Air
and the
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The Swedish
NGO Secretariat
on Acid Rain

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Foreword

The effects of air pollutants on people and the environment are considerable. Damage to health, changes in global climate, acidification of fresh waters, corrosion of materials, erosion of cultural treasures, losses in biodiversity and in agricultural crop yields, are some of the more obvious effects.

The aim of this publication is on the one hand to single out the causes and extent of the problems of air pollution and climate change, and on the other to describe the available remedies. Since the polluted air moves freely across national frontiers, international cooperation is a prerequisite for success in countering these problems.

Especially important but often overlooked are the connections between aspects of this issue that tend to be treated separately. Looking at solutions in particular, it is found that concerted action is needed – amounting in brief to a cessation of the use of fossil fuels. Since a total changeover will take time, specific measures will have to be directed in the short term towards reducing atmospheric emissions. Deferring action may turn out to be very expensive indeed.

It is our hope that this publication will prove a useful source of information for anyone wishing to gain an overview of the problems of air pollution and climate change. Appropriate individual behaviour as well as wise political moves will be highly dependent on the public being well informed.

Göteborg, January 2004

Per Elvingson
Christer Ågren

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The air we breathe

Even at low concentrations some pollutants in the air have major effects on people and the environment. Today, these effects on our health are an increasingly urgent incentive to take action.

Breathe in. What is it you inhale? Air of course. But what is air – apart from something that we consume several million litres of each year?

One-fifth oxygen, the rest nitrogen, would probably be the answer of most people who have given it any thought. And they would be right – almost. But around one per cent of air is made up of other gases. Mostly this is argon, a harmless gas that does not react with anything at all. It is the remaining fractions of the last per cent – a small drop in the ocean of air – that this book deals with!

HEALTH, ACIDIFICATION, THE GREENHOUSE EFFECT... AND HEALTH AGAIN

Air pollution is not a new phenomenon in mankind's history. Even for cavemen, lighting a fire undoubtedly had its drawbacks. Historical records contain accounts of plant damage caused by air pollution from smelting works during the time of the Roman Empire, right at the start of our modern calendar. Serious health problems caused by domestic coal fires in London were also described at the end of the thirteenth century.

Until the industrial age truly arrived, air pollution was generally a very local problem. If anything was done to reduce emissions it was in order to improve people's health. In that respect tall chimneys were clearly a blessing – the pollutants were diluted and just "disappeared".

By the end of the 1960s it became apparent that, despite appearances, the atmosphere is actually a fairly thin layer around the Earth and is far from a limitless dumping ground – sooner or later most emissions fall back to Earth.

This realization was partly triggered by growing acidification problems, which led to a sharp fall in fishing yields in many lakes and waterways in Scandinavia, and turned out to be the result of long-range movement of air pollutants.

At the end of the 1980s the question of air and the environment became a worldwide issue when climate change and the thinning of the ozone layer were placed high on the political agenda. The fact that mankind's emissions could have an effect on the climate had however been known since the end of the nineteenth century.

As air issues became a worldwide concern the regional air pollution issues became more complex – now it was no longer just about the acidification of lakes, but also about soil, damage to forests, eutrophication and ground-level ozone.

Over the past decade, health issues have once again come into focus at local and regional level. In particular the effects of particles and ground-level ozone on our health have attracted growing publicity.

Building tall chimneys was an early – although not particularly long-term – solution to local air problems.

A QUICK GUIDE TO USING THIS BOOK

One of the ambitions in writing this book was to draw attention wherever possible to the important and often overlooked links that exist between problems that are usually considered independently.

The book therefore starts with two chapters that aim to give a collective picture of how air pollutants influence nature and people.

These are followed by four chapters which each describe one problem area: climate effects, acidification, eutrophication and ground-level ozone. Each of these chapters looks at the air pollutants that are involved, what happens chemically and physically, how far emissions need to be reduced in order to rectify the problems and how things might turn out in the future.

The two final chapters return to the wider perspective. The penultimate one deals with the opportunities to take action. This shows that the problems can be solved and that we would profit by doing so. One key issue is reducing the use of fossil fuels. The obstacles to taking action are also discussed. The final chapter reports on what is happening at the political level.

Because the main aim of this book is to give a broad picture and pass on a basic knowledge there are few references in the body of the text. The most important sources, and references to more in-depth information, are instead given at the end of the book. More detailed source references can be obtained from the Swedish NGO Secretariat on Acid Rain.

Unfortunately there is not space for all the interesting aspects even in a book as thick as this! Among other things, the problems of heavy metals and persistent organic pollutants – which occur partly as air pollutants – have been excluded.

2

Air pollution and nature

Biodiversity on our planet is decreasing as a result of human activities. Air pollution is not the main cause of this, but certain types of ecosystems are particularly vulnerable and/or affected by it. One of the most serious aspects of air pollution is that its effects reach everywhere – even in nature reserves and areas that are otherwise protected from our interference.

This chapter describes how air pollution affects ecosystems, both globally and regionally. To make it easier to understand the role of air pollution a short introduction is first given to how ecosystems work. The importance of climate for the ecosystems is then described, followed by a run through of the known effects of air pollution on different natural environments. Finally the effects of air pollution are discussed in relation to other types of human influence.

NATURE – HOW IT WORKS

There is a widespread conception that when nature is left in peace by mankind it reaches some sort of equilibrium or "ecological harmony". But this is not the whole truth. There is of course a certain degree of balance in nature. The most important evidence for this is that it still exists. But often balance is equated with lack of change. In fact nature is changing all the time – there is a constant battle to conquer more living space, both within and between species. Who wins the battle varies from one time to the next, depending on variations in climate and other living conditions. Chance also plays a certain role.

The influence of mankind – in the form of hunting, fishing, forestry or air pollution – means that we interfere in the processes of change that are constantly taking place. For instance, if we add nitrogen to a nutrient-poor grass heath we can get a completely new ecosystem, since the competition rules are changed – some species are strongly favoured by this fertilization and are able to displace the others.

It all depends on circumstances

It is not obvious how an individual, such as a spruce tree, will react if it is exposed to air pollution. Firstly, all spruce are genetically unique individuals and have different degrees of inherent resistance to stress (just like us!). And secondly their response depends on other environmental factors.

The term stress is often used to describe the pressure that the surroundings exert on an individual. A plant, for example, can be stressed by drought, lack of nutrients, competition and attack by parasites – and by air pollution.

As a stress factor, air pollution can act in many different ways. Some gases for instance are directly toxic. Acidifying substances can act indirectly by restricting access to nutrients in the soil. Nitrogen fallout makes living conditions more difficult for many species, but improves them for others. Climate-modifying gases can change precipitation patterns and cause greater drought stress, etc.

In each case it is the cumulative effect of the different stress factors that decides whether an organism is harmed or not. A given dose of a pollutant or a specific climate change can therefore have very different effects. The role or air pollutants is further complicated by the fact that they may reinforce or cancel out the effects of each other.

THE IMPORTANCE OF CLIMATE

The present distribution of ecosystems around the world – from the polar ice caps to the equatorial rainforests – is a result of the climate that has prevailed over recent millennia. Viewed over the long term, the climate has always varied widely, but usually at a fairly slow rate. If current fears of global warming become a reality, two main groups of effects can be expected in the natural ecosystems:

- "Transition problems", the extent of which will depend on the rate of warming and the way that the landscape is divided up.
- New zones of colonization, which will be determined by how much the temperature rises overall, how precipitation patterns change, etc.

What makes the current threat of climate warming so special is its speed. Changes that have in the past taken thousands of years could happen in just a few decades.

During the relatively slow course of natural climate variation it is assumed that the majority of plants, including long-lived species such as trees, would manage to migrate with "their" climate zone. Transition problems have probably been fairly minor, although these variations have doubtless wiped out a number of species that were unable to keep up with the fluctuations. Some species that are only able to spread slowly are still moving northwards in Europe in response to the disappearance of the inland ice 10,000 years ago.

By analysing the occurrence of pollen in peat moss and lake sediment researchers have been able to show how different types of vegetation have taken over from each other since the last ice age. It is not certain that these pollen archives reflect the maximum ability of the species to spread. It is however apparent that if the extent of warming is as large as predicted, many species will have difficulty keeping up.

The way that ecosystems move in practice is also worth commenting on. Trees and other plants cannot sprout feet and start heading north. In any given ecosystem there is a gradual process of change during which certain species are left behind, new ones appear and some old ones die off.

One complication in the migration of species is the presence of natural and man-made barriers. The sea is a barrier to many land species, in the same way as the land is to organisms that live in lakes. Our use of land has also fragmented the landscape in such a way that biologically diverse environments are often like isolated islands – e.g. an ancient forest reserve in a sea of cultivated forest or a meadow in a sea of farmland.

Different species have very different abilities to cope with the necessary migration. The ones that do best seem to be those whose strategy is to produce a large number of offspring early in life. These species can quickly colonize new habitats. Things are more difficult for long-lived species that have few offspring and limited ability to spread. The former group includes many species that benefit from disruption and are already favoured by human activity – while the latter includes those that are already hard pressed.

GLOBAL EFFECTS

Biodiversity is generally threatened to a much greater extent by our use of land than by air pollution – at least at present. But a major climate change over a short period could have both far-reaching and lasting consequences. Moreover, air pollution affects all natural environments, including those which, for various reasons, we do not exploit, such as mountain heaths and raised bogs, as well as those we have decided to protect, such as nature reserves and national parks.

Ecosystems under threat

A number of ecosystems have been identified as especially sensitive to changes in temperature and precipitation patterns:

Coral reefs. Coral reefs – the highly diverse ecosystems that exist in the tropical oceans between the Tropics of Capricorn and Cancer – are among the most threatened environments. This is because the coral polyps that build the reefs, in symbiosis with single-celled algae, are very sensitive to temperature. In recent years the tropical oceans have also been unusually warm. The coral polyps are stressed by heat and this has led to coral bleaching in all the tropical oceans. Many of these corals will probably never recover. Some researchers believe that a rise of just one degree in the water temperature is a serious threat to coral reefs worldwide.

Mangrove swamps. The mangrove swamps, thickets of trees on stilt-like legs along the coasts of tropical areas, stabilize the coasts and provide habitats and breeding grounds for a very large number of aquatic species and land species. They are threatened by rising sea levels. There is limited opportunity to retreat inland, since the land there is often already used for other purposes.

Mountain ecosystems. Vegetation does not just vary with climate in the north-south direction. There is also climate-dependent variation with altitude. There are alpine environments on mountain peaks even in warm regions. These can be regarded as islands in a "sea" of surrounding lowlands. If the climate gets warmer and the vegetation zones creep up the mountainsides there is nowhere for the species that live at the top to go.

Boreal forests. The large coniferous forests that form a belt around the Arctic currently cover 17 per cent of the Earth's land surface. The extent of these forests may shrink greatly in the future as a result of climate changes. Heat and drought mean that forests in the south are disappearing or being transformed into temperate forest at a quicker rate than the coniferous forests in the north are able to advance across the tundra. Attack by insects and fungi can be expected to increase since these are favoured by warmer temperatures, and because drought may become a growing problem for trees in many areas, especially the central areas of continents.

Mountain heaths and tundra. The northernmost ecosystems have limited opportunities to move further north if it gets warmer, since the Arctic Ocean forms a boundary. Model calculations indicate that the area of tundra could be halved over the next century, even with a relatively moderate temperature rise.

The Arctic. The ice cap that makes up the Arctic may shrink considerably as a result of warming. This reduces the habitats of those species that are adapted to the current conditions, such as the polar bear.

Rainforests. The temperature change is expected to be relatively small nearest the equator, where the rainforests are located. But on the other hand these forests are home to many highly specialized species that are sensitive even to small changes in temperature and rainfall.

Many species are threatened

The average global temperature does not need to rise particularly dramatically to pose the threat of extinction for many land species due to their habitats changing or disappearing.

In a study presented in the journal Nature in January 2004 a group of researchers showed that a massive 35 per cent of the species studied in a series of areas with a rich biodiversity may be threatened with extinction by the year 2050, even if global warming is limited to 2.5–3.0°C. The researchers fear that well over one million species may be threatened by extinction if the results of the study are applied on a global scale, and that even more species will be added to the list if the temperature rises more than 3°C – although the latter was not covered by the study.

The same study shows, however, that an active climate policy could save many species from the risk of extinction. In a low global warming scenario (0.8–1.7°C) the proportion of threatened species is halved in comparison with the scenario for a temperature rise of 2.5–3.0°C.

Imbalance between light and temperature

Some natural processes are governed by temperature, which may change in the future, and others by the length of day, which is unaffected by greenhouse gases. This means problems for certain species. One example is a species of hummingbird in North America, whose migration is triggered by the length of day. It arrives in its summer home in the Sierra Nevada just as certain alpine plants come into flower, so the bird has plenty of food and the plants get pollinated. However, the flowering of these plants is not controlled by length of day, but by the thawing of the snow, which could happen a full two months earlier if the level of greenhouse gases in the atmosphere doubles. A partnership that has been fine-tuned over millennia could therefore be upset totally within a short period of time.

Higher level of carbon dioxide

The rising level of carbon dioxide in the air does not just affect the climate. It also has a direct influence on plants, since they use the carbon dioxide for photosynthesis. Some species are better than others at making use of the increased availability. It is difficult to say how this will affect ecosystems, but there is reason to believe that this "fertilization" with carbon dioxide could shift the balance of competition in a similar way to the increased availability of nitrogen, even if it does not have such dramatic consequences.

The higher level of carbon dioxide in the air also improves the ability of plants to conserve water, since the same amount of carbon dioxide can be absorbed in a shorter time. This means that the stomata on their leaves do not have to be kept open as long, which in turn reduces evaporation.

Other air pollutants

Acidification, eutrophication and ground-level ozone affect ecosystems in many parts of the world, but the effects are primarily regional and local. The following section describes in more detail what is happening in Europe.

REGIONAL EFFECTS

The problems related to air pollution that have had the greatest impact on ecosystems in Europe are the acidification of nutrient-poor fresh water and the acidification and eutrophication of many land environments. These processes have caused major harm and the impoverishment of nature. It is also possible that increased levels of ground-level ozone have affected some plant communities on land.

The extent and scope of all these problems are expected to decrease in coming decades in Europe, not least due to international agreements to reduce emissions of several air pollutants. The biggest question for the future is what will be the effects of the increased levels of greenhouse gases in the atmosphere.

The following describes what has happened so far and what is feared may happen in northern European ecosystems.

The sea

Seawater contains a plentiful supply of buffering substances and is therefore not threatened by acidification.

The atmospheric deposition of nitrogen compounds does however pose a serious problem, in the form of eutrophication. For example, it is calculated that up to one-third of the nitrogen that enters the Baltic Sea originates from airborne fallout. In seawater it is generally the availability of nitrogen that limits biological reproduction, while in fresh water phosphorus is the limiting factor, at least where water is poor in nutrients.

The deposition of nitrogen means that algae, whether mobile or immobile, get a real boost to growth. This changes the entire ecosystem. The increase in biological production in surface water also has consequences lower down. When dead plants and animals eventually reach the bottom it takes a lot of oxygen to decompose them. In unfavourable cases the oxygen may be completely used up, which kills off most of the bottom fauna.

Not much is known about how life in our marine areas is affected by changing climate. It is feared that a warmer climate and increased precipitation will lead to greater leaching of nitrogen from the land to the sea, and hence aggravate the problems of eutrophication.

Lakes and waterways

Acidification is the most important effect of air pollution on bodies of fresh water. Several different mechanisms cause extensive biological changes:

Some organisms are sensitive to low pH. This is true of a number of shell-bearing organisms such as molluscs, mussels

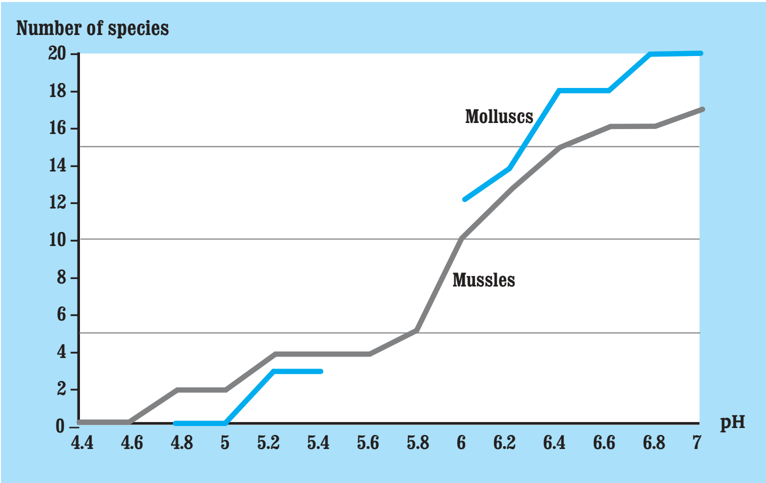


FIGURE 2.1. Molluscs and mussels disappear when the pH drops. (pH-status, No. 4, 1998.)

and many crustaceans, including crayfish. Figure 2.1 shows the relationship between pH and the number of species of molluscs and mussels in Norwegian waters. Mayfly larvae have also been found to be sensitive to changes in pH.

The elevated levels of dissolved aluminium in water that are caused by acidification affect some organisms. This is the case for the eggs and fry of many species of fish. The adult fish are less vulnerable and may live on, even though the stock has stopped reproducing. Some fish are more sensitive than others. This is illustrated in figure 2.2, along with a number of other changes that take place.

The rise and fall in numbers of some species does not depend directly on acidification (low pH values or high concentrations of dissolved aluminium), but is an indirect effect of fish disappearing. The presence of fish has a strong governing effect on the distribution of species in lakes.

Lake acidification also affects birdlife. Fish-eating birds, such as divers, merganser and osprey are put under pressure, while insect-eaters, such as goldeneye are favoured.

Among plants, certain bog mosses are favoured by acidification, while many plants at the water edge suffer, partly be-

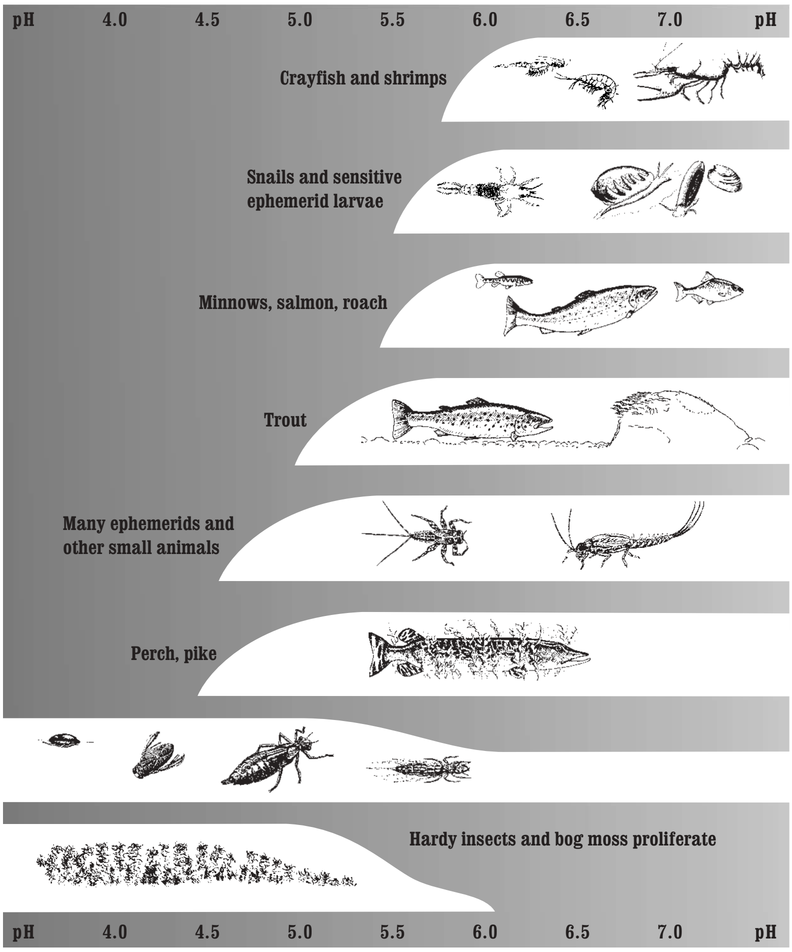


FIGURE 2.2. The sensitivity of different groups of plants and animals to the acidification of lakes and waterways.

cause they are overgrown by mats of bog moss. The number of species of phytoplankton falls dramatically. In nutrient-poor lakes with a pH value above 6 there are normally around fifty species, while only ten or so remain in an acidified lake.

Acidification is largely a problem in naturally nutrient-poor lakes and waterways. Worst affected is water that is high up in the catchment areas.

Eutrophication is another problem that affects surface water, as a rule mostly in agricultural areas. In most cases the eutrophication of fresh water has little to do with air pollution – here it is usually phosphorus that limits growth, and the phosphorus comes mainly from agricultural land and sewage outflows, not from the air.

In certain cases the airborne deposition of nitrogen can also affect life in fresh water. In some lakes, mainly those that are relatively rich in nutrients, growth is limited by the availability of nitrogen. The deposition of nitrogen can then contribute to eutrophication.

A warmer climate also affects life in lakes. If the ice season becomes shorter, the algal bloom occurs earlier in spring, and the distribution of species is affected, including a fall in numbers of diatoms. Bacterial activity is expected to increase, which makes more nutrients available and aggravates the problems of eutrophication. If precipitation increases it will also lead to an increase in the influx of nutrients from the surrounding land.

Warmer water also affects life under the water surface. Fish such as salmon, salmon trout, vendace and char have difficulty finding sufficient cold water in the southern reaches of their natural habitats. Because lakes and waterways are naturally fragmented there is little opportunity for them to seek out more suitable climatic conditions.

Forests

Air pollutants affect forests in many different ways. In the case of trees, the increased level of carbon dioxide in the air favours their growth, as does the deposition of nitrogen. Other substances, such as ozone, are harmful and can make trees more vulnerable to the natural stress that is always present to some degree, in the form of drought or attack by insects or fungi for example.

Many organisms in the forest are much more sensitive to pollutants than the trees. Widespread changes in the distribution of species have been reported in large parts of Europe, primarily in connection with acidification and the deposition of nitrogen – see the factfile on pages 28–29. But it is rarely easy to establish exactly which effects depend on what. At the same time as the level of air pollution has increased there have also been major changes in the forestry practice.

Many reasons for damage to forests

Although trees are not the most sensitive species in the forest they will be given a little more attention here – after all, their survival is a prerequisite for the existence of the forest.

There are a number of examples of forests suffering severe damage and death around large local sources of emissions of sulphur, fluoride, heavy metals and ammonia, which are undoubtedly caused by air pollutants. However, there have been much fewer such cases in Europe in the last few decades.

When it comes to the relationship between air pollutants and damage to forests elsewhere, the picture is complex. These effects must be seen as the result of interaction between different stress factors. It is not possible to point to air pollution as the only culprit for forest damage, such as the thinning of crowns, that has been observed in Europe in recent decades, with the possible exception of those areas where the burden of air pollution has been extremely high.

In many more cases air pollution may be a contributing factor to forest damage. The following are some of the effects of air pollutants, the importance of which varies from place to place:

Direct plant damage, caused by gases and acids in direct contact with leaves and needles. The greatest impact is probably due to ground-level ozone. The levels over almost the whole of Europe are so high during summer that they can damage trees and other plants.

Soil acidification, which is mainly caused by acid fallout, but to some extent also by the harvesting of biomass by the forestry industry. When soil is acidified certain nutrients are leached out, while others are bound more tightly to the soil. The leaching out of base cations (such as potassium, calcium and magnesium) in particular is feared to lead to a shortage or imbalance in nutrients that could threaten the long-term health of the forest. Recent research indicates, however, that coniferous trees seem to be able to counter the shortage of nutrients through symbiosis with mycorrhizal fungi and bacteria in their root systems. Other effects of soil acidification include a rise in the concentration of metals in the soil water, which can cause root damage and slow down decomposition in the soil.

Excess nitrogen, caused by nitrogen deposition (as nitrate and ammonium). Nitrogen is usually a scarce resource in all ecosystems, and airborne deposition generally leads to increased growth. One disadvantage, however, is that the crowns of trees grow faster than their root systems. Because the same root volume has to supply a greater mass of leaves or needles this is thought to increase the risk of desiccation. With a high supply of nitrogen, trees also become more vulnerable to frost and possibly to attack by parasites.

Changes in the occurrence of mycorrhizal fungi may be harmful for trees. This effect is due primarily to the deposition of nitrogen, and to some extent by soil acidification.

Warmer climate has both benefits and drawbacks for trees in the forest. The effects depend on how much the temperature and rainfall change, as well as how fast this happens. Increasing temperatures means that existing vegetation zones would be pushed strongly northwards. In northern Europe broad-leaf trees may flourish at the expense of coniferous trees. In southern Europe there is a risk that higher temperatures and reduced precipitation could knock out entire ecosystems.

Alpine environments

In the long term there may be major changes in alpine environments, such as the Scandinavian mountains and the mountain ecosystems of central Europe. In Scandinavia the tree line has already moved north, and with a temperature rise of 3–4 degrees the only areas of bare mountain left would be in the most upland regions in the north. Plant and animal life on the remaining mountain heaths would also change. Among the species whose habitats would shrink are the gyr falcon and arctic fox, which are already threatened.

One consequence of warmer climate is that decomposition speeds up, and the availability of nutrients – mainly nitrogen

– increases, at least for a while. Nitrogen is normally scarce in mountain ecosystems and the changing conditions could therefore lead to dramatic changes in vegetation. This would put slow-growing species at a particular disadvantage.

Open countryside

In Europe there are large areas of open countryside that have rich biological variety. A few of these areas are naturally free of trees, including certain wetlands. Most have been created by man and are part of what we call cultivated landscape: meadowland, pastureland, heaths, etc.

What is common to the latter is that they have developed as a result of long-term use, sometimes over thousands of years. Haymaking, grazing and burning have continuously removed nutrients. Over time, diverse ecosystems have developed in response to the scarcity of nutrients, particularly nitrogen. In the case of naturally open land, raised bogs and poor fens also have a mixture of species that are adapted to the relatively acidic, nutrient-poor conditions.

Less intensive management, and subsequent overgrowth, is the biggest threat to meadowland, pastureland and heaths today. Another problem is the use of artificial fertilizer. The nitrogen that this brings mostly favours various tall grasses and plants, which displace a host of other species.

The nitrogen that is deposited from the air acts in the same way as artificial fertilizer on natural, nitrogen-poor ecosystems – although the dosage is smaller and spread over a long period. The nitrogen accumulates in the plants and in the ground, and sooner or later the flora changes, in some cases gradually, but in others suddenly and dramatically.

In those parts of Europe where nitrogen deposition is especially high, e.g. the Netherlands, Denmark and the UK, major changes have been reported in vegetation due to the atmospheric deposition of nitrogen. This has often occurred in combination with a stress factor, such as attack by insects or fungi. Even raised bogs, which are normally very nutrient-poor environments, are significantly affected by the atmospheric fallout.

The boreal forests of the northern hemisphere are among the ecosystems that may shrink markedly as the climate gets warmer.

The airborne attack by nitrogen is a threat to all open, nutrient-poor land, even where we try to protect and preserve it through good management and the creation of reserves.

Ground-level ozone can also change ecosystems and may to some extent counter the effects of nitrogen. Research has in fact shown that species with an "expansive lifestyle" – those that are favoured most by the deposition of nitrogen – are also the most sensitive and suffer the most damage when the concentration of ground-level ozone increases.

Other air pollutants also have a certain influence on biodiversity in open countryside. The levels of sulphur dioxide and probably also nitrogen oxides affect the growth of lichens. Soil acidification and increased levels of carbon dioxide in the air may disturb the existing balance of competition and hence change the distribution of plant species. See also the factfile on the following pages.

SENSITIVE GROUPS OF ORGANISMS

Here are a few examples of the ways that different groups of plants and animals are affected by acidification, deposition of nitrogen and ground-level ozone:

ALGAE are a diverse group of plants. In fresh water there are many single-celled algae as well as several species of stoneworts (charophyta) that are sensitive to acidification and eutrophication. Some types of algae flourish in acidified lakes. On land there are single-celled green algae, which are favoured by nitrogen.

LICHEN AND MOSSES, unlike the higher plants, do not have a waxy layer to protect the cells from outside influences. They also lack roots and therefore take up water and nutrients directly through their cell walls. This makes them sensitive to air pollutants, especially high levels of sulphur dioxide, and to acidification of the substrate (e.g. bark) they live on. A large number of species in Europe have become much less common and in places have disappeared entirely, at least partly due to air pollution. Some lichens are particularly sensitive, such as lungwort (genus Lobaria). In recent years researchers have reported a slow recolonization by lichens, both in cities and rural areas, mainly as a result of falling levels of sulphur dioxide in the air.

FUNGI and HIGHER PLANTS are affected by air pollution in a similar way. Species that tolerate acid soil conditions – including high concentrations of aluminium ions – are spreading, as are species that are favoured by easy access to nitrogen. There is a general decrease in species that require high pH levels and/or a plentiful supply of base cations in the soil, as well as those that cannot compete in nitrogen-rich environments.

For fungi and higher plants the deposition of nitrogen compounds is likely to be a greater threat to diversity than soil acidification. The composition of natural ecosystems is largely determined by the availability of nitrogen in forms that plants can use, which in most cases is a scarce resource. When this is supplied to nitrogen-poor ecosystems it allows a few species to thrive at the expense of others, and entire ecosystems are disrupted.

Fungi that live in co-operation (symbiosis) with higher plants – mycorrhizal fungi – are generally sensitive to the deposition of nitrogen, although there are some exceptions. Mycorrhizal fungi are very important for a whole host of higher plants. Their root filaments act as an extended root system that helps the plant to take up water and nutrients. New research has shown that the hyphae of fungi do not just take up the nutrients that are dissolved in soil water, but are also able to "eat rock", i.e. they can produce their own acids that break down the minerals in the soil and release base cations.

SENSITIVE GROUPS OF ORGANISMS, continued

In exchange for water and nutrients the fungi get carbohydrates, which the plant manufactures by using sunlight for photosynthesis. Mycorrhizal fungi also provide biological defence for the tree – as long as they are present they can protect the roots from attack by other fungi.

In field trials it has been shown that fertilization with nitrogen has little effect on the quantity of mycorrhiza in the soil, but that the number of species drops sharply, as does the formation of fruiting bodies. We do not yet know how this affects ecosystems.

INVERTEBRATES. A variety of changes are taking place in acidified lakes, see page 20 ff. and figure 2.2. On land many types of molluscs have declined in acidified areas. A range of soil organisms, including earthworms, are also sensitive to reductions in pH.

The increased availability of nitrogen favours those organisms that live and feed on the plants that are thriving. This is the case with the shield bug, a beetle that lives on wild chervil. On the other hand species that depend on plants that are in decline are put at a disadvantage.

FISH. Some species are very sensitive to acidification, others more tolerant. See figure 2.2.

FROGS. Reproduction problems can occur in acidified water, and eggs do not develop if the pH is too low.

BIRDS. Red-throated and black-throated divers, osprey and dippers get their food from water. Their numbers have all been found to decline in acidified areas. Researchers have also reported thinning of the eggshells of certain bird species, probably because they have ingested more aluminium and less calcium as a result of acidification.

MAMMALS. Elevated levels of cadmium have been found in the livers and kidneys of elk, deer and other mammals in areas of Sweden with acidification problems. One reason for this may be soil acidification, which increases the mobility of cadmium and some other metals in the soil. Whether this affects the health and reproductive ability of these animals is not known. The otter is negatively affected by the reduced availability of fish in acidified waterways.

DECOMPOSERS. A variety of worms, microorganisms and fungi play a vital role for the function of ecosystems. They live by breaking down dead plant and animal matter, and by doing so make the nutrients that were originally taken from the soil available again. Decomposition takes longer in an acid environment, partly because earthworms disappear when the pH drops. However there are big gaps in our knowledge of how microorganisms react to the changes in soil chemistry caused by air pollution.

Climate changes are another threat to the biodiversity of open countryside. Despite the expected rise in global precipitation the climate models indicate that conditions in southern Europe will become much warmer and drier – almost desert-like in places. Coastal meadows and wetlands are threatened by the rise in sea level. They may become flooded, and in the worst case disappear entirely, if farmland, settlement or the lay of the land prevent them from migrating inland. Other rare natural environments are similarly threatened if they cannot propagate naturally through the modern cultivated landscape.

MAN AND NATURE

Let us end this chapter where we began, by looking again at the way that nature is constantly changing. Air pollution adds a new factor to the game in which all species are striving to maximize their living space. Some are favoured by it, others disadvantaged. Mankind has always influenced its surroundings in a similar way, through cultivation, forestry and other forms of development.

This should not be seen as an attempt to dismiss the effects that air pollution has on us and the world around us. It has already put great pressure on a host of sensitive species, and many more are at risk. The important conclusion is that mankind's influence on the environment cannot be considered in isolation from the other processes that are constantly at play in nature. What is new and more serious about the situation today is the extent, the intensity and the speed of our influence.

3

Air pollution and man

Air pollution affects us in many ways, perhaps more than we realize. It not only affects our health, directly and indirectly, but also our finances. Materials erode and corrode, cultural treasures are lost and production from agriculture and forestry is reduced.

This chapter first describes the effects on our health, followed by the ways in which air pollution affects our opportunities to exploit the forest, soil and water. Finally it looks at the effects on materials and structures. Information on how the economy is affected is given under each heading, and to some extent also in chapter 8.

HEALTH EFFECTS

Many air pollutants are toxic when inhaled and therefore have direct effects on our health. Added to these are a wide variety of indirect effects that are discussed later in this chapter, including the increased mobility of many metals and the effects of climate change.

Toxic air

Although the concentrations of air pollutants are in general on the way down in Europe, the problems remain considerable – especially as regards ground-level ozone and small parti-

TARGET VALUES AND LIMIT VALUES

A number of target values and limit values have been set up with the aim of confining the pollutants to permissible levels.

Target values, such as those from the World Health Organization, are only recommendations, and so are not binding. These are set at levels aimed to protect human health.

Limit values on the other hand are binding, and because they are compulsory their economic consequences have been taken into account when deciding on them.

It has not been possible to determine any minimum dose below which there will be no ill effects from carcinogenic substances. Resort has therefore been made to a **medical low risk level** that will keep the risk of getting cancer under a certain level, for example 1 in 100,000, for individuals who are exposed to the specified concentration throughout their lifetime.

Percentile figures are often used when stating limit values. If for example a one-hour mean value is given as a 98th percentile it means that in one year (8760 hours) the limit value must not be exceeded for more than 175 hours. For a 99th percentile the limit value may be exceeded for 88 hours per year. For a daily mean value, the 98th and 99th percentiles represent seven and four excursions per year respectively. In those cases where no percentile figures are given, a maximum daily or annual mean value applies that should not be exceeded.

Note that the values given apply to one pollutant at a time. The level of knowledge is still generally insufficient to give levels that take into account any combined (additive) effects of different substances.

cles. In some areas, too, the situation continues to become worse.

Air pollution is not easily measured, comprising as it almost invariably does a mixture of many different substances, some of which are more toxic than others. By interacting in some cases, they become even more harmful. For example, sulphur dioxide can affect lung tissue in such a way that carcinogenic substances can penetrate more easily into the cells of the lungs.

The effects of breathing toxic substances may range from a slight feeling of discomfort to premature death. Those most at risk are children, the elderly, asthmatics and people with heart and circulatory problems. Sensitivity varies very widely, however, from one individual to another.

This examination of harmful substances in the air cannot be comprehensive – the exhaust fumes from a petrol engine alone contain thousands of different substances. The description instead focuses on some of the most important substances and groups of substances.

The risks to health come mainly from the following pollutants in outdoor air:

Nitrogen dioxide

When inhaled, nitrogen dioxide (NO_2) can penetrate relatively deep into the airways, where it can cause irritation and damage to tissue. It can also aggravate both asthma and allergic reactions. It also impairs the defence mechanisms of the lungs against bacteria, viruses, and other air pollutants such as

TABLE 3.1. Nitrogen dioxide.

	1-hour mean value	Annual mean value
WHO target value (WHO 2000)	200 $\mu g/m^3$	40 $\mu g/m^3$ (health) 30 $\mu g/m^3$ (vegetation; $NO+NO_2$)
EU limit value, applies from 2010 (A)	200 $\mu g/m^3$ (B)	40 $\mu g/m^3$ (health) (C) 30 $\mu g/m^3$ (vegetation; $NO+NO_2$) (C)

(A) European Union 1999, Directive 1999/30/EC.

(B) Must not be exceeded more than 18 times per calendar year.

(C) Applies from 19 July 2001.

ozone and particulate carcinogens. Repeated exposure to nitrogen dioxide, either alone or in combination with other factors, is suspected of triggering asthma in children. The target and limit values that apply at present are shown in Table 3.1.

Nitrogen oxides moreover have significant indirect effects on health through their contribution to the formation of ground-level ozone and their conversion in the air to very small particles. See below.

The main contributor to the concentrations of nitrogen oxides in urban surroundings is usually road traffic. In most European countries the levels of nitrogen oxides in urban air have risen with the growth in road traffic, but are now decreasing thanks to the growing number of vehicles that are fitted with catalytic converters.

According to calculations by the EU Commission for 1995, 65 per cent of Europe's urban population lived in areas where levels exceeded the annual mean value of 40 μg/m^3 laid down in the forthcoming standard. A more recent estimate by the European Environment Agency (2002) indicates that this figure has fallen to just over 40 per cent. Further reductions are expected, but in 2010 it is still expected that the limit value will be exceeded in many areas if no further action is taken.

TABLE 3.2. Sulphur dioxide.

	10-minute mean value	1-hour mean value	max. 24-hour mean value	annual mean value
WHO target value (WHO 2000)	500 μg/m^3	–	125 μg/m^3	50 μg/m^3 (health)
EU limit value, from 2005 [A]	–	350 μg/m^3 [B]	125 μg/m^3 [C]	20 μg/m^3 [D]

[A] European Union 1999, Directive 1999/30/EC.

[B] Must not be exceeded more than 24 times per calendar year.

[C] Must not be exceeded more than 3 times per calendar year.

[D] To protect ecosystem. Applies outside urban areas, with effect from 19 July 2001.

Sulphur dioxide

Sulphur dioxide (SO_2) also causes irritation of the airways. Long-term exposure in combination with airborne particles increases the likelihood of respiratory infections in children. Further effects on health can be traced to the part played by sulphur dioxide in the formation of particles in the air (see below).

The main sources of emissions are the burning of coal and oil. The contribution from road traffic is small. Current target and limit values are given in table 3.2.

In most parts of Europe levels of sulphur dioxide have fallen considerably in recent decades, thanks to improved emission controls for power stations, cleaner fuels, increased use of district heating, etc. According to calculations by the EU Commission, however, in 1995 one quarter of the urban population of Europe was exposed to levels higher than the forthcoming limit values for both one-hour and 24-hour exposure. This percentage is expected to fall to 2–11 per cent by 2010 as a result of decisions already taken.

Particles

Through the use of sophisticated statistical methods and more powerful computers, researchers have been able to identify links between exposure to particles (PM) and a variety of effects on health even at levels that had previously been considered safe.

A large number of studies made both in the US and in Europe have shown that when the concentration of small particles in air rises, even from low levels, there is a rise in mortalities from respiratory, cardiac and circulatory diseases, and more people seek hospital care for bronchitis and asthma.

Even exposure to low levels for long periods is considered harmful. The long-term effects have not yet been very well researched, but living in regions where there are high concentrations of particles is believed to reduce life expectancy.

Calculations have shown that in Austria, Switzerland, and France small particles (PM_{10}) at current levels in air give rise to 40,000 premature deaths a year in these countries, and the average life expectancy of people living in an urban environment is reduced by 18 months. Furthermore, these particles trigger half a million asthma attacks each year and lead to a total of 16 million lost person-days of activity.

A recent study on the health impact of particles in 19 European cities with a total population of 32 million concluded that reducing the levels of PM_{10} by just 5 µg/m^3 would prevent more than 5500 premature deaths annually in those cities.

It is the very smallest particles that are believed to be the most harmful, because when they are inhaled they can penetrate deep into the lungs. Their shape and chemical composition as well as their size are thought to influence their harmfulness, as do the substances that adhere to their surface.

Particles are now generally measured as PM_{10}, where PM stands for particulate matter and the number 10 indicates the maximum diameter in micrometres (actually particles of such a size that 50 per cent pass through a given sampling filter). For several years an even finer fraction, $PM_{2.5}$, has also been measured in the US. This gives a better measure of the smaller particles, and presumably a better indication of the effect on health. In recent years a start has been made on measuring $PM_{2.5}$ in the EU too, although the present standards only apply to PM_{10}. Some measurements have also been initiated to study the very smallest particles, such as PM_1 and $PM_{0.1}$.

Particles are classed as either primary or secondary:

Primary particles are those that are formed during combustion, but may also consist of dust, small soot flakes, pollen, etc. Major sources are combustion processes (often small-scale burning) and internal combustion engines (primarily diesel engines). At present the extent of these emissions and their distribution among sources are not fully known. Emission inventories are however being developed and improved.

Secondary particles consist mainly of sulphate and nitrate salts that are formed in the air from sulphur dioxide and nitrogen oxides. Any source that emits these substances therefore contributes to their formation.

Secondary particles are small and can remain suspended in the air for long periods. There is extensive transboundary migration of these particles – in most places only a small proportion is traceable to local emissions, and a large percentage, particularly of the finest fractions, consists of secondarily formed particles.

TABLE 3.3. Particles (PM_{10}).

	Max. 24-hour mean value	Annual mean value
WHO target value (WHO 2000)	dose-response	dose-response
EU limit value, from 2005 (A)	50 $\mu g/m^3$ (B)	40 $\mu g/m^3$
Prel. EU limit value 2010 (A)	50 $\mu g/m^3$ (C)	20 $\mu g/m^3$
Guide value proposed by IMM (D)	30 $\mu g/m^3$	15 $\mu g/m^3$
Current levels in Europe		10 $\mu g/m^3$ remote areas

(A) European Union 1999, Directive 1999/30/EC.
(B) Not to be exceeded more than 35 times per year.
(C) Not to be exceeded more than 7 times per year.
(D) IMM = National Institute of Environmental Medicine, Sweden.

The WHO guidelines do not set any target values for airborne particles, since it is considered unlikely that a level will be found that does not have harmful effects. Instead, they give a dose-response link, see figure 3.1. In Sweden the National Institute of Environmental Medicine (IMM) has proposed limit values well below the levels so far considered acceptable. See table 3.3.

According to calculations by the EU Commission for 1995, almost 90 per cent of Europe's urban population was living in areas where particle levels exceeded the maximum 24-hour mean and annual mean values of the forthcoming EU standard. This proportion is expected to fall to around two-thirds by 2010 as a result of decisions already taken in respect of emission controls for combustion plants and vehicles, as well as of sulphur levels in fuels.

Volatile organic compounds

These comprise a very large group of pollutants. Some are fairly harmless, while others are extremely toxic. They can occur either as gases or bound to particles, and several of the substances in this group contribute to the formation of

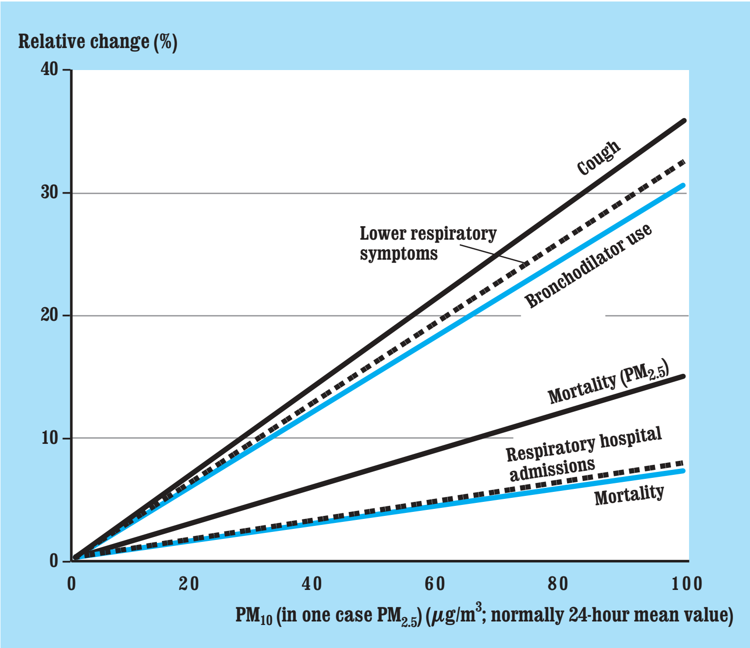


FIGURE 3.1. Link between particles in ambient air and effects on health. Dose response link at exposures below 20 $\mu g/m^3$ is however uncertain. (WHO. Air Quality Guidelines for Europe. 2nd edition, 2000)

ground-level ozone – which probably is the most significant health effect of this group as a whole.

The group includes known carcinogens such as benzo-(a)pyrene, ethene and benzene, as well as various aromatic hydrocarbons. Among the nitrated polyaromatic hydrocarbons (nitro--PAH) are some of the most carcinogenic substances known to man, several of which are present in diesel exhaust fumes.

Petrol-driven cars that have ineffective catalytic converters, or none at all, are a major source of emissions of volatile organic compounds in urban air. Small-scale combustion, such as the household burning of wood or coal, can also make a significant contribution.

TABLE 3.4. Benzene.

	Annual mean value
EU limit value, applies from 2010 (A)	5.0 μg/m^3
Low risk level (B)	1.3 μg/m^3
Current levels, urban environment, Europe	1–10 μg/m^3 background level 20–50 μg/m^3 roadside

(A) European Union 2000, Directive 2000/69/EC.

(B) Assessment by National Institute of Environmental Medicine, Sweden. Lifetime exposure to this concentration gives rise to 1 case of cancer per 100,000 inhabitants.

At present the limit values in the EU are only for benzene, but standards are also being worked out for polyaromatic hydrocarbons (PAH).

In most European cities the levels of benzene in the air exceed the medical low risk limits by a large margin. For current limit values and levels, see table 3.4.

According to calculations by the EU Commission for 1995, 50 per cent of Europe's urban population lived in areas where benzene levels exceeded the annual mean value of 5 µg/m^3 set out in the forthcoming EU standard. This percentage is expected to fall to 13 per cent by 2010 as a result of decisions already taken, primarily regarding traffic-related emissions.

Ozone

Ozone is a powerful oxidant and can give rise to eye irritations and irritations of the airways that lead to a reduction in lung capacity, even at relatively low concentrations. Because ozone is a gas with low solubility in water it can penetrate deep into the lungs. During periods of elevated levels a larger number of people are admitted to hospital emergency departments with respiratory problems (see table 3.5). When concentrations rise, even from relatively low levels, the need for increased medication of asthmatic children and increased mortality are among the observed effects. Long-term exposure, even to relatively low concentrations, can lead to permanent lung damage according to new research in the US.

TABLE 3.5. Link between hospital admissions due to respiratory disease and measured ozone levels, according to epidemiological studies. (WHO, 2000)

Increase in ozone levels (µg/m³) for 1 hour	8 hours	Increase in hospital admissions
30	25	5%
60	50	10%
120	100	20%

High levels occur primarily in spring and summer, since ozone formation is a process that is driven by sunlight. Every year concentrations in Europe exceed by a large margin the eight-hour mean target value of 120 µg/m³ recommended by the WHO to protect human health. Following such episodes high levels can also occur in areas with relatively clean air.

Following national and international agreements that will result in measures to reduce the emissions of nitrogen oxides and volatile organic compounds, episodes of high ozone levels are expected to fall over the next few decades. Levels over Europe are however also affected by emissions from all over the northern hemisphere, which means that increasing emissions in Asia, for example, could counteract the effectiveness of abatement measures in Europe. For target values, see table 3.6.

Carbon monoxide

Carbon monoxide is easily absorbed by the blood, and reduces its ability to transport oxygen. High levels can lead to unconsciousness and death. The main source of emissions is petrol-driven cars that do not have catalytic converters. These are steadily disappearing and current levels of carbon monoxide in outdoor air are probably harmless in most cases. High levels can however occur in multi-storey car parks, garages, tunnels, etc. One reason to further restrict emissions of carbon monoxide is that it contributes to the formation of ground-level ozone. In 2002 the EU decided that the limit value of 10 mg/m³ for outdoor air should not be exceeded after 2005.

TABLE 3.6. Ozone.

	One-hour mean value (health)	Eight-hour mean value (health)	Three-month mean value (vegetation)
WHO target value (WHO 2000)	–	120 μg/m^3	-
EU standards [A]	180/240 μg/m^3 [B]	120 μg/m^3 [C]	AOT40 [D] = 18000 μg/m^3 hours [E]
EU long-term objective [A]	–	120 μg/m^3	AOT40 [D] =6000 μg/m^3 hours
Proposed target value by IMM [F]	80 μg/m^3	–	–

(A) European Union 2002, Directive 2002/3/EC.

(B) At 180 μg/m^3 (information threshold) the population should be informed, and at 240 μg/m^3 (alert threshold) short-term actions should be taken.

(C) Target value for 2010, not to be exceeded more than 25 times per year.

(D) AOT40 = Accumulated exposure over the threshold 40 ppb.

(E) Target value for 2010.

(F) IMM = National Institute of Environmental Medicine, Sweden.

Lead

Lead causes brain damage, especially in children. In the EU, levels of lead in the air have fallen dramatically thanks to the fact the lead is no longer added as an octane enhancer to petrol. The addition of lead to petrol was totally prohibited throughout the EU from the year 2000, although some countries have been allowed a few years for the phasing out process.

Asthma and allergies

In many industrialized countries the incidence of asthma and allergies has risen sharply in recent decades. So far no explanation has been found. The incidence of hypersensitive reactions is thought to be due to hereditary dispositions as well as environmental factors. One as yet unexplained phenomenon

THE EU FRAMEWORK DIRECTIVE

In September 1996 the EU Council of Ministers adopted the directive on ambient air quality assessment and management (96/62/EC). This is a framework directive that, among other things, lays down how monitoring systems should be set up so that information on measurements is made accessible to the public. So far the directive has been supplemented by three subsidiary directives. The first was adopted in 1999 and covers sulphur dioxide, nitrogen dioxide, particles (PM_{10}) and lead (1999/30/EC). The second, which covers benzene and carbon monoxide, was adopted in 2000 (2000/69/EC), and the third (2002/3/EC), which deals with ground-level ozone, was adopted early in 2002. In July 2003 the Commission presented a proposals for a fourth daughter directive, covering polyaromatic hydrocarbons (PAH) and a number of heavy metals.

The framework directive says nothing about how the limit values should be achieved; that is up to each member country to decide. However, it does require that corrective measures should be taken if the standards are not met. The specified limit values are minimum standards. This means that member countries can introduce stricter standards if they wish.

is the much greater increase in western Europe than in eastern Europe.

Researchers do not believe that air pollution is a critical factor that could account for this rise, partly because the rise has taken place at a time when the levels of pollutants have fallen. Nevertheless air pollution does play an important role in this context. Nitrogen dioxide, sulphur dioxide, ozone, and particles have all been shown to aggravate and in some cases trigger symptoms of asthma in susceptible individuals. Ozone and nitrogen dioxide have also been proved to increase sensitivity to pollen among sufferers of hay fever. This is because these pollutants damage the mucous membranes of the airways, so that allergenic substances are more likely to trigger a reaction.

Inversions and episodes

When weather conditions are stable, usually during periods of high pressure and light winds, the levels of various air pollutants can occasionally rise by a factor of ten or more, locally or

INVERSIONS AND EPISODES

When weather conditions are stable, usually during periods of high pressure and light winds, the level of pollution in the air can rise to very high levels.

In winter this is generally due to an **inversion**, a weather condition that causes the temperature of the air to increase with height above ground level. This results in very little mixing of the air. Inversions occur most often on clear nights with little wind, usually in combination with high pressure, which allows the heat in the ground to radiate out into space. Heat from the sun generally breaks up the inversion during the day, but occasionally it may hang over an area for several days. Concentrations of various pollutants – primarily sulphur dioxide, nitrogen oxides and particles – underneath this "lid" can then rise very sharply and may appear from a distance as a brownish yellow haze hanging over the area.

Inversions are usually local, but can even affect entire regions. The brown coal areas of the northern Czech Republic are a notorious example. When emissions were at their worst the concentration of sulphur dioxide reached almost 1000 $\mu g/m^3$. During the famous London smog in December 1952 a daily average value of 5000 $\mu g/m^3$ was measured, which is probably a world record.

In summer, the concentrations of various air pollutants can become exceptionally high during periods of fine weather, when a high-pressure front is "parked" over the same area for a long time. The air is not mixed very much and the concentration of ground-level ozone in particular often reaches harmful levels. In sunny summers this phenomenon occurs over large parts of Europe. When these polluted masses of air begin to move and pass over an area they are often referred to as **episodes**, short periods when the concentrations of pollutants in the air are greatly elevated.

regionally. In winter the main pollutants involved are sulphur dioxide, nitrogen oxides and small particles. In summer, the levels of ozone and other oxidants rise the most. See also factfile above.

Acidification and health

The mobility of many metals increases in acid environments. The human body needs small amounts of certain metals, such as copper, manganese and iron. But if the concentrations are too high they quickly become harmful. Other metals, such as mercury, cadmium and aluminium, serve no purpose in the human body. Some of them are toxic at very low concentrations.

Aluminium is one of the most widely occurring metals in the Earth's crust, but it is tightly bound in various minerals. The concentrations of various aluminium ions increase significantly when water becomes acidic. These are highly toxic to some aquatic organisms. It is not clear whether they affect humans.

The average levels of **cadmium** in groundwater have been shown to be three times higher in water with a pH value under 5, compared with water that has a pH above 6. However, we get most cadmium from food. The cadmium uptake of crops rises when the pH of the soil drops. For non-smokers, cereal products and vegetables contribute 75 per cent of the total intake of cadmium on average.

The concentrations of cadmium that parts of the population are exposed to are already close to the levels at which kidney damage can occur. Cadmium is also suspected of giving rise to bone embrittlement at relatively low exposures. Our uptake of cadmium increases significantly if we are deficient in iron.

Copper is used in water pipes. When water is acidic it can dissolve the metal that pipes are made of. High levels of copper discolour porcelain and can cause diarrhoea in children.

Fish that have high levels of **mercury** are found mainly in acidified lakes, although the reason for this is not fully known. There is nothing to indicate that acidification should increase the leaching of mercury from soil into water. In contrast to many other heavy metals, mercury remains tightly bound to humic substances in the soil, even when the pH drops. A more likely reason is that acidification reduces the amount of biomass in acidified lakes, so the mercury that is present becomes more concentrated. Another theory is that the fallout of sulphur may favour the bacteria that are able to convert (methylate) mercury to produce a phase that is taken up by organisms more easily.

As far as is known, the vitality of aquatic organisms is not directly affected by high levels of mercury. However, man is often at the very top of the food chain. For us, the regular consumption of fish containing high levels of mercury can be harmful. In Sweden, women who are pregnant, breastfeeding or plan to have children are advised to avoid fish from lakes entirely, since even small amounts of mercury can cause brain damage in embryos.

The climate and health

If the climate changes it also affects our health. Even if the mean temperature during the year rises just a few degrees it could mean that there are several times as many hot days. Severe heat waves usually lead to many elderly people dying prematurely. The number of very cold days is generally decreasing worldwide.

Many researchers fear that a warmer climate will lead to more extreme weather conditions. This would also mean more injuries and deaths due to flooding, hurricanes, etc., as well as extensive material damage. Because of this the big insurance companies are taking the enhanced greenhouse effect very seriously.

Another expected effect of a warmer climate is the wider occurrence of diseases that are spread by insects and various parasites, e.g. malaria and bilharzia (schistosomiasis), since the parasites and their hosts can extend their habitats. In the case of malaria the expected climate change over the next century could mean that 60 per cent of the Earth's population live within the risk zone, compared with 45 per cent today. Areas that are currently malaria-free, such as mountain regions in the tropics, could be affected.

A warmer climate can also give rise to more cases of food poisoning and water poisoning, since living conditions would be more favourable for bacteria and parasites.

The availability of drinking water, food, housing and opportunities to earn a living are naturally of central importance to people's health, and these necessities may be more difficult to obtain if the climate changes. In general it is those who are already poor who are expected to be worst hit by climate change, since they have the least resources to take preventive action and counter measures.

OTHER EFFECTS

Air pollution and forestry

In northern Europe, forest growth is largely dependent on the length of the growing season, which will increase if it gets warmer. The extent of the increase in production will however depend on how the availability of water and nutrients changes. These are the factors that govern growth over large parts of Europe.

The availability of nutrients may increase, since decomposition will speed up if the climate gets warmer. Nutrients will circulate faster, and this could support increased production.

Most scenarios point to warmer, more humid weather in the north, with a consequential increase in growth. In central and southern Europe, however, the temperature rise is likely to be combined with a sharp reduction in rainfall, which would be a major problem for the existing forestry industry.

The higher level of carbon dioxide in the air is itself favourable for forest growth – since plants use carbon dioxide for photosynthesis, and if there is more carbon dioxide in the air the trees can also conserve water better. But in practice the ability of plants to exploit this fertilization with carbon dioxide will often be limited by some other factor.

Another way that air pollution can promote growth is through the fallout of nitrogen. The deposition of nitrogen serves to fertilize the forest. Fallout over large parts of Europe amounts to several tens of kilogrammes of nitrogen per hectare each year.

Not just benefits

Air pollution also has a number of major drawbacks for the forestry industry:

- Some species of trees do not like warmer weather. Norwegian spruce (*Picea abies*) needs a gradual fall in temperature in order to acclimatize for winter, otherwise it becomes very sensitive to frost in early spring. Scots pine (*Pinus sylverstris*) is better at coping with warmer and drier climate, but may be driven out by broad-leaf trees that are favoured more than coniferous trees.

- Many forest pests – especially insects and fungi – are favoured by a warmer and more humid climate.
- Acid fallout acidifies the soil and, among other things, reduces the availability of important nutrients for trees. It also slows down decomposition.
- Ground-level ozone damages plants. Several studies in Europe indicate that ozone is an important contributory factor to damage in Norwegian spruce and beech (*Fagus sylvatica*). In southern Sweden it is estimated that current ozone levels result in a loss of yield from spruce of up to around 10 per cent over a forest generation.

Air pollution and agriculture

A crucial issue for agriculture worldwide is the availability of water. For instance, availability in summer is expected to fall in central areas of continental Europe and around the Mediterranean as a result of the enhanced greenhouse effect. The climate in already dry areas of southern Spain may become almost desert-like. Conditions for farming may change drastically in many parts of the world, resulting in food shortages and social problems. The seriousness of these problems will depend largely on the extent of the climate changes. It is a fairly obvious conclusion that the people who have the least opportunity to adapt – the poor – will be affected worst of all.

In northern Europe it is likely that agricultural yields will rise – the growing season may be extended by a few months and precipitation can be expected to increase. On the negative side, however, the higher temperatures could also lead to increased attacks by insects and fungi.

Ozone is probably the pollutant that causes the largest harvest losses in agriculture today. A warmer climate could lead to increased formation of ground-level ozone. In Europe it is estimated that today's levels could give rise to annual harvest losses worth over 6 billion euro. Of these losses, one third is attributed to wheat, one fifth to potatoes, and one tenth to sugar beet. Other crops for which individual losses account

Generally speaking 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.

for more than 3 per cent of the total economic loss are pulses, grapes, maize, sunflower, cotton, rapeseed, and tomatoes.

Air pollution and fishing

Fishing in northern Europe will probably be affected by a warmer climate, although it is difficult to say how. Cod spawning is, for example, relatively temperature-dependent. More severe effects are feared in tropical waters. Coral reefs are extremely sensitive to rises in temperature and a large proportion of the fish that are caught in coastal areas in tropical seas depend on the coral reefs for their survival. These fish are also the main source of protein for millions of people.

The eutrophication of seas that airborne nitrogen fallout contributes to has both positive and negative effects on fish. One positive effect is that the increased availability of nutrients leads to increased production throughout the ecosystem. On the negative side, some species may be driven out and the shortage of oxygen may lead to the disappearance of fish from large areas (if eutrophication is severe).

In Scandinavia, acidification due to air pollution is probably the largest single cause of damage to fish stocks, mainly to the annoyance of anglers. Most of the lakes affected are small and commercial fishing has hardly been affected.

Buildings, infrastructure and cultural heritage

A long list of civil structures in our society are being destroyed or are in danger as a result of air pollution.

Climate effects

The largest future threats in this area worldwide are likely to be the rising sea level, increased precipitation and a possible increase in extreme weather conditions due to the changing climate. The heavier winter rain that is predicted will increase the risk of flooding along rivers and waterways in large parts of Europe.

In the wealthy parts of the world we are to some extent prepared to cope with more extreme weather conditions, although the effects could still be serious. The situation could be much worse in places that have poor economic resources and where a large proportion of the population live and work in low-lying areas, such as coastal cities, flood deltas and coral islands. One billion people currently live within 30 kilometres from the coast, and on average the population in these areas is growing twice as fast as in the world as a whole.

In addition to flooding, problems can also occur through salt permeation into groundwater, leading to lack of fresh water. With a combination of rising sea level and more storms, hundreds of millions of people are at risk of losing their homes and/or their means of earning a living.

Corrosion

The effects of wind and weather naturally mean that all materials will decay sooner or later, but air pollution speeds up this process. Buildings, vehicles, metal structures, statues, rock carvings, museum artefacts, water pipes, electrical cables etc., are all attacked and damaged. Objects made of limestone and some types of sandstone are especially vulnerable to acid substances, but not even the hardest granite can resist entirely (see figure 3.2).

The greatest damage is caused by sulphur dioxide, which is corrosive in both gaseous form and when converted into sulphuric acid. Nitrogen oxides also contribute to the damage, partly through the formation of corrosive nitric acid, and partly by reinforcing the damaging effects of sulphur dioxide. Ozone and other oxidants react readily with organic substances. They contribute mainly to the breakdown of textiles, leather and rubber. As a result of its oxidizing ability ozone

FIGURE 3.2. A survey of the 3000-year-old rock carvings in Bohuslän on the west coast of Sweden in the 1990s showed that 80 per cent of the carvings had suffered erosion damage, and studies have shown that the erosion rate then was four times higher than in the 1930s.

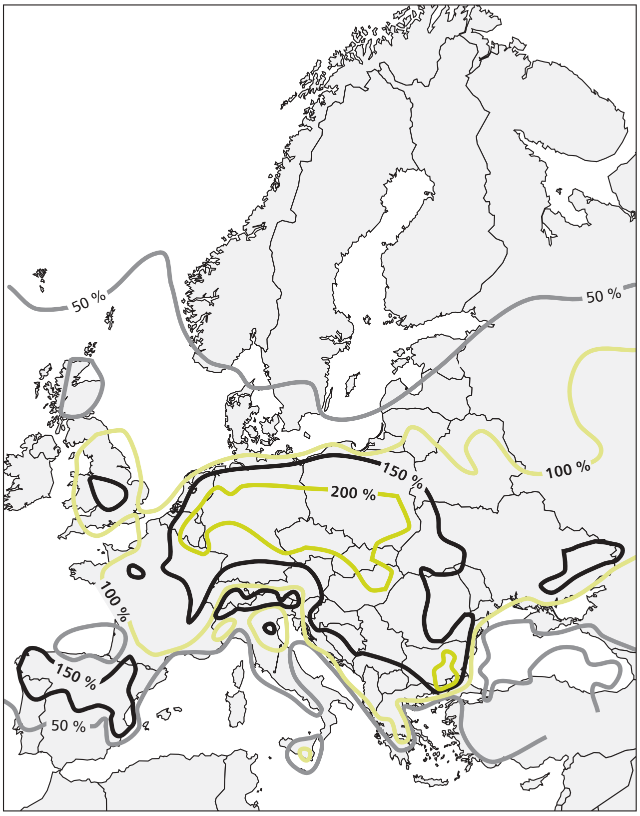


FIGURE 3.3. Copper corrosion rates above the background rate (in %). (EEA, Air Quality in Europe, 2002)

can also increase the corrosiveness of compounds of sulphur and nitrogen oxides.

Dry fallout is considered to do more damage than wet, since it can dissolve in the film of condensation on various surfaces and remain there for a long time. This can lead to high concentrations that are highly corrosive, since the pollutant is dissolved in such a small quantity of water. It also means that the pollutant can be "reused" as long as it remains there. It may dry out in the meantime, but can go back into solution whenever the surface becomes moist, with dew for example.

Rain on the other hand, even if it is acidic, washes the pollutants away.

Major economic losses are caused by the acceleration of corrosion due to air pollution. The annual damage to modern buildings and materials in Europe was estimated at 11 billion euro in 1995. Added to this is the extensive and serious damage caused to our cultural heritage, which in many cases is impossible to repair or measure in economic terms.

In northern Europe this corrosion has decreased markedly during the 1990s, thanks to reduced emissions of acidifying substances. However it is still estimated that corrosion over large parts of Europe is at least twice as rapid as the natural background rate, see figure 3.3.

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

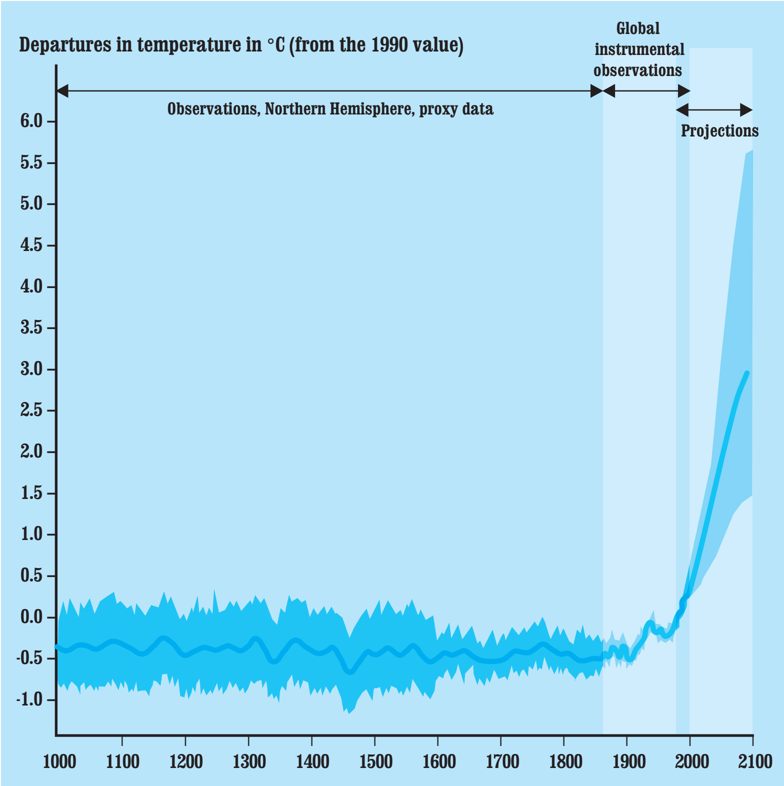


FIGURE 4.1. Variations of the Earth's surface temperature 1000–2100. The temperature over the period 1000–1900 has been reconstructed from historical data. 20th century values are recorded data and the 21st century values are those predicted by the IPCC scenarios. (Climate Change 2001: Synthesis Report.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

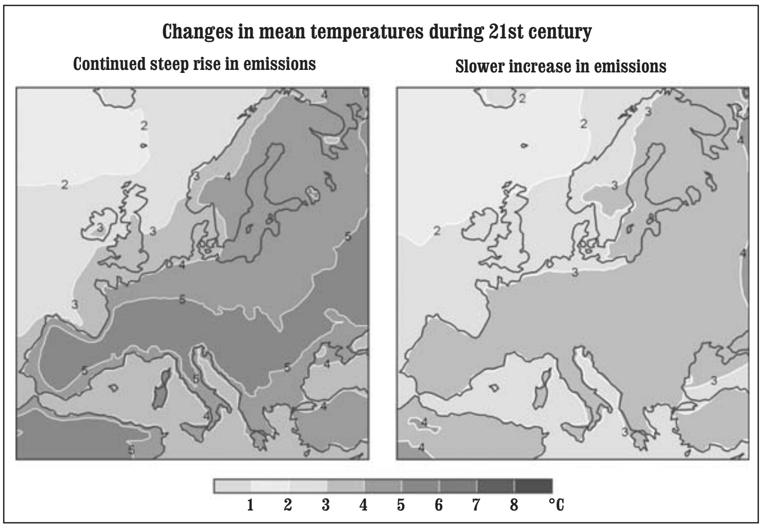


FIGURE 4.2. Changes in average annual temperature (°C) in Europe 2000–2100. The map on the left shows what would come from a continued rapid increase in greenhouse-gas emissions, that on the right the result of a slower rate of increase (predicted increase in global mean temperature 3.3 and 2.4°C respectively).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

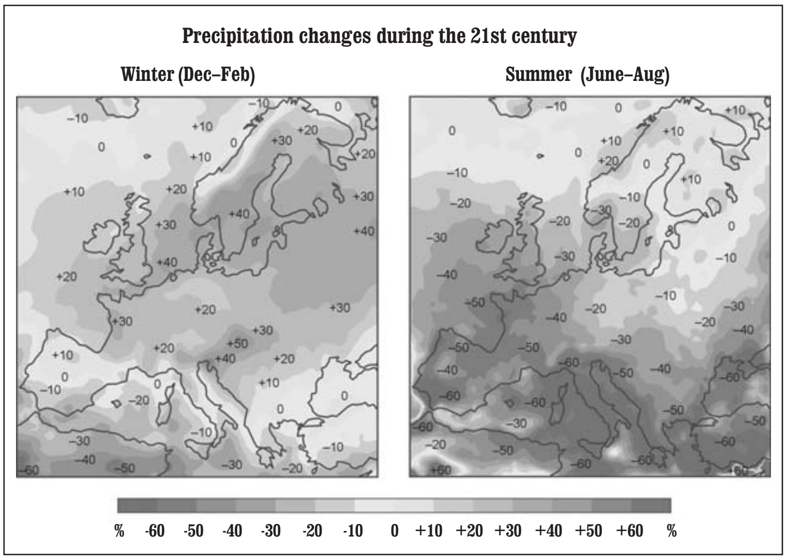


FIGURE 4.3. Changes (in per cent) in winter and summer precipitation, 2000–2100. During the winter period (December-February) the precipitation increases over most of the continent. The rainfall may also be heavier. In summer the climate will be noticeably drier, especially in southern Europe. (A Warmer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

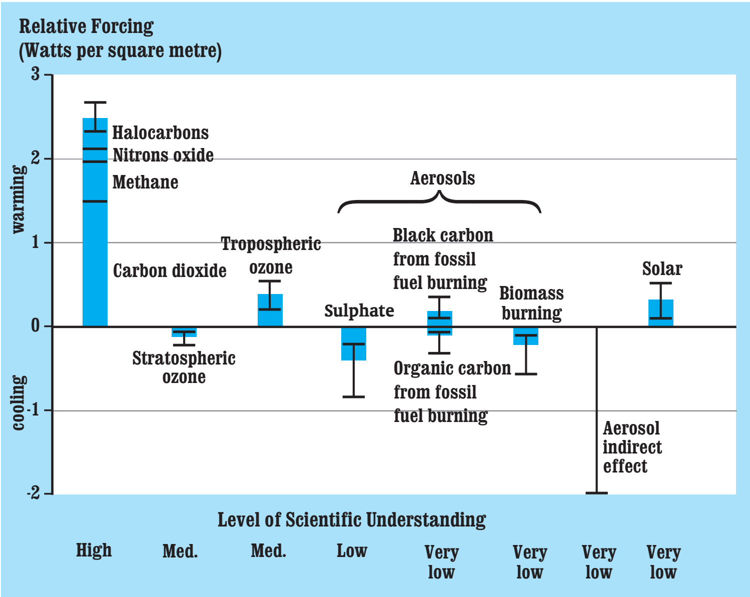


FIGURE 4.4. Estimation of how emissions of greenhouse gases and aerosols, from the pre-industrial age until the present, will affect the Earth's radiation balance.

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%**

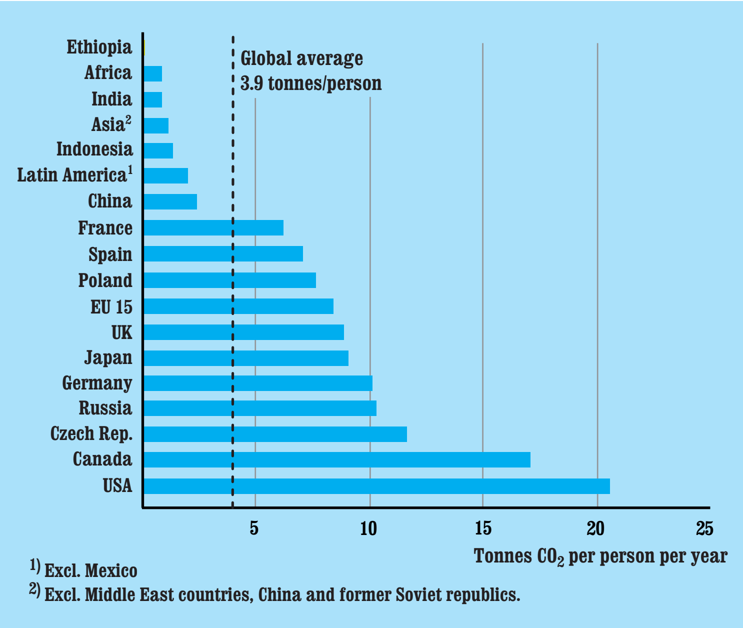


FIGURE 4.5. Emissions of fossil carbon dioxide per person per year in different countries and regions. Tonnes of CO_2 per capita, data for the year 2000. (CO_2 Emissions from Fuel Combustion 1971–2000. 2002 Edition. International Energy Agency, Paris, France.)

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%**

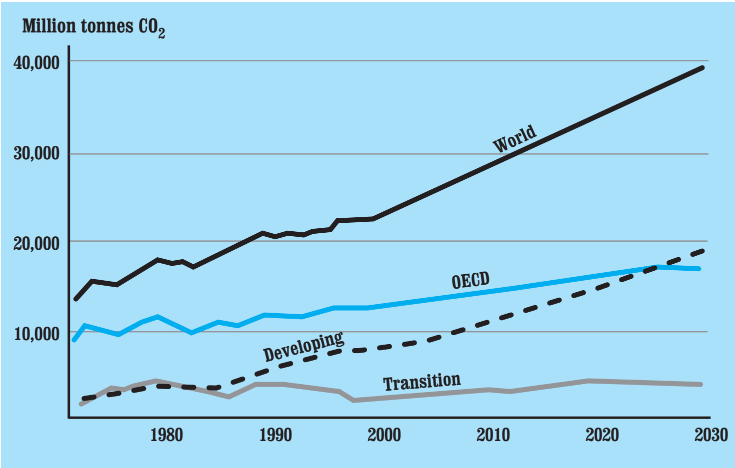


Figure 4.6. It is important that all the countries in the world are involved in future negotiations on limiting emissions of greenhouse gases. The graph shows the expected trend for energy-related emissions of carbon dioxide under business as usual. (Beyond Kyoto. Energy Dynamics and Climate Stabilisation.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

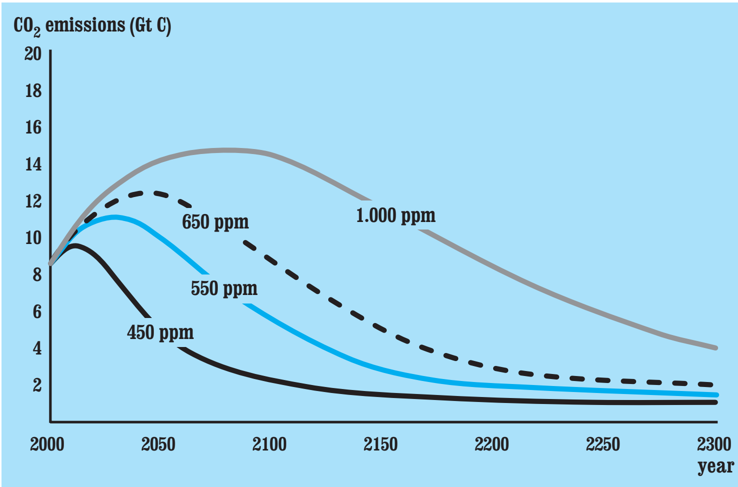


FIGURE 4.7. If emissions of carbon dioxide develop as shown by the lines in the diagram, the concentration of carbon dioxide in the atmosphere will stabilize at the level indicated in the relevant graph. The effect in terms of mean global temperature rise is shown in table 4.3. (Climate Change 2001: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

5

Acidification

Acidification as an environmental problem was first given serious attention in the late 1960s. However, its effects began to appear long before that, and we now know that emissions of acidifying substances cause serious damage to nature, to ourselves and to our built environment.

This chapter explains the chemical changes that take place in soil and water when they are acidified, the various causes, why some areas are affected while others are not, how much emissions must be reduced, and whether the affected areas can recover.

The effects of acidification on nature and people are described in chapters 2 and 3 respectively.

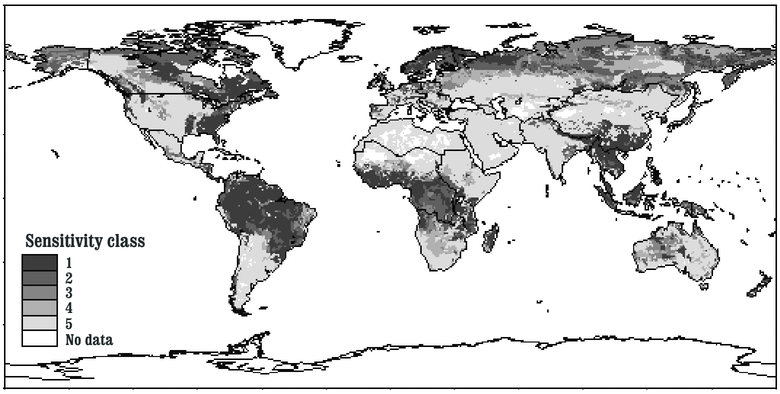


FIGURE 5.1. Sensitivity to acid deposition around the world. The darker the shade on the map, the greater the sensitivity to acid deposition. (Global assessment of acidification and eutrophication of natural ecosystems. Report UNEP/DEIA&EW/TR.99-6 and RIVM 402001012. AF Bouwman and DP van Vuuren, 1999.)

WHICH AREAS ARE AFFECTED?

There are two main factors that determine which areas are affected by acidification:
1. The amount of acid deposition.
2. The resistance of the soil.

When soil has a high content of easily weathered minerals it can absorb a relatively large amount of acid deposition without becoming acidic. But if the minerals in the soil do not weather easily, as is the case in large parts of the Scandinavia peninsular for example, there is little natural resistance. If the resistance of the soil is low then lakes are also sensitive to acid deposition.

Figure 5.1 is a preliminary survey of the sensitivity of ecosystems on a worldwide scale. In those cases where high sensitivity is combined with a high level of acid deposition – as in parts of Europe, North America, east Asia, West Africa and

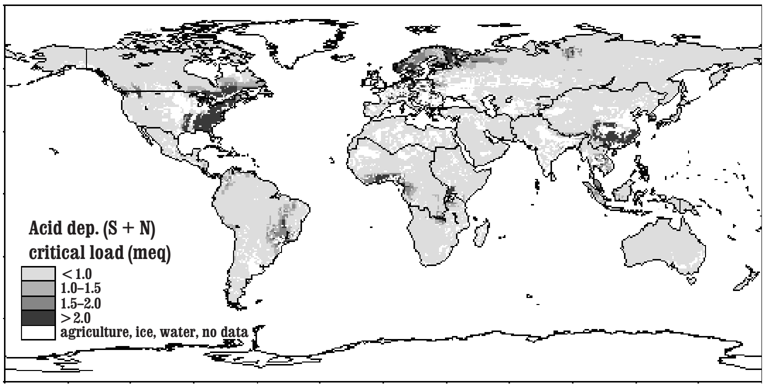


FIGURE 5.2. Areas where the critical loads for acid deposition on land-based ecosystems is exceeded. Where the ratio is higher than 1, the deposition of acid pollutants is greater than the soil can tolerate in the long term, i.e. the critical limit is exceeded. Deposition data from 1992. (Global assessment of acidification and eutrophication of natural ecosystems. Report UNEP/DEIA&EW/TR.99-6 and RIVM 402001012. AF Bouwman and DP van Vuuren, 1999.)

northern parts of South America – acidification problems occur sooner or later.

Figure 5.2 shows the places in the world where the critical loads for acid deposition are exceeded. We will come back to the situation in Europe later in this chapter.

SOIL ACIDIFICATION

Soil is acidified slowly as a result of natural processes. This has been going on since the end of the last ice age, but has been greatly accelerated by forestry and acid deposition. The most serious consequences can be summarized in three points:

1. Plant nutrients are leached out. Nutrients that are important to plants, particularly base cations (mainly magnesium, potassium and calcium), are leached out by the added acid. This, combined with lower pH levels, can lead to the displacement of sensitive species of plants. Growth in the forest can be affected by the reduction in the availability of nutrients, although it does seem that coniferous trees in symbiosis with mycorrhizal fungi and bacteria can speed up weathering to some extent themselves if needed. Several studies have shown that, over the last 50 years, forest land in southern Sweden has lost around half its reserves of base cations that are available to plants.

2. Toxic metals are freed. When soil is acidified it increases the concentration of free aluminium ions in the water that is in the soil, and these are potentially toxic to the root systems of plants. The mobility of many heavy metals also increases when soil becomes more acidic (see figure 5.3). Perhaps the most serious consequence of the higher metal concentrations is their negative effect on many of the decomposers that live in the soil.

3. Phosphates become bound. Increasing levels of dissolved aluminium also affect plants indirectly. The "released" aluminium ions are able to bind the vital nutrient phosphorus (in the form of aluminium phosphate) and make it less accessible to plants. The shortage of phosphate is aggravated by the fact that decomposition in the soil slows down under acid

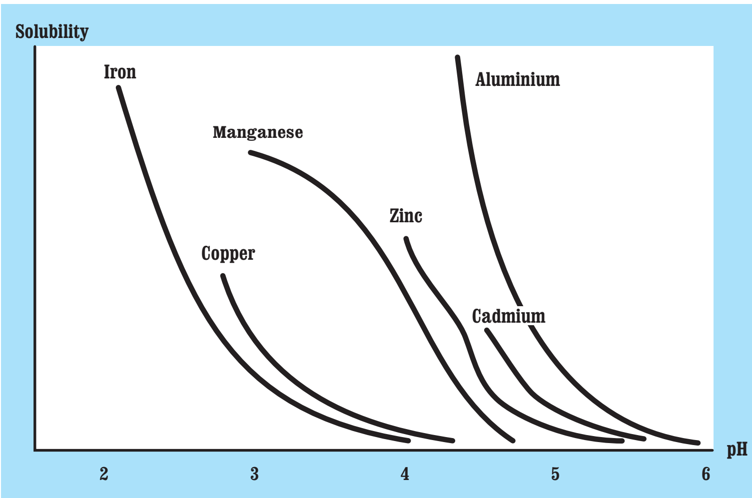


FIGURE 5.3. Release of metals from mineral soil at different pH levels.

conditions. In addition to phosphate, certain important micro nutrients – such as molybdenum, boron and selenium – also become less accessible to plants when soil is acidified.

Until the 1980s most soil researchers believed that the soil could hardly be affected by acid deposition. Later studies show a different picture however. When earlier soil sampling trials were repeated in southern Sweden it was found that the pH level had fallen by between 0.3 and 1.0 pH units in just a few decades. Similar results have been obtained in Austria and Germany, as well as other places. This reduction has not just taken place in the upper layers of the soil, but deep down in the mineral soil, which indicates that the main cause is acid deposition.

Liming as a countermeasure

The acidification process can be countered by liming. This raises the pH level and tops up reserves of exchangeable cations (increases the base saturation), while also reducing the concentration of free aluminium ions. Lime acts like a filter in the upper layer of the forest soil, where it can capture and neutralize future acid deposition before it has time to leach out base cations and/or dissolve toxic aluminium.

The effect of the added lime penetrates slowly into the soil, at roughly one centimetre per year, but on the other hand persists for a long time in the future. The liming of soil can therefore help counter the acidification of surface water in the long term. A dosage of 3–5 tonnes of lime per hectare is estimated to protect soil from acidification for 20–30 years with current levels of acid deposition in southern Sweden.

ACDIFICATION OF SURFACE WATER

A small proportion, perhaps one tenth, of the water in lakes reaches them in the form of precipitation directly on the water surface. The rest comes via the land. The quality of surface water therefore depends to a large extent on the characteristics of the surrounding land.

The natural buffering system in lakes and waterways is provided by bicarbonate (HCO_3^-), that reaches the water from the surrounding land. Bicarbonate is released by the weathering of minerals on land and during the decomposition of organic matter. Lakes and waterways that are surrounded by easily weathered types of soil or cultivated land are constantly fed with significant amounts of bicarbonate and therefore generally have good resistance to acidification. However, water that is surrounded by soil that does not weather easily usually has limited buffering capacity, and acidification can occur if acid is added.

The chemical limits that are commonly used to classify water as acidic are a pH value below 6.2 and an alkalinity (buffering capacity) of less than 0.05–0.10 milli-equivalents of HCO_3^- per litre. Acidified surface water is water in which the pH and/or alkalinity have fallen significantly below pre-industrial levels. Lakes that have pH levels lower than 5.6, and zero or insignificant alkalinity (less than 0.02 meq/l) are classified as very acidic.

One change that occurs in acidified lakes that is important for biological life is that the concentration of inorganic aluminium rises. In non-acidified water the levels of inorganic aluminium are generally very low, but when the pH drops below 5.5 the level increases sharply. The aluminium ions come mainly from the surrounding soil, where they are released when the soil is acidified. The damage to fish stocks that occurs in acidic water is largely due to elevated levels of toxic aluminium compounds.

It is not just chemical measurements that demonstrate the presence of acidification. One visible sign is that the water becomes clearer. This is mainly because the humic substances that normally colour the water precipitate out and fall to the bottom when the water becomes acidic. Decomposition slows down, which means that leaves and other organic matter often collect on the lake beds. As already mentioned, a number of biological changes also take place, see chapter 2.

Many acidic lakes

At present, acidification damage to flora and fauna in lakes and waterways has mainly been reported in Norway, Sweden, Finland and Scotland, and in parts of eastern North America.

The Scandinavian peninsula is dominated by hard types of rock that are slow to erode, which means that the environment is sensitive to acidification. In the worst affected parts of Sweden more than half the lakes have suffered damage.

A survey in 1990 estimated that around 14,000 Swedish lakes out of the 85,000 that are larger than one hectare were acidified. Without liming, this number would have been 17,000. In the worst affected regions in southern and south-west Sweden over half the lakes had suffered damage through acidification. At the same time it was estimated that around one third of the country's 300,000 kilometres of waterways were markedly acidified.

A co-ordinated study of the lakes in several north European countries was carried out in 1995, but since new methods were used it is not possible to compare this data with the figures for 1990. The 1995 study does however indicate that the average resistance of the lakes to acid deposition (alkalinity) is slowly improving – which means that a slow process of recov-

pH AND BUFFERING

A defining property of acids is their ability to release hydrogen ions (H^+). Acidification is the effect of increasing the concentration of hydrogen ions. The concentration of these ions in a solution is used as a measure of acidity, and is normally expressed in the form of a pH value. A low pH means a high concentration of hydrogen ions and hence an acid solution. Water that is neither acid or basic is called neutral and has a pH of 7. The pH scale is logarithmic, which means that the pH drops by one unit when the concentration of hydrogen ions increases by a factor of ten. A solution with a pH of 6 is ten times more acidic than one with a pH of 7. At a pH of 5 the solution is a hundred times more acid than at pH 7.

There are natural processes that counteract the addition of acid. These processes, known as buffer reactions, are able to neutralize the acid that is added. In a lake it is the availability of bicarbonate (HCO_3^-) that determines the buffering capacity. This availability depends largely on the characteristics of the surrounding soil. Soil has several buffering systems, but the most important in the long term is the weathering of various minerals.

ery has begun. This is presumably a result of the halving of sulphur deposition since the early 1980s.

Acid shock

If the flow of water is rapid it minimises the contact between water and soil. This means that the minerals in the soil do not have time to neutralize the acidic substances in the water, with the result that the pH can drop rapidly over a short period. This can even happen in areas with limestone bedrock, which would normally be considered to give protection against acidification problems.

These so-called acid shocks happen when snow thaws in spring and occasionally when there is heavy autumn rain, and they mostly affect small waterways but also lakes. They last for perhaps just a couple of days or a week, but can still have considerable effects on ecosystems – perhaps just as serious as if the water was acidified all year round. They also occur at a time when many fish are spawning or when the young have recently hatched, which makes them especially vulnerable. They can even lead to the death of large numbers of fish.

Liming of lakes and waterways

If finely ground limestone ($CaCO_3$) is added to water it raises the pH and increases resistance to acidification. The liming of lakes and waterways is carried out on a large scale in Sweden and Norway. In Sweden around 7500 lakes and 11,000 kilometres of waterways are now limed each year. Annual Swedish grants for liming during the 1990s have been around 150–200 million kronor (approx. 20 million euros), while the figure for Norway is around 100 million kroner.

The goal of liming is partly to restore acidified lakes and waterways, and partly to increase the resistance of the lakes and waterways that are at risk but not yet affected. Because the water in a lake is constantly being replaced, liming must be repeated every few years. In running water, lime dosing equipment is used to continuously add lime to the water. In order to raise the pH in small waterways, and to increase the duration of the effect when lakes are limed, part of the lime is often spread on wetlands in the catchment area. This causes damage to plants, including killing off bog moss, but the area is limited and the benefits are generally considered to outweigh the harm.

WHAT CAN NATURE TOLERATE?

For a period of about ten years from middle of the 1980s a great deal of research was put into estimating the amounts of pollutants that nature can tolerate without harming it. These limits to what "nature can tolerate" are called critical loads.

The international definition of critical load for acidification is *"the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function"*. Although the definition leaves some room for interpretation, its foundation is that the limits must be set for the most sensitive organisms and ecosystems. For practical reasons the limits are however based on key organisms in different types of ecosystems. In contrast to medical limit values, for example, these critical loads do not include any safety margins.

Forest soil

In forest ecosystems, trees are used as the key organism, and the measurement used to decide how much acidification a tree can "tolerate" is the ratio between base cations and aluminium ions in soil water. Base cations are released during the weathering of soil, as well being supplied by airborne deposition. Aluminium ions are brought into solution by acid deposition. As long as weathering is able to keep this ratio higher than 1, i.e. when there are more base cations available to plants than aluminium ions, the critical limit is not exceeded.

The reason for setting the threshold at 1 is based on a large number of studies that have shown that trees can suffer root damage when the ratio falls below this value. This choice of limit value has been criticized, partly because most of the studies were carried out on young trees in a laboratory environment, so there is some uncertainty about the way that trees react in the considerably more complex conditions that exist in different types of forest soil.

Weathering is key factor

The most important factor in determining the critical load for acid deposition is the weathering ability of the minerals in the soil. The faster they weather, the more base cations are released and the more acid deposition can be neutralized. The most vulnerable soils are in areas where the bedrock is dominated by gneiss, granite and other slow-weathering types of rock. Here, the limit for forest soils is often less than 200 hydrogen ion equivalents per hectare per year. This corresponds to 3 kilograms of sulphur, assuming that sulphur is the only acidifying agent. In areas with rock types that weather more readily, such as greenstone and, even better, limestone, the soil can tolerate considerably higher levels. See table 5.1.

However, it is not just the chemical properties of the soil that decide how much acid deposition can be neutralized. Vegetation, soil depth, the size of soil particles, temperature

TABLE 5.1. Critical loads for acidification of forest soils. (Critical loads for sulphur and nitrogen. P. Grennfelt & J. Nilsson [Eds.] Nordic Council of Ministers, Report 1988:15. Copenhagen, 1988.)

Class	Minerals controlling weathering	Total acidity, H^+ eq/ha · yr	Equivalent amount of S, kg/ha · yr
1	quarts, k-feldspar	<200	<3
2	muscovite, plagioclase, biotite (<5 %)	200–500	3–8
3	biotite, amfibole (<5 %)	500–1,000	8–16
4	pyroxene, epidote, olivine (<5 %)	1,000–2,000	16–32
5	carbonates	>2,000	>32

and the deposition of base cations also affect the buffering capacity. Long contact time and a large contact area between soil particles and the water that is supplied are favourable for neutralization. Shallow, coarse-grained soils can therefore tolerate considerably less deposition than deep, fine-grained soils.

Low temperatures lead to increased sensitivity, since they slow down weathering in the soil and plant growth – the latter reduces nitrogen uptake and increases the risk that nitrogen will have an acidifying effect. A warmer climate could possibly increase resistance to acid deposition, since it would speed up the weathering processes. A number of other factors also come into play however, so the net effect is difficult to predict.

The map of Europe (figure 5.4) is an attempt to weigh together all the factors that influence the tolerance of soils to acid deposition.

Lakes and waterways

The critical loads for surface waters and groundwater generally follows that of the soil, since sensitivity is closely linked to soil properties. The critical limits for lakes are generally given as a pH of 6.0 and a buffering capacity – or acid neutralizing capacity, ANC – of 0.02 milli-equivalents per litre. If conditions become more acidic than this we know that fish and other sensitive aquatic organisms are likely to suffer harm.

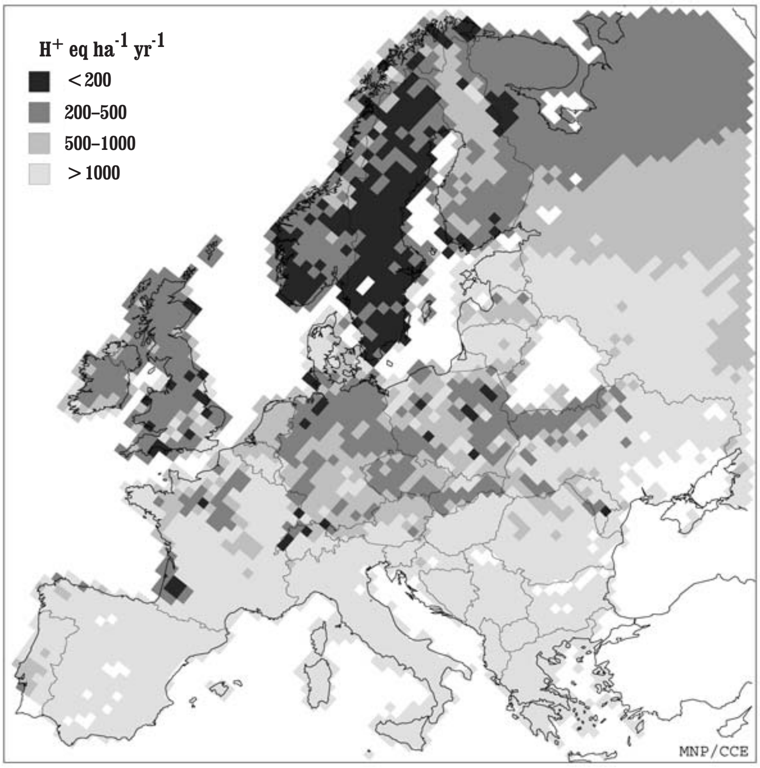


FIGURE 5.4. Critical loads for acidity in Europe. The map shows the deposition of hydrogen ions that forest soils and surface water can tolerate without being acidified. At each load level 95 per cent of the ecosystems in the relevant square are protected. (Max Posch, Coordination Centre for Effects, RIVM, Netherlands, 2003.)

Europe yesterday, today and tomorrow

If acid deposition exceeds the critical limit value, acidification damage will occur sooner or later. Calculations show that the critical limit value for acid deposition was exceeded over approximately 207 million hectares of European ecosystems in 1980.

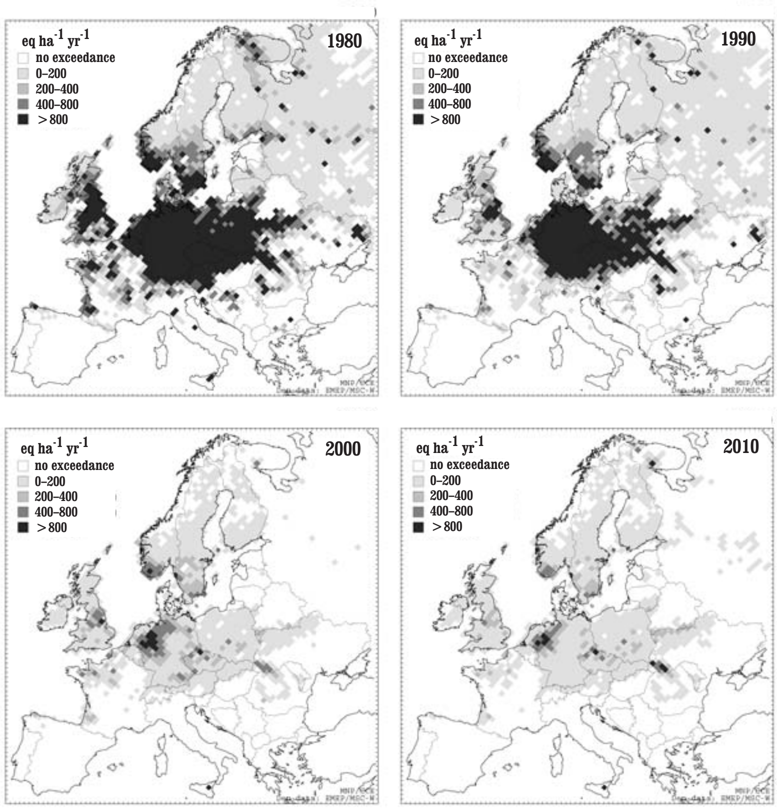


FIGURE 5.5. Areas where the critical loads for acidity were exceeded in 1980, 1990 and 2000, and the forecast for 2010. The latter is based on all countries meeting their undertakings in the Gothenburg Protocol. (Max Posch, CCE/RIVM, the Netherlands, 2003.)

Emissions have fallen since then however. New, still preliminary calculations at a higher resolution indicate that the exceeded area had shrunk to about 38 million hectares by 2000. If all countries that have signed the Gothenburg Protocol do as promised (see table 9.2) and if emissions in non-signatory countries develop as officially projected this area will stabilize at 38 million hectares in 2010 – less than one fifth of its size in 1980. The four maps in figure 5.5 illustrate the progress.

It is important to note that acidification damage in an area can last for a long time, even when the critical limit is no longer exceeded.

CAUSES OF ACIDIFICATION

In some areas the acidification of soil and water is a natural process that has been going on ever since the last ice age. But natural acidification is a slow process, and by far the most dominant cause of today's problems is the airborne deposition of acidifying substances – sulphur, nitrogen oxides and ammonia – as well as the harvesting of biomass. The contributions made by the various components vary, depending on local circumstances.

Sulphur deposition, in the form of sulphuric acid, is generally the most important. Because sulphate ions, which are negatively charged, are only taken up by vegetation or retained in the soil in small amounts, the majority remain in the percolating water and carry with them the positively charged base cations. On their way through the soil the hydrogen ions that accompany sulphate deposition are replaced with base cations or react with minerals in the soil. Some of the hydrogen ions remain in the soil and acidify it. Others pass with the sulphate and base cations into the groundwater and surface water, and acidify these too.

In the case of **nitrogen pollutants**, which originate from emissions of nitrogen oxides and ammonia, the situation is more complex, since they only cause acidification under certain circumstances, see factfile on next page. The collective contribution of nitrogen deposition to acidification varies a great deal with the area and time. In Sweden, the contribution of nitrogen deposition to acidification has been estimated at 5–30 per cent, with the highest value in the south. In parts of southern Norway, where the soil is very shallow, a large proportion of nitrogen deposition passes straight through without being taken up by vegetation, and there the contribution of nitrogen deposition to acidification is estimated as 40 per cent.

The harvesting of biomass, i.e. normal forestry operations, also leads to soil acidification, see page 101.

NITROGEN CAUSES ACIDIFICATION – SOMETIMES...

Because nitrogen in a form that is available to plants is a scarce resource in almost all ecosystems, plants quickly take up most nitrogen that is deposited.

If the nitrogen is deposited as nitric acid (HNO_3) the plants take up the nitrate ion (NO_3^-) and in exchange release another negatively charged ion, usually OH^- or HCO_3^-, which neutralizes the hydrogen ion from the nitric acid. When this happens the nitric acid does not therefore contribute to acidification (although it does contribute to eutrophication).

If the nitrate ion is not taken up by plants it can be leached out, and neutralization does not take place. In this case the deposition is acidifying. This can happen when the activity of the ecosystem is low, e.g. in winter, or when large amounts are deposited in a short time, e.g. when snow thaws, but also if the plants are unable to take up all the nitrogen that is supplied. The surplus can then be leached out. This phenomenon has been observed in areas with a high nitrogen load and soil that is relatively poor in nutrients, for example in parts of the Netherlands and northern Germany, and locally in south-western Sweden and southern Norway.

Ammonium ions (NH_4^+) that are taken up by vegetation cause acidification, since hydrogen ions are generally released in exchange. The situation is worse if the ammonium ion is first converted into nitrate and then leached out. Nitrification, the microbiological conversion to nitrate, is an acidifying process that releases hydrogen ions. Nitrification also increases the risk of nitrogen leaching, since nitrate is more mobile than ammonium in the soil. Nitrification is favoured by relatively high pH levels and if more ammonium is supplied than the vegetation is able to cope with immediately.

Sulphur emissions

Coal and oil consist of the remains of organisms that were deposited on the beds of lakes and seas several hundred million years ago. These were then slowly transformed into fossil fuels. Because all living matter contains sulphur this element is later released when coal and oil are burned. The amount of sulphur that a given fuel contains depends on when and where it was formed. Low-sulphur oil from the North Sea, for instance, contains only a few tenths of a per cent of sulphur, while some types of coal from Spain may have a sulphur content of between five and ten per cent. Fossil gas is practically sulphur-free.

In addition to the burning of coal and oil, some industrial processes, such as roasting of sulphur-containing ores, also make a considerable contribution to sulphur emissions.

During combustion the sulphur in the fuel reacts with the oxygen in the air to form sulphur dioxide gas (SO_2), the fate of which is described later in this chapter.

The gas itself is toxic to both people and plants. The critical level for forest trees has been determined as 10–20 micrograms per cubic metre ($\mu g/m^3$) as an annual mean value. The most sensitive organisms are believed to be certain lichens, which can be damaged by annual mean levels as low as 10 $\mu g/m^3$. In the 1970s and 1980s the critical levels were exceeded by a wide margin, especially in central and eastern Europe. In Europe today these levels are only exceeded in certain hot-spot regions.

Sulphur dioxide can also contribe to the formation of particles, see chapter 3.

Sulphur emissions worldwide

Annual worldwide emissions of sulphur produced by man were estimated at just over 70 million tonnes (expressed as S) in 1990. The global trend is upwards, mainly due to increased use of fossil fuels in many Asiatic countries. In East Asia, where there is rapid industrial expansion, it is expected that current emissions will double within a few decades if no countermeasures are taken.

Globally, it is calculated that the sulphur emissions produced by mankind are around three times higher than the natural emissions from volcanoes, bacterial production of dimethyl sulphide in the sea, anaerobic decay, etc. Over northern Europe, the eastern US and parts of China, emissions from human activities are around ten times higher than natural emissions.

Sulphur emissions in Europe

Anthropogenic emissions of sulphur rose sharply from the end of the Second World War until the end of the 1970s. Between 1980 and 2000 emissions from land-based sources in Europe fell by 70 per cent – from 53 to 15 million tonnes of sulphur dioxide a year (see table 5.2).

TABLE 5.2. European emissions of sulphur dioxide (SO_2), nitrogen oxides (as NO_2), and ammonia, 1990 and 2000. Unit: 1000 tonnes a year. (EMEP, 2003.)

	SO_2		NO_x (as NO_2)		Ammonia	
	1990	2000	1990	2000	1990	2000
Austria	79	38	204	196	52	54
Belgium	362	165	334	329	99	81
Denmark	180	28	277	209	133	104
Finland	260	74	300	236	38	33
France	1323	654	1897	1441	779	784
Germany	5322	638	2728	1584	736	596
Greece	493	483	290	321	79	73
Ireland	186	131	118	125	112	122
Italy	1651	758	1938	1372	466	437
Luxembourg	15	3	23	17	7	7
Netherlands	202	92	570	413	232	152
Portugal	273	274	272	385	106	102
Spain	2102	1484	1207	1335	327	386
Sweden	106	57	334	252	54	57
United Kingdom	3719	1188	2759	1737	341	297
Sum EU-15	**16273**	**6067**	**13255**	**9952**	**3561**	**3285**
Albania	72	58	24	29	32	32
Bosnia & Herzeg.	482	419	79	55	31	23
Belarus	637	143	285	135	142	142
Bulgaria	2008	982	361	185	144	56
Croatia	180	58	88	77	37	23
Cyprus	46	50	18	23	4	4
Czech Republic	1881	264	544	321	156	74
Estonia	252	95	68	41	24	9
Hungary	1010	486	238	185	124	71
Iceland	24	27	26	28	3	3
Latvia	95	17	80	35	44	12
Lithuania	222	43	158	48	109	50
Norway	52	27	224	224	23	25
Poland	3210	1511	1280	838	508	322
FYR Macedonia	107	105	39	30	17	16
Moldova	265	12	100	17	49	25
Romania	1311	912	546	319	300	221
Russia	4671	1997	3600	2357	1191	650
Serbia & Monten.	508	387	211	158	90	79
Slovakia	542	124	215	106	63	30
Slovenia	196	96	63	58	24	19
Switzerland	42	19	154	96	72	68
Ukraine	2783	1029	1097	561	729	358
Sum non-EU	**20596**	**8861**	**9534**	**5926**	**3916**	**2312**
Sum Europe	**36869**	**14928**	**22789**	**15878**	**7477**	**5597**
Sum Int. shipping	2829	2829	3991	3991	–	–
Sum Eur.+ ships	**39698**	**17757**	**26780**	**19869**		
Turkey	1590	2112	644	951	321	321

There are several reasons for this fall. Some countries, such as Germany and Sweden, have focused deliberately on emission control. In other countries the reduction has come about because it was economically advantageous to switch from coal to gas (UK), or because of a sharp fall or change in the nature of industrial production (several countries in central and eastern Europe). There are also countries where emissions have continued to rise in recent years – in Turkey for instance they have doubled between 1980 and 2000.

A major proportion of emissions comes from large combustion plants. At the end of the 1990s it was calculated that the hundred largest individual point sources were responsible for over 40 per cent of the total emissions of sulphur dioxide from land-based sources in Europe. 80 of these 100 sources were power plants – almost all coal-fired.

At the same time as emissions from land-based sources have fallen significantly in recent decades, emissions from international shipping have increased. In 2000 the annual emissions from international shipping in the seas surrounding Europe – the Baltic Sea, the North Sea, the north-eastern Atlantic, the Mediterranean and the Black Sea – amounted to 2.8 million tonnes of sulphur dioxide.

Nitrogen emissions

Air consists of four-fifths nitrogen gas (N_2). However, nitrogen gas can only be exploited as a nutrient by nitrogen-fixing bacteria, and indirectly by plants that live in symbiosis with such bacteria (e.g. legumes). Most plants take up nitrogen in the form of nitrate (NO_3^-) or ammonium (NH_4^+), or in some cases in organic form (amino acids).

When air is heated to high temperatures, as in combustion, the nitrogen and oxygen in the air react to form **nitrogen oxides**. Nitrogen oxides, NO_x, is the collective name for nitrogen monoxide, NO, and nitrogen dioxide, NO_2. Nitrous oxide, N_2O (laughing gas), is also a nitrogen oxide, but it is usually described separately and is not included in the emission figures for nitrogen oxides given in this book.

The amount of nitrogen oxides that is formed depends mainly on the combustion temperature – the higher, the more nitrogen oxides are formed. The nitrogen content of the fuel, where present, also contributes to formation.

The main source of **ammonia** emissions is manure. The amount that evaporates depends primarily on how the manure is handled during storage and spreading.

In addition to acidification, emissions of nitrogen oxides and ammonia also contribute to eutrophication, see chapter 6. Nitrogen oxides can also cause health problems and damage to plants, as well as contributing to the formation of particles and ground-level ozone, see chapters 2 and 3.

The critical level for plant damage caused by **nitrogen oxides** has been set at 30 µg/m^3 as an annual mean value. This level is usually exceeded in urban environments and near roads with heavy traffic. The corresponding critical level for **ammonia** is 8 µg/m^3 as an annual mean. This level is only exceeded locally in areas with extensive livestock farming and agriculture.

Nitrogen emissions worldwide

In most countries the main sources of emissions of **nitrogen oxides** are the combustion of coal and oil in power stations and emissions from vehicles. Manmade emissions worldwide are estimated at around 35 million tonnes a year, calculated as nitrogen (N). These emissions are largely due to the combustion of fossil fuels and are concentrated in the industrialized parts of the world, where they are many times higher than naturally occurring emissions. The actual magnitude of the latter is however difficult to give with any precision.

By far the largest source of **ammonia** emissions is livestock farming. Ammonia evaporates from manure during storage and when it is spread on fields. Worldwide emissions originating from human activity were estimated to be 43 million tonnes a year in 1990, calculated as nitrogen (N).

Nitrogen emissions in Europe

Emissions of **nitrogen oxides** from land-based sources in Europe rose slightly between 1980 and 1990. Since then they have fallen from 23 million tonnes a year in 1990 to barely 16 million tonnes a year in 2000, a reduction of just over 30 per cent, see table 5.2. A significant source that is not included in the figures above is international shipping in the waters around Europe. These emissions are rising and in 2000 amounted to 3.9 million tonnes a year.

For Europe as a whole, roughly 50 per cent of nitrogen oxides come from road traffic, 20 per cent from combustion plants and 15 per cent from other mobile sources (contracting machinery, etc.).

90 per cent of **ammonia** emissions in Europe come from agriculture and they are highest where livestock farming is most intensive, e.g. in the Netherlands, Denmark and northern Germany. There is a shortage of information about ammonia emissions in many countries, but according to statistics emissions have fallen by 25 per cent between 1990 and 2000 – from 7.5 to 5.6 million tonnes per year, see table 5.2.

Conversion, transport and fallout

Most **sulphur** is emitted in the form of sulphur dioxide (SO_2). As a result of chemical reactions in the air this sulphur dioxide is then converted into sulphuric acid (H_2SO_4). The sulphuric acid takes the form of droplets or small particles. The sulphuric acid molecule dissolves in water to form two hydrogen ions (H^+) and one sulphate ion (SO_4^{2-}).

More than 90 per cent of emissions of **nitrogen oxides** consist of nitrogen monoxide (NO). This is converted relatively quickly in the air into nitrogen dioxide (NO_2). Nitrogen dioxide can then be converted into nitric acid (HNO_3), which mostly ends up on particles and in droplets of water. Some is deposited in vapour form. Nitric acid dissolves in water to form hydrogen ions (H+) and nitrate ions (NO_3^-).

The **ammonia** that is released can form ammonium ions (NH_4^+) on contact with water vapour in the atmosphere, which raises the pH level of rainwater (the ammonia bonds with a hydrogen ion and therefore acts as a base). However, this pH raising effect disappears if and when the ammonium ion is taken up by vegetation, since the plants give off acidifying hydrogen ions in exchange for ammonium ions. The ammonium ion can also be converted into nitrate by bacteria in the soil, a process that is also acidifying.

Long-range transport

Sulphur compounds and oxidized nitrogen compounds are among the substances that can be transported long distances, up to thousands of kilometres in the air. In many countries the majority of acid deposition actually comes from other countries.

Compared with sulphate and nitrate, ammonium tends to be deposited closer to the source of emissions – it is estimated that half of it falls within a radius of one hundred kilometres. Some ammonia can however react with sulphuric acid in the air to form small particles (ammonium sulphate), which can be transported very long distances. The average transport distance is still shorter for ammonium than for sulphates and nitrates, but all three are important in the long-range transport of air pollutants across Europe.

Imports and exports

The information on the import and export of pollutants that is given here comes from the European Monitoring and Evaluation Programme (EMEP), and is based on a model in which the whole of Europe is divided into a grid system. The size of each square was originally 150 × 150 kilometres, but it is now 50 × 50 kilometres. Each country contributes information about the level of emissions, square by square. With the aid of air chemistry models and meteorological data it is then possible to calculate how the emissions spread and where fallout occurs.

All European countries import and export air pollution. Depending on the level of the emissions and the predominant wind direction some are net exporters, i.e. more pollution leaves the country than falls on it, while others, such as Sweden and Norway, are net importers. Sweden's own contribution to sulphur deposition across the country amounted to just 7 percent in 1998 – more than nine-tenths came from abroad.

Around 60 per cent of the nitrogen deposition over Sweden comes from emissions of nitrogen oxides, and 40 per cent

FIGURE 5.6. The origins of acid deposition over Sweden. (EMEP Report 1/2000.)

SULPHUR DIOXIDE
(1998, thousands of tonnes)

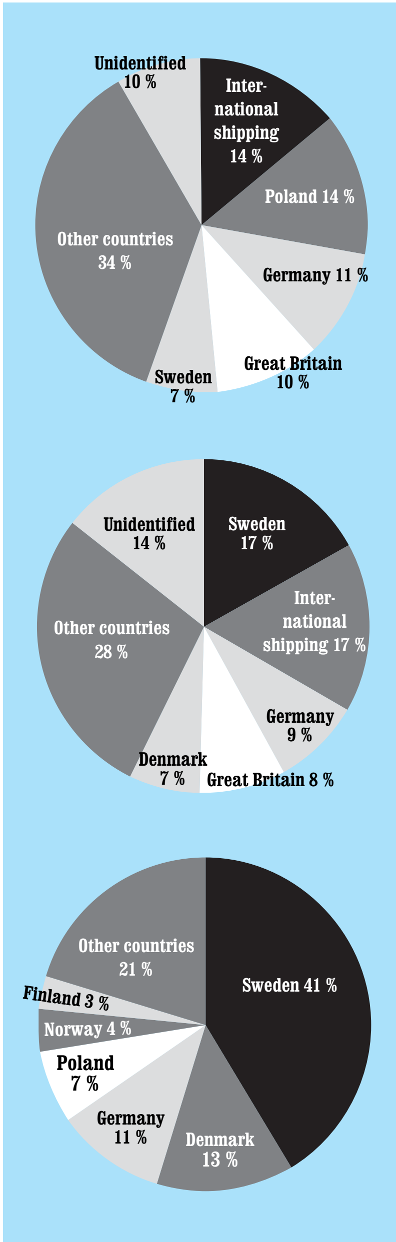
Total deposition over Sweden: 144,000 tonnes S. Imported from other countries: 133,000 tonnes S. (Exported Swedish emissions: 14,000 tonnes S.)

NITROGEN OXIDES
(1998, thousands of tonnes)

Total deposition over Sweden: 107,000 tonnes N. Imported from other countries: 89,000 tonnes N. (Exported Swedish emissions: 60,000 tonnes N.)

AMMONIA
(1998, thousands of tonnes)

Total deposition over Sweden: 63,000 tonnes N. Imported from other countries: 37,000 tonnes N. (Exported Swedish emissions: 23,000 tonnes N.)



from ammonia. The proportion of nitrogen oxides that were imported was 83 per cent. Ammonia does not travel such long distances, and a larger proportion of the ammonia that was deposited therefore came from domestic sources – 41 per cent in 1998. The countries that contribute the most of each pollutant are shown in figure 5.6.

Pollutant fallout

Because European emissions of sulphur dioxide have fallen since the start of the 1980s the deposition of sulphur has also decreased. Reductions of 50 per cent have been reported from western Sweden and southern Norway since 1989. The greatest reduction has been in dry deposition. Emissions of nitrogen compounds have also fallen in Europe during the 1990s, but no major change has been seen in deposition levels so far.

Harvesting of biomass

While they are growing the trees in the forest take up more positive than negative ions. The positive ions include several important nutrients, e.g. Ca^{2+}, Mg^{2+} and K^{+}. To avoid becoming electrically charged the trees exchange these for hydrogen ions, which are also positively charged, but acidifying. The soil therefore becomes more acidic when the forest is growing. But when the trees eventually die and decompose the process is reversed. In a system that is left to its own devices the end result is no significant acidification.

The harvesting of biomass, however, means that the soil remains acidified. The removal of nutrients – and hence the residual acidity – is roughly doubled if branches and twigs are harvested rather than just the trunks of trees. But even normal forestry operations often remove more from the soil's reserves of base cations than weathering is able to release. And the more that is harvested, the greater the acidification it causes.

This impoverishment of the soil has increasingly been brought to attention in countries such as Sweden in recent years. It has been proposed that the removal of nutrients along with biomass must be compensated for, for example by spreading wood ash, possibly in combination with liming. There are critics of this approach, however. Swedish nature-conservation organizations believe that forestry should be carried out on nature's terms – they do not want to see an "agricultural" system in which nutrients must be added on a regular basis.

CAN NATURE RECOVER?

Thanks to reductions in the deposition of acidifying substances, a slow improvement can now be seen in the water chemistry of many acidified lakes and waterways in Sweden. The recovery process that can be expected in the future is being studied closely. In the early 1990s Swedish researchers took a practical approach to this question by building a roof over an entire catchment area on the Swedish westcoast.

The 6300-square-metre roof trapped all the precipitation and water from the tree canopy, while an equal amount of unacidified water was spread by a sprinkler system under the roof. This led to a 95 per cent reduction in acid deposition. As a result, the amount of acid substances that was added was no

A 6300-square-metre roof has halted acidification in a small catchment area at Lake Gårdsjön on the west coast of Sweden. Measured changes in soil chemistry and run-off water have helped researchers to model the future.

greater than the soil was able to neutralize – i.e. the critical load was not exceeded. This is an essential requirement for sustainable recovery.

Once the roof was in place a number of major changes were observed within a short time. The outflow of sulphur and toxic aluminium compounds from the area into surface water dropped markedly after a few years. But the pH of the run-off water remained unchanged and the concentration of base cations remained low. This is seen as a sign that the soil is in the process of recovery – the buffer of exchangeable ions that was drained by acid deposition is now slowly being replenished.

But this also means that the situation remains critical for the organisms that live in the surface water. The soil reacts slowly, and the effects of reducing deposition will only benefit the aquatic organisms once the soil has made a decent recovery.

Along with information about measured deposition from some twenty locations in southern Sweden and existing knowledge about how the soil works, the results of the roof project have been used to build up a mathematical model. This has been used to make forecasts of likely developments over coming decades.

The conclusion of researchers is that if sulphur deposition is reduced by 70 per cent – in other words a slightly smaller improvement than has been agreed internationally for the year 2010 – the level of acidification will fall in most places. However, this reduction is not generally large enough to allow the soil to recover, i.e. to regain its own resistance to acid deposition.

In the poorest soils, where acidification has already reached an advanced stage, reductions in emissions are needed that are considerably greater than those already agreed. And even with such a scenario it may take a long time to repair the damage that decades of acid deposition have already caused. Because of the depth and composition of the soil this could take centuries. In other parts of the country, where there has been less overall acid deposition, recovery ought to be faster.

In summary it may be worth pointing out that even if the soil and surface water are gradually able to recover their original chemical identity it is not certain that the ecosystems will be restored. The extent to which this happens depends, among other factors, on the ability of various species to spread. And some things will never be the same. For example the impoverishment of genetic diversity within species that has been caused by acidification is irreversible.

6

Eutrophication

The deposition of nitrogen compounds favours forest growth, but at the same time leads to the chemical disruption of a long list of ecosystems on land and in the sea, and results in the impoverishment of biodiversity.

Most people probably think of stagnating lakes when eutrophication is mentioned. In fresh water environments eutrophication is almost always caused by phosphates, since phosphorus is the substance that usually limits biological growth in water.

On land and in the sea, however, it is nitrogen that is the limiting factor in the majority of cases. The deposition of nitrogen – originating from emissions of nitrogen oxides and ammonia – therefore acts as a fertilizer in nature.

While this favours some species of plants that can easily make use of the extra nitrogen, it does so at the expense of others. It also affects the growth of mycorrhizal fungi. The impoverishment of ecosystems that results from the deposition of nitrogen is a real and very serious problem in large parts of

Europe. The increased growth rate that results from nitrogen deposition also increases biological acidification, see factfile on page 93.

Another important effect of nitrogen deposition, at least in those parts of Europe where it is most extensive, is that nitrate ends up in the groundwater, where it causes problems in the production of potable water.

This chapter describes the emissions into the air that cause these problems, the areas that are affected, how much nitrogen deposition nature can "tolerate", and gives an idea of the extent to which recovery is possible. The biological effects of nitrogen deposition are described in chapter 2.

CAUSES

The atmospheric deposition of nitrogen compounds in Europe is due, in roughly equal parts, to emissions of nitrogen oxides and ammonia. The problems are largely unrestricted by national borders, especially in the case of nitrogen oxides and their transformation products. Ammonia is generally not transported such long distances. The emissions, transport and deposition of nitrogen compounds are described in detail in chapter 5.

Note that it is not just airborne nitrogen that ends up in nature. In many environments nitrogen is also added in the form of fertilizer. Large amounts are spread on fields, and sometimes also on natural grazing land, which leads to impoverishment of the natural flora. Fertilizer is also spread on forest land to increase forestry yield. In addition to direct deposition, nitrogen also reaches the sea through leaching from the land and discharges from wastewater treatment plants and individual households.

WHICH AREAS ARE AFFECTED?

The atmospheric deposition of nitrogen compounds in Europe is greatest in the Netherlands, Belgium, France, southern England, northern Germany, and northern Italy. The reason why the situation is worst in areas with intensive agriculture is that a large part nitrogen from ammonia, 90 per cent of which comes from livestock farming, is deposited relatively close to the source of emissions.

The amounts involved are not small by any means. In local areas of the Netherlands, for instance, annual deposition on forest soil can exceed 100 kilograms of nitrogen per hectare. This is roughly the same amount as is spread as a fertilizer dose on intensively farmed fields. In southern Scandinavia the annual atmospheric fallout on forest soil is 10–20 kilograms per hectare, and in the far north just a few kilograms.

WHAT CAN NATURE TOLERATE ON LAND?

In order to get a picture of the areas that are affected by eutrophication it is not sufficient to determine the quantities deposited – we also need information about the sensitivity of the ecosystems. But nitrogen has a twofold effect; it causes both eutrophication and acidification. This fact, together

The fallout of atmospheric nitrogen is a threat to biodiversity in many nitrogen-poor ecosystems, such as this heath with pasque flowers (Pulsatilla vulgaris).

with the complexity of the nitrogen cycle, makes it difficult to give unequivocal critical loads for different ecosystems.

Mass balances

One way to define the critical load for nitrogen is to calculate the level at which nitrogen starts to leak from the system into the groundwater. This is done with the aid of what are known as mass balances. These look at the way that nitrogen is converted in the ecosystem – its uptake by vegetation, fixing in

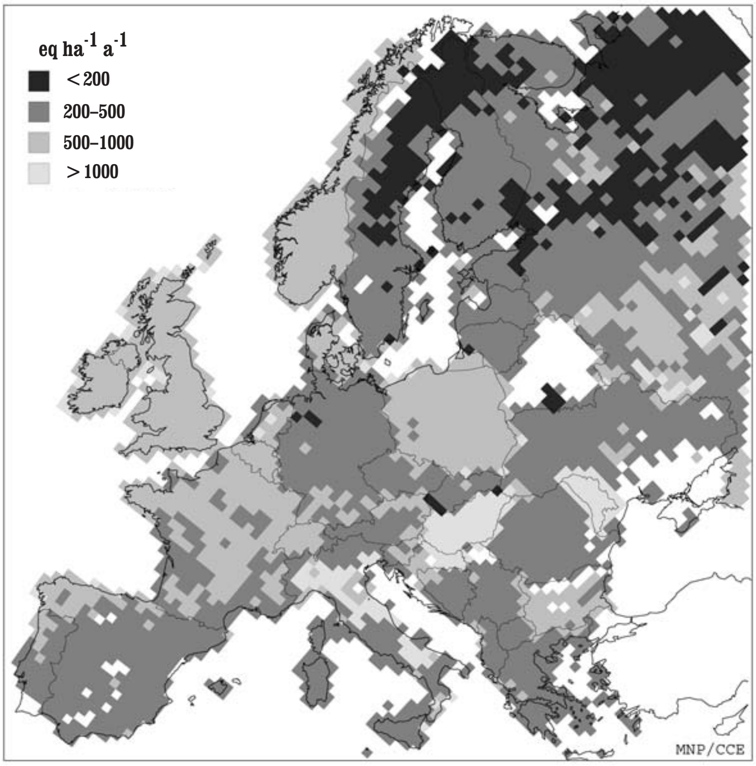


FIGURE 6.1. Critical loads for nitrogen, Europe. Nitrogen-equivalents per hectare per year. The darker the shade, the greater the sensitivity. (Max Posch, CCE/RIVM, Netherlands, 2003.)

the soil, conversion by micro-organisms in the soil (nitrification and denitrification), its removal if biomass is harvested, etc. These plus and minus entries are then weighed against each other to give a measure of how much nitrogen can be added without the loss from the system exceeding a certain limit.

Calculations of mass balance show that Swedish forest soils can take between 3 and 20 kilograms of nitrogen per hectare each year, for areas of low and high productivity respectively, without increasing nitrogen leakage from the system. In virgin forest, where no nitrogen is removed through the harvesting of biomass, the critical load has been calculated as 1–3 kilograms per hectare each year. Figure 6.1 shows the critical load limits calculated using the mass balance method for the whole of Europe.

Uncertainties in models

It should be said that there are forest researchers who question the validity of this model, since it has been possible to add considerably higher doses of nitrogen during field trials without observing any increase in leakage. One explanation of this may be that the addition of nitrogen changes the ecosystem in such a way that it is able to take up more nitrogen. The addition of nitrogen may also have important environmental effects that come into play before leakage into groundwater occurs.

It is also possible that the models underestimate the capacity of soils to lock up nitrogen. This capacity has been calculated using historical data, but without making allowance for the fact that a large amount of nitrogen has probably disappeared from the system as a result of recurring forest fires.

From experience it seems that the risk of nitrogen leaking from forest soil is small if annual deposition is less than 10 kilograms per hectare. In the range 10–25 kilograms the degree of leaching increases in certain locations. When annual deposition exceeds 25 kilograms per hectare there is significant leaching out, and many soils become saturated with nitrogen, i.e. the rate of loss equals the rate of supply.

Calculations based on mass balances show that in 1990 the critical load for nitrogen was exceeded over an area of roughly

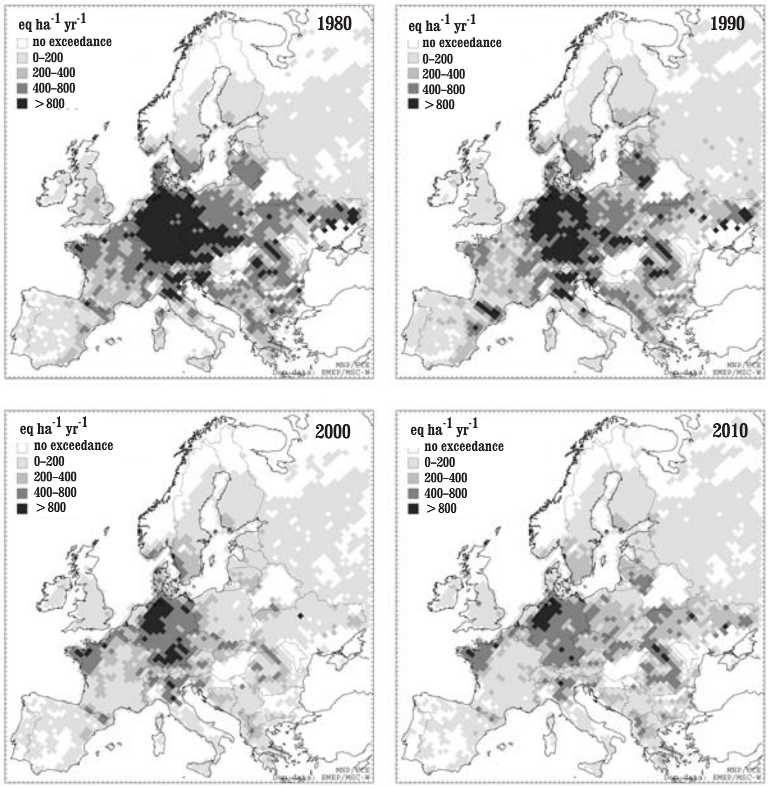


FIGURE 6.2. Areas where the critical loads for eutrophication were exceeded in 1980, 1990 and 2000, and the forecast for 2010. The latter is based on all countries meeting their undertakings in the Gothenburg Protocol. (Max Posch, CCE/RIVM, the Netherlands, 2003.)

213 million hectares of European ecosystems. Emissions have fallen since then however.

Preliminary calculations indicate that the exceeded area had shrunk to 140 million hectares by 2000. If all signatory countries do as promised under the Gothenburg Protocol (see table 9.2) and if emissions in non-signatory countries develop as officially projected the area will however increase to 159 million hectares in 2010. This increase is mainly due to projected increased emissions of nitrogen compounds in some large eastern European countries. The four maps in figure 6.2 illustrate the progress.

Changes in ecosystems

Another way of determining the critical load for nitrogen is to study the deposition levels of nitrogen at which visible changes start to appear in ecosystems, e.g. changes in the composition of species. The results of such surveys are shown in table 6.1.

TABLE 6.1. Empirical critical loads for nitrogen deposition to natural and semi-natural ecosystems – *some examples*.

Ecosystem type	kg N/ha · yr	Indication of exceedance
Temperate and boreal forests	10–20*	Changes in soil processes, ground vegetation and mycorrhiza. Increased risk of nutrient imbalances and susceptibility to parasites.
Tundra	5–10*	Changes in biomass and species composition, decrease in lichens.
Arctic, alpine, and subalpine scrub	5–15(*)	Decline in lichens, mosses, and evergreen scrubs.
Dry heaths	10–20**	Transition heather to grass, decline in lichens.
Sub-Atlantic semi-dry calcareous grassland	15–25**	Increase in tall grasses, decline in diversity.
Non-Mediterranean dry acid and neutral closed grassland	10–20*	Increase in graminoids, decline in typical species.
Raised and blanket bogs	5–10**	Change in species composition, N saturation of Sphagnum.
Poor fens	10–20*	Increase in sedges and vascular plants, negative effects on peat mosses.
Soft water lakes	5–10**	Isoetid species negatively affected.
Coastal stable dune grasslands	10–20*	Increase in tall grasses, decrease in prostrate plants, increased N leaching.

** Reliable   * Quite reliable   (*) Expert judgement

Knowledge in this area is however incomplete, since it is difficult to establish which changes are due to nitrogen deposition and which are caused by other changes, such as the way that land is used. Moreover, changes only appear in the flora after the critical limit has been exceeded, and in some cases only after it has been exceeded for an extended period of time.

A further obstacle to establishing critical limits in this way is the lack of reference material. It is unusual to find comparative data that stretches back more than 50 years, and it is probable that significant effects had already taken place in many areas by the 1950s.

The critical load is also affected by a number of chemical and physical factors. Researchers recommend that the lower values in table 6.1 are used when the weather is cold or dry, during long periods of frost and/or when there is a limited supply of base cations. Conversely, the high values can be used when the weather is warm, humid, free from frost and when there is a good supply of base cations, or if nitrogen is removed from the system through use of the land, for haymaking or grazing for example.

Quite recently researchers also discovered that the chemical form of nitrogen has a significance on the effects that occur in ecosystems – it makes a difference whether nitrogen is supplied as nitrate or ammonium ions. There is still inadequate knowledge in this area.

NITROGEN IN THE SEA

Eutrophication problems in the sea are largely due to the supply of nitrogen, although the supply of phosphorus is also significant (however, phosphorus is not regarded as an airborne pollutant and is not considered in detail here).

Most nitrogen reaches the sea as run-off from the surrounding land. Some of this is airborne nitrogen that is deposited on land and then leaches into surface water and is carried to the sea. In the case of the Baltic Sea it is estimated that the nitrogen that is deposited directly on the water surface accounts for around a third of the total supply.

There is some risk that the transport of nitrogen from the land to the sea will increase in the future. This is because deposition on many types of land leads to a gradual build-up of

The airborne attack by nitrogen is a threat to biodversity in all open, nutrient-poor land, even where we try to protect and preserve it through good management and the creation of reserves.

nitrogen that could be released as a result of human actions, see below.

Another aspect worth mentioning is that a warmer climate leads to faster decomposition of organic matter, with a risk of increased leaching of nitrogen from the land into the sea.

No critical load limit has been established for nitrogen in the sea.

IS NATURE RECOVERING?

Emissions of nitrogen oxides in Europe are expected to decrease markedly in the future. Reductions are also expected in emissions of ammonia, although not to the same extent.

As with acid deposition it is of interest to find out what happens in the soil and in ecosystems when the supply decreases.

In a number of places in Europe researchers have built roofs over small areas of forest to shield them from pollutant deposition. In all these trial areas it has been found that the amount of nitrogen leaking from the system falls considerably soon after the supply is stopped, even though the load has been high for a long time and a large reserve of nitrogen has therefore built up in the soil. The same effect has been observed when forest fertilization trials lasting several years have come to an end.

The store of nitrogen in the soil does not decrease as quickly as the leaching out of nitrogen. Large amounts may be bound up in vegetation and humus layers, and in many cases nitrogen is conserved very effectively; little of it disappears. Interference, such as forestry felling or liming of the soil can accelerate decomposition, however, and lead to the risk of increased leakage. This risk may remain for a long time.

Vegetation responds very slowly to reductions in the supply of nitrogen. In the trial areas that are covered by a roof, no change has yet been seen, even though almost ten years have passed since deposition was greatly reduced. This is probably because the soil and plants are still "charged" with nitrogen that is continuing to circulate within the system. Only when the supply of nitrogen starts running out will the original plants be able to compete again, but this recolonization may take a very long time.

7

Ground-level ozone

An important group of pollutants are the photochemical oxidants. Common to these is that they are formed by other pollutants in the air through the action of sunlight, and they are highly reactive.

Ozone (O_3) usually makes up more than 90 per cent of the oxidants in the air. This chapter looks at how ozone is formed, its current levels and trends, and touches briefly on the reductions in emissions of ozone-forming substances that are needed in order to avoid harm to people and plants.

OZONE AT HIGH AND LOW ALTITUDES

The ozone layer in the stratosphere, at an altitude of 10–40 kilometres, protects us from ultraviolet radiation from the sun and is an essential requirement for all higher life on the Earth.

When ozone is present at ground level it may be harmful to people, animals, plants and materials. The first effects of ozone and other photochemical smogs on our health are irritation of the eyes and mucous membranes. At higher levels the irritation becomes more troublesome, and additional effects such as headaches and breathing difficulties can occur.

In plants, it has been found that damage can occur at concentrations only slightly higher than current background levels. This has a significance on yields from agriculture and forestry, as well as affecting natural ecosystems.

The effects on nature and people are described in more detail in chapters 2 and 3. The rising background level of ozone also helps to reinforce the greenhouse effect.

SUMMER AND SUN

Oxidants are reactive substances, and the term photochemical indicates that they are formed in reactions that are driven by the energy in sunlight.

The way that ozone is formed is described on opposite page. In addition to sunlight there must also be nitrogen oxides and volatile organic compounds in the air. Volatile organic compounds are a large group of diverse hydrocarbons with differing propensities to take part in ozone formation. The most effective contributors are alkenes, aldehydes and aromatic compounds. Methanol and ethanol react slowly and only make a small contribution.

The concentration of ozone is generally highest on sunny days in late spring and summer, during periods of high pressure. Sunshine accelerates ozone formation, and the high pressure means that air masses move slowly, resulting in little mixing of the air. The overall effect is that high concentrations can build up.

HOW OZONE IS FORMED

Ozone is formed by various chemical processes whose sequence is complicated but relatively well known. A simplified description might look as follows:

It is a prerequisite for ozone formation in the troposphere that sunlight breaks down nitrogen dioxide. This results in the formation of nitrogen monoxide and a highly reactive oxygen atom:

(A) NO_2 + sunlight → NO + O•

The free oxygen atom can then react with oxygen gas to form ozone:

(B) O• + O_2 → O_3

If there are no volatile organic compounds in the air, the ozone reacts again with the nitrogen monoxide to reform nitrogen dioxide:

(C) NO + O_3 → NO_2 + O_2

This process does not lead to the formation of high levels of ozone. It is formed and used up at roughly the same rates.

In order for larger quantities of ozone to be formed, other substances must intervene and convert nitrogen monoxide into nitrogen dioxide, so that breakdown of the ozone molecules in reaction (C) is reduced or ceases altogether. This process is fuelled by certain so-called radicals, which are formed when volatile organic compounds are broken down by sunlight.

The nitrogen dioxide that is formed when volatile organic compounds are involved in the reaction process can be reused for further ozone formation in accordance with reactions (A) and (B). High levels of ozone can therefore build up when volatile organic compounds, nitrogen dioxide and sunlight are all present at the same time.

It may seem surprising that the level of ozone is often lower in an urban environment and close to major roads than in the background air. The explanation for this is that car exhaust fumes, when they are released, contain a large amount of nitrogen monoxide and only a small amount of nitrogen dioxide. As shown by reaction (C), nitrogen monoxide is able to “soak up” ozone, and can therefore reduce the ozone levels locally.

When the ozone is used up, nitrogen dioxide is formed instead, and this can then take part in reactions that form many new ozone molecules. High ozone levels can therefore build up at several tens of kilometres distance from the source of the emissions.

Travelling long distances

Although ozone is highly reactive and breaks down relatively quickly, once it has formed it can be carried considerable distances in the air. Periods when levels rise temporarily due to movement of this type are generally referred to as episodes. Ozone is very much a transboundary air pollution problem. But in locations that are downwind of areas with high emissions of ozone-forming substances (large cities or densely populated areas with heavy traffic) the local contribution can still be significant.

In addition to the ozone that is formed close to ground level, ozone is also formed at slightly higher altitudes, where it contributes to the background level. The gases that are active in forming this ozone are primarily nitrogen oxides, carbon monoxide and methane. The background level is contributed to by emissions not only from Europe but from the whole of the northern hemisphere.

CRITICAL LEVELS

As with acidification and eutrophication, attempts have been made to estimate nature's "tolerance level" to ozone exposure. In the case of gaseous substances these tolerance limits are expressed as critical levels (see factfile, next page). Attempts have also been made to establish a critical level below which there is no harm to people's health.

In the case of the effects of ozone on plants it is the total (accumulated) dose that is of most interest. The critical level is calculated from the length of the time and the amount by which the ozone level exceeds a given threshold value. The threshold has been set at 40 parts per billion (ppb). For sensitive crops the critical level is set at 3000 ppb hours daytime during a three-month growing season (May–July). This exposure is believed to result in crop losses of less than 5 per cent. (To find out how ppb hours are calculated, see factfile.)

For trees in a forest the critical level has been set as 10,000 ppb hours, calculated in daytime over a six-month growing period. One element of uncertainty in this respect is that, for practical reasons, almost all trials have been carried out on young trees. It is not clear whether older trees are more or less

CRITICAL LEVELS

Critical levels are usually defined as "the concentration of pollutants in the air above which directly harmful effects can occur in plants, ecosystems and materials, according to the current state of knowledge".

Critical levels are generally given for one pollutant at a time. However, polluted air almost always consists of a mixture of substances, which in many cases can aggravate each other's effects (synergism). If the effects of this interaction are to be taken into account in calculations then the critical levels should as a rule be set at lower values in order to avoid harm.

The exposure index that is used for ozone, AOT40, requires some further explanation. Taking a threshold value of 40 ppb of ozone, we then count how many ppb hours this level is exceeded (AOT stands for Accumulated Exposure over a Concentration Threshold). If the level is 50 ppb for one hour this counts as 10 ppb hours, while a level of 39 ppb for one hour is not counted at all (the threshold of 40 must be exceeded by at least one ppb).

Critical levels for harmful effects on vegetation have been determined for sulphur dioxide, nitrogen oxides and ammonia, as well as ozone.

sensitive than younger ones – the studies carried out point both ways.

There have been insufficient studies on natural vegetation, but it is believed that the critical level for crops can also be applied to wild flora. Researchers have not found any indications that show they have greater sensitivity, in fact the opposite seems likely. Variations in sensitivity between different species could however lead to changes in ecosystems.

The AOT40 measurement is actually a rather blunt instrument, since a given ozone level in the air can give rise to very different effects. The uptake by plants varies with air and soil humidity. In dry weather the stomata of plants are mostly closed, so the ozone uptake is low compared to when the humidity is high. Figure 7.1 therefore overestimates the effects in dry, warm areas, and underestimates them in cool, moist areas, such as Scandinavia.

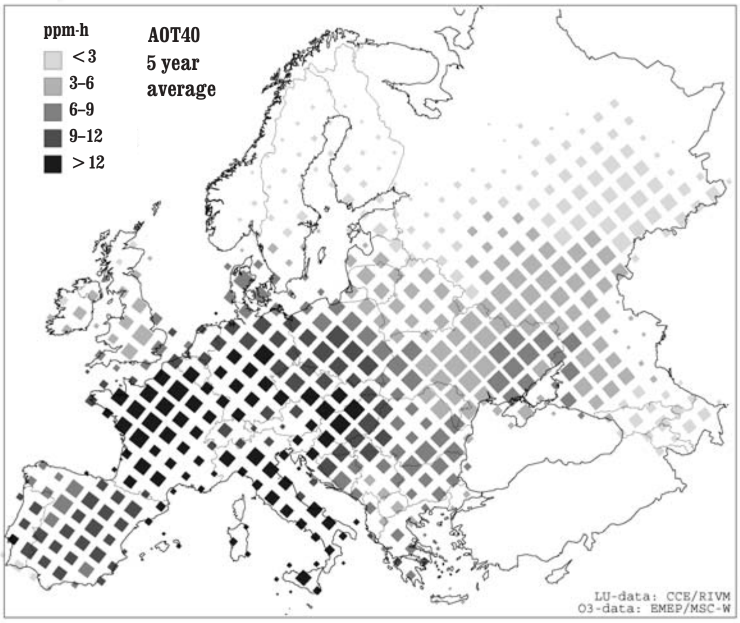


FIGURE 7.1. Exposure of agricultural crops to ground-level ozone. The map shows a five-year average of estimated AOT40 values, i.e. the number of ppm hours that the ozone level exceeds the threshold value of 40 ppb. The critical level is 3 ppm hours (1 ppm hour = 1000 ppb hours). The darker the shade, the greater the exposure. The size of the squares is proportional to the area of agricultural land in each 150 × 150 km square. (Max Posch, CCE/RIVM, the Netherlands, 2000.)

CONTINUING HIGH LEVELS

Measurements that have been in progress since the 1950s show that the levels of ozone in the air over Europe have risen by an average of 2 per cent a year, and that the background level today is two to four times as high as it was in the 1950s. The critical levels, which were presumably only exceeded occasionally at the start of the last century, are now exceeded regularly over almost all of Europe. Figure 7.1 shows where and by how much the critical level for ozone damage to crops is exceeded. The critical level for forest trees is not exceeded as often or as much as that for crops.

The limits that have been set to protect people's health are also regularly exceeded by a significant degree. The situation is worst in the Mediterranean countries of Italy, France, Greece and Spain, and in parts of Germany.

It has been possible to detect two different trends in ozone levels over the past decade, which to some extent cancel each other out:

- There seem to be fewer occasions when levels are really high. It is believed that this is because emissions of ozone-forming substances in Europe have decreased markedly.
- The background level is rising throughout the northern hemisphere because emissions of ozone-forming substances – nitrogen oxides, carbon monoxide and various hydrocarbons, including methane – are still rising, especially in Asia.

The latter trend is worrying since the harmful effects of ozone are largely due to cumulative exposure over a long time – short periods when levels are high are not as important in this respect.

EMISSIONS OF OZONE-FORMING SUBSTANCES

Ozone is formed, as mentioned above, by nitrogen oxides and volatile organic compounds. Emissions of **nitrogen oxides** are described on page 96.

Emissions of **volatile organic compounds** are still relatively poorly mapped out, but the major sources are exhaust fumes from motor vehicles, evaporation of solvents from paints and varnishes, and small-scale combustion. The petrochemical industry can also produce high emissions locally.

It may be worth pointing out in this context that volatile organic compounds cause other problems in addition to contributing to ozone formation. Many of them are highly toxic to people. Some also contribute to the breakdown of the atmospheric ozone layer and/or act as greenhouse gases.

Emissions of VOCs in Europe

According to the emissions data that is reported to the Convention on Long-range Transboundary Air Pollution the manmade emissions of VOCs in Europe totalled just under 16 million tonnes (excluding methane) in the year 2000, which represents a reduction of 35 per cent since 1990, when around 24 million tonnes were emitted. Emissions from each country are shown in table 7.1.

The downward trend is due in part to active measures in many countries, including the introduction of catalytic converters on petrol-driven cars, and partly to economic recession and changes in production in the eastern European economies in the early 1990s. The international undertakings of countries for the year 2010 are shown in table 9.2.

Natural emissions of VOCs

Plants give off considerable amounts of volatile organic compounds that can also affect ozone formation. These emissions are certainly less than manmade emissions, but they are of the same order of magnitude. The most important in this context is probably isoprene, which is primarily given off by broadleaf trees.

However, computer modelling indicates that the role of this substance in ozone formation in Europe is fairly small. This is because the highest emissions into the air occur in southern Europe, where ozone formation is limited by the availability of nitrogen oxides. In those parts of Europe where volatile organic compounds are the limiting factor in ozone production, isoprene emissions from forests are relatively low in comparison with anthropogenic emissions. It is however possible that periods of high ozone levels in Spain, for instance, are aggravated by the isoprene given off by broadleaf trees.

A group of substances that are chemically related to isoprene are terpenes. Some of these, especially monoterpenes, are also volatile. These are mainly given off by coniferous trees. Emissions are high, almost as high as those of isoprene, but their role in ozone formation is probably fairly minor.

TABLE 7.1. European emissions of non-methane volatile organic compounds, 1990 and 2000. Unit: 1000 tonnes a year. (EMEP 2002)

	1990	2000
Austria	345	232
Belgium	274	233
Denmark	162	129
Finland	224	161
France	2473	1726
Germany	3220	1605
Greece	255	305
Ireland	111	90
Italy	2041	1557
Luxembourg	19	15
Netherlands	492	278
Portugal	371	463
Spain	1555	1453
Sweden	498	304
United Kingdom	2425	1418
Sum European Union	**14465**	**9969**
Albania	31	34
Bosnia & Herzegovina	51	42
Belarus	533	225
Bulgaria	217	120
Croatia	105	80
Cyprus	14	14
Czech Republic	441	227
Estonia	88	34
Hungary	205	173
Iceland	13	10
Latvia	143	69
Lithuania	108	61
Norway	294	367
Poland	831	599
Macedonia	19	17
Moldova	157	22
Romania	772	638
Russia	3668	2450
Serbia & Montenegro	142	129
Slovakia	262	89
Slovenia	44	40
Switzerland	279	159
Ukraine	1369	271
Sum non-EU	**9786**	**5870**
Sum Europe	**24251**	**15839**
Sum Int. shipping	84	84
Sum Europe + ships	**24335**	**15923**
Turkey	463	726

HOW MUCH MUST EMISSIONS BE REDUCED?

In order to bring down ozone levels far enough to prevent EU target values from being exceeded, emissions of both nitrogen oxides and VOCs must be reduced. However, in some areas it is more important to reduce emissions of nitrogen oxides, while in others volatile organic compounds are the priority. The deciding factor is how many times each molecule of nitrogen oxide takes part in the ozone-forming reaction before it is converted into nitric acid.

In areas with a high pollutant load, as in central Europe, this transformation is relatively quick. So in this case it is emissions of volatile organic compounds that set the limit for how much ozone is formed. But the cleaner the air, the more ozone molecules can be formed by each molecule of nitrogen oxide. In Scandinavia, for example, nitrogen oxides are therefore the limiting factor in ozone formation.

Emissions of ozone-forming substances in Europe are expected to fall quite sharply over the coming decade. The way this could affect ecosystems and people's health can be seen in table 9.3. There is some uncertainty about development in other regions however – the ozone levels in Europe are to some extent affected by emissions in the whole of the northern hemisphere. Another element of uncertainty is the feared rise in temperature, which could lead to increased formation of ground-level ozone.

8

Reducing emissions

There is good potential for reducing emissions of most pollutants to levels that nature and people can tolerate, without making major economic or material sacrifices. Many of these measures also have socioeconomic benefits.

Emissions of the major air pollutants are closely linked with our use of energy. They can effectively be reduced in two ways: either through technical measures, such as flue-gas treatment at a coal-fired power plant, or through measures that change the system, such as reducing energy use so that the coal-fired power plant is no longer needed.

The technology approach and system change approach are not mutually exclusive – in fact it can be difficult to separate them. But system change will often take a long time, while technical change can give quick results. And even after the energy system has undergone major change, emission control technology will still be important to keep emissions of many pollutants at a low level.

Certain air pollutants, such as carbon dioxide, cannot currently be removed at reasonable cost. Reducing these emissions will require system change that will mean using less fossil fuels. This itself is something of a key issue, since it would reduce emissions of many other air pollutants at the same time. For example, most emissions of sulphur dioxide and nitrogen oxides arise from the burning of fossil fuels, as do a large part of the emissions of volatile organic compounds, heavy metals, etc.

This review therefore looks first at system change, followed by technical measures and their potential. Calculations are then presented which show that it is profitable to clean the air. Finally we discuss what is needed to bring about these changes.

SYSTEM CHANGE

Reducing our consumption of finite energy sources – fossil gas, oil, coal and uranium – requires major changes to the entire energy system. Of the current global energy supply, almost 90 per cent comes from finite resources, see figure 8.1.

One driving force for change in the energy system is the fact that the available reserves of fossil gas and oil are relatively limited, and within a few decades prices are likely to start rising, leading to reduced consumption. There are, however, still large reserves of the dirtiest fossil fuel – coal – which itself does not place any limits on future emissions of carbon dioxide.

Nuclear power is sometimes put forward as a way of reducing emissions of air pollutants, particularly the greenhouse gas carbon dioxide. The potential is limited, however, partly because the fuel, uranium, is a finite resource, and the technology is expensive, complex and unsuitable in geologically and politically unstable regions. It is generally believed that nuclear power ought to be phased our in order to achieve a sustainable energy system.

The third main report of the Intergovernmental Panel on Climate Change, published in 2001, states that the development of technology that helps reduce emissions of climate-changing gases has been rapid over the last five years. Areas that are men-

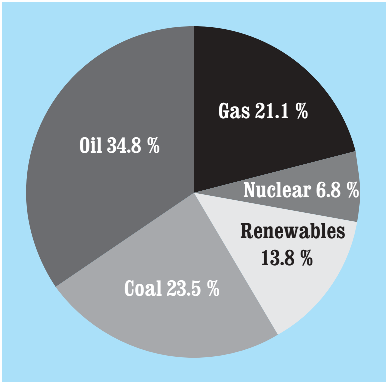


Figure 8.1. Fuel shares of world total primary energy supply. (Renewables in Global Energy Supply. IEA Fact Sheet. International Energy Agency, 2002.)

tioned specifically are wind farms, fuel cells and the harvesting of biofuels. It also reports that the cost of reducing emissions of greenhouse gases is not that high. Emission levels in 2010–2020 can be brought below those of the year 2000 at a low cost – and around half the reduction is actually profitable.

The following section describes the opportunities for using energy more efficiently and increasing our use of renewable energy sources.

Using energy more efficiently

Using energy efficiently is about getting more benefit from the same or a smaller amount of energy. Theoretically there are excellent opportunities for reducing energy consumption in this way. For example, the efficiency of a petrol-driven car – the percentage of the energy supplied that does useful work – is less than 20 per cent. A common coal-fired power plant has an efficiency of 30–35 per cent, while a new power plant with gas turbines can achieve almost 60 per cent. Converting a power station from pure electricity generation to combined heat and power generation can more than double its efficiency at a stroke. The most energy-efficient refrigerator on the market uses just a third as much electricity as the average model. A modern low-energy light bulb rated at 11 watts shines just as brightly as a 60-watt incandescent bulb. Making steel from scrap requires just a third of the energy it takes to it make from raw materials. And so on – the list is long.

According to the EU Commission there is great potential for improving the efficiency of energy use within the Union – it is estimated that around one-fifth could be saved at no additional cost, if the right incentives are used (these are discussed later in this chapter).

To ensure that the technical potential to use energy more efficiently actually leads to a reduction in energy use, two things are required:

- That the new technology is actually used. A common obstacle is that the consumer lacks sufficient information, or that energy makes up such a small fraction of the cost that it is not considered when deciding to buy a new refrigerator or car, for example.
- That we do not compensate for the lower operating costs by increasing our usage – for example by driving longer distances if a car uses less fuel.

Renewable energy

Even after major improvements in efficiency have been made, society will still require a large supply of energy. On average, the sun provides a very large influx of energy, and eventually solar energy will probably become by far the dominant source of energy. We need to make use of just one ten-thousandth of the incident solar radiation to meet the world's entire energy requirements. For example, the total current global consumption of electricity could be provided by solar panels covering 12 per cent of the area of the Sahara. The amount of solar energy stored by green plants through photosynthesis is ten times greater than the total domestic energy consumption worldwide, and we currently only use 1 per cent of the solar energy that is captured by photosynthesis. One complication, of course, is that the availability of solar radiation and bio-energy are unevenly distributed around the world.

The renewable energy sources that are best for air quality are probably solar energy for heating, and solar panels, wind power, hydroelectric power and wave power for generating electricity. None of these sources produces any waste products

THE VEHICLES OF THE FUTURE

An electric vehicle without batteries – that's a fuel cell vehicle in a nutshell. It works something like this:

The fuel cell itself can be likened to a refillable battery. It has a cathode, an anode and an electrolyte that permits the passage of ions, but not electrons, between the electrodes. Hydrogen gas is supplied to the anode, and oxygen (from the air) is supplied to the cathode. This generates an electric current that is used to drive electric motors, just as in a "normal" electric vehicle. Because there is no combustion it does not produce any air pollutants – the only waste product is water.

So the fuel is hydrogen. This can be supplied as pure hydrogen, or produced onboard from other fuels that contain hydrogen, such as methanol or petrol. It is also possible to run the cell directly on methanol, without first producing hydrogen.

Just how clean and energy efficient a fuel cell will be depends entirely on how the fuel is produced. Ideally the hydrogen gas could be produced in the future by using electricity from solar panels to electrolyse water. But if the hydrogen is instead produced using electricity from power plants fired by fossil fuels there is hardly any environmental benefit at all.

Fuel cell technology has become the vehicle industry's main focus of development towards the zero emission vehicle – a development that is primarily driven by the strict requirements laid down in California and several other US states. But despite several large manufacturers insisting that they will have fuel cell vehicles on sale shortly, it is likely that the big breakthrough will take a few decades yet. Fuel cells are still extremely expensive and there is some uncertainty over which fuel will win out in the future.

In the meantime, conventional internal combustion engines will probably be refined further. Volkswagen, for example, produces a version of its Lupo that uses just 3 litres of diesel per 100 kilometres, and expects to bring this down to 2 litres within a few years. Hybrid vehicles already exist, and more are likely to appear. These have electric motors, but the batteries are backed up by a small internal combustion engine, giving good energy efficiency and low emissions of air pollutants.

The 2003 version of Toyota Prius, a hybrid car that uses 0.43 litres of petrol per 100 km.

directly or makes a significant demand on the Earth's finite resources.

Biofuels are also a renewable source of energy, but they have a greater environmental impact than those mentioned above. Firstly, they produce nitrogen oxides, volatile hydrocarbons and particles when the biofuel is burned, and secondly, extensive exploitation of biofuel can impoverish the soil and have negative effects on biodiversity.

High fossil dependency for transport

Transport is possibly the sector of society where a transition to renewable energy is most difficult of all. This is partly because the energy demand seems to grow all the time (we travel and send goods more often and further afield), and partly because many forms of transport are almost totally dependent on oil. As in other areas it is important both to improve efficiency and gradually switch to renewable fuels. The potential for improving the efficiency of vehicles themselves is very high, especially for cars, see factfile on previous page.

However, because we seem to have an almost insatiable demand for travel, it will probably be necessary not just to improve the efficiency of vehicles, but also to try and influence the overall demand for transport, for example by infrastructure planning to minimize transport and by using economic incentives.

The biggest obstacle to a widespread shift to renewable energy at present is the combination of price and political inertia. Fossil fuels are generally cheap to the consumer and are likely to remain so for some time, even though wind power can now often compete on price with new coal power. One important issue is of course how different sources of energy are taxed. The political inertia is reinforced by the influence of powerful lobby groups that feel their position is threatened (e.g. oil companies) and by our general aversion to change.

Fundamental change is not necessarily all that far off, however. For example, a report produced on behalf of Greenpeace (1999) shows that electricity from solar panels does not need to cost more than conventional electricity, assuming that the panels are manufactured on a large scale. It is estimated that benefits of scale could reduce the price by a factor of four. In the political arena it is noticeable that a growing number of corporate leaders are expressing support for the phasing out of fossil fuels and that several large oil companies and car manufacturers have left the lobby organizations that try to oppose change.

TECHNICAL SOLUTIONS

This sections looks at the emission control technology that is on offer to reduce emissions of air pollutants from energy generation, transport and agriculture, and how far it is possible to go with technical measures alone. Some technical solutions can help to reduce emissions of carbon dioxide, but for this pollutant in particular the measures that are described under system change above are generally more important.

Energy sector

The big combustion plants in Europe, which are mainly used for electricity generation, produce extensive emissions of sulphur dioxide and nitrogen oxides. With the aid of technical solutions these can be reduced by more than 90 per cent. See factfile on next page for details.

The vast majority of large plants are coal-fired and therefore also produce high emissions of carbon dioxide. Technology is being developed to trap and store this carbon dioxide underground, for example in empty gas and oil deposits. However, it must be considered doubtful whether such methods can ever compete with measures that are able to replace fossil fuels – especially as these measures often lead to major secondary benefits such as health improvements, since they also reduce emissions of many other air pollutants.

Transport sector

Diesel-driven vehicles are more energy-efficient than petrol-driven vehicles, but generally emit more nitrogen oxides and harmful small particles. Technology for reducing emissions from diesel vehicles does exist but is not currently widely used because of lax environmental requirements.

SULPHUR AND NITROGEN OXIDES FROM COMBUSTION PLANTS

By far the largest proportion of sulphur emissions in Europe comes from the combustion of coal and oil. These emissions can be reduced by choosing **natural low-sulphur grades of coal and oil**. The sulphur content can also be reduced through technical measures, such as **fuel desulphurization**. Sulphur emissions can be eliminated by **switching fuel** entirely, for example, from coal or oil to fossil gas, since the gas is practically sulphur-free. Another advantage of gas over coal and oil is that it produces more energy per volume of carbon dioxide emitted.

The **combustion process** itself has a big effect on the level of emissions of nitrogen oxides. In simple terms it can be said that emissions increase with rising combustion temperature, and that the combustion of hard coal produces the most nitrogen oxides, oil a little less and gas least of all. New power plants often use **low-NOx burners**, which can halve emissions for a low cost. Another method is to burn coal and other solid fuels in a **fluidized bed**. The fuel is fed by compressed air into a floating bed consisting of sand, where combustion takes place at relatively low temperature, which reduces the formation of nitrogen oxides. **Sulphur-binding substances**, usually lime, can be added during both fluidized bed combustion and conventional combustion. This allows a large proportion, from 40 to over 90 per cent, of the sulphur to be trapped and removed with the ash.

After combustion there are various ways of cleaning the flue gases. Emissions of sulphur dioxide are usually reduced by **flue-gas de-sulphurization**. The most widely used method involves spraying the flue gases with lime in wet or dry form. This makes it possible to remove more than 95 per cent of the sulphur from the flue gases. One drawback is that this reduces the efficiency of the plant as a whole by 1–2 per cent, since the process requires energy.

Nitrogen oxide levels in flue gases can also be reduced. One common method is **selective catalytic reduction**, in which the flue gases are passed through a catalytic converter after adding ammonia. The end product is mainly nitrogen, and nitrogen oxide levels are reduced by between 80 and 90 per cent. Smaller plants often use a simpler **non-catalytic reduction method**, which is cheaper but also less effective. This generally reduces emissions of nitrogen oxides by 50–70 per cent.

Over the last decade a number of **combined reduction methods** have been developed, all of which reduce the level of sulphur dioxide and nitrogen oxides in flue gases in a single stage. Several of these are reported to be able to reduce levels of both pollutants by over 95 per cent, but as yet there are few plants in operation on a commercial scale.

One new technology that has so far only been tested in a small number of plants is **pre-gasification** of the fuel. First the fuel is pre-gasified in a low-oxygen environment, which causes a large proportion of the pollutants to precipitate out. The gas that is formed can then be further cleaned, and then burned at high efficiency. This technology can in principle be used for all types of solid and liquid fuel.

Heavy vehicles are in most cases diesel-driven and produce high emissions of nitrogen oxides and particles. Emissions of volatile hydrocarbons and particles can be reduced with the aid of oxidative catalytic converters, particle filters and/or cleaner fuels. Increasingly strict emission requirements will compel the use of technology to remove nitrogen oxides, for example by selective catalytic reduction (SCR). The potential to reduce emissions is especially good for working vehicles, since emissions from these engines have been unregulated until recently.

The **quality of fuel** has a major influence on the level of emissions from both petrol-driven and diesel-driven vehicles. Fuel with a low sulphur content is especially important in this respect, since sulphur impairs the efficiency of catalytic converters and itself leads to the formation of very small particles. A low sulphur content also makes it easier for vehicle manufacturers to combine low fuel consumption with low emissions of nitrogen oxides and hydrocarbons.

In addition to petrol and diesel oil there are also a number of **alternative fuels**. In light of the increasingly strict emission requirements for conventional vehicles a transition to other fuels would not greatly benefit air quality. However, these fuels can help to reduce emissions of carbon dioxide, assuming that they are produced from renewable energy sources.

Current emissions from **shipping** can be reduced considerably. The easiest way to reduce sulphur emissions is by switching to low-sulphur oils. New technology that is currently undergoing development and testing is seawater scrubbing, which removes sulphur from the exhaust gases with the aid of seawater, and is reported to give a reduction in SO_2 emissions of up to 90–95 per cent. To reduce emissions of nitrogen oxides there are several different technologies, including selective catalytic reduction (SCR) of a similar type to that used in combustion plants, which are able to reduce emissions of nitrogen oxides by more than 90 per cent. Low-sulphur oils are now used widely by vessels on Swedish shipping routes, thanks to differentiated shipping dues and port fees. Reducing speeds at sea could reduce fuel consumption and emissions of air pollutants significantly.

In the case of **air traffic**, improvements in engine technology can be expected to reduce fuel consumption and emissions of air pollutants somewhat, but it is unlikely that there will be any dramatic changes. Emissions from air travel are relatively small, but are increasing rapidly. They also have more significant effects than corresponding emissions at ground level, as a result of the rather different conditions that exist at the altitudes at which planes fly.

In summary it can be said that there are no technical obstacles to making vehicles considerably cleaner and more energy-efficient than today (with the possible exception of air travel). The critical factors in the development of emissions are the application of existing and new technology, the extent of future travel and transport, and the form of transport we choose.

Agriculture

Agriculture accounts for most of the emissions of ammonia into the air. If farmyard manure is handled in the wrong way more than half the ammonia content can evaporate before the manure reaches the soil. It is important that the manure is spread at the right time and in the right weather conditions, and that it is quickly ploughed down in the soil. The losses are especially high in warm and windy weather, and are considerably lower in cool, damp weather. If the temperature is so low that the soil is frozen, however, the losses can increase, since nitrogen in the form of ammonium cannot make sufficiently good contact with the soil particles. The losses during storage, which can also be considerable, are greatly reduced if manure pits are covered.

Although this is actually more an issue of system change, it should be pointed out that modern industrialized agriculture is hardly sustainable in the long term. By shifting towards more “organic” farming methods the supply of nitrogen in the form of artificial fertilizer would be reduced. This would itself act as a strong incentive to conserve the nitrogen available to crops, for example by minimizing the evaporation of ammonia. Another change that would favour sustainable production and reduce emissions of ammonia would be to reduce livestock farming (and hence meat consumption), which could be done by removing existing subsidies.

More efficient conservation of the nitrogen available to plants also reduces the formation of the greenhouse gas nitrous oxide in soil. Agriculture also makes a marked contribution to emissions of the greenhouse gas methane. Various adaptations would make it possible to reduce these emissions, including technical changes to the cultivation cycle.

How far can technology take us?

As part of the negotiations on reducing emissions of air pollutants in Europe, computer models were used to create various scenarios to illustrate the costs and benefits of reducing emissions of substances that contribute to acidification, eutrophication and the formation of ground-level ozone. One of these scenarios involves using the best available emission control technology to reduce all emissions. Structural measures, such as changing fuels, improving energy efficiency and changes in lifestyle are therefore not included.

If this MFR scenario (MFR stands for maximum technically feasible reductions) was implemented it would reduce emissions in Europe as follows compared with 1990 levels, (based on the assumption that energy consumption increases by 15–20 per cent during the period):

- Sulphur dioxide -90 per cent
- Nitrogen oxides -80 per cent
- Ammonia -42 per cent
- Volatile organic compounds -75 per cent

The models show that the environmental situation would be dramatically improved. But not even these very large reductions are sufficient to eliminate environmental problems entirely.

Technical solutions alone are therefore insufficient to achieve the long-term environmental goals. It may also be necessary to use energy more wisely, use more emission-free energy sources and make changes in transport systems and lifestyle. Many structural changes also involve considerably lower costs than the maximum use of emission control technology.

REDUCING EMISSIONS IS OFTEN PROFITABLE

There are several reasons why it is difficult to assess the economic damage that air pollution causes to society – and the benefits of reducing it. Many of the effects simply have no price tag. Despite this a number of attempts have been made to compare the costs and benefits of various packages of measures.

One example is the calculations carried out to assess the effects of the Gothenburg Protocol (see page 152). The annual cost of implementing the protocol was estimated at 2.8 billion euros, and its benefits at 12.8 billion euros by 2010, in other words the benefit is four to five times the cost. The most important item on the benefit side was reduced harm to people's health, mainly as a result of lower levels of harmful particles, but reduced damage to modern materials and agricultural crops also contributed.

The benefit would have been even greater if the member countries had followed the scenario that was proposed to achieve the agreed environmental targets. The cost was naturally higher than for the protocol – 8.5 rather than 2.8 billion euros by the year 2010 – but the benefits would have risen even more, from 12.8 to a massive 42.3 billion euros by the year 2010.

This is not all. The measures are likely to be even more profitable than the figures suggest. The cost-benefit analyses actually exaggerate the costs and underestimate the benefits:

- A number of important plus items, including reduced damage in ecosystems and reduced erosion of objects with a valuable cultural heritage, are not included, since they have no agreed price tag.
- The costs of measures are greatly exaggerated, since they are based solely on the use of technical measures to reduce emissions. In reality it is almost always cheaper to make ef-

Jänschwalde power plant in eastern Germany still burns lignite, but after it had been fitted for flue-gas desulphurization in 1993 its emissions of sulphur dioxide dropped from 157,000 to 20,000 tons a year.

ficiency improvements or switch fuel than to take the most expensive technical countermeasures. In addition the price of emission control technology tends to fall with time – for example the cost of flue-gas desulphurization has halved over the past decade.

Multiple benefits

The cost/benefit analyses that were carried out (for the EU emission ceilings directive, for instance) were based on a conventional energy scenario in which EU emissions of the greenhouse gas carbon dioxide were expected to rise 8 per cent by 2010. If we instead use an energy scenario that takes into account EU promises under the Kyoto Protocol (minus 8 per cent) the cost of the package of measures drops by a full 40 per cent. This is because emissions of sulphur dioxide and nitrogen oxides are reduced "for free" when carbon dioxide emissions are curbed. It therefore pays to attack several problems at the same time!

There are also studies that show that reducing emissions of carbon dioxide largely pays for itself, because emissions of harmful substances are reduced at the same time. There are no secondary benefits of this type if we try to reduce the climate effects of using fossil fuels by pumping carbon dioxide into bedrock or planting more trees.

ESTIMATING THE COSTS OF POLLUTANTS

In 2002 the European Commission published figures showing estimates of the financial costs of several air pollutants to society. They cover the following types of damage:

- Acute (short-term) effects of fine particles, sulphur dioxide (SO_2) and ozone on mortality and morbidity.
- Chronic (long-term) effects of fine particles on mortality and morbidity.
- Effects of SO_2 and acidity on materials used in buildings and other structures of no significant cultural value.
- Effects of ozone on arable crops.

Due to lack of information, some types of damage have been omitted. Among them are the effects on ecosystems, cultural heritage and visibility.

In terms of prices in 2000, the average damage caused in the EU by one tonne of pollutants emitted over rural areas is put at 14,000 euros if the pollutant is fine particles ($PM_{2.5}$), 5200 for SO_2, 4200 for NO_x and 2100 euros for volatile organic compounds. These being average figures, they mask however the great variations between member states, as can be seen from table 8.1. The costs will moreover be extra high when fine particles and SO_2 are emitted in cities, since more people will then be exposed. In a town of 100,000 inhabitants, for instance, costs are estimated at 33,000 euros per tonne of fine particles emitted, and 6000 euros for SO_2. This damage is over and above that for the whole country. The larger the city, the higher the cost will be per tonne of emitted pollutant.

HOW CAN IT BE DONE?

There is no shortage of opportunities to reduce emissions of pollutants. Many of them are cheap or even profitable to society. The following is a selection of possible measures.

Regulation

Direct regulation has been the most widely used control method in the past. Emission standards have had a major influence on cutting emissions from combustion plants and vehicles. Strictly formulated requirements have in many cases encouraged the development of efficient new emission control technology. Air quality standards have also had some restraining effect.

TABLE 8.1. Estimated costs of damage from emissions in rural areas and at sea. Euros per tonne of pollutant emitted.

	SO_2	NO_x	$PM_{2.5}$	VOCs
EU countries				
Austria	7200	6800	14000	1400
Belgium	7900	4700	22000	3000
Denmark	3300	3300	5400	7200
Finland	970	1500	1400	490
France	7400	8200	15000	2000
Germany	6100	4100	16000	2800
Greece	4100	6000	7800	930
Ireland	2600	2800	4100	1300
Italy	5000	7100	12,000	2800
Netherlands	7000	4000	18,000	2400
Portugal	3000	4100	5800	1500
Spain	3700	4700	7900	880
Sweden	1700	2600	1700	680
United Kingdom	4500	2600	9700	1900
Average EU15	5200	4200	14000	2100
Sea areas				
Baltic Sea	1600	2100	2500	1000
North Sea	4300	3100	9600	2600
English Channel	5900	5400	12000	1900
Eastern Atlantic	4500	4800	9100	1500
Mediterranean	4700	6200	10000	1700

Standards are not only used to control emission and levels, but also factors such as electricity consumption. For example, consumer standards for refrigerators in the US have helped reduce their energy consumption by two-thirds since 1978. Similar systems also exist for reducing the fuel consumption of cars.

Removing subsidies

The price of services or goods often decides how much is consumed – if the price is low, consumption is high.

Each year enormous sums are given as direct subsidies for fossil fuels. According to the Worldwatch Institute, individual countries subsidized their domestic coal industries to the value of 63 billion dollars a year in 1999. If these subsidies were reduced or removed, coal would be a more expensive fuel and demand would fall.

Another issue is whether subsidies should be used to increase the use of "environmentally good" commodities, such as wind power or train travel. Most economists believe not. Subsidies often lead to a turnaround in the market place and result in artificially high consumption. Subsidies can possibly be used to help a new technology get over the initial threshold. But in the long run it is preferable to have fair pricing that includes the environmental costs of different goods and services. Such a pricing system would not make train travel cheaper, but it would be more expensive to fly and travel by car.

Putting a price on the environment

One problem is that in many countries it costs nothing, or very little, to pollute the air. This leads to "over-consumption" of our common natural resource, the air. But if what is free today is given a price, and the resulting cost is charged to the polluter, it reflects more fairly what the use of various energy sources, for instance, actually costs society. "Dirty" energy, such as coal power, would become more expensive, while the price of "clean" energy, such as wind power, would remain un-

If each power generator had to pay for the environmental effect it caused it would increase the cost of power from coal and make wind power more competitive at the same time.

changed. Economists call this the "internalization of external costs".

A major benefit of environmental charges or taxes compared with regulation is that they often result in the cheapest and simplest measures being implemented first. One difficulty is deciding the level they should be set at to achieve the desired effect on emissions. Introducing economic incentives is a slow process in many countries, but once they are in place they work quickly and effectively. In Sweden there are several successful examples of the use of charges and taxes to reduce emissions of pollutants (see factfile page 143).

Differentiated charges and taxes are a further type of economic incentive. For example, a very large proportion of ships in Swedish waters run on low-sulphur oil, thanks to the differentiation of shipping dues and port fees based on sulphur emissions. The system is designed so that "dirtier" ships pay more than before, and "cleaner" ships pay lower fees, but total revenues are unchanged.

Trading emission rights

One drawback of environmental taxes, as well as emission standards, is that the effect on total emissions cannot be reliably predicted. If the aim is to reach a certain target within a given time period then the trading of emission rights may be an alternative. This method has been used since 1995 for emissions of sulphur dioxide from power plants in the US, where it has resulted in significant cost savings. The attraction is that it places a ceiling on total emissions. If it is expensive to reduce emissions at one power plant, emission rights can be bought from another plant where the cost of reducing emissions is lower. As a result of such trading the total cost is expected to be half what it would be if the requirement was imposed on each plant individually.

When it comes to the climate issue, trading in emission rights is a subject of hot debate. In strictly economic terms it is clearly an advantage if measures are taken where they are cheapest – the effect on the climate will be the same wherever emissions occur. However, the ability to buy extra emission allowances somewhere else could mean that the transition by industrialized countries to a sustainable energy system – which must take place sooner or later – is delayed.

Eco-labelling and purchasing requirements

Another market-based method of reducing emissions of air pollutants is the eco-labelling of cars, fuel, wood-burning stoves, goods freight, etc. Classification and eco-labelling make it possible to introduce differentiated taxes and charges as described above. Consumers can also use the system to choose the products that are best for the environment. Companies, authorities and individual consumers can also specify their own environmental requirements when deciding on a purchase. The combined effect is that manufacturers make better improvements to their products and do so faster than required by legislation.

FINANCIAL CARROTS

In the early 1990s Sweden introduced a sulphur tax and a levy on emissions of nitrogen oxides, both of which contributed to a reduction in acidifying emissions.

The **sulphur tax** was introduced in 1991 and applies to oil, coal and peat. However, fuels used in shipping, refinery processes and in industry are exempt. The tax rate is 30 kronor per kilogram of sulphur emissions. Between 1990 and 1995 the average sulphur content of heavy oils dropped from 0.65 to 0.35 per cent. For light heating oils and diesel oil it fell from 0.2 per cent to less than 0.1 per cent. The sulphur tax is estimated to have helped reduce Swedish emissions by almost 20,000 tonnes of sulphur dioxide per year, which is nearly 30 per cent of the overall reduction between 1989 and 1995.

The **nitrogen oxides charge**, which was introduced in 1992, applies to stationary combustion plants above a certain output. The levy is 40 kronor per kilogram of nitrogen dioxide emissions, but the money that is collected is paid back to the plants in proportion to the amount of useful energy they supply. A plant that has high emissions in relation to the energy it produces gets little or nothing back, while those with low emissions in relation to their energy production make a significant profit. The charge is estimated to have made a major contribution to the halving of emissions per unit of energy produced by the plants involved between 1990 and 1996.

Both the sulphur tax and the nitrogen dioxides levy have been highlighted as examples of well-designed incentives by the OECD and in an inventory by the European Environment Agency.

The consumer as decision-maker

The individual's choice has a big influence on his or her environmental impact. This applies to everything: from the food we eat, to the way we live, heat our house and how we travel from day to day and when on holiday.

In principle the customer is always right. If we do not want to buy artificially fertilized and pesticide-sprayed carrots, fuel-guzzling cars or electricity from coal power then these products will not be manufactured.

Power to change

By combining a variety of measures it is possible to avoid most environmental problems. A combined strategy could entail increasing the incentives that lead in the desired direction and at the same time weakening or removing those that have the opposite effect. Investment in research and development also plays an important role in building a sustainable future.

But what is needed in order for something to be done? Society is after all made up of people with many different viewpoints. Those who want to develop a sustainable society relatively quickly have not had the strongest voice so far. A fundamental requirement for change is the development of strong opinion in favour of an environmentally sound society, both among individuals and among decision-makers in industry and politics.

For this to happen it requires better knowledge at all levels about both the problems and the opportunities. The spreading of information and knowledge are therefore important tools, initially to gain acceptance for the necessary political decisions. With stronger public opinion on the environment, politicians will feel they have the support to push through effective legislation, including economic incentives.

Last but not least, information can help increase the proportion of the population who choose environmentally healthy products when shopping, which is clearly very important in light of how individual behaviour affects the overall environmental situation. The scope for changing people's lifestyles by means of information alone is however relatively limited according to several studies.

9

Political development

Previous chapters have shown that emissions of air pollutants are much higher than nature can tolerate, but also that it is possible to reduce them greatly – the technology exists and the price is not unreasonable. But what is happening in society, what decisions are being made, are we heading in the right direction?

This chapter first describes various international agreements, then looks at developments within the EU.

INTERNATIONAL AGREEMENTS

At international level there are a number of agreements, or conventions, that have been reached with the aim of regulating emissions of air pollutants.

The climate convention

The basis of international policy for cutting down emissions of greenhouse gases is the UN Framework Convention on Climate Change, which was signed by some 150 nations in the course of the United Nations conference at Rio de Janeiro in 1992. It came into effect in 1994, and by December 2003 this convention had been ratified by 194 parties.

It has as an "ultimate objective" the stabilizing of greenhouse gas concentrations in the atmosphere "at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system."

What that level should be is not indicated. The text merely says that it "should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

It is a stated principle of the convention that the industrialized nations, being responsible for by far the greatest part of the emissions, both now and in the past, should take the lead in combating climate change and its damaging effects.

The convention calls for no legally binding commitments on the part of the signatories. The so-called Annex I countries do however have a non-binding aim to have returned their emissions of greenhouse gases to 1990 levels by the year 2000. These countries, now numbering 41, include members of the former Eastern Bloc as well as the ordinarily recognized industrialized nations. Far from all succeeded in that aim. It could however be said that it was attained if the group's emissions are reckoned as a whole – largely because emissions dropped by almost 40 per cent in the countries with economies in transition.

Binding commitments came at Kyoto

A first step towards quantified commitments as a means of attaining the aim of the climate convention was taken when the Kyoto Protocol was signed in 1997.

Under this protocol the industrialized nations have made legally binding undertakings with regard to their emissions of greenhouse gases for the period 1990 to 2008–2012 (average for the five years). Some countries will be allowed to increase their emissions, or freeze them at current levels, but most will have to make reductions (see table 9.1). The overall reduction for the Annex I countries was expected to be 5.2 per cent when the protocol was signed.

Emissions from aviation and marine bunker fuels used in international transport do not enter into any national undertakings.

The protocol embraces six greenhouse gases that are combined in a "basket", so that individual gases are translated into CO_2 equivalents, which are then added up to produce a single figure.

The base year against which the reductions of the main greenhouse gases – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – will be measured is 1990, except for some countries with economies in transition, while reductions in the emissions of three long-lived industrial gases – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and

TABLE 9.1. Commitments under the Kyoto Protocol. Required changes from 1990 to 2008–12.

Increases (%)	Freezing (%)	Reductions (%)
Iceland +10	New Zealand, Russia, Ukraine 0	Croatia -5
Australia +8		Canada, Hungary, Japan, Poland -6
Norway +1		USA -7
		EU (collectively), Bulgaria, the Czech Republic, Estonia, Latvia, Lithuania, Liechtenstein, Monaco, Romania, Switzerland, Slovakia, Slovenia -8

sulphur hexafluoride (SF_6) – will be measured against either 1990 or 1995.

The protocol emphasizes that "demonstrable progress" towards meeting its aim must have been made by 2005, and reports with evidence of this submitted by January 1, 2006. Talks on targets for the second commitment period must start by 2005.

Details fixed at Bonn and Marrakech

The negotiations at Kyoto took such a long time that when the meeting ended and the protocol had been signed, some unresolved matters still remained. There had been particular difficulty in arriving at rules for the use of flexible mechanisms and carbon sinks, and further meetings had to be held to determine how the protocol was to be interpreted and how it was to function in practice. Much of this was decided at Bonn and Marrakech during the summer and autumn of 2001.

Flexible mechanisms. These include emissions trading and the opportunity for any country to pay for the reduction of emissions in another country, then add the result to its own score. As several of the parties, including the EU, wanted to limit the opportunities to use flexible mechanisms, it was finally decided that if used they should be "supplemental to domestic action," and that such action must constitute "a significant element" of the effort to meet commitments. No limit was however set for the extent to which these mechanisms could be employed.

Carbon sinks concern measures such as deforestation and reforestation that aim to increase nature's ability to bind carbon. Many countries wanted to have the opportunity to count any increased uptake of carbon by trees and soil as a reduction in their emissions. It was decided that sinks could be used up to the limit set for each country in a separate table, although concessions that had to be made to Russia, Canada, and Japan have meant that these countries will now be able to use sinks to a greater extent than other countries.

Sanctions. A party failing to meet its commitments will have its emission quota reduced for the following period by the surplus amount, plus an extra 30 per cent.

US opts out

The United States – which answered for a good third of the Annex I countries' emissions of carbon dioxide in 1990 (see figure 9.1) and has the world's largest emissions per capita – abandoned the protocol in March 2001, with the excuse that it excluded 80 per cent of the world's population and would, moreover, be detrimental to the US economy. In February 2002 President Bush presented a national policy on climate change, with voluntary targets that are likely to lead to an increase in emissions of more than 30 per cent over 1990 levels by 2010. This increase in emissions in the US, combined with full exploitation of carbon sinks, is estimated to mean that the Annex I countries will increase their combined emissions by 9 per cent over the period 1990–2012, instead of reducing them by 5.2 per cent.

The US withdrawal means that the protocol will have to be ratified by almost all the other Annex I countries if it is to be legally binding. It will come into effect after it has been ratified by at least 55 parties to the convention, including Annex I countries representing at least 55 per cent of the carbon dioxide emissions in 1990 from this group. It now only needs Russia to ratify – which it has repeatedly promised to do. Without Russia or the US it cannot come into force.

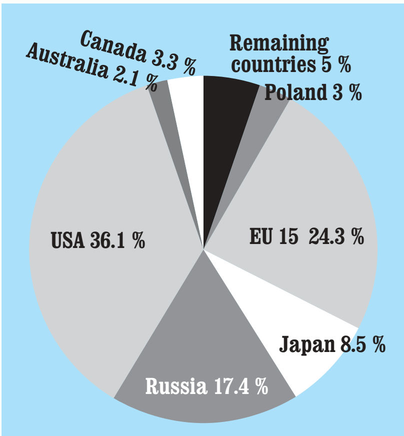


Figure 9.1. The Annex I countries' share of CO_2 emissions in 1990. In order to be enforced, the Kyoto protocol must have been ratified by enough countries to account for 55 per cent of emissions. Since the US (and Australia) do not intend to ratify, Russia must do so to make up the difference.

Continuous negotiation

It is said in the protocol that negotiations concerning the next period for commitments (after 2012) must start at the latest by 2005 (provided that the protocol will come into force).

So far, most of the developing countries have rejected all suggestions that they should cut emissions, maintaining that it is the rich countries that have caused the problem and should therefore be the first to be required to deal with it. But the developing countries' emissions are increasing. The Annex I countries are most likely to demand some form of binding commitment from the developing ones for the period after 2012.

It will be important to decide how reductions are to be distributed. It might be better, instead of using overall percentage figures, to use emissions per inhabitant as the measure. If all individuals were allotted an equal volume of emissions – as might seem reasonable – the industrialized countries would have to reduce their emissions a great deal, while some developing countries could be permitted a slight increase.

The emission levels of individual countries and the reductions that are deemed necessary are presented in chapter 4.

The Convention on Long-range Transboundary Air Pollution

When Sweden and Norway asserted, early in the 1970s, that the acidification of lakes in their countries could be ascribed to the effects of air pollutants transported over long distances, there were many who expressed doubts. But shortly after, in mid-decade, facts came to light that confirmed the theory, and after a period of negotiation, in 1979 some thirty nations signed the Convention on Long-range Transboundary Air Pollution. This is a convention that was worked out within the ECE, the UN Economic Commission for Europe, of which all the countries of Europe are members, as well as the United States and Canada.

In a text that is very generally worded it says that the signatories shall "endeavour to limit and, as far as possible, gradually reduce and prevent air pollution," and in order to fulfil that aim shall "use the best available technology that is economically feasible." The Convention came into force in 1983, after ratification by the legislatures of the required two-thirds of the signatory states.

Sulphur, nitrogen oxides, and VOCs

Of more interest than the Convention text itself are the succeeding protocols. First to come was that on **sulphur** in 1985, in which the twenty-one signatories committed themselves to reducing their emissions of sulphur into the air by at least 30 per cent between 1980 and 1993. Some countries, such as the UK, Poland, and Spain, chose however not to sign. In the event, all those that had signed fulfilled their commitments, and several of those that had not – including the three just mentioned – did in fact cut their emissions by more than 30 per cent. Those that succeeded best were Austria, Sweden, and Finland, all of which attained 80-per-cent reductions.

The next was the protocol on **nitrogen oxides** of 1988, ratified by twenty-eight countries agreeing to restrict their emissions to 1987 levels after 1994. As an expression of dissatisfaction at the weakness of this protocol, twelve countries issued an independent declaration promising to reduce emissions of nitrogen oxides by 30 per cent by 1998, from the levels of any year between 1980 and 1986. The figures for 1994 show that several countries did not manage to fulfil even the modest commitment to freeze their emissions. Of the twelve that were aiming at a 30-per-cent reduction, less than half succeeded. It should perhaps be noted that no penalties are to be imposed, either in the Convention or in the protocols, for failure to live up to commitments.

A protocol on the limitation of **volatile organic compounds** was ready in 1991. Ratified by twenty-one nations, this protocol allows several options. Most countries have agreed to reduce their emissions of hydrocarbons by 30 per cent by 1999 (from what they were in 1988 or any other year between 1984 and 1990). Three countries with low emissions need only ensure that their figures do not exceed 1988 levels. Emission statistics indicate that at least eight of the countries that signed for a reduction of 30 per cent have failed to live up to their commitment.

The **second sulphur protocol** was signed in 1994 and has been ratified by twenty-four individual countries as well as the EU. This protocol used a new approach – the so-called critical loads concept – with computer models being used to estimate the likely cost and possible effects of assumed future emission scenarios. This effects-based approach meant that different requirements were set for each country – the aim being to attain the greatest effect for the environment at the least overall cost. Some not very rigorous requirements for large combustion plants are also included in this protocol.

In 1998 two new protocols were added to the Convention. One, which aims to reduce emissions of **heavy metals**, concentrates initially on cadmium, lead, and mercury. The aim of the other is to control, reduce, or eliminate emissions of **persistent organic pollutants** (POPs) into the environment. Sixteen substances are the declared targets of a first step, although – as in the case of heavy metals – new ones can be added later. These two protocols came into force in 2003.

The Gothenburg Protocol

The most recent agreement under the Convention is the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone – also called the multi-effect protocol, which aims to cut emissions of four pollutants: sulphur dioxide, nitrogen oxides, volatile organic compounds, and ammonia, by setting country-by-country emission ceilings to be achieved by the year 2010. It was formally adopted in Gothenburg, Sweden, in December 1999, and has been signed by 31 countries.

In technical terms this was a complicated task that required, among other things, further development of the RAINS computer model in order to handle the large and growing amount of information about emissions, the costs of measures, distribution of deposition and effects, etc., in each European country. On the basis of an analysis of different emission scenarios, the countries reached agreement on the environmental targets that should be achieved in each area by 2010. In the next phase the model was used to divide the emission reductions needed to achieve the agreed environmental targets between the various countries. As in the second sulphur protocol this resulted in different requirements for different countries. The

TABLE 9.2. Signatories of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. (Canada and United States excluded.) For each country figures are given for emissions in 1990, their undertakings by 2010 (in both cases in thousands of tonnes) and the percentage change over the period. Countries in bold type have ratified. (Emission data 1990 from EMEP, undertakings 2010 and status of ratification from CLRTAP Secretariat, December 2003.)

	Sulphur dioxide			Nitrogen oxides			VOCs			Ammonia		
	1990	PRO	Change %	1990	PRO	Change %	1990	PRO	Change %	1990	PRO	Change %
Austria	79	39	-51	204	107	-48	345	159	-54	52	66	27
Belgium	362	106	-71	334	181	-46	274	144	-47	99	74	-25
Denmark	180	55	-69	277	127	-54	162	85	-48	133	69	-48
Finland	260	116	-55	300	170	-43	224	130	-42	38	31	-18
France	1323	400	-70	1897	860	-55	2473	1100	-56	779	780	0
Germany	5322	550	-90	2728	1081	-60	3220	995	-69	736	550	-25
Greece	493	546	11	290	344	19	255	261	2	79	73	-8
Ireland	186	42	-77	118	65	-45	111	55	-50	112	116	4
Italy	1651	500	-70	1938	1000	-48	2041	1159	-43	466	419	-10
Luxemb.	15	4	-73	23	11	-52	19	9	-53	7	7	0
Netherl.	202	50	-75	570	266	-53	492	191	-61	232	128	-45
Portugal	273	170	-38	272	260	-4	371	202	-46	106	108	2
Spain	2102	774	-63	1207	847	-30	1555	669	-57	327	353	8
Sweden	106	67	-37	334	148	-56	498	241	-52	554	57	-90
UK	3719	625	-83	2759	1181	-57	2425	1200	-51	341	297	-13
EU 15	16273	4044	-75	13251	6648	-50	14465	6600	-54	3561	3128	-12
Armenia	72	73	1	46	46	0	81	81	0	25	25	0
Bulgaria	2008	856	-57	361	266	-26	217	185	-15	144	108	-25
Croatia	180	70	-61	88	87	-1	105	90	-14	37	30	-19
Czech R.	1881	283	-85	544	286	-47	441	220	-50	156	101	-35
Hungary	1010	550	-46	238	198	-17	205	137	-33	124	90	-27
Latvia	95	107	13	80	84	5	143	136	-5	44	44	0
Liechtens.	0.11	0.11	0	0.52	0.37	-29	0.99	0.86	-13	0.20	0.15	-25
Moldova	265	135	-49	100	90	-10	157	100	-36	49	42	-14
Norway	52	22	-58	224	156	-30	294	195	-34	23	23	0
Poland	3210	1397	-56	1280	879	-31	831	800	-4	508	468	-8
Romania	1311	918	-30	546	437	-20	772	523	-32	300	210	-30
Slovakia	542	110	-80	215	130	-40	262	140	-47	63	39	-38
Slovenia	196	27	-86	63	45	-29	44	40	-9	24	20	-17
Switzerl.	42	26	-38	154	79	-49	279	144	-48	72	63	-13

requirements were assigned according to cost-effectiveness, i.e. to achieve the environmental targets at the lowest overall cost for Europe as a whole.

However, when the time came for the final negotiations it turned out that none of the countries was prepared to reduce emissions as much as needed to achieve the environmental targets. Instead there were more negotiations and compromises – the final results are shown in table 9.2.

Dealing with several environmental effects and several pollutants in a coordinated manner, in a single protocol, should boost overall cost-effectiveness. Provided that the signatories to the protocol actually stick to the ceilings set for them, and that the emissions in the non-signatory countries do not increase, overall European emissions of sulphur dioxide may be expected to fall by at least 63 per cent, nitrogen oxides and volatile organic compounds by 40 per cent, and ammonia by 17 per cent, between 1990 and 2010.

While the agreed emission reductions provide another important step in the right direction, they are far from sufficient for achieving the environmental quality targets for 2010 that were agreed by European countries in January 1999. Compared with what will be needed to meet the internationally agreed long-term aim – no more exceeding of the critical loads for pollutants anywhere – they are of course even more inadequate.

The Gothenburg Protocol is scheduled for review and revision around 2004–2006. But such negotiations must wait until the protocol is brought into force, which requires that sixteen countries must have ratified. So far (December 2003) only six countries have done so.

Improvements and uncertainties

The effects the Gothenburg Protocol is expected to have on people and the environment are shown in table 9.3. As can be seen from the table there will be a tangible reduction in the area over which critical loads for acidification and eutrophication are exceeded, although extensive problems still remain. The changes can be seen in figure 5.5 (page 91) and 6.2 (page 110).

It should be noted that the information in table 9.3 is laden with uncertainty. Alternative estimates for Sweden, with

Table 9.3. Expected effects on the environment of the Gothenburg Protocol ("PRO") by 2010. The figures assume that all signatory countries do as promised under the Gothenburg Protocol (see table 9.2) and that emissions in non-signatory countries develop as officially projected. The column headed "change" gives the percentage reduction compared with 1990. (Integrated Assessment Modelling for the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Europe. M. Amann et al., 1999.)

	Acidification[1]			Ozone AOT60[2]			Ocone AOT40[3]			Eutrophication[4]		
	1990	PRO	Change %	1990	PRO	Change %	1990	PRO	Change %	1990	PRO	Change %
EU 15	37.0	5.3	-86	1260	398	-68	12.4	6.8	-45	66.8	47.6	-29
Non-EU countries	56.3	9.8	-83	305	82	-73	9.5	5.4	-43	98.5	60.7	-38
Total for Europe	93.3	15.2	-84	1566	480	-69	21.9	12.2	-44	165.3	108.4	-34

1 Area of ecosystem where deposition of acidifying substances exceeds the critical load (units: million hectares).

2 Cumulative exposure index for health effects of ozone (million inhabitants × ppm × hours).

3 Cumulative exposure index for effects of ozone on vegetation (km^2 × excess × ppm × hours).

4 Area of ecosystem where deposition of nitrogen exceeds the critical load for eutrophication (million hectares).

higher-resolution data for deposition and critical loads, show that the area that is overloaded with acid deposition is around three times larger than indicated. Note also that the figures refer to the area where the critical load is exceeded, not the real environmental situation. In many ecosystems it is probable that it will take decades, perhaps centuries, for viable living conditions to be restored for many organisms.

Shipping and aviation

One large but almost wholly unregulated source of emissions of sulphur dioxide and nitrogen oxides is shipping (see factfile on next page). The air pollution annex to the MARPOL convention, which was adopted by member countries of the UN's International Maritime Organization (IMO) in autumn 1997, leaves a lot to be desired. It has proved very difficult to get the IMO to incorporate environmental policy in its activities, partly because the voting rights are based on vessel ton-

EMISSIONS FROM SHIPPING

The emissions of air pollutants from ships engaged in international trade in the seas surrounding Europe – the Baltic, the North Sea, the north-eastern part of the Atlantic, the Mediterranean and the Black Sea – were estimated to have been 2.6 million tonnes of sulphur dioxide (SO_2) and 3.6 million tonnes of nitrogen oxides (NO_x) a year in 2000.

While emissions from land-based sources are gradually coming down, those from shipping show a continuous increase. As a result, when the fifteen EU member countries have fulfilled their commitments in accordance with the directive on national emission ceilings, and assuming that the growth in emissions from shipping will be 3 per cent per year, by 2010 the latter will be equivalent to four-fifths of the EU total for sulphur and nearly three-quarters of that for nitrogen oxides (see table below).

	Sulphur dioxide (SO_2)		Nitrogen oxides (NO_x)	
	land-based	shipping	land-based	shipping
1990	16.4	2.0	13.4	2.8
2000	5.8	2.6	9.5	3.6
2010	3.9[1]	3.3[2]	6.6[1]	4.6[2]

[1] Projection according to the EU directive on national emission ceilings.

[2] Assuming an annual growth of 3 per cent.

nage, which gives a strong influence to a small number of flag countries that have large shipping fleets.

The situation is almost as bad when it comes to aviation and air pollution. The UN's International Civil Aviation Organization (ICAO), has only just begun to take environmental issues into account, and the requirements that are imposed on emissions and noise are very generous. Emissions from the aviation sector are currently relatively low, but are growing rapidly. There are also fears that emissions at high altitudes have powerful effects on climate.

THE EU AND THE AIR

Up to the early nineties, EU policy in regard to air pollution had tended to be fragmented. Such directives as existed were either those setting air quality standards for a few selected air pollutants or others to control emissions from certain defined sources such as large power plants and road vehicles.

Strategic approach

Some first steps towards a more clearly aimed and strategic policy could be seen in the fifth environmental action programme, which was presented in 1992 and contained proposals for long-term environmental objectives both for air quality and acidification.

The former stated that "all people should be effectively protected against recognized health risks from air pollution," and that "permitted concentration levels of air pollutants should take into account the protection of the environment." For the acidifying, ozone-forming, and eutrophying pollutants – sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia – the aim was that there should be "no exceeding ever of critical loads and levels".

Also dating from 1992 was the auto-oil programme, aimed at setting new environmental requirements for road vehicles and motor fuels. The requirements were to match certain defined aims for air quality and accord with the World Health Organization guidelines. They were to be cost-effectively attained by 2010. That programme, which was concluded in 1996, resulted in several new directives being adopted in 1998 and 1999.

The mid-nineties also saw the emergence of a framework directive on air quality as well as a completely new directive for the integrated prevention and control of the pollution of air, water, and land (IPPC). The framework directive on air quality provided the springboard for various daughter directives setting limits on the concentrations of several individual air pollutants.

Strategy for combating acidification

In the wake of the fifth environmental action programme and under the influence of the Convention on Long-range Transboundary Air Pollution, the Commission presented in March 1997 a strategy for combating acidification within the EU which included an all-sector-embracing analysis to enable some clearly defined environmental targets to be attained as cost-effectively as possible by 2010. Presented as interim targets, these were to be regarded as first steps towards achievement of the long-term objectives of the fifth environmental action programme.

The acidification strategy was later supplemented by a similar one to cut down the concentrations of ground-level ozone. The two of them laid the foundation for a Commission proposal to limit emissions – a directive setting binding national ceilings for the emissions of four acidifying and ozone-forming air pollutants, which was formally adopted in 2001. Moreover, the acidification strategy came to involve a revision and tightening up of two important directives: one for controlling the sulphur content of liquid fuels, and the other on emissions of SO_2, NOx and particles from large combustion plants.

CAFE – Clean Air for Europe

The more strategically oriented work on air quality that was initiated in the nineties will now be followed up by a programme called CAFE, Clean Air For Europe, which was presented by the Commission in 2001. The need for this programme derives from the fact that several directives of importance for emission levels and air quality are due for revision around 2004, and to achieve proper results it will, in the view of the Commission, be necessary to gather them into a single programme. The idea is that CAFE should evolve into an on-going, cyclical programme, in which 2004 will only mark the first milestone. It will also be the first of the so-called thematic strategies announced in the sixth environmental action programme.

The CAFE programme will deal mainly with particles and ground-level ozone, both because of their serious effects on health, and the fact that much will have to be done if concentrations are to be brought down to acceptable levels. Outstanding problems in respect of acidification and eutrophication will however also be given attention, and a watch will be kept on developments with regard to pollutants that are as yet unregulated, as well as on what is happening in "hot spot" areas with exceptionally extensive pollution.

One advantage of this more strategic and resolute action at EU level, as envisaged in the CAFE programme, is that it should be able to bring about a more rapid and pronounced reduction in member states' emissions of pollutants. A further consideration is that such action by the EU will make it possible to put greater pressure on other European countries, outside the EU, to reduce their emissions by taking a more active stance in the context of the Convention on Long-range Transboundary Air Pollution.

Directives and decision making

EU legislative measures that directly affect emissions and concentrations of air pollutants are listed in the factfile pages 162–163. Over and above these there are however a number of directives and other moves at EU level that can have an indirect effect – such as those aimed at reducing the emissions of greenhouse gases, and others capable of influencing developments in the energy, transportation and agricultural sectors.

Most EU decisions on environmental issues are reached by means of a codecision procedure, which means that the European Parliament has an equal say in the matter as the Council of Ministers. As a result the decision-making process can be fairly long-winded – it often takes two years between a proposal from the Commission and the final decision being taken by the Council of Ministers.

Climate-changing gases

In the run up to the 1997 climate convention in Kyoto the negotiating position of the EU countries was that emissions of greenhouse gases should be reduced by 15 per cent between 1990 and 2010, but the reduction that was agreed after the negotiations was 8 per cent (despite the Commission showing that a reduction of 15 per cent would be profitable for the EU).

In the negotiations that followed the Kyoto Protocol the EU countries played a driving role, and the Commission put forward a series of strategies, programmes and proposals to enable the union to meet its undertaking to reduce emissions by 8 per cent. The way in which this collective undertaking is shared between the member countries is shown in table 4.2 (page 71). Over the period 1990–2000 emissions have fallen by 3.5 per cent.

The environmental target set by the Council of Ministers is that the mean global temperature should not rise by more than 2°C above the pre-industrial level, and that a carbon dioxide concentration of less than 550 ppm should be the guiding figure for global restriction and reduction measures.

Sustainable development

In 1998 the Cardiff process was established in the EU in an effort to integrate environmental issues in all EU policy, for example in trade, structural funds, agriculture, energy and transport. So far there have been few visible results, but this work could be important in the longer term. At a meeting of heads of state and government (European Summit) in Gothenburg in June 2001 a rather generally formulated sustainability strategy was adopted for the EU, which highlights the climate issue as a priority area.

Good or bad?

In order to balance the relatively positive picture of EU environmental work that is given above it is fair to mention some negative aspects too.

- The main goal of the EU is to develop a free internal market, which could result in extensive goods freight.
- Countries that have low environmental ambitions can successfully veto important decisions. It has, for example, been impossible to introduce a substantial tax on carbon dioxide emissions so far. The reason is that decisions on harmonized taxes require unanimous agreement between all member countries.
- EU structural funds (which give support to the poorest member countries) and the Trans European Networks project are subsidizing large investments in new transport infrastructure, in many cases in the form of new roads. Substantial subsidies to agriculture also counteract environmental targets to a large extent.
- The EU decision-making process is largely closed, which reduces the opportunities for transparency and effective influencing of public opinion. The organization also favours those parties that are economically strong and have the ability to supply the Commission with their own analyses and information.

Whether the EU as a whole is good or bad for the environment is a question that can hardly be answered. Even if the analysis is limited solely to air pollution there are no simple answers. It is however clear that, in recent years, the cooperation has spurred on those countries that were previously "worst in class" and which are still dragging their heels. On the other hand, the countries that are pushing for improvement could possibly have made even more headway if they had not been forced to make compromises.

Expansion into the east

A number of eastern and central European countries are to become members of the union over the next few years, which could lead to some improvement in the environmental situation in Europe. However, the effect is not expected to be dramatic. There is also a risk that existing member countries will slacken the pace to allow the new members to catch up with their legislation. In any event it is clear that the decisions that are taken within the union already have a large influence on environmental work in the candidate countries, since harmonization with EU regulations is a condition for membership. On the other hand many of these changes would probably be implemented anyway, regardless of EU membership.

EU DIRECTIVES AFFECTING EMISSIONS AND CONCENTRATIONS OF AIR POLLUTANTS

In the case of products that can travel across national borders, such as vehicles and fuels, the EU requirements are usually harmonization requirements, i.e. the same requirements must apply in all member countries. Stationary installations (e.g. combustion plants) and air quality standards are instead covered by minimum requirements, i.e. each member country is free to set stricter national requirements if it wishes.

Directive on national emission ceilings for acidifying and ozone-forming air pollutants (2001/81/EC): Sets binding ceilings to be attained by each member state by 2010. Covers four air pollutants: sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia. The directive covers the same pollutants as the Gothenburg Protocol (see page 152) and both have developed in parallel. Table 9.4 shows each country's undertaking. The member countries' aggregate emissions of these four pollutants are to be reduced by 77, 51, 54, and 14 per cent respectively between 1990 and 2010. In comparison with the Gothenburg Protocol the differences in emission undertakings are not that large. More importantly, the EU legislation means that the countries that do not fulfil their undertakings can be brought before the European Court of Justice and fined.

The directive is scheduled for review and revision in 2004, when it is expected that proposals will be made to extend it to small particles and to set new ceilings. The aim of the directive is to limit emissions in order to move towards the long-term objectives of not exceeding critical loads and of effective protection of all people against recognized health risks from air pollution.

Control of emissions from large combustion plants (2001/80/EC): Covers plants with a rated thermal capacity of at least 50 MW. Contains emission limits for sulphur dioxide, nitrogen oxides and dust, varying according to the age and capacity of the plants, as well as the type of fuel burned. Not only tightens up the requirements for new plants, but also introduces for the first time emission limits for existing ones. Review and possible revision expected in 2004.

Sulphur content of certain liquid fuels (99/32/EC): Sets the maximum permitted concentration for sulphur in heavy fuel oil used in the EU at 1 per cent as from 2003, and for gas oils at 0.2 per cent, to be reduced to 0.1 per cent from 2008. Discussions are proceeding on a Commission proposal for revision in order to include marine bunker fuel (heavy fuel oil used in ships).

Quality of petrol and diesel fuels (2003/17/EC): Prescribes 350 and 150 ppm as maximum sulphur content for diesel and petrol respectively. As of 2005 the figure will be lowered in both cases to 50 ppm (0.005 per cent) and by 2009 it will be lowered even further, to 10 ppm.

Emissions of air pollutants from road vehicles: Three directives addressing mainly the emissions of nitrogen oxides, non-methane volatile organic compounds, and small particles. The directive for passenger cars and light commercial vehicles (98/69/EC) specifies emission standards to be introduced in two steps – the first put in place in 2000 and the second coming into force in 2005. Directive 99/96/EC takes a similar stepwise approach for heavy vehicles, but with the inclusion of a third step (for 2008). Directive 97/24/EC, as amended by 2002/51/EC, sets emission standards for two and three-wheeled vehicles, mopeds and motorcycles.

Framework directive on ambient air quality assessment and management (96/62/EC): Provides the means for setting limit values on the concentrations of pollutants in the air through daughter directives. See factfile on page 42 for details. Review and revision of the first daughter directive is expected to take place in 2004.

IPPC, Integrated pollution prevention and control (96/61/EC): Aims at preventing or reducing pollution of air, water and land through a comprehensive system of permits. It applies to a significant number of activities, mainly industrial. Since the end of 1999 new installations are required to have a permit issued in compliance with the directive, which means they are expected to employ best available techniques (BAT). The same applies to existing plants, which however have until 2007 to comply. Guidance as to what is regarded as BAT for various sectors of industry is given in reference documents, so-called brefs. The bref for large combustion plants is expected to be adopted in 2004. (Altogether 30 to 35 brefs will be published and regularly updated).

Use of solvents in industry (99/13/EC): Intended to cut down the emissions of volatile organic compounds arising from the use of organic solvents in some twenty industrial processes. Concerning the VOC content of paints and varnishes, the Commission proposed in December 2002 to set EU limits in two stages, starting in 2007.

Emissions from engines for non-road machinery (97/68/EC): Applies only to compression (diesel) engines with power outputs of 18 to 560 kilowatts. The new directive 2002/88/EC extends the scope of directive 97/68/EC so that it also covers small spark-ignition (petrol) engines such as are used in lawn mowers, chainsaws, etc. In December 2002 the Commission proposed to set stricter limits on the emissions of NOx and particles from diesel engines in two steps, in 2006 and 2011. Emissions from tractors used for instance in agriculture and forestry are regulated by directive 00/25/EC.

Emissions from pleasure boats (2003/44/EC): An amendment to directive 94/25/EC, this regulates emissions of air pollutants as well as noise. Its main effect as regards air pollutants will be to reduce emissions of VOCs from new two-stroke marine engines sold after 2005.

A Community Strategy on Air Pollution from Sea-going Ships was presented in November 2002. It includes among others a proposal for modifying directive 99/32/EC on the sulphur content of liquid fuels so as to extend its scope to include heavy bunker fuel oils (see above). It also announces the Commission's intention to investigate and put forward proposals for economic instruments.

TABLE 9.4. Emissions by EU countries in 1990 and undertakings for 2010 in the national emission ceilings (NEC) directive (1000 tonnes).

	SO_2		NO_x		VOC		NH_3	
	1990	2010	1990	2010	1990	2010	1990	2010
Austria	79	39	204	103	345	159	52	66
Belgium	362	99	334	176	274	139	99	74
Denmark	180	55	277	127	162	85	133	69
Finland	260	110	300	170	224	130	38	31
France	1323	375	1897	810	2473	1050	779	780
Germany	5322	520	2728	1051	3220	995	736	550
Greece	493	523	290	344	255	261	79	73
Ireland	186	42	118	65	111	55	112	116
Italy	1651	475	1938	990	2041	1159	466	419
Luxemb.	15	4	23	11	19	9	7	7
Netherl.	202	50	574	260	492	185	232	128
Portugal	273	160	272	250	371	180	106	90
Spain	2102	746	1207	847	1555	662	327	353
Sweden	106	67	334	148	498	241	54	57
UK	3719	585	2759	1167	2425	1200	341	297
Sum EU	16273	3850	13255	6519	14465	6510	3561	3110

FURTHER INFORMATION

Publications

Acid News. Magazine with reports mainly from Europe on the problems of acidification and air pollution, and measures that are being taken to counteract them. Four issues a year, delivered free on request. Published by the secretariat. Also available in electronic format, see www.acidrain.org

Europe's environment: the third assessment (2003). 341 pp. Published by the European Environment Agency, Kongens Nytorv 6, 1050 Copenhagen K, Denmark. Internet: www.eea.eu.int

Environmental signals. Indicator report, intented to be published annually by the European Environment Agency. The EEA also publishes reports on trends in European air quality. EEA, address as above.

Integrated Assessment Modelling for the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Europe (1999). By M. Amann, et al. Publicatiereeks lucht & energie nr. 132. 65 pp. Published by the Dutch Ministry of Housing, Spatial Planning and the Environment. Available from Distributiecentrum VROM, Postbus 2727, 3440 GC Nieuwegein, The Netherlands. Also available at www.iiasa.ac.at/rains.

Cost-Benefit Analysis for the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Europe (1999). By M. Holland, et al. Publicatiereeks lucht & energie nr. 133. 84 pp. Published by the Dutch Ministry of Housing, Spatial Planning and the Environment. Available from Distributiecentrum VROM, address as above.

EMEP reports. Annual reports from the Convention on Long-range Transboundary Air Pollution giving the latest figures on national emissions and transboundary fluxes of air pollutants within Europe. Available from the Norwegian Meteorological Institute, Box 43-Blindern, N-0313 Oslo 3, Norway. Internet: www.emep.int.

Modelling and Mapping of Critical Thresholds in Europe: CCE Status Report 2003 (2003). Eds. M. Posch, J-P Hettelingh, J. Slootweg and R.J. Downing. A report explaining how the mapping of critical loads is done, including background material supplied by each country, as well as resulting maps. 132 pp. Can be ordered from The Coordination Centre for Effects, c/o RIVM/MNV, P.O. Box 1, 3720 BA Bilthoven, The Netherlands. Also available in pdf format, together with previous reports, at www.rivm.nl/cce.

Global assessment of acidification and eutrophication of natural ecosystems (1999). By L. Bouwman and D. van Vuuren. Published by UNEP/RIVM. The full report is available in pdf format at www.rivm.nl/env/int/geo.

Ground-Level Ozone – A Threat to Vegetation (1999). Edited by H. Pleijel. A general survey of the problem of ground-level ozone, especially in regard to its effects on crops, forest trees, and natural vegetation. Report 4970. 112 pp. Published by the Swedish Environmental Protection Agency, 106 48 Stockholm, Sweden. E-mail orders: natur@cm.se

A Warmer World (2003). By C. Bernes. A popular presentation of the climate change problem. Presents, in addition, new projections of what could happen to the climate of Europe over the next hundred years. 168 pp. Published by the Swedish Environmental Protection Agency, address as above.

IPCC Third Assessment Report: Climate Change 2001. Synthesis Report. Contains the Synthesis Report itself, the Summaries for Policymakers and Technical Summaries of the three Working Group volumes, and supporting annexes. 398 pp. Published by the Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge CB2 2RU, England. Internet: www.cambridge.org/ipcc. Extensive summaries are available in several languages in pdf format from www.ipcc.ch/pub/reports.htm.

Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide (2003). Report on a WHO Working Group. 94 pp. Published by WHO Regional Office for Europe, Copenhagen, Denmark. Avaible at: www.euro.who.int/document/e78992.pdf

Air Quality Guidelines for Europe. Second Edition. (2000) WHO Regional Publications, European Series, No. 91. 273 pp. Published by WHO Regional Office for Europe, Copenhagen, Denmark. Also available online at www.who.dk.

Yearbook of International Co-operation on Environment and Development 2002/2003. (2002) Eds. O. S. Stokke and O. B. Thommessen. Provides key data concerning the most important international environmental agreements, a series of articles by independent experts, and presentations of major intergovernmental organizations as well as NGOs. 334 pp. By the Fridtjof Nansen Institute, published by Earthscan Publications, 120, Pentonville Road, London N1 9JN, UK. See also www.greenyearbook.org.

Film

Sex, Sulphur, and a Fishy Business is the name of a film with the subtitle "A kind of twisted documentary on acid rain in Scandinavia". It explains acidification problems in an unconventional way. Available from the Secretariat, single copies free of charge.

Internet

An updated list of links to relevant websites can be found at www.acidrain.org/links.htm.

CREDITS

Photographs

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THE SWEDISH NGO SECRETARIAT ON ACID RAIN

The essential aim of the Swedish NGO Secretariat on Acid Rain is to promote awareness of the problems associated with air pollution, and thus, in part as a result of public pressure, to bring about the required reduction of the emissions of air pollutants. The eventual aim is to have those emissions brought down to levels – the so-called critical loads – that the environment can tolerate without suffering damage.

In furtherance of these aims, the secretariat operates as follows, by

- Keeping under observation political trends and scientific developments.
- Acting as an information centre, primarily for European environmentalist organizations, but also for the media, authorities, and researchers.
- Publishing a magazine, Acid News, which is issued four to five times a year and is distributed free of charge.
- Producing and distributing information material.
- Supporting environmentalist bodies in other countries by various means, both financial and other, in their work towards common ends.
- Acting as coordinator of the international activities, including lobbying, of European environmental organizations, as for instance in connection with meetings of the Convention on Long-Range Transboundary Air Pollution.
- Participating in lobby and campaign activities in connection with development of EU legislation relating to air quality and climate change, as well as meetings of the UN Framework Convention on Climate Change.

The work of the secretariat is largely directed on the one hand towards central and eastern Europe (the accession countries, Russia and Ukraine), and on the other towards the European Union and its member countries. By emitting large amounts of sulphur and nitrogen compounds, all these countries add significantly to acid depositions over Sweden.

As regards the eastern European countries, activity mostly takes the form of supporting and cooperating with the local environmentalist movements. Since 1988, for instance, financial support has been given towards maintaining information projects on energy, transport and air pollution. All are run by local environmentalist organizations.

The secretariat was formed in 1982 with a board now comprising one representative from each of the following organizations:

- Friends of the Earth Sweden
- Swedish Anglers' National Association
- Swedish Society for Nature Conservation
- Swedish Youth Association for Environmental Studies and Conservation
- World Wide Fund for Nature Sweden