3 Keeping climate change within sustainable limits: where to draw the line?

What is covered in this chapter?

One of the big questions in controlling climate change is "how far do we go in limiting climate change?" The climate has already changed and greenhouse gases in the atmosphere today will lead to further change, even if emissions were completely stopped overnight. Emissions are increasing strongly. Social and technical change is slow, and so is political decision making. There are also costs to be incurred. So where to draw the line? This chapter will look at the normative clauses that are part of the Climate Convention, the role of science in decision making, and some of the political judgements that have been made. It will explore the emission reduction implications of stabilization of greenhouse gas concentrations in the atmosphere. It will investigate how such reductions can be realised. It will look into the role of adapting to a changed climate as part of the approach to manage the risk of climate change. Finally, costs of doing nothing will be compared to the costs of taking action.

What does the Climate Convention say about it?

The United Nations Framework Convention on Climate Change[1] (to be referred to as UNFCCC or Climate Convention), signed at the 1992 Rio Summit on Environment and Development and effective since 1994, has an article that specifies the 'ultimate objective' of this agreement[2]. It says:

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference 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.*

This text has far reaching implications. It mandates stabilization of greenhouse gas concentrations in the atmosphere, which will require eventually bringing emissions of greenhouse gases down to very low levels (see below). It also specifies explicit criteria for what that concentration level ought to be:

- the level should be chosen so as to avoid 'dangerous man-made interference' with the climate system, meaning as a minimum that:
  - ecosystems can still adapt naturally
  - food production is not threatened
  - economic development is still sustainable
- the speed at which concentration levels (and therefore the climate) are allowed to change should also be limited.

What risks and whose risks?

Most of these criteria are about the negative impacts of climate change on ecosystems and the economy (see Chapter 1). The point about sustainable economic development however also implies concern about the response to climate change. In theory a radical response in cutting emissions or spending a fortune on protective measures to cope with climate change could threaten sustainable development. So there are two sides to this problem of choice: the risks of climate change impacts on the one hand and the risks of responding to it on the other. Balancing those two risks is an essential element of making decisions on what is 'dangerous'.

The other important dimension is *whose risk* we are looking at. Climate change impact will be very unevenly spread. Within countries and between countries there will be huge differences in vulnerability of people. Low lying island nations will be threatened in their very existence, long before sea level rise is going to be a major issue for many other countries. Livelihoods of poor people in drought prone rural areas will be endangered long before most people in rich countries begin noticing serious local climate impacts (see more detailed discussion in Chapter 1). In general this requires an attitude of protecting the weakest. What is no longer tolerable for the most vulnerable groups ought to be taken as the limit for the world.

The multimillion dollar question is of course what that 'dangerous' level precisely is. At the time the UNFCCC was agreed there was no way that countries could agree on a specific concentration level. And after 14 years of further discussion that is still the case.

Should science give us the answer?

Control of climate change can be achieved through stabilizing concentrations in the atmosphere. This limits global mean temperatures and that reduces climate change impacts. To stabilize concentrations requires emissions to go down to very low levels. The lower the stabilization level, the earlier these low emissions levels should be reached. Figure 3.1 shows these relationships in a simple manner.

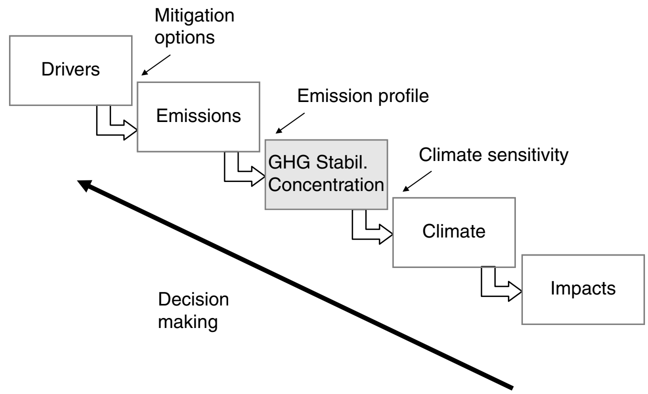

Figure 3.1 **Schematic drawing of stabilizing concentrations of GHGs in the atmosphere and the upstream and downstream relationships with emissions, temperatures, and impacts.**

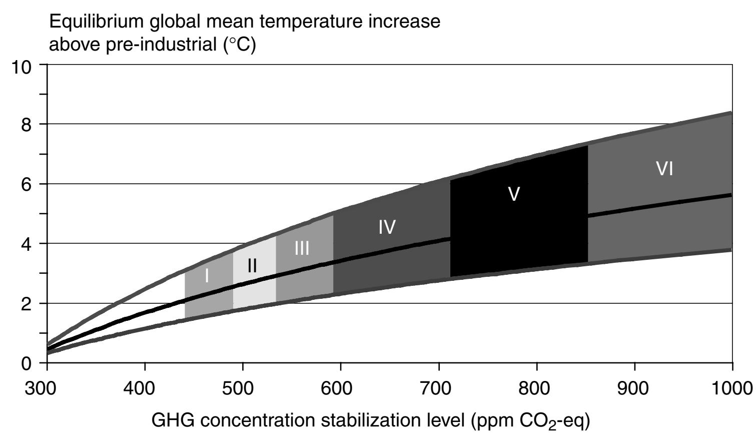

Figure 3.2 **Concentrations of CO_2 and other greenhouse gases (expressed as CO_2-equivalent) and equilibrium temperature increases for a range of stabilization levels. Temperatures given on the y-axis are equilibrium temperatures, i.e. temperatures that belong to a stabilization level after the earth system has come to a steady state. These temperatures are higher than the temperature at the time the stabilization level is reached initially. Category numbering (roman numbers I to VI) represent categories of stabilization levels as used in the IPCC assessment.**
Source: IPCC Fourth Assessment Report, Working Group III, figure SPM.8.

As summarized in Chapter 1, there is a fairly straightforward relationship between the mean global temperature and the impacts that can be expected, even if there are still significant uncertainties and gaps in our knowledge. Figure 3.2 shows in a nutshell how greenhouse gas concentration levels relate to global mean temperature and Figure 3.3 how climate change impacts relate to global mean temperature increase (above the pre-industrial temperature level).

What is striking in Figure 3.2 is the large uncertainty about global mean temperatures corresponding to a certain stabilization level of greenhouse gas concentrations (for instance at a concentration of 600 ppm CO_2-eq the corresponding temperature lies between 2.5 and

5°C).Why is this? It is caused by the uncertainty in the so-called ‘climate sensitivity’. As explained in Chapter 1, climate sensitivity is defined as the warming for a doubling of CO_2 concentrations in the atmosphere. The best estimate of that climate sensitivity at the moment is 3°C (the black line in the middle of the band in Figure 3.2), but with an uncertainty range of 2–4.5°C (reflected in the range shown in the figure) and the possibility that it is even higher. This means there is a 50% probability that temperatures will be 2°C or less above those in the pre-industrial era at a concentration level of 450ppm CO_2-equivalent, but there is also a 50% probability that they will be 2°C or higher. There is even a 17% probability that temperatures at that concentration will be above 3°C.

Another important point is that the equilibrium temperatures referred to in Figure 3.2 are slightly different (several tenths of a degree) from the temperatures at the time concentrations have been stabilized. This is caused by the time it takes for oceans to get into equilibrium with the atmosphere. For the higher stabilization levels it can take centuries before the equilibrium temperature is reached.

We now have a lot of scientific information on the impacts of climate change, as summarized in Chapter 1. Figure 3.3 shows what kinds of climate change impacts can be avoided when limiting global mean temperatures.

GMT range relative to pre-industrial	Geophysical systems Example: Greenland ice sheet	Global biological systems Example: terrestrial ecosystems	Global social systems Example: water	Global social systems Example: food supply	Regional systems Example: Polar Regions	Extreme events Example: fire risk
>4–6	Near-total deglaciation	Large-scale transformation of ecosystems and ecosystem services More than 35% of species committed to extinction	Severity of floods, droughts, erosion, water quality deterioration will increase with increasing climate change	Further declines in global food production	Continued warming likely to lead to further loss of ice cover and permafrost. Arctic ecosystems further threatened, although net ecosystem productivity estimated to increase	Frequency and intensity likely to be greater, especially in boreal forests and dry peat lands after melting of permafrost
3.6–4.6	Commitment to widespread to near-total deglaciation 2–7 m sea level rise over centuries to millennia	Global vegetation becomes net source of C	Sea level rise will extend areas of salinization of ground water, decreasing freshwater availability in coastal areas		While some economic opportunities will open up (e.g. shipping), traditional ways of life will be disrupted	
2.6–3.6	*Lowers risk of near-total deglaciation*	Widespread disturbance, sensitive to rate of climate change and land use; 20–50% species committed to extinction. *Avoids widespread disturbance to ecosystems and their services, and constrains species losses*	Hundreds of millions of people would face reduced water supplies	Global food production peaks and begins to decrease. Lowers risk or further declines in global food production associated with higher temperatures		
1.6–2.6	Localized deglaciation (already observed due to local warming), extent would increase with temperature	10–40% of species committed to extinction *Reduces extinction to below 20–50%, prevents vegetation becoming carbon source* Many ecosystems already affected	Increased flooding and drought severity *Lowers risk of floods, droughts, deteriorating water quality and reduced water supply for hundreds of millions of people*	Reduced low latitude production. Increase high latitude production	Climate change is already having substantial impacts on societal and ecological systems	Increased fire frequency and intensity in many areas, particularly where drought increases
0.6–1.6	*Lowers risk of widespread to near-total degiaciation*	*Reduces extinctions to below 10–30%; reduces disturbance levels*		Increased global food production *Lowers risk of decrease in global food production and reduces regional losses (or gains)*	*Reduced loss of ice cover and permafrost; limits risk to Arctic ecosystems and limits disruption of traditional ways of life*	*Lowers risk of more frequent and more intense fires in many areas*

Figure 3.3 **Relationship between concentration stabilization levels and the impacts that can be expected at the respective equilibrium temperatures. Text in italics indicates reduction of risks.**

Source: IPCC Fourth Assessment Report, Working Group III, figure 3.38 and table 3.11.

Still, a choice on where to draw the line regarding what level of climate change would constitute a ‘dangerous’ situation is a matter of value judgement. Science and scientists are not supposed to make such value judgements. These kinds of decisions should be left to political processes, because they involve the weighing of various risks, involve ethical questions, and are inherently subjective.

Scientists are just human beings, they have certain personal convictions and perspectives and so it happens that some of them make statements about what ought to be done. As a citizen they of course have every right to speak out. As scientists they should limit themselves however to showing the implications of different degrees of climate change and of the costs of taking action. Their role is to inform decision makers, not to step into their shoes. Even then it is difficult to completely eliminate personal perspectives.

This attitude has not always prevailed. In 1987, the UN Advisory Group on Greenhouse Gases proposed limits to climate change: not more than 1–2°C above the pre-industrial era temperature, a change in global mean temperature of not more than 0.1°C per 10 years, and a sea level rise of not more than 0.2–0.5 m above the 1990 level. These proposals were based on the then available scientific information about impacts on ecosystems and the risk of melting of large ice masses on Greenland and the Antarctic. Nevertheless they were pure value judgements. Fortunately, after the establishment of the UN Intergovernmental Panel on Climate Change (IPCC) in 1988, science returned to a more objective and informative role. The ‘mantra’ of IPCC for its assessment reports is ‘policy-relevant, but not policy prescriptive’. It means the IPCC is not making recommendations. It lays out the implications of different choices, but does not make a judgement of what is right or what is wrong.

In the next section you can read how emission reductions are connected to stabilization levels and temperature limits.

What are the implications of stabilizing greenhouse gas concentrations in the atmosphere?

The relationship between increase of global mean temperature and concentrations of greenhouse gases in the atmosphere has been discussed above. But what are the implications for global emissions? As outlined in Chapter 2, for any level of stabilization of concentrations, emissions have to go down to very low levels. The lower the concentration level, the sooner this has to happen. Figure 3.4 shows what this means for emissions of CO_2 for stabilization levels between 450 and 650 ppm CO_2 equivalent (see Box 3.1 for explanation of these units and where we are now).

Calculations like this are done with the help of global carbon cycle models, factoring in all natural and man-made emission sources and fixation of CO_2 in land, vegetation, and oceans. Comparable models for other greenhouse gases are also used. See Box 3.2 for a description.

Box 3.1 How to express concentration levels and where are we now?

Concentrations of greenhouse gases in the atmosphere are expressed in parts per million by volume (ppm). In order to capture the cumulative effect of the various greenhouse gases (and aerosols) and have a simple unit, their combined contributions are expressed in ppm CO_2-equivalent; in other words, the CO_2 concentration that would give the same warming effect as the sum of the individual concentrations of the individual gases (and aerosols).

The 2005 atmospheric concentration levels, expressed as CO_2-equivalent concentrations, were as follows:

CO_2: 379 ppm
All Kyoto gases (see Chapter 2): 430 ppm CO_2 equivalent
All greenhouse gases (incl. gases with ozone depleting potential (ODP)): 455 ppm CO_2 equivalent
All greenhouse gases and aerosols: 375 ppm CO_2 equivalent

(Source: IPCC Fourth Assessment Report, Synthesis Report, p 20, notes to table SPM.6)

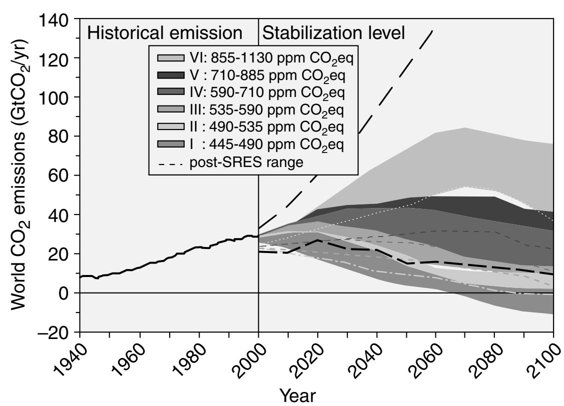

Figure 3.4 **CO_2 emission reductions required to achieve stabilization of greenhouse gas concentrations in the atmosphere at different levels, compared to 2000 emission levels. The wide bands are caused by different assumption about the emission trends without action (so-called 'baselines') and different assumptions about timing of reductions. Emission trajectories are calculated with various models (see also Box 3.2).**
Source: IPCC Fourth Assessment Report, Synthesis Report, figure SPM 11. See Plate 8 for colour version.

As is obvious from Figure 3.4, the emission reductions required for certain stabilization levels are not precisely known. This is caused by different assumptions in the calculations about 'no-action' emission trends (baselines) and timing of reductions. In other words, there are different ways to get to a specific stabilization level.

If we look a bit closer at required emission reductions, it is clear the implications are enormous. For a stabilization level of 450 ppm CO_2 equivalent (roughly what is

Table 3.1. **Characteristics of stabilization scenarios, the resulting long term equilibrium global average temperature, the sea level rise component from thermal expansion, and the required emission reductions**

CO_2 concentration at stabilization (2005 = 379ppm)	CO_2eq concentration at stabilization including GHGs and aerosols (2005 = 375 ppm)	Peaking year for CO_2 emissions[a,b]	Change in global CO_2 emissions in 2050 (% of 2000 emissions)[a,b]	Global average 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	°C	metres
350 – 400	445 – 490	2000 – 2015	−85 to −50	2.0 – 2.4	0.4 – 1.4
400 – 440	490 – 535	2000 – 2020	−60 to −30	2.4 – 2.8	0.5 – 1.7
440 – 485	535 – 590	2010 – 2030	−30 to +5	2.8 – 3.2	0.6 – 1.9
485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4
570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9
660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7

[a] The emission reductions to meet a particular stabilization level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks.
[b] Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure SPM.3).
[c] The best estimate of climate sensitivity is 3°C.
[d] Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilization of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilization of GHG concentrations occurs between 2100 and 2150.
[e] Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries.
Source: IPCC Fourth Assessment Report, Synthesis Report, Table SPM.6.

required to keep global mean temperature rise to 2°C), global CO_2 emissions would have to start coming down by about 2015 and by 2050 should be around 50–85% below the year 2000 levels. For a 550ppm CO_2 equivalent stabilization level (leading to about 3°C warming), global CO_2 emissions should start declining no later than about 2030 and should be 5–30% below 2000 levels by 2050. In light of the expected upward trend of global CO_2 emissions (40–110% increase between 2000 and 2030) and the time it takes for countries to agree about the required action and to implement reduction measures, these reduction challenges are staggering. The impact of the Kyoto Protocol is a drop in the ocean compared to this. It is expected to lead, by 2012, to a slight slowdown of the increase in emissions, but is insufficient to stop the increase in emissions. Table 3.1 lists the required emission reductions for different stabilization levels.

How can drastic emission reductions be realized?

Options for reducing greenhouse gas emissions fall into five categories:

- more efficient use of energy and energy conservation (= not using energy)
- using lower carbon energy sources (switching from coal to gas, renewable energy, nuclear)
- capturing of CO_2 from fossil fuels and CO_2 emitting processes and storing that in geologically stable reservoirs
- reducing emissions of non-CO_2 gases from industrial and agricultural processes
- fixing CO_2 in vegetation by reducing deforestation, forest degradation, protecting peat lands, and planting new forests.

Many technologies are commercially available today to reduce emissions at reasonable costs. These technologies will be further improved and their costs will come down. By 2030 several other low carbon technologies that are currently under development will have reached the commercial stage (Table 3.2). Chapters 5, 6, 7, 8, and 9 will discuss these options in detail for the major economic sectors.

Knowledge of the available technologies is not enough to answer the question of whether substantial reduction of emissions can be achieved in the long term. What is also needed is the expected development in the absence of climate change action (the baselines). Furthermore there are limitations to the speed with which power plants and other infrastructure can be replaced by low carbon alternatives. By putting the information about technologies, their cost over time, the rate at which they can be implemented, and the baseline into computer models, the resulting emissions over time can be calculated for any assumed scenario of climate change action. Calculations can also be done in a 'reverse mode'. Then the desired emission reduction profile is determined first, based on a carbon cycle model of the earth system. The emission reduction options are then applied until the required reductions from a baseline are met. The cheapest options are applied first, followed by the more expensive ones. Box 3.2 describes the calculation process for one of these models.

Table 3.2. Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities

Sector	Key mitigation technologies and practices currently commercially available.	Key mitigation technologies and practices projected to be commercialized before 2030
Energy Supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal, and bioenergy); combined heat and power; early applications of CCS (e.g. storage of removed CO_2 from natural gas)	Carbon capture and storage (CCS) for gas, biomass, and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorized transport (cycling, walking); land use and transport planning	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cooking stoves; improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; a wide array of process-specific technologies	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency	Improvements of crop yields
Forestry/ forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing

Table 3.2. (*cont.*)

Sector	Key mitigation technologies and practices currently commercially available.	Key mitigation technologies and practices projected to be commercialized before 2030
	of forestry products for bioenergy to replace fossil fuel use	technologies for analysis of vegetation/soil carbon sequestration potential and mapping land use change
Waste	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization	Biocovers and biofilters to optimize CH_4 oxidation

Source: IPCC Fourth Assessment Report, Working Group III, Table SPM.3.

Box 3.2 The IMAGE-TIMER-FAIR Integrated Modelling Framework

Calculations of how to achieve deep reductions consist of the following steps:

- Make an assumption about a baseline of emissions without action
- Set an atmospheric concentration objective
- Define clusters of emissions pathways for a period of 50–100 years or longer that match the concentration objectives with the help of a built-in model of the global carbon cycle. In determining those emission pathways limitations are set for the speed at which global emissions can be reduced (usually 2–3% per year globally)
- Then a set of measures is sought from a built-in database of reduction options and costs that, from a global viewpoint, achieve the required emission reductions. The selection is done so that costs are kept to a minimum, i.e. the cheapest options are used first. In substituting baseline energy supply options with low carbon ones the economic lifetime of existing installations is taken into account and so are other limitations to using the full potential of reduction options.

All calculations are performed for 17 world regions. For calculating regional reductions and costs, the global reduction objectives are first divided between these regions using a pre-defined differentiation of commitments. The resulting regional reduction objectives can then be realized via measures both inside and outside the region. Emissions trading systems allow these reductions to be traded between the various regions.

The model can produce calculations of the cost of the reduction measures. The costs always concern the direct costs of climate policy, i.e. the tonnes reduced times the cost per tonne. No macroeconomic impacts in terms of lower GDP, moving of industrial activity to other countries, or the loss of fossil fuel exports can be calculated. Reference is made to other analyses. Co-benefits, such as lower costs for air pollution policy, are not included in the calculations. (Source: Van Vuuren et al. Stabilising greenhouse gas concentrations at low levels: an assessment of options and costs. Netherlands Environmental Assessment Agency, Report 500114002/2006)

Table 3.3. Estimate of the total cumulative technical potential of options to reduce greenhouse gas emissions during the period 2000–2100 (in $GtCO_2$-eq)

Option	Cumulative technical potential ($GtCO_2eq$)
Energy savings	>1000
Carbon capture and storage	>2000
Nuclear energy	>300
Renewable	>3000
Carbon sinks	>350
Non-CO_2 greenhouse gases	>500

Source: From climate objectives to emission reduction, Netherlands Environmental Assessment Agency, 2006, http://www.mnp.nl/en/publications/2006/FromClimateobjectivestoemissionsreduction. Insightsintotheopportunitiesformitigatingclimatechange.html

Technical potential of reduction options

The emission reduction that can be obtained from a specific reduction option is of course limited by the technical potential of that option. The technical potential is what can technically be achieved based on our current understanding of the technology, without considering costs. However, part of the technical potential could have very high costs. A first check of the viability of scenarios for drastic emission reduction is to compare the overall need for reduction with the total technical potential for all options considered. Table 3.3 shows estimates of the cumulative technical potential of the most important reduction options for the period 2000 to 2100. These are so-called conservative estimates, i.e. they give the minimum potential that is available.

The total technical potential for all options combined for this whole century is of the order of 7000 billion tonnes CO_2-equivalent[3]. This can then be compared with required cumulative reductions of 2600, 3600, and 4300 billion tonnes CO_2-equivalent for stabilization at 650, 550, and 450ppm CO_2-equivalent, respectively[4]. This first order comparison thus shows even the lowest stabilization scenario considered (450 ppm CO_2-equivalent) to be technically feasible.

Replacement of existing installations

The next step in the calculations is to combine introduction of reduction options in specific regions to a portfolio in such a way as to minimize costs. This means taking the cheaper options first. But it also means that reduction technologies are introduced to the extent they can be absorbed in the respective sector. For example, most models assume existing electric power plants are not replaced until their economic lifetime is reached. Low carbon energy supply options (e.g. wind power) in the model calculations thus only are used for replacing outdated power plants and for additional capacity needed.

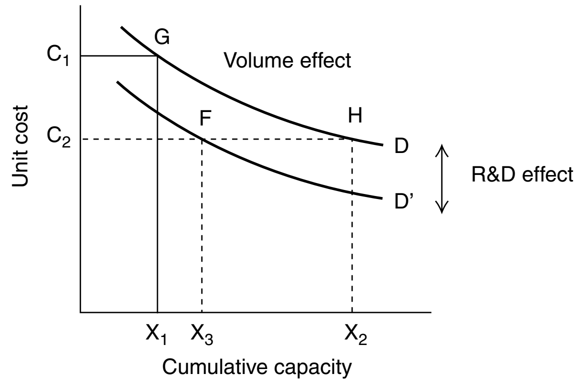

Figure 3.5 **Cost reduction of technologies as a result of learning by doing (costs go down proportional to the cumulative capacity built, as in line D) and as a result of Research and Development (costs go down when R&D delivers results, as in line D′). Cost reduction from c_1 to c_2 can be obtained by expanding capacity from x_1 to x_2, or, alternatively, by R&D investments and increasing capacity from x_1 to x_3. R&D is usually more important in the early stages of development of a technology. When a technology is more mature the capacity effect usually dominates.**

Source: Tooraj Jamasb, Technical Change Theory and Learning Curves: Patterns of Progress in Energy Technologies, Working paper EPRG, Cambridge University, March 2006.

Technological learning

Over time technologies become cheaper because of improvements in research and development and cost savings due to the scale of production. This is called 'technological learning' (see Figure 3.5). As an example, the price of solar (PV) energy units over the period 1976–2001 dropped 20% for each doubling of the amount produced.

These technological improvements and cost reductions are explicitly incorporated in the 'no action' case (the so-called baseline): efficiency of energy use increases; costs of renewable energy come down; and new technologies enter the market, even without specific climate change action. Traditional fossil fuel technologies also improve and costs come down unless fossil fuel prices go up (which happened recently). The effect of specific climate change action leading to increased deployment of technologies with lower emissions comes on top of this.

How important the baseline improvements are is shown in Figure 3.6. If technology had been frozen at the 2001 level, emissions in the baseline would have been twice as high by 2100.

Emission reductions

Figure 3.7 shows the outcome of calculations with one particular model[5] for a stabilization level of 450 ppm CO_2-equivalent. These results are typical for model calculations aiming at stabilization at this level. The right hand panel shows the contribution of the various

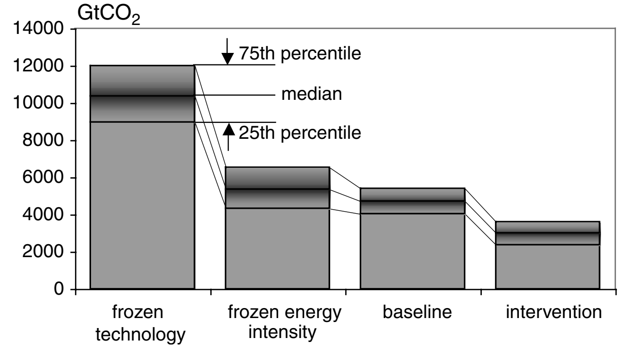

Figure 3.6 **Cumulative emission of greenhouse gases over the period 2000–2100 for different assumptions about technological learning. 'Frozen technology' assumes technologies do not improve beyond their current status; in the baseline normal technological learning is assumed as happened in the past; the intervention case assumes additional climate change action to reduce emissions. Note the large difference between 'frozen technology' and the baseline, showing the importance of technological learning.**

Source: IPCC Fourth Assessment Report, Working Group III, fig 3.32.

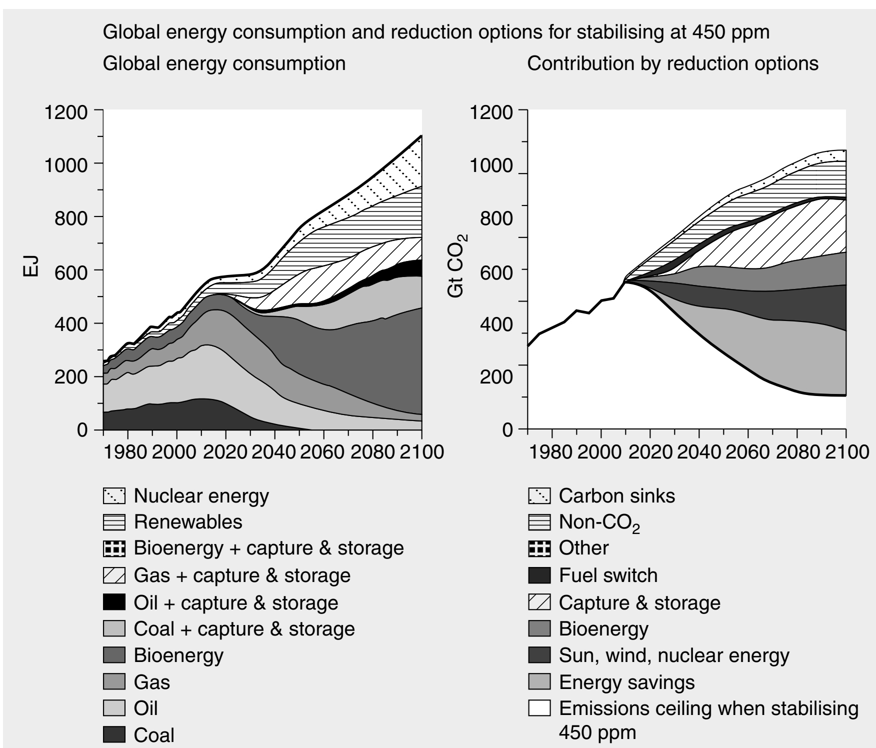

Figure 3.7 **Contribution of reduction options to the overall emissions reduction (right hand panel) and changes in the energy supply system for stabilization at 450ppm CO_2-eq.**

Source: From climate objectives to emission reduction, Netherlands Environmental Assessment Agency, 2006, http://www.mnp.nl/en/publications/2006/FromClimateobjectivestoemissionsreduction.Insightsintotheopportunitiesformitigatingclimatechange.html.

reduction options ('wedges'). One thing that stands out in this figure is the large contribution of energy efficiency improvement and CO_2 capture and storage (CCS). Energy efficiency is a relatively cheap option with a lot of potential. When the cost of achieving substantial reductions increases, CCS is more attractive than other more expensive options. The contributions of non-CO_2 gas reductions take place at an early stage, reflecting the relatively low cost of these options.

The left hand panel of Figure 3.7 shows the changes in the energy supply system as a result of implementing reduction options. The energy supply system continues to rely on fossil fuels (about 80% in 2005 and about 50% in 2050, but half of it will be 'clean fossil' (with CO_2 capture and storage). Fuel switching (from coal and oil to gas) and additional forest planting (so-called 'carbon sinks') play a very modest role. Biomass energy however gets a major share in the energy supply system after the middle of the century.

Different models give different results. An important reason for this is the different assumptions about the cost of reduction options, leading to a different order in which these options are introduced. Omission of certain options from the model and assumptions about availability of options, economic lifetimes of power plants or industrial installations, and economic growth also contribute to these model differences. Forest measures (forest planting and avoidance of deforestation) and CCS are for instance not included in the AIM model. Figure 3.8 shows a comparison of the relative contribution of reduction measures for three different models.

Similar differences in energy supply options are produced by the various models. The AIM model for instance shows a very high proportion of renewable energy by 2100 in the low level stabilization case, while other models do not. The main reason for this

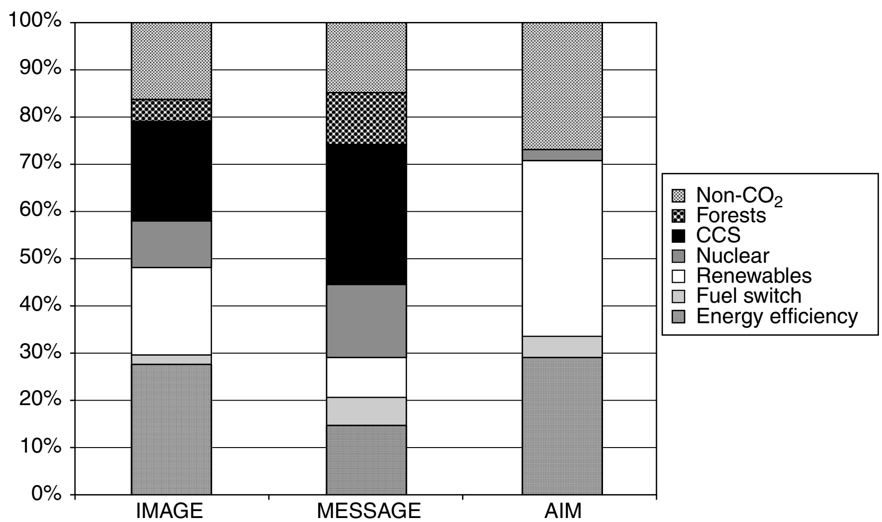

Figure 3.8 **Relative contribution of reduction measures to cumulative reductions in the period 2000–2100 in three models for stabilization at about 500 ppm CO_2-eq.**

Source: IPCC Fourth Assessment Report, Working Group III, figure 3.23.

variation of course is the absence of CCS from the available reduction options. There are also significant differences in total energy consumption in the various model outcomes as a result of different assumptions on the cost and potential of energy efficiency improvements.

Better to adapt to climate change than to avoid it?

The task of restructuring the energy system in order to achieve the lower stabilization levels is enormous. The political complications of getting global support for it are huge. Therefore the suggestion is sometimes made to focus efforts on adaptation to climate change as a way to manage the climate change risks. Is this a sensible approach? Let us investigate what adaptation means.

Societies have adapted to climate variability and climate change for a long time: building of dikes and putting buildings on raised foundations against floods, water storage and irrigation systems to cope with lack of precipitation, adjustment of crop varieties and planting dates in agriculture, and relocation of people in areas where living conditions have deteriorated greatly. Planned adaptation, i.e. adaptation in anticipation of future climate change, is beginning to happen[6]. In the Netherlands, for instance, management plans for coping with increased river flows and higher sea levels have been adjusted and substantial investment in overflow areas for river water and strengthened coastal protection against sea level rise are being made[7]. In Nepal adaptation projects have been implemented to deal with the risk of glacial lake outburst floods caused by melting glaciers[8].

There are many possible ways in which to adapt to future climate change. Table 3.4 lists some typical examples for a range of economic sectors, together with relevant policy actions and problems or opportunities.

Many adaptation options are serving other important objectives, such as protecting and conserving water (through forest conservation and efficient irrigation), improving productivity of agriculture (moisture management of soils), improving the protection of biological diversity (protection of mangrove forests, marshes), and creating jobs (infrastructural works)[9].

Most climate change impacts will occur in the future. Developing countries that are the most vulnerable to climate change need to develop their infrastructure and economic activity to improve the living conditions of their people and to create jobs. This means there are enormous opportunities to integrate climate change into development decisions right now. There is no need to wait until climate change impacts manifest themselves. In other words, development can be organized so that societies become less vulnerable to climate change impacts: development can be made ‘climate-proof’ (see Chapter 4).

There are serious limitations to adaptation. Adaptation will be impossible in some cases, such as melting of big ice sheets and subsequent large sea level rise, loss of ecosystems and species, and loss of mountain glaciers that are vital to the water supply of large areas. And even where adaptation is technically possible, it must be realised that the

Table 3.4. Selected examples of planned adaptation by sector

Sector	Adaptation option/ strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; *italics* = *opportunities*)
Water	Expanded rainwater harvesting; water storage and conservation techniques; water re-use; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; *integrated water resources management*; *synergies with other sectors*
Agriculture	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological & financial constraints; access to new varieties; markets; *longer growing season in higher latitudes*; *revenues from 'new' products*
Infrastructure/ settlement (including coastal zones)	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; *integrated policies and managements*; *synergies with sustainable development goals*
Human health	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognize climate risk; strengthened health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; *upgraded health services*; *improved quality of life*
Tourism	Diversification of tourism attractions and revenues; shifting ski slopes to higher	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives,	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse

	altitudes and glaciers; artificial snow making	e.g. subsidies and tax credits	impact on other sectors (e.g. artificial snow making may increase energy use); *revenues from 'new' attractions*; *involvement of wider group of stakeholders*
Transport	Realignment/relocation; design standards and planning for roads, rail, and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; *improved technologies and integration with key sectors (e.g. energy)*
Energy	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; *stimulation of new technologies*; *use of local resources*

Source: IPCC Fourth Assessment Report, Synthesis Report, table SPM.4.

capacity required to implement it and the costs of doing it might be prohibitive. Think of people on low lying islands, poor farmers in drought prone rural areas in Africa, people in large low lying river delta regions, or on vulnerable flood plains in densely populated parts of Asia. But also in highly developed areas there are serious limitations to adaptation as the huge impacts of hurricane Katrina in New Orleans in 2005 and the heat wave in Europe in 2003 showed[10].

Given the limitations of adaptation, it does not appear to be a good strategy to rely only on adaptation. Limiting climate change through emission reductions (mitigation) can avoid the biggest risks that cannot realistically be adapted to. Mitigation does not eliminate all risks however. Even with the most ambitious efforts that would keep global average temperature rise within 2°C above the pre-industrial level, there is going to be substantial additional climate change. Adaptation to manage the risks of that is needed anyway. Adaptation is also needed to manage the changes in climate that are already visible today. Adaptation and mitigation are thus both needed. It is not a question of 'either-or' but of 'and-and', or, in other words, 'avoiding the unmanageable and managing the unavoidable'[11].

What are the costs?

The first question is: 'costs of what?' Too often only the costs of controlling climate change are considered. The costs of inevitable adaptation to a changed climate are usually forgotten, although it is clear that the less is done on emissions reductions, the more needs to be done on adaptation. But what is worse is that the 'costs of doing nothing', i.e. of the impacts of uncontrolled climate change, are often completely ignored. That distorts the picture. In other words, the only sensible way to look at costs is to look at both sides of the balance sheet: the cost of reducing emissions on the one hand and the costs of adaptation and the costs of the remaining climate change impacts on the other. In fact, to get a realistic picture of the true costs, the indirect costs and the benefits of taking action need to be included also as a correction to the mitigation costs. Many actions to reduce emissions have other benefits. A good example is the avoidance of air pollution when coal is replaced by natural gas in order to reduce CO_2 emissions.

Mitigation costs

Costs of mitigation can be expressed in several ways. One is the cost of avoiding 1 tonne of CO_2 (or a mixture of gases expressed as CO_2-equivalent). Knowing how many tonnes you need to avoid under a specific mitigation programme, and multiplying that number with the cost per tonne, gives you the total costs of that programme (in fact investment and operational costs, but often called 'abatement costs').

There is also another cost perspective: the cost to the economy as a whole, or how much the overall 'wealth' (expressed for instance in the GDP of a country) is affected by mitigation policies. There no simple relationship between the two cost measures. Expenditures as such do not reduce wealth. In fact the opposite is true: more economic activity (expenditures) means a higher GDP. However, spending money on reducing greenhouse gases normally means that money is not spent on something else. Many other economic (but not all) activities produce more wealth than reducing greenhouse gas emissions and therefore overall wealth could be reduced as a result of mitigation action. The 'foregone increase of wealth' (by choosing mitigation instead of more productive activities) is then the macro-economic cost of that mitigation action. Note that the cost of the damages due to climate change is not included. Nor are the effects of adaptation[12].

Expenditures for mitigation in long-term mitigation strategies leading to stabilization of greenhouse gas concentrations in the atmosphere can be substantial. As outlined above, over time more and more costly reduction options need to be implemented in order to drive down emission to very low levels. The deeper the cuts in emissions, the higher the cost of the last tonne avoided will be (called the 'marginal cost'). Figure 3.9a shows how the marginal cost develops over time for different stabilization scenarios.

The marginal cost is shown for a typical set of stabilization calculations as a function of time for different stabilization scenarios. Ambitious scenarios lead to a stronger increase of marginal costs. Total abatement costs are determined by the average costs and the volume of the required reductions. These costs are shown in Figure 3.9b. To put cost

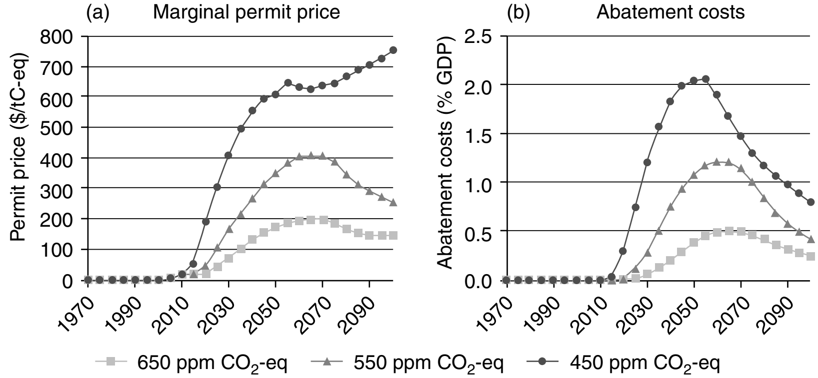

Figure 3.9 **(a) Development of the marginal cost of a tonne of CO_2-eq avoided for different scenarios. (b) Abatement costs expressed as % of global GDP for the same stabilization scenarios as in (a). For all scenarios an IPCC SRES B2 baseline was used.**

Source: Van Vuuren et al. Stabilising greenhouse gas concentrations at low levels: an assessment of options and costs, Netherlands Environmental Assessment Agency, Report 500114002/2006.

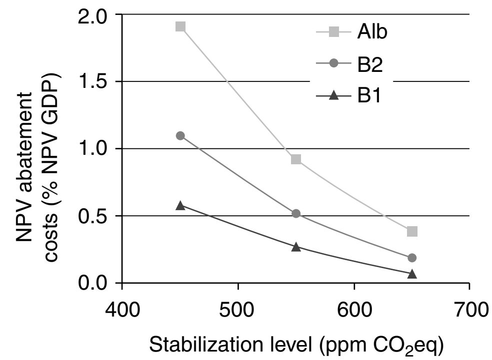

Figure 3.10 **Discounted (Net Present Value) of cumulative abatement costs for different stabilization levels, expressed as % of discounted GDP, for different baselines.**

Source: Van Vuuren et al. Stabilising greenhouse gas concentrations at low levels: an assessment of options and costs, Netherlands Environmental Assessment Agency, Report 500114002/2006.

numbers in perspective, they are usually expressed as % of global GDP. For low level stabilization they can go up to about 1–2% of GDP in the period around 2050. This means that for ambitious stabilization scenarios expenditures for emission reduction would be of the same order of magnitude as those for all environmental measures taken today in most industrialized countries.

To make cost comparisons easier, costs can be accumulated over the century and expressed as the so-called 'net present value' (future costs discounted to the present). Typical numbers found for this cumulative cost are 2–3% of global GDP for the most stringent scenarios (leading to low stabilization levels) and most pessimistic assumptions, to less than 1% for higher stabilization levels and more optimistic assumptions[13].

Table 3.5. Coverage of sectoral estimates of adaptation costs and benefits in the literature (size of check mark indicates degree of coverage)

Sector	Coverage	Cost estimates	Benefit estimates
Coastal zones	Comprehensive – covers most coastlines	√	√
Agriculture	Comprehensive – covers most crops and growing regions	–	√
Water	Isolated case studies in specific river basins	√	√
Energy (demand for space cooling and heating)	Primarily North America	√	√
Infrastructure	Cross-cutting issue – covered partly in coastal zones and water resources. Also isolated studies of infrastructure in permafrost areas	√	–
Heath	Very limited	√	–
Tourism	Very limited – winter tourism	√	–

Source: OECD, Economic aspects of adaptation to climate change, 2008.

Costs are not only affected by different stabilization levels, but also by assumptions about the trends without action (so-called baselines). Baselines that reflect high growth economies, heavily relying on fossil fuels, lead to higher abatement costs (see Figure 3.10).

Adaptation costs

Adaptation is a local issue. Building a picture of global adaptation costs therefore requires summing up a large number of local and regional studies, which is where the problem lies. Studies are limited. In terms of coastal defence and agriculture the coverage of studies is reasonable. Beyond that, coverage is poor. Where coverage is reasonable, studies are not harmonized, making it very difficult to get an aggregate cost number. Avoided risks are not clearly defined, so that it is unclear what precisely is achieved for a certain additional investment (see Table 3.5).

For coastal defence in response to rising sea levels many studies were undertaken in all parts of the world. Cost estimates for small low lying island states are the highest: for most countries close to 1% of GDP per year, with much higher numbers for the Marshall Islands, Micronesia, and Palau. The costs are somewhat lower for coastal countries[14]. But studies have not been standardized regarding the sea level rise to which adaptation is tailored.

Studies on adaptation in agriculture have focused on minimizing productivity loss. Outcomes show that productivity loss can be reduced by at least 35% and sometimes can be avoided completely or additional yields can be obtained (meaning current practices are not optimal). Reliable data on cost are not available, and usually rough estimates are made on increasing R&D (something like 10%), agricultural extension (also 10% or so), and investment (2% increase)[15].

For the water sector only one rough estimate is available currently and that one only looks to 2030. It suggests at least US$10 billion per year is needed in that timeframe, which is small compared to the US$50 trillion annual world GDP. For infrastructure, health, and tourism there are only a few isolated studies available.

Notwithstanding a poor knowledge base, attempts have been made to estimate global adaptation costs across all sectors. The Worldbank did a study based on investments that are sensitive to climate change. Others followed this method. The numbers for global adaptation costs range from about 10 to 100 billion US$/year. Studies undertaken by the Climate Change Convention are based on sectoral data and are higher: 30–170 billion US$/year. Later studies arrive at higher numbers, with the highest being about 0.3% of global GDP. These numbers are very uncertain however and could easily be proven wrong by more detailed studies undertaken in the future.

Co-benefits

Strong reductions in greenhouse gas emissions can help address other problems, air pollution being one of them. Reducing fossil fuel use does not only reduce emissions of CO_2, but also of small particles, SO_2, and NOx that cause serious health problems. When the reduction in health problem is quantified in dollar terms (although that is tricky because of the assumptions that have to be made), this covers a significant part of the mitigation costs. Or, in other words, net mitigation costs are much smaller. When avoidance of crop damage and damage to ecosystems due to better air quality is added, net mitigation costs go down further still[16].

There are other co-benefits. Energy efficiency measures and a shift to renewable energy sources will reduce imports of oil and gas, improving the energy security of many countries. Employment can be generated through labour intensive energy efficiency improvements in existing buildings and production and installation of renewable energy installations[17]. Figure 3.11 shows the magnitude of some of these co-benefits for different stabilization scenarios. For the most stringent 450 ppm CO_2equivalent scenario, reduction in loss of life due to air pollution and oil imports is of the order of 30%.

Costs of climate change damages

Attempts have been made to express the damages from climate change in monetary terms. This is an extremely difficult exercise. There are large uncertainties about regional

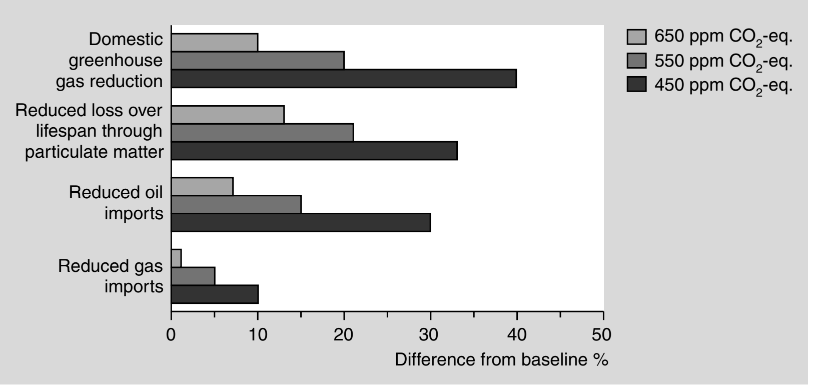

Figure 3.11 **Co-benefits of climate policy for air quality and energy security in 2030 for different stabilization scenarios. Improvements are shown as % of the baseline.**
Source: Van Vuuren et al. Stabilising greenhouse gas concentrations at low levels: an assessment of options and costs, Netherlands Environmental Assessment Agency, Report 500114002/2006.

impacts, because not every region has been studied enough and, more importantly, because climate change at regional and local scale cannot yet be predicted with certainty. In many areas it is, for instance, not yet known if the climate will get wetter or dryer. Climate models are not sophisticated enough yet.

But even knowing the impacts does not mean these impacts can be translated into costs. For things that have a market value, such as food, it is relatively simple: loss of production can be converted into a loss of income for the farmer. Lack of drinking water can be translated into costs by calculating, for instance, the costs of building pipelines to bring drinking water from other regions or of producing drinking water from sea water. Costs of building sea walls and dikes to protect against sea level rise can also be calculated. But how can a value be placed on the loss of land that can no longer be protected or abandonment of islands and relocation of people? When it comes to human disease or death or loss of species and ecosystems, it becomes even more problematic to attach a monetary value[18]. This is the first source of uncertainty and of differences in outcomes from different studies.

Then there is the choice of which impacts to include. Should low probability, high consequence events such as slowing of the ocean circulation or melting of the Greenland ice cap be included or not? And if so, how is the impact quantified? Is mass migration as a result of an area being no longer suitable for habitation covered? If climate change is going to be worse than the current best estimate, are the impacts of that evaluated or not? This is the second reason for the large uncertainties and differences between study outcomes.

A third major factor in the uncertainty of cost calculations is the so-called discount factor. This reflects the value attached to impacts in the future versus those happening today. In most economic calculations future costs are given a lower value, the argument being that future generations will have higher incomes and more options. Costs go down by a certain percentage per year they lie in the future. This is the discount rate. In fact a discount rate is the inverse of an interest rate on an investment made today. Just as a capital grows over time with a certain interest rate, so a future cost is reduced to a present cost with a certain discount rate. For costs of regular economic activities these discount rates can range from a few per cent to 10–15% or more.

What does this mean? For a discount rate of 5%, the cost counted today will only be less than 50% of the cost that is incurred 10 years into the future. This implies that costs of climate change impacts that may happen 50 or 100 years into the future in fact count as almost zero today. In such a situation, and certainly when it comes to impacts over a period of 100–200 years that may to some extent be irreversible and potentially catastrophic, such discount factors are widely seen as ethically unacceptable. Very low or even zero discount rates are then advocated for such situations. The Stern review[19] for instance chose a very low discount rate on exactly those grounds. However, there is no general consensus on the exact value of the different discount rates for such situations, explaining why outcomes of cost estimates can vary widely.

The fourth cause of uncertainty in calculations of cost of impacts is the relative weight. Do we simply add up costs or give them a weighting based on the size of the population that is affected? And do we weigh all costs equally, or are costs in poor countries or for poor people given more weight from a fairness point of view? The loss of a certain amount of money has a much bigger impact on a poor person than on a rich one. This is called equity weighting. In some calculations this is applied, in others not, which makes a big difference.

Notwithstanding this myriad of problems, calculations have been made. It will be no surprise that they span a wide range as a result of different assumptions and smaller or larger coverage of potential impacts. They are also very likely underestimating the real costs. Costs can be expressed in different ways: as a percentage of GDP or as the costs per tonne of CO_2 or CO_2-equivalent emitted today.

Many estimates express the total costs as a percentage loss of GDP, for a given degree of climate change. GDP is a measure of economic output. For a global average temperature increase of about 4°C, most estimates show a global average loss that varies from 1% to 5% of global GDP, with some studies going up to about 10% loss for about 6°C warming. Developing countries are facing higher than average losses[20]. Even a single catastrophic event, such as a major tropical cyclone, can cause enormous damage in poor countries. The drought in Southern Africa in 1991–1992 for instance caused a drop in income in Malawi of over 8%. Hurricane Mitch caused damages in Honduras totalling about $1250 per inhabitant, 50% more than the per capita annual income.[21]

The Stern review used similar numbers to express the damages from climate change impacts as referred to for the Honduras case, namely the loss of consumption or income per person. This gives a more direct idea of the economic impact as felt by people, because it does not include the economic output generated by 'clean-up' activities as a result of climate change impact damages. Stern came to much higher estimates of losses than most of the other estimates mentioned above, i.e. 5–20% of GDP for temperature increases of 7–9°C. This stronger warming assumption, which by the way is well within the range of estimates for the next 200 years or so, is of course one explanation. They also used a very low discount rate, applied equity weighting, and included the risk of much stronger climate change than the best estimate available today. These assumptions are not unrealistic however.

Costs can also be expressed in a different way by calculating the total future damages that are caused by 1 tonne of CO_2 emitted today and to discount these future costs to today. That produces the so-called ‘social cost of carbon (SCC)’. Estimates for this SCC vary widely, for the reasons given above. Based on available studies the estimate is US\$5–95 per tonne of CO_2-equivalent emitted today. Some studies give lower or higher numbers. The advantage of using this SCC is that it can easily be compared with the costs of avoiding this amount of CO_2-equivalent emissions. Since most emission reduction technologies have a cost of less than US\$100 per tonne today, avoidance becomes attractive. For emissions in the future the SCC will be higher, because damages increase at higher greenhouse gas concentrations in the atmosphere. For a tonne emitted in 2030 for instance the SCC is estimated to be something like US\$10–190 per tonne of CO_2-equivalent. This is of the same order of magnitude or higher than the expected costs of drastic reductions of emissions, leading to stabilization at very low concentrations (of the order of US\$30–120/tCO_2-eq). This does not yet take into account the fact that the SCC is very likely underestimated because of the limitations of the current studies.

Risk management

How should all these factors be weighed up when deciding where to draw the line on climate change? The answer is ‘risk management’. That means considering the risks of climate change impacts, how reduction of greenhouse gas emissions, increasing forest carbon reservoirs and adaptation could reduce those risks, what the costs and co-benefits of those actions are, and what policy actions would be needed to realize these actions. This is not a simple process.

There are basically two different approaches to this risk management problem:

- determine what a ‘tolerable’ risk of climate change impacts is (political judgement based on scientific evidence), determine how this can be achieved at the lowest possible costs, and then consider if this is practicable from a policy point of view
- do a cost–benefit analysis to compare the monetized climate change damages with the cost of taking action, ensuring the costs are not higher than the benefits

Political judgement: the EU’s 2 degree target

The first approach has been chosen by the European Union. At the political level the European Union formulated its ‘two degree target’ in 1996. Based on the then available scientific information, as summarized in the IPCC’s Second Assessment Report, the EU proposed a limit of 2°C above the pre-industrial level as the ‘maximum tolerable level’ of climate change for global use and adopted it as guidance for its own policies. It was reconfirmed at the highest level of heads of state and prime ministers of the EU Member

States in 2007[22]. This 2°C target has been the basis for the EU's negotiating position for the Kyoto Protocol, its unilateral policy, adopted in 2007, to reduce EU greenhouse gas emissions to 20% below 1990 levels and its position on a new agreement to follow the Kyoto Protocol (30% reduction below 1990 levels by 2020 for all industrialized countries). It has been endorsed by a few other countries and many non-governmental environmental organizations.

When setting the 2 degree target the EU kept an eye on the costs, co-benefits, and required policy for achieving this target (but not in the form of a cost–benefit analysis), although the available scientific and technical information was limited at the time. Since 1996 much more information has become available, which shows that staying below 2°C of warming compared to pre-industrial levels is going to be tough, although not impossible and not very costly. In fact no studies so far show specific reduction scenarios that achieve a lower temperature increase without early retirement of power plants and industrial installations.

Most countries responsible for the biggest share of global greenhouse gas emissions have been reluctant to state a long term goal for controlling greenhouse gases and climate change. Japan came the closest with its proposal of reducing global emissions to half their 2005 level by the year 2050[23]. This was subsequently endorsed by the G8 leaders in 2008 in Japan, but with a significant weakening: the base year was omitted[24]. The reasons behind that are that the formulation as proposed by Japan is significantly weaker than what the EU 2 degrees target requires (a 50–85% reduction compared to 1990). At the other end of the spectrum the USA was not even ready to subscribe to the Japanese proposal. More recently, leaders of the major economies have expressed support for a 2°C limit.

Cost–benefit comparison

When applying a traditional cost–benefit analysis, monetized costs of climate change impacts are compared with the costs of mitigation, adaptation, and co-benefits. Unfortunately, a reasonable estimate of the global costs of adaptation cannot be given, nor can the co-benefits be quantified. This leaves us with a comparison between the costs of impacts (without adaptation) and the cost of stabilizing greenhouse gas concentrations at specific levels. Even that comparison is problematic, particularly due to the huge uncertainty in the costs of the climate change damages (see above). When we take the lowest level of stabilization that was assessed by the IPCC (i.e. 445–490ppm CO_2-eq) and we look at the cost of the last tonne avoided (the so-called marginal cost) in 2030, we see a range of something like US\$30–120/tCO_2-eq (see above). This is of the same order of magnitude as the damages of a tonne of greenhouse gases emitted, expressed as the 'social costs of carbon' (US\$10–190/tCO_2-eq, see above). In light of the underestimation of the cost of impacts and the co-benefits of mitigation action (positive, but not quantified), it seems to make sense to take aggressive action, because benefits are higher than the costs[25].

The Stern review came to the same conclusion, in a much more unambiguous way. They compared the costs of aggressive actions (1–2% of GDP) to the costs of the damages without controls (5–20% of GDP) and concluded that taking aggressive action is

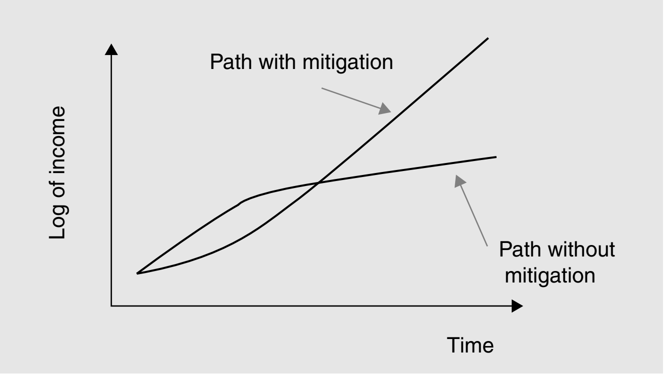

Figure 3.12 **Schematic drawing comparing economic growth paths for a situation with and without mitigation.**
Source: Stern review on the economics of climate change, Figure 2.3.

much cheaper than doing nothing. As indicated above the difference with the IPCC results comes from the assumptions the Stern review made on the discount rate, the inclusion of low probability, high consequence impacts and the equity weighting they applied[26]. The schematic drawing in Figure 3.12 illustrates nicely that in the short term mitigation costs lead to lower economic growth, but that this is compensated later by the negative impacts of climate change on the economy.

So what do we know now?

This chapter shows how the critical question on the appropriate level of stabilization of greenhouse gas concentrations in the atmosphere can be approached. It indicates that global average temperature increase can be limited to 2°C compared to pre-industrial and reasonable costs. This is only the case if aggressive action in the short term is taken. It also clarifies that many risks of climate change, particularly the most serious ones, can be avoided in this way. Adaptation remains important however, because at 2°C warming there will still be many negative impacts, affecting many people, particularly in developing countries. From a risk management perspective taking this aggressive action is justified.

Notes

1. See also Chapter 12.
2. See UNFCCC, http://www.unfccc.int.
3. The technical potentials of the various options cannot be simply added, because there could be overlaps and competition between some of the options for certain parts of the economy.
4. From climate objectives to emission reduction, Netherlands Environmental Assessment Agency, 2006, table 1, http://www.mnp.nl/en/publications/2006/FromClimateobjectives-toemissionsreduction.Insightsintotheopportunitiesformitigatingclimatechange.html.

5. IMAGE-TIMER 2.3; more information can be found in Van Vuuren et al. Stabilising greenhouse gas concentrations at low levels: an assessment of options and costs, Netherlands Environmental Assessment Agency, Report 500114002/2006.
6. IPCC Fourth Assessment Report, Working group II, ch 17.2.
7. http://www.verkeerenwaterstaat.nl/english/topics/water/water_and_the_future/water_vision/.
8. IPCC Fourth Assessment Report, Working Group II, box 17.1.
9. IPCC Fourth Assessment Report, Working Group II, ch 17.2.2.
10. IPCC Fourth Assessment Report, Working Group II, ch 17.4.2.
11. Confronting climate change: avoiding the unmanageable and managing the unavoidable, United Nations Foundation, 2007.
12. IPCC Fourth Assessment Report, Working Group III, ch 2.4.
13. IPCC Fourth Assessment Report, Working Group III, ch 3.3.5.3.
14. Agrawala S, Frankhauser S (eds) Economic Aspects of Adaptation to Climate Change, OECD, Paris, 2008.
15. See note 14.
16. IPCC Fourth Assessment Report, Working Group III, ch 11.8.
17. See also Chapter 10.
18. Economic methods for attaching a monetary value to a human life consider for instance the life-time 'earning power' (income over life-time). This automatically leads to a much higher value of a human life in rich countries than in poor countries. This raises serious ethical problems. An intense political debate on this issue started when the 1995 IPCC Second Assessment Report, Working Group III was released in which such calculations featured.
19. Stern review: the economics of climate change, chapter 2.
20. IPCC Fourth Assessment Report, Working Group II, ch 20.
21. Stern review, chapter 4.3.
22. European Council conclusions, March 2007.
23. See the 'Cool Earth 50' proposal as outlined in the speech of Prime Minister Abe, http://www.mofa.go.jp/policy/environment/warm/coolearth50/speech0705.html.
24. http://www.khou.com/sharedcontent/projectgreen/greenarticles/stories/070808kvueG8climate-cb.35fb6506.html.
25. IPCC Fourth Assessment Report, Working Group III, ch 3.5; the discussion there takes into account the wide range of estimates for damages in the literature and the full range of outcomes of stabilization studies. The conclusion of the IPCC did not take into account the co-benefits.
26. Stern review: the economics of climate change, ch 13.