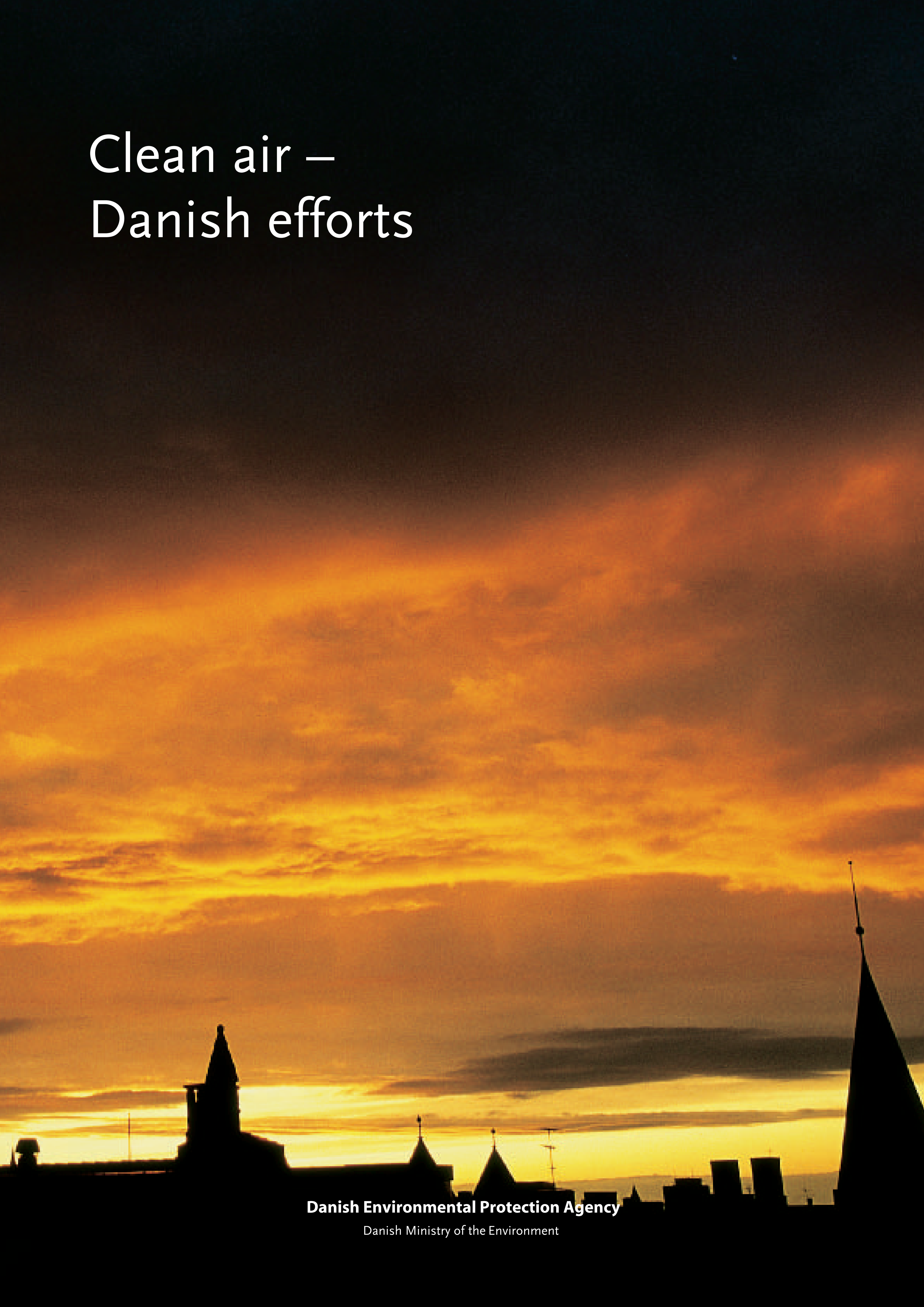

Clean air – Danish efforts

Danish Environmental Protection Agency

Danish Ministry of the Environment

Clean air – Danish efforts

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Preface

Pure air is a human right, as are clean drinking water and food. Polluted air is hazardous and has negative impacts not only on Man, but also on soil, water areas, plants and animals and Man.

Unfortunately it is not possible to secure air that is completely free of pollution. Human activities will always put pressure on our atmospheric environment to a larger or smaller extent. But recent decades have shown that it is possible to limit the pressure significantly.

Within the UN Economic Committee for Europe, UNECE, the agreement on the Gothenburg Protocol is a large step towards limitation of air pollution in the whole of Europe. The protocol will result in less disease and fewer premature deaths due to poor air quality. And it will benefit the fauna and flora that is today exposed to acidification and eutrophication.

The protocol is a good example of a modern, rational and economically efficient strategy. Clear-cut targets for the environmental improvements expected have been set up. The emissions will be reduced most where action is cheapest and has the largest effect. And several compounds are regulated at the same time, to account for their comprehensive impact. Actions are taken in international co-operation and on a scientific basis.

On the occasion of the Danish ratification of the protocol in June 2002 the Ministry of the Environment publishes this leaflet in order to give a broad outline of the Danish and international efforts to combat air pollution and present the state of our atmospheric environment. Although we have made great efforts, not all problems are solved. We must put greater resources into the investigation of the health aspect of particles – and especially the fine particles – in the air. But also other pressures, e.g. nitrogen and dioxin, must be reduced.

In the global perspective we have made great efforts to fully outphase the ozone depleting compounds in Denmark, but internationally Denmark has still an important role to play.

The greatest challenge we are facing today is, however, the threat of climate changes caused by human activities. All observations indicate that the global population – with its emissions of greenhouse gasses – influences the global climate and has started a process whose longsighted consequences we can only guess. The Danish Government has met this challenge with a very ambitious target set out in the Kyoto Protocol under the UN Climate Convention. Even though we have come very far in relation to a number of issues, the many different environmental problems presented in this pamphlet will probably be in focus also in the years to come.

Steen Gade
Director-General
Danish Environmental Protection Agency

A problem of increasing dimensions

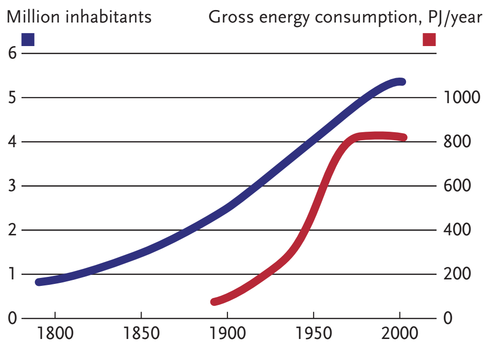
Since the beginning of the 19th century the world population has increased from about one to six billions. The energy consumption has increased even more. Together with increased agricultural production, this growth has resulted in increasing air pollution with significant impacts.

The London smog with sulphur dioxide and soot was notorious for centuries, and it was not before a catastrophic episode in 1952, when pollution was than 20 times higher and there were several thousand extra deaths, that effective legislation was carried through. A corresponding – but less dramatic – development has been seen in Copenhagen.

Across all borders

To begin with the problem was partly solved by dispersing pollution from high stacks, but of course it did not disappear. Instead most of the sulphur dioxide emitted in Denmark was carried with the wind to other countries, predominantly Sweden and Norway.

In this way the precipitation was acidified, resulting in ecological damages in large parts of Europe – e.g. deaths of fish in a number of Swedish lakes. It had now become a phenomenon with a geographical extension of several thousand kilometres and a time horizon of decades. A UN conference in Stockholm in 1972 created political attention, and in 1979 the Geneva Convention on transboundary air pollution was established and signed. As a result European sulphur emissions have – by use of cleaner fuels and flue gas purification at large combustion plants – been more than halved. The Danish emissions have even been cut down to about one tenth. Also emissions of nitrogen compounds and hydrocarbons that put pressure on the ecosystems have been reduced. In Sweden with many sensitive areas, the loaded area is now halved.



Growth in Danish population and energy consumption
During the 20th century the Danish population more than doubled, from below 2.5 million to more than five million inhabitants. This has resulted in increasing energy consumption and more intensive agriculture and, thus, increasing pressure on the environment.
The population is still slowly increasing, mainly due to immigration, but the energy consumption is stabilised and will be reduced.
The great challenge of the future – both nationally and globally – is to decouple development and environmental pressure: to establish "sustainable development".

In the cities

In step with – and partly because of – the reduction of the transboundary pollution, the air quality in the cities has in several ways been improved.

Today air pollution in many big cities is dominated by emissions from car traffic. And it is a complicated matter, because many different compounds react mutually in the atmosphere, before they start to have impacts – either in the city or at long distances.

The most serious urban problem today appears to be particles. The relations are not fully understood, but especially small particles from diesel cars are thought to be dangerous. In Copenhagen the particles may result in hundreds of extra deaths per year among sensitive persons.

Research and international collaboration

The problem with air pollution used to be simple. Everybody could see the black smoke that came out of a low chimney – and their number was so small that it did not became a serious problem when the smoke was carried with the wind to other places. Now this has changed, because air pollution is dispersed at all geographical scales and the relation between emissions of contaminants, the resulting pollution of the air, and the impact of the pollution, are very complicated.

Effective management therefore requires monitoring and research. We must know the

causes of pollution and how we can solve the problems in the cheapest and most efficient way. Interplay of many technical disciplines is required.

It is necessary to follow the development to detect unfortunate tendencies and to investigate whether regulatory measures have had the expected impact. And these activities must be carried out by international co-operation. If these conditions are fulfilled it will be possible directly to reduce the impact.

When the NEC Directive on national emission ceilings in Europe was acceded in the EU in October 2001 and the Gothenburg Protocol in December 1999, binding limits for permitted levels of air pollution from the individual countries were determined for the first time.

It has been estimated that if the Gothenburg Protocol is fully implemented, the acidified areas in Europe will be reduced by

Air pollution used to be a "here and now" problem. At the fireplace in a house in the Iron Age, the quality of the air could be worse than in a street in a modern city. But when the fire was out, the smoke disappeared and the surroundings were not affected any further. Later the problems increased in scale – both geographically and in time. Today emissions from a Danish power plant can contribute to the acidification of a Swedish lake and be part of the reason why an atoll on the other side of the globe will be submersed in some hundred years. Therefore today's struggle against air pollution is not merely a local matter. It is a question of distribution of burdens between the individual nations and our responsibility towards the coming generations.

85%, the eutrophied areas by 65%, and areas suffering from ozone pressures by 50%. It is further expected that the impact on human health will be significantly reduced. However, emissions of atmospheric pollutants from international shipping are still not under control. In step with reductions of emissions from landbased sources, emissions of i.a. sulphur dioxide from the shipping trade will become increasingly important.

Problems on a global scale

In the industrialised world the problems with transboundary air pollution is recognised, and the technological possibilities for solving them are available, although there is still a long way to go. In the developing countries and in the former communist countries, the economic growth still causes serious environmental damage. However, it is probably only a question of time and use of existing modern technology before the problems will be solved.

What is more serious is that global growth has moved the problems one level up, in terms of both time and geographical extension. Now it is no longer a question of compounds that can be removed by using other fuels and raw materials or by installing filters on stacks and exhaust pipes. When coal, oil or gas are used in the energy sector, the unavoidable end product in the combustion process is the gas carbon dioxide. Together with other greenhouse gasses carbon dioxide is emitted in so large amounts and has so long lifetimes in the atmosphere that the concentration increases globally. This changes the energy balance in the atmosphere and thus poses threats of climate changes that can affect the conditions for both humans and nature on the entire globe.

New challenges

Scientific investigations and international co-operation have become even more important, now that environmental problems have been moved to a global scale with a time horizon of several hundred years. Here model calculations play a decisive role. They not only give an overview of all the data that has been collected in the real world. One can also ask questions like: "What would happen if...?" The answer is not always pleasant.

The content of the leaflet

The leaflet describes first a few basics in the abatement of air pollution. Then a few concrete problems that lead up to the Gothenburg Protocol, and EU's national ceilings for limitation of transboundary air pollution in Europe are addressed. Finally Danish efforts relating to the global problems with depletion of the ozone layer and the anthropogenic climate changes are briefly described.

Information to the reader

Emissions of air pollution are most often indicated as weight (e.g. tons per year). Concentration in the air is expressed in µg (one millionth gram) per cubic meter.

From emissions to impacts

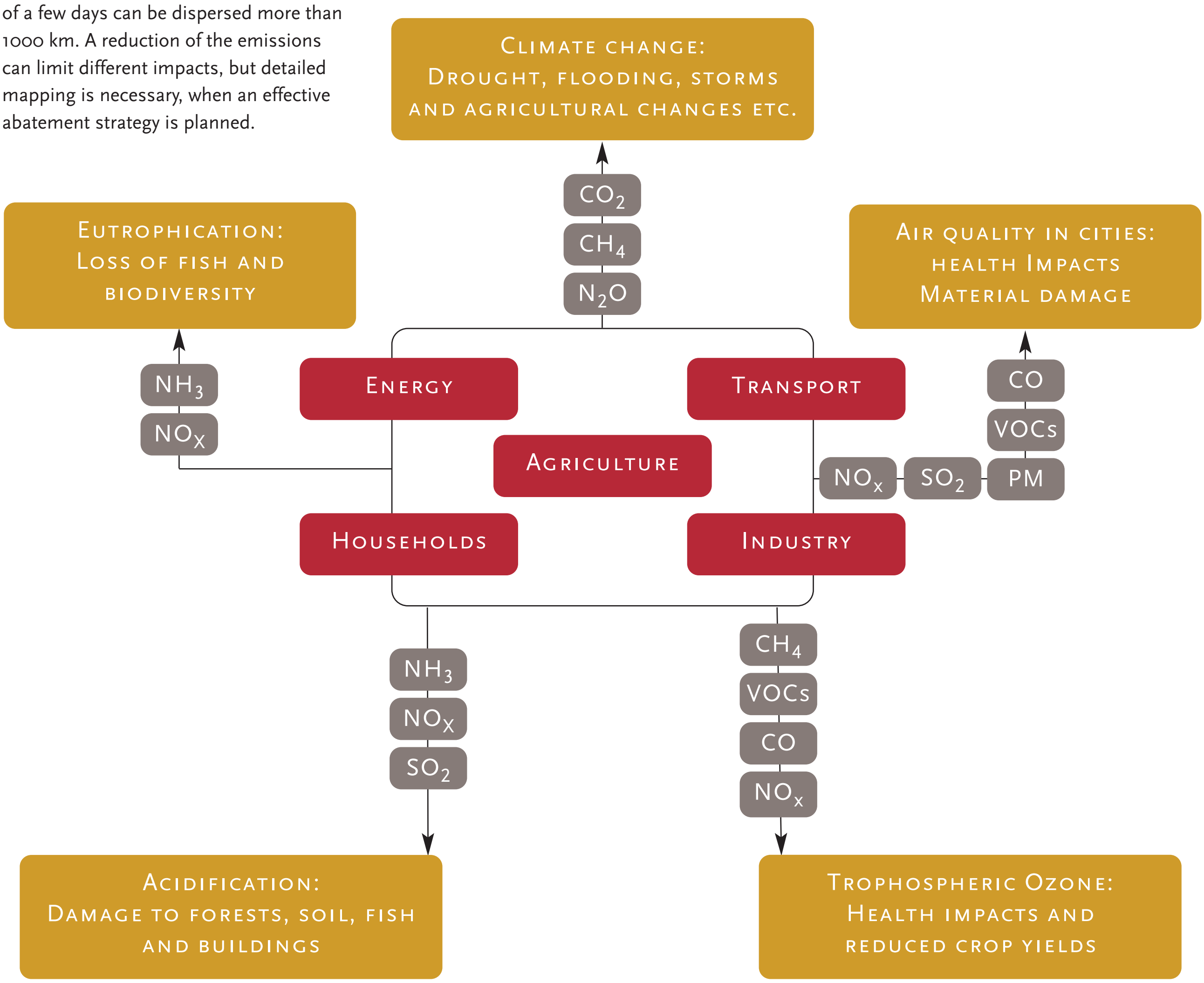
Air pollution may create a number of environmental problems: poor living conditions for animals and plants, health problems with premature deaths among humans, material disintegration and climate changes.

Many compounds have the same impacts, and many sources emit the same compounds. Any reduction of pollution emissions will thus have a series of advantages. A reduction of emissions of sulphur dioxide will thus limit the ecological damages, the degradation of materials and the pressure on human health. It is more complicated for nitrogen oxide, which takes part in a series of chemical processes in the atmosphere.

A further complication is that different areas are not equally sensitive. In this connection the concept *critical load* is defined. Pollution levels below the critical load are expected not to cause significant impacts on nature and the environment.

The critical load is not the same for dif-

The individual compounds come from many sources and have many different impacts that overlap and interact. Compounds with a lifetime in the atmosphere of a few days can be dispersed more than 1000 km. A reduction of the emissions can limit different impacts, but detailed mapping is necessary, when an effective abatement strategy is planned.



ferent areas, but depends on vegetation, soil, climate etc. A calcareous soil in Denmark can, thus, be more robust than sensitive natural areas in e.g. Norway and Sweden.

Pollution sources

Air pollution is mainly caused by combustion, evaporation or biological processes.

Pollution from combustion

Any combustion forms new chemical compounds. The main constituent of the fuel, carbon, reacts with atmospheric oxygen and forms carbon dioxide (CO_2). Some of the atmospheric nitrogen (N_2) "burns" and forms nitrogen oxide (NO_x). Combustion can further be incomplete, leading to formation of carbon monoxide (CO), soot/particles, polyaromatic hydrocarbons (PAH) and different volatile organic compounds (VOC). Finally most fuels contain impurities. Most important is the content of sulphur in coal and oil that burns to sulphur dioxide (SO_2). But also incombustible constituents that may e.g. contain heavy metals are important.

Pollution by evaporation

Volatile fuels (e.g. petrol) can be spilled or evaporate during transport, filling and running. Many processes in industry and crafts (e.g. surface treatment with paint) evaporate organic compounds.

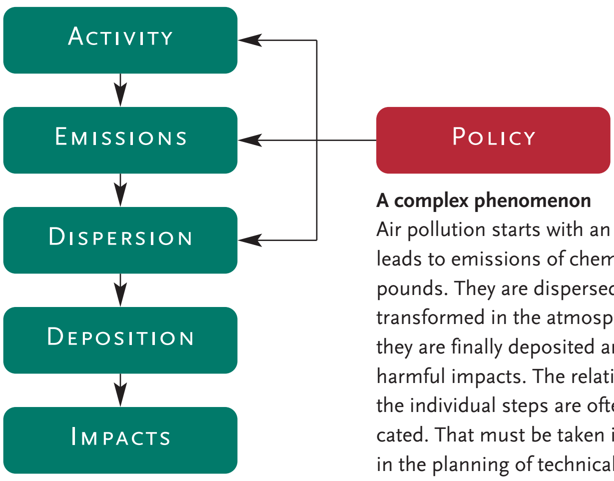
Pollution from biological processes

Biologically related air pollution often arises from agriculture, where storing and use of manure and commercial fertilisers cause formation and emissions of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O). Methane is further formed by anoxic fermentation in the digestive system of domestic animals, especially ruminants, e.g. cows.

Methane and nitrous oxide are also formed by biological processes in wetlands. Human influence in the form of changes of land use can therefore change emissions. The same applies to evaporation of organic compounds from vegetation – especially coniferous. The border between natural and anthropogenic emissions of pollution is, thus, not clear-cut.

Long-range transport of air pollution

The amount of air pollution that is *emitted* in a given country depends upon the size of the country, its degree of industrialisation, its energy sources and many other parameters. But it is absolutely not the same amount that is *deposited*. The possibility that contaminants are carried by the wind means that meteorological conditions are decisive. As appears from the table, a predominantly westerly wind means that countries like Norway and Sweden receive much more air pollution than they emit. The opposite applies for UK, Belgium and Germany. In



A complex phenomenon

Air pollution starts with an activity that leads to emissions of chemical compounds. They are dispersed and possibly transformed in the atmosphere, before they are finally deposited and cause harmful impacts. The relations between the individual steps are often complicated. That must be taken into account in the planning of technically and economically efficient abatement measures.

The significance of long-range transport

Only a minor part of the sulphur emitted will be deposited in the same country. The table shows how much sulphur is emitted in different countries, further the amount that is deposited in the country itself, and finally the total amount that is deposited in the country.

	Emissions	Deposited nationally	Total deposition in country
Denmark	54	7	35
Sweden	34	12	123
Norway	15	5	76
United Kingdom	813	263	333
Germany	705	35	389
Belgium	117	17	44

(Rounded values for 1997 in 1000 t.) (Data from EMEP)

In a street canyon pollution from cars is only dispersed with great difficulty, and high levels can build up. At an open motorway the same emission of contaminants is rapidly dispersed and thus causes much lower local concentrations. But all emissions pollute at longer distances.

all cases only a minor amount of the emitted pollution is deposited in the country itself.

In this game Denmark is for various reasons fortunate. The country's distribution on minor islands means that pollution sources are never located as closely as in foreign megacities or industrial areas. And Denmark has practically no strongly polluting industry. A flat landscape and much wind allow effective dispersion, and because of our predominantly westerly wind in combination with the larger cities being situated on east coasts, large parts of the pollution are blown out of the country. That, however, does not exclude that pollution can arise during special meteorological conditions. Also local urban areas can be strongly polluted – especially in case of heavy traffic.

A complex phenomenon

All these conditions demonstrate that a simple percentage reduction of national emissions is neither fair nor economically effective.

Although air pollution always starts with emissions of substances, normally much happens before the unwanted effects appear. During dispersion the compounds can be transformed before they are deposited on soil and plants or inhaled by humans. Sometimes it is only after the compound has passed a food chain that the harmful effects appear.

Further a series of compounds are not only dispersed with the air, but also through other paths. Eutrophication, with resulting oxygen deficiency, is thus caused both by washing out of nutrients from agriculture and by deposition of nitrogen compounds from the air. For the inner waters the contaminants are also carried in the water.

Danish environmental regulation

Already in the late 1960's air pollution with sulphur dioxide was recognised as air pollution, which had to be limited, if only for health reasons. The sulphur content of fuel oils was therefore regulated in 1972.

The Environmental Protection Act

With the Environmental Protection Act in 1974 the authorities were empowered to restrict i.e. emissions to the air from about 7,000 polluting industries. Together with guidelines on limitation of air pollution the Environmental Protection Act was an efficient instrument to reduce the local environment and health risks presented by industry. The guidelines and the Environmental Protection Act have been revised several times, and in recent years these direct regulatory measures have been supplemented with economic management tools and optional arrangements, e.g. environmental labelling and agreements on energy and environmental management.

The Danish breakthrough in the regulation of emissions of sulphur dioxide and nitrogen oxide came in 1982, when the Acidification Committee was established. Both in Scandinavia and in EEC it was at that time recognised that acidification in sensitive areas could cause significant damages to soil and ecosystems. The Committee was to investigate how the Geneva Convention on transboundary air pollution could be fulfilled, and further, evaluate the need to limit emissions of sulphur dioxide and nitrogen oxide and the technical and economical possibilities of doing so.

The work of the committee was followed up by a reduction of emissions from Danish power plants. The power plants' emissions of sulphur dioxide are limited by flue gas desulphurisation, whereas emissions of nitrogen oxide can be reduced with different technologies. The reduction of emissions from the power plants is continuously strengthened, and today carbon-fuelled power plants operate without flue gas desulphurisation, and only very few power plants do not control emissions of nitrogen oxides. Regulation of emissions from power plants is one of the most important tools in Danish efforts to fulfil our obligations under the Geneva Convention.

Other important elements in the improvement of the air quality are the Ministry of the Environment's current strengthening of the regulations on sulphur content in both oil and coal products, as well as the recent taxes on the sulphur content in fuel and power plant emissions of sulphur dioxide.

Action in the Ministry of the Environment to control air pollution.

Air pollutants	
Sulphur dioxide, SO_2	☺
Lead, Pb	☺
Nitrogen dioxide, NO_2	😐
Carbon monoxide, CO	☺
Volatile hydrocarbons, VOC´s	😐
Dioxins	☹
Particles	☹

☺ The level is acceptable
😐 Not quite acceptable, more should be done
☹ Not acceptable, more shall be done

Dioxin

A serious accident at a factory in Seveso in Northern Italy in 1976 released large amounts of dioxin to the surroundings. Shortly afterwards damages appeared on vegetation, animals and humans. Immediately the world's population realised the tremendous toxicity of dioxin. After the accident attention focused on the sources of dioxin, and major concern was directed towards incineration. The Danish Environmental Protection Agency reacted by closing a number of minor plants without flue gas purification and by tightening the requirements for construction and operation and for purification at the remaining plants. Recently the EU has adopted very strict limits to permissible emissions of dioxin from utilities, and in Denmark similar requirements have been imposed on Danish industries.

Heavy metals

Desulphurisation at power plants and purification of flue gas from incineration plants have together with rules in the air pollution control guidelines reduced emissions of heavy metals, e. g. lead, cadmium, nickel, copper and mercury. In Denmark environmental problems with heavy metals are not as big as in many other countries.

Transport

Within the transport sector Denmark and the EU have taken early action to regulate emissions to the air. During the 1970's increasing awareness arose of the health impact on the nervous system as a consequence of the steadily increasing content of lead in air. There was no doubt that the dominant source was the lead content of petrol, and in 1978 the first of many EU regulations on lead in petrol appeared.

With the phasing out of the lead content in petrol the exhaust gasses from cars no longer contributed an important part of the air pollution, which especially hit the urban population. In 1990 Denmark introduced strengthened requirements to the exhaust from cars: all new cars should be fitted with catalytic converters, and in 1993 a similar regulation was adopted by the EU, which Denmark has since applied. With the strengthened requirements emissions of nitrogen oxide, hydrocarbons and carbon monoxide from cars have been reduced in step with the renewal of the car park with catalytic converters. This has to a large extent been the reason why the limit values for the nitrogen oxide levels in the air have by and large been observed and are expected to be so in the future.

Particles

One of the problems with air pollution that was recognised very early was emissions of dust from incineration plants, power plants and industrial activities. From 1974 air quality guidelines have laid down limits to these emissions, and they are today limited as far as technically possible by means of filters. Health problems related to particles in the air are therefore solely due to emissions from vehicles, especially diesel cars. The Ministry of the Environment has initiated an extensive investigation of how this problem is solved most efficiently.

Monitoring of air pollution

Monitoring of the air quality

The Ministry of the Environment's efforts also include surveillance of the atmospheric content of many compounds, e.g. SO_2, NO_2, lead, carbon monoxide and ozone. Measurements are carried out both in cities and in the countryside. They give a good impression of the exposure of the population to air pollution and how much originates in other countries. A significant supplement to the measurement is model simulations, which can give important information on the possible effects of new interventions to control the pollution level. The calculations can also give a more detailed picture of the geographical distribution of the pollution.

Limit values for air quality

Monitoring of air quality does not in itself indicate whether the pollution level is satisfactory or not. Only when the measurements are compared with health standards can the results be evaluated. In March 1983 the Ministry of the Environment issued its first guidelines setting out limit values for the content of sulphur dioxide and dust. The guidelines served to implement EU directives in Denmark. Later limit values for nitrogen dioxide and ozone were introduced.

In 1996 the EU introduced a new concept for evaluating and managing air quality by adopting a framework directive to be implemented by daughter directives. To date directives have been adopted for the atmospheric content of sulphur dioxide, nitrogen oxides, particles, lead, benzene, carbon monoxide and ozone. A directive on the atmospheric content of arsenic, cadmium, nickel and PAH is being drawn up. Limit values and the Danish levels are mentioned in the following sections.

Most important Danish legislation on air pollution control:

September 6, 1972:
Limits to sulphur in oil

June 13, 1973:
Environmental Protection Act entering on force in 1974 provides for environmental approval and reduction of pollution from industrial enterprises.

June 21, 1977:
Regulation of lead in petrol.

March 24, 1983:
Limit values for atmospherric contents of sulphur dioxide and particulates.

May 23, 1984:
Reduction of sulphur dioxide from power plants.

March 12, 1987:
Limit values for atmospheric contents of nitrogen dioxide.

December 10, 1987:
Regulation of approved waste incineration plants.

April 5, 1989:
Reduction of sulphur dioxide and nitrogen oxides from power plants.

October 1, 1990:
Requirement for catalytic converters in new private cars.

October 15, 1990:
Reduction of emissions of sulphur dioxide, nitrogen oxides and particles from large combustion plants.

January 4, 1991:
Regulation of waste incineration plants.

March 11, 1994:
Limit values for atmospheric contents of ozone.

September 14, 1998:
Reduction of air pollution from tractors, contractors' equipment etc.

September 17, 1998:
Tax on sulphur.

July 9, 2001:
Limit values for atmospheric contents of sulphur dioxide, nitrogen dioxide, nitrogen oxides, lead and particulates.

Danish energy policy

The major cause of emissions of air pollutants in Denmark is the use of fossils fuels – i.e. of coal, oil and gas products. Therefore the emissions are closely related to the national energy policy that has been implemented in a series of action plans.

From coal to oil and back to coal

Traditionally coal has been the dominating source of energy in Denmark, but in the years after the second world war oil played an increasing role and contributed in the beginning of the 1970's about 90%. With the energy crisis in 1973 and the dramatically increasing oil prices it became evident that Denmark must be made less vulnerable to changes in supply security and energy prices. In the first energy plan from 1976 *(Energy Policy 1976)* the main objective was to reduce our dependence on oil, to direct the supply towards natural gas and nuclear power, but also to use coal and renewable energy. The immediate result was a change to coal in the electricity production and application of natural gas and renewable resources. The introduction of nuclear power was postponed. At the same time the increase in energy consumption was slowed down by means of energy saving campaigns and economic instruments.

Environmental issues played a modest role, and an investigation in 1980 concluded that even with an increase in coal consumption by a factor of five from 1975 to 1989 the problems could be handled. The question of climate changes was not addressed at all.

Danish gas and oil

An energy plan in 1981 was based on domestic production of gas and oil and continued efforts to save energy, i.a. for space heating, including an extension of district heating based on combined power-heat production. Still, however, the main objectives were supply security and economic efficiency.

In 1985, after years of discussion, the Danish Parliament definitively decided to remove nuclear power from Danish energy

Efficient energy production and energy savings are essential elements in the abatement of air pollution. The transport sector is a critical area in Danish environment and energy policy. Attempts to limit car traffic by increasing use of public means of transport and bicycles have so far had modest success.

policy. In the same year an international conference on greenhouse effect, climate change and ecosystems created a political understanding that emissions of carbon dioxide could be the overwhelming problem of the future.

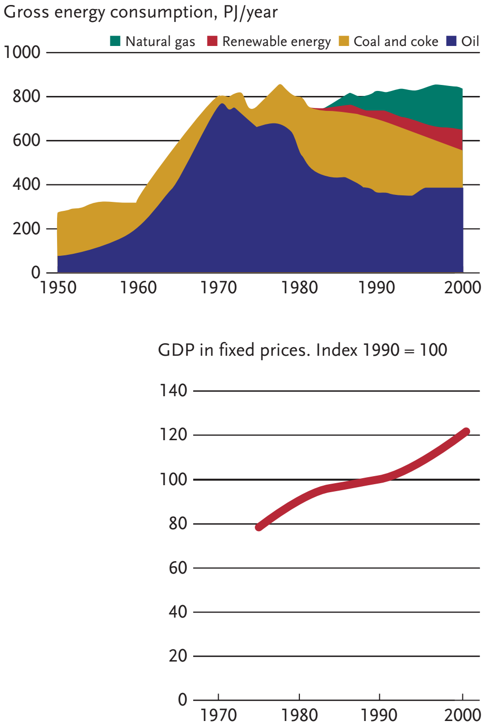
The Brundtland Report and what followed

On April 27th 1987, the Brundtland Commission published its report *Our Common Future*. Earlier technological development was seen as a threat to the environment and had been discussed in terms of limits to growth. Now development was seen as a necessary prerequisite in the fight against poverty and environmental degradation. It should, however, be sustainable. As a preliminary goal it was proposed that energy consumption per capita in the industrialised countries should be halved within 40 years (i.e. before 2027), thus enabling a 30% increase in the developing countries.

The environment in focus

As a direct consequence of the Brundtland Report the *Energy 2000 Action Plan for Sustainable Development* was published in 1990. Now the environment was seriously set in focus. The energy consumption, as it was in 1988, should be reduced by nearly 15% before 2005, and emissions of carbon dioxide, sulphur dioxide and nitrogen oxide by 20, 60 and 50% respectively. *Energy 2000,* however, did not address the transport sector, as it was recognised that the sector was facing a necessary and unavoidable development, and, therefore, a specific action plan was drawn up: the government's transport plan of action for environment and development. The energy consumption and emissions of carbon dioxide should only be stabilised before 2005 and then reduced by 25% before 2030. As appeared later, even this target has not been easy to reach. Emissions of nitrogen oxide and hydrocarbon should be reduced by 40% before 2000, by 60% before 2010 and further up to 2030. Emissions of particles should be halved before 2010 and be further reduced up to 2030.

Energy consumption and economic growth



From the end of 1950's and up to 1970 the Danish gross energy consumption more than doubled. since then it has by and large been stabilised, although the mix of energy sources has changed drastically. Since 1980 the production of renewable energy has more than tripled. The largest increase has been for wind power.

The gross domestic product has increased much more than the energy consumption. The reason is partly a change towards less energy consuming activities, but also more efficient production of electricity and district heating, with strongly increased use of combined power and heat production (about a doubling since 1980). In addition, energy is used more efficiently by insulation of buildings, more effective domestic appliances etc.

By and large we have managed to decouple economic growth and the ensuing welfare from the increase in energy production and the related pollution.

(Source: Danish Energy Agency)

The threat of climate changes

The most recent official energy plan, *Energy 21* from 1996, focuses on emissions of carbon dioxide and maintains the goal of a 20% reduction in 2005. At the same time the concept *ecological footprint* was introduced in the debate, and a stabilisation of the atmospheric concentration of carbon dioxide of 450 ppm was recommended. By this it was recognised that much more extensive reductions of carbon dioxide would be necessary. A decrease in the total energy consumption of about 17% up to 2030 is assumed. At the same time an almost complete phase-out of coal, a nearly unchanged use of oil and gas and a large increase in renewable energy sources were assumed. More than half of the electricity and district heat production shall be based on renewable energy in 2030.

The environmental target for the development in the energy sector is dominated by the national climate commitments under the Kyoto Protocol. The declared goal therefore focuses on reduction of emissions of carbon dioxide. It is obvious, however, that by and large any reduction in the use of fossil fuels will result in a reduction of emissions of a series of other more direct air pollutants – notably sulphur dioxide, nitrogen oxide and hydrocarbons.

Sulphur and acidification

Sulphur dioxide is together with soot the classical urban pollution, which causes respiratory trouble, soiling and material disintegration. Sulphur pollution arises mainly because organic materials, comprising both fossil fuels and bio fuels, contain sulphur. During combustion the sulphur is oxidised to sulphur dioxide (SO_2). In the atmosphere it is further transformed to sulphate (SO_4^{-2}) that is deposited either as salts or as sulphuric acid and is a significant reason why precipitation polluted with sulphur becomes acid.

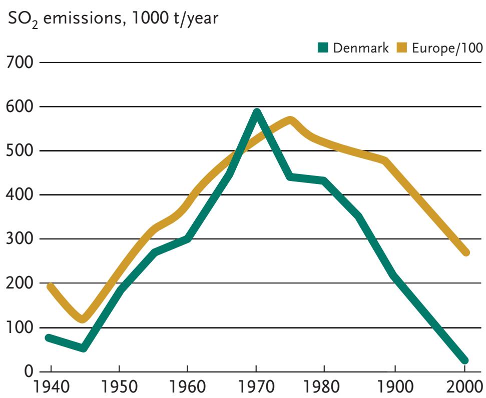
Until the early 1970's it was the general political assumption that sulphur pollution was a local problem and could be solved by cleaner fuels in residential furnaces and high stacks dispersing the pollution from power plants. It was, however, a short-sighted solution. In June 1981 Statens Naturvådsverk (Swedish Environmental Protection Agency) published a report where the problem was spelled out as shown in the box.

”That the fish have died in thousands of lakes is something we have known for many years. But not until recently have we been able to establish that drinking water from springs and wells may, in consequence of acidification, contain sufficient amounts of toxic heavy metals to be a threat to health. That forest trees on acidified land may begin to show slower growth is so far only a suspicion – it will be at least another two decades before we know for certain”

At that time 18,000 of Sweden's 85,000 large lakes were acidified and half of them to a degree that seriously harmed fish life. The Swedish area where the critical load for acidification is exceeded is now more than halved, from above 80% to below 40%.

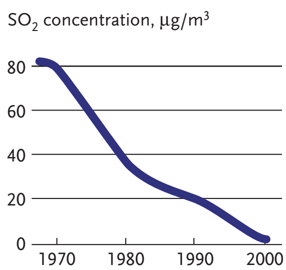
Danish emissions

In Denmark the sulphur content in oil has been regulated since 1972 and SO_2 emissions from power plants and combined power-heating plants since 1984. The rules have been tightened several times, and taxes



Emissions of sulphur dioxide
Danish emissions of sulphur dioxide peaked around 1970 and have since been reduced to around 1/10. The pattern is by and large the same as for Europe as a whole.

(Sources: EMEP, Risø, NERI)



Concentrations of sulphur dioxide
The reduction of emissions of sulphur has been a contributing factor for the heavy decrease of concentrations in Danish cities. Around 1970 the yearly average in Copenhagen was about 80 µg/m³. Today it is below 5 µg/m³. For comparison, the EU limit value is 20 µg/m³.

(Source: NERI)

on sulphur were introduced in 1998. By use of cleaner fuels and desulphurisation of flue gas in power plants it has been possible to reduce Danish emissions of sulphur dioxide from nearly 600,000 tons per year to below 50,000 tons. Thus the target set for 2010 in the ECE and EU agreements (55,000 tons) is already achieved.

To this must, however, be added a significant, but not yet regulated contribution from shipping in the Danish waters. In 1990 to 2000 it was 133,000 tons per year and thus more than twice the contribution from land-based Danish sources. This contribution, however, is of minor importance for the air quality in urban areas, since ferries use cleaner fuel in harbours.

Sulphur dioxide in Danish cities

Efforts to reduce airborne sulphur pollution have contributed significantly to a reduction in local levels. It does not exclude, however, that under special meteorological conditions high peak values can appear. In the 19th century the average concentration of sulphur dioxide in the centre of Copenhagen must have been nearly 100 $\mu g/m^3$ during the winter. When measurements proper were initiated in the beginning of the 1960's it was about 80 $\mu g/m^3$. The impacts can still be seen in the form of deteriorated sandstone monuments and corroded statues. Today the levels of sulphur dioxide are less than 5 $\mu g/m^3$ and thus significantly below both current and planned limit values.

A corresponding development has been seen in other cities in Denmark and abroad, caused by several conditions: less sulphur in fuel oil and coal, regulation of emissions from power plants, and increased use of natural gas that does not contain sulphur. A contributing factor is increasing use of district heating often based on combined power and heat production in large plants with high stacks and flue gas desulphurization.

Extensive damages to ecological systems focus attention on transboundary sulphur pollution. The phenomenon, however, is complicated, and with decreasing emissions of sulphur the largest acidifying contribution today comes from nitrogen. Also pollution with ozone can be important. The recent years' growing occurrence of the "red" Norway Spruce in Denmark may be related to climate change.

Nitrogen and eutrophication

Air pollution with nitrogen compounds is more complicated than sulphur pollution. Like sulphur dioxide (SO_2), nitrogen dioxide (NO_2) immediately irritates the respiratory system and harms vegetation. Furthermore, NO_2 can be oxidised and contribute to acidification. However, NO_2 can under the influence of sunlight react with hydrocarbons and form photochemical oxidants, of which ozone (described in the following section) is the most important.

Finally, nitrogen has a fertilising effect. Air pollution with nitrogen compounds therefore contributes to the eutrophication that puts pressure on sensitive nature. Also the deposition of nitrogen to inner Danish waters is a contributing cause of oxygen deficiency.

Through chemical processes in the soil ammonia can liberate hydrogen ions and, thus, contribute to acidification.

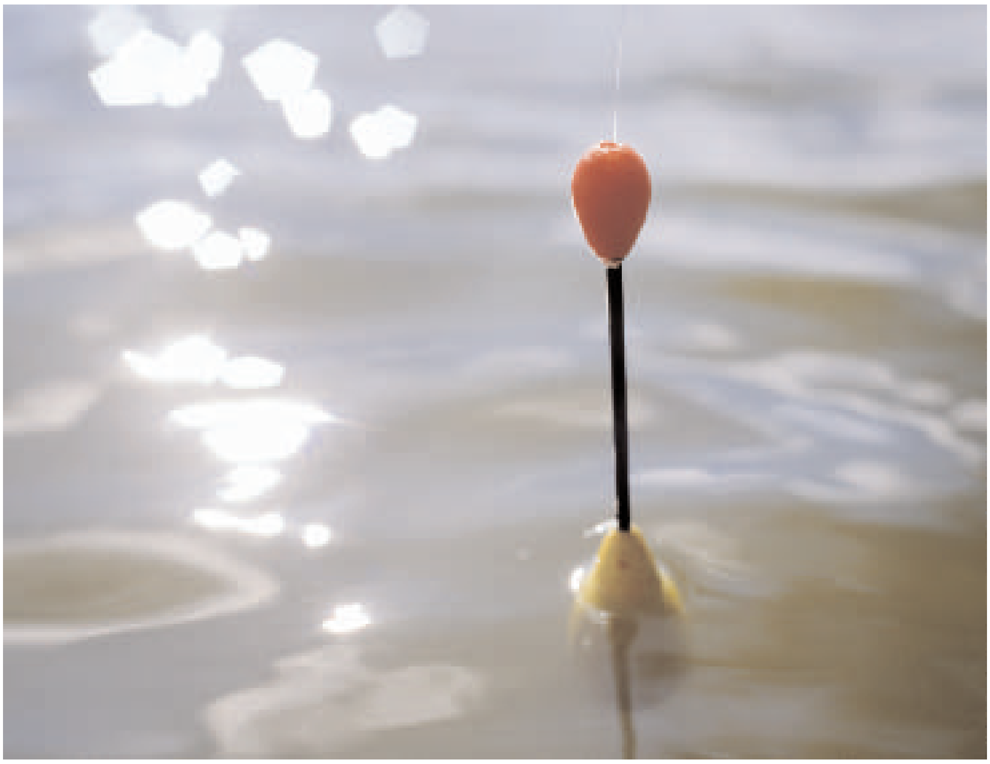
Formation and emissions of nitrogen oxides

As was the case with sulphur dioxide, pollution with nitrogen dioxide is mainly due to combustion – partly because the fuels contain nitrogen compounds. But also nitrogen in the combustion air is oxidised – first into nitrogen monoxide (NO) and later in the atmosphere into NO_2, which is the actual harmful compound.

Danish emissions of nitrogen oxide expressed as NO_2 increased to about 300,000 tons per year in the middle of the 1980's. It then remained nearly constant until the middle of the 1990's, but is now reduced to about 200,000 tons per year. The reason has mainly been installation of low-NO_x burners and de-NO_x equipment in power plants and district heating plants. Increasing use of catalytic converters in cars has at the same time more than counteracted the increase in traffic. Emissions today, however, are still larger than the EU and ECE targets for 2010 of 127,000 tons a year.

Nitrogen dioxide in Danish cities

In the last decade, the yearly average of nitrogen dioxide in Danish cities has also fallen, although not as fast as the emissions. In Copenhagen, thus, from about 50 to 40



Air pollution with nitrogen compounds contributes to eutrophication of the aquatic environment. This can result in extensive oxygen deficiency and fish deaths. For the total inner waters around Denmark about 1/4 of the bio-available nitrogen comes via the air. Also for natural ecosystems, where the species are adjusted to a nutrient-poor environment, pollution with nitrogen compounds may change the composition of the species and reduce their number.

μg/m³. This corresponds to the present EU limit value, whereas the level envisaged is 30 μg/m³. The reason why the decrease has not yet been larger is, partly, that the NO_2 level depends upon the occurrence of ozone in the air.

Ammonia

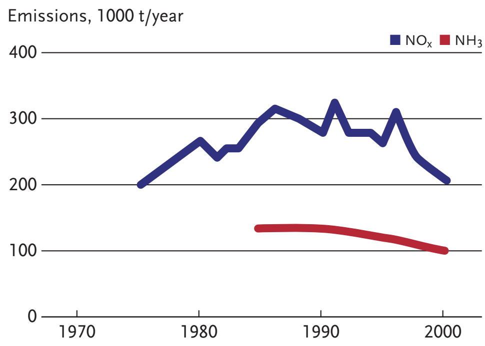
Nitrogen is also present in the form of ammonia (NH_3) – a gas that is i.a. formed in bacterial decomposition of organic material. Earlier ammonia was only discussed in connection with odour problems, although in fact it is not the ammonia, but a series of degradation products that cause the greatest nuisances. In Denmark emissions of ammonia are almost exclusively due to agriculture – in particular evaporation in connection with application of nitrogen fertilisers (including manure). Only 2% are due to traffic.

In agriculture nitrogen in different forms of fertilisers and atmospheric deposition is added to the soil. In return, nitrogen is removed with crops and animal products. The nitrogen surplus constitutes the environmental problem proper. This includes the loss of nitrogen in the form of emissions of ammonia to the atmosphere, now in the order of 100,000 tons per year. It has been reduced by about 30% since 1985 i.a. by application of other foodstuffs, by sealing manure containers and by using dragging tubes in the distribution of the manure.

Further, in 2000-2001 a new ammonia action plan to limit the evaporation was adopted. It is expected that Denmark will be able to reach the EU and ECE target for emissions of ammonia in 2010 (39,000 tons) as a result of i.a. the *Action Plan for the Aquatic Environment II.*

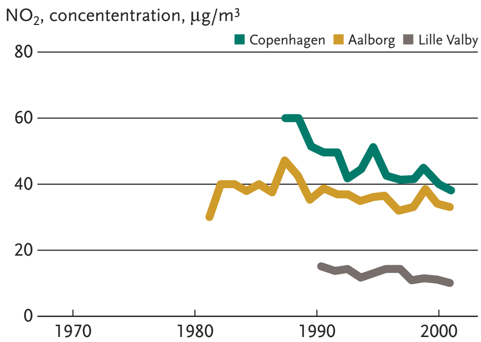
Exceedance of critical loads

In Denmark the total area where the critical load is exceeded is only very modest, but it includes agricultural land, cities etc. Of the natural area proper, which constitutes 15-20%, still about half is loaded above the critical limit of eutrophication load. In recent years a minor reduction seems to have occurred, but more exact inventories have not been drawn up.



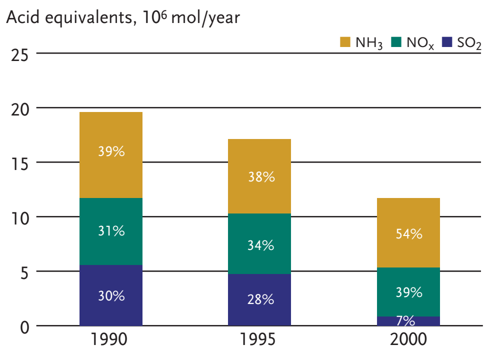
Emissions of nitrogen oxides and ammonia
Danish emissions of nitrogen oxide peaked in the late 1980's, and have now fallen by about 30%. According to recent inventories emissions of ammonia have fallen by about 30% since 1985.

(Sources: Risø and NERI)



NO_2 in urban and rural air
The concentration of NO_2 in Danish air has also been reduced, but not as fast as emissions.

(Source: NERI)



Total acidifying emissions
Sulphur dioxide, nitrogen oxide and ammonia all have an acidifying effect. The emissions can be expressed with a common unit: acid equivalents. The sum has fallen in Denmark by about 40% in the recent decade, and ammonia is now dominating. This, however, does not give a direct impression of the actual load, which is strongly influenced by transboundary pollution with a significant contribution from sulphur.

(Source: NERI)

Organic compounds

– and photochemical smog

Volatile hydrocarbons (Volatile Organic Compounds, VOC) are organic compounds which are of great significance to the impacts on health and the environment caused by air pollution. They can contribute to the formation of photochemical air pollution, give rise to odour nuisances or simply be hazardous. Usually a distinction is made between methane (CH_4) and the other volatile hydrocarbons (NMVOC, non-methane VOC). Methane is a greenhouse gas, but is chemically not particularly active. It therefore plays a minor role as direct pollution. Non-volatile hydrocarbons can, however, also affect health, as particles or adsorbed to the surface of particles.

Formation and emissions of hydrocarbons

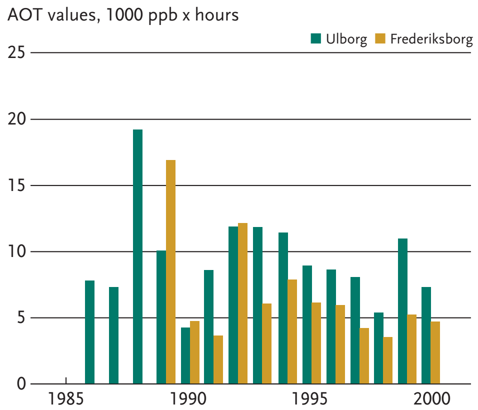
VOC`s have many sources: evaporation of fuels, incomplete combustion, releases in industrial processes, use of organic solvents etc. Danish emissions have been largely constant at well over 200,000 tons per year from 1985 to 1990. It was then reduced to less than 15,000 tons per year in 2000, mainly because of the introduction of 3-way catalytic converters in petrol cars and reduced use of organic solvents. Both the EU's and the EEC's emission ceiling for 2010 is 85,000 tons per year, which – in view of the development – should be possible to achieve.

Ozone

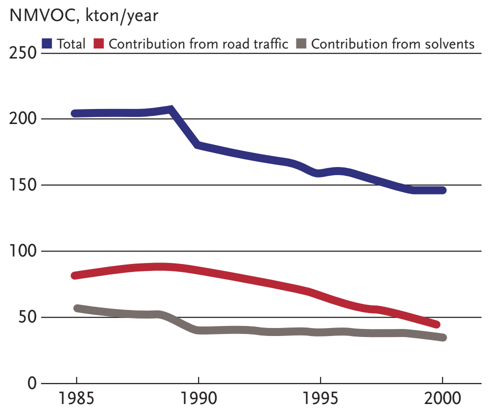
Ozone (O_3) is a reactive form of oxygen (O_2), in which the molecules have three atoms instead of two. In relation to the environment, ozone plays two different roles: In the stratosphere it forms the so-called ozone layer that shields against short wave UV-radiation. At low altitude, on the other hand, it is a contaminant that attacks respiratory systems, certain materials and vegetation.

Due to its reactivity ozone can influence the mucous membranes in the eye and in the respiratory system. Especially persons with respiratory diseases are sensitive and will at elevated levels experience an aggravated health condition.

As an air pollutant ozone is not a com-



Ozone load measured at forest stations
Ozone load on vegetation is measured as AOT (Accumulated exposure over a Threshold) which is a product of the time in which the levels exceed a critical level, e.g. 40 ppb, and this exceedance. The diagram shows AOT_{40} values measured at Ulborg and Frederiksborg forest stations. It appears that Ulborg situated to the west is generally exposed to the largest load, that it is frequently above the 10,000 ppb x hours a year, which is considered a critical level. For many years this situation has remained fairly stable.
(ppb is parts per billion) (Source: NERI)



Emissions of hydrocarbons
Danish emissions of hydrocarbons have been reduced by about 25% since 1985.
(Source: NERI)

Volatile organic compounds can under the influence of sunlight react with nitrogen oxide and form ozone, the most important element of the so-called photochemical air pollution. Ozone is harmful for the respiratory system and for vegetation. In Danish cities the concentration is generally low, but in rural areas elevated concentrations result in loss of crop yield.

pound that is emitted, but a so-called secondary pollution – something that is formed from other, primary pollutants. The primary pollutants are nitrogen oxides and hydrocarbons that under the influence of sunlight react and form of series of so-called photochemical oxidants. Ozone is the most important.

In Southern Europe photochemical air pollution (photochemical smog) is often an urban phenomenon generated by car traffic. In the cities in Northern Europe, however, decomposition of ozone dominates as a consequence of emissions of NO from cars, and the levels are generally lower than in the countryside. Here the highest concentrations appear in the summer and at south easterly wind. The reason is that during high-pressure episodes in Eastern and Central Europe high ozone concentrations build up and are transported to Denmark.

Consequently, it is not possible for Denmark to control ozone levels by national reductions of emissions. Ironically, the levels in Copenhagen are generally lowest on weekdays, when the traffic is most dense, and pollutants (especially nitrous oxide) consume ozone.

Economic evaluations of damage

In Denmark no detailed calculations have been made of the negative economic impact of ozone on the agricultural sector in the form of reduced crop yield. But an estimate of damages on wheat, grass and production forest is DKK 0.5 to 2 billion (Euro 65-260 million) per year. This is in agreement with similar Swedish estimates. Such figures must, however, be considered with caution in a world with overproduction and economically subsidised agriculture. It has never been attempted to evaluate the economic impact on natural vegetation and health in Denmark.

Other hazardous compounds

A series of organic compounds are hazardous in themselves. By measurements and calculations of emissions, the permissible load of these compounds in the atmospheric environment is regulated when plants are approved. In recent years a few compounds have, however, attracted special interest.

Dioxins

The so-called dioxins comprise 210 closely related polychlorinated dibenzodioxines (PCDD) and furanes (PCDF). Their transport in the environment is complicated. The main source is combustion, typically incineration of material containing chlorine, but dioxin is also formed in e.g. straw and wood stoves.

Primarily, dioxin is an air pollutant, but it is not direct inhalation, that is crucial for the impact on health. Dioxins, which are very stable, are deposited on the soil and water surfaces. As they are fat-soluble they move easily from the soil and water to the food chains and are then absorbed through the food. This also means that it can be dispersed in various ways.

Dioxins are some of the most toxic compounds known. They are carcinogenic, they may have endocrine-disrupting effects, and inflict damages to the unborn child. Special attention has been given to the content of dioxin in mother's milk.

In 1998 WHO (World Health Organisation) established a tolerable daily intake (including the related PCB) at between 1 and 4 pg/kg bodyweight, while at EU level the tolerable daily intake has been fixed at 2 pg/kg. At the same time it is estimated that the load in Europe is an average of 2-6 pg/kg. The Danish Veterinary and Food Administration has on the basis of data from other countries conservatively estimated that the Danish intake is about 5 pg/kg. Although the content of dioxin in food and mother's milk is falling, there is every reason to continue efforts to reduce the load. The Minister for the Environment has in collaboration with the Minister for Food, Agriculture and Fisheries prepared a dioxin action plan to reduce dioxin emissions and provide new knowledge on sources and pollution of food and environment.

Further, the Minister for the Environment has issued a statutory order under which the incineration plants must observe a limit value of 1.1 nanogram dioxin per cubic meter flue gas by the end of 2004. So far it appears that this is possible at about 90% of all utilities. Industry is faced with similar requirements.

Many organic compounds are hazardous. Even if they start as air pollution, they may go a long way through dispersion in the atmosphere and the food chains before the impacts appear. This may make it difficult to trace the sources and reduce emissions. Dioxin in mother's milk is a typical example.

The EU has further established limit values for a series of animal foodstuffs in particular. The objective is to reduce the total human exposure to dioxin by at least 25% in 2006.

Polycyclic organic material

Combustion of material – typically wood and oil products with cyclic hydrocarbons – generates a series of mutagenic and carcinogenic compounds. The polycyclic aromatic hydrocarbons (PAH) are the most important.

Environmental concern for these compounds dates back to the 19th century, when many incidences of skin cancer were observed in workers in the tar industry. The first carcinogenic compound, benzo(a)pyrene was identified in tar in 1933, but it was not before the 1970's that the relation with air pollution became evident. Volatile PAH is in the gaseous phase, but the heavier and carcinogenic PAH has a tendency to attach to particles. Inhalation of such particles in the working environment has been shown to cause lung cancer.

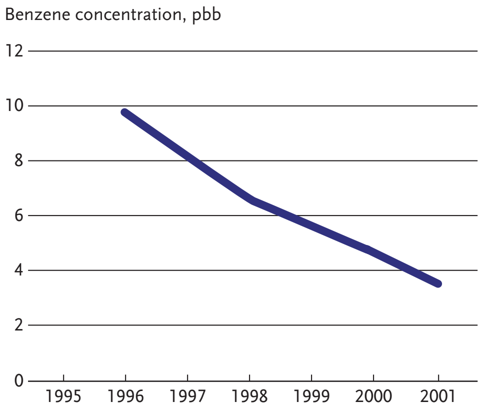
In Denmark measurements were carried out at the Copenhagen Airport in 1988-89, and concentrations of about 2 ng/mg^3 were found. At the busy street H.C. Andersens Boulevard in central Copenhagen up to 10 ng/m^3 were measured.

As part of the report to UNECE, emission inventories have been prepared for four compounds: Benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and indeno-(1,2,3-cd)pyrene. Total emissions in 2000 were about 11,000 kg. There are minor contributions from traffic and mobile sources, but nearly 3/4 come from increasing combustion of wood in private fireplaces.

Benzene

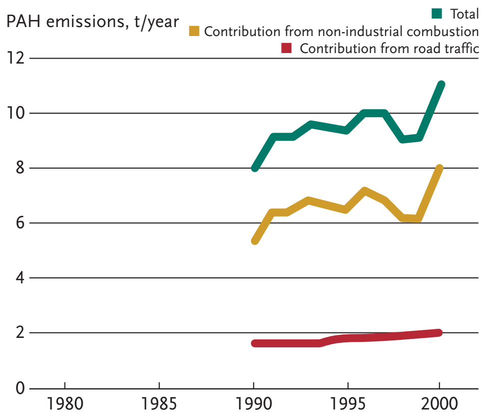
As described earlier lead is now completely removed as an additive to petrol in Denmark, and, thus, lead in the air has practically disappeared. But it has not been without side-effects, because it was necessary to control the octane number of the petrol buy changing its composition.

Some years ago it appeared that urban air contained the carcinogenic hydrocarbon benzene. A closer investigation indicated that benzene solely arises from unburned components in petrol. The refineries were therefore interested in introducing quickly a new technology for production of petrol with a low content of benzene. The reduction of the content of benzene in motor fuel has been documented by analysis of samples from Statoil at Kalundborg and Shell at Fredericia. In both cases the content was reduced from 3.5% to 1% during the summer of 1998. At the same time it was shown that the content of benzene in the air at the very busy street Jagtvej in Copenhagen has within a few years been reduced from about 10 µg/m^3 to 3.4 µg/m^3. The EU limit value for 2005 is 5 µg/m^3. The problem with benzene is therefore largely under control.



Concentration of benzene
On the very busy street Jagtvej in Copenhagen the concentration of benzene has fallen drastically since the middle of the 1990's when a reduction of the content of benzene in petrol was introduced.

(Source: NERI)



Emissions of PAH
Danish emissions of PAH (Poly Aromatic Hydrocarbons) have increased in recent decades, when the emissions have been measured. The main source is small firing units – i.a. open fireplaces and wood burning stoves.

(Source: NERI)

Lead and other metals

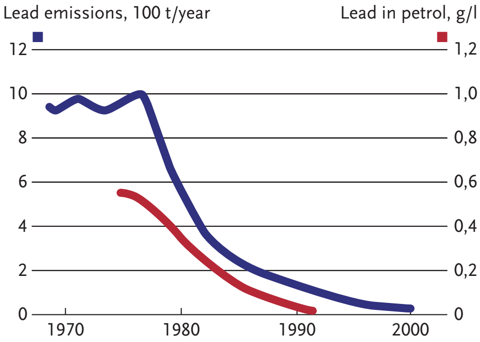
Many metals are poisonous, and WHO has proposed limit values for a series of them. The new EU directives for air quality will – beside lead – apply to cadmium, arsenic, nickel, and possibly mercury.

Lead

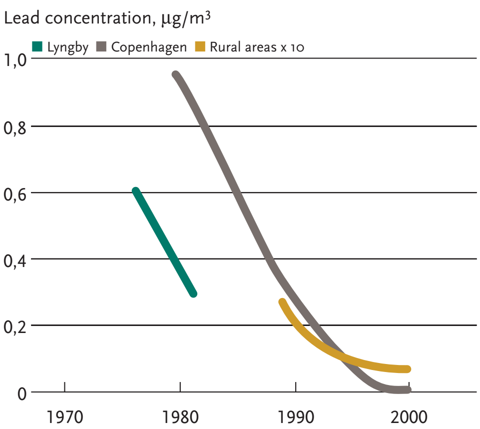
For many years lead was added to motor vehicle petrol in order to increase the octane number for motors with higher compression, and, thus, improve efficiency. Apart from the surroundings of certain industrial installations, these lead additives were the absolutely dominating source of lead in the air in Danish cities.

Denmark has, like the other EU countries, introduced limits for the content of lead in petrol. Measures were first taken in 1978, the rules were tightened during the 1980's, and since 1984 there has been no lead in the petrol – and not in the EU since 2000. The result has been almost complete disappearance of lead from the urban air, the present level in Copenhagen is approx. 15 µg/m³ or only 3% of the EU's planned limit value for 2010 (0.5 µg per m³).

This does not mean, however, that the human lead load has fallen correspondingly, because lead, like other heavy metals, can also be taken up with food. In this connection it is important to note that the concentration of lead in Danish rural areas has always been significantly lower than in the cities and to a large extent is influenced by long-range transport. Therefore, in relative terms, the lead load is not equally reduced. Since 1990 lead concentrations have fallen to about one third (from 25 to 8 µg/m³), and the deposition of lead has fallen correspondingly. The concentrations in the soil will, however, remain fairly constant, since the lead does not disappear, but remains in the soil.



Lead in petrol and lead emissions
Lead additives in motor vehicle petrol used to be the dominating source of air pollution with lead in Danish urban areas and along busy roads. Starting in 1978 the permitted lead content has gradually been reduced to zero. The result has been a corresponding decrease of total lead emissions in Denmark.



Lead in urban air and in rural areas
In the same period the lead concentration in urban air has fallen to about 1/100. The concentration in rural areas (approx. 1/10 of that in urban areas) – and thus of the lead deposition – has not been equally reduced measured in relative terms. The reason is a significant contribution from long-range transport.

(Source: NERI and City of Copenhagen)

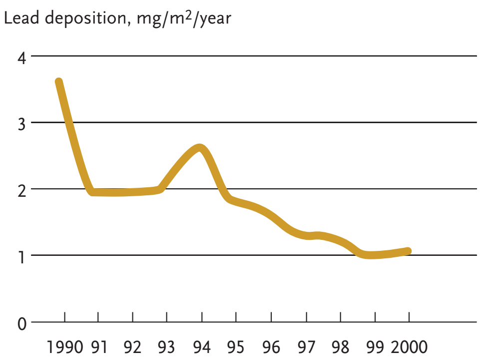
Elevated levels of lead in the blood can reduce intelligence. Some scientists have even dared the hypothesis that extensive lead poisoning contributed to the fall of the Roman Empire. Air pollution with lead has largely disappeared in Denmark, but it is not the only source of lead in humans.

Other metals in the air

Emission inventories for other heavy metals than lead – for example cadmium, mercury, nickel and zinc – show less distinct, but in most cases significant reductions in recent years, due to purification of emissions from power plants, incineration plants and industrial plants. Also concentrations of a series of heavy metals in urban air have fallen, but as there appears to be many different sources it is difficult to point to one single reason.

Heavy metals in soil

In 1996 it was concluded that the present deposition of heavy metals is generally very small compared to the natural content in the soil. It is therefore not expected to be an acute problem. As deposition can take place directly on the eatable parts if the plants, there is still reason to follow closely the development for especially lead, cadmium and mercury.



Lead deposition in Danish rural areas

During the last decade lead deposition in rural areas (average of measurements at Tange and Keldsnor) has been more than halved. Similar, but smaller reductions have been observed for i.a. zink and copper.

(Source: NERI)

Large and small particles

Pollution with particles results in increasing illness, deterioration of general wellbeing and shorter lifetime of persons who are particularly exposed to respiratory diseases.

In contrast to gaseous air pollutants, particles are not a well-defined compound. They occur in varying sizes, shapes and chemical composition. Often the compounds attached to the surface of the particles are important – and not the particles themselves. In addition their size is determining for how long they stay in the atmosphere, and how easy they are deposited in e.g. human lungs.

Roughly, particles are divided into three size groups: coarse (larger then 2.5 µm), fine (smaller than 2.5 µm) and ultrafine (smaller than 1 µm). It appears that the fine and ultrafine particles are most hazardous.

Health impacts

Foreign estimates suggest that the average lifetime is reduced by about half a year per 10 µg/m³ PM_{10}. If this estimate is applied to larger Danish cities, the reduction of the average level by 1/3 will reduce mortality by about 400 per year of 1 mio. inhabitants.

If the smallest particles are the most dangerous, it is because larger particles predominantly consist of worn road surface or compounds from natural sources that are not especially dangerous. Further, a given weight contains a much larger number of particles if they are small than if they are large. And their total surface is larger.

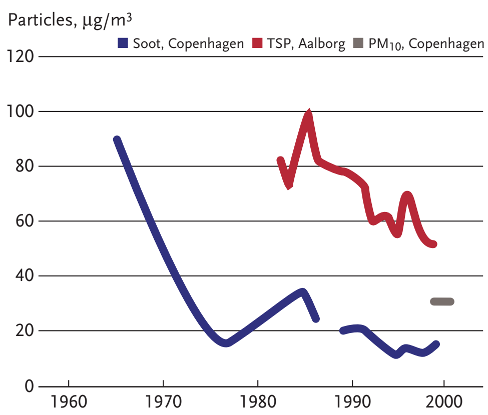
Most countries have established limit values for the mass of particles. Regulation on this basis may therefore be less efficient, because it is not the dangerous part that is directly regulated.

Particles in the air

Particles in the form of soot was, together with sulphur dioxide, the main component in the "classical" urban air pollution, and it was measured by blackening of filter paper. Soot has now largely disappeared from Danish open air due to cleaner fuels and better combustion systems possibly equipped with smoke filters.

Today the main part of the particles in the air is due to traffic – especially diesel cars – and other mobile sources. The rest can be industrial emissions e.g. from cement production or arise from natural sources as soil, vulcanos, forest fires or sea-spray.

The total amount of dust (total suspended particulate matter) is measured by weighting filters, and halving of the yearly averages since the beginning of the 1980's has been observed. The amount of particles below 10 µm (PM_{10}) has only been measured for a couple of years, and so far no trend has been observed.



Particles in Danish urban air

Emissions of soot and larger particles have been strongly reduced by the use of cleaner fuels and improved combustion and purification technology, and their concentrations in urban air have fallen correspondingly. Very small particles have been measured for too short a period to show any trend. Soot is measured in the very busy street Stormgade in Copenhagen, TSP (Total Suspended Particulate Matter) is measured i.a. in the city of Aalborg. PM_{10} (the weight of particles below 10 µm) is measured on the busy street Jagtvej in Copenhagen.

(Sources: HLU and NERI)

Danish research

Danish scientists are in the front of the development. Knowledge is still insufficient, but in recent years the basis for decisions has been improved. In the appropriation act funds have been allocated until 2004 to a special research programme on air pollution, especially on particles in the air.

The institutions under the Ministry of the Environment collaborate with a number of other Danish experts. It is expected that the programme will give the Ministry a much better understanding of the health consequences of particles in the air, and where the particles come from – and thus indicate the regulatory measures with the largest reduction potential.

Particulate pollution was earlier soot from heating units. It could i.a. make it impossible to dry clothes in the open air, and it may also be the reason why umbrellas were originally black. Today small particles especially from traffic are most important. They are invisible to the naked eye, but they can be inhaled. The particles may have serious effects on human health, and may aggravate the condition of sensitive persons suffering from respiratory and heart diseases. Compounds on the particles can also have a number of impacts, e.g. be carcinogenic.

From the Geneva Convention

– to the Gothenburg Protocol and the NEC directive

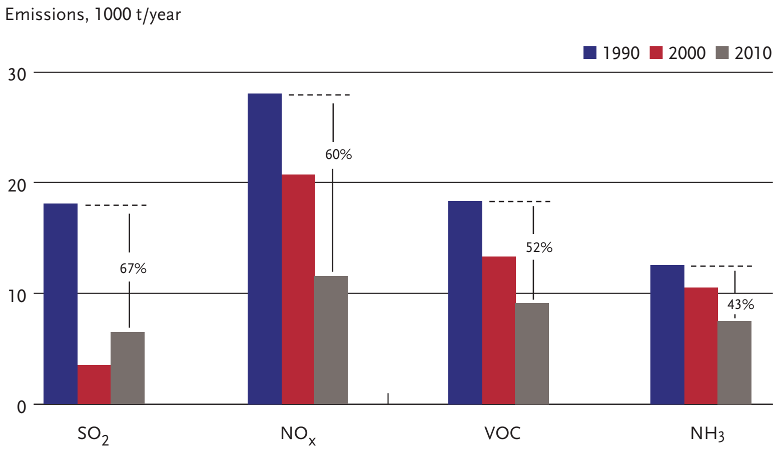
In 1976 the Nordic environment ministers proposed a European convention on transboundary air pollution, especially with sulphur compounds. After negotiations in ECE, 34 countries and the EC Commission signed the Geneva Convention in 1979. The convention came into force in 1983, and has now been ratified by 47 countries on the European continent plus the US and Canada.

The convention is a framework convention that is supplemented with more specific protocols. So far 8 such protocols have been worked out and signed. Five of them are in force.

Air pollution can be transported across national borders, and it is therefore not always possible for individual countries to regulate the air quality and the deposition of harmful compounds by national regulation. An effective abatement of air pollution requires international collaboration. The Geneva Convention forms the framework of the only forum on the European continent where the common problems in relation to air pollution can be addressed.

The first protocol deals with financing of the technical scientific basis. Within this framework data have been collected, air and precipitation quality have been measured, and model calculations of the atmospheric dispersion have been carried out since 1985. By means of emission prognoses and model calculations it is further possible to evaluate the future pollution and the results of planned regulation. This has played a key role in later negotiations on protocols that aim at regulating emissions of sulphur dioxide, nitrogen oxide, hydrocarbons, heavy metals and POP.

The culmination of this work is the Gothenburg Protocol, which was signed in 1999. It is both a "multi-pollutant" and a "multi-effect" protocol aiming at reducing acidification, eutrophication and damages from tropospheric ozone. The strategy is a comprehensive effort against transboundary pollution with sulphur dioxide, nitrogen oxide, hydrocarbons and ammonia.



Danish emissions and targets for the four compounds in the Gothenburg Protocol
The diagram shows Danish emissions in the reference year 1990 and in 2000. Further are shown the emission ceilings that Denmark is committed to as signatory to the Gothenburg Protocol and the adoption of the EU directive on national emission ceilings.
Both within the UN Economic Commission for Europe (ECE) and at EU level, work is done to control transboundary air pollution. For Denmark the results are identical.

(Source: Danish Environmental Protection Agency)

The objectives of the Gothenburg Protocol

The protocol has been negotiated on the basis of model calculations founded in national mapping of critical loads and the costs of reducing emissions. And it puts ceilings for emissions of the four mentioned compounds for each country in 2010.

The protocol operates with fixed targets for improvement of the state of the environment in all the areas comprised. The emission reductions, however, are carried out where it is most cost-effective, i.e. where the benefits to the affected areas are largest, and where actions have so far been taken at least towards emission control and further efforts therefore will be relatively cheap.

When the protocol is fully implemented in 2010 Europe's emissions of sulphur must be reduced by at least 63%, NOx emissions by 41%, VOC emissions by 40% and emissions of ammonia by 17% – all relative to emissions in 1990.

The protocol also sets out strict limit values for emissions from specific sources, e.g. incineration plants, power plants, chemical treatment plants plus cars and lorries. It is required that the best available technology is used in order to keep emissions down. VOC emissions from products like paints and aerosols must also be reduced. Finally, farmers must take specific measures in order to control emissions of ammonia. Guidelines decided in connection with the protocol suggest a series of abatement technologies and economic instruments for the emission reductions in the relevant sectors, including transport.

It is estimated that when the protocol is implemented, European areas suffering from too high acidification levels will be reduced from 93 mill ha in 1990 to 15 mill ha in 2010. Areas suffering from too high a degree of acidification will have fallen from 165 mill ha in 1990 to 108 mill ha.

The number of days with too high ozone levels will be halved. That means that the number of life years lost as a consequence of chronic effects of ozone loads will be about 2.3 mill. lower in 2010 than in 1990. And there will be about 47,500 fewer premature deaths as a result of ozone and particles in the atmosphere. The amount of vegetation that is exposed to too high ozone levels will be reduced by 44% compared to 1990.

The EU directive on national emissions

In parallel with ECE also the EU has taken action to reduce long-range transport of air pollution. The principal objective is the same: a cost-effective comprehensive reduction of impacts of acidifying, eutrophying and ozone forming compounds (SO_2, NO_x, VOC and NH_3). The EU Commission has calculated proposed emission ceilings for each of the 15 EU countries – the so-called NEC (National Emission Ceiling) directive, which was adopted in October 2001.

In spite of a common basis for calculations the results are different, primarily because no account is taken of areas that are sensitive to acidification in Norway, which is not a member of the EU. For Denmark the ceilings for the four compounds are identical.

Consequences for Denmark

Danish emissions of SO_2, NOx, VOC and NH_3 are already so strictly regulated that the required reductions will be achieved if current legislation and existing environmental goals are fulfilled. For nitrogen oxide, however, the fulfilment will to some extent depend upon electricity export and Denmark's implementation of the Kyoto Protocol.

It is also worth noting that even full compliance with the Gothenburg Protocol can only be considered a preliminary goal. It will not be sufficient to fully protect Danish nature and environment.

The hole in the sky

– the CFC gasses and the Montreal Protocol

CFC (chloro-fluoro carbons) is a common name for a series of industrially produced gasses. They are under normal conditions extremely stable and completely non-toxic. They have therefore had a series of practical applications, e.g. as heat medium in refrigerators, as propellant in spray cans or fire extinguishers, and in the production of insulating foam. For many years they were considered an environmental asset.

In the beginning of the 1980's, however, it became evident that their great stability might be the explanation of a newly observed global environmental threat: the depletion of the atmosphere's ozone layer.

Depletion of the ozone layer

Ozone (O_3) is at low altitudes an air pollutant that harms both vegetation and human health. In the stratosphere 15-50 km above the ground, however, ozone provides a necessary shield against biologically active ultraviolet radiation from the sun – the so-called UV-B radiation. The great stability of the CFC gasses and thus their long lifetime in the atmosphere mean that they can be mixed only poorly in the stratosphere. Here they are broken down by the ultraviolet radiation and form free chlorine atoms that transform ozone to ordinary oxygen. In a chain process a single CFC molecule can decompose many ozone molecules.

Depletion of the ozone layer will result in an increase of the UV-B at ground level and a range of unwanted effects. Most feared is the increased incidence of i.a. skin cancer. It is, thus, estimated that a 1% reduction of the ozone layer will increase the risk of non-melanomium by 2%. The significance for the far more dangerous malignant melanomium is, however, less clear.

On a larger scale i. a. plankton algae can

Sunlight is an essential condition for higher forms of life. For humans the lack of sunlight can cause serious health and sometimes mental problems. But direct radiation from the sun also contains ultraviolet radiation that is harmful to biological systems. Normally it is partly filtered out by the ozone layer in the stratosphere. It is therefore a serious matter if the ozone layer is depleted.

be harmed. As they constitute the first link in the marine food chain, it may have consequences that can escalate through the whole system.

International efforts

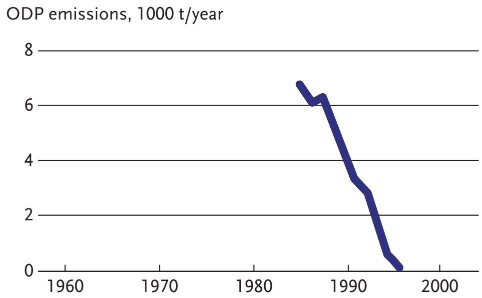
Already in 1985 the Vienna Convention on the Protection of the Ozone Layer was signed, and in 1987 the more concrete Montreal Protocol. It has later been tightened, in step with the provision of new knowledge on ozone depleting compounds and the possibilities for phasing them out. The industrialised countries committed themselves to stopping the use of the five most important CFC's before 1996, whereas the developing countries must stop the use before 2010. There are also agreements for three halones (similar compounds that contain bromine), which have been used especially for fire extinguishers. Further, it has been planned to phase out a series of substitutes with minor ozone depleting efficiency.

The development in Denmark and the World

Denmark has rapidly outphased the use of ozone depleting compounds. For practical reasons the effect of all the relevant compounds is expressed in terms of the most important CFC, CFC-11. In 2001 the Danish consumption measured as CFC-11 equivalents had fallen by 99%.

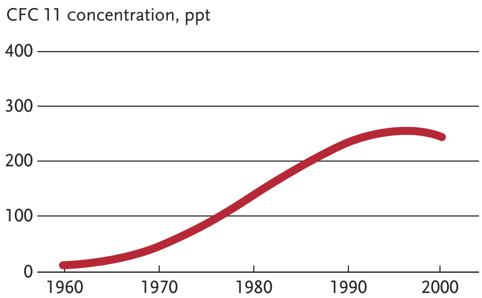
Also internationally phasing out has been successful, although a fall in the production of CFC has been accompanied by rising production of the less harmful substitutes. In the future the most important challenges will be to ensure that the developing countries can meet the requirements of the Montreal Protocol to phase out HCFC (hydro-chloro fluorocarbons) and methyl bromide, to fight illegal trade and, finally, to identify and control new ozone depleting compounds.

The problem thus appears to be on its way towards a solution. But even with fulfilment of the most recent international agreement, the ozone layer will not be fully restored until approx. the middle of this century.



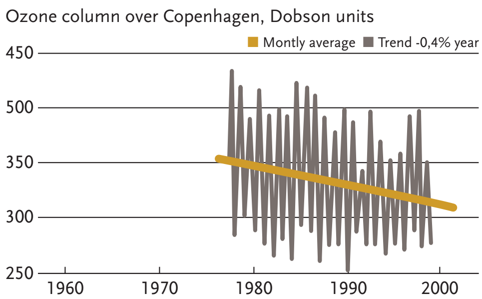
Danish consumption of ozone depleting compounds
Since international work with protection of the ozone layer started in the beginning of the 1980's, the Danish consumption of ozone depleting compounds has by and large been phased out. Here is shown – in amount of controlled ozone depleting compounds – the consumption expressed in terms of CFC-11 equivalents.

(Source: Danish Environmental Protection Agency).



The global average of the CFC-11 concentration
Although the global mean value of CFC-11 concentrations appears to have peaked, it will take at least decades before the impact on the ozone layer is below the critical level.

(Source: IPCC).



The ozone column over Denmark
The average ozone column over Denmark has, since measurements started in 1978, fallen by about 10%. Under cloud-free conditions, when people preferably enjoy the sunlight, the harmful ultraviolet radiation increases by nearly 15%. Nevertheless, this is still significantly less than possible exposure during the summer holiday in Southern Europe.

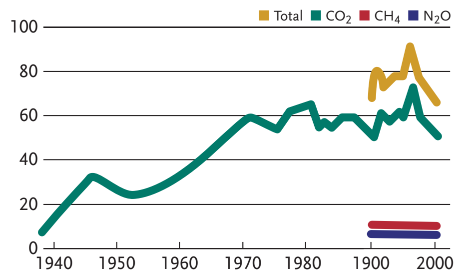
(Source: DMI).

Global warming –
the greenhouse gasses and the Climate Convention

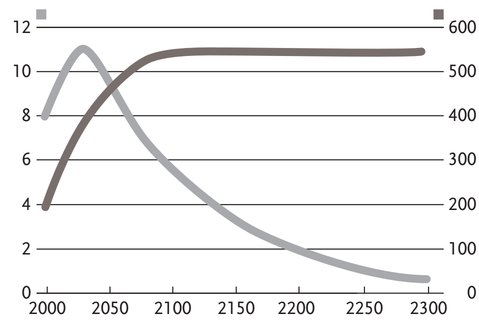
The importance of the composition of the atmosphere for the energy balance of the earth and thus for the global climate has been recognised since the beginning of the 19th century. In the 1890's the Swedish meteorologist Arrhenius calculated that the doubling of the concentration of CO_2 could result in a global warming of 5-6°C. In the 1930's it became evident that the temperature was indeed increasing, but it did not receive much attention. Partly because it was considered almost an advantage, partly because such questions generally lost in the competition for political attention against social problems after the First World War, the economic depression in the 1930's, and the prelude to the Second World War.

In the years after the Second World War scientific interest in the phenomenon increased, but not until an international conference on "Green house effect, climate change and ecosystems" in 1985, was it politically recognised that it could be a problem with global impact on the environment.

Danish emissions of carbon dioxide (CO_2) and other greenhouse gasses
Danish emissions of carbon dioxide increased slowly up to the middle of the 1990's and are now slightly decreasing. The values in 1975, 1990 (reference year) and 2000 were nearly identical, about 50 Mt. per year. Emissions of other greenhouse gasses, expressed in CO_2 equivalents, have been almost constant since 1990.
(Sources: NERI, Risø, Danish Energy Agency)



Stabilisation scenario
To stabilise the content of carbon dioxide in the atmosphere at twice the "natural" level (550 ppmv), it requires that global emissions are halved in the next decade and then further reduced.
(Source: IPPC).



The threat of climate change

The increased greenhouse effect and the threat of anthropogenic global warming have a time perspective reaching many centuries ahead. And it is a far more controversial phenomenon than the depletion of the ozone layer.

Different areas on Earth will be affected differently, and not all negatively. Denmark, seen in isolation, will be fairly well situated if plans for the expected climate changes are made in time – especially within forestry and in connection with construction of large infrastructures. A rising sea level resulting from global warming can, however, also in Denmark cause problems in low lying coastal areas.

Generally the developing countries will be hit hardest, since they are both the most vulnerable and have the poorest possibilities for adaptation. Necessary action to reduce emissions of greenhouse gasses affects all society's sectors for many years and will in the developing countries conflict with a justified wish for economic development.

The IPCC stabilisation scenarios

Partly as a result of the Brundtland Report on environment and development, the UN Environment Programme (UNEP) and the World Meteorological Organisation (WMO) established the so-called Intergovernmental Panel of Climate Change (IPCC) in 1988. IPPC has i.a. investigated the goal that the atmospheric content of carbon dioxide and other climate gasses shall be stabilised at a level twice the level before the industrialisation accelerated in the beginning of the 19th century. In this scenario, the global impact will be acceptable, but certainly not without environmental problems. To achieve this goal, however, the global emissions – after an almost unavoidable increase for some decades, must be halved compared to the present level before 2100, and then in the following decades be further reduced. And that must be accomplished simultaneously

Only very limited Danish areas are virgin nature, and the large fraction of this is found along the coast. In warmer climate with rising sea level, low lying areas that are comprised by the EU birds directive will be threatened.

with a situation where the world population probably doubles, and the developing countries will increase their material standard of living. Thus a goal that is significantly more ambitious and farsighted than that of the Brundtland Commission. On a per capita basis this will require much more extensive reduction of emissions in countries like Denmark. This may not be technically impossible, but, politically, a great challenge.

The Climate Convention

After a series of preparatory meetings the UN organised in 1992 in Rio de Janeiro a world conference on environment and development. Here 155 parties signed a framework convention on climate change (UNFCCC). It aims at a stabilisation of the concentration of greenhouse gasses in the atmosphere. The ultimate objective is quoted in the margin.

The convention thus expresses a general intention and recognises that climate changes cannot be avoided completely. What will then be considered an acceptable combination of "dangerous, "sufficient" and "sustainable" will depend upon political considerations.

Between politics and science

The convention came into force in 1994, and subsequently a series of meetings have taken place with the signatories in the COP (Conference of the Parties). The third and so far most important conference took place under great public attention in Kyoto, Japan, in December 1997. It was concluded with the adoption of a protocol, applying to carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluoric carbons (HFC), perfluoro carbons (PFC) and sulphur hexa fluoride (SF_6). Freon compounds that are both greenhouse gasses and ozone-depleting substances, were not considered, because they are already regulated in the Montreal Protocol.

The targets of the Kyoto Protocol

With respect to specific emission reductions, however, only modest results were obtained. The industrialised countries, including Russia and Eastern Europe, must – together – reduce their total emissions of greenhouse gasses – expressed as CO_2 – by 5.2% in the period 2008-2012 compared to 1990 levels. A few countries were permitted directly to increase their emissions. These modest reductions have later been undermined, i.a. it has been permitted to set off emissions against sinks for carbon dioxide, i.a. forestation. Further, since some countries, including the US, are not likely to participate, it is very doubtful whether the target will be reached.

On the average the EU countries must reduce their emissions of greenhouse gasses by 8%. In the subsequent distribution of reduction figures, Denmark accepted to reduce emissions by 21%. In 2002 a regulation was issued limiting the use of the potent greenhouse gasses HFC, PFC and SF_6. However, in practice the total contribution is modest. In 2003 the Danish Government will consequently present a number of concrete proposals on tools to be used to reach the reduction target for the most important greenhouse gasses – especially carbon dioxide. This will in the years to come be Denmark's greatest environmental challenge.

The ultimate objective of the UNFCCC (The United Nations Framework Convention on Climate Change) is: "a stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

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– Danish Ministry of the Environment: www.mim.dk
– Danish Environmental Protection Agency: www.mst.dk
– National Environmental Research Institute: www.dmu.dk
– Danish Energy Agency: www.ens.dk

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Clean air – Danish efforts

Lakes are deprived of fish, the number of flora and fauna species is falling, harvest yields are reduced, disease and premature deaths prevail. These are some of a range of harmful effects caused by air pollution. Through targeted efforts, both at EU and UN level, we have succeeded in reducing or solving a number of these problems. The most recent achievement was the adoption of the Gothenburg Protocol – a huge step forward in our efforts to reduce air pollution all over Europe. However, a number of problems remain to be solved. Urban transport is still a source of danger to human health. Emissions of sulphur dioxide from international shipping are still not regulated. Dioxin and other dangerous compounds still threaten animals and Man. The depletion of the ozone layer has not been definitely curbed. And perhaps the largest problem: the risk that greenhouse gas emissions will influence the Earth's climate, is still unsolved. This leaflet gives an outline of air pollution control efforts made in Denmark.

The leaflet is available free of charge at
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