Topic 5 – The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development (15 May 2007)

5.1 Risk management perspective

Decision-making about the appropriate level of adaptation and global mitigation over time involves an iterative risk management process that includes mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity, and attitudes to risk. {WGIII SPM}

Risk management techniques can explicitly accommodate sectoral, regional, and temporal diversity, but their application requires information about not only the most likely projected climate change under specific scenarios, but also impacts and opportunities arising from lower-probability but higher-consequence events. Risk is the product of likelihood and consequence. The likelihood that a climate impact will be associated with a key vulnerability or important opportunity is dependent on characteristics of natural and human systems that are path dependent and site specific. {SYR 3.3, Table 3.2; WGII 20.9, SPM; WGIII 3.5,3.6, SPM}

5.2 Key vulnerabilities, impacts and risks – long term perspectives

Compared to results assessed in the Third Assessment Report, there are now stronger "reasons for concern". They are derived from (1) better understanding of the magnitude of impacts and risks associated with increases in global mean temperature and CO_2, including vulnerability to present-day climate variability, (2) more precise identification of especially affected sectors, groups and regions, and (3) growing evidence that unmitigated emissions over the 21st century could commit[1] the climate system to the risk of very large impacts on multiple century time scales[2]. {WGII 4.4, 5.4, 19.3.7, TS 4.6; WGIII 3.5, SPM}

The Third Assessment Report (TAR) found that vulnerability is a function of exposure (e.g., low-lying islands or coastal cities) and sensitivity (e.g., flooding of coastal cities and possible investments in defensive measures if, when and where adaptive capacity is sufficient and actually realised). The TAR also demonstrated that adaptation can influence sensitivity to climate change while mitigation can influence the rate and extent of climate change and hence exposure. Both conclusions are confirmed in this assessment. {WGII 20.2, 20.7.3}

Climate risks and associated vulnerabilities[3] (as well as climate opportunities) vary across space, time, sectors and regions. No single metric can adequately describe the diversity of key vulnerabilities. Nor can any single metric support their ranking. A sample of relevant

[1] The term "commit" is used as in AR4 WGII and is derived from the notion of risk and the possibility of crossing thresholds of irreversible change.
[2] Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium. {WGI 7.3, 10.3, SPM}
[3] Vulnerabilities can be measured in terms of a multitude of metrics or numeraires (for example, monetary currency, millions at risk of hunger or water stress, species facing extinction, abrupt physical changes).

impacts, expressed in many different metrics, is provided in Table 3.2. The estimation of key vulnerabilities in any system, and damage implied, will depend on the rate and magnitude of climate change and development status, which also determines adaptive capacity. {WGII 19.ES, 19.1.2.3, 19.1.2.5}[4]

The five "reasons for concern" that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to "aid readers in making their own determination" about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in this assessment. {TAR WGII Chapter 19; WGII SPM}

Risks to unique and threatened systems. There is new and stronger evidence of observed effects of climate change on unique and vulnerable systems (such as polar and high-mountain communities and ecosystems) consistent with the expected effects of warming. This has increased confidence in projected effects. Levels of adverse impacts are with *very high confidence* projected to increase with global mean temperatures. {WGII 2.4, SPM}

- Significantly high adverse effects of climate change on ecosystems and species at lower temperatures and in the predictions of significant extinctions as a consequence of climate change are new findings since the TAR. Above 1.5-2.5°C [5] global average temperature increase, predominantly negative effects on biodiversity and ecosystem services such as water and food supply are projected. Above 3.5-4°C warming significant (>40%) extinctions are projected. {SYR 3.3; WGII 4.4, SPM}
- Corals are vulnerable to increases in sea surface temperature and a major new finding is the high risk of widespread adverse effects: increases of 1-3°C in global average temperature are projected to result in more frequent coral bleaching events and increases of over 2.5-3.0°C projected to result in widespread coral mortality. {WGII 6.4}

Risks of extreme weather events. There is much more information since the TAR on the sensitivity and vulnerability of human and natural systems to the effects of projected changes in extreme event frequency, duration and/or intensity.

- Recent extreme climate events have demonstrated a higher sensitivity to climate extremes in both developing and developed countries. {WGII 1.3, 2.2, 2.5, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3}
- Projected increases in tropical cyclone intensities with warming, in combination with sea level rise, are now expected to cause more intense storm surges, with damages exacerbated by more intense rainfall inland and stronger winds including damages to coral reefs, crop production, infrastructure and increased risk water- and food-borne diseases. {SYR 3.2.2; WGI SPM; WGII 19.3}
- Decreased water availability and increased drought in the dry tropics and subtropics, beginning at current temperatures, and intensifying with warming. {SYR 3.3; WGI 10.3; WGII 1.3, Figure 3.4}
- Increasing coastal damage from floods and storms with sea level rise {WGI Table TS-4; WGII 19.3, Table 19.1}
- Increased floods in many regions due to increased frequency of heavy rainfall, which in many regions is projected to increase with higher temperatures and in some

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[4] Working Group II identifies seven criteria from the literature that are often used to identify key vulnerabilities: these are listed in section 5.8. {WGII 19.2}

[5] Unless otherwise stated above the 1980-1999 average.

locations by earlier melting of snowpacks and wastage of glaciers. {WGI 10.3; WGII 3.3.1, 19.3}

- Increased frequency and severity of heat waves *very likely* in many regions, with reduced crop yield in some regions, increased wildfire dangers, increased mortality, increased water demand and water quality problems. {SYR 3.2.2; WGI 10.3, SPM; WGII SPM Table SPM-2}

Distribution of impacts and vulnerabilities. New evidence since the TAR provides new insights into the distribution of impacts and vulnerability across systems, sectors, regions and communities. Substantial improvements have occurred in the prediction of regional patterns of climate change, including precipitation. {WGI 11.2-11.7, SPM}

Some new findings are:

- Serious and adverse regional effects on future water availability are projected in glacial and snow pack fed river basins in China, India and the Andean region affecting hundreds of millions of people; their timing and temperature thresholds vary from place to place. {SYR 3.3; WGII 3.4.3}
- Substantial negative impacts on agricultural production and food security in low-latitude regions, particularly in Africa where effects could be severe, are predicted due to reduced water availability and increased frequency of droughts beginning at current temperatures. {WGII 5.4, 5.3, 9.3ES}
- Observed adverse impacts of climate change on high-mountain communities are with *very high confidence* projected to increase as temperatures increase. Melting of inter-tropical mountain glaciers is projected to cause flooding and adverse effects on water resources in affected regions and these glaciers might disappear in a few decades with around 1^{o}C of additional global average warming. {WGII 19.3, Table 19.1}

Amongst the risks confirmed and strengthened since the TAR are:

- Asian mega-deltas are especially at risk due to large populations and high exposure of hundreds of millions of people to flooding due to sea-level rise, storm surges and river flooding. {SYR 3.3; WGII Table 10.9, 10.6}
- Sea-level rise is likely to threaten vital infrastructure and water resources that support the socio-economic well-being of small island communities and as well heavily impact coral reefs, fisheries and other marine-based resources which often form a large part the local economies. {WGII 16.3}

The uneven distribution of impacts is further underlined by benefits expected for some sectors and regions in the short to medium term under moderate amounts of warming, for example more navigable northern sea routes, increased water availability in some regions, increased global food and timber production, and fewer deaths due to cold exposure in middle and high latitudes. {WGII 3.4, 5.4, 8.4, 15.4}

Net aggregate impacts. Aggregate estimates of impacts mask enormous inequity in the distribution of net impacts (even those assessed in terms of market damages) and enormous uncertainty in natural and social parameters (e.g., climate sensitivity and discount rate, respectively). Because regional disaggregates show increased vulnerability in many regions, there is some evidence that initial net market benefits from climate change (particularly when aggregate estimates are computed using population weights) will peak at a lower magnitude and therefore sooner than was concluded in the TAR. Recent studies have included some of these previously unassessed aspects, such as flood damage to agriculture and damages from increased cyclone intensity. These studies imply that the physical impacts and costs associated with these neglected aspects of climate change may be very significant. It is also *likely* that there will be higher damages for larger magnitudes of global mean temperature increases than estimated in the TAR. {WGII 19.3, 20.6.2, 20.7.3}

Risks of large scale singularities: abrupt or irreversible changes.[6] Determining whether trigger points exist and the timing of processes that could lead to abrupt or irreversible changes remains difficult, although advances have been made. The risk of large-scale abrupt change *this century* due to changes in ocean circulation is *very unlikely*. Ice sheet models project a gradual widespread loss of ice from the Greenland ice sheet if warming were to be sustained for millennia. There is, nonetheless, a risk that larger sea level contributions from the ice sheets could occur on century time scales, because ice dynamical processes not included in current models could increase the rate of ice loss, and could also lead to contributions from Antarctica. Complete deglaciation of the Greenland ice sheet would raise sea level by 7 metres over millennia and could be irreversible. Many terrestrial, freshwater and marine species are projected to be at far greater risk of extinction with warming over 2^{o}C above pre-industrial than in the geological past. Higher emissions scenarios are projected to lead to the late summer disappearance of a major fraction of Arctic sea ice over the 21st century, with an increased risk of extinction of sea ice dependent species. {SYR 3.4; WGI 10.3, Box 10.1; WGII 4.ES, Box 4.3, 19.3.7}

5.3 The relationship between adaptation and mitigation

Both adaptation and mitigation can with *very high confidence* help to reduce the risks of climate change for natural, managed and human systems. Adaptation is necessary both in the short term and in the longer term, even for the lowest stabilisation scenarios assessed. Mitigation is necessary because reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation, if it is possible, will be available only at very high social, environmental and economic costs. {WGII 17.2, 17.3, 18.4, 18.6, SPM}

The general relationship between the mitigation required for achieving different concentration stabilisation levels and the resulting adaptation needs and residual impacts is shown schematically in Figure 5.1. This shows the avoided impacts due to mitigation, the reduction due to adaptation and the residual impacts for a two alternative stabilisation targets (with common baseline emissions). The relative timing and effort of mitigation is described at 5.6.

[6] Singularities are defined in the AR4 as the property of something which may behave irregularly, abruptly, non-linearly or in a discontinuous manner in response to smoothly changing driving forces, which is broadly consistent with the TAR. An example given was that of large scale species extinction due to smoothly increasing levels of climate change. Most of the risks reviewed in WGI 10 and WGII 19 relate to climate system or geophysical risks. For further discussion the reader is referred to TAR WGII 19.6.

Relationship between mitigation, adaptation needs and residual impacts

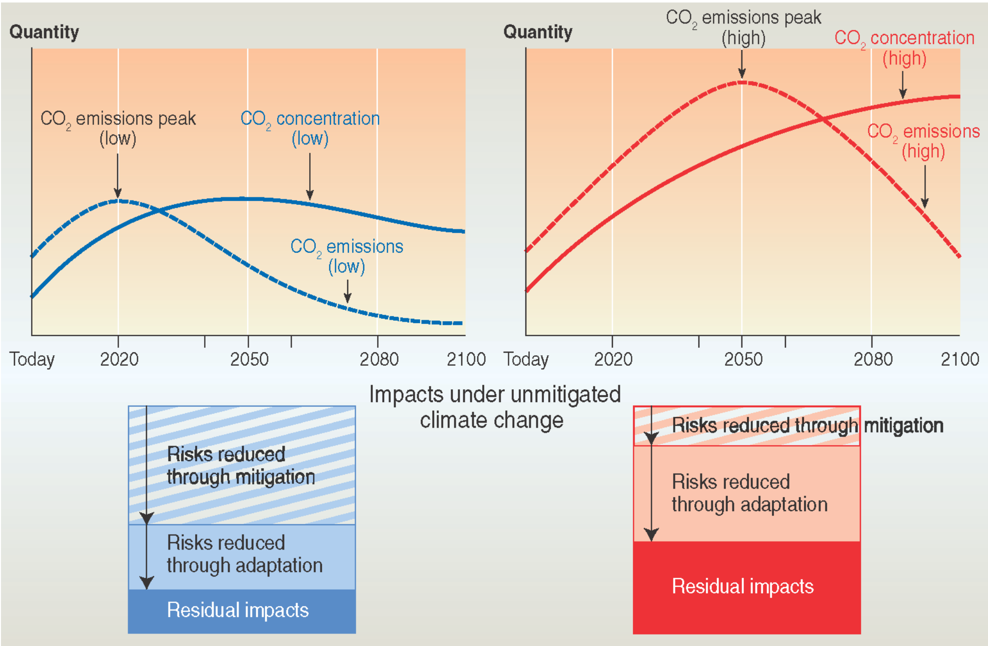

Figure 5.1. Relationship between mitigation, adaptation needs and residual impacts for different stabilisation scenarios. Stabilising CO_2 concentrations at lower levels requires emissions to peak relatively earlier. The blue and red bars indicate the contribution of mitigation and adaptation in reducing the risk of residual impacts (compared to a case without any climate policy) for a high and low stabilisation case respectively. Stabilisation at low levels reduces the need for adaptation and the risk of major impacts, but requires more mitigation over the course of this century. Some adaptation and residual impacts might be unavoidable even at very low stabilisation levels. This figure is a generic illustration for stabilisation of CO_2 concentrations at high and low levels, and therefore has no units on the response axis.

Due to inertia in the climate system, benefits of mitigation measures in terms of avoided climate change would take several decades longer to materialise than benefits from adaptation, which can also address vulnerability to current climate variability. The required extent of adaptation depends on both the scale and distribution of short- to medium term mitigation measures, related investments and policies. Global mean temperature changes greater than 4ºC above 1990-2000 levels (about 4.6ºC above preindustrial levels) would with *very high confidence* lead to major increases in vulnerability, exceeding the adaptive capacity of many systems. {SYR 4.2; WGII 17.4, 18.1, 18.4, 19.ES}

There are barriers, limits and costs to adaptation (*high confidence*)[7]. {WGII TS.5.1}

Adaptation will be ineffective in some cases (such as for biodiversity and natural ecosystems e.g. loss of Arctic sea ice and polar bear survival, disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres[8]) and less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). Barriers include both the inability of natural systems to adapt to the rate and magnitude of climate change, as well as technological, financial, cognitive and behavioural, and social and cultural constraints. The adaptive capacity

[7] See Topic 4 Table 4.2 for barriers to mitigation. {WGIII 2.5, 4-10, SPM}
[8] While it is technically possible to adapt to several metres of sea level rise the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation {WGII 17-27}

of natural ecosystems is limited and there is *high confidence* that the ability of many ecosystems to adapt naturally is *likely* to be exceeded this century. {WGII 4.ES, TS.5.1, SPM}

Efforts to mitigate greenhouse gas emissions need to account for inertia in the climate and socioeconomic systems. {WGI 10.3, 10.4, 10.7; WGIII 2.3.4}

After greenhouse gas concentrations are stabilised, the rate at which the global mean temperature increases is expected to slow within a few decades. Small increases in global mean temperature could still be expected for more than several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that gradually decreases from that reached before stabilisation due to ongoing heat uptake by oceans. The eventual contributions from the ice sheets could be larger than that from thermal expansion. {WGI 10.7}

Mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, and the higher adaptation needs associated with higher levels of warming. In the more stringent mitigation scenarios described in the literature, concentrations peak and then drop to reach the ultimate target stabilisation level. The climate system consequences, impacts and effects of such peaking or overshooting scenarios, including for risk assessment are beginning to be examined. In scenarios where concentrations peak and drop, the realised surface warming and especially the sea level increase will never approach the equilibrium warming level associated with the peak concentration. {WGI 10.7; WGII 7.6, 17.2, 17.4, 19.4.2.2, SPM; WGIII 3.3, 3.5, 7.12, 11.6.2, SPM}

5.4 Emission trajectories for stabilisation levels

Global emissions must peak and then decline to meet any of the assessed stabilisation levels. The lower the stabilisation level, the more quickly this peak and decline would need to occur and the lower are the long-term equilibrium temperature consequences. {WGIII 3.3, 3.5, SPM}

Global CO_2 emissions pathways for a range of stabilisation levels and the corresponding global mean equilibrium temperature changes are summarised in Figure 5.2.[9] In its assessment, WGIII grouped the stabilisation scenarios into different categories for ranges of stabilisation levels (category I to VI).

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of greenhouse gas concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. {WGIII 3.3, 3.5, SPM}

[9] Estimates for transient temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global mean temperature is approaching the equilibrium level between 2200 and 2300. Note though that in particular for the much lower stabilisation scenarios with overshoot of greenhouse gas concentrations above the stabilisation level (category A1 and A2, Figure 5.3), the equilibrium temperature may be reached already considerably earlier than 2200.

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.2) and resulting long term equilibrium temperate changes. {WGIII 3.5, SPM}

The extent to which risks of major impacts on vulnerable systems can be reduced, avoided or delayed in the long term depends on the scale of mitigation effort and investments over the next two to three decades. Table 5.1 summarises the required emissions levels for different groups of stabilisation concentrations and the associated equilibrium global mean temperature increase, using the 'best estimate' of climate sensitivity (see also Figure 5.2 for the *likely* range of uncertainty). Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak, and requires greater emissions reductions by 2050. {WGIII 3.3, SPM}

Table 5.1. Characteristics of post-TAR stabilisation scenarios. {WGI 10.7; WGIII Table TS-2, Table 3.10}

Category	CO_2 concentration [a]	CO_2-equivalent Concentration [a]	Peaking year for CO_2 emissions [b]	Change in global CO_2 emissions in 2050 (% of 2000 emissions) [b]	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity [c], [d]	Global average sea-level rise above pre-industrial at equilibrium from thermal expansion only [e]
	ppm	ppm	year	percent	ºC	metres
I	350 – 400	445 – 490	2000 - 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4
II	400 – 440	490 – 535	2000 - 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7
III	440 – 485	535 – 590	2010 - 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9
IV	485 – 570	590 – 710	2020 - 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4
V	570 – 660	710 – 855	2050 - 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9
VI	660 – 790	855 – 1130	2060 - 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7

Notes:

a) *Atmospheric CO_2 concentrations have increased by about 100 ppm since pre-industrial times, reaching 379 ppm in 2005. The best estimate of total CO_2-equivalent concentration in 2005 for all long-lived greenhouse gases is about 455 ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375 ppm CO_2-equivalent.*

b) *Ranges correspond to the 15^{th} to 85^{th} percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios.*

c) *The best estimate of climate sensitivity is 3ºC. {WGI SPM}*

d) *Global mean temperature at equilibrium is different from expected global mean temperature at the time of stabilisation of greenhouse gas concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of greenhouse gas concentrations occurs between 2100 and 2150.*

e) *Values for sea-level rise from thermal expansion are estimated using relatively simple climate models (one low resolution AOGCM and several EMICs). These values result from a relatively uniform warming throughout the deep ocean which is expected at equilibrium. Ranges are based on the best estimate of 3ºC climate sensitivity. Equilibrium sea-level rise is for the contribution from thermal expansion only and does not include contributions from ice sheets, glaciers and ice caps.*

Thermal expansion of the ocean will cause an inexorable sea level rise that is much larger than that projected for the 21^{st} century. Stabilisation at for example 445-490 ppm CO_2-eq would produce slow sea level rise due to thermal expansion over more than a thousand years of 0.4-1.4m, assuming a best estimate of climate sensitivity of 3°C (Table 5.1). The corresponding values for stabilisation at 590-710 ppm CO_2-eq are 0.6-2.4 m. If greenhouse gases and aerosols were to be stabilised at year 2000 levels, thermal expansion alone would be expected to lead to slow further sea level rise of 0.3-0.8 m. These long-term commitments to sea level rise have major implications for world coastlines in a warmer world and do not include contributions from ice sheets, glaciers, or ice caps. The long time scale response of thermal expansion and ice sheets implies that mitigation strategies that seek to stabilise greenhouse gas concentrations at or above present levels (radiative forcing) and then surface temperature, do not stabilise sea level rise for more than a millennium. {WG1 10.7}

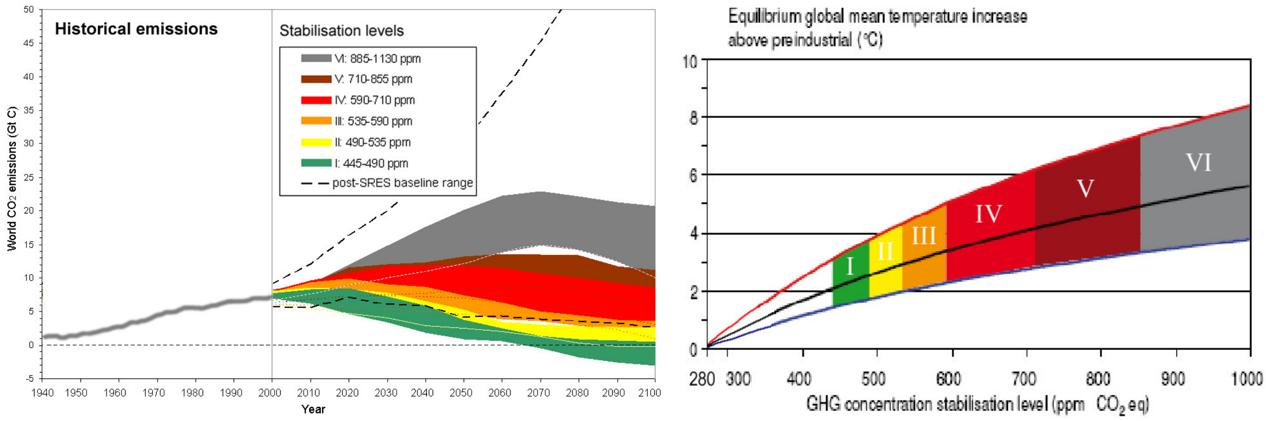

Figure 5.2. Global CO_2 emissions for 1940 to 2000 and ranges for alternative groups of stabilisation scenarios (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global mean temperature increase above preindustrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). Right-hand panel shows ranges of global mean temperature change above pre-industrial, using (i) "best estimate" climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of *likely* range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of *likely* range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of post-SRES baseline scenarios. Emissions ranges of the stabilisation scenarios correspond to the 10^{th} – 90^{th} percentile of the full scenario distribution.

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change. Climate carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate carbon cycle feedback, model studies suggest that stabilising CO_2 concentrations at, for example, 450 ppm[10], could require that cumulative emissions over the 21^{st} century be reduced from an average of approximately 2460 [2310 to 2600] $GtCO_2$ to approximately 1800 [1370 to 2200] $GtCO_2$. {WGI 7.3, 10.4, SPM}

[10] Note that based on the range of multigas scenarios reviewed such a CO_2 concentration scenario would involved substantial emissions of other greenhouse gases raising the overall radiative forcing to about 550 ppm CO_2-eq. To stabilise at 1000 ppm CO_2 (which with other greenhouse gases emissions in multigas scenarios would correspond to about 1800 ppm CO_2-eq.) this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] $GtCO_2$ to approximately 4030 [3590 to 4580] $GtCO_2$. {WGI 7.3, 10.4, SPM}

5.5 Relationship between cost of mitigation and long-term stabilisation targets

The macroeconomic cost of mitigation generally rises with increased stringency of the stabilisation target and is relatively higher from baseline scenarios with high emissions. There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445 ppm CO_2-eq, are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.[11] {WGIII 3.3, 13.3, SPM}

Table 5.2. Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {WGIII 3.3, 13.3}

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction [(a)] (%)		Range of GDP reduction [(b)] (%)		Reduction of average annual GDP growth rates (percentage points) [(b), (c)]	
	2030	*2050*	*2030*	*2050*	*2030*	*2050*
590 – 710	0.2	0.5	-0.6 – 1.2	-1 – 2	< 0.06	< 0.05
535 – 590	0.6	1.3	0.2 – 2.5	slightly negative – 4	< 0.1	< 0.1
445 – 535 [(d)]	Not available		< 3	< 5.5	< 0.12	< 0.12

Notes: Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.

a) Global GDP based market exchange rates.

b) The median and the 10th and 90th percentile range of the analyzed data are given.

c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.

d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

5.6 Technology flows and development

There is *high agreement* and *much evidence* that the range of stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades. This assumes that appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and for addressing related barriers. The lower the stabilisation levels, especially those of 550 ppm CO_2-eq or lower, the greater the need for more efficient RD&D efforts and investment in new technologies during the next few decades. {WGIII SPM}

[11] Most models use a global least cost approach to mitigation portfolios and with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs represent global averages and are given for a specific point in time. Estimated costs will increase if some regions, sectors (e.g. land-use options) or gases are excluded. Estimated costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. In models that consider induced technological change projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level. {WGIII SPM}

Investments in and world-wide deployment of low-greenhouse gas emission technologies as well as technology improvements through public and private Research, Development & Demonstration (RD&D) would be required for achieving stabilisation targets as well as cost reduction.[12] Figure 5.3 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of individual technologies varies over time and region and depends on the baseline development path and the analyzed stabilisation level. Stabilisation at low levels (490-540 ppm CO_2-eq.) requires early investments and substantially more rapid commercialisation of advanced low-emissions technologies over the next decades (2000-2030) and higher contributions across abatement options in the long term (2000-2100) (Figure 5.3). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed. Appropriate incentives could address these barriers and help realise the goals across a wide portfolio of technologies. {WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}

Despite large uncertainties concerning the contribution of individual technologies, the majority of the emissions reductions are estimated to come from the energy sector (60-80 % of total emissions reductions). Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and timescales. For lower stabilisation levels, scenarios put more emphasis on the use of low carbon energy sources, such as renewable energy and nuclear power, and the use of CO_2 capture and storage (CCS). In these scenarios improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past. Modern bioenergy could contribute substantially to the share of renewable energy in the mitigation portfolio. (Figure 5.3) {WGIII 3.3, 3.4, TS.3, SPM}

Cumulative emission reductions for alternative mitigation measures to 2030 and 2100

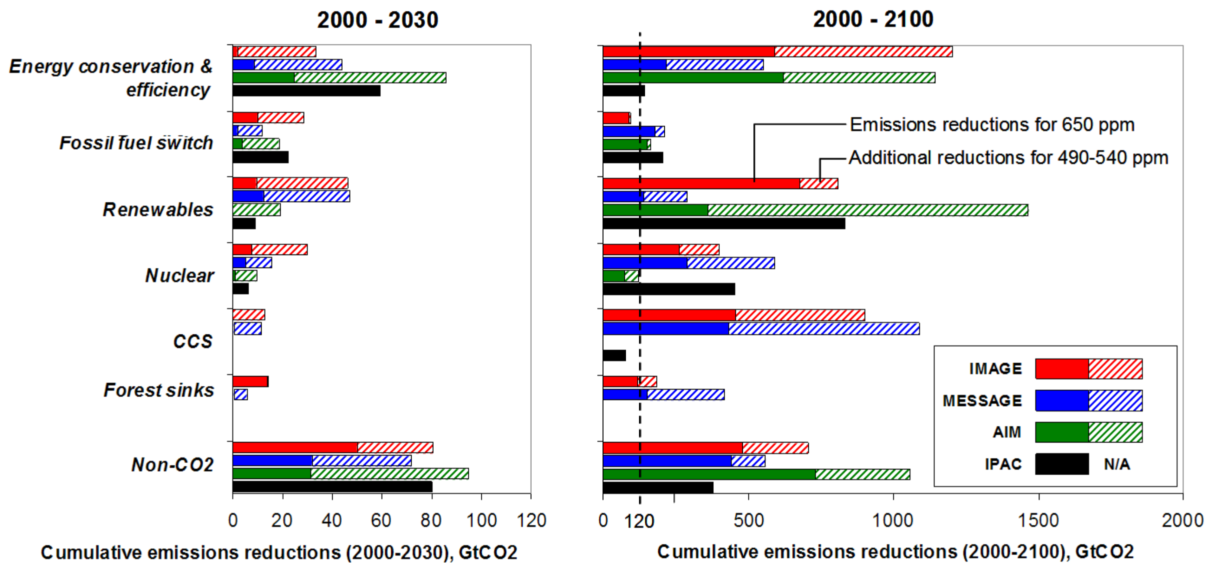

Figure 5.3. Cumulative emissions reductions for alternative mitigation measures for 2000 to 2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490-540 ppm CO_2-eq) and intermediate levels (650 ppm CO_2-eq) respectively. Dark bars denote reductions for a target of 650 ppm CO_2-eq and light bars the additional reductions to achieve 490-540 ppm CO_2-eq. Note that some models do not consider mitigation through

[12] By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level {WGIII 2.7, 3.4, 4.5, 11.5, 13.2}.

forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes carbon capture and storage from biomass. Forest sinks include reducing emissions from deforestation. Mitigation from baseline scenarios with intermediate emissions between 6000 to 7000 $GtCO_2$ (2000-2100). {WGIII Figure SPM-9}

5.7 Many impacts can be avoided, reduced or delayed by mitigation.

The rate and magnitude of future human induced climate change and their associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.1 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change in the second half of the 21st century. This implies that some of the impacts at the high temperature end of Table 3.2 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Table 3.2. {SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}

The most stringent stabilisation scenarios assessed in the WGIII AR4 would lead to CO_2-equivalent concentrations of 445-490 ppm, and to best-estimate equilibrium global temperature change of 2-2.4°C above pre-industrial temperatures, or about 1.5-1.9°C above 1980-1999 average temperatures. In contrast, CO_2-equivalent concentrations of 590-710 ppm would imply a best-estimate equilibrium global warming of 3.2-4.0°C above pre-industrial temperatures, or about 2.7-3.5°C above 1980-1999 averages. Depending on the concentration pathway and climate sensitivity, transient warming during the 21st century could be more or less than the long-term equilibrium warming levels cited here for specific concentrations. {SYR 3.2; WGI 10.7; WGIII SPM}

Choices between these or other ranges could reduce, delay or avoid the risk of a range of key impacts. Most impacts are expected to increase with global mean temperature, but little is known about system-specific thresholds. Regional differences from global mean damage estimates could be large. {SYR 3.3; WGII 19.2, 20.6, SPM}

Limiting global average warming to below about 3°C relative to 1980-1999 (about 3.5°C above preindustrial) would (see also Table 3.2):

- reduce the risk of significant (>40%) extinctions around the globe {WGII 4.4}
- avoid decrease of cereal productivity in some mid- to high latitude regions {WGII 5.4}
- limit loss of global coastal wetlands to less than 30%. {WGII 6.4}

Limiting warming to below about 1.5°C relative to 1980-1999 (about 2.0°C above preindustrial) would in addition (see also Table 3.2):

- reduce the risk of 10-40% extinction of species assessed so far, and reduce changes in structure and functioning of terrestrial, marine and other aquatic ecosystems, including widespread coral mortality {WGII 4.4, 6.4}
- avoid decrease of productivity for some cereals in low latitudes {WGII 5.4}
- reduce from tens of millions to a few millions the additional number of coastal people flooded each year {WGII Table 20.6}

Some impacts, such as increased coral bleaching, decreasing water availability and increased risk of drought in the subtropics and tropics, significant species range shifts and increased wildfire risks, would not be avoidable even if warming is kept below about 1.5°C relative to 1980-1999 (or about 2°C above pre-industrial levels), but their severity would be reduced compared to greater levels of warming. {SYR 3.3}

While most of these impacts could occur during the 21st century depending on warming, some impacts could occur over much longer (millennial) time scales under sustained warming, such as sea-level rise of up to 7 m resulting from the possible deglaciation of the Greenland ice sheet. Maintaining global average temperatures below 1.9 to 4.6°C above pre-industrial levels would reduce this risk. However, even in the absence of major ice sheet loss, long-term thermal expansion of oceans alone is projected to result in sea-level rise of 0.2 to 0.6 m per degree of global average warming above present over the next millennium. {SYR 3.2: WGI 10.7}

The costs of mitigation, assessed in 5.5, need to be weighed within a risk management perspective against the specific impacts, the necessary investments in adaptation, the co-benefits of mitigation and adaptation efforts, and the avoided damages from climate change. The scale and timing of greenhouse gas mitigation involves balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay (*high agreement, much evidence*). In addition, climate sensitivity is a key uncertainty for risk management and in particular for mitigation scenarios that aim to meet a specific temperature level: if climate sensitivity is high then the timing and level of mitigation is earlier and more stringent than when it is low. {WGIII 3.4, 3.5, 3.6, SPM}[13]

5.8 Broader environmental and integration issues

It is *very likely* that climate change will result in net economic costs into the future. Aggregated across the globe and discounted to today, these costs will, with *high confidence*, grow over time. Unabated climate change, with *very high confidence*, threatens sustainable development and would impede achievement of the Millennium Development Goals (MDG) in the longer term. {WGII 20.6, 20.7, SPM}

Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. {WGIII 3.5, SPM}

Climate change will interact with major global environmental concerns and broader trends, including water, soil and air pollution, health hazards, and deforestation, and their combined impacts may compounded in the future in the absence of integrated mitigation and adaptation measures {WGII TS 26, 33,44,50, WGII SPM 13}

Making development more sustainable, either incrementally or by changing development paths, can significantly reduce vulnerability to climate change by promoting effective mitigation and adaptation, but implementation may require resources to overcome multiple barriers. {WGII 20.8; WGIII 12.2, SPM}

[13] This uncertainty is illustrated in Figure 5.2.

Both adaptive and mitigative capacities can be enhanced by making development more sustainable. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through reduced emissions). The capacity to adapt to climate change is not evenly distributed within nations, and it is highly differentiated within countries, where multiple processes of change are influenced by poverty, unequal access to resources, food insecurity, HIV/AIDS, globalisation, various forms of environmental degradation and risks, natural hazards and disasters. {WGII 17.3, 18.6, 20.3, SPM; WGIII 2.1, 2.5, 12.1, SPM}

Synergies between adaptation and mitigation measures can, with *very high confidence*, be effective in supporting efforts to cope with climate change through the middle of this century. It is, though, *more likely than not* that climate risks will exceed the capacity to adapt by the end of the century without significant mitigation in the meantime. It is *very unlikely* that the efforts to reduce vulnerability either directly or indirectly through improving underlying determinants of adaptive and mitigative capacities will be sufficient to eliminate all damages associated with climate change especially over the long-term. {WGII 20.3, 20.8}

5.9 Key Vulnerabilities and Article 2 of the United Nations Framework Convention on Climate Change

Article 2 of the Framework Convention (UNFCCC) clearly articulates its ultimate objective:

> *"to achieve stabilisation of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference (DAI) with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."*

The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with "dangerous anthropogenic interference" with the climate system, in the terminology of Article 2. This assessment has identified systems, sectors, regions and communities that are particularly vulnerable to climate change taking into account magnitude, timing, irreversibility of possible impacts, confidence in assessment, and potential for adaptation. Scientific assessment of climate change summarised in this report cannot directly answer the question about what constitutes "dangerous anthropogenic interference" because doing so involves value judgements. Science can, however, facilitate informed debate about assessing "dangerous interference" by offering expert considerations of the global, regional, and local risks associated with climate change, the equity issues surrounding the uneven distribution of those risks (including the identification of societies and systems that are or will become most vulnerable to climate impacts) and the feasibility of achieving alternative emission pathways. Interpreting Article 2 is necessarily a dynamic process, because the meaning of "dangerous" would vary across the globe and evolve with changes in scientific knowledge, social values, development status, and political priorities. There is increasing recognition in the literature that considerations of fairness, justice, or equity require examination of the distribution of impacts, vulnerability, and adaptation potential.{SYR 3.3; WGII 19.1, 19.2}

In this assessment, seven criteria were identified in the literature to help policy makers determine what might make a risk, impact or vulnerability "key" and thus, what some might consider to be “dangerous”: magnitude of impacts, timing of impacts, persistence and reversibility of impacts, potential for adaptation, distributional aspects of impacts and vulnerabilities, likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates, and “importance” of the system(s) at risk. Some of the key vulnerabilities identified using these criteria have been described above. {WGII 19.2}

One of the themes that emerges strongly from this assessment and the consideration of key vulnerabilities and impacts is a sharp differentiation on a regional basis, often with those in the weakest economic and/or political position being most susceptible to damages. This assessment can inform the discussion of such issues, but it cannot provide conclusive answers, as judgments must be made for that task aggregated on a global basis from a set of regional considerations. In this context, choices about future emission pathways in relation to Article 2 would depend on the degree of risk society is prepared to accept in meeting or exceeding any given temperature level and associated impacts, taking into account the economic costs of mitigation over a given time frame. {WGII Table 19.1, 19.3.3}