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HEALTH IMPACTS FROM TRAFFIC RELATED AIR POLLUTION IN DANISH URBAN AREAS

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Abstract

In most of the European cities air pollution has changed in recent years; previously the most serious problem was sulphur dioxide and soot from minor domestic heating plants; this has largely been solved by introduction of cleaner fuels and change in infrastructure. Now the increasing traffic emissions, notably of nitrogen oxides and volatile organic compounds, with the ensuing photochemical air pollution, attract most attention.

Denmark has, for a series of geographical and meteorological reasons, relatively clean air. In urban areas, however, where the emission density is high and the dispersion of pollution is limited, impacts on human health and well-being must be considered. In the planning of a rational abatement strategy, including emission and air quality standards, it is not sufficient to determine pollution levels, it is also important to investigate to what extent people are actually exposed to them. Further, it is necessary to establish the relative contributions from various human activities.

Statement of the problem

Ambient concentrations and impacts of air pollution depend not only on emissions, but also on dispersion. In this respect Denmark is in a favourable position:

- The country is "diluted" with inland waters, and the average emission density is consequently low
- The flat landscape and the meteorological conditions facilitate dispersion
- The wind is often blowing from west, where there are no nearby foreign sources,
- and many Danish cities are positioned on east coasts; therefore the pollution often blows out of the country

For Denmark as such, and as a very rough average, only one third of the emitted pollution is deposited within the borders, the rest is "exported"; in return Denmark "imports" pollution corresponding to one third of the national emissions. In rural areas the pollution levels are therefore to a large extent determined by transboundary pollution, but in urban areas, where the emission densities are high and the dispersion is limited, local sources dominate.

The air quality in Danish cities has been monitored systematically since 1982 by the National Environmental Research Institute in collaboration with the National Agency of Environmental Protection and local authorities (*Kemp, Palmgren* 1994). It must be emphasised however, that the measurements have only been carried out at selected, typical sites (up to about 35) and thus demonstrate general levels and tendencies, but do not offer a detailed mapping of the pollution. Although some sites with heavy traffic were chosen, it can not be excluded that higher pollution levels occur e.g. in street canyons; this must be investigated with model calculations in individual cases.

Since about 1970 the urban air pollution has changed significantly. Previously the most serious problem was sulphur dioxide and soot from minor domestic heating plants; to a large extent this pollution is now reduced by use of cleaner fuels, improved technology and a widespread switch to district heating. Now the increasing traffic attracts most attention.

All types of traffic and transport contribute directly or indirectly to air pollution, but mainly road traffic, and notably urban traffic, has a significant direct impact on human health and wellbeing. The emissions from cars are partly due to incomplete combustion and partly to oxidation of atmospheric nitrogen. They comprise carbon monoxide, nitrogen oxides (mostly nitrous oxide), particles, and several hundred different volatile hydrocarbons. Diesel and petrol cars have a different emission pattern; of special importance is the emission of particles due to inhomogeneous combustion in diesel engines (for a general survey see e.g. *Möller* 1990).

The formerly important lead pollution has virtually disappeared with the introduction of lead free petrol; this may on the other hand involve a higher average content of aromatic compounds (i.a. benzene) in the fuels. A modest emission of sulphur dioxide from diesel cars will be further reduced with increasing use of light diesel oil. Even now however, all national transport activities contribute only 6-7 % to the total emission of sulphur dioxide. And even in the centre of Copenhagen the average SO_2 level is below 20 $\mu g/m^3$ - far below limit values.

In addition to "primary" pollutants, which are directly emitted, it is imperative to consider "secondary" pollutants, which are formed in the atmosphere; of increasing importance are ozone and related photochemical oxidants.

However, in studies of impacts on human health, and consequently also in the planning of a rational abatement strategy (including emission and air quality standards), monitoring of pollution levels is not enough; it must also be established to what extent people are actually exposed to these levels. Finally, of course, it must be investigated, what impacts such an exposure has - both on individuals and on populations.

The individual pollutants and their impacts

Carbon monoxide

The national road traffic contributes 70% to the national CO-emission and completely dominates the CO-pollution in Danish urban areas. WHO guidelines are 10 mg/m^3 for maximum 8 h. averages and 30 mg/m^3 for 1 h. means; they are touched at monitoring stations in Copenhagen, and exceedings in some street canyons can not be excluded.

Carbon monoxide substitutes oxygen in haemoglobin with a relative affinity of 200 and can thus cause oxygen deficiency. In healthy persons a few % of substitution (COHb%) result in reduced reactivity and power of concentration; higher levels affect the cardiovascular and central nervous systems. The WHO guidelines secure that the COHb% is below 2.5-3% for the non smoking part of the population, and only in special situations with low ventilation (tunnels, multi-storey car parks) can critical levels be expected.

Nitrogen dioxide

Nitrogen oxides are byproducts in all combustion processes, and road traffic only contributes 35% to the total national emissions; the relative contribution to urban pollution levels however, is significantly higher. In spite of increasing emissions of total nitrogen oxides (NO + NO_2) and corresponding increasing levels of NO, no significant increase in NO_2-levels have been observed; this is probably because the formation of NO_2 is limited by the available ozone (*Hertel et al.* 1995). Typical yearly averages at urban monitoring stations are 40 µg/m^3. The 98-percentiles of 1 h. means are often above 100 µg/m^3; the EU-limit value for 1 h. means of 200 µg/m^3 has not been violated, but a more stringent guideline of 135 µg/m^3 is occasionally touched.

In the respiratory system nitrogen dioxide is converted to nitrates and nitric acid, which acts as irritants. For longer exposures the lung structure, the lung metabolism, and the resistance against infections are impaired.

Volatile organic compounds

Hydrocarbons comprise a series of compounds, many of which have a direct effect on the respiratory system. Some have also chronic effects; thus benzene can cause leukaemia, PAHs and dioxines are carcinogenic, and dioxines affect the immune system.

The main anthropogenic sources of volatile organic compounds (VOC) are combustion processes and evaporation of solvents. National road traffic contributes with about 60% to the total Danish emission; local traffic must thus be the dominating source of urban air pollution. Since the various VOCs have very different properties, determinations of total atmospheric concentrations are of limited value in evaluation of health effects. So far however, measurements of actual levels are scarce - partly because the concentrations are low, and the necessary analytical technique can be complicated - partly because combustion processes lead to formation of several hundred individual compounds.

The most detailed Danish investigations of health threatening hydrocarbons have concerned polyaromatic hydrocarbons (PAH), where typical urban levels of individual compounds (i.a. benzo(a)pyrene) are 1 ng/m^3 during summer and 4 ng/m^3 during winter (*Poulsen et al.* 1995, *Nielsen et al.* 1995). An earlier investigation (*Ostenfeldt* 1989) suggests that in the city centres the primary source is traffic; in residential areas private wood stoves dominate. *WHO* (1987) estimates that 9 out of 100,000 exposed to 1 ng/m^3 of B(a)P over a lifetime will be at risk of developing cancer. A more conservative Danish study (*Nielsen et al.* 1995) estimates that for residents in Copenhagen and similar areas, the air pollution with PAH and other mutagens will cause, as a maximum, five lung cancer cases each year among 1,000,000 individuals. In rural areas the risk is much lower.

Since 1994 average diurnal concentrations of 17 hydrocarbons have been measured in campaigns in central Copenhagen (*Hansen, Palmgren* 1995). The measurements were mainly aimed at compounds of photochemical interest, but showed i.a. average levels of benzene of the order of 6 ppb and toluene of 14 ppb at street level. A strong correlation with levels of carbon monoxide indicates that traffic is the main source. *WHO* (1987) recommends no safe level for benzene, but estimates a lifetime risk of leukaemia of 4 out of 1,000,000 exposed to a concentration of 1 $\mu g/m^3$ - corresponding to about 0.3 ppb. Toluene has a series of effects on the central nervous system, but the *WHO* (1987) "lowest-observed-effect level" of 375 mg/m^3 (100 ppm) is well above the Danish levels.

Photochemical oxidants

Ozone and other photochemical oxidants are formed in a series of competing reactions between nitrogen oxides and volatile organic compounds under the influence of sunlight. Since both primary and secondary pollutants can be transported over long distances, there are no simple relations between local emissions and pollution levels. In central and southern Europe high levels are frequent in urban areas, but in Denmark the dominant reaction is a removal of ozone in reactions with nitrogen monoxide, emitted from motor vehicles, to form nitrogen oxides. Therefore ozone levels are generally higher in the countryside and in residential areas (annual mean values about 50 $\mu g/m^3$ and 1 h. mean 98-percentiles about the double) than in city centres. Although high values can be recorded at roof tops, lower values are generally found at ground level, typically 20 $\mu g/m^3$ in open areas and 10 $\mu g/m^3$ in streets with heavy traffic.

Ozone is a strong oxidizing agent, which reacts with macromolecules in the surface layers of the respiratory organs. Irritation and headache are observed for 1 h. means above 200 $\mu g/m^3$ - for children and asthmatics down to 100.

An EU-directive indicates three limit values: For daily averages 65 $\mu g/m^3$, for 1 h. means 200 $\mu g/m^3$, and for running 8 h. averages 110 $\mu g/m^3$. Information or alarm must be issued, if the 1 h. mean exceeds 180 $\mu g/m^3$ or 360 $\mu g/m^3$ respectively. It appears that the 8 h. limit value, which is primarily aimed at protecting human health, is only exceeded of the order of 10 times per year, and then at roof tops or in rural areas. Information is issued a few times per year. The possible health effects of ozone in Denmark may thus not so much be related to the compound itself as to its influence on the level of nitrogen oxide.

Peroxyacetylnitrate (PAN) is likewise formed in photochemical reactions, but in minor quantities and with less impact. The effects in Denmark are negligible.

Particles

Particles reduce - especially in combination with sulphuric acid - the cleaning ability of the respiratory system and the resistance against infections. They further act as carrier for a series of pollutants (dioxines, PAH, heavy metals) some of which are carcinogenic.

The concentration of total suspended particulates (TSP) has a yearly average in the centre of Copenhagen of about 70 $\mu g/m^3$ and a 95-percentile of daily averages of about 150 $\mu g/m^3$. This is about half of the limit values of 150 and 300, respectively. At a few locations with heavy traffic so called "black smoke" is determined; the levels, which indicate the particulates due to incomplete combustion - notably in diesel cars - are about 40 $\mu g/m^3$.

Total suspended matter (TSP) includes particles too large to be inhaled (greater than about 10-15 μm), whereas fine particles (less than about 2.5-3.5 μm) are believed to cause health effects deeper in the lungs. Therefore, fine particles less than 2.5 μm ($PM_{2.5}$) may be a better indicator of health effects from particles, but so far no relevant Danish measurements have been performed.

Population exposure assessment

Concept of exposure

Exposure to a pollutant is defined as a person's contact with a pollutant of a certain concentration during a certain period of time. For population exposure, the target for exposure is defined as the physical boundary of a person. To take into account the temporal and spatial variations in air pollution levels, the concept of integrated personal exposure has been introduced as the integration of concentration levels over certain time intervals. Since however, people spend time at different locations, the integrated personal exposure must be calculated taking into account different micro environments and the time-activity pattern of the population. A micro environment is a location or area with a more or less homogeneous pollution concentration in time and space e.g. indoor at home, outdoor at home, at work, or in busy streets. Studies of the time-activity pattern of the population may determine the time fraction the population spends in each micro environment.

Purposes of population exposure assessment

Assessment of the population's exposure to air pollution has three general goals: exploration, definition of health impacts, and regulation (*Tardiff, Goldstein* 1988). Exploratory studies determine the distribution of exposure in the population, sources to or trends in exposure etc. Studies of health impacts of exposure may be epidemiological studies. Regulatory studies determine the effectiveness of control strategies or serve surveillance and monitoring purposes.

Association between exposure and health effects

The exposure will cause an internal dose of the body through inhalation of the air pollutants. The dose is the amount of material actually delivered across the boundary of the body to the target organ; it depends on the physiology and activity, thus e.g. an individual has elevated breathing rate when bicycling. Some contaminants undergo transformation in the metabolic process producing products that determine the actual biological effect. This biological effective dose of a target organ may cause a health effect.

In population exposure assessment, time resolution is crucial and must be relevant for the potential health effect of the air pollutant. Therefore, the time averaging of the measured or modelled air pollutant in question must have at most the same time averaging as the health effect that the exposure may cause. For example, short-term exposure to high peaks of nitrogen dioxides or ozone may cause asthmatic symptoms to sensitive individuals. In this case, short time averaging is necessary. On the other hand, if the health effect is associated with long-term exposure, which is the case for carcinogenic species, the time averaging may be longer.

Methods of assessment

Population exposure can be carried out both directly and indirectly (*Williams* 1991).

In the direct methods individuals are outfitted with personal monitors, which record actual concentrations of pollutant in the air inhaled by the individual. One example of such a method is the personal badge-type passive sampler for NO_2, which may give integrated personal exposure over a longer period, say one day or a week. The advantage of personal monitors is that the exposure is related directly to the individual. The disadvantages are that they normally are expensive, if a large representative group of individuals in a population is to be monitored. Furthermore, monitors are only available for relatively few pollutants. Finally they have relatively long sampling periods, which may be a problem with short term effects.

In the indirect methods, the exposure of individuals or groups is determined by combining measured and/or modelled concentrations with data on the time-activity pattern of the population. A simple approach is to use fixed location monitoring as a proxy for personal exposure, simply assuming that the population in the area of the monitoring station is exposed to the same air pollution and have the same time-activity pattern. A more comprehensive approach is to use measurements and/or modelled concentrations obtained from diverse micro environments and to collect data of the time-activity pattern of individuals, groups or the entire population within a geographic area. The advantage of using fixed location monitoring is that an exposure frequency may be based on continuously measured concentrations with short sampling times. Fixed location monitoring is available for many, but not all relevant, air pollutants - and only with a limited time resolution.

Personal biological monitoring is an indirect method, using samples from the human organism. The approach has a direct link to the potential health effects. The approach assumes that the metabolic product of a pollutant present in the body is an indicator of exposure. There are two types of biological monitoring: exposure markers, where the metabolic product is measured in bodily fluids or excreta, and effect markers involving measurements of biological responses in cells and tissues.

Data on the time-activity pattern of individuals may be obtained by using questionnaires e.g. in diary form. An electronic equivalent of a diary may be used e.g. personal electronic data loggers where the individual presses an appropriate key on a personal device, when he enters a new micro environment. Statistic data on the time-activity pattern of the population may also be used for more general studies.

Until recently population exposure assessment has primarily been based on measurements obtained by outdoor fixed location monitoring and multi-micro environment monitoring using fixed or personal monitoring. The use of air quality models for population exposure assessment is still in an early stage. Models have been developed to predict levels of various air pollutants on different scales like long-range models for regional background concentrations, urban scale models to predict urban background concentrations, street canyon models to predict concentrations in streets, and indoor/outdoor models to predict indoor pollution with outdoor origin. The advantage of air quality models is their capability to predict concentrations in environments, where only few measurements are available; models can also be used in historic studies as well as scenario studies. They are usually based on short averaging times (e.g. one hour) allowing for prediction of peak concentrations, time series and frequency distributions. Furthermore, models facilitate mapping of air pollution concentrations. One of the disadvantages of models is their often detailed requirements of input data on emissions and meteorology.

Danish population exposure related to traffic air pollution

In Denmark only few studies of population exposure assessment, related to traffic air pollution, have been carried out. Some are in progress with focus on health impacts using an epidemiological approach for selected population groups as e.g. children.

Below general statistic figures on demography and time-activity patterns of the Danish population are presented to give an idea of the Danish population's exposure to traffic induced air pollution.

Demography

All other things equal, the ambient air pollution concentration levels increase with increasing size of city, with traffic intensity in street environments, and decrease from the city centre to the outskirts and further to the rural areas. As shown in table 1, about 1.8 million persons live in areas where relatively high air pollution levels can be expected. About 1.1 million persons live in medium sized cities with moderate air pollution levels and 2.3 million persons live in small towns, villages and rural areas with low air pollution levels.

People living along busy streets will experience the highest exposure to air pollutants from traffic. According to the *Ministry of Traffic* (1993) about 485,000 households are exposed to high levels of traffic noise (above 55 dB(A)). The majority of households exposed to the highest levels of traffic noise are located in the largest cities and along the approach roads in the cities especially in Copenhagen. These locations will also experience relatively high air pollution levels. With an average 2.2 members per household about 1.1 million persons live along streets with potentially high air pollution levels.

Time activity pattern

Besides the demography of the population, the time-activity pattern of the population is important for exposure assessment. Based on a large Danish time-activity study (*Andersen* 1988) carried out in 1987 for persons of age 16 to 74, average statistics can be derived for time-activity pattern relevant for exposure assessment. This study shows that the average adult Dane spends about one hour on transport, one hour outdoor and 22 hours indoor per day.

City type (inhabitants)	Inhabitants
Copenhagen (capital)	617 000
Greater Copenhagen besides Copenhagen	722 000
Large cities (above 100,000)	460 000
Medium sized cities (10,000 to 100,000)	1 075 000
Small towns (1,000 to 10,000)	1 094 000
Villages and rural areas (0-1,000)	1 194 000

Table 1. Demography of the Danish population as number of people living in different city types. Copenhagen comprises the municipalities of Copenhagen, Frederiksberg and Gentofte. (*Danmarks Statistik* 1994).

Mode of transport:	Time, minutes
Passenger car, as driver or passenger	31
Bicycle	7
Walking	7
Bus	6
City train	2
InterCity train	2
Aircraft, ship etc.	2
Total	57

Table 2. The time consumption in minutes of the about one hour the average adult Dane of age 16 to 74 spends on transport per day distributed by the mode of transport. (*Ministry of Traffic* 1994).

Another study (*Ministry of Traffic* 1994) of the Danish population's travel habits in 1992, with the similar age group as above, also showed that the average Dane spends about one hour on transport per day. The distribution by mode of transport, which is shown in table 2, is important for exposure assessment, since the highest air pollution levels will occur in busy streets. People spend 14 minutes outside walking or bicycling, and part of this time will be spend in busy streets. On a daily basis people spend 37 minutes inside a passenger car or a bus; more than half of this time is excepted to be in city traffic. The exposure of drivers and passengers further depends on the outside/inside ratios of the different pollutants. People spend another 6 minutes inside trains, aircrafts or ships, where the exposure to ambient air pollutants is expected to be low.

Conclusion: A need of comprehensive studies

It is well established that car exhaust contains a series of compounds, which may be harmful to human health and well being. Some of the impacts are immediate (e.g. irritation of the respiratory system) and some are long term (e.g. cancer). It has also in various Danish investigations (e.g. *Frøsig* 1993, *Rindal* 1992) been shown that there is some correlation between air pollution levels and morbidity. However, assessments of the health impact of air pollution from a specific activity as traffic are by no means a simple matter. They involve in principle four elements:

- Measurements and/or calculations of the relevant pollution levels
- Establishment of the relative contribution of the specific activity
- Evaluation of the exposure of individuals or populations
- Studies of the eventual health effects, including possible combination effects

So far no fully comprehensive assessment has been performed in Denmark. One of the reasons may be that the air quality monitoring originally, to a large extent, was intended as an administrative tool, which could demonstrate current trends and check, whether limit values were exceeded too often. This does *not* in itself offer a sufficiently detailed description of the actual air pollution for evaluation of impacts on human health. The current Danish monitoring programme, which is strongly coupled to model calculations, will be much better suited.

Mainly polluted, densely populated areas with less than half of the Danish population were covered, and here inhabitants are only subjected to the recorded pollution levels a fraction of the time . All in all this may tempt to overestimate the impact on the population as such. On the other hand, our knowledge concerning a series of potentially harmful pollutants - notably fine particles and hydrocarbons from car exhaust - is rudimentary. With better information from current and future research on these two points a quantitative description may be possible.

Background

The paper is based on ongoing studies: *Larsen, P.B., Poulsen, M., Fenger, J.,Jensen, S.S.* (1995). Sundhedsmæssig vurdering af luftforurening fra vejtrafik (Evaluation of Health Effects of Air Pollution from Road Traffic). To be published by The Danish Environmental Protection Agency.

Population exposure is the subject of a Ph.D. project by one of the authors: *Jensen, S.S.*(1995). Modelling of Population Exposure to Traffic Air Pollution. The fifth International Symposium on Highway and Urban Pollution. Copenhagen, 22-24 May 1995.

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