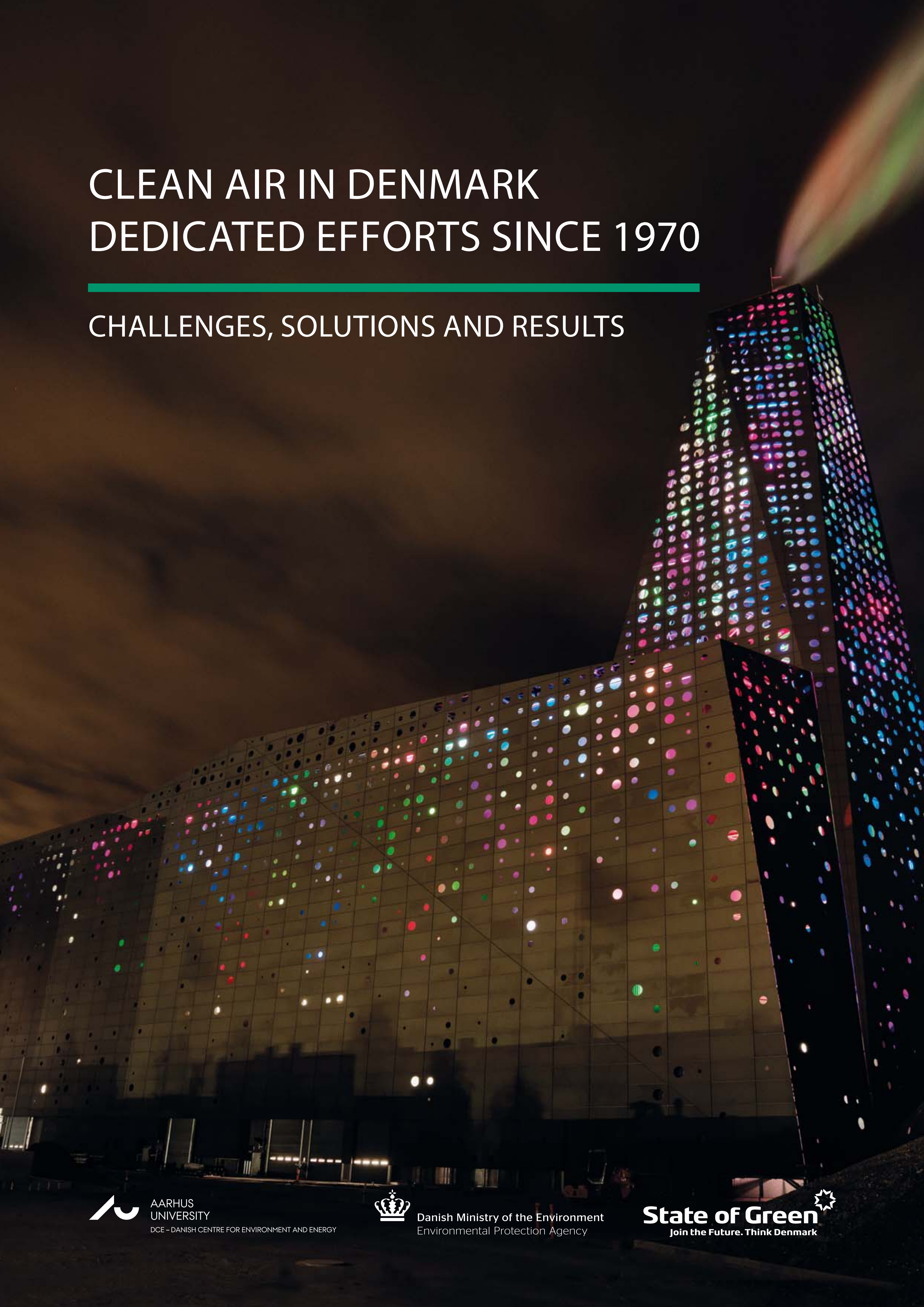
CLEAN AIR IN DENMARK
DEDICATED EFFORTS SINCE 1970

CHALLENGES, SOLUTIONS AND RESULTS



AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Danish Ministry of the Environment
Environmental Protection Agency

State of Green
Join the Future. Think Denmark

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– Challenges, Solutions and Results

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Front page photo: The Energy Tower. Company KARA/NOVOREN's new combined heat and power (CHP) plant in Roskilde, just west of Copenhagen. The new Waste-to-Energy plant uses the most up-to-date technology, thereby exploiting energy from waste a lot better while further benefitting air quality and the environment as such. The architecture by Dutch architect Erick van Egeraat is a significant part of the construction. © Jeppe Sørensen, KARA/NOVEREN

Photo this page: A day at the beach at Amager, 5 km from the city center of Copenhagen, ©Amager Strandpark I/S

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FOREWORD

ECONOMIC GROWTH AND CLEAN AIR FOR ALL

Economic growth delivers better living for millions around the world through industrial development, better transport, modern energy systems and more. But often it also causes serious problems due to air pollution.

Air pollution as a side-effect to economic growth and development is currently threatening citizen's health, and leading to very significant costs and serious environmental damages all around the world.

But the connection between growth and increasing air pollution can be overcome.

Denmark has been a first mover in combatting air pollution since the 1970s. We have brought down air pollution from industrial and energy production to a minimum. Emissions of sulphur dioxide have decreased from approximately 600.000 tons in 1970 to 13,000 tons in 2014. Emissions of dioxins have decreased by about 70 % and the use of ozone-layer-depleting substances as well as lead in fuel have been abandoned, to mention a few of the results.

In the same period the Danes have enjoyed an economic growth of 215 %.

One of the main outstanding air pollution problems in Denmark is emissions of ammonia from pig production. But the development is going in the right direction. From 1985 to 2014, as the Danish pig production increased with 40 %, the emissions of nitrogen were reduced with 40 %.

The benefits and possibilities of these front runner efforts are now apparent to us, and with this publication, the aim is to share the lessons learned.

It is my hope that readers may find inspiration for concrete solutions to air pollution problems, which can assist in "jumping the curve", and breaking the link between economic growth and air pollution.

Kirsten Brosbøl
Danish Minister for the Environment

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christianiabikes.com

A MULTI-FACETTED PROBLEM WITH SOLUTIONS

Impacts of air pollution include; health effects related to episodic events as well as to long-term exposure, loss of biodiversity due to acidification and eutrophication, degradation of the stratospheric ozone layer that protects life on earth from UV radiation, loss of crops due to ozone stress in the lower atmosphere as well as climate change due to releases of climate forcers in the form of greenhouse gasses and particles. It is important to understand the nature of all these effects and how these are related to man-made releases in order to select the right solutions – locally as well as globally – in order to avoid that regulation aimed at solving/ reducing one type of impact does not enhance other negative impacts. Acidification is of minor importance in Denmark due to high content of calcium carbonate in Danish soils, but all the other environmental effects have been or are still of concern in Denmark.

Air pollution abatement is a complex task, since airborne pollutants are emitted from multiple man-made as well as natural sources and affect health, climate and the environment on scales ranging from local to global. The effective abatement of air pollution levels calls for holistic solutions and cooperation on the national, European and even global scale. These solutions must include a range of initiatives that promote certain behaviours, the development of new technologies, and a move towards more environmentally friendly products. In Denmark, some of the environmental problems relating to air pollution have been resolved over the past few decades, whereas others persist and will require further attention in the years to come. This book is devoted to describing these problems, and how they have been handled over the past few decades. We focus on describing the actions and initiatives that have been successful and effective in the abatement of air pollution in Denmark, and at the same time we identify the main parties – such as ministries, politicians, industry, agriculture and NGOs – that have been involved.

Children is one the most sensitive groups concerning air pollution. Photo: Colourbox.

ACIDIFICATION

When acid gases and particles are deposited on the ground, they can cause problems for the local ecosystems. The acids can disturb the balance of the ecosystem, and lead to wash out of essential nutrients from the soil. In the 1970s and 1980s, the acidification of Swedish and Norwegian lakes was a serious problem that had to be treated by liming the lakes, i.e. adding calcium carbonate. The high content of calcium carbonate in most Danish soils means that acidification has never been as severe a problem in Denmark as it has been in Sweden and Norway. However, Danish sulphur emissions have in the past contributed to these problems in the other Nordic countries, and the substantial reductions in Danish sulphur emissions over the past three decades have thus been an important factor in the reduction of this problem.

HUMAN HEALTH

It is well established that human exposure to air pollution can lead to both short-term and long-term health effects in the population. Short-term effects are the result of episodic events of elevated air pollution levels, whereas long-term effects are the results of long-term exposure to air pollution. The latter could for example occur due to the city centre location of one's residence, but also be the result of long-range transport

The political ambition is to make Copenhagen the world's leading bicycle city by the end of 2015, thereby also improving the air quality in the Danish capital. This goal is definitely within reach. 45 percent of all Copenhageners use bicycles to go to work, school, university etc., the city offers more than 300 km's of bicycle paths, and the popular "free token bikes" give the visitors an opportunity to get around on two wheels most of the year. Photo: Kasper Thye, www.copenhagenmediacenter.com

of pollution to the entire country. Most of these negative health effects are believed to be associated with particle pollution. However, ground level ozone, heavy metals, various organic pollutants and nitrogen oxides also play a role. Although pollutant levels in Denmark are generally moderate, it is evident that negative health outcomes amongst the Danish population have been and still are associated with air pollution. These negative health outcomes include hospital admission, days of restricted activity level, premature death related to cardiovascular and respiratory illness and diabetes, as well as various types of cancer. The highest air pollution exposures generally occur in urban areas. However, the contribution from long-range transport means that exposure to airborne fine fraction particle pollution is fairly homogeneous over the entire country, and is only slightly elevated in cities.

EUTROPHICATION

Excess nutrient input (eutrophication) strongly affects the natural environment. In marine coastal waters, algal blooming may be followed by severe oxygen deficits in bottom waters. When the algae die and are deposited on the ocean floor, oxygen in the bottom waters is depleted by the degradation of the dead algae. In severe episodes, this may lead to the death of fish and benthic fauna (animals living on the bottom) in the coastal zone. Oxygen depletion in bottom waters has been observed in Inner Danish waters almost every year since the 1980s. Both waste water input and surface water run-off generally constitute the principle source of nitrogen to Inner Danish waters. The relative importance of the atmospheric input has been increasing as inputs from these two sources have declined over the past three decades.

For terrestrial (living or growing on land) ecosystems, high nutrient input above a certain ecosystem-specific critical load will in the long term lead to a reduction in ecosystem biodiversity. Photo: Kirsten Bang.

The input of atmospheric nitrogen to Danish terrestrial natural environments is generally high, due to high emissions of ammonia from local agriculture in combination with the long-range transport of nitrogen from the European continent. In 2010, the European Environment Agency estimated that more than 40 % of natural environments in European Union Member States have critical atmospheric nitrogen load exceedances, with Denmark amongst the most affected due to its high atmospheric nitrogen loads.

DEGRADATION OF STRATOSPHERIC OZONE

The ozone layer in the stratosphere protects life on earth from harmful UV radiation emitted by the sun. In the 1980s, it was revealed that man-made emissions to the atmosphere of long-lived gases such as CFCs (commonly known as Freon) can seriously degrade the ozone layer. CFCs were used as, for example, insulation in refrige-rators and windows. It became evident that the degradation of the ozone layer was affecting health, nature and the climate. During recent decades, initiatives have been taken to find substitutes for CFCs and other gases that may degrade the stratospheric ozone layer.

CROP LOSS

Ground level ozone is an air pollutant that has a negative health impact, but also affects vegetation. In the lower atmosphere, ozone is formed through reactions involving nitrogen oxides and hydrocarbons in the presence of sunlight. Denmark is located at fairly high latitude, which limits the intensity of solar radiation. This means that ground level ozone does not build up in high concentrations locally, as for example occurs in Southern Europe. High concentrations of ground level ozone appear in Denmark (and the rest of Scandinavia) when high pressure systems over central Europe force air masses north. In addition to impacting on human health, the high concentrations that result during these episodes may also affect vegetation and crops during the growth season, leading to reduced crop yield. Studies from America indicate that US losses in crop yield are very substantial, however ozone levels in Denmark are more moderate, and their impact on crops is thus also smaller.

CLIMATE CHANGE

The greenhouse effect is essential to life on Earth - it is the greenhouse effect that keeps temperatures on Earth at a level that supports living organisms. The Earth is to some extent a self-regulating system. However, man-made releases of gases and particles to the atmosphere in recent decades have affected our climate by increasing the greenhouse effect. The scale of this effect is global, but in recent years there has been significant focus on the local fingerprints concerning releases of climate forcing atmospheric species.

OUTLINE OF THIS BOOK

The first chapter of this book describes a chain of events that begins with activities in society, which lead to atmospheric emissions, from which follow an impact on health, the environment and climate, leading to mankind's response as we try to prevent negative impacts from taking place. The following two chapters concern environmental regulation and energy policy in a Danish context. The subsequent nine chapters outline the specific pollutants that have negative impacts, and detail the abatement strategies that have been carried out in Denmark. The pollutants (and their effects) are sulphur (acidification), carbon monoxide (health), nitrogen (eutrophication and health), airborne particles (health and climate), organic pollutants (health and climate), ground level ozone (health), organic hazardous pollutants (health and the food web), heavy metals (health), CFC gases (degradation of stratospheric ozone), and greenhouse gases (climate). The last chapter of the book provides a summary of the lessons learned in Denmark relating to the abatement of Danish air pollution.

FROM EMISSIONS TO IMPACT

Air pollution has various negative impacts on health, the environment, and climate – impacts that depend on many factors and take place on a wide range of temporal and spatial scales. For many of the impacts several pollutants play a role, and in some cases it may be difficult to determine which of these has played the most important role in the specific context of interest.

The areas through which human activities lead to environmental pressures in the form of air pollutants are: agricultural activities, industry, transport, energy production, and activities in private households. These activities lead to the release of air pollutants to the ambient environment, introducing climate forcing aerosols to the atmosphere and resulting in the exposure of humans and the environment to gas and particle pollution, and the degradation of stratospheric ozone. These outcomes can lead to impacts on health, the environment and climate in the form of climate change, degradation of the ozone layer, negative health effects in the population, eutrophication (nutrient enrichment) problems in marine and terrestrial ecosystems, loss of crops, and the degradation of buildings and materials.

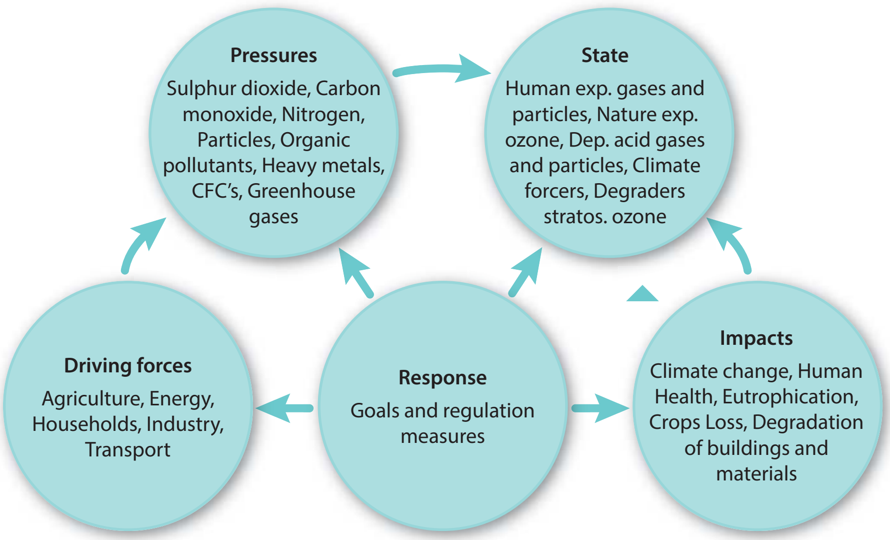
Meteorology, and especially wind conditions, governs the dispersion and transport of pollutants. Some pollutants are emitted directly to the atmosphere from either natural or man-made sources, whereas others are formed through chemical reactions between pollutants that take place in the atmosphere. Some pollutants have extremely short atmospheric residence times, whereas others remain for decades. Concentrations of some pollutants may be dominated by local emissions, whereas those of others may be governed by long transport. Air pollutants may leave the atmosphere following chemical degradation, or they may be deposited on the Earth's surface following scavenging – either through direct deposition when they come into contact with the surface, or via cloud and rain droplets. Pollutant levels are thus the result of competition between emissions, the chemical formation processes that builds concentrations up, scavenging by chemical degradation and deposition that reduce concentrations, and dispersion and transport, which dilute pollutants or removing them from a specific area. The vastly different paths followed by different pollutants during their lifetime in the atmosphere also affect their impact in relation to health, the environment and climate. In the following chapters the pollutant groups will be handled one by one, and discussed in relation to Danish abatement strategies and how successful these have been.

POLLUTANT SOURCES

Air pollutants may be emitted from combustion, evaporation, or biological processes.

EMISSIONS FROM COMBUSTION

Any combustion, whether it relates to industry, energy production or wild fire, leads to the formation of new chemical compounds. The main constituent of fuel, carbon, reacts with oxygen and forms carbon dioxide. In addition, some of the atmospheric nitrogen "burns" and forms nitrogen oxides. If the combustion is incomplete, it can lead to the formation of carbon monoxide, soot and other particles, poly-aromatic hydrocarbons, as well as various volatile organic compounds. Most fuels contain impurities. An important impurity in relation to air pollution is sulphur, which is released from combustion as sulphur dioxide, whilst incombustible constituents like heavy metals may also be emitted with exhaust gases.



Modified version of the DPSIR (Driving forces, Pressures, State, Impact, and Response) conceptual model developed by the Dutch environmental research institute RIWM in the 1980s. Societal conditions (such as economic, organizational, social, technological, and physical factors) affect agriculture, energy/ heat production, households, industry and transport and thus mediate emissions of atmospheric pollutants. These emissions lead to concentrations, exposures and depositions of pollutants that affect climate, human health, materials, the environment, and agricultural production.

EMISSIONS BY EVAPORATION

Volatile fuels may evaporate during transport or refuelling, or due to fuel spillages or incomplete combustion. Various construction-related processes such as treatment of surfaces with paint and varnish can lead to the evaporation of volatile organic compounds. Manure from animal production in agriculture leads to the evaporation of ammonia and methane from manure storage facilities and stables, as well as during the application of manure to fields.

EMISSIONS FROM BIOLOGICAL SOURCES

Methane, nitrogen monoxide and nitrous oxide are formed in biological processes in wetlands. Man-made changes in land use affect these emissions, and the same applies to evaporation of volatile organic compounds from vegetation. The latter is a major source of hydrocarbons in the atmosphere and takes place from vegetation in natural and semi-natural ecosystems as well as from crops in agricultural fields. The border between natural and man-made emissions is thus not clear-cut.

LONG-RANGE TRANSPORT OF POLLUTANTS

The amount of air pollution emitted in a given country depends on a number of factors: the size of the country, the degree of industrialization, the energy sources available, the level of agricultural activity, the climatic conditions, and so on. The fraction of the pollution that deposits inside the country from which it has been emitted depends likewise on several factors. Amongst these factors are the rate of chemical conversion, the solubility of the pollutant and its reaction products, as well as meteorological parameters such as precipitation, wind speed, and the prevailing wind directions. The two tables below show two sets of data concerning reactive nitrogen compounds for Denmark and some of its surrounding countries. The distinct difference between these two groups in the fraction of locally emitted nitrogen that is also deposited locally is mainly a result of a significant difference in deposition velocity. Nitrogen oxides need to be chemically converted to compounds that are quickly deposited, before they are being scavenged from the atmosphere. This means that nitrogen oxides from Danish sources are mainly transported out of the country before depositing, whereas ammonia deposits quickly – indeed about 20 % is typically deposited within 2 km of the source. We will return to these compounds in the following chapters of the report.

Emission and deposition data concerning nitrogen oxides in Denmark and selected neighboring countries in 2011 (Schultz et al. 2013). Deposition data are obtained from EMEP (The European Monitoring and Evaluation Programme) model calculations performed at EMEP MSC-West at the Norwegian Meteorological Institute.

	Emissions (Gg NO_2)	Deposited nationally (100 Mg N)	Total deposition in country (100 Mg N)
Denmark	126	4	186
Sweden	145	62	799
Norway	178	47	437
United Kingdom	1033	269	633
Germany	1293	605	1710
Belgium	210	16	142

Emission and deposition data concerning ammonia and its reaction product ammonium in Denmark and selected neighboring countries in 2011 (Schultz et al., 2013). Deposition data are obtained from EMEP model calculations performed at EMEP MSC-West at the Norwegian Meteorological Institute.

	Emissions (Gg NH_3)	Deposited nationally (100 Mg N)	Total deposition in country (100 Mg N)
Denmark	74	138	272
Sweden	52	184	637
Norway	26	102	246
United Kingdom	290	838	1187
Germany	563	112	3143
Belgium	67	128	295

Photo: Søren Kjeldgaard, Aarhus University.

Status for air pollution control	Targets	Impacts
Sulphur dioxide, SO_2	✓ (green)	✓ (green)
Lead, Pb	✓ (green)	✓ (green)
Nitrogen dioxide, NO_2	✓ (red)	✓ (yellow)
Carbon monoxide, CO	✓ (green)	✓ (green)
Polycyclic hydrocarbons, PAHs	✓ (green)	✓ (yellow)
Volatile hydrocarbons, VOCs	✓ (green)	✓ (yellow)
Dioxins	✓ (green)	✓ (yellow)
Particles	✓ (green)	✓ (red)
Ammonia	✓ (red)	✓ (red)
Greenhouse gasses	✓ (green)	✓ (red)
The level is acceptable	✓ (green)	
Not quite acceptable, more should be done	✓ (yellow)	
Not acceptable, more shall be done	✓ (red)	

Photo: Jesper Rais, Aarhus University.

DANISH ENVIRONMENTAL REGULATION

Regulation of air pollution in Denmark during the past two decades has been the result of a combination of Danish initiatives, and the implementation of international conventions and EU directives.

AIR POLLUTION FROM INDUSTRY AND ENERGY

Already in the late 1960s, sulphur dioxide was recognised worldwide as an air pollutant with various negative impacts on health and the environment. This led in 1972 to the regulation of the sulphur content of fuel oils in Denmark. Through the Danish Environmental Protection Act of 1974, the authorities were empowered to restrict for example air emissions from the industry and energy sectors, and the Act proved to be an efficient instrument for reducing local air emissions, associated health risks, and odours. Denmark joined the Geneva Convention on Long-range Transboundary Air Pollution in 1979 under the United Nations Economic Commission for Europe. The background to the introduction of the convention is that it was recognised that acidification and eutrophication due to the emission of sulphur dioxide and nitrogen oxide cause significant damage to ecosystems in sensitive areas, when critical loads are exceeded.

In 1990 the Danish Ministry of Environment issued a comprehensive set of industrial air pollution control guidelines, which were revised in 2001. In parallel, the EU emission requirements for large combustion plants was introduced and BAT (Best Available Technology) were imposed by the EU directive on Integrated Pollution Prevention and Control (IPPC) for large combustion sources as well as other major polluting industries.

Through the introduction of end-of-pipe technologies and the regulation of the sulphur content of fuels, this led to a significant reduction in emissions from Danish power plants.

Residential emissions are the only source that has increased emissions since 1990 due to increase in numbers of woodstoves and their use. Although woodstoves are only a supplementary heat source in about one third of all homes and only used during winter emissions still make up about 2/3 of national $PM_{2.5}$ emissions, more than 4/5 of PAH emissions and more than half of dioxin emissions. The Danish Ministry of Environment regulated the particle emissions for new woodstoves by executive order in 2008 leading to decrease in emissions since 2008, and has carried out several awareness campaigns of how to light a fire with low particle emissions.

The Danish company Morsø has been making cast-iron wood burning stoves for more than 150 years. Its newest batch, the Morsø 6600, is eco-labelled with the Nordic "Svanemærket". Pictured left is the Morsø 6670 stove. Morsø's wood-burning stoves meet some of the strictest environmental standards in the world. In particular, they meet the Norwegian Standard NS 3058/3059, which sets out stringent requirements on minimising particle emissions.
Photo: Morsø.

The initiatives taken to reduce emissions from power plants have been implemented in several steps, including the implementation of environmental taxes for sulphur dioxide and nitrogen oxides. One of the results has been that sulphur dioxide concentrations in Denmark today are a factor of 20 lower than the levels in 1982 (see also chapter 6).

In 2001, the EU established the NEC Directive (National Emission Ceilings). The NEC Directive was used to set reduction targets for four pollutants known to play a central role in acidification, eutrophication and the elevation of ground-level ozone pollution, to be fulfilled by 2010. These four pollutants were sulphur dioxide, nitrogen oxide, volatile organic compounds and ammonia.

Desulphurisation at power plants and the purification of flue gas from waste incineration plants have, together with the rules set out in the Danish industrial air pollution control guidelines, reduced emissions of heavy metals such as lead, cadmium, nickel, copper and mercury. Environmental problems with heavy metals are limited in Denmark, compared with many other countries.

In 1976, a serious accident at a factory in Seveso, Northern Italy, led to the release of large amounts of dioxin to the surrounding environment. This resulted in severe damage to vegetation and animals as well as humans in the area around the plant. The Danish

Ministry of Environment reacted to this severe incident by closing a number of minor waste incinerator plants in Denmark that were operating without flue gas purification, and by tightening the general requirements for Danish waste incineration plants. The EU has subsequently adopted very strict emission limits, and similar requirements have accordingly been imposed on Danish industries and incinerators.

AGRICULTURE AND AIR POLLUTION

Based on special Danish guidelines, ammonia evaporation from agriculture is regulated in order to reduce releases from ammonia sources. The main aim here is to reduce nitrogen deposition to nearby sensitive ecosystems. Odours from livestock have also been regulated in order to reduce odour nuisance for those living in the vicinity of sources. A number of national Action Plans for the Aquatic Environment have been implemented since the late 1980s, in order to reduce nutrients inputs to the aquatic environment. Despite long-term efforts to reduce emissions, critical loads of nitrogen are still exceeded in many areas of Denmark (see chapter 8).

TRANSPORTATION AND AIR POLLUTION

During the 1970s, there was increasing awareness in Denmark and worldwide concerning the negative impact of lead on health. It was shown that lead affects the nervous system, and this finding led to pressure for regulation of the use of lead in petrol. In 1978, the first of many EU regulations on lead in petrol was introduced. The result has been that lead concentrations in Danish urban streets have decreased by a factor of about one thousand (see chapter 12).

In 1990, Denmark introduced strengthened emission requirements for road traffic vehicles, forcing all new cars to be fitted with catalytic converters in order to reduce emissions of carbon monoxide, volatile organic compounds and nitrogen oxides. In 1993, a similar regulation was adopted by the EU, and the EU emission standards for road traffic vehicles were progressively strengthened over subsequent years. This regulation has again led to improvements in air quality close to roads and in urban areas in Denmark. Similarly, the fuel content of benzene, sulphur and aromatics has been regulated. As a result of vehicle emission standards, all new cars and vans in EU have been equipped with particle filters since 2010-2011, to be extended to trucks and busses from 2014-2015. The use of particle filters is leading to significant reductions of particles from exhaust gases.

MOST IMPORTANT DANISH LEGISLATION ON AIR POLLUTION AND CLIMATE GAS CONTROL:

1970s

Limits to sulphur in oil (1972) and lead in petrol (1977).

Environmental Protection Act enters into force (1974).

Geneva Convention on Long-range Transboundary Air Pollution (1979).

1980s

Air quality limit values for sulphur dioxide and particulates (1983).

Reduction of sulphur dioxide from power plants (1984), and sulphur dioxide and nitrogen oxides (1989).

Air quality limit values for nitrogen dioxide (1987).

Regulation of waste incineration plants (1987).

1990s

Catalytic converters in new cars (1990).

Reduction of emissions of sulphur dioxide, nitrogen oxides, and particles, from large combustion plants (1990).

Reduction of nitrogen oxides from gas engines and gas turbines (1990).

Regulation of waste incineration plants (1991).

Air quality limit values for ozone (1994).

Integrated Pollution Prevention and Control (1996).

Reduction of emission from off-road vehicles (1998).

Tax on sulphur (1998).

2000s

National Emission Ceilings (2001).

Air Quality directives adapted (2001, 2008).

Particle emission standard for woodstoves (2008).

IMO regulation of SOx and NOx in ship emissions (2008).

National air quality plan (2008).

2010s

Low Emission Zones (LEZ) in large cities (2010).

No purchase and annual owner taxes for electric vehicles (2010).

Particle filters on new cars and vans (2010-2011).

Sulphur Emission Control Areas (SECAs) for Baltic Sea and North Sea (2010).

National air quality plan for NO2 (2011).

5.75 % biofuels for transport (2012).

Industrial Emission Directive, e.g. regulation of large combustion plants, waste incineration and other major polluting industries.

The Danish Ministry of Environment has supported the preparation and implementation of a number of action plans relating to traffic and the environment for local government, e.g. the promotion of bicycles. About 45 % of all commuter trips within Copenhagen are by bicycle, and this fraction is planned to be increased to 50 % by 2020. In addition, a shift to alternative fuels is being promoted. In recent years electric vehicles have been promoted by their exempting them from purchase and annual owner taxes for the period 2010-2015, and by providing free parking for electric cars in some cities. Since 2012, all petrol and diesel for transport sold in Denmark has been required to contain an average of 5.75 % biofuel due to EU regulation, and this is expected to increase to 10 % by 2020. International ship emissions affecting Denmark are regulated by the International Maritime Organization (IMO) and the content of sulphur in marine fuels for use in Danish harbours are due to EU regulation.

The Danish Ministry of Environment introduced Low Emission Zones (LEZ) in the four largest cities in 2008-2010, requiring older trucks and busses to be equipped with particles filters to reduce particle exhaust in the urban area. A subsidy scheme for implementing particles filters supported the regulation. Photo: Britta Munter, Aarhus University.

INTEGRATED AIR QUALITY MONITORING

Monitoring of air quality in Denmark is based on a combination of air quality measurements and air quality modelling, taking advantage of both methods for a cost-effective programme. Measurements are used to study trends in actual concentrations and depositions at monitoring stations, and model calculations are used to obtain information on concentrations and depositions at locations where measurements are not performed. Both measured and modelled data are used for source attribution, and the modelled data additionally for studying expected trends and future scenarios, including the impact of implemented and planned as well as potential future regulations.

MONITORING OF AIR QUALITY

Beginning in 1981, the Danish Ministry of the Environment has, together with expert institutions, built up a national air quality monitoring program that measures key pollutants in urban and rural areas. In 1983, the Danish Ministry issued the first air quality limit values for sulphur dioxide and dust, and limit values for nitrogen dioxide and ozone were subsequently issued.

Since 1996 the Danish air quality monitoring program has, in accordance with the EU Air Quality Directive, studied 13 pollutants in order to check compliance with air quality limit values. In 2013 Denmark was only exceeding the annual nitrogen dioxide limit value at one station, in a busy street in Copenhagen, however the PM_{10} limit value has been exceeded in recent years. In response to these exceedences, the Danish Ministry of the Environment has prepared Air Quality Action Plans for PM_{10} and nitrogen dioxide in Denmark.

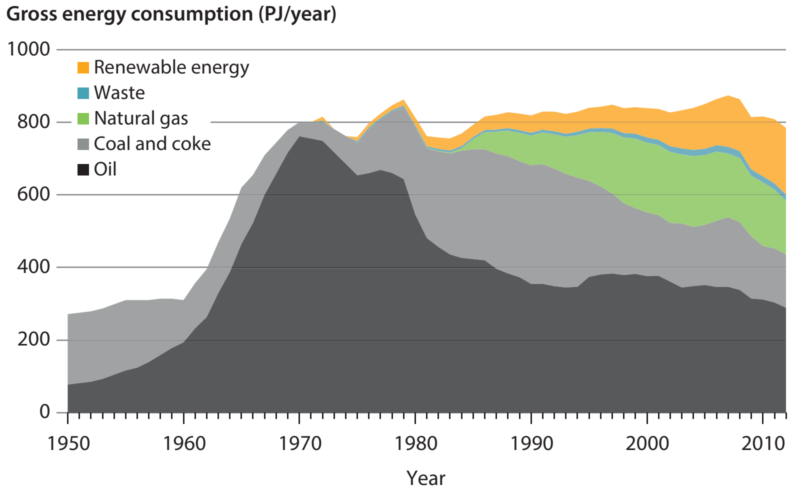
MODELLING OF AIR QUALITY

The Danish Ministry of Environment has, in cooperation with expert institutions, developed a capacity for air quality model simulations for decision-support. This constitutes a significant supplement to the measurement program. Air quality modelling provides information on the geographical distribution of pollutants, enables source apportionment, provides short-term forecasts and health impact assessments, and allows for the future impact of scenarios relating to different policy options to be assessed. Measurements and model results are made freely available to the public via TV, the internet, and through publications.

Danish energy policy is a success. A significant proportion (in 2014 around 40 %) of the Danish electricity is generated by wind turbines, mainly in off-shore parks. Danish wind turbine producers are key players on the international marked due to their high quality turbines. Biogas and solar energies are contributing to a decreasing dependence on fossil fuels.

DANISH ENERGY POLICY

An active Danish energy policy that focuses on energy efficiency, energy diversification and the development of renewable energy has resulted in a resilient energy system in Denmark, with co-benefits for both climate and the environment. This policy has also produced a growing industry of environmentally friendly products within a number of sectors, including wind energy, biogas, solar energy, and insulating materials.



From the end of 1950s up to 1970, Danish gross energy consumption more than doubled, with a high dependence on imported oil. Since then it has been stabilised and diversified.

THE OIL CRISES OF THE 1970S

Denmark's energy policy took shape after the oil crises in the 1970s. When oil prices rose in 1973, Denmark was among the OECD (Organisation for Economic Co-operation and Development) countries that were most dependent on oil for their energy supply. More than 90 % of all energy was produced from imported oil. The first Danish energy plan was launched in 1976, designed to ensure energy security in Denmark, and at the same time reduce the dependency on imported oil. Environmental considerations were not given much consideration at that time, and climate change was not considered at all.

ComBigaS, a Danish company situated in the western part of Jutland, supplies complete turnkey biogas plants designed to optimal use of different sources of biomass and their safe handling, which makes it easy to change the biomass input. A standard plant can be easily accommodated on individual farms without the negative environmental and landscape effects. Photo: ComBigaS.

The implementation of nuclear power production in Denmark was part of the 1976 national energy plan, but this was removed from Danish energy policy in 1985 after years of discussion and very strong public opposition organised by NGO's (non-governmental organizations) amongst other groups.

TRANSITION OF THE ENERGY SECTOR

An early decision in Danish energy policy was to generally prioritise energy savings, but also to work towards a diversified energy supply, to include significant use of renewable energy.

The policy measures within Danish energy policy have focused on the implementation of combined heat and electricity production based on coal, municipal heat planning, and the implementation of a more or less nation-wide natural gas grid that now covers the major urban areas in the country. Furthermore, the energy efficiency of buildings has undergone extensive improvement in Denmark, whilst support for renewable energy, research and development of new environmentally friendly energy technologies, and the ambitious use of energy taxes aimed at reducing general energy consumption as much as possible have all been introduced

In combination with successful oil and natural gas production from the Danish part of the North Sea, this energy policy meant that Denmark went from being a huge importer of oil back in 1973, to become more than self-sufficient in energy from 1997 onwards. The Danish production of oil and natural gas from the North Sea peaked during the years 2004-06, but gas and oil reservoirs are expected to be depleted by 2040 – although new extraction technology as well as new *oil* field discoveries will partly compensate the anticipated decline in production.

IMPROVING ENERGY EFFICIENCY

Danish experience shows that through an active energy policy focused on energy efficiency and use of renewables, it is possible to sustain high economic growth whilst simultaneously reducing fossil-fuel

Since the 1980s it has been possible to decouple energy consumption and economic growth, since Gross Domestic Product has increased by 80% while energy consumption has remained stable. Energy intensity has consequently decreased. (Source: Danish Energy Agency).

Photo: Søren Kjeldgaard, Aarhus University.

dependency. At the same time, this policy helps to protect the climate and the environment. Since 1980, the Danish economy has grown by around 80 % while energy consumption in the country has remained more or less constant, and carbon dioxide emissions have even been reduced over the same time period. Denmark is one of the most efficient users of energy when compared with the other EU Member States, as well as when compared with the OECD countries.

RENEWABLE ENERGY

The target for the Danish Government is that Denmark's energy and transport sectors should be supplied by 100 % renewable energy by the year 2050. The parliaments 2012 political Energy Agreement introduced the intermediate objectives that by 2020, 35 % of total energy consumption should be renewable, 50 % of electricity consumption should be provided by wind power, gross energy consumption should be reduced by 7.6 % compared with 2010 levels, and greenhouse gas emissions should be reduced by 34 % compared with 1990 levels.

The Danish energy sector is on the right track as the share of renewable energy has increased from zero in 1970 to 26 % of gross energy consumption in 2012. Renewable energy sources include solid biomass, wind, bio degradable waste, biogas, biofuels, and others (heat pumps, geothermal heat). Electricity from wind power has increased from 2 % in 1970 to 29 % in 2012 of Danish electricity consumption. For the Kyoto period 2008-12, Denmark committed to an ambitious greenhouse gas reduction target of 21 % in relation to 1990 levels, and this target was met. Denmark is in fact expected to surpass the EU objectives of a 20 % reduction in greenhouse gas emissions compared with 1990 levels, a renewable energy share of 20 %, and a 20 % improvement in energy efficiency by 2020.

HEAT SAVINGS IN BUILDINGS

Heat savings is an important part of the Danish energy policy. Since 1961, there have been energy requirements for new Danish buildings. These requirements were tightened in 1977 following the oil crises, and the requirements have been tightened even further several times since. However, existing buildings were not neglected, and initiatives were taken in order to produce improvements. In 1978, the Danish government introduced state subsidies for energy improvements to existing buildings in Denmark, and these subsidies lasted until 1984. The energy performance of new buildings is regulated in the Danish building code. The energy performance covers energy for heating, cooling, ventilation, domestic hot water and lighting. Today, the heat demands of new buildings in Denmark have been reduced to about 25 % of what they were before 1977. In 2020, new building requirements will lead to "nearly zero" energy consumption buildings in Denmark, with the small amount of energy needed covered primarily by renewable sources.

COMBINED HEAT AND POWER PRODUCTION

The implementation of combined heat and power production (CHP) has been an important measure by which energy efficiency in Denmark has been increased. With more than 55 % of the net energy demand for heating being supplied by district heating systems, Denmark has one of the highest shares of district heating in the world. In 1980, only 18 % of the electricity produced at thermal plants was produced in combination with heat production. In 2011, this share had increased to 63 %. The extensive use of CHP has reduced Danish gross energy consumption by about 14 %. The expansion in CHP has been supported by state subsidies (Act from 1977), the establishment of a legal framework for Danish municipal heat planning, and financial incentives for small-scale CHP plants.

ENERGY SAVINGS IN INDUSTRY

Until 1993, Danish industry was exempted from energy and carbon dioxide taxes due to export interests. In order to encourage companies to save energy, a carbon dioxide tax on industrial energy consumption was introduced in 1993, and since then this tax has been continuously developed. Danish enterprises can get a reimbursement of this tax, provided that they make an agreement with the authorities on specific energy saving projects, and enterprises can in addition apply for subsidies for these projects.

In 2005, the European carbon dioxide emission trading scheme (ETS) was introduced. A large part of carbon dioxide emissions from Danish industry was covered by this scheme. Following the introduction of the ETS, the Danish carbon dioxide tax was changed. Danish industries covered by the ETS were exempted from carbon dioxide tax, while the tax for enterprises not covered by the scheme was set at the carbon dioxide quota price.

ENERGY AND ROAD TRANSPORT

Despite high Danish taxes on petrol and diesel as well as high Danish purchase taxes on new cars, fuel consumption related to road transport has grown steadily over the last 40 years due to an increasing vehicle fleet and an increasing number of km travelled on the Danish road network. Since 1997, the annual car owner tax in Denmark depends on fuel consumption per km for the specific type of vehicle. In recent years the energy efficiency of road traffic vehicles has increased, due to EU regulation of carbon dioxide emissions from cars, and the introduction of eco-labelling of cars. The renewable share of energy consumed as fuel during road transport is very small – only 3 % in 2011. One of the reasons that this number is so low is that it is more expensive to use renewable energy within the transport sector than it is in other sectors. Electric cars have been exempted from purchase tax in Denmark since 2011, but despite this the number of electric vehicles in the Danish car fleet is increasing very slowly.

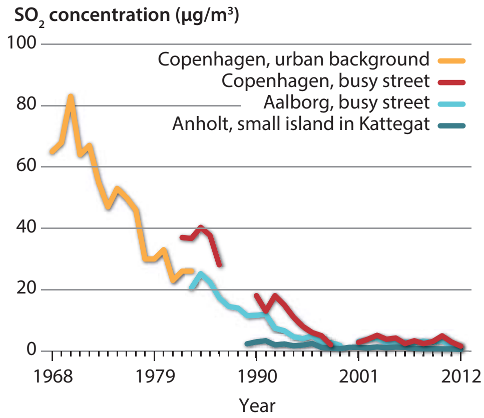
Since 2012, all petrol and diesel for road vehicles sold in Denmark must contain an average of 5.75 % biofuel due to EU legislation, and it can be expected that this will be increased to 10 % from 2020 onwards.

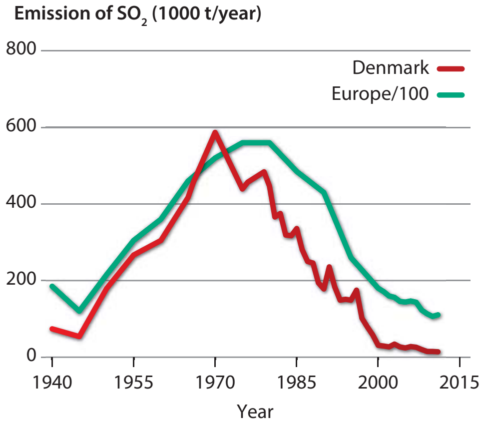
Combustion of fossil fuels like oil and coal has the side effect that the sulphur contained in the fuels leads to the formation of sulphur dioxide (SO_2) and particulate sulphate. When present in the atmosphere, these pollutants can have significant negative impacts on human health. Awareness of the negative health impact of sulphur emissions comes from two historical episodes – one in the Meuves Valley in Belgium in 1930, and secondly and perhaps more importantly the famous London smog episode in 1952. Both episodes led to a large number of casualties, and turned our focus to centralized heat and power production. Today, most Danish houses thus use district heating, whilst the power plants where this heat is produced clean sulphur from their emissions with great efficiency.

In the 1980s there was significant focus on sulphur emissions related to diesel engines, and lowering the sulphur content of diesel has reduced these emissions very significantly. Danish emissions of sulphur dioxide peaked around 1970, while total European emissions peaked 10-15 years later. The small peaks in the Danish emissions since then are due, amongst other factors, to years with high export of electricity to other Nordic countries due to low production from hydro power.

Today sulphur concentrations have been reduced considerably, and the impact on health and the environment likewise reduced significantly. Natural sources such as volcanic eruptions and biogenic sulphur from sea algae have started to play an increasing role in relation to ambient concentrations, due to the significant reductions in man-made emissions.

Concentrations of sulphur dioxide have been decreasing since 1970 due to the rapid decrease in sulphur emissions. Concentration reductions have been much larger in the three cities than on Anholt, a small island situated close to the major ship traffic lanes of the Kattegat. This is because land based emissions were regulated earlier and much more aggressively than were ship emissions.






Cruise ship at the Langelinie quay in Copenhagen. Photo: By&Havn.

SULPHUR AND ACIDIFICATION

In the 1970s it was recognized that emissions of sulphur, besides affecting human health, also had a severe impact on the environment. Deposition of sulphate and other acidifying compounds (nitrate and ammonium, see chapter 8) leads to severe damage to lakes in Northern Scandinavia, as well as to the so-called "forest death" in central Europe. Moreover, it was found that the depositing acidifying compounds were the result of long range atmospheric transport from sources up to a thousand kilometres away. The recognition of these impacts motivated a long series of both Danish and European regulations of the emissions during the second half of the 20th and the beginning of the 21st century. These efforts have significantly reduced the impact of airborne sulphur pollution in Denmark compared with the situation just 40 years ago.

DANISH AND EUROPEAN EMISSIONS

Denmark began to regulate sulphur emissions in 1972, and since this time has generally been somewhat ahead of many of the other European Countries in this respect. In 1972, the content of sulphur in oil was regulated, and in 1984 this was extended to cover sulphur dioxide emissions from power plants and combined power and district heating plants. In the time since then, the rules have been tightened several times, taxes have been introduced, and limits on the sulphur content of diesel were introduced in 1999 and 2005. The technical solutions to these regulations were reduced sulphur content of fuels, and use of desulphurisation "filters" by combustion plants. Moreover, a shift in energy production towards an increasing use of gas and wind turbines has also resulted in a reduction in emission. All in all, these measures have proven to be very effective and have led to a 97 % reduction in Danish emissions.

The transboundary nature of airborne sulphur pollution has led to strong regulation of European sulphur emissions, first through the Gothenburg protocol under the Geneva Convention on long range transport of air pollution, and later followed up by the EU air quality directives. The regulatory measures that were agreed involved the introduction of binding national emission ceilings, to which the member states and parties of the convention had to comply from 2010 onwards. This has led to an approximately 70 % reduction in total European emissions. The regulations have been so effective that Denmark was already complying with the 2010 sulphur emission ceiling in 2000, and in 2012 Danish emissions were only 25 % of the national emission celling.

SULPHUR DIOXIDE IN DANISH CITIES

Danish and European reductions of sulphur emissions have led to a significant reduction in urban concentrations of sulphur dioxide in Denmark. In around 1970, the annual mean urban background concentration was measured at 70–80 µg/m^3 in Copenhagen, suggesting that concentrations must have been well above 80 µg/m^3 in the busiest streets. Both Danish and European emissions reached their maxima in the early 1970s, and it is likely that during this period concentrations also peaked in Denmark. Today, Danish concentrations of sulphur dioxide have reduced to less than 3 % (about 1–2 µg/m^3) of the levels seen in the early 1970s. Moreover, concentrations of sulphur dioxide are far below the EU limit value for the protection of human health. The health impact of sulphur dioxide in Denmark is thus marginal. However, particulate sulphate levels in Denmark have not been reduced as much as those of sulphur dioxide due to the long range transport nature of the former. Concentrations of particulate sulphate are today about 15 % of the levels seen in the early 1980s, meaning that particulate sulphate still has an impact on human health in Denmark (see chapter 9).

NATURAL ECOSYSTEMS

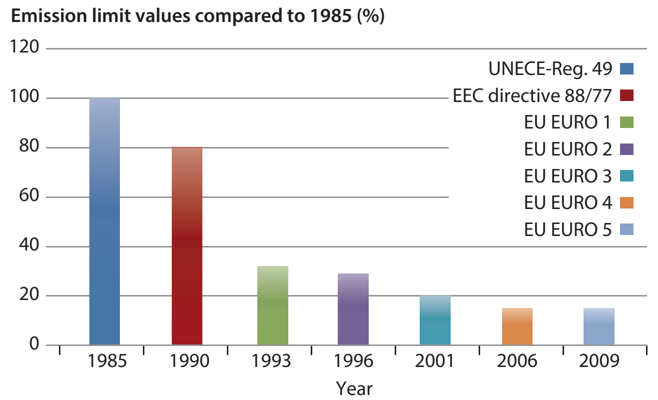
The acidifying effects of depositions of both sulphur dioxide and particulate sulphate had a significant negative impact on both aquatic and terrestrial ecosystems over the second half of the 20th century. As an example, fish were seriously harmed in about 20 % of Swedish lakes. The large decrease in sulphur emissions has changed this picture. During the period 1990 to 2010, the area of sensitive ecosystem within the EU that receives acidifying depositions above critical load has reduced by 92 %, and today acidifying deposition is only a minor problem for Danish natural ecosystems. Moreover, emissions of nitrogen compounds are today responsible for the major part of the remaining acidifying deposition (see chapter 8).

SHIP EMISSIONS

The regulation of sulphur emissions began with regulations targeting land based sources, as these were the biggest emitters and the easiest to regulate. Due to the very successful reduction of the land based sources, focus shifted to ship emissions that have, until recently, avoided regulation, meaning that fuels were used whose sulphur content was over 100 times greater than that of the diesel used by road traffic. In 2007, shipping emissions contributed about 40 % of the sulphur dioxide in Denmark.

In 2005, the International Convention for the Prevention of Pollution from Ships was extended to also include regulation of air pollution from ships. In addition, the Baltic Sea and North Sea have become a Sulphur Emission Control Area with more stringent emission controls, leading to a reduction from about 1.5 % sulphur content in fuel before 2007 to below 0.1 % in 2015. The stepwise regulation of the sulphur content has so far led to a reduction in ship emissions in Danish marine waters of about 40 %. The reductions in concentrations of sulphur dioxide observed at the Danish monitoring stations since 2007 are most likely due to mainly reductions in the ship emissions.

Carbon monoxide is emitted following the incomplete combustion of fuels. When combustion is taking place in the presence of sufficient oxygen, emissions will usually generally be low and therefore not lead to concentration levels at which severe health effects may be the result. Back in the 1960s and 1970s, carbon monoxide levels in Danish urban streets could become high due to less efficient motor technology and less strict and regular control of road traffic vehicles. In the past, carbon monoxide levels in heavily trafficked streets in Denmark may have been at levels that can lead to negative health effects. Today, the regulation and control of emissions of carbon monoxide is generally efficient, and levels in Danish cities are far below the limit values in the EU directive, and thus not considered health damaging.

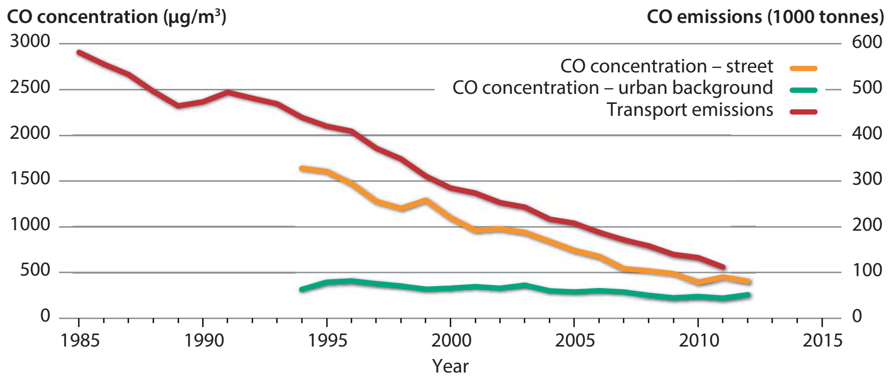


In 1985, the first recommendations for limit values for emissions of carbon monoxide from vehicles were adopted by the United Nations Economic Commission for Europe (UNECE). The first legally binding limits came through the EU via the Euro norms. The Euro 1 limit values resulted in a large reduction of emissions of carbon monoxide, and were so strict that they required the use of catalytic converters. The subsequent Euro norms have continued this reduction in emissions, though at a slower speed. The years are valid for personal cars while the Euro norms for heavy duty vehicles came one year later.

Photo: Britta Munter, Aarhus University.

CARBON MONOXIDE AND HEALTH

Incomplete combustion of fuels leads to the production of carbon monoxide, which can have a negative impact on health since inhalation of carbon monoxide reduces the lungs ability to absorb oxygen. Very high concentrations of carbon monoxide can completely block oxygen uptake in the lungs, and lead to acute death.



In 1985, the first recommendations for limit values for emissions of carbon monoxide (CO) were adopted by the United Nations Economic Commission for Europe. The first legally binding limits came through the EU via the Euro norms. The Euro 1 limit values resulted in a large reduction in emissions of CO, and were so strict that they required the use of catalytic converters. The subsequent Euro norms have implemented more increasingly stringent emission limits, though the rate of increase has been declining.

Ambient concentrations of carbon monoxide are usually much lower than the levels that cause death, but in the past there may have been cases in Denmark where concentrations have been high enough to have an impact on human health. The link between carbon monoxide and human health was one of the earliest to be established in relation to air pollution and human health. As a result of this, emissions of carbon monoxide were among the earliest to be successfully regulated. Today, ambient concentrations of carbon monoxide in Denmark and other European countries are typical so low that their impact on health is insignificant compared to those of other air pollutants.

DANISH AND EUROPEAN EMISSIONS

At the beginning of the 1980s, traffic exhaust was the main source of carbon monoxide, accounting for about two thirds of emissions. Regulation of emissions from cars has to a large extent been driven at the European level. The first regulations were introduced in 1984 under the United Nations Economic Commission for Europe, which adopted standards for the maximum allowable emissions of carbon monoxide from road traffic vehicles. In 1990, the European Economic Community followed up by tightening these rules, and in 1993 the EU introduced the so-called Euro 1 standard for cars, a set of rules regulating the most important exhaust emissions. This standard more than halved the emissions permitted by petrol driven cars. Emissions have been reduced further through the subsequent Euro 2-4 standards. Similar standards have been adopted for other types of vehicles, albeit several years after they were introduced for passenger vehicles.

Danish regulations for road traffic emissions have followed these European regulations, although Denmark was ahead of Europe in the early years. In 1990, three years in advance, Denmark introduced the emission requirements of the Euro1 standard that in practice required that all new petrol cars had to deploy a so called three-way catalytic converter. These catalytic converters reduced emissions of carbon monoxide by more than 90%. Nowadays, catalytic converters are also applied for diesel cars, vans and heavy duty vehicles.

By 2011, EU regulations had resulted in a reduction of traffic emissions to only 20% of those seen in 1985. During the same time period, there was an increase in emissions of carbon monoxide from stationary sources. This was the result of the increased use of wood as a fuel for heating domestic houses. Wood burning is now the largest source of carbon monoxide emissions in Denmark.

CARBON MONOXIDE IN DANISH CITIES

Results from the monitoring of carbon monoxide have shown that concentrations, as expected, are highest close to those streets with the greatest traffic load. Moreover, concentrations in 2012 were reduced by 80% compared with levels in 1994, when monitoring began. Due to the increased use of wood burning, there has been a much slower reduction in urban background concentrations, and the difference between the urban background and the busiest streets is much smaller than it was back in 1994. Today, concentrations in Danish cities are far below the EU limit values, and the impact on human health has been significantly reduced. Nowadays, carbon monoxide plays only a minor role when compared with other air pollutants in Denmark.

HEALTH EFFECTS OF CARBON MONOXIDE

Carbon monoxide releases are no longer believed to have a severe health impact in Denmark, with the exception of those relating to malfunctioning domestic heating devices which, in very unfortunate situations, can cause fatalities. Regular control of vehicles, boilers, stoves etc. keeps the risk at a minimum, since proper combustion in combination with catalytic converters keep the emissions sufficiently low to avoid potentially harmful concentrations.

About 78 % of the air in the lower atmosphere consists of nitrogen gas (N_2), however this gas is in a non-reactive form. Reactive nitrogen compounds are those that take part in chemical and biological processes in the environment. These are present in trace amounts, and appear in two groups of compounds in different forms: a reduced and an oxidized form.

Ammonia and ammonium: Ammonia (NH_3) is mainly emitted due to animal production in agriculture, but a small part is related to catalytic converters in petrol driven vehicles. Atmospheric ammonia deposits quickly to almost any surface, and about 20 % of emitted ammonia is thus deposited within about 2 km of its source. However, in the presence of acid gases and aerosol particles, ammonia reacts to form particulate ammonium (NH_4^+). If the transporting air mass does not meet precipitation events, the particulate ammonium can stay in the atmosphere up to 10 days and be long-range transported over distances of more than 1000 km.

Nitrogen oxides: The nitrogen oxides comprise nitrogen monoxide (NO) and nitrogen dioxide (NO_2), both of which are emitted during combustion processes where the high temperatures achieved lead to the conversion of atmospheric nitrogen gas. Nitrogen oxides are emitted through all kinds of combustion processes, but the major sources are combustion in industry, heat and energy production, and combustion related to transport. Ozone (O_3) and a number of peroxy radicals can convert nitrogen monoxide to nitrogen dioxide, whilst photo dissociation in the presence of sunlight can convert nitrogen dioxide back to nitrogen monoxide. Nitrogen oxides are converted further when nitrogen dioxide reacts with hydroxyl radicals to form nitric acid (HNO_3). Nitric acid sticks to any surface and is quickly deposited to the ground, reacts with ammonia, or is taken up by airborne particles. In the latter two cases, nitric acid is converted to particle phase nitrate (NO_3^-) that, just like ammonium, can stay in the atmosphere up to 10 days and be long-range transported over distances of more than 1000 km.

Photo: Jesper Rais, Aarhus University.

NITROGEN – EUTROPHICATION AND HEALTH

Levels and loads of atmospheric nitrogen compounds have been reduced substantially over the past two decades. De-NOX applications in heat and energy production plants as well as industry have substantially reduced nitrogen oxide releases, and here has the Danish environmental industry played an important role. Likewise have releases from road traffic been substantially reduced by the introduction of catalytic converters. Danish ammonia emissions are substantial due to a very large animal production. During a 20-years period from the mid 1980's where the pig production was increased by 60 %, the ammonia emissions were decreased by 25 % due to initiatives from the farmers in combination with national legislation. However, despite the substantial improvements, the atmospheric nitrogen compounds still contribute to negative health effects in the Danish population, and the deposition of nitrogen still exceeds critical loads for sensitive ecosystems in Denmark.

Danish nitrogen oxide emissions have been reduced substantially over the past two decades. All Danish power plants are today equipped with De-NOx devices, many of wh ich were developed by Danish companies. This photo shows De-NOx applications developed by the Danish company Haldor Topsoe. Photo: Haldor Topsoe.

The atmosphere contains a lot of non-reactive nitrogen gas. In the following, this non-reactive nitrogen gas is disregarded, and nitrogen refers only to the reactive nitrogen compounds that take part in physical, chemical and/or biological processes in our surrounding environment. Atmospheric nitrogen compounds have a substantial direct and/or indirect impact on several of the major environmental problems that are related to ambient air pollution. The direct environmental impacts of atmospheric nitrogen compounds include:

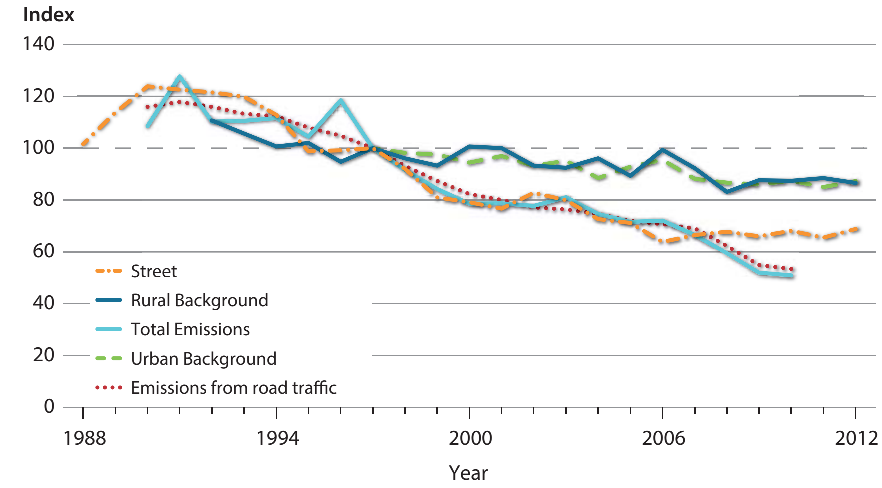
- Acidification
- Eutrophication (nutrient enrichment)
- Health

Since atmospheric nitrogen gases contribute to the formation of ozone and airborne particles, these compounds also have an indirect impact on environmental problems like climate change, loss of crop yields and poor visibility.

EMISSIONS OF NITROGEN OXIDES

Danish emissions of nitrogen oxides reached about 300,000 tons (expressed as tons nitrogen dioxide) in the middle of the 1980s. In the 1990s, this had reduced to about 200,000 tons, and in 2011 was down to about 125,000 tons. These emission reductions were achieved mainly by the implementation of DeNOx applications in power plants and major polluting industrial plants - an area where technologies have been and still are being developed in Danish industry. The introduction of DeNOx applications meant that the nitrogen oxide emissions from the energy sector where reduced by about a factor of three during the time period from the middle of the 1990s to 2010.

Nitrogen oxide emissions from Danish energy production and industry are expected to decrease further in the years to come, due to new regulatory initiatives. In 2010, the Danish government implemented a new environmental tax on nitrogen oxide emissions related to the combustion of fossil fuels. This environmental tax is meant as an incentive for Danish consumers of fossil fuels (mainly the energy sector and industry) to further reduce emissions. When first introduced, the rate of taxation



This plot shows Danish emissions of nitrogen oxides – both in total and those related only to road traffic – and concentrations of nitrogen dioxide measured at Danish street, urban background and rural background monitoring stations. Emissions have been steadily decreasing over the last two decades due to regulation, whereas the decrease in ambient air concentrations has levelled out over the most recent 5 to 6 years.

was set at 5 DKK per kg nitrogen released. Today it has increased to 25.9 DKK per kg nitrogen, and it will be further increased to 26.4 DKK per kg nitrogen in 2015.

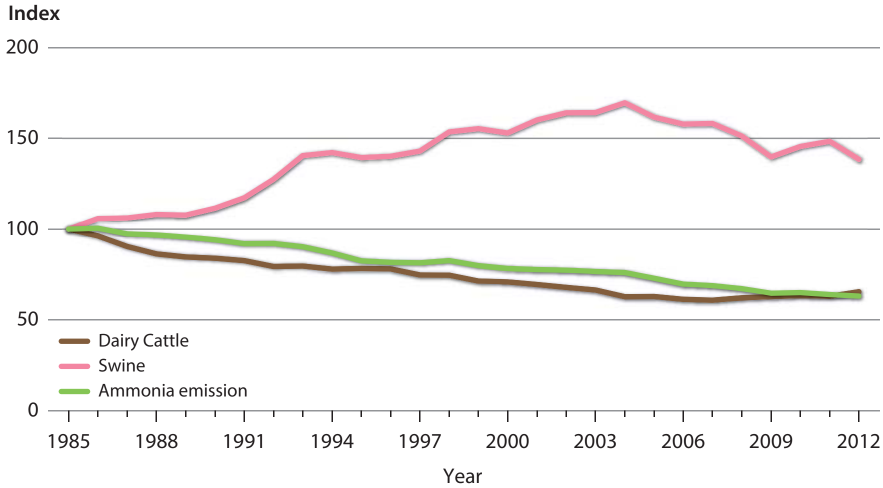
Danish road traffic emissions were also reduced substantially during this time period, as a result of the introduction of catalytic converters to the car fleet during the 1990s. Use of 3-way catalytic converters became a legislator requirement of new petrol vehicles in 1990, and this change could be seen in the gradually decreasing concentrations in urban streets during the 1990s as the Danish car fleet was gradually updated. During the last decade, there has been a substantial increase in the number of diesel vehicles in the Danish car fleet. These diesel vehicles emit larger amounts of nitrogen dioxide, and the ratio between the nitrogen monoxide and nitrogen dioxide emitted by diesel vehicles is thus substantially different from that of petrol vehicles.

NITROGEN DIOXIDE IN DANISH CITIES

Nitrogen dioxide is an airway irritant and has a direct impact on human health, whereas nitrogen monoxide is considered harmless at the concentrations found in our ambient environment. The groups most sensitive to exposure to nitrogen dioxide are people with airway illnesses, the elderly, and children. The health impact of nitrogen dioxide is mainly an issue in urban areas, where levels are generally highest, due mainly to high emissions from road traffic and the presence of buildings, which act as a shield to the wind and thereby give poor dispersion conditions.

In recent years, trafficked streets in many larger European cities (including Danish cities) have experienced exceedences of air quality guidelines for nitrogen dioxide. Inside trafficked urban streets, the local

road traffic is by far the dominating source of nitrogen oxide concentrations. Most of the nitrogen oxide emitted is in the form of nitrogen monoxide. However, for Danish road traffic, the relative fraction that is emitted as nitrogen dioxide has increased substantially in recent years. This is mainly a result of the increasing fraction of diesel vehicles in the car fleet. The nitrogen oxide emissions of diesel engines generally include a higher fraction of nitrogen dioxide than those of their petrol counterparts, due to a higher combustion temperature. Furthermore, the fraction of directly emitted nitrogen dioxide has increased substantially for diesel driven vehicles, from fractions in the order of 5–10 % in the 1980s to fractions in the order of 20–40 %. This increase has been the result of the introduction of oxidative catalytic converters to modern diesel vehicles. This means that despite a substantial decrease in total concentrations of nitrogen oxides, the decrease in nitrogen dioxide concentrations has levelled out – including in Danish urban streets – in recent decade.



During a time period during which Danish pig production doubled, Danish ammonia emissions were reduced substantially as a result of lower nitrogen content in animal feed and better manure handling. The plot shows the relative development in swine production, cattle production and total ammonia emissions in Denmark during the time period 1985 to 2012.

DEPOSITION OF NITROGEN OXIDES

Nitrogen oxides deposit relatively slowly to the ground. However, nitrogen dioxide is converted in the atmosphere into compounds that are efficiently removed from the atmosphere, mainly by uptake in cloud and rain droplets. This conversion from nitrogen dioxide into more soluble compounds takes time, and nitrogen dioxide therefore has a typical atmospheric residence time of about 24 hours. This fairly long residence time, in combination with the fact that Denmark is a small country, means that only a few percent of the nitrogen oxide emitted from Danish sources is deposited inside Denmark (see the tables and the discussion in chapter 3). The majority is transported out of the

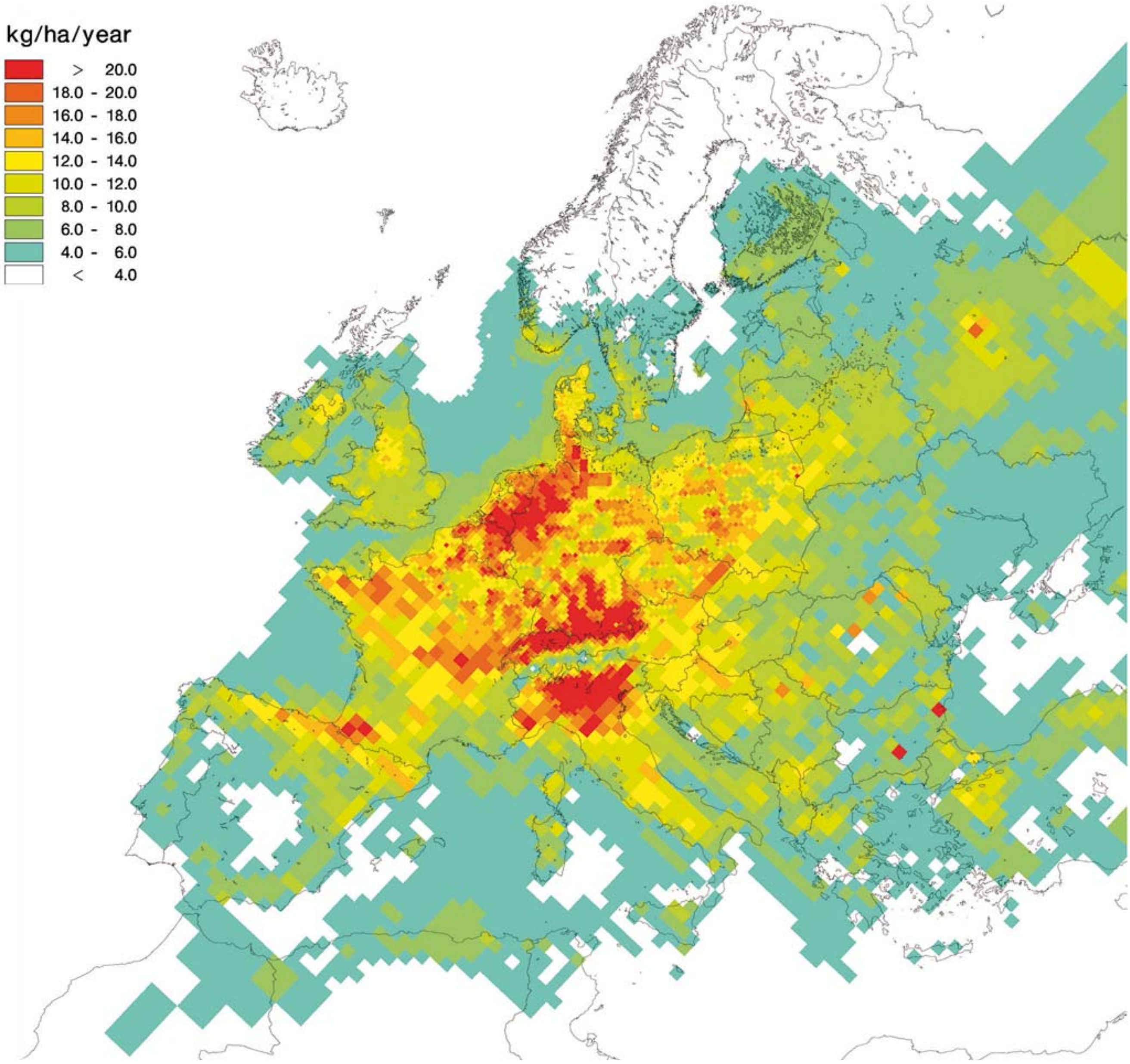
Atmospheric nitrogen deposition in Denmark has decreased over the past two decades, as a result of emission reductions in Denmark and in other European countries. Despite this, the current input of atmospheric nitrogen to the Danish environment has a negative impact, with the most sensitive Danish ecosystems under pressure. Danish coastal waters experience algal blooming episodes almost every late summer / autumn, followed by oxygen depletion in bottom waters when the algae die, deposit and are degraded. In worst cases, this leads to the death of fish and benthic fauna. About 30 % of nitrogen input to coastal waters comes from atmospheric nitrogen deposition. About 40 % of sensitive Danish terrestrial ecosystems have atmospheric nitrogen inputs that exceed their critical load values - exceedences that on the long-term may lead to shifts in the ecosystems towards systems with lower biodiversity.

country before deposition can occur. Most of the nitrogen oxide compounds deposited to Danish areas are thus reaction products that have been emitted in other countries and transported to Denmark, where they are mainly washed out of the atmosphere by rain.

AMMONIA EMISSIONS

Danish agriculture is very intensive, with substantial animal production. This animal production leads to high emissions of ammonia, and there has been substantial pressure from environmental organizations to reduce these emissions since the 1980s. In the 1990s, the agricultural sector took initiatives to reduce ammonia emissions and thereby lower the impact on the environment and health. Despite a 60 % increase in pig production over the time period 1985 to 2005, ammonia emissions from Danish agriculture decreased by only about 25 %. Pig production peaked in around 2004 at 60 % above the 1985 level. From 2004 to 2012, pig production decreased by about 20 % to a level of 40 % above 1985 production. However, throughout the entire period 1985 to 2012, the reductions in ammonia emission have been almost steady. In 2012, emissions were down by about 40 % compared with emissions in 1985.

These reductions in ammonia emissions were the result of regulation, but also of initiatives taken within the Danish agricultural sector. A very efficient initiative taken in the 1990s was to reduce the nitrogen content of the animal feed used by Danish farms. Concerning regulation,



new legislation forced Danish farmers to apply manure only when their fields have crops growing in them. Danish farmers therefore established storage facilities on their farms, in order to store the manure e.g. throughout the winter. Furthermore, farmers were required to apply manure direct injection into the soil, in order to prevent the use of diffusers. The amount of manure to be applied to a given field was restricted, and animal producers were required to have access to enough fields to which the manure could be applied. Substantial research-efforts have been made by agricultural research institutes in cooperation with governmental research institutes, in order to determine the best available technology for optimising manure application.

DEPOSITION OF ATMOSPHERIC NITROGEN

In Denmark, about half of atmospheric nitrogen deposition is related to ammonia/ammonium, and the other half to the deposition of nitrogen oxides and their reaction products. However, close to single farms with intensive animal production, the local ammonia contribution may dominate over that of nitrogen oxides.

Due to the general reduction in emissions of nitrogen in Europe, the atmospheric deposition of nitrogen to terrestrial and marine ecosystems has decreased over the past two decades. It has been estimated that the typical background deposition (i.e. deposition in areas without very local sources) of nitrogen before the industrial revolution was about 2 kg N/ha/year, and when it peaked in the 1990s it was about 20 kg N/ha/year. Today it is in the order of about 15 kg N/ha/year. It should be noted that the most sensitive terrestrial ecosystems are believed to have critical loads of 5–10 kg N/ha/year; where the critical load is the amount the ecosystem can receive before it starts changing into an ecosystem with generally lower biodiversity.

DCE has developed and operates on routine basis a series air pollution models (http://envs.au.dk/en/knowledge/air/models/). This plot shows calculated annual atmospheric nitrogen deposition over the European area in 2012. Calculations are performed with the Danish Eulerian Hemispheric Model (DEHM) with a spatial resolution of 50 km × 50 km, except for an area with higher resolution over the Danish area and close surroundings where the resolution is 5 km × 5 km.

IMPACT ON ECOSYSTEMS

Algal growth in marine waters is generally limited by the availability of nitrogen. Increasing nitrogen input leads to algal blooming episodes; episodes that are observed in Danish inner waters almost every late summer and autumn. Since the 1980s, the decomposition of dead algae following blooming episodes in Danish inner marine waters has led to frequent episodes of oxygen deficits in bottom waters. In the worst cases, these episodes have been associated with the death of fish and benthic fauna. In order to abate eutrophication of marine waters, the Danish parliament has launched four consecutive aquatic action plans aimed at reducing nutrient input to Danish marine waters. In the 1990s, it was estimated that atmospheric nitrogen contributed about 30 % of nitrogen input to Danish inner waters. As waste water inputs have decreased due to the implementation of waste water treatment plants and initiatives to reduce nitrogen run-off from agriculture, the importance of this contribution has been increasing.

When atmospheric nitrogen compounds deposit to the ground, they act as nutrient input to the environment. The European Habitat Directive sets protection targets for valuable nature habitats. This is implemented through critical load target values for various types of sensitive ecosystems, defined in the European Natura 2000 network.

For the Danish terrestrial environment, it was estimated in 2006 that 40 % of sensitive areas experienced exceedences of critical nitrogen loads. Despite various abatement strategies, it is believed that the most sensitive ecosystems will continue to experience critical load value exceedences for many years to come.

CONTRIBUTION TO PARTICLE POLLUTION

Ammonia deposits fast, and may thus affect the environment close to the ammonia sources, but it also reacts quickly with acid gases and particles. In the latter case it ends up as ammonium, in fine fraction particles ($PM_{2.5}$) (see Chapter 6). Most particulate nitrate also ends up in fine fraction particles ($PM_{2.5}$), and thus both nitrate and ammonium contribute to the fraction of atmospheric particles that has mainly been associated with negative health effects in the population. In general, inorganic compounds (sulphate, nitrate and ammonium) constitute about 30 % of fine fraction particles. It is, however, still not well known what it is about particle pollution that causes health effects. It is generally believed that the chemical composition is of importance in terms of health effects, but most studies have been devoted to mass of fine fraction particles and have not been able to associate health impacts with the various constituents of the particles.

SOIL ACIDIFICATION

Although ammonia is a base, it can contribute to the acidification of soils. Ammonia that deposits to soil surfaces will usually be absorbed by the soil, and converted within the soil water to ammonium. The dissolved ammonium may subsequently be nitrified into nitrite and nitrate by nitrifying bacteria, in processes that release hydrogen ions into the soil. If the excess hydrogen ions are not taken up by biomass and converted to methane, these surplus hydrogen ions will lead to acidic soils. The remaining nitrogen may either return to the atmosphere, be stored in the soil, be taken up by plants, or be removed from the soil during runoff or leaching.

Airborne particulate matter consists of numerous different kinds of particles, all with different physical and chemical characteristics that define their fate and environmental impact. The chemical content determines the water solubility of the particles, and thereby to what extent they are removed from the atmosphere by precipitation. Moreover, some particles consist of chemical compounds with low toxicity (i.e. sea salt), whilst others consist of compounds with high toxicity (i.e. heavy metals or organic pollutants like carcinogenic PAH (Polycyclic aromatic hydrocarbons)). The physical characteristics of particles, such as their shape and size, are very important in determining the rate by which they are removed from the atmosphere by deposition, and also their ability to penetrate into the lungs, with associated health effects.

It is common practice to group the airborne particles into different classes, depending on their size. These particle sizes range from a few nanometers to tens of micrometers:

Ultrafine particles: This group contains particles with diameters from a few nanometers up to 100 nanometers. These particles are very small, and hence they are measured by their number per cm^3. They originate mainly from local sources like traffic and wood burning, however newly formed particles produced in chemical reactions in the atmosphere are also found in this group.

$PM_{2.5}$: Particles with diameters up to 2.5 micrometers. The majority of $PM_{2.5}$ is the result of the long range transport of particles originating outside Denmark. $PM_{2.5}$ is regarded as the most important group of particles in relation to the negative impact of air pollution on human health.

PM_{10}: Particles with diameters up to 10 micrometers, and hence $PM_{2.5}$ is a constituent of PM_{10}.The major part of PM_{10} comes from long range transport of particles originating outside Denmark, however, local sources like transport, dust, and sea spray also contribute significantly to PM_{10}.

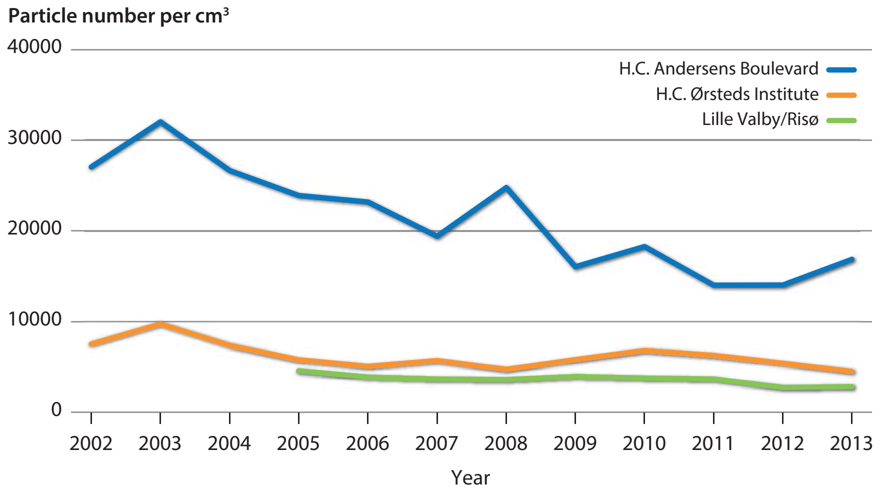
Total suspended particles: This includes particles with diameters up to about 20 micrometers, and hence includes PM_{10} (and thereby also $PM_{2.5}$ and ultrafine particles, since they are part of PM_{10}).

$PM_{2.5}$, PM_{10} and TSP are all measured by their mass (microgram per m^3).

Photo: Thomas Ellermann, Aarhus University.

AIRBORNE PARTICULATE MATTER AND HEALTH

Particulate matter (PM) is the common name used to define a group of air pollutants based solely on the fact that they occur as particles in the atmosphere. Particulate matter is a diverse air pollutant that consists of thousands of different kinds of particles with different shapes and sizes, as well as different physical and chemical properties. And it is all of these properties that determine the environmental impact of the particles. Moreover, particulate matter is interlinked with all of the air pollutants dealt with in the other chapters of this book.



Particle number concentrations at Danish street, urban background as well as rural monitoring stations have decreased over the past decade. This trend has been observed on H.C. Andersen's Boulevard, a street in central Copenhagen, at the Copenhagen urban background station situated at the H.C. Ørsted Institute, and at the rural background station at Lille Valby/Risø.

Airborne particulate matter is involved in more or less all of the major problems that relate to air pollution:

- Acidification
- Eutrophication (nutrient enrichment)
- Health
- Climate change
- Visibility
- Degradation of materials

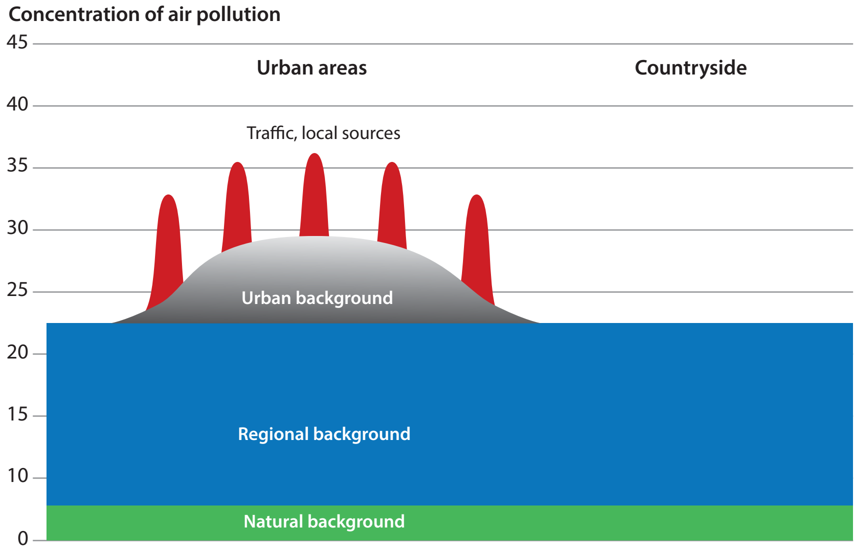
Formation of ground based ozone is one of the few examples of the environmental effects of air pollution for which particulate matter does not have a direct impact. Today, the impact on human health is the highest concern in relation to airborne particulate matter, and this is therefore the main focus of this chapter.

TRANSBOUNDARY AIR POLLUTION

A significant proportion of airborne particles undergoes long-range transport in the atmosphere. Under extreme conditions, even relatively large particles may be transported over longer distances. Following severe storm events over the Sahara, Saharan sand has been seen to reach even as far as Denmark. Particulate air pollution is thus a transboundary problem. A dominating part of rural and urban background particulate matter in Denmark is thus the result of emissions that have taken place in other European countries. However, the degree of long range and transboundary transport depends heavily on particle size.

The fine and coarse particle fractions (particles larger than 100 nm) undergo the most extreme atmospheric transport. If an air parcel does not meet precipitation events, particles in the fine and coarse fraction may be transported for 8–10 days and cover more than 1000 km before being deposited to the ground. In ambient air in Denmark, more than two thirds of fine and course particles originate at sources outside Denmark.

In contrast to the fine and coarse particles, the tiny ultrafine particles (smaller than 100 nm) are mainly of local origin. As an example, more than half of the ultrafine particles in a typical busy street are the result of direct emissions from traffic inside the street itself. The short transport of ultrafine particles is not because these particles "disappear", but because within seconds to a few minutes, ultrafine particles grow to a larger size (i.e. coagulate), and hence changes properties.



Fine fraction particles in urban areas are dominated by the long-range transport component that includes contributions from both natural and anthropogenic sources. Local sources in the urban area consist mainly road traffic, however domestic heating may also contribute to the city increment (the urban background). On busy streets, the traffic on the street itself may contribute significantly to fine fraction particle levels.

DCE operates the Danish air quality monitoring program which includes rural stations, as well as stations in urban background and trafficked streets (http://envs.au.dk/en/knowledge/air/monitoring/). The photo shows the particle measurement instruments for measuring $PM_{2.5}$ and PM_{10} at the urban background station in Copenhagen. This station is located on the roof of the H.C. Ørsted Institute Building of Copenhagen University. Photo: Stephan Ingemann Bernberg, Aarhus University.

REDUCTION MEASURES

Due to the transboundary nature and the many sources of particulate air pollution, it has long been evident that abatement of particulate air pollution requires a whole palette of measures at both national and international level. Moreover, reductions are required both for the precursors from which secondary atmosphere particles are formed, and for directly emitted primary particles.

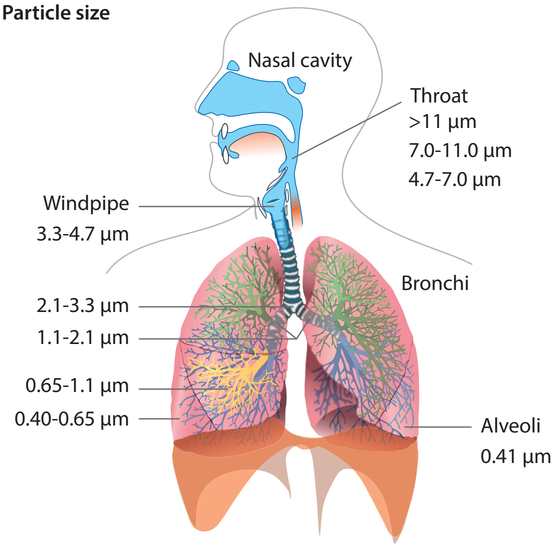
Some of the earliest abatement measures concerned reductions in the emission of sulphur through the combustion of fossil fuels. The major Danish (as well as most European) combustion plants are now equipped with desulphurisation technology that significantly reduces emissions. Moreover, power plants have shifted to cleaner fuels (i.e. less coal) and the energy sector has moved towards the use of more clean energy production (i.e. more gas, wind turbines etc.). At the same time, district heating and reduced energy consumption over the past two decades in domestic homes as well as in industrial facilities have played an important positive role. All in all, this has led to significant reductions both in the emission of primary particles, and in the number of secondary particles produced in the atmosphere following emissions of sulphur dioxide and nitrogen oxides.

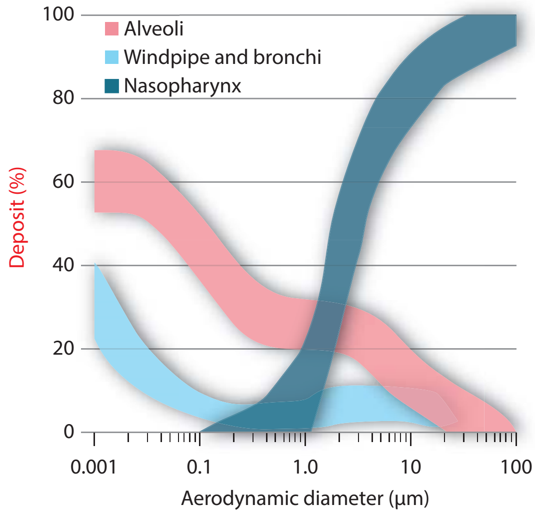
EMISSIONS OF PARTICLES AND PRECURSORS

Agricultural activities contribute directly to emissions of primary particles, but also to secondary particles via emission of ammonia. The Danish agricultural sector has developed a series of technical solutions that have reduced the ammonia emissions and thereby in turn reduced the formation of particles in the atmosphere.

The transport sector contributes significantly to atmospheric particulate matter, via the gasses emitted in vehicle exhaust, direct emission of (mainly) ultrafine particles, and – mainly in the coarser fraction – also the wear of tires and road material as well as the resuspension

Particle size





Particle size play a significant role in determining where in the respiratory system particles deposit, and thereby also in the type of health effect.

of dust. Use of cleaner fuels and the introduction of catalytic converters have led to significant reductions in emissions of sulphur dioxide, nitrogen oxides and volatile organic compounds, and these have reduced the traffic contribution to long range transported air pollution.

The direct emission of particles with exhaust fumes has long been very low for petrol driven vehicles. In contrast, diesel driven vehicles contributed significantly to emissions of ultrafine particle and soot, until it became widely accepted that it was necessary to use particle filters. Today, legislation requires that all new diesel cars and all vans and heavy duty vehicles must be equipped with particle filters. Despite all these efforts to reduce the traffic contribution to particulate matter from direct emissions in vehicular exhaust, there is still a significant contribution to particle pollution from road traffic. This is mainly due to particle emissions related to wear of brakes, tires, asphalt etc. Such emissions are generally difficult to reduce.

The other main source of primary particles in Denmark is the burning of wood for household heating. Today, wood burning contributes about 60 % of Danish direct emissions. So far it has not been possible to reduce these emissions significantly, due to an increase in the use of wood as a fuel. However, a new generation of wood stoves that significantly reduce emissions has been developed by wood stove manufactures. Through both an increase in awareness of the problem and better knowledge on good practice amongst wood stoves users, it is believed that these emissions will be reduced over the coming years.

All these practical measures taken by the different sectors have of course proceeded hand in hand with the Danish government increasingly regulating emissions of the various air pollutants that contribute to atmospheric particulate matter. The many initiatives taken in order to reduce the negative impact of airborne particulate matter have led to significant reductions in the direct emission of primary particles and of precursors to secondary particles. This has clearly decreased particulate air pollution.

REDUCTIONS IN LEVELS OF PARTICULATE MATTER

Over the past two decades, a number of methods have been used to measure particulate matter. Changes in measurement methods have made the evaluation of long term trends in Danish particulate matter concentrations somewhat difficult. However, despite these difficulties, it is evident that concentrations of particulate matter in Denmark are several times smaller today than those of the 1960s.

The first Danish measurements of soot were initiated in the 1960s, and showed soot concentrations in Copenhagen of close to 100 micrograms per m^3. During the following decades, soot concentrations were reduced to about 20 % of this level. The measurement method by which these numbers were obtained has later been found to be inaccurate. However, the observed tendencies in the measurements are believed to be correct, and these clearly show the impact of the early initiatives that were taken to reduce ambient particulate air pollution.

In the 1990s, the only particle measurements made by the Danish monitoring program were of Total Suspended Particulate Matter (TSP). However, standards in this area changed during this period, and in recognition of these developments, Danish measurements of particulate matter were also changed. In 2001, measurements of PM_{10} substituted the TSP measurements, and in 2007–2008 some PM_{10} monitors were changed to $PM_{2.5}$ monitors, in order to keep pace with developments relating to fine fraction particles. These changes followed international development in air pollution science, but they were also necessary in order to comply with the requirements of EU air quality directives that standardized measurement of particulate matter in Europe. European air quality directives have at the same time introduced several limit values for particle mass, that member states were obliged not to exceed. In Denmark, the limit values for PM_{10} were exceeded several times in the period immediately following their implementation, but since 2009 there have been no real exceedences of these limit values. Reductions in the levels of PM_{10} are the result of both national and international initiatives on air pollution. Both types of reduction are necessary, since both sources in Denmark and sources in other parts of Europe contribute to PM levels in Denmark. Measurements show that Danish levels of $PM_{2.5}$ are well below the limit value of the EU directives.

The ambient concentrations of ultrafine particles have been measured in Denmark since 2002, at a few monitoring stations in and around Copenhagen. These measurements show that concentrations have halved within just 10 years. The reductions are believed to be related to cleaner combustion in vehicles, as well as in energy and heat production, but also to a decrease in the precursor pollutants that lead to the production of new secondary particles.

HEALTH IMPACT

It has long been clear that severe health effects are associated with episodic smog (the combination of smoke and fog) events like those that occurred in the Meuves Valley, Belgium in 1930 and in London, United Kingdom in 1952. At that time, episodic events were associated with elevated sulphur pollution (sulphur dioxide and particulate sulphate) from local sources (from local smelters in Meuves, and from domestic heating and cooking in London). In 1994, the American six cities study showed a surprisingly strong association between levels of fine fraction particle pollution and the mortality rate in a number of American cities. This study attracted a lot of attention to the long term health effects of particle pollution, and initiated a variety of health assessment studies worldwide, including studies in Europe and Denmark that related various negative health outcomes to air pollution.

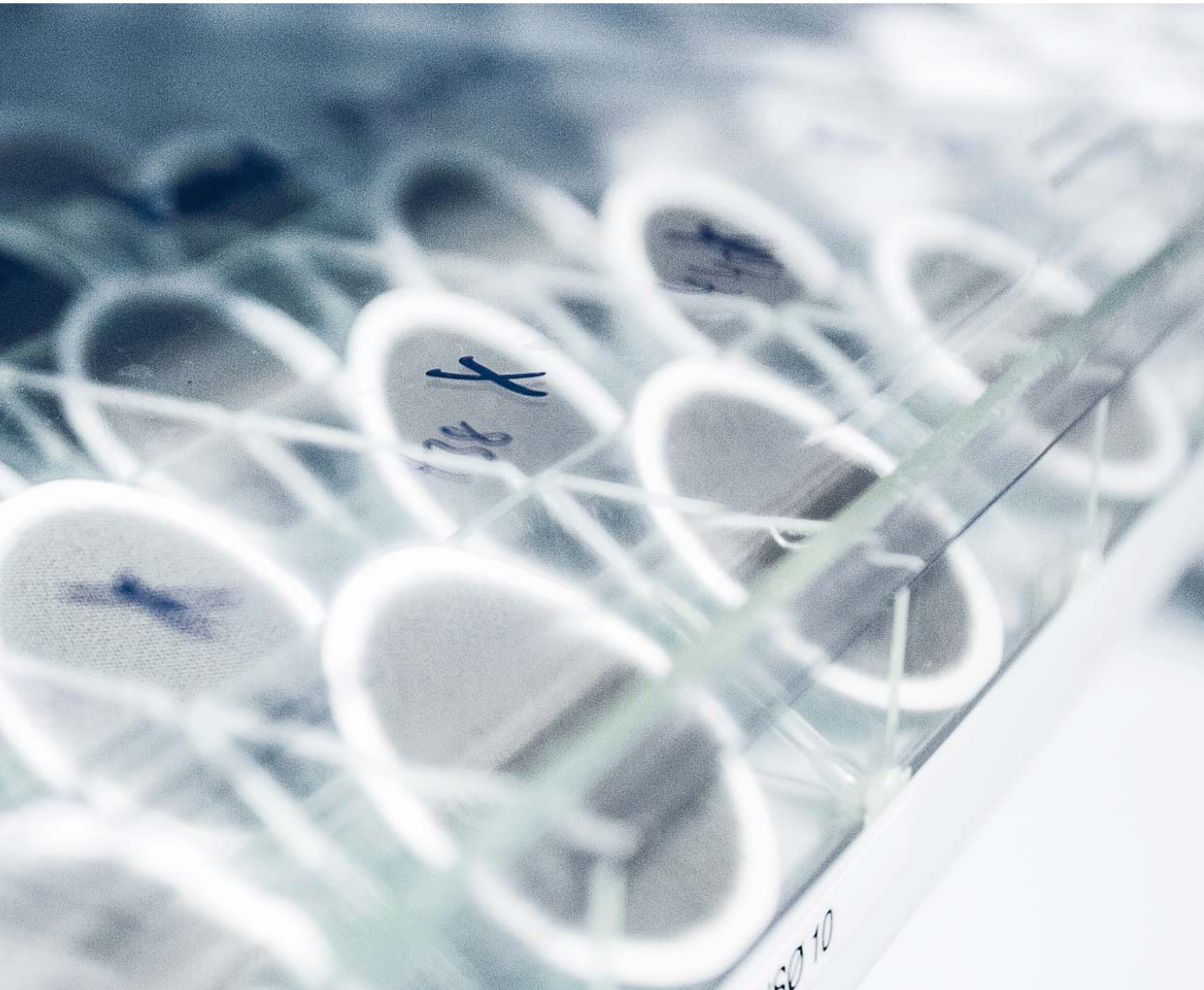
As stated previously, particle pollution is a complex mixture of different sized particles

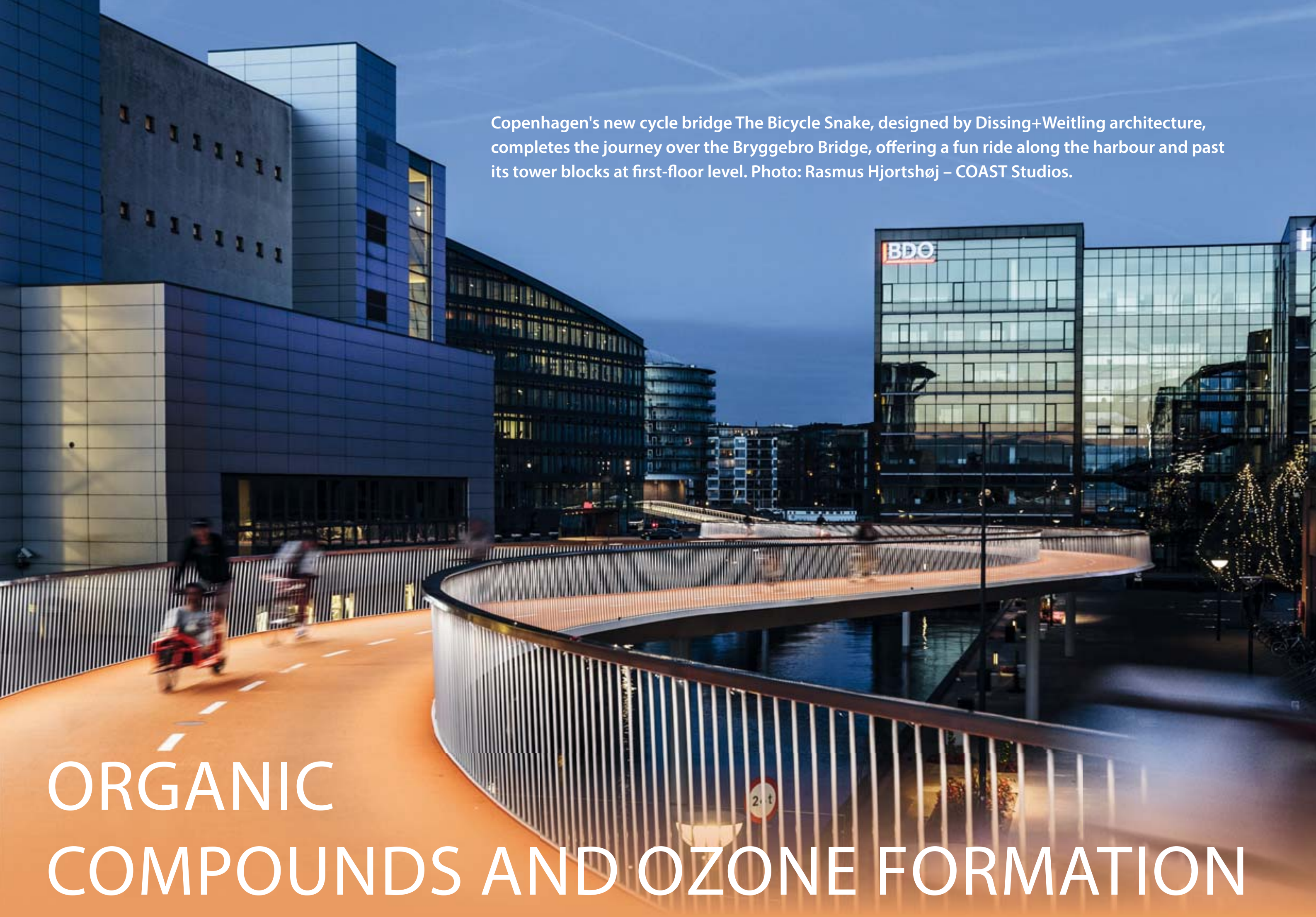

Photo: Lise Balsby, Aarhus University.

with different physical and chemical properties, and it varies considerably from one site to another. Ultrafine particles can penetrate deep into the respiratory system, but for various reasons only a few studies have been able to demonstrate health effects for particles in the ultrafine size fraction. The most pronounced relationships with health effects have been found for fine fraction particles. However, recent studies have indicated that soot may be more strongly linked with health effects than are fine fraction particles (which, as previously described, contain various types of material). Scandinavian studies involving Danish researchers have indicated that wood smoke particles are more carcinogenic than soot particles, but that the human body is better at removing the hydrophillic wood smoke particles from the lung tissue than the hard and solid soot particles.

Despite relatively moderate levels of air pollution in Denmark, health assessment studies in Denmark have been able to demonstrate relationships between health effects and particulate air pollution. This is most probably due to the precise health registers and good exposure assessment tools. Surveys carried out by DCE, AU indicate that particle pollution was responsible for about 3,500 premature deaths in Denmark in 2011. This is a substantial reduction compared with the figure of 4,200 premature deaths that was estimated for the year 2000, and forecasts suggest that this figure is likely to have fallen to about 2,300 premature deaths in 2020.

In addition to premature deaths, air pollution has been associated with a variety of other negative health effects. Danish studies have shown relationships with various airways diseases, cardiovascular disease, cancer, and even diabetes.





Copenhagen's new cycle bridge The Bicycle Snake, designed by Dissing+Weitling architecture, completes the journey over the Bryggebro Bridge, offering a fun ride along the harbour and past its tower blocks at first-floor level. Photo: Rasmus Hjortshøj – COAST Studios.

ORGANIC COMPOUNDS AND OZONE FORMATION

In the stratosphere ozone protects life on earth from UV radiation, in the lower atmosphere it is a pollutant with negative impact on health and vegetation. In Northern Europe including Denmark, the solar radiation is not sufficiently strong to lead to local formation of ozone. Episodes are therefore generally the result of transport episodes from the European continent. Hydrocarbons play a role in the formation of ozone but some are also health hazardous in high concentrations. Benzene in urban areas was lowered by reducing content in road traffic petrol.

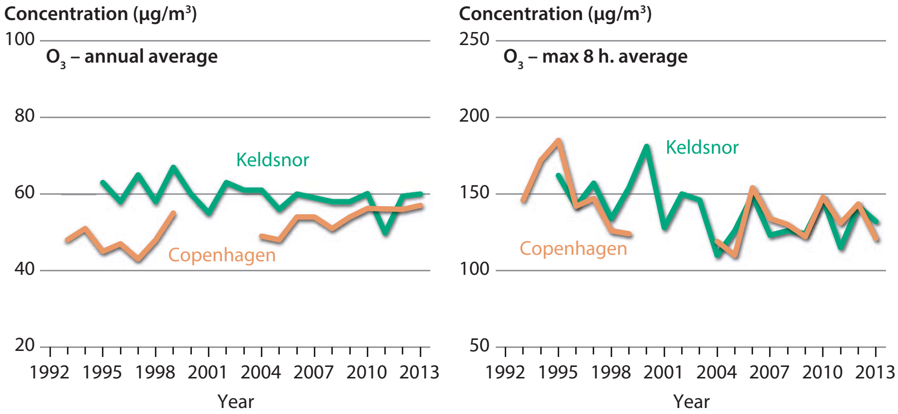
At low altitude in the atmosphere, ozone is considered an air pollutant with harmful effects on health, materials and the environment. Ozone is an irritant of the mucous membranes in the eyes and respiratory system. People suffering from allergies and respiratory illnesses may experience aggravated symptoms at elevated ozone concentrations. In Scandinavia, situated in the Northern parts of Europe, the intensity of solar radiation is generally not sufficiently strong to lead to the local formation of ozone in large quantities. In Denmark, ozone episodes are usually the result of transport from the European continent during high pressure situations over central Europe that force air masses towards Scandinavia. In urban areas, ozone is removed through a reaction with nitrogen monoxide, emitted locally by mainly road traffic. Ozone concentrations in Danish urban areas are thus generally lower than those found in rural areas. Measurements from Denmark show, in agreement with results from other European countries, that annual mean ozone values have been slowly increasing over recent years, whereas maximum values have been decreasing.

EMISSIONS OF VOLATILE ORGANIC COMPOUNDS

Volatile organic compounds (VOC's) come from a variety of sources: evaporation of fuel (during storage and handling as well as due to incomplete combustion), releases related to industrial processes, use of organic solvents, as well as some very significant natural sources. During the late 1980s, Danish emissions of volatile organic compounds were largely constant at well over 200,000 tons/year, but during the 1990s these emissions were reduced to about 150,000 tons/year. This reduction was mainly a result of the introduction of 3-way catalytic converters to petrol driven vehicles, but also due to reductions in the use of organic solvents. These emission reductions have continued in recent years, meaning that Danish emissions of volatile organic compounds in 2010 were less than 90,000 tons/year.

METHANE

Man-made emissions of methane have reduced, together with the emissions of non-methane volatile organic compounds, over the past three decades. Methane is an important greenhouse gas and plays a very important role in the formation of ozone in remote areas. The degradation of methane takes several years, but concentrations are substantial (currently more than 1.8 ppm). Measurements at remote locations like Mouna Loa in Hawaii have shown that despite reductions in man-made emissions of methane, ambient atmospheric methane concentrations have increased substantially between pre-industrial times and the 1990s.



Plot showing the trend in the annual mean (upper plot) and maximum 8 hour mean (lower plot) for ozone concentrations, at a rural site (Keldsnor) and an urban background site (Copenhagen), both of which are in Denmark, during the period1990 to 2012. It is evident from the figure that whilst annual mean values have changed only marginally, maximum values have decreased slightly over the period shown.

Since then, concentrations have continued to increase, albeit at a considerably slower rate. The increasing methane concentrations are believed to be part of the explanation into why annual mean ozone concentrations are not decreasing, despite reductions in non-methane volatile organic compounds and nitrogen oxides from man-made sources.

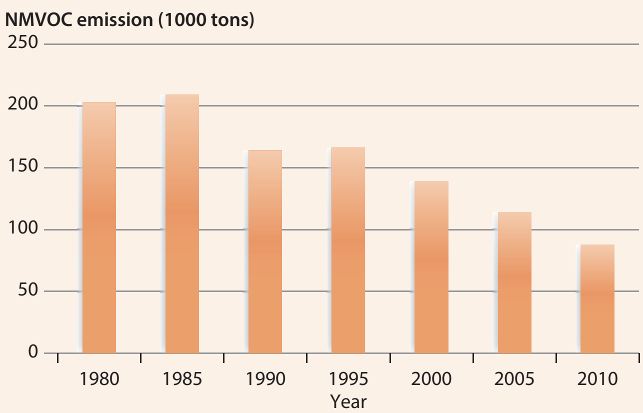
BENZENE

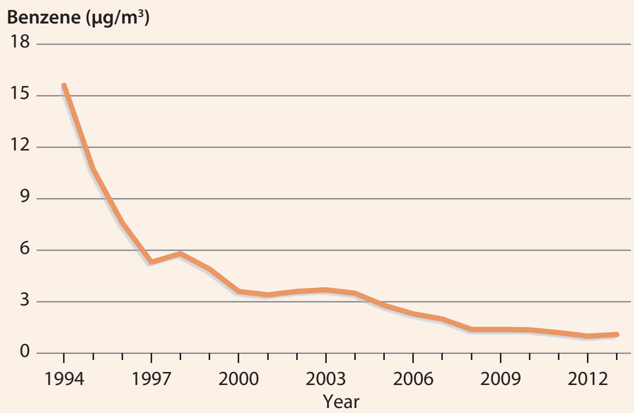
Benzene at high concentrations is carcinogenic, and human exposure to high concentrations thus increases the risk of developing cancer. Benzene arises from unburned components in petrol. In the early 1990s, urban air quality monitoring revealed that urban street concentrations of benzene in Danish and other European countries exceeded air quality guidelines. Due to the phasing out of lead, it became necessary to change the composition of the fuels in motor engine petrol, in order to ensure a sufficiently high octane number (this ensures better combustion in the motor). In order to reduce benzene in Danish urban streets, Danish refineries therefore introduced new technologies to the petrol production process, enabling them to produce fuels with the necessary octane number but with a low benzene content. This took place in the mid-1990s. During the summer of 1998, measurements documented that the Statoil refinery at Kalundborg and the Shell refinery in Fredericia had lowered the benzene content of their petrol from 3.5 % to 1 %. During the next few years, benzene concentrations at Jagtvej in Copenhagen decreased from about 10 µg/m³ in 1996, to 3.4 µg/m³ in 2001. Current benzene levels in Danish urban streets are considerably below the limit values stipulated in the EU Directive.

High up in the atmosphere (the stratosphere), ozone protects life on earth from harmful ultraviolet radiation, but in the lower atmosphere (the troposphere) it is a pollutant and is harmful to both the environment and health. Ozone is a secondary pollutant, meaning that it is not emitted, but formed in the lower atmosphere through photochemical reactions under the influence of sunlight. The precursors of tropospheric ozone are nitrogen oxides (see Chapter 8) and hydrocarbons. Hydrocarbons (or organic pollutants) may be of either natural or man-made origin. Emissions from vegetation generally dominate, and these natural pollutants also play an important role in the formation of ozone in the lower atmosphere.

Since methane is usually the most abundantly emitted of the volatile organic compounds, it is common to talk about non-methane volatile organic compounds (NMVOC). Man-made emissions of volatile organic pollutants have been decreasing over the past two decades, whereas ozone has not decreased to the same extent.

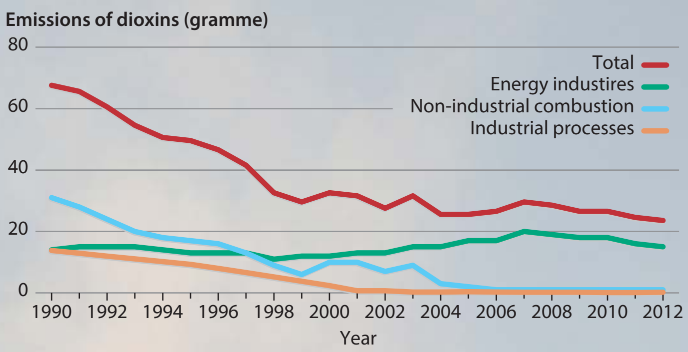
A number of man-made organic compounds are hazardous to health, and some of these are regulated. One example is benzene, for which concentrations in urban air decreased substantially when the content of this organic compound was reduced in petrol. Benzene is regulated because it is carcinogenic, but many of the organic compounds may also act as precursors for tropospheric ozone. After particles, ozone is considered as the most important pollutant in relation to population health. In addition, ozone has damaging effects on crops, as well as vegetation in natural and semi-natural ecosystems.





ORGANIC HAZARDOUS COMPOUNDS

Organic hazardous substances appear in low concentrations in the ambient environment, but may affect both the environment and public health, e.g. due to their ability to bio accumulate. The following three important groups of hazardous organic pollutant will be discussed in a Danish context: dioxins, poly cycling hydrocarbons and pesticides.



Danish emissions of dioxins and furans have decreased by about 66 % since 1990. However, this decrease has been most pronounced for large combustion plants (mainly waste incineration plants) and industrial processes (mainly steel production). The remaining emission is related to the waste sector, where emissions from uncontrolled combustion such as burning of cars and buildings, etc. are a significant and relatively constant source.

This section focuses on hazardous organic pollutants from man-made sources. The sources of these pollutants are mainly industrial processes, waste incinerators, and use of pesticides, as for example occurs due to the intensive agricultural methods practiced in Denmark.

Some organic compounds are hazardous in themselves. Some have been regulated through the Protocol on persistent organic pollutants under the Convention on Long-Range Transboundary Air Pollution. Persistent organic pollutants are organic substances that are toxic, persistent, bio accumulates, prone to long-range transboundary atmospheric transport and deposition and are likely to cause significant adverse effects to human health or the environment.

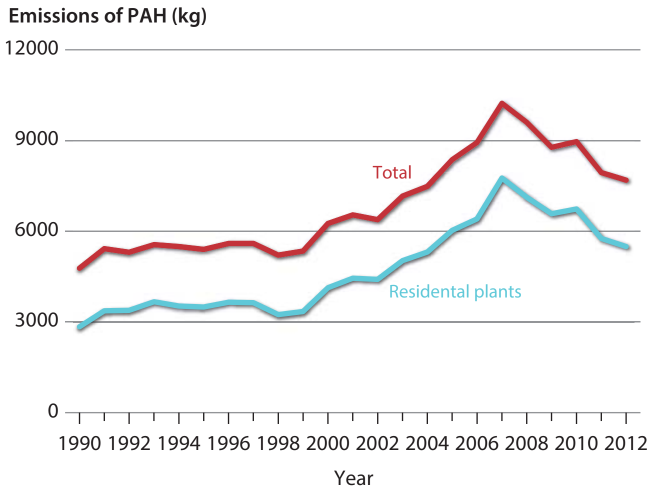
Danish researchers, together with Danish wood stove producers, have developed stoves with significantly reduced emissions. Stoves with the Nordic Swan mark need to comply to certain requirements regarding emissions, but recent research suggests it may be possible to reduce emissions much further in the near future.

Photo: Thomas Ellermann, Aarhus University.

DIOXINS

The term "dioxins" covers 210 complex compounds that are different congeners of dibenzo-dioxins and dibenzo-furans. The main source of these pollutants is combustion of materials that contain chlorine. These materials include different waste fuels, but "clean" fuels such as coal and biomass also contain some chlorine that, during combustion, can lead to the formation of dioxins. Due to the bio accumulating effect, it is not direct inhalation that possesses the greatest threat to human health, but rather the deposition of these compounds on land and water surfaces, from where the dioxins enter the food chain. Those of the compounds that are fat-soluble can then easily be transferred through the food chain.

Danish waste incineration plants have been regulated since the early 1990s. The first specific regulation targeting emissions of dioxins and furans from waste incineration came in 2003, when a statutory order set a limit value on dioxins and furans of 0.1 ng per cubic metre flue gas. Through the 1990s, emissions were reduced due to the implementation and improvement of other abatement systems, including flue gas desulphurisation. The legislative limit value, which had entered into force by the end of 2004, necessitated further technical measures to be implemented at many plants. The Danish government decided that all waste incineration plants should have dioxin abatement measures in place by the end of 2004, regardless of whether the emission limit value could be achieved through other measures. In response, all waste incineration plants were equipped with dioxin abatement capabilities such as the injection of activated charcoal into flue gas prior to it passing though particle removing instruments. As a result of this regulation, emissions of dioxins and furans decreased by about 96 % between 1990 and 2012. Other sectors, such as cement production and steel production, also reduced the emissions of dioxins and furans during this period, while emissions from small combustion installations in households have shown an increasing trend (see section on polycyclic aromatic hydrocarbons).



Emission of polycyclic aromatic hydrocarbons (PAHs) is dominated by emissions from residential plants, where the main sources of PAHs are the combustion of wood and straw.

POLYCYCLIC AROMATIC HYDROCARBONS

Formation of polycyclic aromatic hydrocarbons (PAH) typically occurs during poor combustion conditions. This makes small combustion installations prone to larger emissions of PAH than larger plants, where combustion efficiency is better. Since the formation of PAH is closely related to combustion conditions, emissions of PAHs are generally correlated with emissions of carbon monoxide. PAH emissions are generally inventoried for the four congeners:

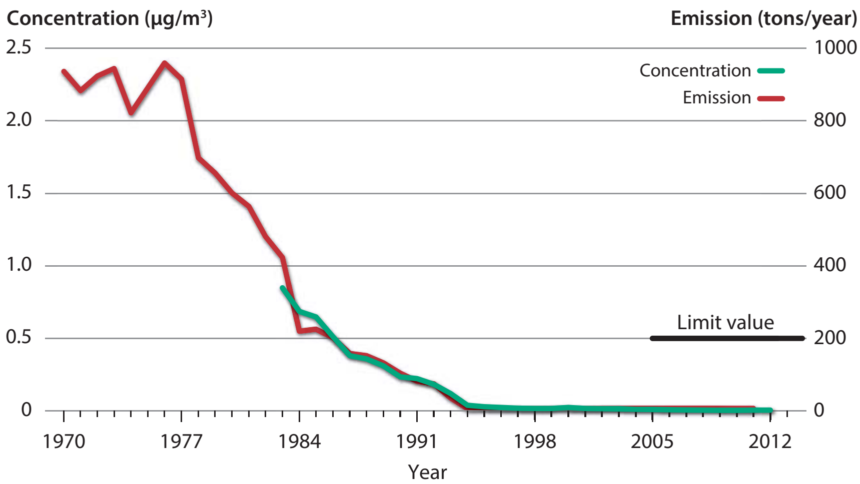
- benzo(a)pyrene,
- benzo(b)fluoranthene,
- benzo(k)fluoranthene and
- indeno-(1,2,3-cd)pyrene.

In response to the increasing emissions from small scale combustion plants, and the increasing emission share of these plants, a statutory order was issued in 2007 that established emission limit values that entered into effect on January 1 2008. For stoves, an emission limit value was established for particulate matter, while for boilers, emission limit values were established for carbon monoxide, hydrocarbons and particulate matter. Currently, a revised statutory order that includes a further tightening the emission limit values is undergoing public consultation. The total Danish emissions of the four PAH compounds increased by 61 % between 1990 and 2012. However, between 2007 (when the emissions peaked) and the present day, a decrease of 25 % has been observed. This decrease is due to more efficient stoves and boilers as a consequence of the established emission limit values.

PESTICIDES

The Danish EPA uses an indicator for pesticide loads. This indicator showed that the consumption of pesticides in Denmark increased by approximately 40 % during the period 2007 to 2012, mainly due to agricultural use. The Danish government has as a response made a pesticide action plan, with the goal of reducing the use of pesticides in Denmark by 40 % over the period 2011 to 2015. In Denmark, there has been a general movement towards use of more environmentally friendly compounds. In 1998, the Danish government agreed with local authorities that the use of pesticides on all public areas in Denmark would be phasing out. This agreement was renewed in 2007.


Photo: Britta Munter, Aarhus University.



Emissions of lead from the transport sector have decreased rapidly due to Danish regulation. Ambient atmospheric concentrations of lead have been measured in trafficked urban roads since 1983, and show a decrease that agrees with the change in emissions. The EU limit value, which was adopted by Denmark, entered into force in 2005 and has never been exceeded, with ambient concentrations far below this value.

It has long been known that heavy metals can have a serious impact on human health, and that the intake of high concentrations of heavy metals will lead to death. However, sub lethal concentrations can also have a serious impact on human health and wellbeing. As an example, it has been shown that even relatively low concentrations of lead can reduce the function of the brain and lower a child's intelligence. Moreover, heavy metals become accumulated within food webs, and hence emissions of heavy metals to the atmosphere can result in high concentrations in human food.

In general, the most important sources of heavy metals are emissions of heavy metal-containing particles from the combustion of fossil fuels and waste. An example is battery waste, which when not recycled can be a significant source of mercury.

HEAVY METALS AND HEALTH

The serious impact of heavy metals on human health, either via direct exposure or via food webs, has led to both national and international regulation of their emission. In the EU, the focus has been on nickel, arsenic, cadmium, lead and mercury. These five heavy metals are here used to illustrate measures taken in Denmark to reduce the negative effects of heavy metals.

COMBUSTION AND WASTE

Regulations concerning the emission of heavy metals are connected to the general regulations concerning emissions from large combustion plants and waste incinerators. Most important are the regulations that ensure the use of desulphurisation "filters" and the purification of flue gas. Moreover, the large decrease in the use of fossil fuels, especially coal, has significantly reduced emissions of heavy metals. As an example, there has been a 90 % reduction in Danish emissions of cadmium since 1990. Reductions in energy production have alone been responsible for 90 % of this reduction. Similarly, there has been a reduction of about 80 % for arsenic and nickel. Concentrations of cadmium, nickel and arsenic in ambient air have decreased by about 50 % since 1990. This is somewhat less than the reduction in Danish emissions, but the difference is due to the long range transport of these compounds to Denmark from other European countries where the decrease in the emission of these compounds has been less pronounced than in Denmark. For all three of these heavy metals, concentrations are less than 15 % of the EU limit value.

LEAD IN PETROL

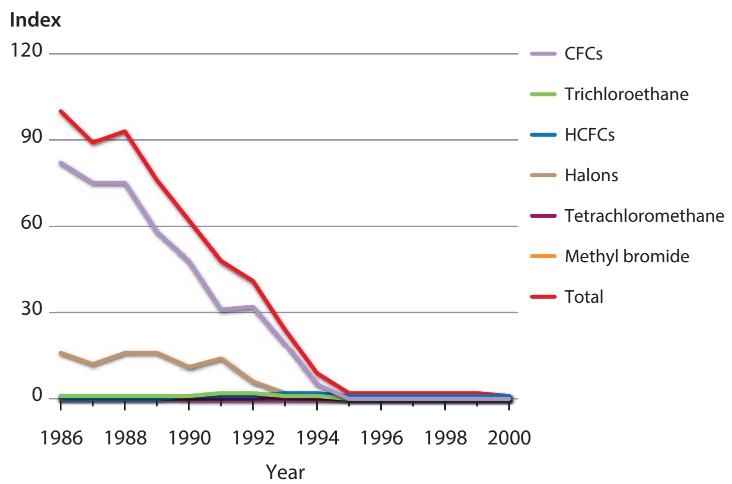
Lead is emitted during the combustion of fossil fuels, but in the past the main emissions of lead were related to use of lead as an anti-knocking agent in petrol. Lead was first introduced to petrol in 1923, and during the following decades – especially after the Second World War – there was a rapid increase in global emissions of lead due to increase in the number of and mileage covered by road traffic vehicles. In 1972, Danish environmental concern of the negative impact of lead emissions resulted in a proposal for an upper limit of 0.40 g lead per litre petrol, down from the standard of 0.54 g/litre. Adoption of this legislation was postponed due to negotiations on a similar regulation in the EEC (European Economic Community, the former EU). The Danish legislation and statutory order was finally adopted in 1977, and came into force in January 1978, two years in advance of the EU. In 1981 Denmark lowered the limit to 0.15 g/litre. Four years in advance of EU. In the mid-1980s, Denmark increased the tax levied on leaded petrol, and this decreased emissions further. Denmark has not banned leaded petrol, but since 1994 leaded petrol has not been sold in Denmark. These regulations have resulted in a rapid decrease in emissions of lead, beginning in 1978. In 1977, Danish emissions of lead were about 920 tons annually, mostly coming from the transport sector. In 1984 it was about 200 tons, in 1994 only about 20 tons, and emissions today are only 1 % of those prior to the onset of regulation. Though the majority of the reduction has been due to the ban on leaded petrol, transportation still accounts for 2/3 of the total emissions, with this being deriving from break dust. The rapid decrease in emissions has off course been followed by a rapid decrease in atmospheric concentrations. The longest Danish time series of lead measurements began in 1983 at street stations in Copenhagen and Aalborg, and these were later followed up by measurements in Aarhus and Odense. These data show a more than hundred fold decrease in lead concentrations, from about 0.8 $\mu g/m^3$ back in 1983 to about 0.005 $\mu g/m^3$ today. The result is that today's level is a factor of one hundred below the EU limit value.

MERCURY

As for many other heavy metals, the main source of mercury emissions is the combustion of coal, which naturally contains mercury. However, mercury differs from the other heavy metals in that it is a liquid at typical temperature and pressure, and hence it is present in the atmosphere both as a gas and in particles. Moreover, it has a complex atmospheric chemistry. Due to mercury's physical and chemical properties it has been used in amalgam tooth fillings, thermometers, pressure gauges etc. Besides man-made emissions, there are also large natural emissions of mercury. Mercury is highly toxic, and there are various examples where mercury pollution has led to both acute and chronic illness as well as death. The life time of mercury in the atmosphere is long, and it has entered the atmosphere it will be spread over the entire globe. It is readily taken up by animal fat, and mercury thus bio accumulates up through food webs. This gives problems in Greenland, because their diet consists to a relative large extent of fish and marine mammals. There has been strong public concern about the negative environmental impact of mercury, and this has led to series of national and international regulations concerning the use and emissions of mercury.

Danish mercury emissions have fallen by about a factor of ten since 1990. This is mainly due to the general regulation of power plants which resulted in the cleaning of flue gas and the decreasing of coal combustion. In addition, the use of mercury in many products has been banned, whilst waste incinerators now have increased flue gas cleaning etc. Similar reductions have occurred in other European countries, and as a consequence the atmospheric mercury burden has decreased. There is no atmospheric monitoring of mercury in Denmark, but Swedish measurements document a significant decrease in the wet deposition of mercury - a decrease that is also in line with reduced emissions. Despite this, there is still concern over the content of mercury in for example salmon from the Baltic Sea. Part of this mercury originates from atmospheric depositions.

Ozone depleting substances (ODS) is a term used for a group of gases, including CFCs (chloro-fluoro carbons), HCFCs (hydro-chloro-fluoro carbons), halons and methyl bromide. The most significant ODSs were CFCs. All of these substances are industrially produced gasses, and are under normal conditions extremely stable and generally non-toxic. They have therefore had a series of practical applications, for example, CFCs and HCFCs have in particular been used as propellant s in aerosol cans, in the production of insulating foams, for chemical cleaning and degreasing, and for laboratory analysis. Halons have been used primarily for fire extinguishing, and methyl bromide for disinfection and as a pesticide. For many years they were considered an environmental asset.



Danish consumption of ODSs, calculated as ozone depleting capacity. (1986 = index 100). Source: Danish EPA.

Photo: Søren Kjeldgaard, Aarhus University.

CFC'S AND THE HOLE IN THE OZONE LAYER

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

DEPLETION OF THE OZONE LAYER

The ozone layer protects the Earth's surface from harmful solar ultraviolet radiation. At ground level, ozone is an air pollutant that has negative effects on human health and vegetation (see chapter 10). However, further up in the atmosphere (15-50 km in the stratosphere), the ozone layer forms a protective shield.

The great stability of the ODSs, and thus their long lifetime in the atmosphere, means that they can be mixed into the stratosphere. In the stratosphere the ODSs are broken down by ultraviolet radiation to form free chloride or bromide atoms that reacts with ozone, converting it to oxygen.

Depletion of the ozone layer results in an increase in UV-B radiation at ground level, with a range of unwanted effects for health and the environment. The most feared human health effect is the increased incidence of e.g. skin cancer.

On a larger scale, plankton algae can be harmed. As they constitute the first link in the marine food chain, this may have consequences that can escalate through the whole food system.

INTERNATIONAL EFFORTS

The work on establishing international regulation of ODSs started in 1980, under the auspices of the United Nations Environment Program, and the first result of this work was the Vienna Convention, signed in 1985. This Convention mainly stated the intent for countries to cooperate on research and the exchange of information.

The Montreal Protocol, signed in 1987, contained binding agreements on the reduction of the consumption and production of a number of ODSs. The protocol is regularly revised, based on scientific, technical, environmental and economic assessments. This has ensured a dynamic protocol that has developed in line with scientific discoveries and technological innovations. All members of the United Nations are Parties to the original protocol, however fewer are Parties to the revised versions from 1990, 1992, 1995, 1997, 1999 and 2007.

In 1990, it was agreed that a temporary fund to assist developing countries in paying for the expenses incurred through reducing the production and use of ODSs should be set up. This fund was later made permanent, and has been an important tool in ensuring the global ratification of the protocol and its amendments.

DEVELOPMENT IN DENMARK AND THE WORLD

In 1988 an action plan was developed in Denmark to combat ODSs. The main initiatives in the plan were: international cooperation at all levels, a national plan for reducing the consumption of ODSs with the goal of reducing their consumption by 50 % by 1995 and to end their use to all intents and purposes by 1999. Furthermore, a tax on CFCs and halons of 30 DKK per kg was put in place, as was legislation that only permitted the use of ODSs until alternatives became available.

A scientific and technological development program was put in place to promote the development and use of alternative substances, technologies, etc. By 1995, Denmark had phased out all use of the majority of ODSs, and only very small amounts of HCFCs remained as it was legal to refill fridges with regenerated HCFCs until 31 December 2014.

Photo: Colourbox.

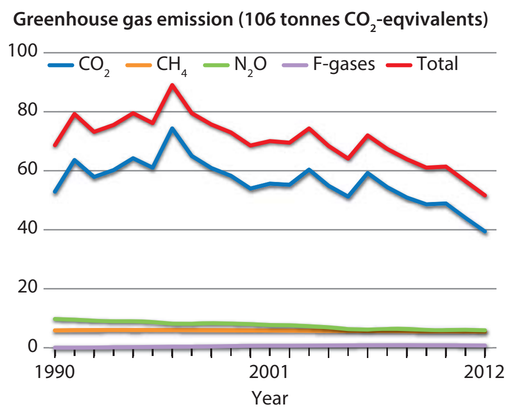
Phasing out has also been successful at the international scale, although a fall in the production of CFCs has been accompanied by an increase in the production of less harmful substitutes. Concentrations of CFC-11, a dominant ODS, has decreased. Concentrations of trichloroethane also decreased significantly, while HCFC-22 concentrations are still increasing. Furthermore, while many of the substitutes used are not being ozone depleting, they have proven to be potent greenhouse gases which contribute to climate change. Hence there is still the need for international focus on the development of scientific and technological solutions to the growing need for refrigeration and air conditioning.

GREENHOUSE GASES AND A CHANGING CLIMATE

The importance of the composition of the atmosphere for the energy balance of the earth, and thus for the global climate, has been recognized since the beginning of the 19th century. In the 1890s, the Swedish meteorologist Arrhenius calculated that the doubling of the concentration of carbon dioxide could result in a global warming of 5-6°C.

At the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992, more than 150 countries signed the UN Framework Convention on Climate Change (the Climate Convention).

On 21 December 1993 the Climate Convention was ratified by a sufficient number of countries, including Denmark, and it entered into force on 21 March 1994. Currently, there are 195 Parties (194 States and 1 regional economic integration organization) to the Climate Convention.



The total Danish emission of greenhouse gases has decreased by 25 % since 1990. Emissions of all three major greenhouse gases have decreased, while emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride have increased.

Middelgrunden offshore wind farm (40 MW) in Øresund, close to Copenhagen. Photo: Kim Hansen from Wikimedia Commons.

The Climate Convention and the Kyoto Protocol covers the greenhouse gases carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. From 2015, nitrogen trifluoride will be added to the list of gases covered by the convention and the protocol. One of the provisions was to stabilise greenhouse gas emissions from industrialised nations by the end of 2000. At the first conference under the UN Climate Convention in March 1995, it was decided that the stabilisation goal was inadequate. At the third conference in December 1997 in Kyoto in Japan, a binding agreement was reached, committing industrialised countries to reduce emissions of six greenhouse gases by 5.2 % by 2008–2012 compared with the corresponding base year value (1990 levels for carbon dioxide, methane and nitrous oxide, and 1995 levels for the fluorinated gases). On May 16, 2002, the Danish parliament voted for the Danish ratification of the Kyoto Protocol.

The European Union had a reduction commitment of 8 % for 2008–2012 compared with the base year. Under the European Union Burden Sharing Agreement, Denmark must reduce emissions by an average of 21 % in the period 2008–2012 compared with the base year emission level. The second commitment period under the Kyoto Protocol is agreed to cover the years 2013–2020. The European Union has a reduction commitment of 20 % for 2013–2020 compared to the base year.

DANISH MITIGATION MEASURES

Since the Brundtland Commission's report, "Our Common Future", in 1987, Danish climate policy has developed in collaboration with the different sectors of society, and in line with international climate policy, and results from related scientific research. Since the late 1980s, a considerable number of measures to reduce emissions of greenhouse gases have been implemented. In 1988 the government issued the Government's Action Plan for Environment and Development. One of the main messages in this plan was the need to integrate environmental considerations into decisions and administration within different sectors. In the following years, a number of ministries have prepared sector action plans in which the environment is an integral element. The sector action plans deal with the entire development in a sector combined with solutions to environmental problems caused by the sector. While some measures were directly targeting reductions in greenhouse gas emissions, others were adopted to combat other environmental issues, e.g. the pollution of the aquatic environment and the reduction of waste generation. These measures also led to a decrease in greenhouse gas emissions caused by reduced emissions from nitrogen leaching and reduced emissions from landfilling.

The implemented measures are wide ranging, and cover many different types such as taxes (on fuels, electricity, waste, methane, carbon dioxide and fluorinated gases), public information campaigns, energy labelling, subsidies, and bans. Danish measures have meant a significant increase in the production of wind power in Denmark, and have made Denmark a world leader in wind power technologies. The current Danish domestic target is a reduction of 40 % in greenhouse gas emissions by 2020 compared with the level in 1990.

DANISH ADAPTATION MEASURES

In March 2008, the Danish government launched the first Danish strategy for adaptation to a changing climate. In December 2012 an action plan for a climate-proof Denmark was launched. This action plan contains a number of initiatives that in general fall within five major areas, – an improved framework for climate change adaptation, knowledge sharing and the need for a common knowledge base, strengthened domestic collaboration and coordination, green transition, and international adaptation efforts. Adaptation to climate change is to a large extent based on local activities, and relies on the efforts of local authorities, companies and citizens. The best knowledge of the specific circumstances relevant to a given area is found with the local stakeholders, and this forms the best basis for decisions related to adaptation measures.

In Denmark there is a strong cooperation between the government, and state level agencies and local municipalities. The government and the municipalities have agreed that the municipalities will increase investment in climate change adaptation of wastewater treatment by DKK 2.5 billion. This agreement also requires that all municipalities carry out a risk assessment and prepare municipal climate change adaptations plans.

CO-BENEFITS WITH AIR POLLUTION

As mentioned, a number of the mitigation measures that have been put in place have had multiple benefits and side-effects. A number of measures implemented to reduce air pollution have had a beneficial effect on the emissions of greenhouse gases, and the other way around. An example is the different measures implemented to reduce fuel consumption in order to reduce greenhouse gas emissions. These measures have also served to reduce emissions of air pollution, mainly nitrogen oxides and sulphur oxides.

A reverse example is the measures implemented in agriculture to reduce the emission of ammonia. These measures have led directly to a decrease in emissions of nitrous oxide.

Occasionally, measures implemented to combat one environmental problem can have an adverse effect on other environmental issues. This is for instance the case with the increased use of biomass in the production of power and heat. The use of biomass in the Danish energy sector has more than doubled since 1990, and this increase is significant both in large combined heat and power plants and in small domestic combustion installations. The increased use of biomass as a replacement for fossil fuels caused a decrease in carbon dioxide emissions, but simultaneously caused significant increases in emissions of specific air pollutants (see chapters 9 & 11 on particles and organic hazardous compounds). The negative impact on air pollution is largest for small combustion installations, but for the large plants there can also be issues related to reducing the efficiency of the nitrogen oxides abatement, and slight increases in emissions of particulate matter.

SUMMARY

This section provides a summary of the text in the previous sections, and highlights the Danish lessons learnt relating to the problems that have arisen from air pollution in Denmark and how these have been dealt with in the past.

DANISH ENVIRONMENTAL LEGISLATION

Danish environmental regulation has been a key driver in relation to reducing atmospheric pollutant emissions, and as well as in relation to improving air quality in Denmark and its neighbouring countries.

An example of such legislation is the Danish regulation of application of manure from animal production in agriculture. Danish farmers are required to restrict the application of manure to fields during the growth season of crops. This restriction means that Danish farmers have been forced to invest in manure storage facilities - facilities that are necessary in order to store manure e.g. during the winter, when there is no crops in the fields. Spreading of manure has furthermore been banned, and manure now has to be injected directly into the soil. These combined restrictions have substantially lowered ammonia emissions, by reducing evaporation to the atmosphere. The result has been a reduction in the nitrogen loading of the surrounding environment.

Another example is the lead additive that is used to increase the octane rating in petrol. Danish legislation removed lead from petrol in 1984 (EU regulation of lead in petrol came in 2000) in order to protect the population from the serious negative health effects of exposure to lead, meaning that emissions and consequently also concentrations dropped tremendously within a very short period of time.

INTERNATIONAL ENVIRONMENTAL LEGISLATION

International environmental regulation under the United Nations (the Geneva Convention on Long-Range Trans-boundary Air Pollution, the Kyoto protocol), the Air Quality Directives, the European Emission Standards, the National Emission Ceiling (NEC) Directive, Integrated Pollution Prevention and Control (IPPC) Directive, and its revision, the Industrial Emission Directive) and the implementation of these regulations in Danish legislation as well as in the legislation of other European countries, has for some pollutants substantially reduced atmospheric pollutant emissions and improved air quality in Denmark and its surrounding countries.

Emission standards means that road traffic emissions have dropped substantially in the past two decades, and this decrease will continue as future emission standards for vehicle engines come into force and as existing car fleets are replaced with new vehicles that comply with the new standards.

The European agreements relating to the NEC directive have substantially reduced emissions of sulphur dioxide, nitrogen oxides and ammonia. These pollutants act as precursors of fine fraction particles ($PM_{2.5}$). These reductions in precursor emissions have substantially lowered ambient air $PM_{2.5}$ levels in Denmark over the past two decades.

TECHNOLOGY PROMOTION

Environmental regulation has promoted environmental technology development by creating a market for end-of-pipe technology and clean technology. The environmental technology has thereby provided a platform for companies working within this environmental technology sector in Denmark.

Examples are the cleaning technology industry, wind turbine producers, and also companies involved in the production of energy efficient windows and insulating materials, both of which help to reduce energy consumption. The Danish wind turbine industry is one of the strongest in the world, and has benefitted substantially from top class research in governmental research institutes through close cooperation. Another example within Danish industry is the insulation material industry, which likewise has a strong international position.

High energy taxes, together with a general environmental concern amongst the public, have led to a general public interest in energy efficient housing. This means that Danish houses in general are well

Photo: Kirsten Bang, Aarhus University.

insulated, and often feature energy efficient windows. This has during certain periods been governmentally supported through the subsidizing the salary of craftsmen providing both repair work and the energy improvement of domestic housings.

INITIATIVES FROM INDUSTRY, FARMERS ETC.

During the 1980s various initiatives were taken to reduce ammonia emissions as a result of eutrophication problems in Danish aquatic and terrestrial natural environments. These initiatives were taken during a period in which Danish pig production doubled. One of the reasons for achieving substantial reductions in ammonia emissions during this period of increasing animal production was the dedicated research efforts of agricultural organisations, in which their own research institutes cooperated with Danish universities. One of the efficient changes in animal production was the implementation of food with low nitrogen content. This initiative substantially lowered the nitrogen content of manure from pig production, and thereby also reduced ammonia emissions from stables and the application of manure.

Another initiative came from the Danish shipping industry, which has reduced sailing speed and thereby – with the cost of higher transport time – substantially reduced energy consumption and thus also the emission of air pollutants related to the use of fossil fuels.

THE COOPERATIVE MODEL

The cooperative model has in general played an important role in relation to the public participation and awareness about environmental issues and reducing environmental pressures in Denmark. The cooperative movement started in Denmark in the late nineteenth century by share-owner grocery shops, and was later used by various types of business.

In relation to emissions of atmospheric pollutants, the cooperative heating systems in building complexes and cooperative organic farming are examples where the cooperative model has been applied in Denmark, played a role in promoting environmental concern, and reducing the pollutant loads exported to the environment. Central heating means more efficient energy management and lower emissions of sulphur dioxide, carbon monoxide and nitrogen oxides.

Green farming means no use of pesticides and thereby a reduced impact on local nature, although ammonia emissions are not necessarily reduced in green animal production.

INFLUENCE FROM LOCAL NGOS

Local NGOs have played a key role in improving public environmental awareness in Denmark, and have had an impact on political decision making. An example is the Danish Bicyclist Organisation, who has strongly promoted the use of bicycles for commuting between home and work, and has cooperated with local authorities on how to improve conditions for cyclists in general. In larger Danish cities like Copenhagen, the local authorities have established bicycle lanes for safety reasons, by separating cyclists from vehicular road traffic. The influence of NGOs and authorities means that in larger Danish cities like Copenhagen and Aarhus, up to 45 % of commuting between home and work is done by bicycle. This is amongst the highest use of bicycles in the western world, and contributes significantly to reducing road traffic emissions.

Green products have been strongly promoted by NGOs, and a substantial part of the Danish population buy mainly green products in order to reduce environmental impacts.

COOPERATION BETWEEN AUTHORITIES

Cooperation between the Danish government and the local municipalities means that various climate change adaptation measures have been taken. Many of these concern avoiding or reducing the worst effects of flooding during extreme precipitation events, but also various initiatives to decrease greenhouse gas emissions.

Danish urban development takes place in accordance with Danish planning law. The municipalities define local industrial areas, separated from residential areas, and thereby reduced the exposures of the population to industrial emissions. The municipal plans have to be approved by governmental authorities.

Environmental zones are established around streams and natural areas within which restrictions are placed on pesticide use, the application of manure, and ploughing. This has proven to be an efficient way to protect the environment by reducing the deposition of airborne pollutants.

Another example in this context concerns wood stove emissions. Domestic wood stoves constitute the largest source of local fine fraction particle emissions in Denmark. According to Danish law, municipalities may in certain cases place restrictions on the use of wood stoves, when local conditions make the dispersion of emissions at low altitude less efficient. There are, however, only single case examples of this.

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http://envs.au.dk/en/knowledge/air/

Danish Ministry of the Environment
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http://eng.mst.dk/topics/air/

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The political ambition is to make Copenhagen the world's leading bicycle city by the end of 2015 and the Danish capital has a vision of becoming CO_2 neutral in 2025. Photo: Tuala Hjarnø, www.copenhagenmediacenter.com