4

The greenhouse effect

There is wide agreement among climate researchers that our emissions of greenhouse gases are affecting the Earth's radiation balance. It will get warmer, but it is still difficult to say how big the effect will be and where it will be greatest.

The effect of mankind's emissions of climate-changing gases is usually called the greenhouse effect. But because the Earth has an atmosphere that contains carbon dioxide and water vapour there is also a natural greenhouse effect. Without the atmosphere the mean global temperature would be -18°C, compared with the actual temperature of around +15°C. Man-made emissions of so-called greenhouse gases increase the heat retention ability of the atmosphere. You could say that they make the "warm mantle" around the Earth somewhat thicker. See factfile on next page.

THE GREENHOUSE EFFECT: HOW IT WORKS

The sunlight that falls on the Earth produces an average energy flux of 340 watts per square metre (W/m^2) of the Earth's surface. One third of this radiation is reflected back by clouds, particles, ice and snow. This portion of the radiation can be said to bounce off our planet and does not affect the energy flux that interacts with matter on the Earth or in its atmosphere. The remaining portion of sunlight, around 240 W/m^2, is on the other hand absorbed by the Earth's surface and atmosphere and is by far the most dominant source of energy for all essential processes on Earth.

Composition of light

The light that comes from the sun consists of fairly shortwave, i.e. high-energy light. A large part of this light is in the visible range of the spectrum, but some has a shorter wavelength, i.e. ultraviolet (UV) radiation, and some has a longer wavelength, i.e. infrared (IR) light. Our planet is much colder than the sun and therefore radiates into space thermal radiation that is much lower in energy and has a considerably longer wavelength.

Heat from the Earth

The sunlight that is absorbed by the planet and the atmosphere, 240 W/m^2, is balanced by an equal amount of heat that is radiated out into the universe. If this balance did not exist, for example if less energy was radiated from the Earth than reached it from the sun, the planet would steadily become hotter and hotter. Considered over a fairly long time period there is always a balance between incident and emitted radiation.

Natural greenhouse effect

Our atmosphere is relatively transparent to the wavelengths of sunlight, but not to the thermal radiation that is emitted from the Earth's surface. This radiation does pass through the primary gases in the atmosphere – nitrogen, oxygen and argon – but carbon dioxide, water vapour and some other so-called greenhouse gases absorb a large proportion of the thermal radiation.

This means that when there is equilibrium between the incident radiation from the sun and the emitted radiation from the Earth quite a lot of heat is stored in the atmosphere. One consequence of this is that the temperature on the Earth's surface is higher than it would have been if the atmosphere had not contained greenhouse gases, in fact 33°C warmer. This is the natural greenhouse effect.

Mankind's influence

Emissions of greenhouse gases mean that the natural greenhouse effect is reinforced. A larger quantity of heat is circulated (captured and re-radiated) in the lower regions of the atmosphere when the incident radiation and emitted radiation are in equilibrium, which means that the temperature on the Earth's surface rises.

WARMING IN PROGRESS

The climate has varied enormously over the course of millions of years. Ice ages and periods of high temperature have alternated with some degree of regularity. The factors that govern these natural climate variations are not known in detail, but it is believed that variations in the intensity of solar radiation and in the Earth's orbit play an important role. The climate also varies over a shorter time scale, but not as widely (see figure 4.1).

Because of the inertia of the climate system it takes a long time between the release of emissions and the appearance of effects that are large enough to overshadow natural variations. But with the help of computer modelling (see factfile on page 57) it is possible to estimate the risks of mankind's influence on the climate.

The scientific aspects of the climate issue have been described in three major assessment reports from IPCC, the Intergovernmental Panel on Climate Change. A much-quoted sentence in its second assessment report (1995) says:

"The balance of our evidence suggests a discernible human influence on global climate."

Knowledge has since been gathered in a number of areas, concerning both natural and man-induced effects. Although some uncertainty still remains, there is now much better agreement between measured effects and those obtained by modelling. In the third assessment report (2001) the IPCC researchers draw the following conclusion:

"In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last fifty years is likely to have been due to the increase in greenhouse-gas concentrations."

In this last report they say the global average surface temperature has risen by 0.6°C (±0.2°C) in the last hundred years. Since 1950 that rate of warming has been about 0.1°C per decade. They also say it is very likely that the 1990s were the warmest decade, globally regarded, and 1998 the warmest year ever recorded since 1861, when instrument records started. In the course of the last century the sea level rose by 10–20 centimetres. No clear trend was found as regards the

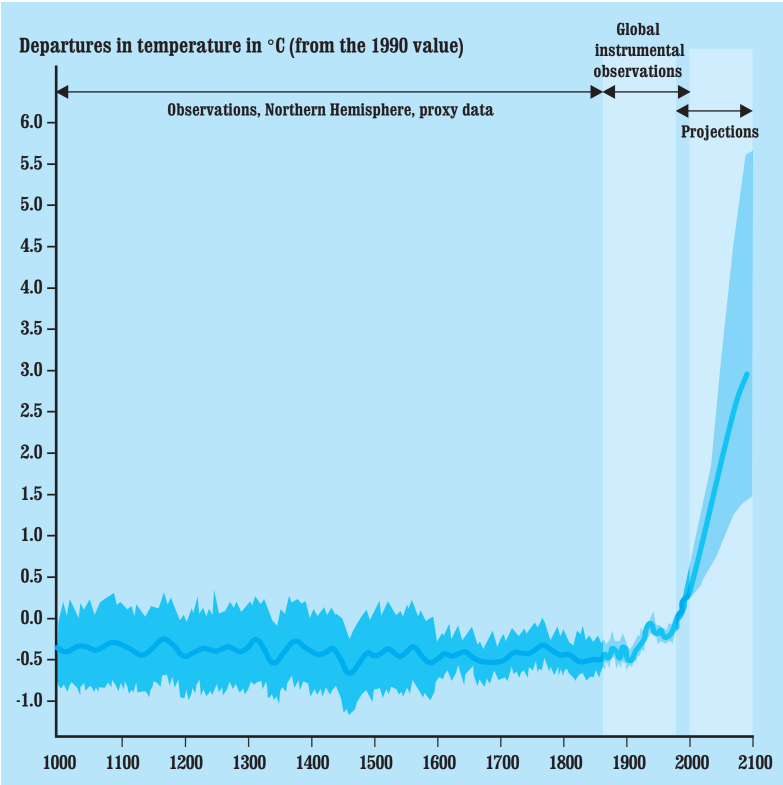

FIGURE 4.1. Variations of the Earth's surface temperature 1000–2100. The temperature over the period 1000–1900 has been reconstructed from historical data. 20th century values are recorded data and the 21st century values are those predicted by the IPCC scenarios. (Climate Change 2001: Synthesis Report. Summary for Policymakers. IPCC 2001.)

frequency of tornadoes, days with thunder, or hailstorms, but the data is said to be limited in this respect.

EXPECTED EFFECTS

An increase of 1.4–5.8°C in the average temperature of the air at sea level is predicted for the period from 1990 to 2100, and temperature will continue to rise for several centuries thereafter. This range is based on the results from around twenty different climate models and takes into account all forty or so emission scenarios used by the IPCC, as well as various assumptions as to the climate's responsiveness to changes in the amount of greenhouse gases in the atmosphere.

The various emission scenarios use different assumptions for population growth, trade and the world economy. In some of them the emissions of greenhouse gases in 2100 are, for various reasons, predicted to be lower than at present. However, none of the scenarios includes active measures for limiting mankind's influence on the climate, so all the scenarios can therefore be seen as taking a "business-as-usual" approach to the climate problem.

Other forecasts in the IPCC's third assessment report are:

- The projected rate of warming is much larger than anything that happened during the 20th century. It appears, too, to have been without precedent in the last 10,000 years.
- The warming process will not be uniform everywhere. The temperature is more likely to increase over land than sea, with the greatest increases in winter temperatures in the far

CLIMATE MODELS

In order to calculate the effects on the future climate, researchers use similar methods as in weather forecasting, but instead of looking one week ahead they may look one hundred years ahead. By varying the data on the amounts of greenhouse gases in the atmosphere, and the sensitivity of the climate to higher levels, etc., it is possible to build up a picture of likely changes in the future climate.

The main factors of uncertainty in the models are the knock-on effects that are likely to occur if it gets warmer. These feedback effects – such as how much the level of water vapour in the atmosphere will rise, how cloud formation and ocean currents will change and how the carbon cycle will be affected – could either reinforce or counteract the expected warming effect.

Although these models have their shortcomings they are still the best source of data we have to evaluate risks and make decisions. It is also worth pointing out that the uncertainties involved in these modelling methods work both ways – the effects could just as well be worse than not so bad.

north – especially in the northern parts of North America and north-eastern and central Asia, where the global mean warming is likely to be exceeded by more than 40 per cent – i.e. at worst it would perhaps mean a temperature rise of over 10°C in just 100 years. A lower degree of warming than the mean is expected in southern Asia in the summer, and in southern South America in the winter.

- Because of the inertia of the climate system the temperature will continue to rise for several centuries after 2100, even if concentrations of greenhouse gases no longer continue to rise. (So the IPCC's hundred-year perspective is in fact far too short to fully describe the effects of emissions).
- Precipitation worldwide is expected to increase by a few per cent. Large increases are predicted in parts of the tropics and close to the poles. But in many temperate and subtropical areas it is probable that precipitation will decrease.

IPCC – THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Recognizing the problem of a potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change, IPCC, in 1988.

The role of the IPCC is to assess the scientific, technical and socio-economic information relevant to the understanding the risk of human-induced change. It does not carry out research, nor does it monitor climate-related data or other relevant parameters. It bases its assessment mainly on peer-reviewed and published scientific and technical literature.

The IPCC completed its First Assessment Report in 1990. The Report played an important role in the development of the UN Framework Convention on Climate Change. The Second Assessment Report, Climate Change 1995, provided key input to the negotiations that led to the adoption of the Kyoto Protocol in 1997.

The Third Assessment Report was adopted in September 2001. Some 2000 scientists representing a variety of disciplines the world over took part in this assessment, and the results were further reviewed both from the political and scientific aspects by representatives of the participating countries. This is probably the most all-embracing assessment of research that has ever been made. A Fourth Assessment Report is scheduled to be ready by 2007.

The tree line is already creeping upwards in the Scandinavian mountains. In a hundred years' time large areas of mountain heath could be covered in forest.

There may be an increase in drought problems in areas such as the Mediterranean, southern Africa, Central America and Australia.

- The frequency of extreme weather events such as cyclones, tornadoes, torrential rain, etc., may rise, but there is insufficient information for accurate assessment. It is expected that the number of extremely hot days will increase, while there will be fewer extremely cold days, all around the world.
- Fears are often expressed as to what will happen to the big ocean currents that carry heat from lower latitudes out towards the poles when the climate becomes warmer. According to the IPCC, most of the modelling points towards a reduction in the transport of heat northwards – and yet to a net warming-up in northern Europe, due to the increased

concentrations of greenhouse gases in the atmosphere generally.

- No complete cut-off of the thermohaline circulation is envisaged before 2100. The IPCC nevertheless warns that beyond 2100 this heat transport could completely, and possibly irreversibly, shut down in either hemisphere, if the increase in greenhouse gas concentrations in the atmosphere is large enough and continues for long enough.
- The rise of 9–88 centimetres that is projected to take place in sea level between 1990 and 2100 is somewhat less than previously anticipated. But here, too, the IPCC issues a warning. The sea level will continue to rise for centuries after the temperature has stabilized. This could mean that the sea level rises several metres higher than it is today.
- If the temperature rise over Greenland reaches 5.5°C, and remains so for a thousand years, it could lead to a general rise in sea level of three metres. The same might happen in the case of the West Antarctic ice sheet, although the data for that is more uncertain. Climate models indicate that the local warming over Greenland is likely to be one to three times the global average.
- Even the warming that is judged to have taken place during the last century (+0.6°C) constitutes a threat to the most sensitive ecosystems. These include coral reefs, atolls, mangrove swamps, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and the remaining native grasslands. The greater any coming temperature rise will be, the more ecosystems and species will be at risk.
- Whereas a marked warming up is likely to have an adverse effect in most parts of the world, a small increase will be bad for some parts but will actually favour others. Generally speaking, however, more people will be harmed than benefited, even by a small increase in temperature. And the higher the rise, the more serious will be the effects. The poorest countries will be the hardest hit.

The effects on nature and mankind are described in more detail in chapters 2 and 3.

Unexpected effects

One consequence of our manipulation of the climate that has become more apparent in recent years is a rise in the risk of unexpected effects. It is easy to think in terms of average values and gradual, steady processes. But there are many indications that the climate, like most complex systems, has certain threshold values. Changes may take place gradually – but once a certain limit is passed major changes could take place in a short time.

The following are examples of such non-linear effects that are being discussed:

- ocean currents, which are driven by differences in temperature between different parts of the world, may stop or change direction, resulting in a change in climate,
- the natural carbon cycle could partially collapse, causing the concentrations of greenhouse gases to rise faster than the models suggest,
- the West Antarctic ice sheet could slide out into the sea, resulting in a relatively rapid rise in the sea level,
- the greenhouse gas methane, which is chemically bound in large amounts in the seabed, could be released into the atmosphere if the water warms up.

Because of feedback mechanisms the consequences could be very long lasting – perhaps permanent.

Expected changes in Europe

The global climate models have a low resolution and do not permit any far-reaching conclusions about what can be expected locally or regionally. A Swedish research project, SWECLIM, has therefore created a regional model for Europe that reveals more detail.

If the mean global temperature is assumed to rise by 3.3°C it is expected that the temperature rise in most of Europe will be somewhat higher, at 4–5°C (figure 4.2). In winter the largest rise will occur in the north, mainly due to changes in the snow and ice patterns that affect the radiation balance.

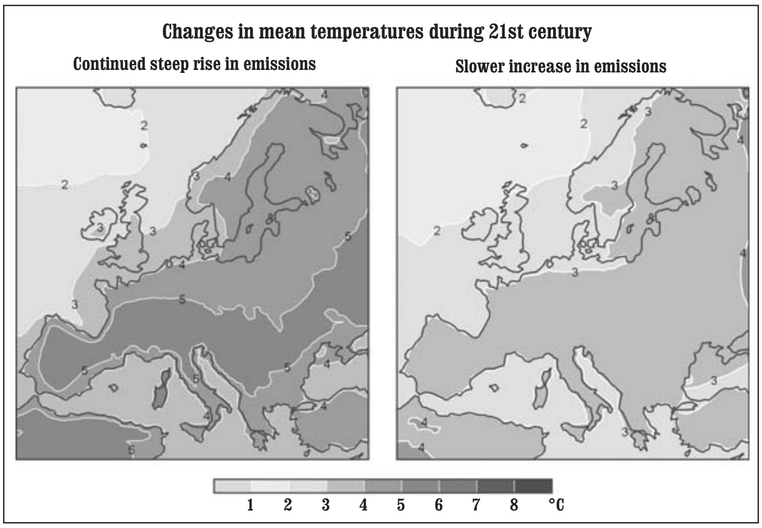

FIGURE 4.2. Changes in average annual temperature (°C) in Europe 2000–2100. The map on the left shows what would come from a continued rapid increase in greenhouse-gas emissions, that on the right the result of a slower rate of increase (predicted increase in global mean temperature 3.3 and 2.4°C respectively). (A Warmer World. Monitor 18. SWECLIM and Swedish Environmental Protection Agency, 2003.)

In summer, on the other hand, the largest temperature rise will be in central and southern Europe, where the mean temperature in France and Spain could rise by as much as 7–8°C. This would mean French weather conditions in southern Sweden and a desert-like climate in large parts of Spain. In addition to the large temperature rise in the Mediterranean area a marked reduction in precipitation is also predicted, perhaps falling to half or less in the summer. See figure 4.3 for details.

Taken as a whole this would mean a considerable deterioration in conditions for agriculture and sun tourism in southern Europe, while northern Europe could obtain higher yields from agriculture. Winter tourism would suffer markedly. The effects on biodiversity throughout the region would be considerable – not least in the Scandinavian mountain chain,

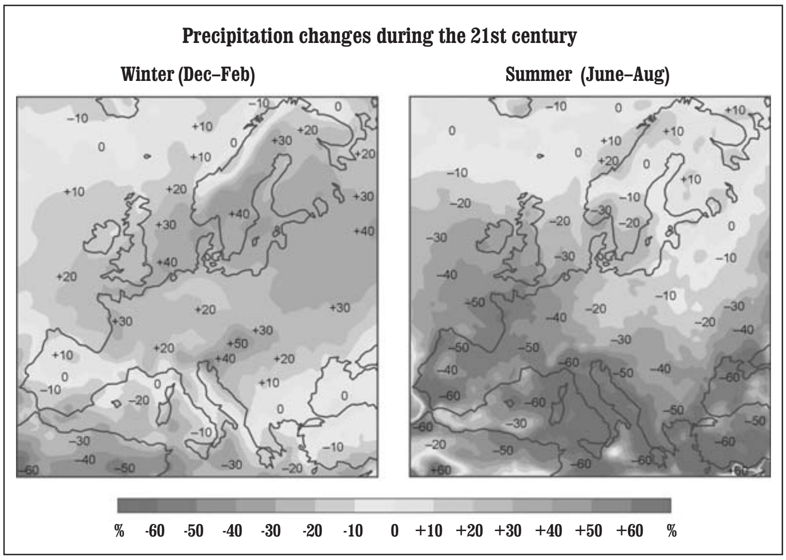

FIGURE 4.3. Changes (in per cent) in winter and summer precipitation, 2000–2100. During the winter period (December-February) the precipitation increases over most of the continent. The rainfall may also be heavier. In summer the climate will be noticeably drier, especially in southern Europe. (A Warmer World. Monitor 18. SWECLIM and Swedish Environmental Protection Agency, 2003.)

where bare mountain could eventually disappear almost entirely.

THE GREENHOUSE GASES

One of the characteristics of the gases that contribute to climate warming is that they are transparent to short-wave radiation from the sun that reaches the Earth, but they are able to absorb some of the heat that is radiated from the surface of the Earth.

The most important gas in this respect is carbon dioxide. Next comes methane and a string of chloro-fluoro compounds, then nitrous oxide, if we look at emissions to date (figure 4.4). Emissions of chloro-fluoro compounds have however fallen considerably over the last decade. Of the cur-

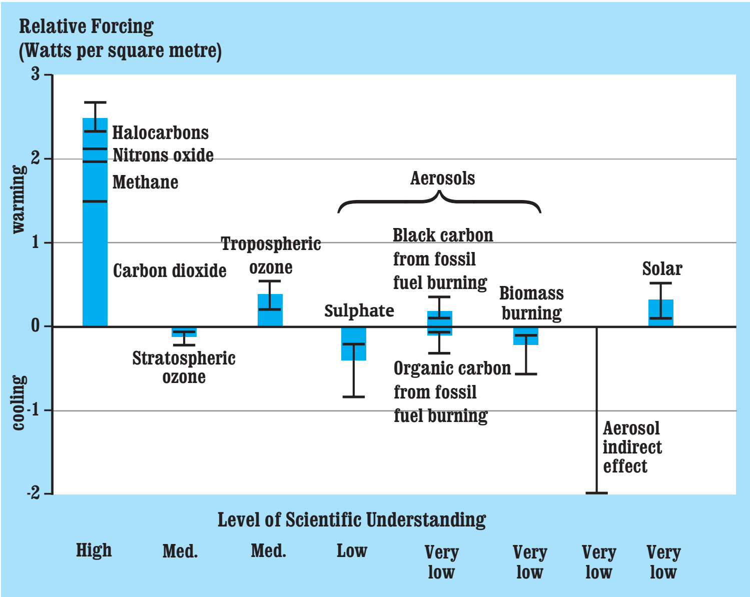

FIGURE 4.4. Estimation of how emissions of greenhouse gases and aerosols, from the pre-industrial age until the present, will affect the Earth's radiation balance.

The bar on the far left shows the direct effects of different greenhouse gases. It shows that carbon dioxide has by far the largest effect.

The next bar, which is negative, is the indirect effect of emissions of stable chloro-fluoro compounds, i.e. those that break down the ozone in the stratosphere.

The third bar reflects the rising level of ground-level ozone, particularly over the northern hemisphere.

The next three bars show the effects of aerosols. As with ground-level ozone, these are mainly present in the air over the northern hemisphere.

The indirect effects of aerosols, shown in the penultimate bar, refer to their influence on cloud formation, but are difficult to assess.

Finally, the natural variations in the intensity of solar radiation are illustrated (1850–1992).

The black vertical lines are error bars that show the element of uncertainty in the estimates.

(IPCC WG I, Third Assessment Report: Summary for Policy Makers. IPCC 2001.)

rent climate-influencing emissions, carbon dioxide accounts for around 70 per cent of the effect, followed by methane, around 20 per cent, then nitrous oxide and fluorinated gases, around 5 per cent each (ignoring the climatic influence of ozone).

Each of these gases is described below. The factfile on page 68 shows how they compare with each other.

Carbon dioxide

Carbon dioxide (CO_2) is by far the most significant greenhouse gas (see figure 4.4). Analysis of ice cores from Greenland and Antarctica show that the pre-industrial concentration of carbon dioxide in the atmosphere was around 280 ppmv (parts per million by volume). In the year 2000 the concentration was just over 30 per cent higher at 368 ppm.

Fossil fuels, which account for roughly 80 per cent of energy supply worldwide, are the main source of carbon dioxide emissions. According to the International Energy Agency, emissions of energy-related carbon dioxide totalled 24 billion tonnes in the year 2000, or 6.5 billion tonnes when calculated as carbon. Roughly 40 per cent each came from coal and oil, and 20 per cent from fossil gas (also known as “natural gas”). Changes in land use (mainly deforestation) over the last 20 years are estimated to have contributed roughly one quarter of

TABLE 4.1. Global emissions of energy-related carbon dioxide, year 2000. Million tonnes of CO_2. (CO_2 Emissions from Fuel Combustion 1971–2000. 2002 Edition. International Energy Agency, Paris, France.)

	1990	2000	Change
Developed countries (Annex I)	13,826	13,838	+0.1%
Developing countries (non-Annex I)	6,803	9,259	+36%
Marine bunkers	364	461	+27%
Aviation bunkers	285	343	+20%
World total	**21,278**	**23,901**	**+12%**

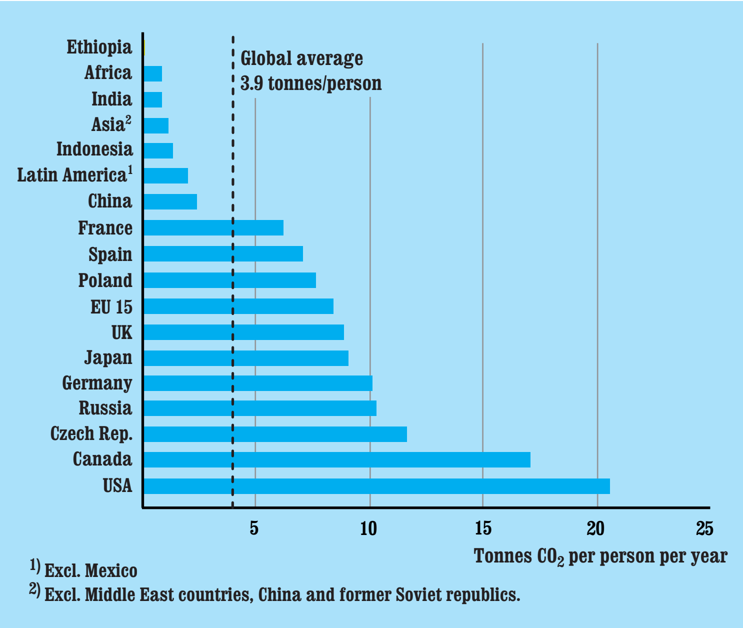

FIGURE 4.5. Emissions of fossil carbon dioxide per person per year in different countries and regions. Tonnes of CO_2 per capita, data for the year 2000. (CO_2 Emissions from Fuel Combustion 1971–2000. 2002 Edition. International Energy Agency, Paris, France.)

the total emissions of carbon dioxide, or around 1.5 billion tonnes of carbon per year.

The trend during the 1990s showed a fairly slow increase in energy-related emissions in developed countries, with a rise of 0.1 per cent between 1990 and 2000, and a considerably faster rise of 36 per cent in developing countries. Overall, this gave a worldwide increase of 12 per cent, see table 4.1. Emissions from developed and developing countries are approaching the same level in absolute figures, but developed countries are home to just one-fifth of the Earth's population. Emissions per capita in developed countries are on average six times as high as those in developing countries. Examples of emissions per capita for different countries and regions are given in figure 4.5.

There are also large differences within groups of countries. For example, the low average rise in emissions in the developed countries during the 1990s was a result of the economic collapse of the former Soviet Union, where emissions fell by a third. The US on the other hand increased its emissions by 17 per cent over the same period. This *increase* in US emissions alone, equivalent to 840 million tonnes of CO_2 per year, is almost as large as the *total* annual emissions from the whole of India, which has a population of just over one billion people. The US alone produces around a quarter of all the carbon dioxide from fossil fuels worldwide.

Once released from fossil storage, carbon dioxide remains in the atmosphere for a very long time and can affect the climate long into the future.

Nitrous oxide

Nitrous oxide (N_2O) is a greenhouse gas with an estimated pre-industrial concentration of 270 ppb (parts per billion). The concentration in the year 2000 was 316 ppb, an increase of 17 per cent. Nitrous oxide remains in the atmosphere for a long time, on average around 120 years. According to international statistics, emissions rose by 40 per cent between 1970 and 1995, although relatively little at the end of this period.

Our knowledge of the extent of emissions and the factors that control them is incomplete, but denitrification is the main source of nitrous oxide in the atmosphere. This process, which is carried out by microorganisms, occurs naturally in the soil. However, the more nitrogen is made available to plants by adding it in the form of fertilizer or through the deposition of airborne nitrogen, the more N_2O is formed.

Another source of N_2O emissions is combustion. In addition to the "common" nitrogen oxides (NO and NO_2) almost all forms of combustion also produce small amounts of N_2O. The exact amount depends largely on the combustion conditions. About a third of current emissions are anthropogenic.

Methane

The pre-industrial concentration of methane (CH_4) is estimated to have been 0.7 ppm. Today the level is more than twice as high, at around 1.8 ppm. Global emissions are reported to have increased by 20 per cent between 1970 and

RELATIVE CONTRIBUTIONS OF DIFFERENT GASES

To assess the effects of different greenhouse gases on the climate, information is needed about the quantities emitted, their ability to absorb thermal radiation in different wavelength ranges, lifetime in the atmosphere and any secondary effects.

By way of illustration it can be mentioned that methane has a lifetime in the atmosphere of around 10 years, compared with around 150 years for nitrous oxide. An example of a secondary effect is that CFC compounds, despite being powerful greenhouse gases, are only expected to make a small net contribution to the greenhouse effect. This is because they break down another greenhouse gas, the ozone that is present in the stratosphere. The two effects partially cancel each other out.

In order to compare the contributions from different greenhouse gases with each other it is usual to calculate how much carbon dioxide would be needed to achieve the same effect on the Earth's radiation balance. This measurement is called GWP, global warming potential, and is measured in carbon dioxide equivalents. Because the lifetimes of the various gases in the atmosphere vary, the time frame that is chosen for comparison is important. Normally it is based on a hundred-year perspective, which gives the following figures:

Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_2O)	310
Hydrofluorocarbons (HFCs)	150–11,700
Perfluorocarbons (PFCs)	6,500–9,200
Sulphur hexafluoride (SF_6)	23,900

Over a shorter time frame the gases that have a short lifetime, such as methane, take on greater relative significance, while the significance of those gases with a very long lifetime increases over a longer time frame.

1990, but since then the level in the air has remained stable. Methane has a relatively short lifetime in the atmosphere, on average 10–15 years.

Methane is formed naturally by the bacterial decomposition of organic matter under oxygen-free conditions. As a result of various types of human activity, emissions of methane have roughly doubled. Rice cultivation, cattle breeding, emissions from coal mines and the leakage of fossil gas represent significant anthropogenic sources around the world, as do the treatment of wastewater and sewage.

Fluorinated compounds

The greenhouse gases mentioned so far occur naturally in the atmosphere. This does not however apply to synthetic fluorinated compounds, which in many cases are very powerful greenhouse gases and have very long lifetimes. Their large warming effect, per molecule, is due to the fact that they absorb radiation in what was previously a totally transparent range of the infrared spectrum.

Perhaps the best-known substances in this group are the chloro-fluorocarbons (CFCs, better known as freons), which have gained publicity mainly through their ability to break down stratospheric ozone. CFCs are also powerful greenhouse gases. Molecule for molecule, some of them are thousands of times more effective than carbon dioxide. CFCs are however being phased out worldwide.

Other substances in this group of gaseous fluorinated compounds that have a significant greenhouse effect are:

- HFCs, which are similar to CFCs but do not contain chlorine and therefore do not affect the ozone layer. Used as replacements for CFCs in many applications. Their atmospheric lifetime is not as long as CFCs and they are not as powerful in their greenhouse effect.
- Sulphur hexafluoride (SF_6), which is used, for example, in the electronics industry.
- PFC, perfluorocarbons (also known as fluorocarbons, FCs), which are emitted during the manufacture of aluminium, and are also used in the electronics industry.

Because the emitted amounts of these substances are small, their contribution to the greenhouse effect is presently just a few per cent, estimated over a hundred-year period. However, worldwide emissions are rising relatively quickly, especially of HFCs, and many of them have effects that last a very long time – the mean lifetime for SF_6 in the atmosphere is for instance estimated at 3200 years.

Ozone

Ozone has the shortest life of all the substances that act as significant greenhouse gases. Its lifetime in the troposphere is just weeks or months. Ozone acts as a greenhouse gas in the lower troposphere, and the concentration has increased on average by 1–2 per cent per year in recent decades. The increase has primarily taken place over North America and Europe, so the climate effects in this case are regional. The causes of ozone formation are described in chapter 7. One special aspect in the climate context is emissions of nitrogen oxides from aircraft in the upper troposphere, where most air traffic takes place. At this altitude nitrogen oxides make a major contribution to ozone formation.

Particles

Particles in the atmosphere affect the radiation balance. Sulphate particles reflect incoming sunlight and hence reduce the amount of solar energy that reaches the Earth's surface. Sulphate particles originate from emissions of sulphur dioxide (see page 93). Calculations indicate that the current concentrations of sulphate particles over the northern hemisphere reduce the Earth's mean temperature by around 0.5°C.

The air also contains particles of black carbon. These can both absorb heat and reflect incident light. Their net effect on the climate is therefore difficult to assess.

Another environmental effect of particles is that they provide condensation sites for water vapour in the atmosphere, which can influence cloud formation and precipitation. In contrast to the main greenhouse gases, particles have a short lifetime in the air, around two weeks.

TABLE 4.2. Emissions by EU countries of the six greenhouse gases covered by the Kyoto protocol, in 1990 and 2000. The changes during this period can be compared with each country's commitment under the Union's internal burden sharing agreement for the period 1990–2008/12 (last column). (Annual European Community greenhouse gas inventory 1990–2000 and inventory report 2002. European Environment Agency, 2002.)

Country	Emissions 1990 (million tonnes CO_2 eq.)	Emissions 2000 (million tonnes CO_2 eq.)	Change 1990–2000 (in per cent)	Commitment 1990–2008/12 (in per cent)
Austria	77	80	+2.7%	-13%
Belgium	143	152	+6.3%	-7.5%
Denmark	69	69	-1.7%	-21%
Finland	77	74	-4.1%	0%
France	552	542	-1.7%	0%
Germany	1,223	991	-19.1%	-21%
Greece	105	130	+21.2%	+25%
Ireland	53	66	+24.0%	+13%
Italy	522	543	+3.9%	-6.5%
Luxembourg	11	6	-45.1%	-28%
Netherlands	210	217	+2.6%	-6%
Portugal	65	85	+30.1%	+27%
Spain	286	386	+33.7%	+15%
Sweden	71	69	-1.9%	-12.5%
UK	742	649	-12.6%	+4%
EU total	**4,208**	**4,059**	**-3.5%**	**-8%**

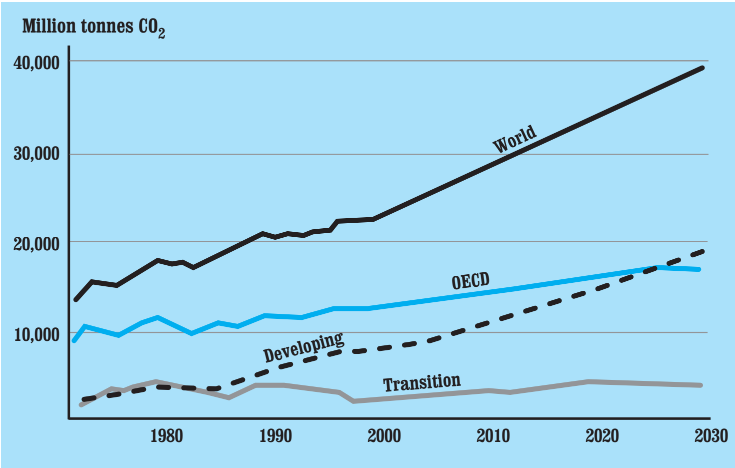

Figure 4.6. It is important that all the countries in the world are involved in future negotiations on limiting emissions of greenhouse gases. The graph shows the expected trend for energy-related emissions of carbon dioxide under business as usual. (Beyond Kyoto. Energy Dynamics and Climate Stabilisation. OECD/IEA, 2002.)

EMISSIONS IN THE EU

Global emissions of greenhouse gases are briefly described above.

The EU countries, with 5 per cent of the world's population, account for around 15 per cent of global emissions of greenhouse gases. Germany alone accounts for roughly a quarter of the Union's emissions. Most emissions of the main greenhouse gas, carbon dioxide, arise from housing (i.e. the use of heating and electricity) and transport, which account for 40 and 25 per cent respectively.

Between 1990 and 2001 emissions of the six greenhouse gases covered by the Kyoto Protocol fell by 2.3 percent. Most of this decrease took place during the first half of the 1990s however, mainly due to changes in the UK and eastern Germany. Since then emissions have remained fairly constant, and between 2000 and 2001 there was a slight increase (the reduction in 1990–2000 was 3.5 per cent, see table 4.2).

Under the climate convention of the Kyoto Protocol the EU has undertaken to reduce emissions of greenhouse gases by 8 per cent between 1990 and 2008–2012 (mean value for these five years). Within the EU however the member countries have reached a burden sharing agreement that means that some countries will reduce emissions more, while other may increase them. See table 4.2.

HOW MUCH MUST EMISSIONS BE REDUCED?

In the case of acid rain it is relatively easy to determine tolerance levels for certain sensitive ecosystems. In forest soils, the fallout must not exceed a rate that can be neutralized by natural weathering. But determining a similar limit for the level of greenhouse gases that nature can "cope with" is difficult for several reasons. It is uncertain how the climate system will react to emissions, and we know relatively little about how nature is affected when the climate changes.

A common starting point for estimating a critical limit for temperature change has been to look at the extent of natural variations in the climate. At the start of the 1990s researchers at Stockholm Environment Institute made an assessment that the temperature should rise by no more than 0.1°C per decade, which was said to represent the fastest natural change that had occurred in the last 10,000 years, and that the maximum rise in the mean global temperature compared with the pre-industrial level should not exceed 1.0 to 2.0°C (low and high risk limits). It was believed that serious effects could be expected in ecosystems if these limits were exceeded.

Subsequent research has shown that ecosystems and people are affected negatively even if the mean global temperature rises by just a degree or so above the pre-industrial level – which is the expected effect of the cumulative emissions to date. With a temperature rise of less than one degree, species such as the Bengal tiger (Ganges delta) and the mountain gorilla (Central Africa) are threatened, and a rise of 1–2°C affects coral reefs, coastal wetlands, the availability of food and water for people, etc.

TABLE 4.3. Expected rise in the Earth's mean temperature (°C) above the pre-industrial level for various levels of carbon dioxide in the atmosphere. Figures in brackets indicate the range of uncertainty. (Climate Change 2001: Synthesis Report. Summary for Policy Makers. IPCC 2001.)

CO_2 concentration	2100	Equilibrium
450 ppm	2.4 (1.8–2.9)	3.2 (2.1–4.5)
550 ppm	2.8 (2.2–3.4)	4.0 (2.5–5.7)
650 ppm	3.1 (2.4–3.8)	4.7 (3.0–6.7)
1000 ppm	3.3 (2.6–4.1)	6.3 (4.1–9.2)

The umbrella organization of the environmental movement on climate issues, Climate Action Network, writes in its position statement (2002) that the global mean temperature increase should be kept less than 2°C above pre-industrial levels, with the temperature being reduced as rapidly as possible after the time of peaking. The rate of change must not exceed 0.1°C per decade in order to allow ecosystems to adapt.

Aiming for zero

If the maximum acceptable temperature rise is set at 2°C above the pre-industrial level it is not clear what atmospheric concentrations of greenhouse gases this represents – it all depends on how sensitive the climate system is, i.e. how much the temperature will change for a given increase in concentration.

The latest report from the IPCC (2001) only states the expected effects on the Earth's mean temperature for carbon dioxide levels from 450 ppm upwards (the figure refers only to carbon dioxide, but the effects of other greenhouse gases are included in the results).

Even this lowest level gives an expected rise greater than the high-risk limit of 2°C described above. By the year 2100 an increase of 1.8–2.9°C is expected above the pre-industrial level (0.2–0.3°C per decade), with the most likely value being 2.4°C . When equilibrium is reached, a few centuries later, the increase will be 2.1–4.5°C (see table 4.3).

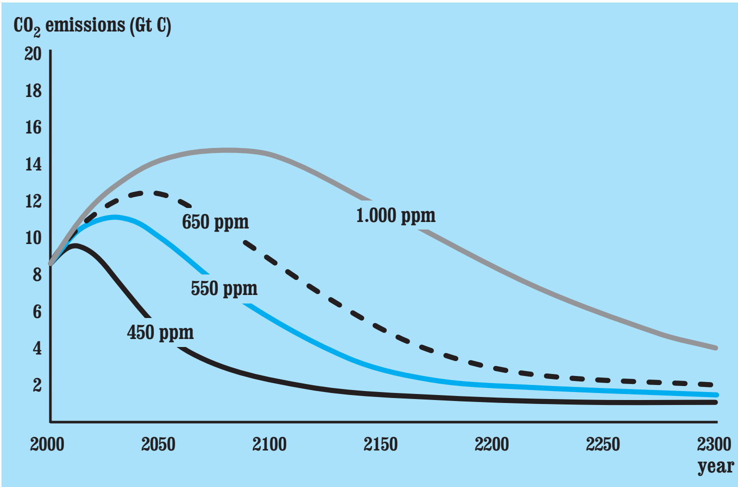

FIGURE 4.7. If emissions of carbon dioxide develop as shown by the lines in the diagram, the concentration of carbon dioxide in the atmosphere will stabilize at the level indicated in the relevant graph. The effect in terms of mean global temperature rise is shown in table 4.3. (Climate Change 2001: Synthesis Report. Summary for Policymakers. IPCC 2001.)

If the level of carbon dioxide is to be stabilized at 450 ppm, which is expected to lead to warming by more than 2°C over the pre-industrial level, global emissions must start to fall within a few decades, and before the end of this century they must have fallen to about 2 billion tonnes of carbon a year – one quarter of present emissions. This level must be further halved in the following centuries to prevent the level from starting to rise again, partly due to the long life of the gas in the atmosphere and the circulation of carbon between the air, ecosystems on land, and the sea. Ways in which global emissions of greenhouse gases could be changed in order to stabilize at different levels are shown in figure 4.7.

To achieve 2 billion tonnes of carbon a year with a population of 10 billion in 2100 (which is possibly a high estimate) emissions of carbon dioxide from fossil fuels must not exceed 0.2 tonnes of carbon per person per year – assuming that deforestation has stopped. The current global average figure is just over one tonne of carbon per person.

Reducing global emissions of greenhouse gases per capita by around 80 per cent will require extensive measures all around the world. The greatest efforts are required in the wealthy countries, where emissions are highest, but many developing countries also need to reduce their emissions from current levels.

To be certain of meeting the goal of restricting the temperature rise to a maximum of two degrees, even greater reductions must be achieved. In this case it is likely that emissions of carbon dioxide must be brought close to zero within a hundred-year period.

COULD MORE TREES CURB THE GREENHOUSE EFFECT?

If tree growth in the forests is faster than the rate at which timber is harvested there will be a net uptake of carbon dioxide. The forests then act as what is generally known as a "carbon sink". A relatively large amount of carbon can also be stored in the upper layers of soil.

The planting of trees is sometimes proposed as an alternative to reducing consumption of fossil fuels in order to curb the rise in levels of greenhouse gases, but there are a number of objections:

Vegetation only has a net uptake as long as the biomass continues to increase. The storage of carbon in the soil will eventually be balanced by increased decomposition, especially if the temperature rises. Temperate forests currently act as an important carbon sink that absorbs a proportion of the carbon-dioxide emissions from fossil fuels. But in just 50–100 years forest ecosystems around the world could be transformed into carbon sources, mainly because of the increase in the rate of decomposition.

Another aspect is that a warmer climate increases the risk that the entire forest ecosystem could break down. If this happened it would help turn the forests into emission sources of carbon dioxide as a result of the decomposition of biomass from dying trees.

Vegetation only has a net uptake of carbon dioxide as long as the biomass continues to increase. The main role of forests in the climate context is probably to replace fossil fuels in the energy sector.

If we look at the possibilities that forests offer on a worldwide scale, around one million square kilometres of new forest – an area roughly four times that of the UK – would have to be planted *every year* in order to soak up the carbon dioxide that is emitted by burning fossil fuels.

Massive forest planting on this scale is unrealistic in a world that has a growing need for land that can be cultivated. There are many reasons to reverse the deforestation trend, but the main role of forests in the climate context is probably to replace fossil fuels in the energy sector.

ADAPTING TO CLIMATE CHANGE

It is unavoidable that the climate will change as a consequence of man-made emissions. It is estimated that emissions of greenhouse gases to date will raise the mean temperature of the Earth by around 1°C. In addition to reducing emissions of greenhouse gases it may therefore be justifiable to take measures to prepare for future changes.

This is easier said than done however, since the climate models give imprecise data at regional level – we simply do not know for sure what we should expect. For activities that take place over a long time scale it may therefore be wise to spread the risks. The forestry industry for example could invest in greater genetic variety and mixtures of species. Agriculture, on the other hand, is more adaptable, since it can switch crops from one year to the next. Land development, dam construction, etc., may need to adapt to effects such as rising sea level and changing precipitation patterns.

When it comes to preserving biodiversity – a task that has an infinite time scale – the threat to the climate should be taken extremely seriously. One way of safeguarding against future changes is to make sure there are effective avenues for species to spread; these are largely lacking in today's industrialized landscape with its patchwork of forestry and agriculture.