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.

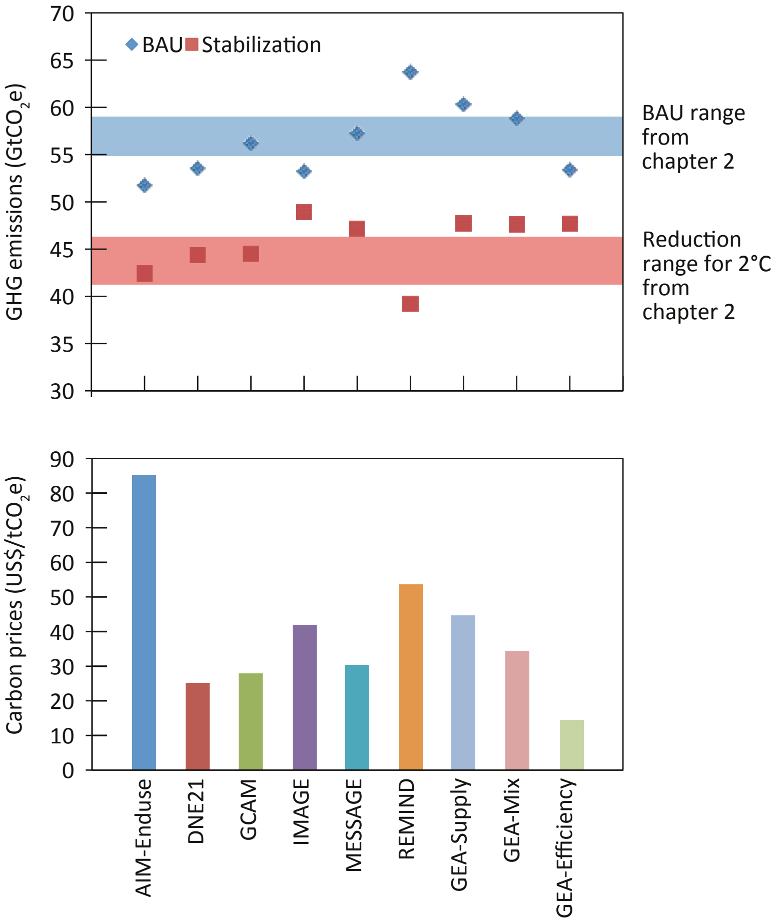
The mitigation scenario with the highest carbon price (Akashi *et al.*, forthcoming) assumes the application of costly innovative technologies which pushes up the price of carbon reductions.

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

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



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.

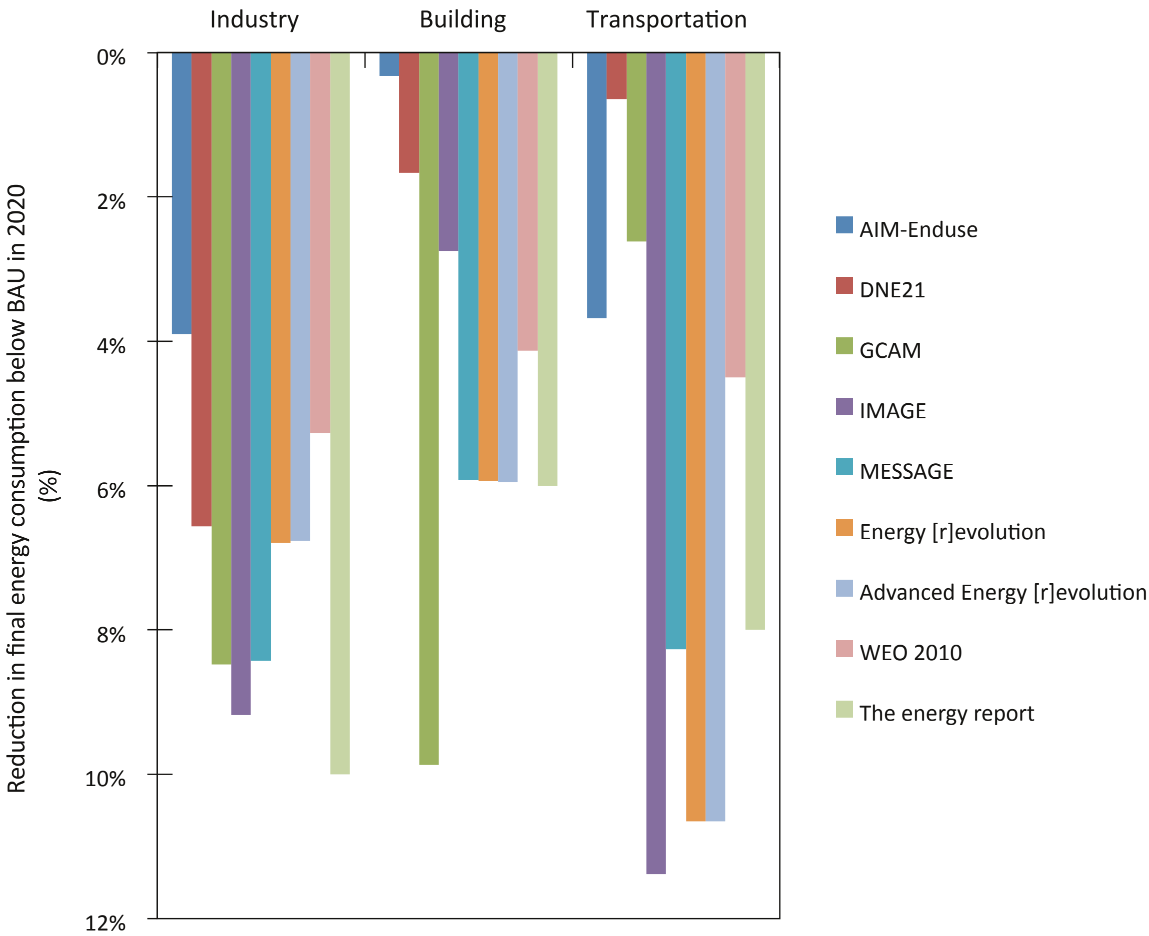
Another indicator of improving energy efficiency is a decrease in energy intensity of the economy over time. For the different mitigation scenarios, energy use per unit GDP decreased from 1.1 to 2.3% per year[19] between 2005 to 2020. Meanwhile, the CO_2 intensity of energy (emissions of CO_2 per unit 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

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.

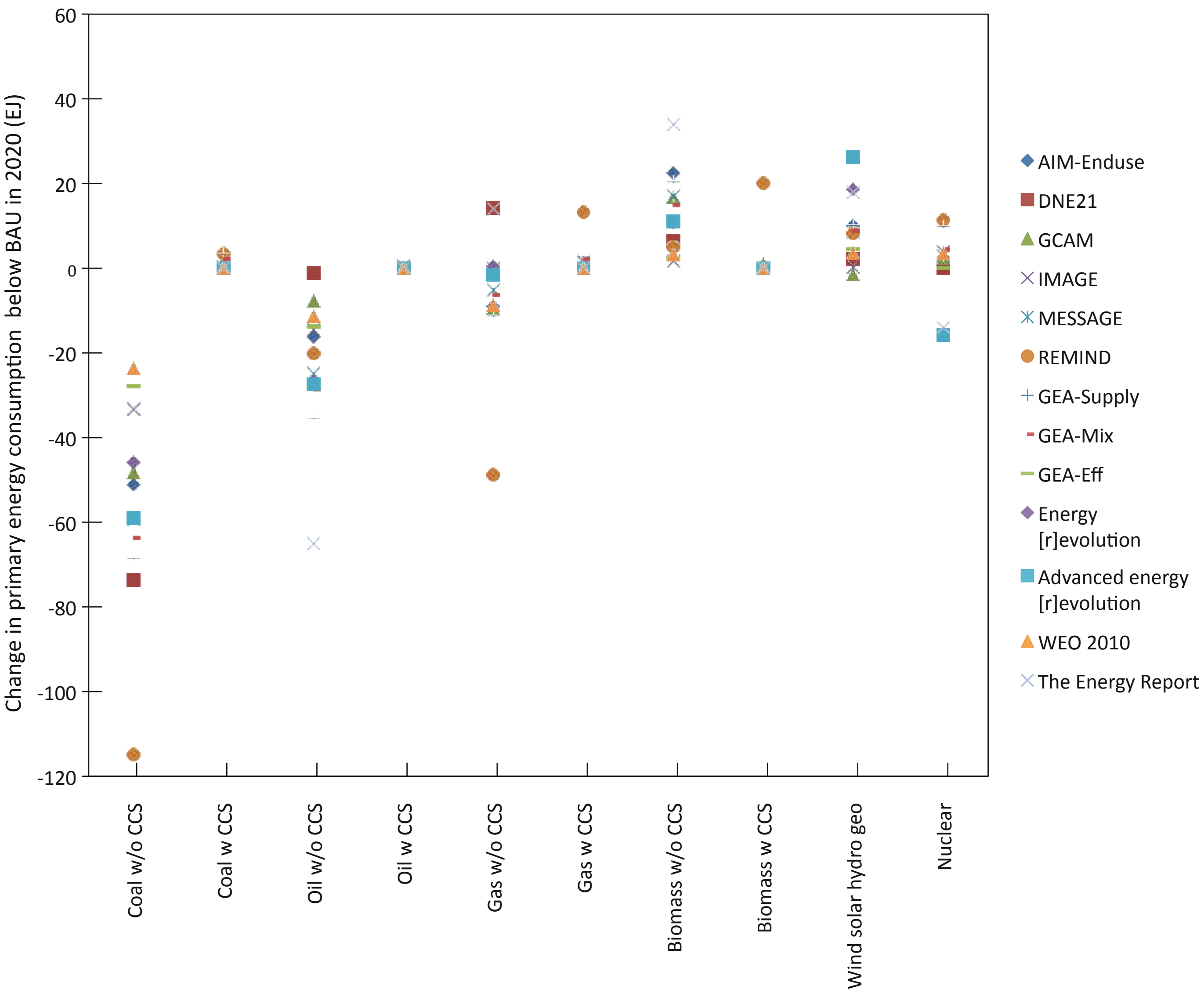
2005. All scenarios indicate an increase in non-biomass renewables from the base year. Nine scenarios whose base year is 2005 indicate increases ranging from 3 to 21 EJ between 2005 and 2020. The DNE21 mitigation scenario computes the lowest share of non-biomass renewables (2%) in part, because it achieves 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$100/$tCO_2e$ (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.