PAUL SCHERRER INSTITUT
PSI

NO. 19 / JULY 2008

ENERGIE-SPIEGEL

FACTS FOR THE ENERGY POLICIES OF TOMORROW

Caution – Particulates!

The fine particulates that we inhale daily can make us ill. In Switzerland three million people live in areas where the pollution limits are exceeded and in some cases it is by massive amounts. Particularly during winter, high-density urban areas can regularly have high, health-damaging concentrations of fine particulates. There are many sources but according to measurements carried out by the PSI the contribution from wood heating is surprisingly large.

Although particulate levels have declined in Switzerland since the end of the 1980's, they are still significantly above the levels recommended by the World Health Organization. Winter weather inversions lead to annual episodes of high particulate burdens. In the villages of the alpine valleys the most significant sources of fine particulates are often wood fires, while in the Swiss midlands traffic plays the largest role. More than half of the so-called aerosols are formed in the atmosphere from gaseous emissions like nitrous oxides, ammonia, sulfur dioxide and organic compounds. Various emissions sources contribute to this problem, including heating systems, traffic, industry and agriculture. The very smallest particles and cancer-causing soot are particularly damaging, and come mainly from diesel motors and wood burning.

Particulates also affect the climate. Aerosols cool through the back scattering of sunlight and influencing atmospheric clouds, and so reduce global warming caused by greenhouse gases like CO_2. In this way particulates oppose the effects of CO_2, although only for the short-term.

Less particulates means less health damages. Efficient reduction measures are already widely available, but short-term cost considerations often hinder the implementation. A long-term solution to this problem needs an entire range of measures, including effective particle filters for diesel motors, anti-NOx systems to reduce the nitrous oxides that are precursors of secondary aerosols, as well as the most particulate-free uses of biomass. Less use of heat and transport fuels in general will also reduce particulate burdens further.

Contents

Where do particulates come from?

Every winter levels of fine particulates in the air are too high. The smallest particles (PM_1) are particularly damaging. But we are not only harmed by direct emissions of particulates – some secondary particulates are formed in the air from other emissions.

Every year the same story: Over the Swiss midlands the sun hides itself behind a high layer of gray overcast between November and March, often for days. This can have a depressing effect not just on spirits, but also on our health. At times when the heating is running full blast, cars are bumper-to-bumper in city traffic jams and weather inversions hinder the air exchange, high levels of fine particulates are at health damaging levels.

The main causes: Traffic, burning wood and industry

These levels have been too high in Switzerland for many years. Fewer emissions from traffic and industry may have improved the situation between 1990 and 2000, but since then change has stagnated.

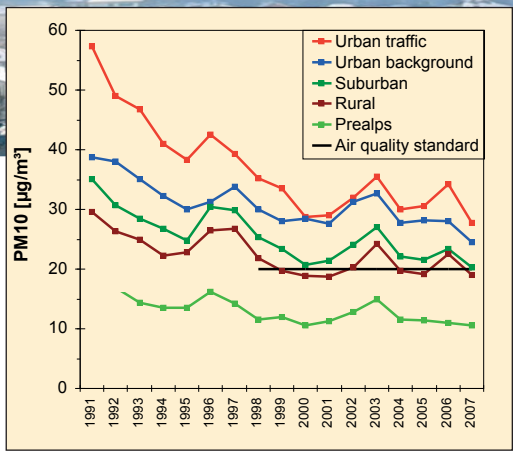
Particulates can vary significantly: Besides soot from diesel exhausts and poorly run wood fires, there are also a number of salts, mostly contained in different gaseous emissions that can develop in the air into aerosol form. On a typical day in the city, these so-called secondary particles can make up a majority of the particle pollution. The chemicals involved in these transformations include nitrous oxides from traffic and industry, sulfur dioxide from oil heating and industry, ammonia from agriculture and hydrocarbons from all of these different sources. In addition, larger and less damaging particulates are produced by mechanical processes like vehicle brakes and dust raised by vehicle turbulence.

The sources of the problem

By combining the measured chemical composition of aerosols with emissions data from the Federal Office for the Environment (FOEN), the contributions of individual sources to the total particulates load can be estimated. The main causes are traffic, wood heating and open fires, and also industry. But one can also not overlook the contributions from agriculture and oil and gas heating. Not all particulates are equally damaging, but soot particles directly emitted from diesel motors and wood heating not only damage the lungs, but can also cause cancer, and must be eliminated as much as possible.

Extensive Measurements

Behind these findings stands an extensive program of measurements by PSI, conducted at many locations across the whole of Switzerland. Most of the stations continuously operated by the federal government and cantons measure PM_{10} particulate levels. These are connected to the legal emissions limits for pollutants. However, these measurements alone give no information on the composition, damage potential and sources of the particulates. Aerosol mass spectroscopy used by PSI determines the volatile contents of particulates at the lowest concentrations, and even short-term variations can be measured. Carbon 14 methods (well known from archeology) to determine the fossil and non-fossil sources of carbon in particulates are being further developed in cooperation with the University of Bern. The combination of these methods allows a full characterization of particles with diameters of less than 1 micrometer (PM_1).

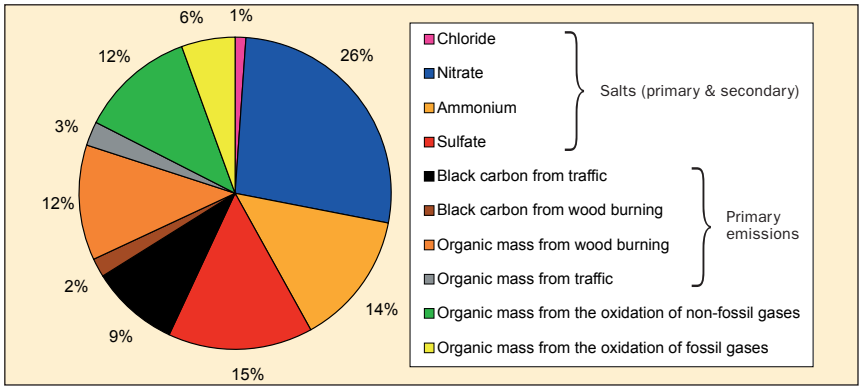


PM_{10} Levels in Switzerland: Average annual values. Source: BAFU 2008

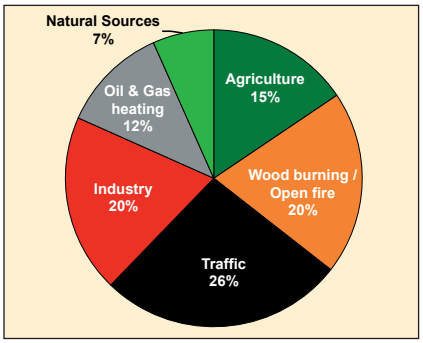
Fine particulates: Defined as particles (also called aerosols) with a diameter of less than ten thousandths of a millimeter (10 µm ≙ PM_{10}). If particles are smaller than 1 µm, they are termed PM_1.

Primary particles: Particles created by combustion processes and emitted directly from cars, heavy equipment, heating, etc., or entering into the air by direct mechanical processes.

Secondary particles: Formed from gaseous precursors in the atmosphere like nitrous oxides, sulfur dioxide, ammonia and hydrocarbons through the processes of chemical transformation, nucleation and condensation.



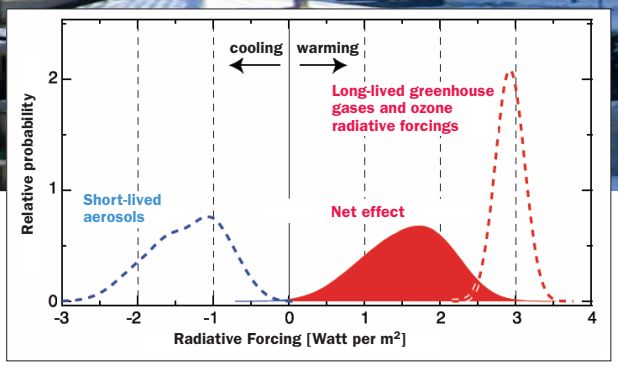
Typical composition of PM_1 particulate in Zurich in winter. (Source: PSI, Prevot et al.)



Average contribution of various sources to PM_1 particulates in Zurich in winter. (Source: PSI, Prevot et al.)

Health and Climate Effects

Our bodies suffer from fine particulates in the air: increasing levels cause difficulties in breathing, chronic bronchitis, asthma, increases in heart, circulatory and cancer disease, and higher mortality. This not only occurs in the vicinity of the pollution sources, but also at remote distances.

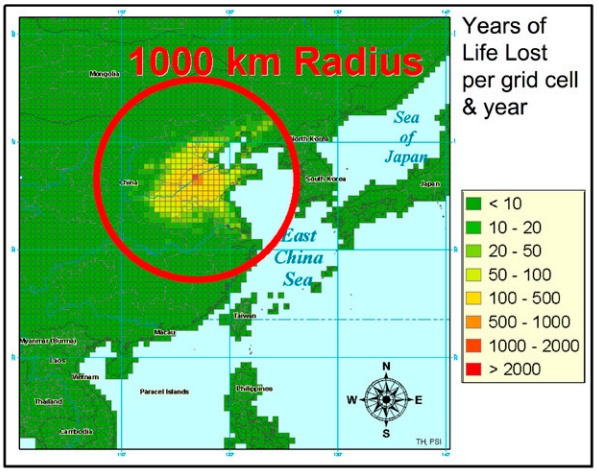


The dotted line drawn in red shows the warming effect (the so-called radiative forcing) of the greenhouse gases and their range of uncertainty; the broader the curve the larger the uncertainty. The dotted blue line shows the cooling effect of aerosols; which have a much higher uncertainty than the greenhouse gases. The net effect (shown by the area in red) therefore also shows a higher uncertainty. This makes predictions of future climate change uncertain (i.e. not whether, but rather how quickly warming will occur). Source: IPCC 2007

The smaller the particle, the deeper it penetrates into the lungs to produce its damaging effects. This can lead, amongst other things, to inflammations that can cause further subsequent illnesses. While particles in the 5 to 10 µm range are filtered out in the nose and throat, and can be removed by natural bodily processes, particles smaller than 1 µm can reach the alveoli in the lungs. From here they can be circulated by the blood throughout the whole body. The very smallest particles can even penetrate individual cells and their nuclei.

> The means to reduce particulates are largely available

The effects have been established by many studies, including those in Switzerland: fine particulates decrease lung function, lead to acute and chronic health damage and raise mortality rates. But the detailed effects of the individual particulate components are still not understood exactly.



Years of life lost (YOLL) per cell and year. Increased mortality through primary and secondary particles from a single large coal plant in China (mid-circle) with a population of between 100,000 and 4 million persons per cell in the affected region. (Source: PSI, Heck)

Underestimated remote effects

Contrary to expectation, particulates are not just a local problem at the source location. Emitted particles and precursors can be transported for hundreds of kilometers. The emissions of one large coal power plant can cause health damages at a distance of over 1000 km. Therefore, the effects always depend upon a complex combination of the strength and location of the emission source, the wind and climatic conditions, and the population distribution and density.

Here in Switzerland the sources are distributed more evenly. But the distances at which the emissions can cause their damage are similar. Particulates measured in Zürich come in part from far distant sources both in Switzerland and beyond, including the open burning of field and forest wastes.

Global shadows

Particulates in the air also affect the climate. These effects have been the subject of intensive research in the ETH domain. PSI has conducted regular measurements at the Jungfraujoch since 1995, with the goal of better quantifying these effects. Although there remain some uncertainties, it is clear that the high emissions of sulfur dioxide, nitrous oxides and primary particulates in all the inhabited areas of the world have a significant cooling effect on the world climate. At first glance this appears positive, reducing concerns about global warming due to CO_2 and other greenhouse gases. In reality, cooling due to particulates masks actual climate change: aerosols only remain in the atmosphere for about a week and so provide a short-term cooling effect, while CO_2 remains effective for decades.

Countermeasures

Concentrations of particulates must be reduced in a lasting way due to health reasons and the technical means are mostly available. Effective particle filters for diesel motors drastically reduce emissions, whether they power private cars, trucks, heavy machinery or tractors. Wood can be burned today with almost no particulate emissions: effective filters for larger heating uses are comparatively economical, and wood gasification provides an alternative. There are also filters already available for smaller wood-fired applications, although their efficiency must still be improved. Better insulation of buildings can also reduce heating demand and its associated particulate precursors.

Further measures are being researched, also at the PSI. For example new anti-NOx processes can reduce nitrous oxide emissions from diesel motors as a complement to particle filters. Research into combustion processes in gas turbines will also help to reduce precursor substances from natural gas, bio-gas and coal power plants.

«Particulates are one of the most urgent environmental problems»

Bruno M.C. Oberle, took his PhD in biology and environmental science at ETH. He has been Director of the Federal Office of the Environment (BAFU, formerly BUWAL) since 1. October 2005. From 1999 to 2005 he was vice-director responsible for technical protection of the environment. Before that Oberle was active as a consultant in the area of environmental management and protection, as well as lecturer of environmental science at ETH.

How do you estimate the health effects from fine particulates on the Swiss population?

From a health perspective, air pollution by particulates is certainly one of the most urgent environmental problems. The air is our most important essential substance for life, because we breathe day and night and cannot protect ourselves from bad air. Inhaling strongly polluted air damages the health, and in the worst cases can even lead to death. In Europe there are annually about 3 million years of life lost as a consequence of air pollution by particulates. In Switzerland alone there are more than 40,000 years of life lost. That represents about 350,000 premature deaths per year in Europe, and 3,000 to 4,000 in Switzerland.

Where do you see the primary causes of the problem, and which measures do you foresee to reduce the burdens? Where do the priorities lie?

The most heavily affected are the 3 million people in cities and urban areas, as well in southern Ticino – especially along heavily traveled roads. The annual particulates limits in some of these locations are exceeded by almost a factor of two. With the particulate action plan launched in 2006, Switzerland has made an important step to reduce particulate burdens, in which the pollutant emissions from diesel vehicles, new wood heating installations and industrial plants will be clearly reduced. The air quality rules also foresee a periodic review of emissions regulations based on the status of the technology available. In this way, the rules can consequently be extended. All these measures to improve air quality have provable positive effects on public health: the latest scientific investigations in Switzerland show that the health of children and adults has improved relatively quickly when the pollutant levels in the air have decreased.

How are the responsibilities shared between the federal and cantonal levels? Is there a dialog that crosses borders between the governments in Europe to reduce particulate levels?

The Swiss federal government is mainly responsible for establishing measures that are permanent and valid for all of Switzerland. Local traffic policies, building energy codes and planning measures are, in contrast, the responsibilities of the cantons, who are also responsible in a large part for the achievement of the air quality standards. International cooperation is important because air pollution crosses borders, and Switzerland has harmonized decisive regulations like exhaust limits with the EU. International contacts take place, for example within the framework of the UNECE Convention on Long Range Transboundary Air Pollution, in EU working groups or in meetings of environmental ministers.

Emissions limits for particulates are lower in Switzerland than in the EU. Why is that so, and what are the resulting consequences?

The decisive authority for establishing emissions limits in Switzerland is prescribed by the environmental law, which obliges the Federal Council to establish emissions limits, compliance with which will ensure the protection of people, animals, plants, earth, etc. from the damaging and burdensome effects of air pollutants. These limits are aimed at the goal of health protection. They agree in a large part with the recommendations of the World Health Organization. The currently valid limits in the EU may in contrast be seen as interim goals in all member states for a given time frame. It can be expected that the EU will establish stricter values at a later time.

> The 3 million people in urban areas are the most heavily affected

How do you see the role for research, and where is research needed?

Research provides politics with the basis upon which measures can be planned and implemented. For example, the particulate limits in Switzerland were established on the basis of the results from the large Swiss cohort-study SAPALDIA. In this respect, research plays a decisive role in the fight for better air. Necessary research includes, among other areas, the characterization, quantification and modeling of emissions from wood heating and the production of frictional dust from materials like vehicle brakes and tires. In addition, the health effects of individual fractions of the mix of particulates still need to be characterized better. For example, is traffic exhaust more damaging than wood smoke, or what are the health effects of particulates from long-distance transport?

Impressum

Energie-Spiegel, or Mirror On Energy, is the newsletter of PSI for the comprehensive analysis of energy systems (Project GaBE). It appears every four months. Contributors to this issue include A. Prevot, T. Heck and U. Baltensperger.

ISSN-Nr.: 1661-5093

Auflage: 15 000 German, 4000 French, 800 English
previous issues as PDFs (D, F, E) at:
http://gabe.web.psi.ch/

Responsible for content:
Paul Scherrer Institut
Dr. Stefan Hirschberg
5232 Villigen PSI, Schweiz
Tel. 056 310 29 56, Fax 056 310 44 11
stefan.hirschberg@psi.ch; www.psi.ch/GaBE

Editor: Christian Bauer

Subscription & Distribution:
energiespiegel@psi.ch

Layout: Paul Scherrer Institut

Energy Systems Analysis at PSI: The goal of energy systems analysis at the Paul Scherrer Institute in Villigen is to analyze present and future energy systems in a comprehensive and detailed way, considering in particular health, environmental and economic criteria. On the basis of Life Cycle Assessment (LCA), energy-economic models, risk analysis, pollution transport models and multi-criteria decision analysis, it is possible to compare different energy scenarios in order to create a basis for political decision-making.

GaBE works together with:
ETH Zürich; EPF Lausanne; EMPA; Massachusetts Institute of Technology (MIT); University of Tokyo; Europäische Union (EU); International Energy Agency (IEA); Organization for Economic Cooperation and Development (OECD); United Nations Organization (UNO)