10 How does it fit together?

What is covered in this chapter?

This chapter discusses the overall mitigation potential at various cost levels, the contributions of the sectors, and the question of where the potential is located. It concludes that the mitigation potential is big enough to bring global emissions back to current levels by 2030. With this potential stabilization of atmospheric concentrations of greenhouse gases at levels of 450ppm CO_2-eq is still within reach, provided that the potential in developing countries is also tapped. Geo-engineering is not needed, and that is comforting, because the risks and uncertainties of such planetary experiments are huge. In all countries substantial potential exists with so-called negative costs (i.e. where investment is profitable), but costs differ as a result of strong differences in national circumstances. Cost for the economy as a whole is limited when cheap options are implemented first. On average annual economic growth rates will not be reduced by more than a few tenths of a percentage point, and that is without taking co-benefits for energy security, health, and employment into account. Investments required for implementing the reduction options will have to shift strongly to efficiency of energy use and low carbon energy, and are bigger than those without stringent climate policy, but are compensated by much lower energy costs. Implementing low carbon technology rapidly in developing countries is crucial to controlling climate change. National priorities in developing countries for modernization, energy security, and trade are the main drivers. Governments in the North and South should remove obstacles and create the right conditions.

Adding up the sector reduction potentials

After looking into the economic reduction potentials for the various sectors in Chapters 5, 6, 7, 8, and 9, it is time to discuss the total reduction potential for the world as a whole. This then should be compared with the reduction needs for the various stabilization levels identified in Chapter 3 to see if low level stabilization is possible.

Adding up sector potentials sounds simple. There are some complications however. When evaluating the sector potentials, reductions in electricity use and heat from power plants and district heating installations were included. This affects the demand for electricity and heat that was assumed in Chapter 5 in estimating the reduction potential for the energy supply sector. To avoid double counting, this needs to be reconciled. The easiest way to do that is to recalculate the energy supply reduction potential for the reduced demand after subtracting the demand reductions from the various energy end-use sectors. In doing so, the reduction potential in the energy supply sector becomes 2.4–4.7 $GtCO_2$-eq/year by 2030, for costs up to US$100/$tCO_2$-eq. Without this correction the numbers were almost twice as high: 4.0–7.2 $GtCO_2$-eq/year[1].

There are other complications. Baseline assumptions in the various sectors are not exactly the same, because available studies differ. And since reduction potentials are sensitive to the baseline assumed, adding up sector potentials introduces additional uncertainty.

The other major problem is the lack of numbers on the potential of some reduction opportunities[2]:

- Fluorinated gases from energy supply, transport, and buildings. There are only a few numbers for 2015: about 0.4 $GtCO_2$-eq/yr for HFCs at costs ranging from negative to above US$100/$tCO_2$-eq[3]
- The potential of Combined Heat and Power in the energy supply sector is uncertain and probably about 0.2–0.4 $GtCO_2$-eq
- Methane from gas pipelines and coal mining in the energy supply sector. Estimates for methane reduction from coal mining for 2020 are 0.2–0.4 $GtCO_2$-eq/year
- Freight transport
- Public transport, urban planning, change of transport mode, and speed limits
- More advanced opportunities in buildings
- Energy efficiency in the non-energy intensive industries
- Reduced use and replacement of energy intensive materials

This means the numbers given are underestimating the reduction potential by at least 10–15%.

Finally, energy prices do have an impact on the calculation of economic reduction potentials. Available data on reduction potentials are usually calculated with oil and gas prices much lower than today. The transport sector is the most sensitive because of the importance of oil. Generally speaking economic reduction potential would be higher if oil prices remain high for a long time. In other sectors, where mostly coal and gas are used, the influence is smaller.

Further it is important to remember that the calculation of economic reduction potential uses ‘social costs’, i.e. longer payback times as used in public sector investments (5–30 years). They calculate what is economically rational for societies as a whole. That is different from the way private sector decision makers look at profitability of investments. They use much shorter payback times. See Box 6.6 for definitions of mitigation potential.

Figure 10.1 shows the results as they emerge from Chapters 5, 6, 7, 8, and 9. Note the large uncertainty ranges. Economic reduction potentials are given for different cost

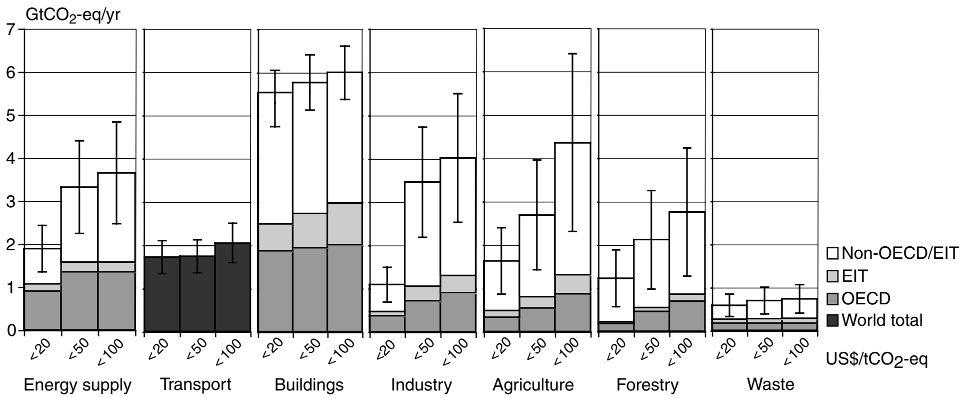

Figure 10.1 **Global economic mitigation potential for the most important economic sectors, for different cost categories and geographical regions. Note: industry and waste have been grouped together in Chapter 8 and are shown separately here; the numbers shown here for forestry are at the low end of the range listed in Chapter 9.**
Source: IPCC Fourth Assessment Report Working group III, fig SPM.4.

levels and for different categories of countries. What is striking is the large share of developing countries in the reduction potential. This is consistent with the general knowledge about low efficiencies of energy use and lack of capital to invest in modern installations. Overall more than 50% of the potential is found in developing countries[4].

Since potentials for measures with negative costs are not available for all sectors, there is just one category of costs up to US\$20/tCO_2-eq in Figure 10.1. However, about 6GtCO_2-eq in total is available at zero or negative costs in 2030.

Reliable quantitative estimates of the potential from behavioural change are not available. They are of course real, but small compared to the potential from technical options.

A global cost curve?

Ideally all sectoral reduction options are grouped into one integrated abatement cost curve. In its latest assessment report the IPCC did not produce such a cost curve, because published data did not allow it. However, McKinsey and Company, in collaboration with Vattenfall and others, making use of their extensive set of private industrial data, did produce such a global abatement cost curve recently[5]. Figure 10.2 shows a simplified version, where only a limited set of reduction options is highlighted (see Box 10.1 for an explanation of how to read such an abatement cost curve). The total reduction potential at costs < € 60/tCO_2-eq (roughly equal to US\$100/t) is about 37GtCO_2-eq/year in 2030. This is considerably higher than the range found in the latest IPCC report (16–31GtCO_2-eq for costs < US\$100/tCO_2-eq).

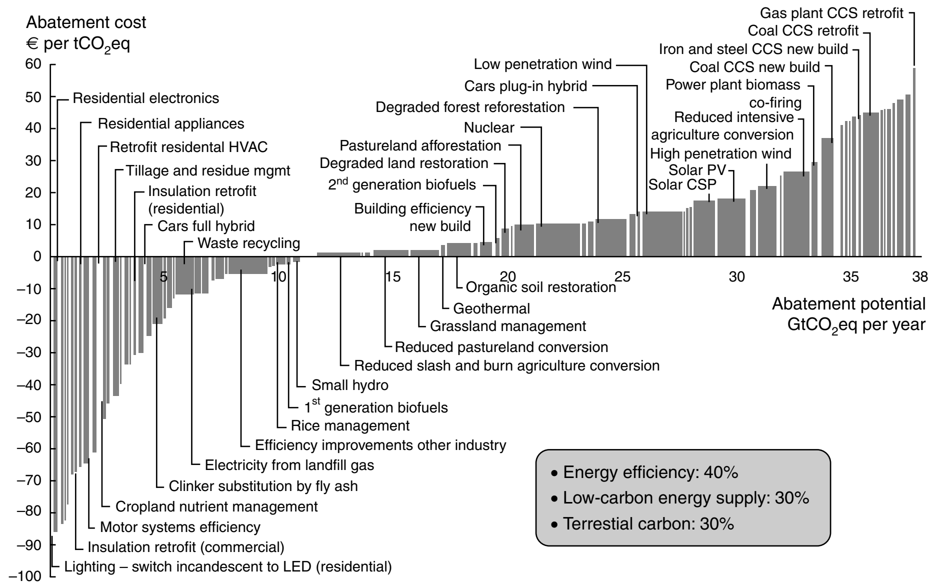

Figure 10.2 **Global greenhouse gas abatement cost curve.**

Source: McKinsey and Company, 2009.

Box 10.1 **How to read an abatement cost curve?**

The abatement cost curve describes two numbers:

1. The potential to reduce CO_2 equivalent (CO_2-eq) emissions. For example, a global infrastructure to use cellulose ethanol as a fuel would reduce CO_2-eq emissions by almost a billion metric tonnes per year in 2030, compared with continuing to use fossil fuels.
2. How much that measure costs for every tonne of CO_2-eq emissions it saves. For example, the abatement cost for cellulose ethanol is calculated by dividing the costs of building and operating a cellulose ethanol infrastructure by the number of tonnes of CO_2-eq it saves compared with the current fuel mix.

The first number, the abatement potential, is plotted on the horizontal axis, and the second number, the cost, on the vertical. The measures have been arranged in order of cost, with the cheapest on the left, and the most expensive on the right. Only measures with an estimated cost of less than € 60/tCO_2-eq are included in the analysis. This is not to make any forecasts about what a potential future carbon price should be, but rather a reflection that a cut has to be made at some price and that it is increasingly difficult to calculate the costs of technologies the further they are from being commercial today.

How does this compare with global top-down studies?

Complex integrated models, describing the whole economy and the climate system, are being used as well to estimate economic mitigation potential (we will call them 'top-down' models; see Chapter 3). They have of course much less detail about the specific elements of sector activities and about mitigation technologies. On the other hand they usually have something that bottom-up analyses lack: an integration of all activities into the overall economy. The advantage is that supply and demand of energy are by

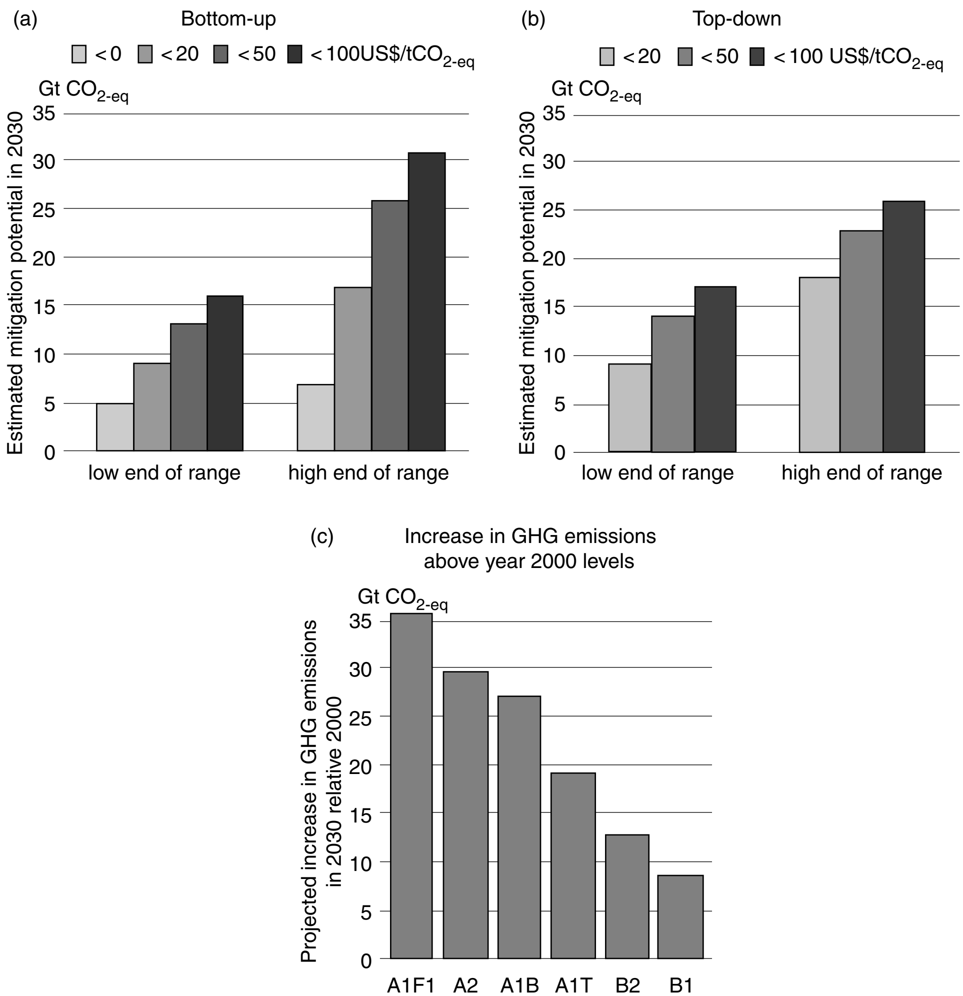

Figure 10.3 **Bottom-up and top-down estimates for the global reduction potential in relation to the estimated emissions increases in the baselines.**

Source: IPCC, Fourth Assessment Report, Synthesis Report, figure SPM.9.

definition the same (in bottom-up studies corrections are needed; see above). And energy prices in these models are the result of demand and supply and automatically adjusted over time (bottom-up studies normally have to assume a certain energy price).

So it is interesting to compare the economic reduction potential estimates from these two different approaches. Figure 10.3 shows they are roughly of the same order of magnitude. That is somewhat of a surprise, because for a long time top-down models used to give much lower estimates than bottom-up assessments. One important explanation was that top-down models assume that no negative cost reduction options exist.

Figure 10.3 also shows that for cost levels up to US\$100/tCO_2-eq the reduction potential is enough to have a good chance of fully compensating the projected growth in the baseline (the bars on the right). In case baseline growth is not that strong (the B1, B2, or A1T scenarios), emissions could even be brought back to below 2000 levels by 2030 at costs up to US\$100/t CO_2-eq.

The consistency of the top-down and bottom-up results only holds for economy wide estimates. At sector level there are large discrepancies. A major reason is the difference in sector definitions between the top-down and bottom-up calculations. Other explanations are the partial coverage of the energy supply sector in bottom-up estimates and their better coverage of the buildings and agriculture sectors[6].

How far do we get with these reduction potentials?

The big question is of course how far we get towards stabilization of concentrations in the atmosphere with these reduction potentials. As discussed in Chapter 3, emissions

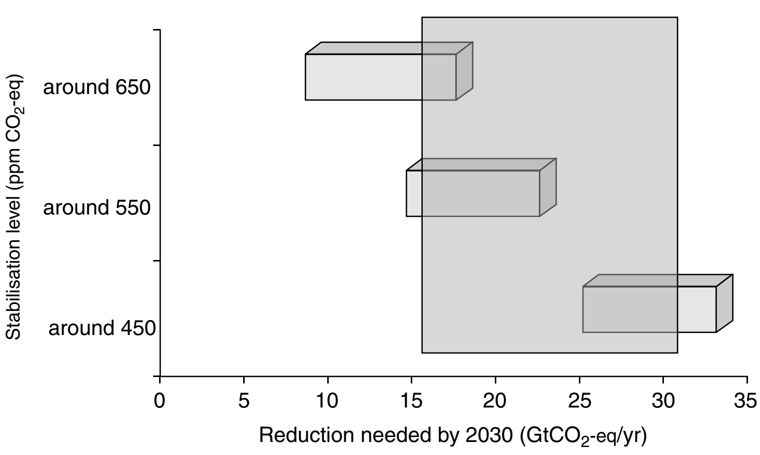

Figure 10.4 **Comparison of available CO_2-eq reduction potential for 2030 (shown as transparent box for costs up to US\$100/tCO_2-eq with minimum and maximum) and CO_2-eq emission reductions needed by 2030 (compared to 2000) for stabilization at various levels expressed in ppm CO_2-eq (range due to different possible baseline emissions).**

Source: IPCC Fourth Assessment Report, Working Group III, table 11.3 and van Vuuren et al. Climatic Change, vol 81(2), March 2007, pp 119–159.

Table 10.1. Comparison of reductions needed for different stabilization levels and economic mitigation potential available

Stabilization level (ppm CO_2-eq)	Global Mean temp. increase at equilibrium (¤C)	Estimated CO_2-eq reduction needed by 2030 compared to baseline[a]	Annex I 2030 CO_2-eq mitigation potential (bottom-up)		Global 2030 CO_2-eq mitigation potential (bottom-up)	
			<US$50/t	<US$100/t	<US$50/t	<US$100/t
445–490 (around 450)	2.0–2.4	25–33	6–9	7–11	12–25	16–31
535–590 (around 550)	2.8–3.2	14–22	6–9	7–11	12–25	16–31
590–710 (around 650)	3.2–4.0	8–17	6–9	7–11	12–25	16–31

[a] Taken from van Vuuren et al for two different baselines (IPCC SRES B2 and A1B).

Source: IPCC Fourth Assessment Report, Working Group III, table 11.3 and van Vuuren et al. Climatic Change, vol 81(2), March 2007, pp 119–159.

trajectories towards stabilization have to peak and then go down steeply. The lower the stabilization level, the earlier this peaking has to occur and the earlier deep reductions need to be reached. Table 3.1 shows the time frames for different stabilization levels. We can combine those data with the reduction potentials for 2030 for costs up to US\$100/tCO_2-eq, shown above. The available reduction potential is underestimated as a result of lack of information and the effect of behavioural change. It can be concluded that emission reduction potentials at costs <US\$100/t are probably sufficient to reach the lowest stabilization level, except where baseline emission growth is very strong. In that case reduction options with costs higher than US\$100/tCO_2-eq need to be added.

What is also relevant is to look at the regional contributions. Table 10.1 shows that industrialized countries alone (OECD countries and countries with economies in transition) cannot deliver enough reductions to stabilize at any level below about 700 ppm CO_2-eq. To achieve the lowest stabilization level, tapping the whole global reduction potential up to US\$100/t is essential.

Do we need to look at geo-engineering options as well?

In discussions about the need for deep emission reductions suggestions have been made that the regular reduction measures, as discussed in Chapters 5, 6, 7, 8, and 9 and summarized above, will not be enough. The reason given for these claims is that the economic potential simply will not be tapped due to lack of political will and resistance from vested interests. This then leads people to propose large scale interventions in the solar radiation that reaches the earth or in the functioning of the planetary carbon cycle. These proposals are usually referred to as 'geo-engineering'[7].

The *first category*, reducing the net solar radiation that reaches the earth, covers for instance:

- Distributing large amounts of fine particles (such as soot or sulphur), metal strips, or other reflecting materials in the upper atmosphere of the earth. This would reduce incoming solar radiation. Such particles would have to be replenished because they would only have a lifetime of several years.
- Installing a kind of mirror in space, at a point that is staying between the sun and the earth, so that incoming solar radiation is reduced. Preliminary calculations say this mirror needs to have a surface of about 100 km^2, which means it would have to be fabricated in space.
- Spraying finely dispersed sea water into low level clouds above the oceans in order to make them[3] 'whiter' and reflect more solar radiation. Early calculations say an amount of water of about 10 m^3 per second would be needed.
- Putting large amounts of floating reflecting strips in the oceans that increase the reflection of solar radiation.

The only experience we have with these proposed planetary engineering methods is what happens when there is a major volcanic eruption where large amounts of sulphate particles are thrown into the upper atmosphere. The effect can be measured. The eruption of Mount

Pinatubo in the Philippines in 1991 threw more than 17 million tonnes of SO_2 into the atmosphere and ash reached heights of more than 30km. It led to a drop in average global temperature of about 0.4 °C and stratospheric ozone depletion increased. The effects lasted for 2–3 years. This phenomenon has led to proposals to dump sulphur particles from high flying airplanes. Other materials also have been proposed. Risks in terms of stratospheric ozone depletion, air pollution, and regional impacts and costs are not well understood.

Other methods mentioned above are purely theoretical at the moment and their side effects not understood. The proposal to seed clouds with finely dispersed sea water could have significant impacts on weather and precipitation patterns.

The *second category*, changing the global carbon cycle, covers proposals to 'fertilize' the oceans with large amounts of iron compounds or nitrogen fertilizer. The idea is to enhance the growth of plankton in areas where iron or nitrogen in ocean water is low and limiting plankton growth. This supposedly would remove carbon from the ocean surface layer through dead plankton biomass that sinks to the ocean floor.

Iron deficiency occurs in about 30% of the oceans, mostly the Southern Ocean and the Pacific Ocean near the equator and near the Arctic. A number of large scale tests have been performed with several tonnes of iron sulphate. Enhanced growth of plankton has been observed. However, the few checks that have been done on how much of the plankton sinks to the ocean floor show only a very limited effect. Less than 10% of the plankton sinks to deep waters. Most of the dead plankton is decomposed and recycled back into the ocean surface layer. There are other problems with ocean fertilization. Very little is known about the impacts of large scale application. It could lead to oxygen depletion of parts of the ocean; it could lead to changes in the plankton composition with unknown consequences for ecosystems and the food chain; it could lead to emissions of methane or nitrous oxide. Nitrogen fertilization has similar problems.

For the time being ocean fertilization has no real value as a mitigation option. The question is if it ever will have, given the huge uncertainties and the risks of doing major damage with large scale operations. Nevertheless there are some commercial operations[8] that claim they can remove CO_2 in this way at attractive costs and they suggest this option to be politically viable. These claims have no chance of being internationally accepted. A much more robust option of dissolving captured CO_2 in ocean waters (see Chapter 5) is widely seen as too risky to be considered as an acceptable mitigation option. Ocean fertilization is an order of magnitude more risky.

In general all geo-engineering proposals have one important deficiency (on top of the uncertainties and lack of understanding of their potential side effects). They do nothing about the direct effects of higher CO_2 concentrations in the atmosphere. The most important consequence of that, acidification of the oceans (see Chapter 1), is therefore not addressed. Serious disruptions of oceanic ecosystems and the food chain can happen as a result of ocean acidification. A second general issue is that geo-engineering proposals are promoted by interest groups that would be losing out as a result of major shifts away from fossil fuel. It draws attention away from using all the existing technologies to drastically reduce CO_2 emissions by gambling on an unproven technology. The third major problem with geo-engineering is the fact that it proposes large scale experiments with the earth. While our first experiment, drawing large amounts of fossil fuel from the earth and burning it to drive human development, is about to lead to disaster, it is proposed to carry out another experiment to counter the impacts of the first. Shouldn't we think twice about this?

How is the overall mitigation picture for individual countries?

For individual countries or groups of countries (such as the European Union) many studies have been done of the national (or group) mitigation potential. Objectives of such studies differ. Finding the optimal implementation of a policy target is one. The EU performed such studies to find the lowest cost implementation of its Kyoto target of −8% compared to 1990. Figure 10.5 shows the sector distribution of the reductions that would give the lowest overall costs. It illustrates the general finding that applying an equal reduction percentage to all sectors is more costly than allowing different percentages in accordance with the relative costs of measures.

Another objective of country studies is to find out if and at what costs deep emission reductions are possible. Japan has studied for instance a 70% reduction of GHG emissions by 2050, compared to 1990[9]. Conclusions were that this is feasible at annual abatement costs of about 1% of GDP in 2050. Economic growth would continue at an average rate of 1–2% per year till 2050, while the population would be shrinking. It showed a strong contribution of energy efficiency, leading to a 40–45% reduction in energy demand. Emission reduction for the respective sectors was estimated at 20–40% for industry, about 70% for transportation, 40–50% for buildings, and a strong transition to low carbon energy supply, based on nuclear, gas with CCS, renewables, and hydrogen.

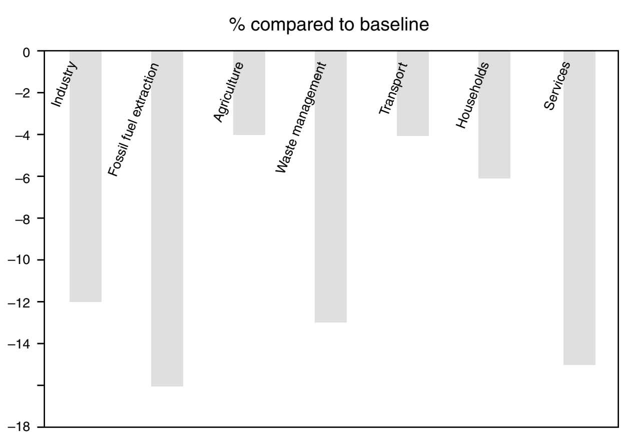

Figure 10.5 **EU implementation of −8% Kyoto target to achieve lowest possible costs: relative contributions of sectors, expressed as reduction percentage compared to the baseline.**
Source: EU DG Environment, http://europa.eu.int/comm/environment/enveco/climate_change/summary_report_policy_makers.pdf.

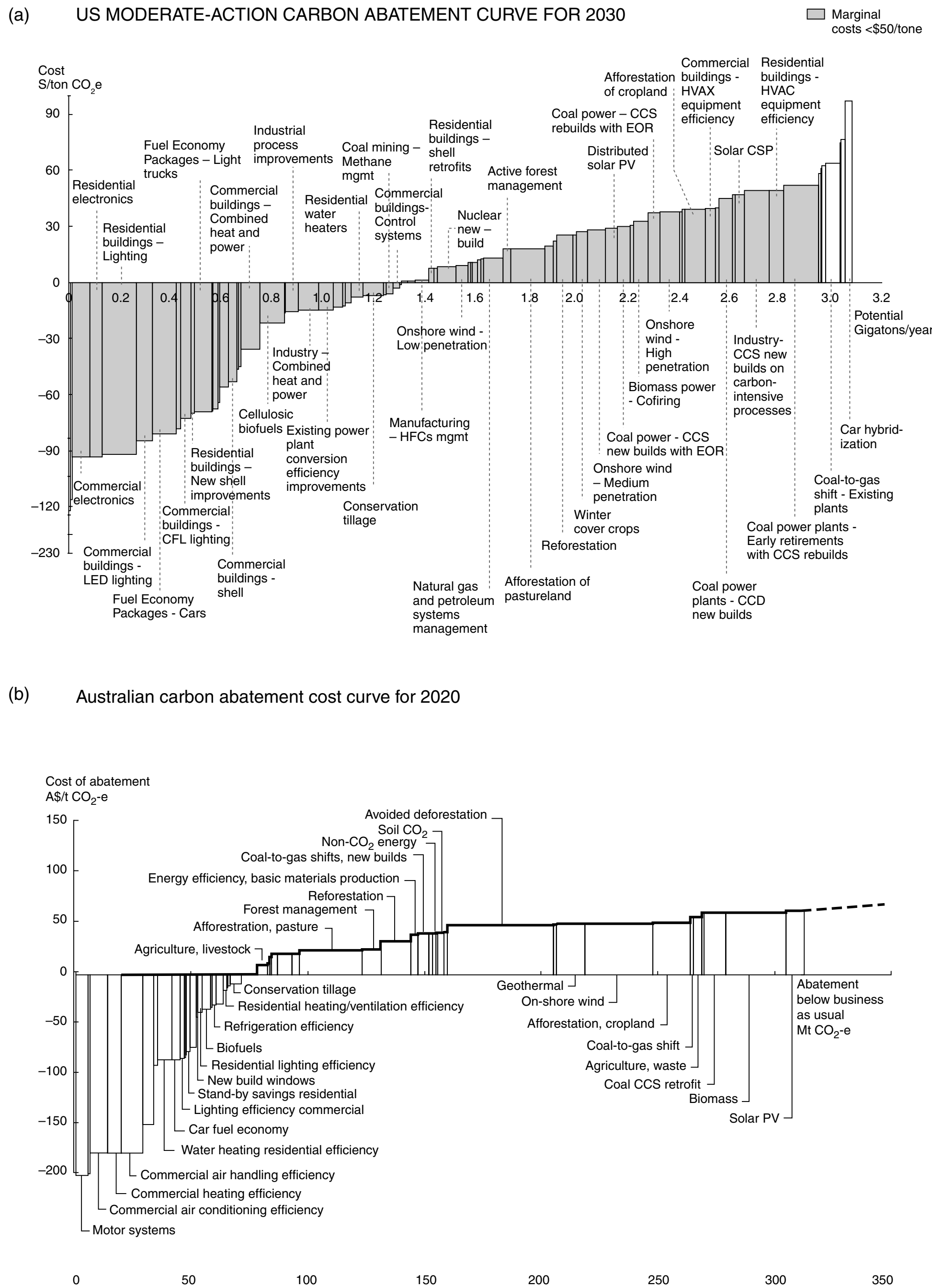

Figure 10.6 **Mitigation cost curves for the USA (a) and Australia (b).**

Source: Reducing US greenhouse gas emissions: how much at what costs?, McKinsey and Company, 2007; An Australian cost curve for greenhouse gas reductions, McKinsey and Company, 2008.

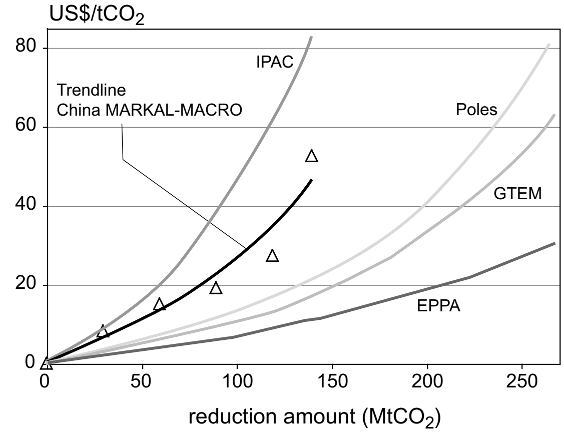

Figure 10.7 **Cost curves for China in 2010, as used in different modelling studies.**
Source: IPCC Fourth Assessment Report, Working Group III, fig 11.6.

National circumstances differ between countries. Some countries have large coal deposits, others have large hydropower resources, while yet others have an economy heavily reliant on agriculture and forestry. Some countries have already implemented policies to promote energy efficiency, others have not. That means the economic potential for mitigation and the type of reduction measures at a particular cost level also vary. In other words: for one specific cost level, reductions compared to the baseline will be different from country to country. The McKinsey-Vattenfall cost curves, as introduced above, illustrate that clearly (see Figure 10.6 for some country examples). These differences in national abatement cost curves are one of the main reasons for the differentiated reduction targets for industrialized countries under the Kyoto Protocol (see further in Chapter 12).

There is one big problem with country cost curves: they are very uncertain. The above examples from the McKinsey studies are not the only ones for the respective countries. Different cost curves are available for any country and available modelling studies are not using the same cost curve. Figure 10.7 gives an example for China. At a cost level of US\$20/tCO_2 avoided, reduction potentials vary by a factor of 4 (between 0.05 and 0.2 GtCO_2/year).

A closer look at the cost of mitigation actions

Costs were referred to when economic mitigation potentials were discussed in Chapters 5, 6, 7, 8, and 9. Those were the costs of emission reductions. They depend on the reductions to be achieved. For a trajectory towards stabilization of atmospheric concentrations of around 450 ppm CO_2-eq, it was shown that measures need to be taken with costs of the most expensive ones going up to about US\$100/tCO_2-eq avoided.

Table 10.2. Cost of mitigation by 2030

Stabilization level aimed at (ppm CO_2-eq)	Global abatement costs (% of GDP)	Macro-economic costs (% of GDP loss in 2030)	Reduction in average annual growth rate until 2030 (percentage points)
Around 650	0.1	−0.6–1.2	<0.05
Around 550	0.3–0.5	0.2–2.5	<0.1
Around 500		<3	<0.12
Around 450	1–1.5		

Source: IPCC Fourth Assessment Report, Working Group III, Chapter 3.3.5.3 and van Vuuren et al. Netherlands Environmental Assessment Agency, 2006.

In Chapter 3 a treatment of economic costs is presented. It discusses the concept of total mitigation costs (the expenditures for realizing reductions). One important notion is that the total costs are obtained by multiplying the tonnes to be reduced by the average cost per tonne (i.e. not with the cost of the last tonne reduced, the so-called 'marginal cost'). For the various ambition levels of global emission reduction, abatement costs are given in Table 10.2. For the most ambitious one, aiming at stabilization at 450 ppm CO_2-eq, global abatement costs in 2030 will be about 1–1.5% of global GDP. This is comparable to the amount spent globally on beverages or on the military today[10].

What about the costs for the economy as a whole?

There is another way of expressing costs and that is the GDP increase 'foregone' by taking emission reduction measures. As discussed in Chapter 3, 'foregone' means that other economic activities, along the lines of what societies have been doing in the past, would have resulted in a larger increase of GDP. Many economic models make the simple assumption that current economies are functioning in an optimal way (i.e. are 'in equilibrium'). In other words, the markets work perfectly and taxes are giving the revenue at the lowest possible economic loss. In such a situation doing something different (i.e. mitigating climate change) would always reduce economic output (GDP). Since this assumption of ideal economies is not the reality, some of the models have implemented ways to simulate suboptimal economies. In such models introducing taxes on emissions can sometimes lead to an improvement of economic output, i.e. an increase in GDP.

There is also the issue of technological change that influences cost estimates from computer models. Most models do not assume any influence of climate policy on the rate at which technological innovation takes place. However, it is plausible that such an influence exists, i.e. more rapid technological innovation with stringent climate policy.

Table 10.3. Selected country Kyoto targets and economic costs

Country/group	Kyoto Protocol target (% of emissions in 2008–2012 below 1990 level)	Estimated GDP change in 2010, compared to a baseline, after US withdrawal
EU-15	−8	−0.05
Belarus	−8	+0.4
Canada	−6	−0.1
Hungary	−6	+0.2
Japan	−6	−0.05
Poland	−6	+0.2
New Zealand	0	
Russian Federation	0	+0.4
Ukraine	0	+0.4
Norway	+1	
Australia	+8	

Note: GDP changes assume full Annex I emission trading.
Source: Boehringer C, Loeschel A. Market power and hot air in international emissions trading: the impacts of US withdrawal from the Kyoto Protocol, Applied Economics, vol 35 (2003), pp 651–663.

When these assumptions are built into the models the costs of achieving certain emission reductions go down. This explains the fairly wide cost ranges as shown in Table 10.2, with some estimates giving ‘negative costs’ (meaning economic benefits).

Individual countries can face costs that are higher or lower than the global average. Individual country costs depend strongly on the international arrangements about contributions of countries to the global mitigation effort. A good example is the Kyoto Protocol agreement for industrialized countries. These countries agreed to achieve a 5% reduction of their collective emissions below 1990, to be reached on average in the period 2008–2012[11]. For each country or group of countries individual reduction percentages were agreed, varying from −8% for the EU-15[12] to +10% for Iceland. The costs of achieving those targets vary between countries. Table 10.3 gives some typical results of economic studies. As can be seen, agreed targets were chosen in such a way that costs for OECD countries would be comparable, while countries with economies in transition were given opportunities to benefit, in light of the drastic economic restructuring they were facing.

The USA and Australia refused to join the Kyoto Protocol because they claimed costs to their economies were too high, although both countries had agreed with the text in Kyoto. Australia joined Kyoto recently after a change in government. Model calculations show that for a situation with USA and Australia participation (in which case there would be a greater demand for emission reduction credits from emissions trading and higher costs to the economy) costs for the USA were of the order of 0.2–0.4 % lower GDP in the year 2010[13]. These costs were not higher than for most other OECD countries and the excessive costs argument was therefore not rational.

Spill-over effects

Climate policy does change the relative value of resources and commodities. In a low-carbon economy the demand for fossil fuels and energy intensive goods will decline, if not in absolute terms, then certainly relative to a baseline (the so-called spill-over effects). Countries exporting fossil fuels and energy intensive goods will then notice the effects. OPEC (Oil Producing Exporting Countries) has made a strong political point about that since the beginning of the international negotiations on controlling climate change. The argument was simple: if actions to control climate change are having a negative impact on our oil revenues, we need to be compensated.

The question is: do they have a point? Economic modelling studies were done to investigate the effects for the implementation of the Kyoto Protocol, where industrialized countries reduce their emissions and OPEC countries have no obligations on their emissions. The results show strongly increasing oil revenues due to increased consumption, but somewhat lower than in the absence of the Kyoto Protocol (the most pessimistic study gave a 25% reduction in 2010 compared to a non-Kyoto baseline). Macro-economically though the impact is relatively small: a decline in 2010 GDP of about 0.05% compared to what it otherwise would have been. And these results did not include the positive spill-overs from enhanced availability of energy efficient technologies. Nor were the sharply risen oil prices of 2007–2008 taken into account. There is so much revenue flowing now to oil exporting countries that the case for compensation has lost steam. The debates however did lead to clauses in the Kyoto Protocol putting an obligation on industrialized countries to minimize the adverse impacts of their mitigation actions on other countries.

Investments

How much money will have to be invested to get to a low carbon economy? Is that money available? And what will be the timing of these investments? These are questions that worry many people.

Let us first look at what needs to be invested in energy supply and energy use anyway, irrespective of climate change control. According to IEA estimates between now and 2030 something like US$22 trillion (22000 billion) will have to be invested to keep up with energy demand and to renew the energy infrastructure. About 50% of this investment will have to be made in developing countries[14]. The 22 trillion is equivalent to about US$1 trillion (1000 billion) per year. Compared to the total investments in infrastructure, buildings, industrial plants, the energy systems, and other things (US$7.8 trillion/year) it is a little more than 10%.

For a low carbon economy, i.e. trajectories towards stabilization at 450–550 ppm CO_2-eq, the energy system needs to be restructured. This means investments will have to shift from fossil fuel based energy supply to energy efficient end use equipment and low carbon energy supply (renewables, fossil fuel with CCS, nuclear). Estimates from IEA[15] show that for a trajectory towards 550 ppm CO_2-eq it takes total *additional* investments in power supply and end use efficiency of about 4 trillion US$ or slightly less than 20% of the investment that would be needed anyway. There are however about two times as much savings in energy costs due to lower fossil fuel use and higher energy efficiency. For a 450 ppm CO_2-eq scenario the additional investment costs are higher, about 9 trillion US$ till 2030 or about 35% of the investments that have to be made anyway. Savings in energy use amount to about 6 trillion US$.

Total investment requirements is one thing, investment by the private sector something else. Social needs may make major shifts in investments attractive, but does that mean individual businesses are making these investments? Energy supply has been privatized in many countries and even where governments control energy supply, criteria for investments follow a business logic. In most circumstances electricity supply companies invest in increased supply at the lowest possible costs. So unless there are regulations forbidding it or real carbon prices, coal based power plants (without CCS) come out as the most attractive option in many places. With CCS for large scale power plants still being too experimental to be mandated by governments, real carbon prices still being zero in most places, natural gas prices as high as they are, and opposition to nuclear power plants still strong in many countries, there are no strong business reasons not to build a traditional coal fired power plant, when taking a short term perspective.

What could change these investment decisions? Protests from environmental groups against coal fired plants can sometimes make a difference for companies who are sensitive to their public image[16]. Expectations about carbon price increases can also lead to different decisions. In the EU for instance there is now a carbon price of about Euro 20/tonne CO_2 (about US$ 30/t) as a result of the EU −8% Kyoto target and the EU Emission trading System. A decision on a further unilateral reduction to −20% below 1990 by 2020 has been taken, which will lead to higher carbon prices. Together with intentions to move to auctioning of emission allowances under the EU ETS, this is now beginning to have an impact on investment decisions by electric power companies.

Timing of investments is critical, since long term stabilization levels depend strongly on how fast emissions will be brought down (see Chapter 3). The most logical approach is to make use of the replacement of existing technology (the so-called capital stock turnover). In modelling studies this replacement takes place after the economic life time. That is the time in which the investments are depreciated (in other words 'is written off'). In practice however, it is very profitable for companies to keep installations going well beyond their economic lifetime. There are no more capital costs, but only operating costs. Even when new installations would have lower operating costs because they are more energy efficient, keeping the old installation going is often more profitable. Only when operating costs are drastically lower or other reasons exist, such as regulations or product specifications, will old installations be scrapped[17]. There is no guarantee that new, low carbon technologies will come in fast, unless there are clear incentives for companies to do so.

How big are the co-benefits?

Reducing GHG emissions has a number of co-benefits. The most important ones are:

- Reduced air pollution: shifts from coal to gas or renewable energy and energy efficiency improvements lead to lower emissions of fine particles and sulphur and nitrogen oxides; lower methane emissions reduce the formation of tropospheric ozone
- Increased energy security: energy efficiency and renewable alternatives for oil reduce the dependence of many countries on oil imports; foreign currency expenditures for oil can be reduced
- Employment: strengthening energy efficiency and production of renewable energy is relatively more labour intensive than large scale fossil fuel based electricity supply

These co-benefits are usually not taken into account when considering the costs of mitigation measures. When factored in, they can make a big difference however.

Reduced air pollution

Air pollution has big impacts on human health, agricultural production, and natural ecosystems. Reducing air pollution can thus have important benefits. For industrialized areas it is well established that a 10–20% CO_2 reduction typically leads to a 10–20% reduction in SO_2 and NOx and a 5–10% reduction in fine particle emissions. The associated health benefits are substantial. If these health benefits are quantified they account for a reduction of mitigation costs of anywhere from US\$2 to more than US \$100/tCO_2 avoided, depending on the assumptions made and the types of air pollution included. This means the health benefits alone could compensate for all of the mitigation costs in certain cases. Agricultural and ecosystem benefits, particularly from reduced tropospheric ozone, will add to these benefits. They have not been well quantified on a global scale. A study for China however showed that a 15–20% CO_2 reduction from the baseline would lead to an agricultural productivity increase that fully compensates the costs of CO_2 reduction[18].

Energy security

Energy security is a top political concern these days. With rising oil prices and oil demand and only a handful of major oil producers, it is primarily the concern about

This chart compares the energy security and climate characteristics of different energy options. Bubble size corresponds to incremental energy provided or avoided in 2025. The reference point is the 'business as usual' mix in 2025. The horizontal axis includes sustainability as well as traditional aspects of sufficiency, reliability, and affordability. The vertical axis illustrates lifecycle greenhouse gas intensity. Bubble placements are based on quantitative analysis and WRI expert judgement.

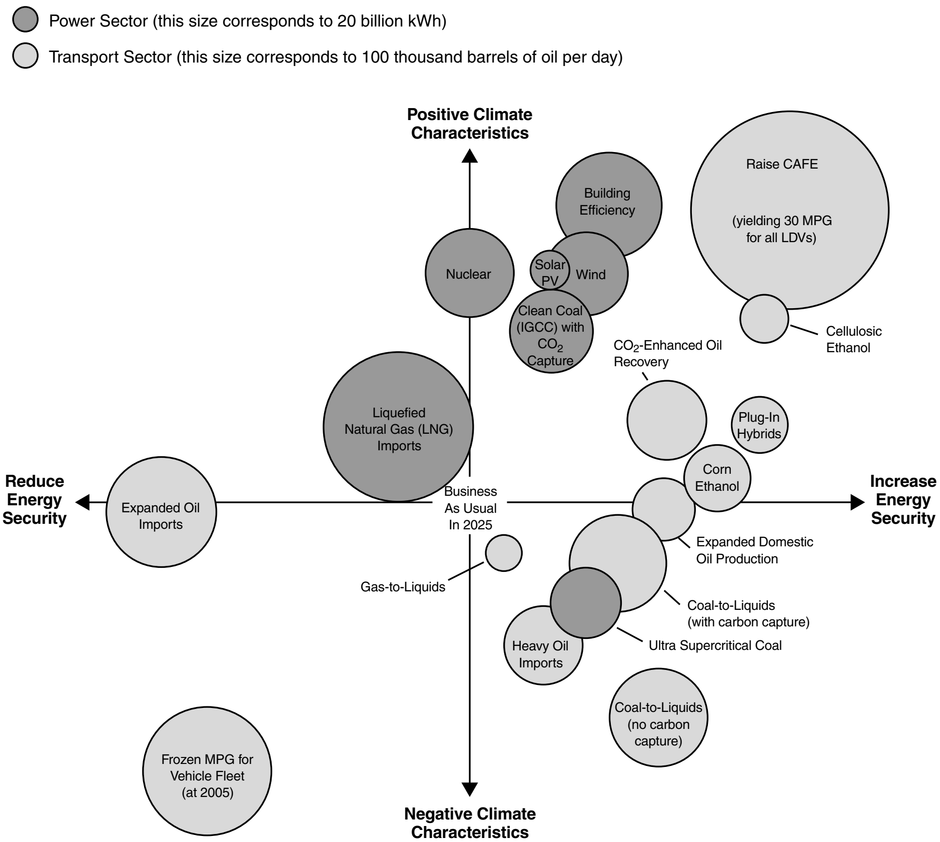

Figure 10.8 **Energy security and climate aspects of different policy options in the USA energy supply and transport sector.**

Source: Weighing US Energy Options: the WRI Bubble Chart, World Resources Institute, 2007.

interruption of oil supply that worries political decision makers. For natural gas the situation is more regionally determined, but in some areas is not much different. Improving energy efficiency and shifts to renewable forms of energy for reasons of climate control go perfectly hand in hand with improving energy security. The other way around however, i.e. taking action to increase energy security, is not always helpful for reducing GHG emissions. A shift from gas to coal for power production or moving towards gasoline production from coal or gas brings us further away from a low carbon economy. In Figure 10.8 the relations between climate control and energy security measures is shown for the USA. It clearly shows there are large win-win opportunities, particularly in energy efficiency improvements for cars and buildings, but also problematic trade-off issues, such as for import of LNG, super efficient coal fired power plants without CCS, and fuels production from coal or gas.

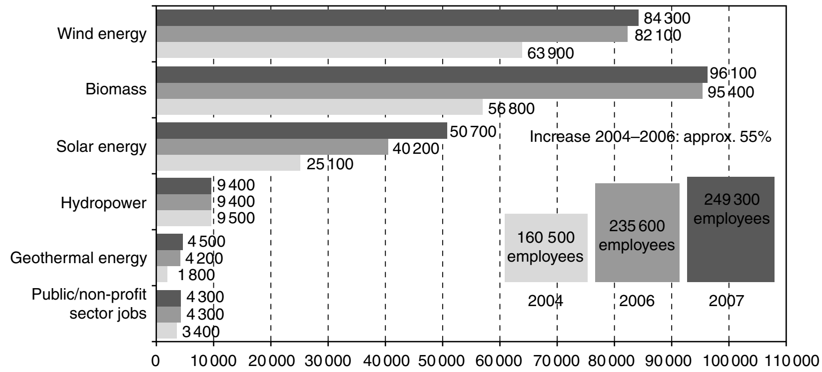

Figure 10.9 **Employees in the German renewable energy sector 2004, 2006 and 2007. Figures for 2006 and 2007 are provisional estimates.**

Source: Modified after graphic from BMU Projekt "Kurz– und langfristige Auswirkungen des Ausbaus der erneuerbaren Energien auf den deutschen Arbeitsmarkt", KI III 1; interim report March 2008.

Employment

Several studies confirm that shifting to a low carbon economy has positive effects on employment[19]. Particularly energy efficiency improvements in the building sector have a good potential to generate substantial additional employment. The European Commission estimated that a 20% energy efficiency improvement in the EU by 2020 would generate a million new jobs. In Germany the strongly growing renewable energy supply industry is now employing about 250000 people (see Figure 10.9), and Polish estimates claim that renewable energy supply is about 10 times as labour intensive as traditional fossil fuel based supply.

Technology transfer

Technology is key to a low carbon economy. As discussed above the technology is available to avoid all of the projected increase of GHG emissions between 2000 and 2030. Most of these technologies are commercially available today and some are expected to be commercialized by 2030. Table 10.4 shows the most important technologies for the various economic sectors.

It was also pointed out above that much of the mitigation potential is found in developing countries (see Figure 10.1), which means these low carbon technologies need to be applied in developing countries without delay. And that requires these technologies to be readily available in developing countries, which is currently often not the case. This is the technology transfer challenge.

The international political debate about technology transfer in the context of controlling climate change has become much polarized. Developing countries take the position that it is the responsibility of OECD countries to make modern low carbon technology available to them at low or zero costs. They normally refer to an article in the Climate Change Convention that commits OECD countries to support developing countries with finance and technology, although that article is formulated very generally. OECD countries reject these claims and point out they do not own the technologies and suggest developing countries make themselves attractive for foreign investment that brings modern technologies. This polarized debate has stood in the way of finding pragmatic solutions to speeding up the diffusion of modern low carbon technology to developing countries.

What do we know about the driving forces and the obstacles for technology transfer? There are three main mechanisms identified.

Technology transfer through foreign direct investment

Foreign Direct Investment (FDI) is often positive for low carbon technology transfer, if foreign companies bring in their own best technology. That is not automatically happening, because companies sometimes are afraid that patented technologies are stolen in countries where the protection of intellectual property rights is not actively enforced. Foreign companies may also be tempted to put second hand technology in place, while they invest in the best available technology at home. For instance, a detailed study of FDI driven technology transfer from three big US automakers to Chinese joint ventures showed that outdated pollution control technology was transferred and little was done to build local technological capabilities[20]. This can of course be prevented if developing countries have the technical and administrative capacity to demand the best technology to be used.

FDI contributes most to capital flows to developing countries. In 2006 it was US$380 billion[21]. For comparison, energy related Official Development Assistance (ODA) was about US$7.5 billion in 2005[22]. It is very hard to identify what the implied low carbon technology transfer in FDI is, but what is known is that about 30% of FDI goes to manufacturing. Most FDI goes to a limited number of developing countries however (see Box 10.2).

Box 10.2 **Ten biggest FDI recipient developing countries (billions of US$ in 2006, accounting for about 60% of all FDI to developing countries)**

China, incl. Hong Kong	113
Brazil	19
Saudi Arabia	18
India	17
Mexico	15
Egypt	10
Thailand	10

UAE	8
Chile	8
Malaysia	6

(Source: UNCTAD World Investment Report 2007)

Investment risk is an important consideration for private sector investors and that risk is determined by a large number of local circumstances in the respective country (so-called ‘enabling conditions’). The most important are[23]:

- Political stability
- Transparent legal and regulatory system
- Skilled labour
- Available financial services and banking provisions

Governments in developing countries have the power, but not always the capacity, to create favourable conditions for foreign investment in low-carbon technology.

Technology transfer through export from developing countries

International trade is another strong driver for low carbon technology transfer, particularly for internationally traded energy intensive industrial products. As discussed in Chapter 8, the latest production plant for chemicals, fertilizer, aluminium, or steel is usually the most energy efficient, whatever its location. The reason is the very competitive international market for these products that make cost reduction through energy efficient production a necessity. It also applies to manufactured products (household appliances, motors, etc.) meant for export to industrialized countries. These products often have to comply with standards on energy efficiency or absence of containment of fluorinated GHGs. This can be a strong driver for low carbon technology transfer.

Technology transfer through domestic innovation

The third – and most interesting – driver for low carbon technology transfer is domestic technology innovation to serve national priorities. Brazil’s sugar cane alcohol development programme (see Chapter 6) is a good example. A national priority to become less dependent on imported oil spurred the development of a modern alcohol industry that is among the most efficient in the world.

The political priority for developing renewable energy in India has led to a strong wind turbine industry, with the biggest company Suzlon now being the 5th largest global wind turbine supplier[24]. The company acquired the best available technology, for instance by buying one of the leading European companies producing gearboxes (see Box 10.3).

China is another good example of this ‘technology transfer through domestic innovation’ approach[25]. Driven by its priority for energy security and its huge domestic market, it has become the world's cheapest supplier of supercritical coal fired plants (with much higher efficiency than traditional coal fired plants). It has also become the biggest producer of solar water heaters (market of US$2 billion per year and 600000 people employed), biogas digesters, wind turbines, electric bicycles, and scooters, and the second biggest supplier of solar PV cells. While electric bicycles and scooters are just a niche market in industrialized countries, China has almost 2000 production facilities and more than 20 million units were sold in 2007, a US$6 billion market (see also Chapter 6). China is already the third largest biofuel producer. Acquiring new technologies from abroad has become an integral part of innovation and does not depend on foreign investment.

Box 10.3 **Suzlon wind energy**

The Suzlon story began in 1995 with just 20 people, and in a little over a decade has become a company of over 13000 people, with operations across the USA, Asia, Australia, and Europe, fully integrated manufacturing units on three continents, sophisticated R&D capabilities, market leadership in Asia, and ranked 5th in terms of global market share.

Faced with soaring power costs, and with infrequent availability of power hitting his business hard, Mr. Tanti looked to wind energy as an alternative. His first encounter with wind energy was as a customer, having secured two small-capacity wind turbine generators to power his textile business. Moving quickly, he set out to acquire the basic technology and expertise to set up Suzlon Energy Limited – India's first home-grown wind technology company.

Suzlon began with a wind farm project in the Gujarat state of India in 1995 with a capacity of just 3 MW and has, at the end of 2007, supplied over 6000 MW world over. Suzlon has grown more than 100% annually and registered a 108% growth in the financial year ended 2007 – over twice the industry average – in a supply restricted environment. Today Suzlon is ranked as the 5th largest wind power equipment manufacturer with a global market share of 10.5%. The company seized market leadership in India over 8 years ago, and has consistently maintained over 50% market share, installing over 3000 MW of wind turbine capacity in the country.

The company adopted innovation at the very core of its thinking and ethos. This led to full backward integration of the supply chain. Suzlon by this approach has developed comprehensive manufacturing capabilities for all critical components – bringing into play economies of scale, quality control, and assurance of supplies. Taking this focus forward, Suzlon acquired Hansen Transmissions of Belgium in 2006. The acquisition of the world's second leading gearbox maker gives Suzlon manufacturing and technology development capability for wind gearboxes, enabling an integrated R&D approach to design ever more efficient wind turbines.

Suzlon's R&D strategy emphasizes the need to lower the cost per kilowatt-hour, in order to create ever more competitive technology and products. Making technology development a central objective, Suzlon has leveraged Europe's leadership, talent, and experience in wind energy technology, setting up R&D centres in the Netherlands and Germany. Combined with a strong engineering backbone in India, the approach brings together the expertise of different centres of excellence to build 'best of all worlds' products.

Looking for growth not just in India, but across the world, Suzlon looked past traditional markets for wind energy, and entered new and emerging high growth markets. This step has success in the rapid global expansion of Suzlon's business with orders from Australia, Brazil, China, Italy, Portugal, Turkey, and the USA.

Suzlon, with its internationalized business model, fully integrated supply chain, and R&D focus on cost per kWh reduction, is today an agile, fast moving organization that is well equipped to take on a dynamic, changing market place with innovative products and solutions. (Source: http://www.suzlon.com)

The three models described above are of course complementary. Essentially they are business oriented with governments creating the right conditions. This model can transform the international political debate on low carbon technology transfer from an 'if you want me to do something you have to give me the technology' approach to an approach driven by national self-interest.

Irrespective of the conceptual model, there are many obstacles to effective low carbon technology transfer, where 'effective' means the best low carbon technology and widespread application, not just some individual projects. For that to happen a large number of things need to be in place. Technical knowledge, including capacity to assess technologies and organizational capacity, is one. Financing, such as availability of capital, understanding of low-carbon technologies by banks, removal of subsidies for fossil fuel based technologies in developing countries that compete with low carbon technologies, and shift of export subsidies in industrialized countries from traditional fossil fuel based technologies to low carbon ones, is another. Lack of standards and transparent regulation, including the presence of corruption, and inadequate enforcement of contracts and property rights create a bottleneck. Incentives to invest in new low carbon technologies are often missing, because of existing tax laws, import restrictions, or other constraints. Lack of business networks and ways to communicate positive results of innovation to other companies hamper the spread of low carbon technologies. If one of the essential components is lacking, the whole process of technology diffusion comes to a halt. The chain is as strong as its weakest link!

These multiple barriers can be overcome by targeted policies however. In developed countries they relate particularly to reforming the system of export subsidies by issuing specific environmental guidelines for export crediting agencies that are active in many countries. Reducing tied aid (mandatory use of finance for equipment from the donor country), actively pursuing low carbon technology introduction in development assistance programmes, and discouraging the misuse of patents by manufacturers of low carbon technologies in developed countries are other important elements. In developing countries policies need to be aimed at education and training, reforming legal, regulatory and financial systems, proper assessment of the technology needs of the country for achieving its development goals, introduction of low carbon standards for technologies, enforcement of intellectual property rights, and stimulating markets for low carbon technologies[26].

Technology development

Although many low carbon technologies are commercially available right now, additional technologies need to be brought from the R&D stage to commercialization in order to have an adequate toolbox to control climate change. Table 3.2 shows some of these technologies that are expected to be commercially available by 2030. Beyond 2030, technologies like biomass based chemical processes and biomass fuelled power plants with CCS need to become commercial, while low carbon technologies already being applied are further improved and made cheaper. This requires a vibrant R&D infrastructure and adequate funding. A sobering fact is that government funding for energy research has gone down since the early 1980s and is now at about half the 1980 level in dollar terms (see also Chapter 11). This can be explained by the massive privatization of energy supply in many countries, but private R&D investments have not compensated much of this loss. Current trends are thus completely opposite to what would be needed to control climate change in the longer term.

Commercialization of technologies is done by the business community, not by governments. So it is important to understand the way companies are handling R&D investments. The objective of a company is to create future profits through new products for which it has to carry out R&D. The market prospects for such new products are therefore critical. In the case of low carbon technologies these market prospects depend heavily on government policy. The clearer governments are about future policies and regulations the better companies can anticipate. Return on R&D investment is also an important consideration. It has been well established that for a society as a whole the return on R&D investments is very good. For an individual company however it is quite uncertain. The reason is that competitors may be more successful with comparable new products or patent protection is not effective. Companies are therefore sometimes hesitant to invest in R&D. Governments can address these risks by providing support in the form of tax deductions or R&D subsidies, something that is fully justified by the high social return on R&D investment[27].

The relation between mitigation and adaptation

In Chapter 3 it was concluded that mitigation and adaptation are both needed to control the risks of climate change. It is a matter of ‘and-and’, and not ‘or’. For that reason it is wise to look for synergies with adaptation, when deciding on a package of mitigation actions. In any case mitigation actions that make societies more vulnerable to climate change ought to be avoided. In some sectors there are strong interactions between mitigation and adaptation. In agriculture and forestry in particular, mitigation measures to enhance carbon sinks in soils can make these soils less vulnerable to drought, which is a good adaptation action. On the other hand, forest and biomass plantations that replace natural forests can reduce biodiversity and food security that is already under stress from climate change. This is therefore a measure that is not good for adaptation. Low carbon

Table 10.4. Synergies and trade-offs between mitigation and adaptation measures

MITIGATION OPTIONS	SYNERGY with adaptation	TRADEOFFS with adaptation
Energy: low carbon supply options, efficiency	• Energy required for adaptation does not increase emissions	• Unsustainable biomass production may reduce resilience and damage biodiversity
Forestry: avoid deforestation, plant trees, soil management	• Reduces vulnerability through water management	• Biodiversity (plantations)
	• Protects biodiversity	• Competition with food production
Agriculture: soil management	• Reduces vulnerability to drought and erosion	

Source: IPCC Fourth Assessment report, Working Group III, ch 11.

energy supply is good for adaptation in the sense that many adaptation measures require energy (water pumping, air conditioning, water desalinization). For synergies and trade-offs between mitigation and adaptation measures see Table 10.4.

Notes

1. IPCC Fourth Assessment Report, Working Group III, ch 11.3.1.3.
2. IPCC Fourth Assessment Report, Working Group III, ch 11.3.1.5.
3. IPCC Special Report on Safeguarding the ozone layer and the global climate system: Issues related to hydrofluorocarbons and perfluorocarbons, 2005.
4. IPCC Fourth Assessment Report, Working Group III, ch 11.3.1.5, table 13.1 and figure SPM.4.
5. Pathways to a low-carbon economy, Version 2 of the global greenhouse gas abatement cost curve, McKinsey and Company, 2009.
6. IPCC Fourth Assessment Report WG III, chapter 11.3.2.
7. IPCC Fourth Assessment Report, Working Group III, ch 11.2.2.
8. See http://www.abc.net.au/science/articles/2008/06/05/2265635.htm, http://www.businessgreen.com/business-green/news/2226689/climos-defends-ocean and www.acecrc.org.au/uploaded/117/797514_18fin_iron_6sept07.pdf.
9. 2050 Japan Low-Carbon Society' scenario team, Japan scenarios and actions towards Low Carbon Societies, 2008, http://2050.nies.go.jp.
10. For GDP numbers: http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:21298138~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html]; for military expenditures: http://www.globalsecurity.org/military/world/spending.htm.
11. The USA was part of this agreement, but never ratified the Protocol.

12. At the time of the Kyoto Protocol agreement in 1997, the EU had 15 member states; the agreed reduction percentages therefore apply to the so-called EU-15.
13. IPCC Third Assessment Report, Working Group III, table TS.5.
14. International Energy Agency, World Energy Outlook 2007, p.94.
15. International Energy Agency, World Energy Outlook 2008, ch 18.
16. For a list of plans and public protests on new coal fired power plants in Germany see http://in.reuters.com/article/oilRpt/idINNLO15053920081001.
17. See Lempert RL et al. Capital cycles and the timing of climate change policy, Pew Center on Global Climate Change, Arlington, USA, 2002 for an in-depth discussion.
18. O'Connor et al, Technical Paper 206, OECD Development Centre, Paris, 2003.
19. IPCC Fourth Assessment Report, Working Group III, ch 11.8.2.
20. See Sims Gallagher K. Foreign Direct Investment as a vehicle for deploying cleaner technologies: technology transfer and the big three automakers in China, PhD thesis, Fletcher School of Diplomacy, Tufts University, Boston, USA, 2003.
21. UNCTAD, World Investment Report, 2007.
22. This is for bilateral and multilateral assistance, see Tirpak D, Adams H. Climate Policy, vol 8(2), 2008, pp 135–151.
23. See for an elaborate discussion IPCC Special Report on Methodological and Technological Issues in Technology Transfer, 2005.
24. http://www.suzlon.com/.
25. See China's clean revolution, Climate Group, London, 2008.
26. See note 24.
27. IPCC Fourth Assessment Report, Working Group III, ch 2.7.2.