *et al.*, 2009), which presented a consensus estimate of 0.96 $GtCO_2e$ for 2005, some 3.2% of global emissions of CO_2.

4.2.2 Emissions projections to 2020 and the outlook for 2050

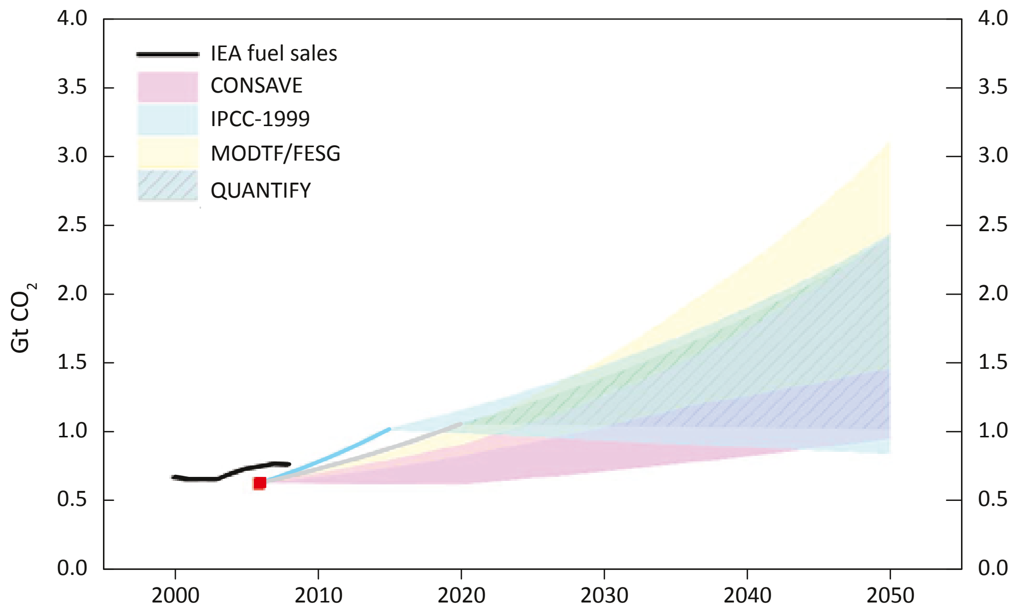
A number of near-term 'forecasts' and longer-term 'scenarios' for aviation and shipping CO_2 emissions have been published in recent years. Forecasts consider the nearer term (e.g. 2020), and are based upon extrapolation of current activity and anticipated growth, and incorporate development of known technologies and their penetration into the global fleet. Scenarios usually consider the longer-term, e.g. 2050, and are often developed from broader assumptions on drivers to growth (typically global GDP) and longer-term projections of technology development.

Aviation. Projections of emissions of CO_2 through to 2050 are available from the IPCC Special Report on "Aviation and the Global Atmosphere" (IPCC, 1999), the CONSAVE[27] project (Berghof *et al.*, 2005), the QUANTIFY project (Owen *et al.*, 2010), and the International Civil Aviation Organization (MODTF/FESG, 2009). These projections/scenarios deal with the 2020 timeframe in different ways, and the data are illustrated in Figure 9. Projections of civil aviation emissions range from 0.62 to 1.16 $GtCO_2e$ in 2020.[28]

Broadly, these projections vary principally with growth assumptions and are variations of BAU scenarios of the future. Some individual scenarios include particular assumptions regarding technologies, or technology targets[29], but for the most part, assume no specific policy intervention.

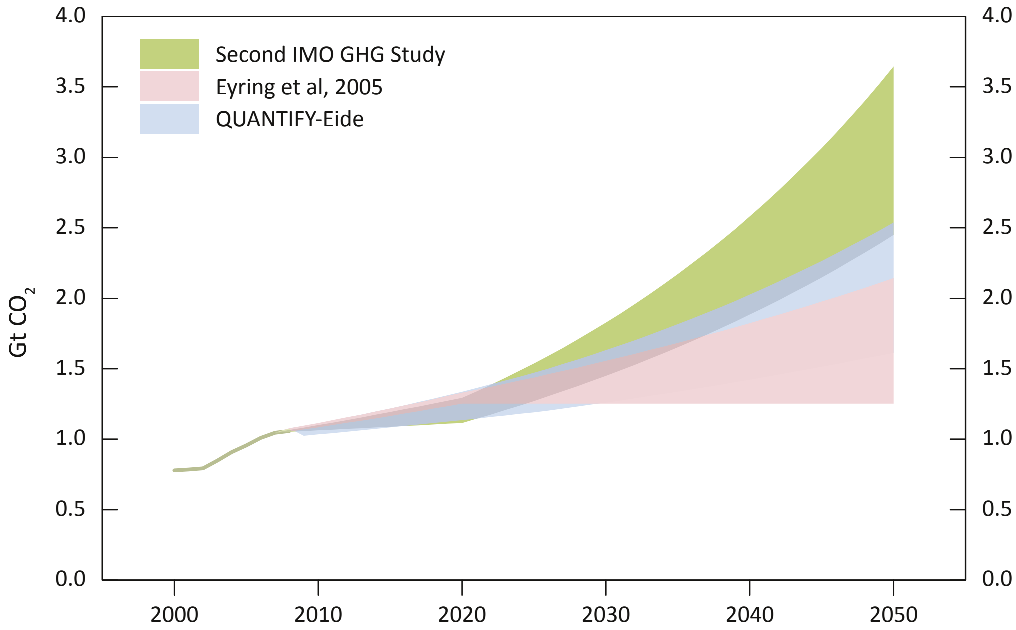
Shipping. Projections out to 2020 and beyond have been made for the shipping sector by (Eyring *et al.*, 2005), the QUANTIFY project (Eide *et al.*, 2007; 2011), and under the Second IMO Greenhouse Gas Study (Buhaug *et al.*, 2009).

Figure 9. Emissions of CO_2 from aviation from 2000, and projections through to 2050. Data from 2000 to 2009 based on IEA fuel sales data. Projections from: MODTF/FESG (2009); QUANTIFY project (based on Owen *et al.*, 2010); IPCC aviation special report (IPCC, 1999); CONSAVE project (Berghof *et al.*, 2005). Data are interpolated from the red dot, which represents a best estimate of civil aviation emissions in 2006 at 0.63 $GtCO_2e$ (see text) to forecast/scenario data points. The solid line (IEA fuel sales) refers to total aviation as compared to the rest of the data which refer to only civil aviation.



27. The CONSAVE 'Down To Earth' scenario was excluded, as the view was taken within MODTF/FESG (2009), which included CONSAVE researchers, that it was not plausible because of its strong reliance on behavioral change, which was deemed unlikely.
28. The lower part of the range may contain scenarios with a technology target. Strictly speaking, this makes them more like intervention scenarios than business-as-usual scenarios.
29. See previous footnote.

Figure 10. Emissions of CO_2 from shipping from 2000 to 2007, and projections through to 2050. Data from 2000 to 2007, IMO Second GHG Study (Buhaug *et al.*, 2009). Projections from: IMO Second GHG Study (Buhaug *et al.*, 2009; Eyring *et al.*, 2005); QUANTIFY project (Eide *et al.*, 2007). Note that projections from Eyring and Eide have been adjusted upwards to calibrate against the 2007 estimate reported by Buhaug *et al.* (2009). Data are interpolated between 2007 and forecast/scenario data points.



Shipping emission projections also cover a range of growth scenarios (using SRES[30]-type assumptions) and envisaged BAU technology and operational improvements, resulting in an envelope of potential emissions from 1.11 to 1.34 $GtCO_2e$ in 2020.

Emissions are illustrated over the 2020 and 2050 timeframes in Figure 10.

4.2.3 Implications of shipping and aviation projections for emissions consistent with a 2 °C target

Here we consider the consequences of the range of published projections for total global aviation and shipping for 2020 (and an outlook to 2050).

A set of emission pathways consistent with a 2 °C target by 2100 is given in Chapter 3. If aviation and shipping emissions are combined, and if they progress according to any scenario, from the minimum to their maximum[31], they account for an increasing share of total emissions. In 2020, aviation and shipping (combined) emissions are expected to range from 1.74 to 2.50 $GtCO_2e$, representing 4.0 to 5.7% of the median total emissions in 2020. In 2050, aviation and shipping (combined) emissions are expected to range from 2.09 to 6.77 $GtCO_2e$, representing 10.0 to 32.5% of the median total emissions in 2050. As aviation and shipping emissions increase percentage-wise, it follows that the sum of emissions from all other sectors would have to proportionately decrease to ensure that total emissions do not exceed the emissions level consistent with a 2°C target.

4.3 Targets, Goals, Measures, and Abatement Potential

4.3.1 Targets and Goals

Aviation. At its 2010 Assembly, the International Civil Aviation Organization (ICAO) agreed to a voluntary goal of a 2% fuel efficiency improvement per year of the global fleet until 2020, and a continued aspirational goal of 2% improvement per year until 2050 (ICAO, 2010b). In addition, the International Air Transport Association (IATA) has declared CO_2 emissions voluntary goals to improve fuel efficiency by 1.5% per year to 2020, 'carbon-neutral growth' from 2020, and a reduction in CO_2 emissions by 50%, relative to 2005 levels, by 2050.

Shipping. Since 2009, the IMO has considered whether international shipping should be subject to an explicit emission ceiling (cap) in the future, or whether a reduction target should be formulated in some other

30. 'SRES' – IPCC Special Report on Emissions Scenarios (IPCC, 2000).

31. As defined by endpoint emissions in 2050 – these particular scenarios do not necessarily have the maximum or minimum emissions in 2020.

way. A wide variety of views have been expressed by IMO member states; some have supported targets, whilst others have expressed concerns about their potential economic impacts as well as equity issues. No conclusion has been reached, although discussions are scheduled to continue at future meetings of IMO's Marine Environment Protection Committee (MEPC).

4.3.2 Measures

'Measures' here are the technological and operational means, or changes in demand, which may reduce emissions, for example, through fuel efficiency improvements from engine and airframe technology design, ship hull design and engine technology improvements, or an increased uptake of less carbon-intensive fuels, etc.

Aviation

Operational measures. Airspace is subject to suboptimal use and interference from weather conditions such that improved air traffic management can potentially facilitate reduced fuel burn. For instance, by adopting a 'continuous descent approach', where an aircraft's descent starts at an optimal point; or following procedures that minimize delays at or around airports. Estimated available efficiency improvements range from 3-10% (NARDP, 2010), although increasing traffic volumes will make it harder to fully optimize operations.

Technological measures. Historically, advances in engine and airframe technologies have been instrumental in improving aircraft fuel efficiency. Technologies that have the potential to improve future efficiency include lighter materials, adaptable wing trailing-edges, open-rotor and geared turbofan engines, and advanced on-board flight management systems, although not all realistically apply to a 2020 timeframe. Current technologies could improve the fuel efficiency of new aircraft types by 19–29% by 2020, relative to current technology, and 26–48% by 2030 (IE Report, 2010)[32]. Changes in engine design alone, such as increasing pressure ratio, could force a tradeoff between reduced emissions of CO_2 versus increased emissions of nitrogen oxides (NO_x) per unit fuel, and require additional attention to combustion technology design.

Biofuels. Low-carbon alternatives to aviation kerosene may include biofuels, although associated indirect emissions must be considered. Lifecycle reductions of up 80% have been claimed (IATA, 2009); the emissions associated with land-use change vary significantly but may reduce carbon-savings or even lead to an increase (Stratton *et al.*, 2010). This chapter, however, follows IPCC guidelines in accounting for indirect emissions elsewhere, i.e. we assume biofuels deliver a 100% reduction in aviation (and shipping) CO_2 emissions.

The contribution of biofuels has been estimated by CCC (2009) to be ≤2% by 2030 under what was described as a "likely" scenario, ~3% for an "optimistic" scenario, and 5% for a "speculative" scenario. Similarly, a 2% market penetration of biofuels by 2020 was deemed feasible by Novelli (2011).

Other measures. Changes in levels of utilization also have the potential to reduce emissions in the aviation sector. Such changes may come about as a result of policies that seek to influence modal shifts (where practicable and environmentally beneficial), or reduce demand. In addition, changes to utilization may come about through other technological developments such as videoconferencing. However, there are not enough globally-applicable studies to provide reliable estimates of emission reductions from demand-related measures.

Shipping

Operational measures. The most effective operational measure for shipping is speed reduction or 'slow-steaming'. Other measures include optimization of ballast and trim, weather routing, propeller maintenance, and increased frequency of hull cleaning.

Speed reductions result in reduced power requirements and fuel consumption (Buhaug *et al.*, 2009, Eide *et al.*, 2011), there being an approximately quadratic relationship between speed and fuel consumption per unit distance. Slow-steaming has been adopted voluntarily because of increased fuel prices and reduced demand, resulting in a ~11% decrease in CO_2 emissions from 2008 for some ship types (Cariou, 2011). Other operational measures have lower abatement potentials, estimated to be ~ 1-5% (Buhaug *et al.*, 2009, Wang *et al.*, 2010).

Technological measures. There are numerous technological measures that can be implemented to improve the fuel efficiency of ships. Wang *et al.* (2010) listed 19 such measures. Eide *et al.* (2011) listed 25 measures of which 17 are 'technological' and provide a detailed analysis of marginal abatement costs. These include modifications of the engine; improvements to hull form, rudder, and propeller; waste heat recovery, and harnessing wind power for propulsion. Not all measures are applicable to all ship types, or to ships of all sizes and some measures exclude others. Their individual abatement potential is generally estimated as ~1-5% (Buhaug *et al.*, 2009, Wang *et al.*, 2010) although a few have theoretical abatement potential of >10%.

32. This report only considered single-aisle (e.g. Boeing 737-800, Airbus A320) and small twin-aisle aircraft (e.g. Boeing B777-200ER, Airbus A330). The metric was fuel-burn per available tonne km at maximum payload, maximum range conditions over a 2000 reference point. .

Modifications to engines for increased fuel efficiency can bring about increases in NO_x per unit fuel, which have impacts on air quality and regional pollution, requiring additional abatement measures or changes in combustion design.

Alternative and low-carbon fuels. Potential alternatives to conventional marine fuels include liquefied natural gas (LNG) and biofuels (Eyring *et al.*, 2005). LNG has a lower carbon to hydrogen ratio than diesel fuels, resulting in ~15% lower CO_2 emissions[33] (Kollamthodi *et al.*, 2008), with co-benefits of reduced emissions of NO_x and sulphur oxides (SO_x). Most types of biofuels can be used in current engines without any need for modifications although the relatively low price of marine fuels makes them uneconomical (Buhaug *et al.*, 2009).

4.3.3 Analysis of potential emissions reductions

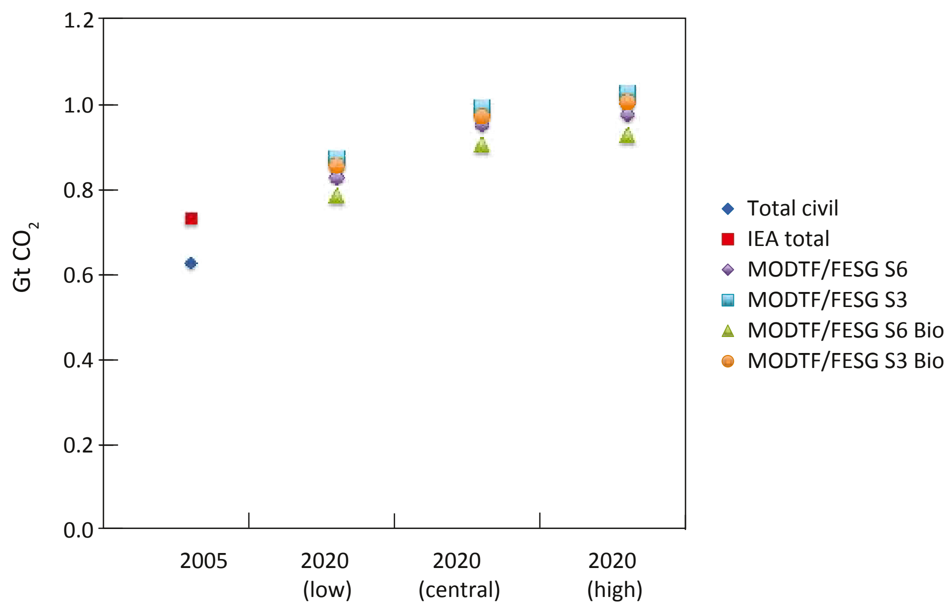
The previous section provides a rich amount of published information about the potential of various measures to reduce emissions. But to obtain an estimate of *total* potential in 2020 it is not advisable to simply add up these numbers. This is because the total potential in 2020 depends on how the aviation and shipping sectors develop up to that time and which particular measures will be most cost-effective under these future conditions. Therefore, in the following sections we analyse results from various scenario studies that make assumptions about the future development of these sectors and the appropriate package of different measures that can be feasibly implemented.

Aviation. ICAO's Committee on Aviation Environmental Protection (CAEP) has prepared a number of projections from 2006 to 2050 (MODTF/FESG, 2009) with three levels of growth, and a variety of assumptions regarding technology and operational improvements. The committee made no assumptions about particular policies that would drive the projections but they did specifically exclude biofuels. These scenarios illustrate plausible emission pathways: Scenario 'S3' (see Figure 11) might be considered a BAU-type projection delivering "low technology and moderate operational" improvements, with emissions projected by 2020 to be 0.88, 1.00, 1.03 $GtCO_2$ (low, central, high projections). Scenario 'S6' is an "optimistic" technology and operational projection, with emissions projected by 2020 to be 0.83, 0.96, 0.98 $GtCO_2$ (low, central, high projections); i.e. around a 5% CO_2 savings over S3.

Applying the "likely" and "speculative" levels of biofuel penetration identified above, we assume an additional 2% reduction on the (MODTF/FESG, 2009) S3 scenario and a 5% reduction on the S6 scenario. The outcomes for these particular projections are illustrated in Figure 11 and are indicative of plausible emission pathways.

We can use Figure 11 to estimate emission reduction potentials in the aviation sector in 2020. As a first

Figure 11. Emissions of CO_2 from aviation in 2005, and potential emissions in 2020 according to (MODTF/FESG , 2009) scenario 'S3' (low, central, high growth) and further reductions possible through additional technological, operational means (scenario 'S6'), and additional reductions from 2% and 5% uptake of low-CO_2 biofuels ('S3-Bio', 'S6-Bio').



33. After accounting for potential increases in methane emissions, hence 'CO_2e'.

approximation of this potential we subtract the bottom and top data in columns 2, 3 and 4 of the figure. From this, we get about 0.1 $GtCO_2$ for emission reduction potential in this sector in 2020.

Shipping. Total emissions amounted to 0.96 $GtCO_2$ in 2005 and are projected to increase to 1.11–1.29 $GtCO_2$ in 2020 under a BAU scenario that assumes a 12% efficiency improvement between 2007 and 2020 (Buhaug *et al.*, 2009) (see column 2 in Figure 12). There are many measures to improve the fuel efficiency of maritime transport (Wang *et al.* 2010, Eide *et al.*, 2011). If all the cost-effective measures listed in Wang *et al.* (2010) were implemented by 2020, emissions are projected to be 0.93–1.37 $GtCO_2$, depending on the actual abatement potential of various measures (the emissions may increase, if all the measures together do not add up to yield a 12% efficiency improvement) (column 3 in Figure 12). If all measures evaluated in Wang *et al.* (2010) were implemented, emissions would decrease to 0.73–1.12 $GtCO_2$ in 2020 (column 4 in Figure 12).

To obtain a first estimate of the reduction potential in the shipping sector, we subtract the minimum value of column 4 in figure 12 from the minimum value of column 2, and the maximum value of column 4 from the maximum value of column 2. In this way we obtain an estimate of 0.2–0.4 $GtCO_2$ for emission reduction potential in the shipping sector in 2020.

4.4 Policies

The measures and potential emission reductions outlined in the previous sections over and above BAU reductions arising by economic pressures can only be driven by policies, put in place by governments and regulators. In addition, some policies may reduce demand by increasing the cost of transport. Here, some of the existing and potential policies to drive such measures are considered.

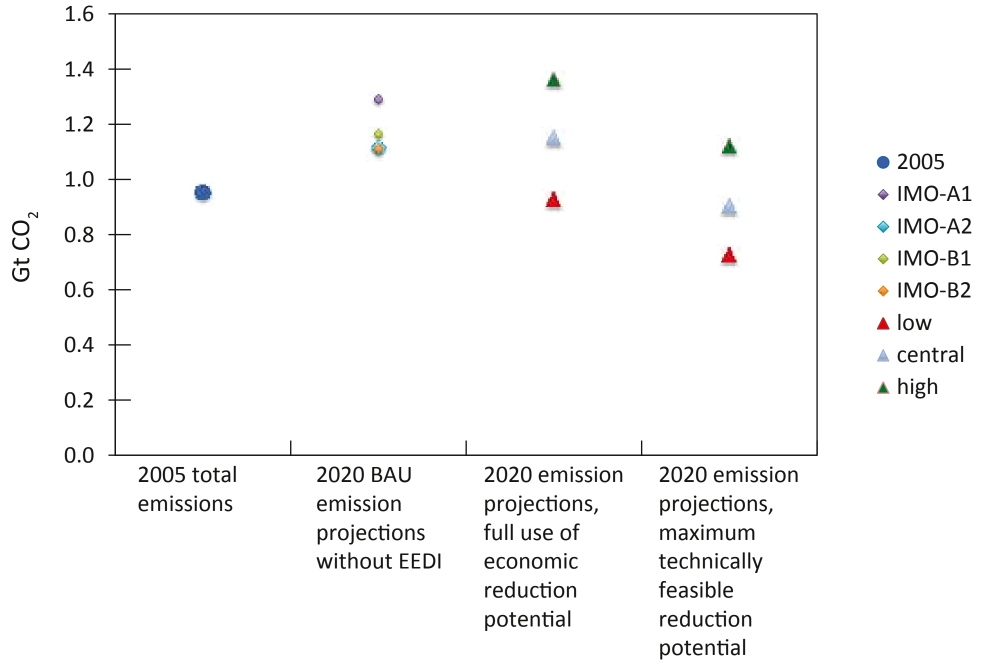
Aviation

Operational policies. There are two major initiatives to improve air traffic management, Europe's SESAR (Single European Sky ATM Research), which aims to achieve a 10% emissions reduction per flight by 2020, and the US NextGen (Next Generation Air Transportation System), which aims to save an average of 1.6 $MtCO_2$ per year to 2018, or 0.7% of annual US (total) aviation emissions.

Technological policies. ICAO's CAEP is currently developing a CO_2 emissions standard for aircraft.

Market-Based Instruments (MBIs). Two types of MBIs attach a price to emissions. These are: charges (such as taxes/levies) and cap-and-trade instruments (such as tradable emissions rights/allowances/permits). In the aviation sector, only cap-and-trade schemes are currently being implemented at an international level: domestic flights are included in the New Zealand Emissions Trading

Figure 12. Emissions of CO_2 from shipping in 2005, and potential emissions in 2020 according to IMO scenarios (Buhaug *et al.*, 2009) and further reductions possible through additional measures and policies.



Scheme (ETS); and both domestic and international flights are included in the EU ETS, scheduled to begin in 2012, although the regulation is currently subject to legal challenge.

ICAO has debated MBIs as a means to reduce the climate impact of aviation since the 1990s, and has published *Guidance on the Use of Emissions Trading* (ICAO, 2008) adopted by the 36th ICAO Assembly in 2007. It is pursuing further work on MBIs for consideration at the 38th Assembly in 2013.

Shipping

Operational policies. IMO has mandated ships to carry a Ship Energy Efficiency Management Plan (SEEMP), from July 2012. The SEEMP provides operators with a framework for the planning, implementation, monitoring, and self-evaluation/improvement of operational measures appropriate to the ship but will also assist in identifying possible technical improvements. Whilst the SEEMP is obligatory, the implementation of measures arising from it will be voluntary.

Technological policies. IMO introduced a mandatory CO_2 standard in 2011, known as the Energy Efficiency Design Index (EEDI) for major classes of new ship built from 2013, representing 72% of emissions from new ships. The mandatory value reduces emissions stepwise to 30% below the reference level (the average energy efficiency index for existing ships of a specific type and size) as of 2025. In the first four years after coming into force, States may waive the requirement for new ships to attain the EEDI. IMO estimates that EEDI will deliver savings of 45-50 Mt CO_2 annually by 2020 and 180-240 Mt CO_2 annually by 2030[34].

Market-Based Instruments (MBI). A number of MBIs have been discussed within IMO, which can be classified in three groups (Davidson & Faber, 2010):

- 'Levy-type' proposals, such as the International Fund for Greenhouse Gas Emissions from Ships, a contribution from bunker fuel purchases, to be used for acquiring offsets;
- Cap-and-trade proposals;
- A baseline-and-credit trading scheme, setting a fleet-average fuel efficiency target.

Whilst it is generally agreed that MBIs may be effective in reducing emissions in the shipping sector, no decision has yet been made on selection or implementation.

4.5 Conclusion

How do aviation and shipping contribute to narrowing the emissions gap in 2020? And what is the potential for reducing their emissions and contributing to bridging the gap?

Under BAU type scenarios, combined global aviation and shipping emissions could add up to 1.7–2.5 $GtCO_2e$ in 2020, according to projections available in the literature, where most of the differences are attributable to different assumed rates of growth of the sectors. This can be compared with the total gap in 2020 between pledged emissions and the 2°C target of 6 to 11 $GtCO_2e$ (Chapter 3).

As to the potential to reduce emissions, we saw previously (Section 4.3.3) that a first estimate of this potential in the global aviation sector was about 0.1 $GtCO_2e$ in 2020. For the global shipping sector this figure was approximately 0.2–0.4 $GtCO_2e$. Therefore, the two sectors together could help narrow the gap by around 0.3–0.5 $GtCO_2e$. These potential reductions represent a significant fraction of projected emissions from these sectors under BAU conditions.

34. http://www.imo.org/MediaCentre/HotTopics/GHG/Pages/default.aspx

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